Module: R2: Intro to RISC-V Assembly
Section: CALL **Task:** RISC-V Function & Pointers

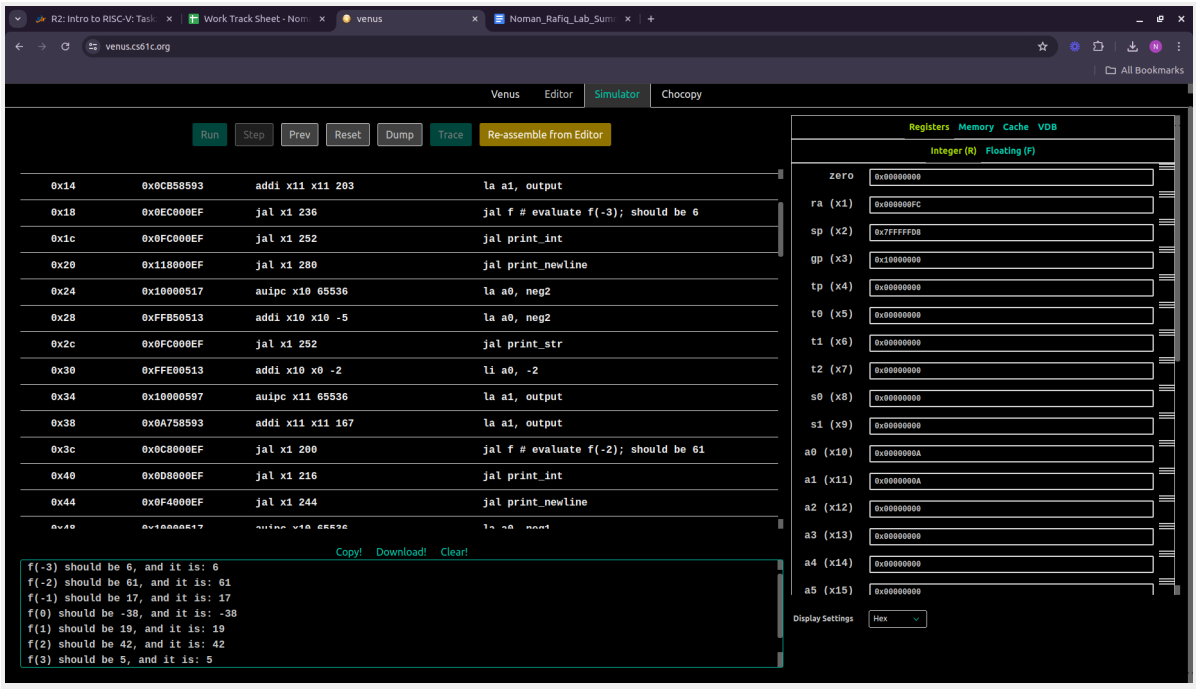
LAB 4 - https://github.com/ImNomanCR7/fa21-lab-starter.git
RISC-V Function & Pointers

Exercise 1: Function without Branches:

- **Code Snippet:**

```
f:
    # YOUR CODE GOES HERE!
    addi a0, a0, 3      # add 3 to a0 to get the index
    slli a0, a0, 2      # shift by 2 bits to calculate offset
    add a1, a1, a0      # a1 = address of output[i]
    lw a0, 0(a1)        # a0 = a[i]
    jr ra               # Always remember to jr ra after your function!
```

Terminal Output:



Exercise 2: Calling Convention Checker

- **Code Snippet:**

```
# Author: Noman Rafiq
# Date: July 2, 2024
# Fixed CC Violations
```

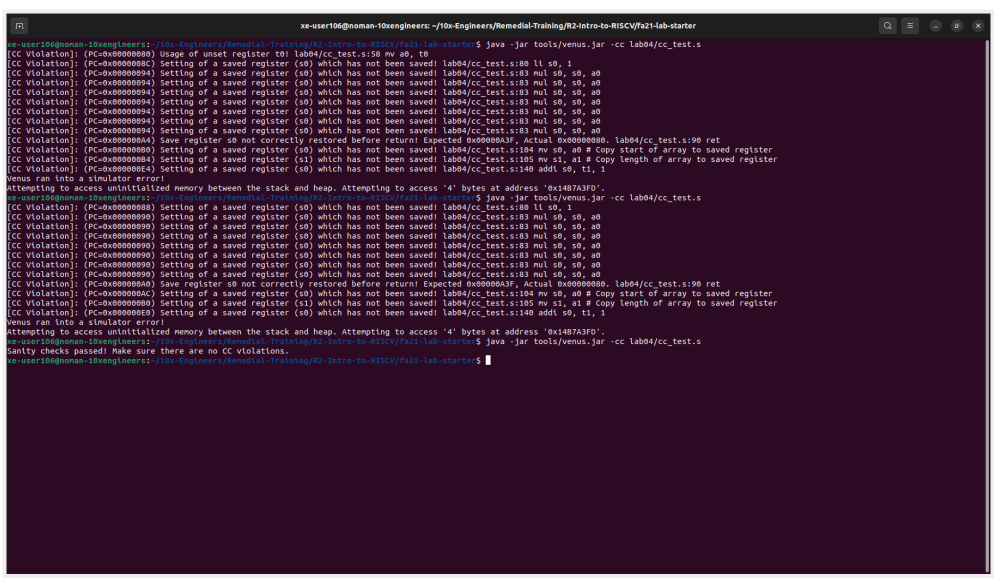
```
.globl simple_fn naive_pow inc_arr

.data
failure_message: .asciiz "Test failed for some reason.\n"
success_message: .asciiz "Sanity checks passed! Make sure there are no
CC violations.\n"
array:
    .word 1 2 3 4 5
exp_inc_array_result:
    .word 2 3 4 5 6

.text
main:
    # We test our program by loading a bunch of random values
    # into a few saved registers - if any of these are modified
    # after these functions return, then we know calling
    # convention was broken by one of these functions
    li s0, 2623
    li s1, 2910
    # ... skipping middle registers so the file isn't too long
    # If we wanted to be rigorous, we would add checks for
    # s2-s10 as well
    li s11, 134
    # Now, we call some functions
    # simple_fn: should return 1
    jal simple_fn # Shorthand for "jal ra, simple_fn"
    li t0, 1
    bne a0, t0, failure
    # naive_pow: should return 2 ** 7 = 128
    li a0, 2
    li a1, 7
    jal naive_pow
    li t0, 128
    bne a0, t0, failure
    # inc_arr: increments "array" in place
    la a0, array
    li a1, 5
    jal inc_arr
    jal check_arr # Verifies inc_arr and jumps to "failure" on failure
    # Check the values in the saved registers for sanity
    li t0, 2623
    li t1, 2910
```

```
    li t2, 134
    bne s0, t0, failure
    bne s1, t1, failure
    bne s11, t2, failure
    # If none of those branches were hit, print a message and exit
normally
    li a0, 4
    la a1, success_message
    ecall
    li a0, 10
    ecall

# Just a simple function. Returns 1.
#
# FIXME Fix the reported error in this function (you can delete lines
# if necessary, as long as the function still returns 1 in a0).
simple_fn:
    li a0, 1
    ret

# Computes a0 to the power of a1.
# This is analogous to the following C pseudocode:
#
# uint32_t naive_pow(uint32_t a0, uint32_t a1) {
#     uint32_t s0 = 1;
#     while (a1 != 0) {
#         s0 *= a0;
#         a1 -= 1;
#     }
#     return s0;
# }
#
# FIXME There's a CC error with this function!
# The big all-caps comments should give you a hint about what's
# missing. Another hint: what does the "s" in "s0" stand for?
naive_pow:
    # BEGIN PROLOGUE
    addi sp, sp, -4
    sw s0, 0(sp)
    # END PROLOGUE
    li s0, 1
naive_pow_loop:
```

```
    beq a1, zero, naive_pow_end
    mul s0, s0, a0
    addi a1, a1, -1
    j naive_pow_loop
naive_pow_end:
    mv a0, s0
    # BEGIN EPILOGUE
    lw s0, 0(sp)
    addi sp, sp, 4
    # END EPILOGUE
    ret

# Increments the elements of an array in-place.
# a0 holds the address of the start of the array, and a1 holds
# the number of elements it contains.
#
# This function calls the "helper_fn" function, which takes in an
# address as argument and increments the 32-bit value stored there.
inc_arr:
    # BEGIN PROLOGUE
    # FIXME What other registers need to be saved? s0 & s1!
    addi sp, sp, -12
    sw ra, 0(sp)
    sw s0, 4(sp)
    sw s1, 8(sp)
    # END PROLOGUE
    mv s0, a0 # Copy start of array to saved register
    mv s1, a1 # Copy length of array to saved register
    li t0, 0 # Initialize counter to 0
inc_arr_loop:
    beq t0, s1, inc_arr_end
    slli t1, t0, 2 # Convert array index to byte offset
    add a0, s0, t1 # Add offset to start of array
    # Prepare to call helper_fn
    addi sp, sp, -4
    sw t0, 0(sp)
    # FIXME Add code to preserve the value in t0 before we call
helper_fn
    # Hint: What does the "t" in "t0" stand for?
    # Also ask yourself this: why don't we need to preserve t1?
    #
    jal helper_fn
```

```
    # Finished call for helper_fn
    lw t0, 0(sp)
    addi sp, sp, 4
    addi t0, t0, 1 # Increment counter
    j inc_arr_loop
inc_arr_end:
    # BEGIN EPILOGUE
    lw ra, 0(sp)
    lw s0, 4(sp)
    lw s1, 8(sp)
    addi sp, sp, 12
    # END EPILOGUE
    ret

# This helper function adds 1 to the value at the memory address in a0.
# It doesn't return anything.
# C pseudocode for what it does: "*a0 = *a0 + 1"
#
# FIXME This function also violates calling convention, but it might not
# be reported by the Venus CC checker (try and figure out why).
# You should fix the bug anyway by filling in the prologue and epilogue
# as appropriate.
helper_fn:
    # BEGIN PROLOGUE
    addi sp, sp, -4
    sw s0, 0(sp)
    # END PROLOGUE
    lw t1, 0(a0)
    addi s0, t1, 1
    sw s0, 0(a0)
    # BEGIN EPILOGUE
    lw s0, 0(sp)
    addi sp, sp, 4
    # END EPILOGUE
    ret

# YOU CAN IGNORE EVERYTHING BELOW THIS COMMENT

# Checks the result of inc_arr, which should contain 2 3 4 5 6 after
# one call.
# You can safely ignore this function; it has no errors.
check_arr:
```

```
    la t0, exp_inc_array_result
    la t1, array
    addi t2, t1, 20 # Last element is 5*4 bytes off
check_arr_loop:
    beq t1, t2, check_arr_end
    lw t3, 0(t0)
    lw t4, 0(t1)
    bne t3, t4, failure
    addi t0, t0, 4
    addi t1, t1, 4
    j check_arr_loop
check_arr_end:
    ret


# This isn't really a function - it just prints a message, then
# terminates the program on failure. Think of it like an exception.
failure:
    li a0, 4 # String print ecall
    la a1, failure_message
    ecall
    li a0, 10 # Exit ecall
    ecall
```



- **What caused the errors in simple_fn, naive_pow, and inc_arr that were reported by the Venus CC checker?**
  - **simple_fn: t0** was used before it was initialized.

    - **naive_pow:** Missing epilogue and prologues.
    - **inc_arr:** Failure to save **s0**, **s1** in prologue/epilogue, and failure to save **t0** before calling **helper_fn**.

- **In RISC-V, we call functions by jumping to them and storing the return address in the ra register. Does calling convention apply to the jumps to the naive_pow_loop or naive_pow_end labels?**
    - No, since they're not functions, we don't need to return to the location the function was called from.

- **Why do we need to store ra in the prologue for inc_arr, but not in any other Function?**
    - inc_arr itself calls another function so it is a caller as well.
    - Since **ra** holds the address of the instruction to continue executing after returning, which is overwritten when we call another function. Therefore we need to save the **ra** before it is overwritten by another call.

- **Why wasn't the calling convention error in helper_fn reported by the CC checker?**
    - Because it is not declared **.globl.**

Exercise 3: Debugging:

- **Code Snippet:**

```
.globl map

.data
arrays: .word 5, 6, 7, 8, 9
        .word 1, 2, 3, 4, 7
        .word 5, 2, 7, 4, 3
        .word 1, 6, 3, 8, 4
        .word 5, 2, 7, 8, 1

start_msg:  .asciiz "Lists before: \n"
end_msg:    .asciiz "Lists after: \n"

.text
main:
    jal create_default_list
    mv s0, a0   # v0 = s0 is head of node list
```

```
    #print "lists before: "
    la a1, start_msg
    li a0, 4
    ecall

    #print the list
    add a0, s0, x0
    jal print_list

    # print a newline
    jal print_newline

    # issue the map call
    add a0, s0, x0      # load the address of the first node into a0
    la  a1, mystery     # load the address of the function into a1

    jal map

    # print "lists after: "
    la a1, end_msg
    li a0, 4
    ecall

    # print the list
    add a0, s0, x0
    jal print_list

    li a0, 10
    ecall

map:
    addi sp, sp, -16
    sw ra, 0(sp)
    sw s1, 4(sp)
    sw s0, 8(sp)

    beq a0, x0, done    # if we were given a null pointer, we're done.

    add s0, a0, x0      # save address of this node in s0
    add s1, a1, x0      # save address of function in s1
    add t0, x0, x0      # t0 is a counter
```

```
    # remember that each node is 12 bytes long:
    # - 4 for the array pointer
    # - 4 for the size of the array
    # - 4 more for the pointer to the next node

    # also keep in mind that we should not make ANY assumption on which
registers
    # are modified by the callees, even when we know the content inside
the functions
    # we call. this is to enforce the abstraction barrier of calling
convention.
mapLoop:
    lw t1, 0(s0)      # load the address of the array of current node
into t1
    lw t2, 4(s0)        # load the size of the node's array into t2

    slli t3, t0, 2
    add t3, t1, t3      # offset the array address by the count
    lw a0, 0(t3)        # load the value at that address into a0

    jalr s1             # call the function on that value.

    sw a0, 0(t3)        # store the returned value back into the array

    addi t0, t0, 1      # increment the count
    bne t0, t2, mapLoop # repeat if we haven't reached the array size
yet

    lw a0, 8(s0)        # load the address of the next node into a0
    mv a1, s1           # put the address of the function back into a1
to prepare for the recursion

    jal  map            # recurse
done:
    lw s0, 8(sp)
    lw s1, 4(sp)
    lw ra, 0(sp)
    addi sp, sp, 16

print_newline:
    li a1, '\n'
```

```
    li a0, 11
    ecall
    jr ra

mystery:
    mul t1, a0, a0
    add a0, t1, a0
    jr ra

create_default_list:
    addi sp, sp, -24
    sw ra, 0(sp)
    sw s0, 4(sp)
    sw s1, 8(sp)
    sw s2, 12(sp)
    sw s3, 16(sp)
    sw s4, 20(sp)
    li s0, 0  # pointer to the last node we handled
    li s1, 0  # number of nodes handled
    li s2, 5  # size
    la s3, arrays
loop: #do...
    li a0, 12
    jal malloc      # get memory for the next node
    mv s4, a0
    li a0, 20
    jal  malloc     # get memory for this array

    sw a0, 0(s4)    # node->arr = malloc
    lw a0, 0(s4)
    mv a1, s3
    jal fillArray   # copy ints over to node->arr

    sw s2, 4(s4)    # node->size = size (4)
    sw  s0, 8(s4)   # node-> next = previously created node

    add s0, x0, s4  # last = node
    addi s1, s1, 1  # i++
    addi s3, s3, 20 # s3 points at next set of ints
    li t6 5
    bne s1, t6, loop # ... while i!= 5
    mv a0, s4
```

```
    lw ra, 0(sp)
    lw s0, 4(sp)
    lw s1, 8(sp)
    lw s2, 12(sp)
    lw s3, 16(sp)
    lw s4, 20(sp)
    addi sp, sp, 24
    jr ra

fillArray: lw t0, 0(a1) #t0 gets array element
    sw t0, 0(a0) #node->arr gets array element
    lw t0, 4(a1)
    sw t0, 4(a0)
    lw t0, 8(a1)
    sw t0, 8(a0)
    lw t0, 12(a1)
    sw t0, 12(a0)
    lw t0, 16(a1)
    sw t0, 16(a0)
    jr ra

print_list:
    bne a0, x0, printMeAndRecurse
    jr ra   # nothing to print
printMeAndRecurse:
    mv t0, a0 # t0 gets address of current node
    lw t3, 0(a0) # t3 gets array of current node
    li t1, 0  # t1 is index into array
printLoop:
    slli t2, t1, 2
    add t4, t3, t2
    lw a1, 0(t4) # a0 gets value in current node's array at index t1
    li a0, 1  # preparte for print integer ecall
    ecall
    li a1, ' ' # a0 gets address of string containing space
    li a0, 11  # prepare for print string ecall
    ecall
    addi t1, t1, 1
  li t6 5
    bne t1, t6, printLoop # ... while i!= 5
    li a1, '\n'
    li a0, 11
```

```
    ecall
    lw a0, 8(t0) # a0 gets address of next node
    j print_list # recurse. We don't have to use jal because we already have where we want to return to in ra

malloc:
    mv a1, a0 # Move a0 into a1 so that we can do the syscall correctly
    li a0, 9
    ecall
    jr ra
```

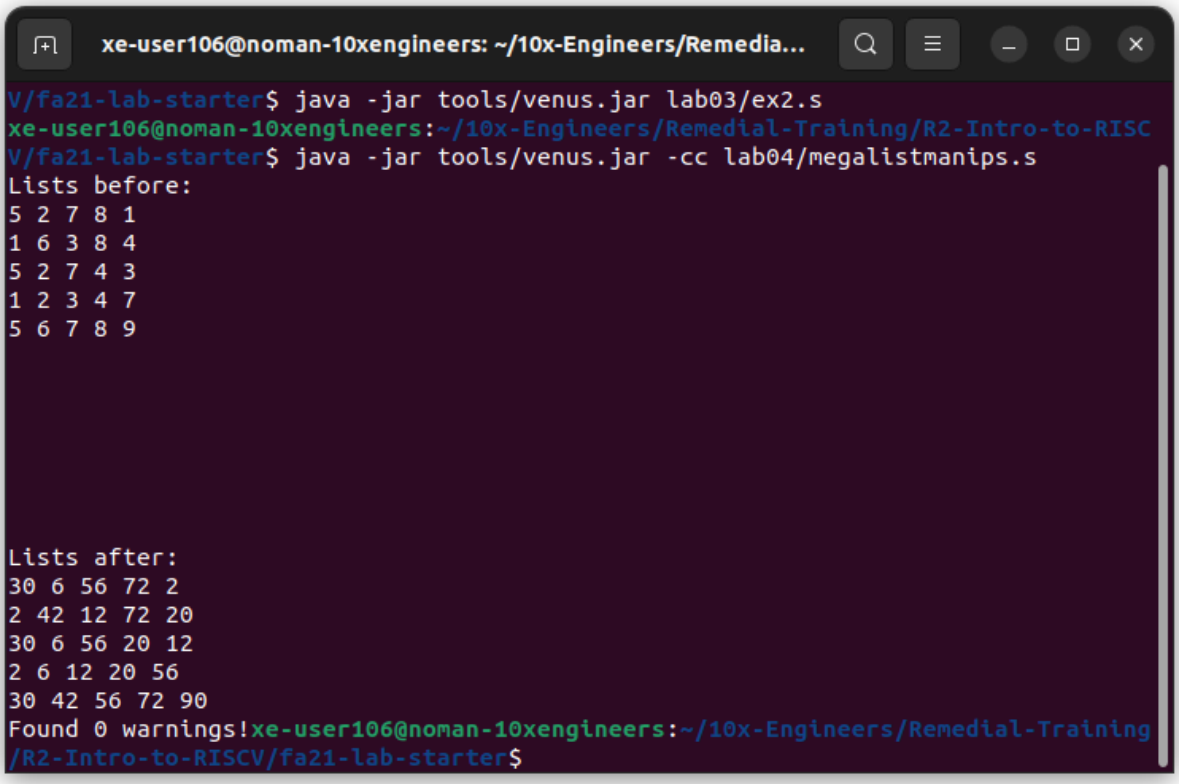
Terminal Output:

Action Items:

- **Find the six mistakes inside the map function in megalistmanips.s.**
    - In the **map** label (line 2) the stack space allocated was of 12 bytes but we need actually 16 bytes since each node is of 12 bytes (- 4 for the array pointer - 4 for the size of the array - 4 more for the pointer to the next node) we need to save these 12 bytes plus the return address on the stack. Total of 16 bytes required.
    - In the **mapLoop** label we have to load the address of the array of current node into **t1**. So in order to load the address into **t1** we should use **lw** instead of add Instruction.
    - In the **mapLoop** label we have to offset the array address by the count but here we are just adding the count to the address and not adding the offset at all.
    - In the **mapLoop** label we have to load the address of next node in **a0** so instead of using the **la** here which takes the label as an input we should use **lw** instructions here.

- In line 84 we have to put the address back into **a1**. We should just use **mv** instructions to copy the address back into a1.
- In the **done** label the stack space deallocated should be of 16 bytes rather than 12 bytes and at the end the it should return back to function. So **ret** instructions should be added at the end.

After resolving the above bugs, the code execution using -cc to check for calling convention violations. Here's the output:



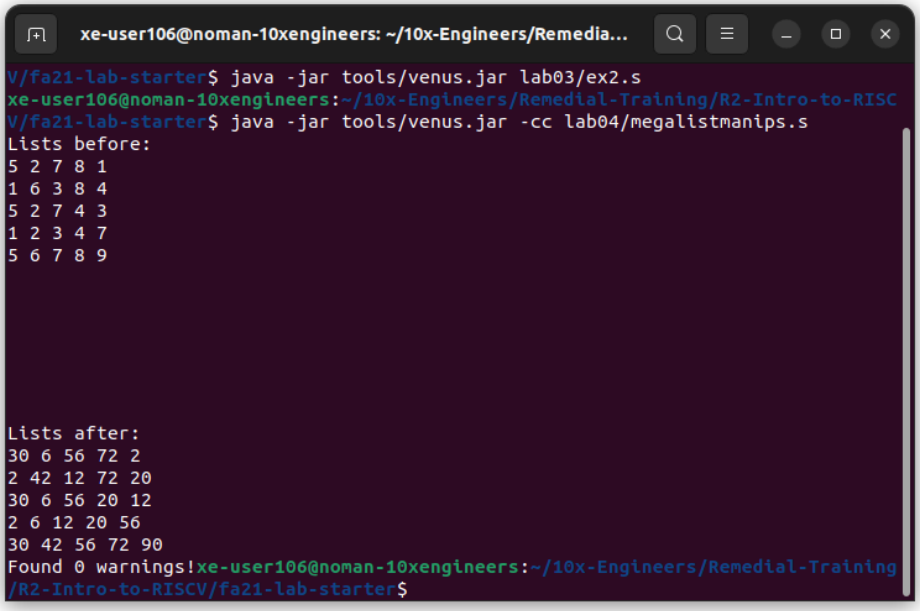
- **For this exercise, we are requiring that you don't use any extra save registers in your implementation. While you normally can use the save registers to store values that you want to use after returning from a function (in this case, when we're calling f in map), we want you to use temporary registers instead and follow their caller/callee conventions. The provided map implementation only uses the s0 and s1 registers, so we'll require that you don't use s2-s11.**

    - Yes! I have not used any saved register other than **s0** and **s1** but I have used a temporary register **t3** to preserve the value of **t1** when **jalr s1** was called.

- **Make an ordered list of each of the six mistakes in the megalistmanips_answers.txt file, and the corrections you made to fix them.**
    - Please refer to the attached **megalistmanips_answers.txt** file. Alternatively, you can find the file here:

      https://github.com/ImNomanCR7/fa21-lab-starter/blob/main/lab04/megalistmanips_answers.txt

- **Save your corrected code in the megalistmanips.s file. Use the -cc flag to run a basic calling convention check on your code locally:**



Exercise 4: Finding and Solving Bugs:

Action Items:

1. **Find the bugs in four of the five accumulators.**
    - **accumulatorone:** In this accumulator the **s0** register was not saved onto the stack before it was used and so the value of **s0** was not preserved.
    - **accumulatortwo:** The stack pointer is incremented by four in the prologue, and decremented by four in the epilogue. This breaks the stack of the caller.
    - **accumulatorthree:** This accumulator is correct there is no issue in it.
    - **accumulatorfour:** The function relies on **t2** being set to zero before running. Otherwise, it returns t2 plus the desired sum.

- **accumulatorfive:** The function doesn't check if the first element is zero. As such, it fails to provide the correct result if the first element is zero, and if the second element is nonzero.

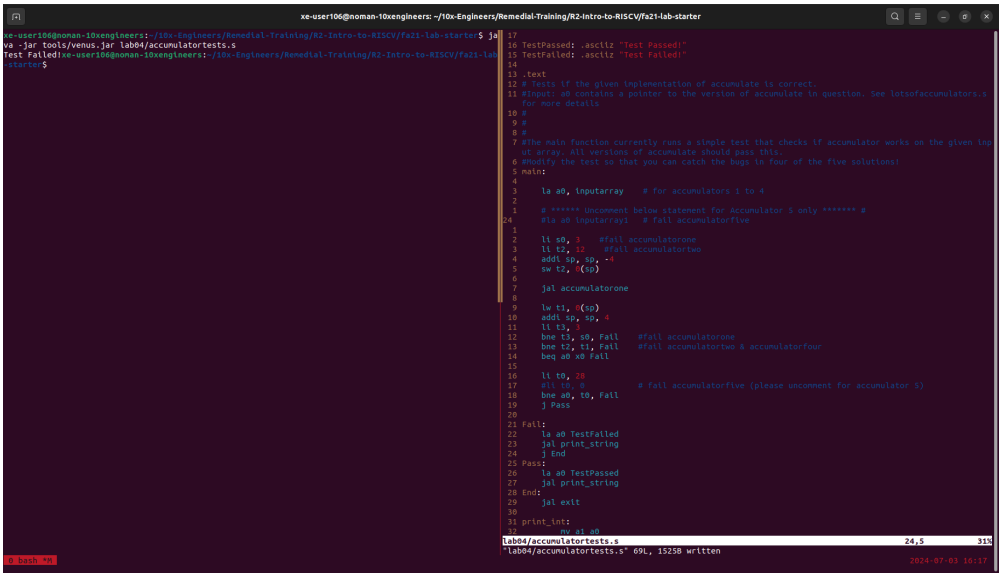
2. **For each broken accumulator, write a test that fails on the broken one, but passes the correct implementation.**
   - ➢ **Code Snippet:**

```
.import lotsofaccumulators.s

.data
inputarray: .word 1,2,3,4,5,6,7,0
inputarray1: .word 0,1,2,3,4,5,6,7,0


TestPassed: .asciiz "Test Passed!"
TestFailed: .asciiz "Test Failed!"

.text
# Tests if the given implementation of accumulate is
correct.
#Input: a0 contains a pointer to the version of accumulate
in question. See lotsofaccumulators.s for more details
#
#
#
#The main function currently runs a simple test that checks
if accumulator works on the given input array. All versions
of accumulate should pass this.
#Modify the test so that you can catch the bugs in four of
the five solutions!
main:

    la a0, inputarray    # for accumulators 1 to 4

    # ****** Uncomment below statement for Accumulator 5
only ******* #
    la a0 inputarray1   # fail accumulatorfive

    li s0, 3    #fail accumulatorone
    li t2, 12    #fail accumulatortwo
    addi sp, sp, -4
```

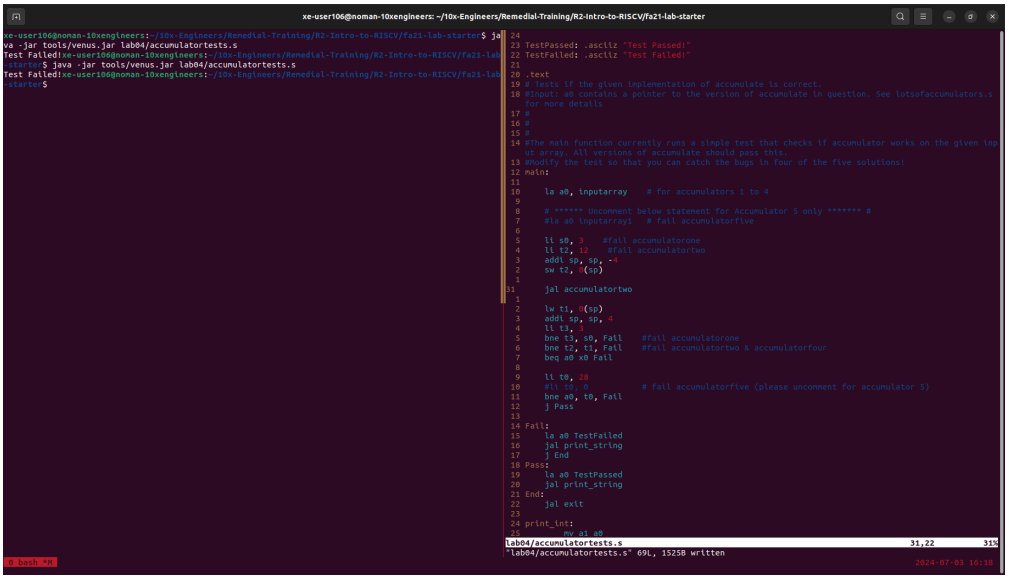
```
    sw t2, 0(sp)

    jal accumulatorfive

    lw t1, 0(sp)
    addi sp, sp, 4
    li t3, 3
    bne t3, s0, Fail    #fail accumulatorone
    bne t2, t1, Fail    #fail accumulatortwo &
accumulatorfour
    beq a0 x0 Fail

    li t0, 28
    li t0, 0           # fail accumulatorfive (please
uncomment for accumulator 5)
    bne a0, t0, Fail
    j Pass

Fail:
    la a0 TestFailed
    jal print_string
    j End
Pass:
    la a0 TestPassed
    jal print_string
End:
    jal exit

print_int:
      mv a1 a0
    li a0 1
    ecall
    jr ra

print_string:
      mv a1 a0
    li a0 4
    ecall
    jr ra

exit:
    li a0 10
```

```
    ecall
```

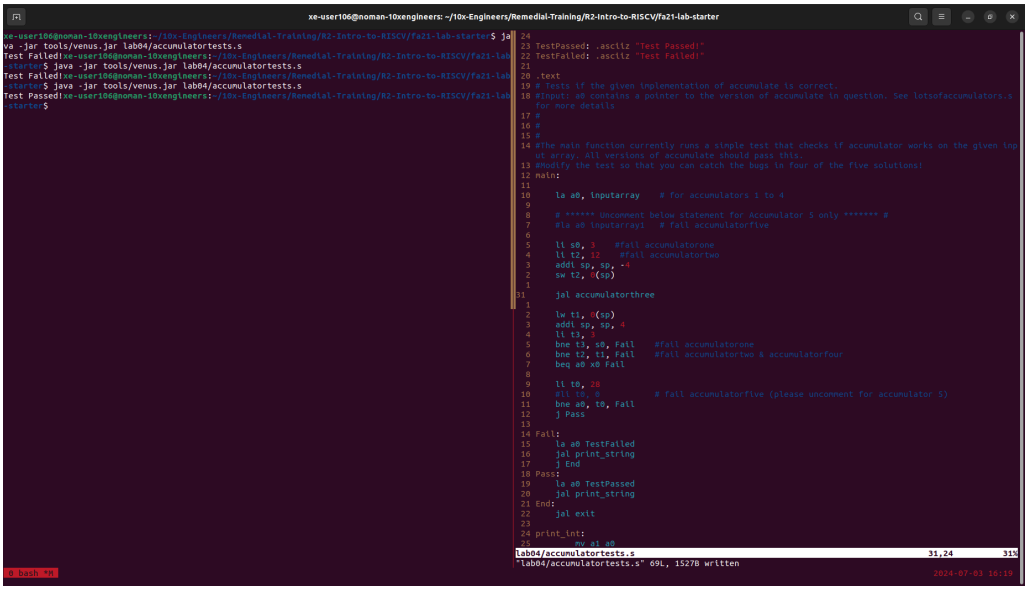
3. **Terminal Outputs for the Accumulators.**
   - **accumulatorone:**



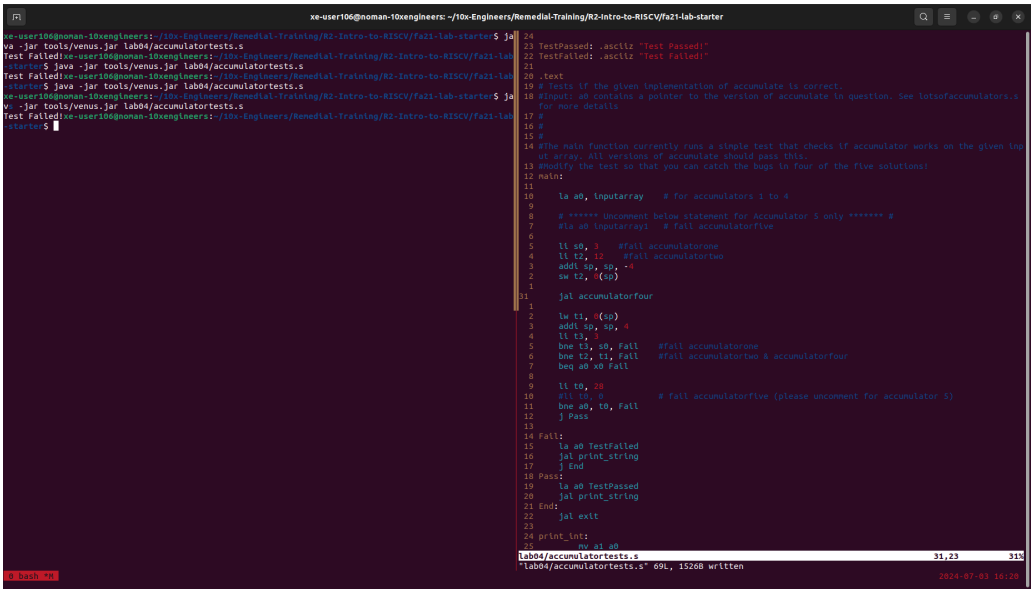
   - **accumulatortwo:**



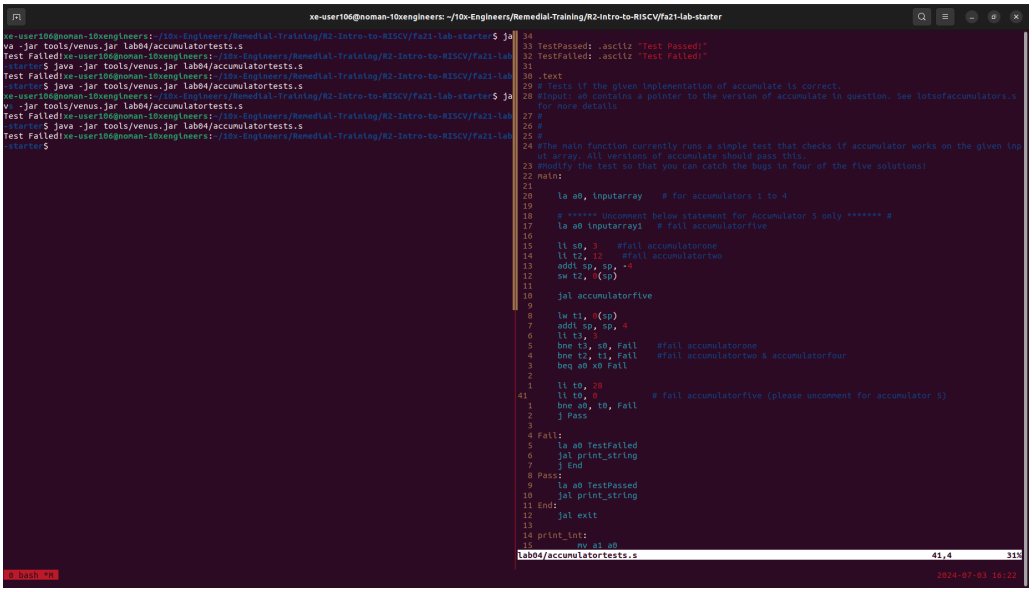
   - **accumulatorthree:**



- **accumulatorfour:**



- **accumulatorfive:**


xe-user106@noman-10xengineers: ~/10x-Engineers/Remedial-Training/R2-Intro-to-RISCV/fa21-lab-starter
xe-user106@noman-10xengineers:~/10x-Engineers/Remedial-Training/R2-Intro-to-RISCV/fa21-lab-starter$ java -jar tools/venus.jar lab04/accumulatortests.s
Test Failed!
xe-user106@noman-10xengineers:~/10x-Engineers/Remedial-Training/R2-Intro-to-RISCV/fa21-lab-starter$ java -jar tools/venus.jar lab04/accumulatortests.s
Test Failed!
xe-user106@noman-10xengineers:~/10x-Engineers/Remedial-Training/R2-Intro-to-RISCV/fa21-lab-starter$ java -jar tools/venus.jar lab04/accumulatortests.s
Test Failed!
xe-user106@noman-10xengineers:~/10x-Engineers/Remedial-Training/R2-Intro-to-RISCV/fa21-lab-starter$
TestPassed: .asciiz "Test Passed!"
TestFailed: .asciiz "Test Failed!"
.text
tests if the given implementation of accumulate is correct.
#input: a0 contains a pointer to the version of accumulate in question. See lotsofaccumulators.s for more details
#
#
#
#The main function currently runs a simple test that checks if accumulator works on the given input array. All versions of accumulate should pass this.
#Modify the test so that you can catch the bugs in four of the five solutions!
main:
la a0, inputarray # for accumulators 1 to 4
****** Uncomment below statement for Accumulator 5 only *******
la a0 inputarray1 # fail accumulatorfive
li s0, 1 #fail accumulatorone
li t2, 12 #fail accumulatortwo
addi sp, sp, -4
sw t2, 0(sp)
jal accumulatorfive
lw t1, 0(sp)
addi sp, sp, 4
li t3, 1
bne t3, s0, Fail #Fail accumulatorone
bne t2, t1, Fail #Fail accumulatortwo & accumulatorfour
beq a0 x0 Fail
li t0, 28
li t0, 0 # fail accumulatorfive (please uncomment for accumulator 5)
bne a0, t0, Fail
j Pass
Fail:
la a0 TestFailed
jal print_string
j End
Pass:
la a0 TestPassed
jal print_string
End:
jal exit
print_int:
mv a1 a0
lab04/accumulatortests.s 41,4 31%
0 bash "M
2024-07-03 16:22