



# Instruction Set Architecture

## Student Solutions Exercises Computer Architecture

## 1 | Instruction-Set Architecture

### 1.1 Simple C-Code to RISC-V Assembler

#### 1.1.1 Students guide

- a) You need the instruction: **add**
- b) You need the instructions: **add, sub**
- c) You need the instruction: **addi**
- d) You need the instruction: **addi**
- e) You need the instructions: **lui, addi**. Beware immediates overflow.
- f) You need the instructions: **lui, addi**. Beware immediates overflow.

*isa/c-to-riscv-01*

### 1.2 Algorithmic C-Code to RISC-V Assembler

#### 1.2.1 Students guide

- a) One variant is with: **bne, add, sub**
- b) One variant is with: **bne, add, j, sub**
- c) One variant is with: **addi, bne, add, j**
- d) One variant is with: **addi, bge, add, slli, j**
- e) One variant is with: **lui, addi, lw, slli, sw**
- f) One variant is with: **lui, ori, addi, bge, slli, add, lw, sw, j**
- g) One variant is with: **addi, add, lb, beq, j**

*isa/c-to-riscv-02*

### 1.3 Machine code to RISC-V Assembler

#### 1.3.1 Students guide

- a) `0x41FE 83B3 = 0100 0001 1111 1110 1000 0011 1011 0011`

op = 51, funct3 = 0  $\Rightarrow$  **add** or **sub** (R-Type Command)



funct7 = 01000000  $\Rightarrow$  **sub**

funct7	rs2	rs1	funct3	rd	op
0100 000	11111	11101	000	00111	0110011
32	31	29	0	7	51

**sub t2, t4, t6**

b) I-Type

*isa/machinecode-to-riscv-01*

## 1.4 Logic operations on registers

### 1.4.1 Students guide

- a) **s3 = 0x46A1 0000**
- b) **s4 = 0xFFFF 01B7**
- c) **s5 = 0xB95E F1B7**

*isa/riscv-execution-01*

## 1.5 Logic operations on values

### 1.5.1 Students guide

- a) **s3 = 0x3A75 0824**
- b) -
- c) -

*isa/riscv-execution-02*

## 1.6 RISC-V multiplication

### 1.6.1 Students guide

**s4 = 0xE000 0000**  
**s3 = 0x0000 0000**

*isa/riscv-execution-03*

## 1.7 Division and modulo

### 1.7.1 Students guide

**s3 = 0x0000 0005**  
**s4 = 0x0000 0002**

*isa/riscv-execution-04*

## 1.8 R-Type to Machine code

### 1.8.1 Students guide

a)



```
add x18, x18, x20
```

R-Type Command

funct7	rs2	rs1	funct3	rd	op
0	20	19	0	18	51
0000000	10100	10011	000	10010	0110011

```
0x0149 8933
```

b) -

c) **0x0092 9BB3**

d) -

e) -

*isa/riscv-to-machinecode-01*

## 1.9 I-Type to Machine code

### 1.9.1 Students guide

a)

```
addi x8, x9, 12
```

I-Type Command

imm <sub>11:0</sub>	rs1	funct3	rd	op
12	9	0	8	19
0000 0000 1100	01001	000	01000	001 0011

```
0x00C4 8413
```

b) -

c) -

d) **0x01B0 1483**

e) -

*isa/riscv-to-machinecode-02*

## 1.10 S-Type to Machine code

### 1.10.1 Students guide

a) **0xFE79 AD23**

b) -

c)

```
sb x30, 0x2D(x0)
```

S-Type Command



imm <sub>11:5</sub>	rs2	rs1	funct3	imm <sub>4:0</sub>	op
0000 001	30	0	0	01101	35
0000 001	11110	00000	000	01101	010 0011

0x03E0 06A3

*isa/riscv-to-machinecode-03*

## 1.11 Real-time system

What is the main difference between a “hard” real-time system and a “soft” real-time system?

### 1.11.1 Students guide

One of those system types is considered as failed if it misses any timing. When/Why is it necessary to be so strict ?

*isa/riscv-to-machinecode-04*

## 1.12 U-Type to Machine code

### 1.12.1 Students guide

0x8CDE FAB7

*isa/riscv-to-machinecode-05*

## 1.13 J-Type to Machine code

### 1.13.1 Students guide

0x0FF8A 60EF

*isa/riscv-to-machinecode-06*



## 2 | Laboratory complement

To help you, feel free to use the [RISC-V interpreter on https://course.hevs.io/car/riscv-interpreter/](https://course.hevs.io/car/riscv-interpreter/) as well as [Ripes](#).



Be careful with variable types!

- **int** type is considered as a signed, 32 bits value.
- **unsigned int** type is considered as an unsigned, 32 bits value.
- If followed by a number (e.g.: **int16\_t**), it means the value is on x bits (here 16). If preceded by a **u**, it is unsigned.

**uint8\_t** is an unsigned byte, whereas **int8\_t** is a signed byte.

### 2.1 Basic calculations

#### 2.1.1 Students guide

a)

```
# a = b + c;
# s0 = a, s1 = b, s2 = c

# b = 1, c = 2
addi s1, zero, 1
addi s2, zero, 2
add s0, s1, s2      # a = b + c
# s0 = 0x00000003
# s1 = 0x00000001
# s2 = 0x00000002

# b = -1, c = 2

...

# s0 = 0x00000001
# s1 = 0xffffffff
# s2 = 0x00000002

# b = -12, c = 2032

...

# s0 = 0x000007db
# s1 = 0xffffffff4
# s2 = 0x000007e7
```

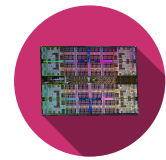
b)

```
# a = b - c;
# d = (e + f) - (g + h);
# s0-s7 = a-h

...

# t0 = 0xffffffffb1
# t1 = 0x000007db
# s0 = 0xffffffff
# s1 = 0x00000002
# s2 = 0x00000003
# s3 = 0xffffffff7d6
# s4 = 0xfffffffff
# s5 = 0xffffffffb2
# s6 = 0x000007e7
# s7 = 0xffffffff4
```

*isa/lab-basic-calc*



## 2.2 Memory access

### 2.2.1 Students guide

```
# Check for sign extension comprehension

# uint16_t a = mem[3];
# mem[4] = a;
# t0 is a
lhu t0, 3(zero) # if lh, the last bit may be 1 -> extended -> wrong number
sw t0, 4(zero)

# int16_t a = mem[3];
# mem[4] = a;
# t0 is a
??? t0, 3(zero) # if lh, the last bit may be 1 -> ???
??? t0, 4(zero)
```

*isa/lab-memory*

## 2.3 Basic algorithms

1. Transmit the 8-bit memory value at address 0x0000'1000 serially, bit by bit, into the **Least Significant Bit (LSB)** of memory address 0x0000'1001. The remaining bits of memory address 0x0000'1001 must be '0'. Calculate the baud rate in  $\frac{\text{Instructions}}{\text{Bit}}$  for the entire transmission.

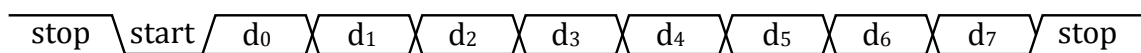


Figure 5 - UART serial transmission

2. Multiply two 4-bit numbers together using one of the commands **bne** or **bge**. The algorithm works as follows: a multiplication is the same as adding the same number x times. For example:  $2 * 9 = 9 + 9 = 18$ .

### 2.3.1 Students guide

1. UART transmission idea:

```
# Serial UART Transmission
# setup
lui s2, 0x00001 # store UART base address
addi t0, zero, 0xA # value to be send for testing
sb t0, 0(s2) # save to memory

# start
lui s2, 0x00001 # store UART base address
addi s1, zero, 0x1 # store mask bit
lb s0, 0(s2) # get value from memory

# send stopbit
sb s1, 1(s2) # send stopbit to memory
addi zero, zero, 0 # nop
addi zero, zero, 0 # nop
```



```
# send startbit
...

# algorithm iteration #1 to #8
...

# send stopbit
addi zero, zero, 0 # nop
sb s1, 1(s2)       # send stopbit to memory
```

## 2. Two numbers basic multiplication with loops idea:

```
# Input values
# a0, a1 = input, a2 = output
addi a0, zero, 9
addi a1, zero, 2

# init output to zero
addi a2, zero, 0

# check if a1 is zero
if a1 == 0 => goto end
decrement a1

accumulate:
    accumulate into a2
    decrement a1
    continue if not 0
```

*isa/lab-basic-algos*

## 2.4 Branching

### 2.4.1 Students guide

#### If / else

```
addi s0, zero, 1 # int a = 1
addi s1, zero, 2 # int b = 2

# if(a == b)
test1:
    bne s0, s1, test2 # imm = 12
# a == b
equal:
    c = 0
    goto end
# else if b > a
test2: # a < b == b >= a
    if a < b => goto a_smaller
# a > b
a_bigger:
    addi s2, zero, 1
    jal end # imm = 8
```



```
# a < b
a_smaller:
    addi s2, zero, 2

end:
# ...
```

### 2.4.2 Switch case

```
# a = s0, mem[2] = s1
lw s1, 2(zero)

# if(b == 0)
bne s1, zero, not0 # imm = 12

# b == 0
li s0, 17
jal end # imm = 48

# b != 0
not0:
    li t1, 3
    # if(b == 3)
    bne s1, t1, not3 # imm = 12

# b == 3
li s0, 33
jal end # imm = 32

# b != 3
not3:
    ...
    # if(b == 8)
    if(b == 8) goto is8_or_12 # imm = 20
    ...
    # if(b == 12)
    if(b == 12) goto is8_or_12 # imm = 12

# b != 8 | 12 (others)
li s0, 99
jal end # imm = 8

# b == 8 | 12
is8_or_12:
    li s0, 10

end:
# ...
```

### 2.4.3 While / Do While

```
// A : simple do-while
addi a5, zero, 10 # int a = 10;
while_entry:
    addi a5, a5, -1 # a--
```





```
bne zero, a5, while_entry # imm = -4

// B : similar
addi a5, zero, 10 # int a = 10;
while_entry:
    addi a5, a5, -1 # a--
    if a >= 0 => goto while_entry

// C : uint32_t instead of int
...
```

#### 2.4.4 For

```
# a is s0, i is s1, mem[0] = s2
lw s2, 0(zero) # loop target

# For the for to work, blte does not exist.
# Thus, since the loop decreases, a > b
# == a-1 >= b (for signed only, else infinite loop)
# so better a >= b + 1
addi s2, s2, 1 # target + 1
li s1, 4      # i = 4
mv s0, zero   # a = 0

jal for_test # imm = 8

for_do:
    add s0, s0, s1
    addi s1, s1, -1 # MUST be at the end of for

for_test:
    bge s1, s2, for_do # imm = -8
```

*isa/lab-branch*



## 2.5 Functions

### 2.5.1 Students guide

- a) A function with context saving which can be optimized      b) A function with too many arguments

```
# a is s0, b is s1
li s0, 1 # a = 1
mv a0, s0 # copy into a0 as funct. arg
jal ra, doubleIt # imm = undef.
mv s1, a0 # b = result

# DO NOT FORGET THE FOLLOWING
# a0 is a scratch register, and we called
# a function
# so we are not sure if a0 is still s0
mv a0, s0
jal ra, doubleItOpti # imm = undef.
mv s1, a0 # b = result

# ...

doubleIt:
    # save context
    addi sp, sp, -4
    sw s0, 0(sp)
    # do a = a * 2
    mv s0, a0
    sll s0, s0, 1
    mv a0, s0
    # restore context
    lw s0, 0(sp)
    addi sp, sp, 4
    jalr zero, ra, 0 # or pseudo jr ra

# If 'a' should be a register
doubleItOpti:
    mv t0, a0
    sll t0, t0, 1
    mv a0, t0
    jalr zero, ra, 0 # or pseudo jr ra

# Most opti version
doubleItOpti2:
    # nothing to save since we can do it
    # with a0 directly
    sll a0, a0, 1
    jalr zero, ra, 0 # or pseudo jr ra
```

```
# a to j in s0-s10
# res in s11
li s0 1
li s1 2
...
li s10 10

# prepare arguments
mv a0, s0
mv a1, s1
...
mv a7, s7
# still two args to pass -> stack
addi sp, sp, -8
# It is important that the caller
# reserves the space. Also, note
# the order in stack.
sw s8, 4(sp)
sw s9, 0(sp)
# call
jal ra, sum
# stack not needed anymore
addi sp, sp, 8

mv s1, a0 # b = result

# ...

sum:
    # do add with aX regs
    add a0, a0, a1
    add a0, a0, a2
    ...
    add a0, a0, a7
    # load i from over sp
    lw t0, 4(sp)
    add a0, a0, t0
    # load j from over sp
    lw t0, 0(sp)
    add a0, a0, t0
    jr ra
```

*isa/lab-fcts*



## 2.5.2 Students guide

### 2.5.2.1 Modulo

```
# RV32IM
# a is s0, b is s1, c is s2
li s0, 9
li s1, 7
remu s2, s0, s1

# RV32I
# Call a div algorithm and take remainder
# Or call a sub loop

# Modulo of power of 2
li s0, 9
li s1, 8
addi t0, s2, -1 # pow 2 - 1
and s2, t0, s0
```

### 2.5.2.2 °F -> °C

The main algorithm is:

```
begin:
    li s0, 550 # degrees fahrenheit

    li s1, 466034 # magic number
    mv s2, s0 # c = f

    # A: c = f - 32
    addi s2, s2, -32

    # B: c = c * 5
    # Variante 1 c*5 with shift
    # slli s3, s2, 2 # c * 4
    # add s2, s3, s2 # c + c (== * 5)
    # Variante 2 c*5 with function
    mv a0, s2
    li a1, 5
    # jal ra, mulFunct # func variant malFunct
    # jal ra, sfmulFunct # func variant sfmulFunct
    jal ra, fmulFunct # func variant fmulFunct
    mv s2, a0

    # C: c = c * 2^n / 9
    mv a0, s2
    mv a1, s1
    # jal ra, mulFunct # func variant malFunct
    # jal ra, sfmulFunct # func variant sfmulFunct
    jal ra, fmulFunct # func variant fmulFunct
    mv s2, a0

    # D: c >= n
    srli s2, s2, 22

# End
```



```
nop
j begin
```

The multiplication functions (from worst to best):

a)

```
# bad O(n_b)
mulFunc: # mulFunc(int a, int b)
# add itself each time
mv t0, a0
addi a1, a1, -1

mul_beg:
bgeu zero, a1, mul_end # if 1 > b
add a0, a0, t0
addi a1, a1, -1
j mul_beg

mul_end:
jr ra

# better O(n_min[a,b])
sfmulFunc: # sfmulFunc(int a, int b)
swap a and b to loop less times
loop to multiply
```

b)

```
# best
fmulFunc: # fmulFunc(int a, int b)
swap a and b to loop less times

mul_is_done:
if b is 0 => goto fmul_end

if b[0] is 0 => goto shift
add:
add t0, a0, t0
shift:
shift a0 left once
shift a1 right once
goto mul_is_done

fmul_end:
mv a0, t0
jr ra
```

The test with  $n = 23$  should work for small numbers but overflow with bigger:

- 100F = 37C; 400F = 204C
- 1000F = 25C -> WRONG

$$\begin{aligned}
 \text{nbBits}_{\text{max\_fahrenheit}} + \text{nbBits}_{\text{mult5}} + \text{nbBits}_{\text{magicNumber}} &= \\
 10(\text{max. } 1000 - 32) + 3 + (n - \text{nbBits}_{\text{div9}} + 1) &= \\
 10 + 3 + (16 - 4 + 1) &= \\
 &= 26 \text{ bits}
 \end{aligned} \tag{1}$$

Because, following Equation 1, if  $n$  is 23  $\rightarrow$  equation gives 33 bits, but we are on 32.

*isa/lab-adv-algos*