



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 _{11:0} | 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 _{11:5} | rs2 | rs1 | funct3 | imm _{4:0} | 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

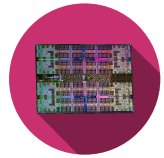
isa/riscv-to-machinecode-05

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)

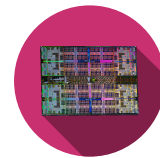
```
# a = b - c;
# d = (e + f) - (g + h);
# s0-s7 = a-h

...

# t0 = 0xffffffffb1
# t1 = 0x000007db
# s0 = 0xffffffff
# s1 = 0x00000002
# s2 = 0x00000003
# s3 = 0xfffff7d6
# s4 = 0xffffffff
# s5 = 0xffffffb2
# 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 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.

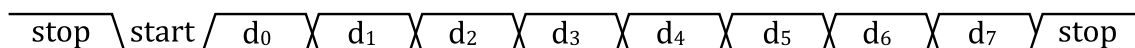


Figure 5: UART serial transmission

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

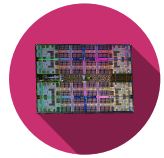
1. UART transmission idea:

```
# 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

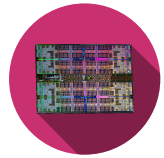
2.4 Branching

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