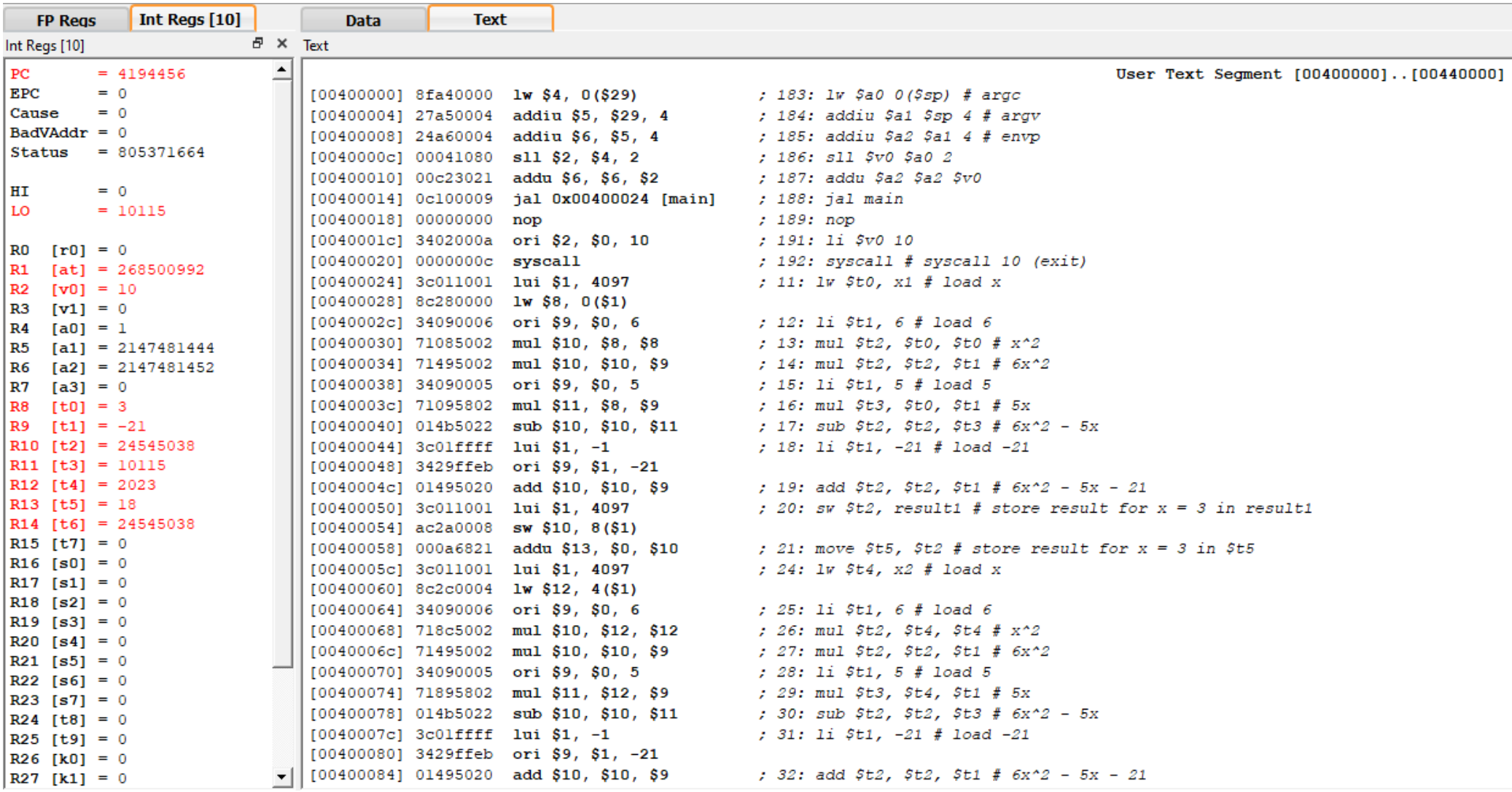
Part 1 – MIPS Arithmeticand Code Optimization. **Relevant assembly files: part1_q1-3.s , part1_q4-6.s**

- **Q1**: There are 22 instruction, 11 for each value of x
- **Q2:**

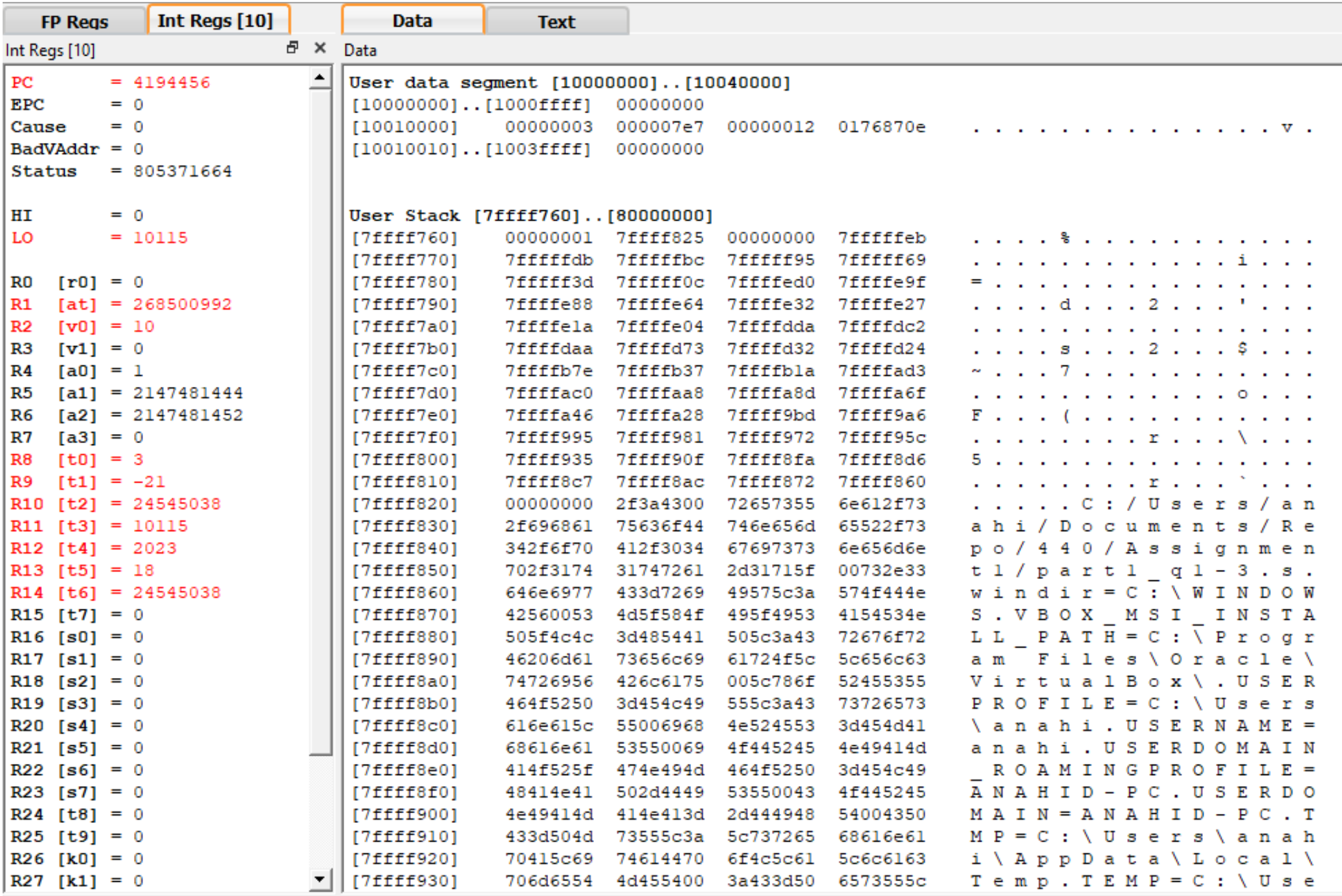
```
.data
x1: .word 3 # x = 3
x2: .word 2023 # x = 2023
result1: .word 0 # store result for x = 3
result2: .word 0 # store result for x = 2023

.text
.globl main
main:
    # evaluate f(x) for x = 3
    lw $t0, x1 # load x
    li $t1, 6 # load 6
    mul $t2, $t0, $t0 # x^2
    mul $t2, $t2, $t1 # 6x^2
    li $t1, 5 # load 5
    mul $t3, $t0, $t1 # 5x
    sub $t2, $t2, $t3 # 6x^2 - 5x
    li $t1, -21 # load -21
    add $t2, $t2, $t1 # 6x^2 - 5x - 21
    sw $t2, result1 # store result for x = 3 in result1
    move $t5, $t2  # store result for x = 3 in $t5

    # evaluate f(x) for x = 2023
    lw $t4, x2    # load x
    li $t1, 6       # load 6
    mul $t2, $t4, $t4   # x^2
    mul $t2, $t2, $t1   # 6x^2
    li $t1, 5       # load 5
    mul $t3, $t4, $t1   # 5x
```

```
sub $t2, $t2, $t3   # 6x^2 - 5x
li $t1, -21     # load -21
add $t2, $t2, $t1   # 6x^2 - 5x - 21
sw $t2, result2  # store result for x = 2023 in result2
move $t6, $t2  # store result for x = 2023 in $t6

# exit
li $v0, 10
syscall
```

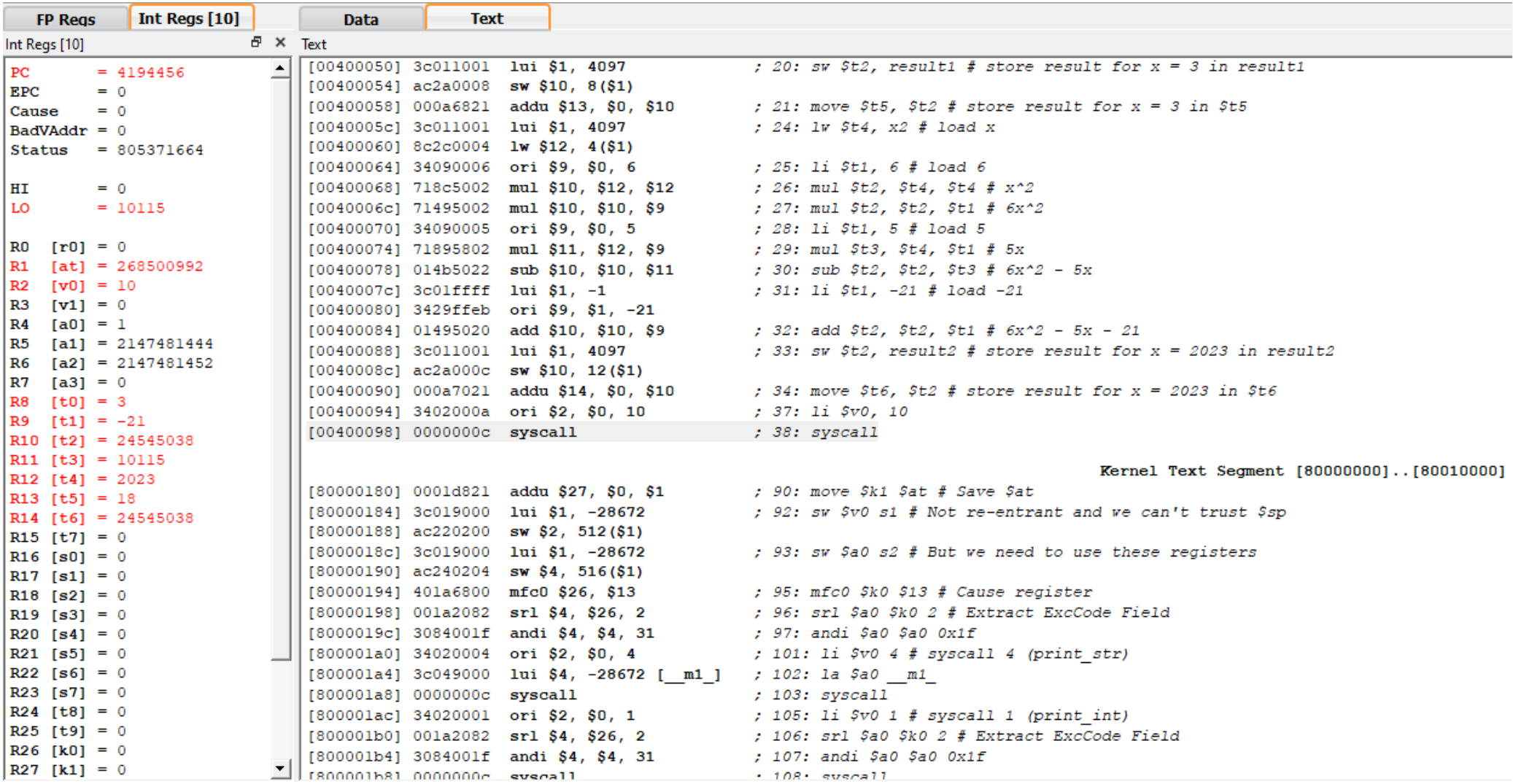
- **Q3:**
    - **a:** the value of f(3) is stored in R13 [t5] = 18



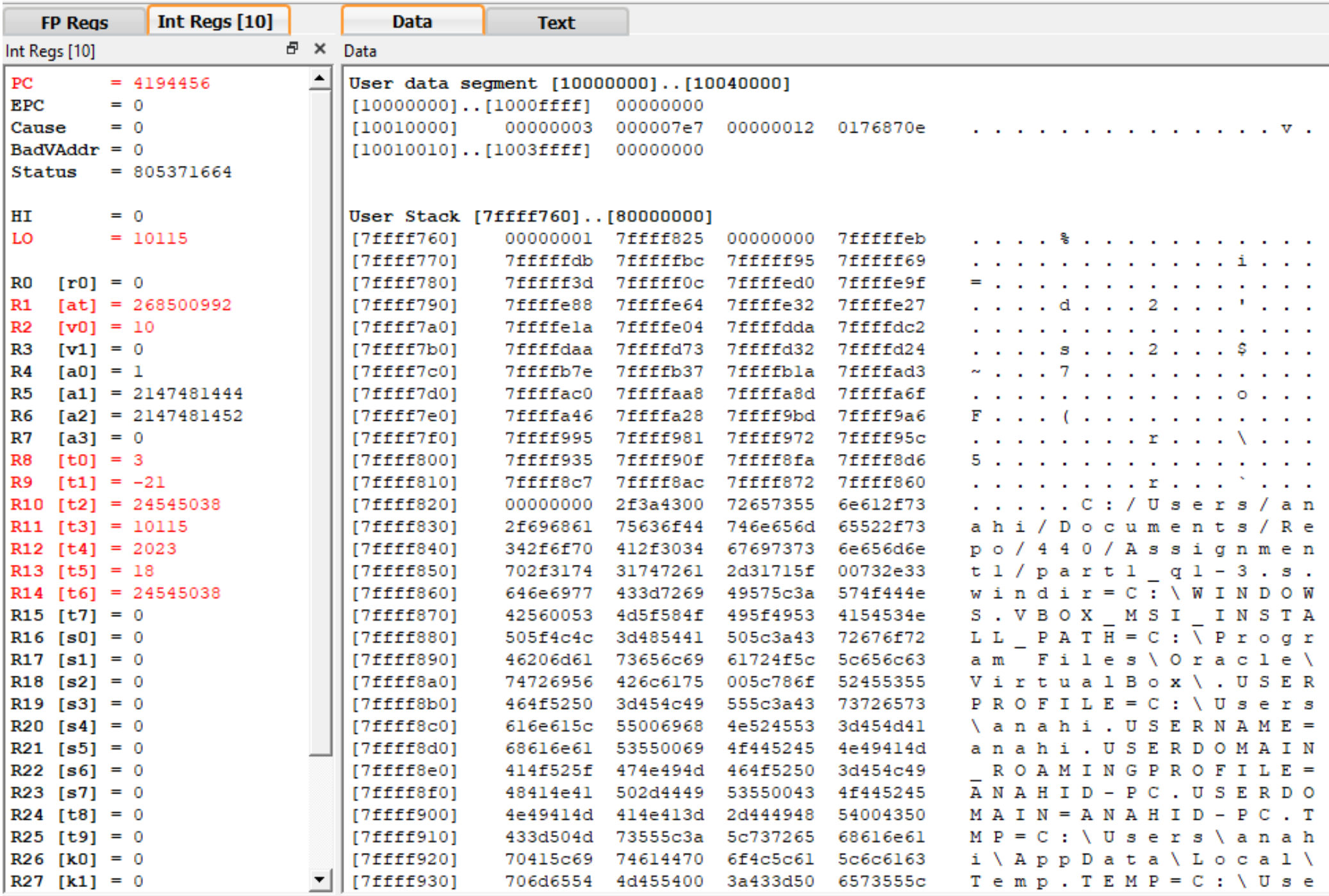
- **b:** the value of f(3) is stored in R13 [t5] = 18


FP Regs
Int Regs [10]
Data
Text
Int Regs [10]
Data
PC = 4194456
EPC = 0
Cause = 0
BadVAddr = 0
Status = 805371664
HI = 0
LO = 10115
R0 [r0] = 0
R1 [at] = 268500992
R2 [v0] = 10
R3 [v1] = 0
R4 [a0] = 1
R5 [a1] = 2147481444
R6 [a2] = 2147481452
R7 [a3] = 0
R8 [t0] = 3
R9 [t1] = -21
R10 [t2] = 24545038
R11 [t3] = 10115
R12 [t4] = 2023
R13 [t5] = 18
R14 [t6] = 24545038
R15 [t7] = 0
R16 [s0] = 0
R17 [s1] = 0
R18 [s2] = 0
R19 [s3] = 0
R20 [s4] = 0
R21 [s5] = 0
R22 [s6] = 0
R23 [s7] = 0
R24 [t8] = 0
R25 [t9] = 0
R26 [k0] = 0
R27 [k1] = 0
User data segment [10000000]..[10040000]
[10000000]..[1000ffff] 00000000
[10010000] 00000003 000007e7 00000012 0176870e . . . . . v .
[10010010]..[1003ffff] 00000000
User Stack [7ffff760]..[80000000]
[7ffff760] 00000001 7ffff825 00000000 7fffffeb . . . . % . . . . . .
[7ffff770] 7fffffdb 7fffffbc 7fffff95 7fffff69 . . . . . i . . .
[7ffff780] 7fffff3d 7fffff0c 7ffffed0 7ffffe9f = ...
[7ffff790] 7ffffe88 7ffffe64 7ffffe32 7ffffe27 . . . . d . . . 2 . . . ' . . .
[7ffff7a0] 7ffffe1a 7ffffe04 7ffffdda 7ffffdc2 . . . . . .
[7ffff7b0] 7ffffdaa 7ffffd73 7ffffd32 7ffffd24 . . . . s . . . 2 . . . $ . . .
[7ffff7c0] 7ffffb7e 7ffffb37 7ffffb1a 7ffffad3 ~ . . . 7 . . . . . .
[7ffff7d0] 7ffffac0 7ffffaa8 7ffffa8d 7ffffa6f . . . . . o . . .
[7ffff7e0] 7ffffa46 7ffffa28 7ffff9bd 7ffff9a6 F . . . (. . . . . .
[7ffff7f0] 7ffff995 7ffff981 7ffff972 7ffff95c . . . . . r . . . \ . . .
[7ffff800] 7ffff935 7ffff90f 7ffff8fa 7ffff8d6 5 . . . . . .
[7ffff810] 7ffff8c7 7ffff8ac 7ffff872 7ffff860 . . . . . r . . . ` . . .
[7ffff820] 00000000 2f3a4300 72657355 6e612f73 . . . . C : / U s e r s / a n
[7ffff830] 2f696861 75636f44 746e656d 65522f73 a h i / D o c u m e n t s / R e
[7ffff840] 342f6f70 412f3034 67697373 6e656d6e p o / 4 4 0 / A s s i g n m e n
[7ffff850] 702f3174 31747261 2d31715f 00732e33 t 1 / p a r t 1 _ q 1 - 3 . s .
[7ffff860] 646e6977 433d7269 49575c3a 574f444e w i n d i r = C : \ W I N D O W
[7ffff870] 42560053 4d5f584f 495f4953 4154534e S . V B O X _ M S I _ I N S T A
[7ffff880] 505f4c4c 3d485441 505c3a43 72676f72 L L _ P A T H = C : \ P r o g r
[7ffff890] 46206d61 73656c69 61724f5c 5c656c63 a m _ F i l e s \ O r a c l e \
[7ffff8a0] 74726956 426c6175 005c786f 52455355 V i r t u a l B o x \ . U S E R
[7ffff8b0] 464f5250 3d454c49 555c3a43 73726573 P R O F I L E = C : \ U s e r s
[7ffff8c0] 616e615c 55006968 4e524553 3d454d41 \ a n a h i . U S E R N A M E =
[7ffff8d0] 68616e61 53550069 4f445245 4e49414d a n a h i . U S E R D O M A I N
[7ffff8e0] 414f525f 474e494d 464f5250 3d454c49 _ R O A M I N G P R O F I L E =
[7ffff8f0] 48414e41 502d4449 53550043 4f445245 A N A H I D - P C . U S E R D O
[7ffff900] 4e49414d 414e413d 2d444948 54004350 M A I N = A N A H I D - P C . T
[7ffff910] 433d504d 73555c3a 5c737265 68616e61 M P = C : \ U s e r s \ a n a h
[7ffff920] 70415c69 74614470 6f4c5c61 5c6c6163 i \ A p p D a t a \ L o c a l \
[7ffff930] 706d6554 4d455400 3a433d50 6573555c T e m p . T E M P = C : \ U s e

- **c:** the value of f(2023) is stored in R14 [t6] = 24545038



- **d:** the value of f(2023) is stored in R14 [t6] = 24545038


FP Regs
Int Regs [10]
Data
Text
Int Regs [10]
Data
PC = 4194456
EPC = 0
Cause = 0
BadVAddr = 0
Status = 805371664
HI = 0
LO = 10115
R0 [r0] = 0
R1 [at] = 268500992
R2 [v0] = 10
R3 [v1] = 0
R4 [a0] = 1
R5 [a1] = 2147481444
R6 [a2] = 2147481452
R7 [a3] = 0
R8 [t0] = 3
R9 [t1] = -21
R10 [t2] = 24545038
R11 [t3] = 10115
R12 [t4] = 2023
R13 [t5] = 18
R14 [t6] = 24545038
R15 [t7] = 0
R16 [s0] = 0
R17 [s1] = 0
R18 [s2] = 0
R19 [s3] = 0
R20 [s4] = 0
R21 [s5] = 0
R22 [s6] = 0
R23 [s7] = 0
R24 [t8] = 0
R25 [t9] = 0
R26 [k0] = 0
R27 [k1] = 0
User data segment [10000000]..[10040000]
[10000000]..[1000ffff] 00000000
[10010000] 00000003 000007e7 00000012 0176870e . . . . . v .
[10010010]..[1003ffff] 00000000
User Stack [7ffff760]..[80000000]
[7ffff760] 00000001 7ffff825 00000000 7fffffeb . . . . % . . . . . .
[7ffff770] 7fffffdb 7fffffbc 7fffff95 7fffff69 . . . . . i . . .
[7ffff780] 7fffff3d 7fffff0c 7ffffed0 7ffffe9f = ...
[7ffff790] 7ffffe88 7ffffe64 7ffffe32 7ffffe27 . . . . d . . . 2 . . . ' . . .
[7ffff7a0] 7ffffe1a 7ffffe04 7ffffdda 7ffffdc2 . . . . . .
[7ffff7b0] 7ffffdaa 7ffffd73 7ffffd32 7ffffd24 . . . . s . . . 2 . . . $ . . .
[7ffff7c0] 7ffffb7e 7ffffb37 7ffffb1a 7ffffad3 ~ . . . 7 . . . . . .
[7ffff7d0] 7ffffac0 7ffffaa8 7ffffa8d 7ffffa6f . . . . . o . . .
[7ffff7e0] 7ffffa46 7ffffa28 7ffff9bd 7ffff9a6 F . . . (. . . . . .
[7ffff7f0] 7ffff995 7ffff981 7ffff972 7ffff95c . . . . . r . . . \ . . .
[7ffff800] 7ffff935 7ffff90f 7ffff8fa 7ffff8d6 5 . . . . . .
[7ffff810] 7ffff8c7 7ffff8ac 7ffff872 7ffff860 . . . . . r . . . ` . . .
[7ffff820] 00000000 2f3a4300 72657355 6e612f73 . . . . . C : / U s e r s / a n
[7ffff830] 2f696861 75636f44 746e656d 65522f73 a h i / D o c u m e n t s / R e
[7ffff840] 342f6f70 412f3034 67697373 6e656d6e p o / 4 4 0 / A s s i g n m e n
[7ffff850] 702f3174 31747261 2d31715f 00732e33 t l / p a r t l _ q l - 3 . s .
[7ffff860] 646e6977 433d7269 49575c3a 574f444e w i n d i r = C : \ W I N D O W
[7ffff870] 42560053 4d5f584f 495f4953 4154534e S . V B O X _ M S I _ I N S T A
[7ffff880] 505f4c4c 3d485441 505c3a43 72676f72 L L _ P A T H = C : \ P r o g r
[7ffff890] 46206d61 73656c69 61724f5c 5c656c63 a m _ F i l e s \ O r a c l e \
[7ffff8a0] 74726956 426c6175 005c786f 52455355 V i r t u a l B o x \ . U S E R
[7ffff8b0] 464f5250 3d454c49 555c3a43 73726573 P R O F I L E = C : \ U s e r s
[7ffff8c0] 616e615c 55006968 4e524553 3d454d41 \ a n a h i . U S E R N A M E =
[7ffff8d0] 68616e61 53550069 4f445245 4e49414d a n a h i . U S E R D O M A I N
[7ffff8e0] 414f525f 474e494d 464f5250 3d454c49 _ R O A M I N G P R O F I L E =
[7ffff8f0] 48414e41 502d4449 53550043 4f445245 A N A H I D - P C . U S E R D O
[7ffff900] 4e49414d 414e413d 2d444948 54004350 M A I N = A N A H I D - P C . T
[7ffff910] 433d504d 73555c3a 5c737265 68616e61 M P = C : \ U s e r s \ a n a h
[7ffff920] 70415c69 74614470 6f4c5c61 5c6c6163 i \ A p p D a t a \ L o c a l \
[7ffff930] 706d6554 4d455400 3a433d50 6573555c T e m p . T E M P = C : \ U s e

- **Q4:** There are 18 instruction, 9 for each value of x
- **Q5:**

```
.data
x1: .word 3 # x = 3
x2: .word 2023 # x = 2023
result1: .word 0 # store result for x = 3
result2: .word 0 # store result for x = 2023

.text
.globl main
main:
    # evaluate f(x) for x = 3
    lw $t0, x1 # load x
    li $t1, 6 # load 6
    mul $t2, $t0, $t1 # 6x
    sub $t2, $t2, 5 # 6x-5
    mul $t2, $t2, $t0 # (6x-5)x
    li $t1, -21 # load -21
    add $t2, $t2, $t1 # (6x-5)x - 21
    sw $t2, result1 # store result for x = 3 in result1
    move $t5, $t2 # store result for x = 3 in $t5

    # evaluate f(x) for x = 2023
    lw $t4, x2    # load x
    li $t1, 6       # load 6
    mul $t2, $t4, $t1   # 6x
    sub $t2, $t2, 5   # 6x-5
    mul $t2, $t2, $t4 # (6x-5)x
    li $t1, -21     # load -21
    add $t2, $t2, $t1   # (6x-5)x - 21
    sw $t2, result2  # store result for x = 2023 in result2
    move $t6, $t2  # store result for x = 2023 in $t6
```

```
# exit
li $v0, 10
syscall
```

- **Q6:**
    - **a:** the value of f(3) is stored in R13 [t5] = 18

FP Regs | Int Regs [10] | Data | Text

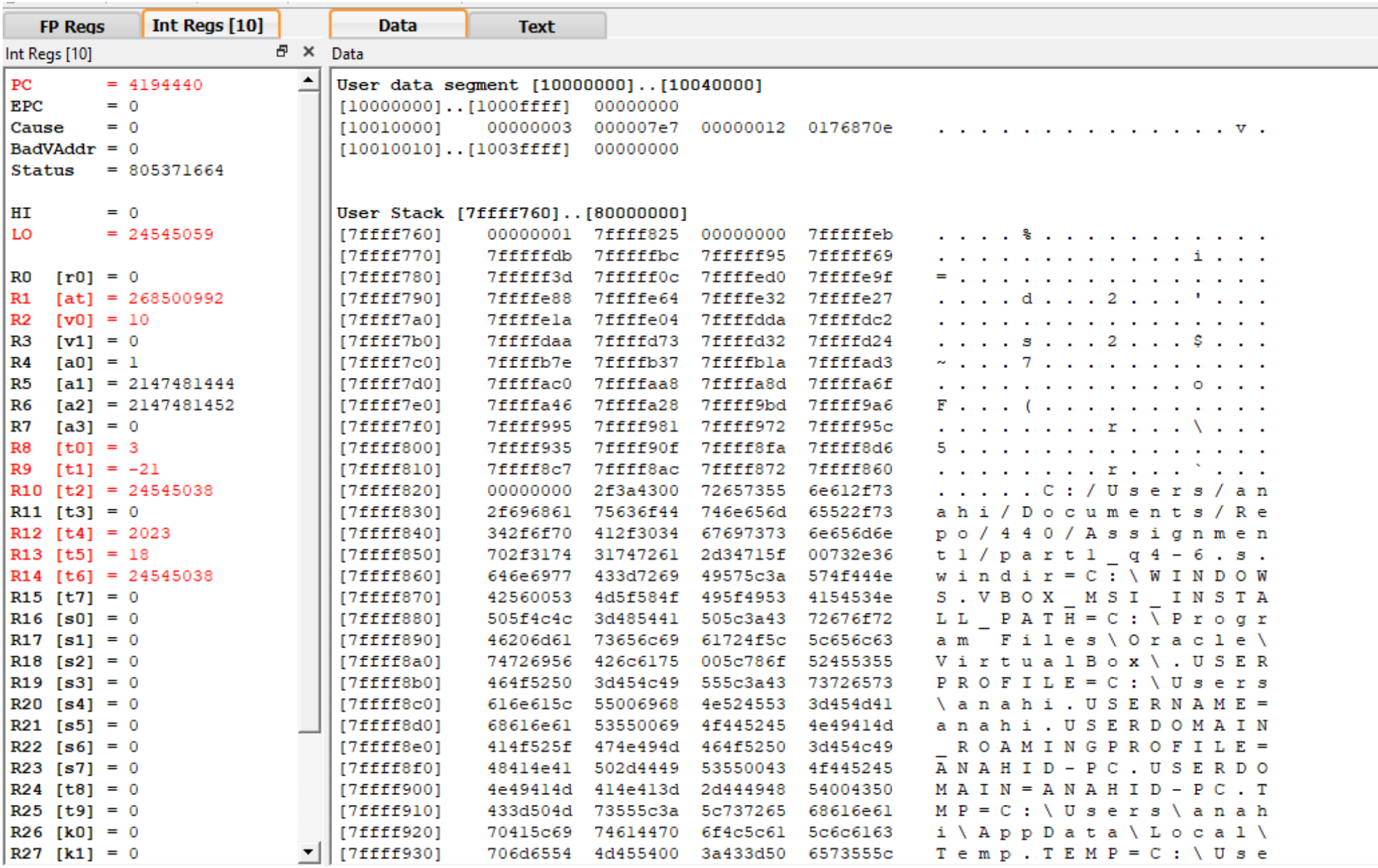
Int Regs [10]

```
PC        = 4194440
EPC       = 0
Cause     = 0
BadVAddr  = 0
Status    = 805371664

HI        = 0
LO        = 24545059

R0  [r0]  = 0
R1  [at]  = 268500992
R2  [v0]  = 10
R3  [v1]  = 0
R4  [a0]  = 1
R5  [a1]  = 2147481444
R6  [a2]  = 2147481452
R7  [a3]  = 0
R8  [t0]  = 3
R9  [t1]  = -21
R10 [t2]  = 24545038
R11 [t3]  = 0
R12 [t4]  = 2023
R13 [t5]  = 18
R14 [t6]  = 24545038
R15 [t7]  = 0
R16 [s0]  = 0
R17 [s1]  = 0
R18 [s2]  = 0
R19 [s3]  = 0
R20 [s4]  = 0
R21 [s5]  = 0
R22 [s6]  = 0
R23 [s7]  = 0
R24 [t8]  = 0
R25 [t9]  = 0
R26 [k0]  = 0
R27 [k1]  = 0
```

Text

```
[00400000] 8fa40000  lw $4, 0($29)            ; 183: lw $a0 0($sp) # argc
[00400004] 27a50004  addiu $5, $29, 4         ; 184: addiu $a1 $sp 4 # argv
[00400008] 24a60004  addiu $6, $5, 4          ; 185: addiu $a2 $a1 4 # envp
[0040000c] 00041080  sll $2, $4, 2            ; 186: sll $v0 $a0 2
[00400010] 00c23021  addu $6, $6, $2          ; 187: addu $a2 $a2 $v0
[00400014] 0c100009  jal 0x00400024 [main]    ; 188: jal main
[00400018] 00000000  nop                      ; 189: nop
[0040001c] 3402000a  ori $2, $0, 10           ; 191: li $v0 10
[00400020] 0000000c  syscall                  ; 192: syscall # syscall 10 (exit)
[00400024] 3c011001  lui $1, 4097             ; 11: lw $t0, x1 # load x
[00400028] 8c280000  lw $8, 0($1)
[0040002c] 34090006  ori $9, $0, 6            ; 12: li $t1, 6 # load 6
[00400030] 71095002  mul $10, $8, $9          ; 13: mul $t2, $t0, $t1 # 6x
[00400034] 214afffb  addi $10, $10, -5        ; 14: sub $t2, $t2, 5 # 6x-5
[00400038] 71485002  mul $10, $10, $8         ; 15: mul $t2, $t2, $t0 # (6x-5)x
[0040003c] 3c01ffff  lui $1, -1               ; 16: li $t1, -21 # load -21
[00400040] 3429ffeb  ori $9, $1, -21
[00400044] 01495020  add $10, $10, $9         ; 17: add $t2, $t2, $t1 # (6x-5)x - 21
[00400048] 3c011001  lui $1, 4097             ; 18: sw $t2, result1 # store result for x = 3 in result1
[0040004c] ac2a0008  sw $10, 8($1)
[00400050] 000a6821  addu $13, $0, $10        ; 19: move $t5, $t2 # store result for x = 3 in $t5
[00400054] 3c011001  lui $1, 4097             ; 22: lw $t4, x2 # load x
[00400058] 8c2c0004  lw $12, 4($1)
[0040005c] 34090006  ori $9, $0, 6            ; 23: li $t1, 6 # load 6
[00400060] 71895002  mul $10, $12, $9         ; 24: mul $t2, $t4, $t1 # 6x
[00400064] 214afffb  addi $10, $10, -5        ; 25: sub $t2, $t2, 5 # 6x-5
[00400068] 714c5002  mul $10, $10, $12        ; 26: mul $t2, $t2, $t4 # (6x-5)x
[0040006c] 3c01ffff  lui $1, -1               ; 27: li $t1, -21 # load -21
[00400070] 3429ffeb  ori $9, $1, -21
[00400074] 01495020  add $10, $10, $9         ; 28: add $t2, $t2, $t1 # (6x-5)x - 21
[00400078] 3c011001  lui $1, 4097             ; 29: sw $t2, result2 # store result for x = 2023 in result2
[0040007c] ac2a000c  sw $10, 12($1)
[00400080] 000a7021  addu $14, $0, $10        ; 30: move $t6, $t2 # store result for x = 2023 in $t6
[00400084] 3402000a  ori $2, $0, 10           ; 33: li $v0, 10
[00400088] 0000000c  syscall                  ; 34: syscall
```

- **b:** the value of f(3) is stored in R13 [t5] = 18


FP Regs
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Text
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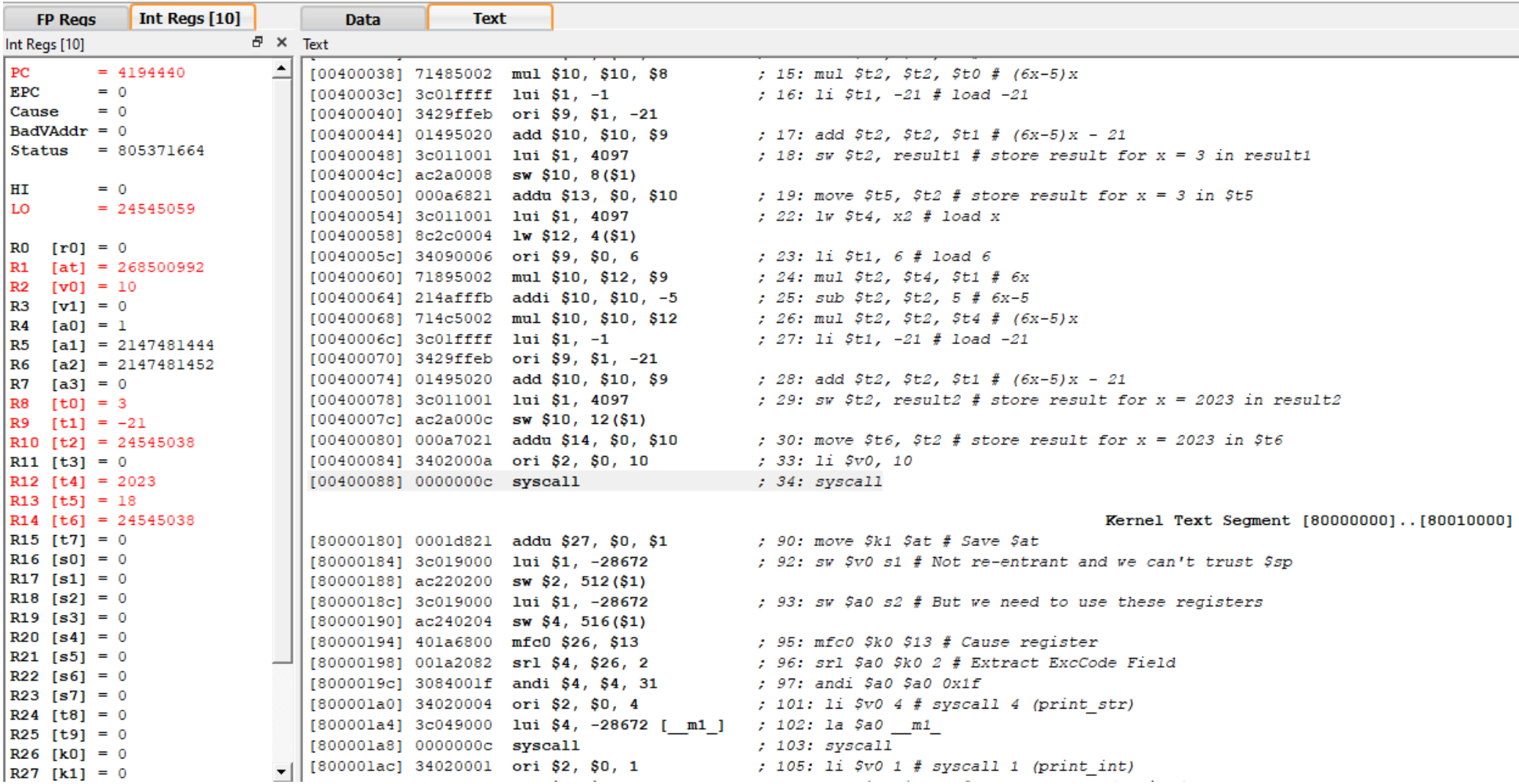
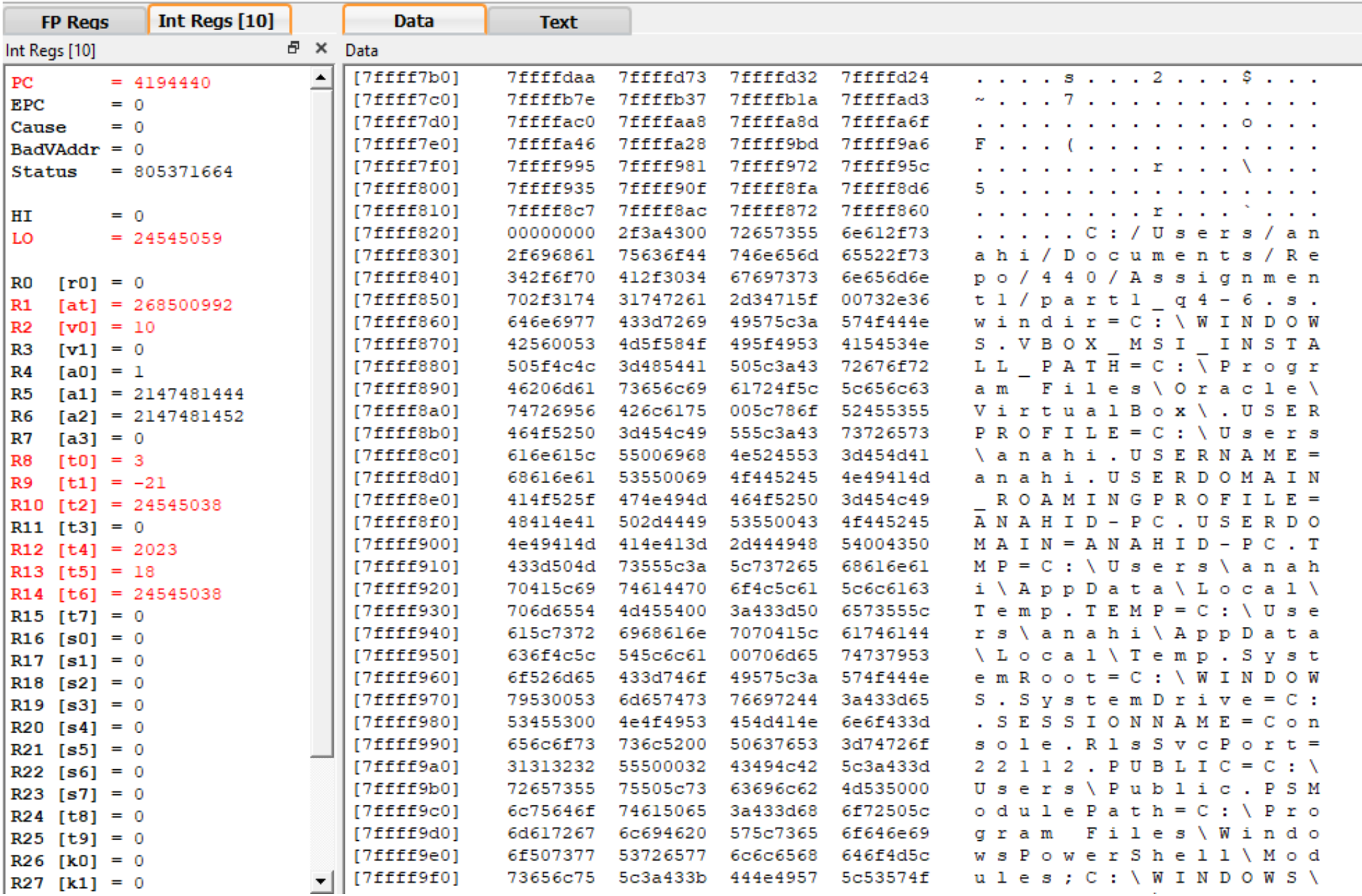
R7 [a3] = 0
R8 [t0] = 3
R9 [t1] = -21
R10 [t2] = 24545038
R11 [t3] = 0
R12 [t4] = 2023
R13 [t5] = 18
R14 [t6] = 24545038
R15 [t7] = 0
R16 [s0] = 0
R17 [s1] = 0
R18 [s2] = 0
R19 [s3] = 0
R20 [s4] = 0
R21 [s5] = 0
R22 [s6] = 0
R23 [s7] = 0
R24 [t8] = 0
R25 [t9] = 0
R26 [k0] = 0
R27 [k1] = 0
User data segment [10000000]..[10040000]
[10000000]..[1000ffff] 00000000
[10010000] 00000003 000007e7 00000012 0176870e . . . . . v .
[10010010]..[1003ffff] 00000000
User Stack [7ffff760]..[80000000]
[7ffff760] 00000001 7ffff825 00000000 7fffffeb . . . % . . . . . .
[7ffff770] 7fffffdb 7fffffbc 7fffff95 7fffff69 . . . . . i . . .
[7ffff780] 7fffff3d 7fffff0c 7ffffed0 7ffffe9f = ...
[7ffff790] 7ffffe88 7ffffe64 7ffffe32 7ffffe27 . . . . d . . . 2 . . . ' . . .
[7ffff7a0] 7ffffe1a 7ffffe04 7ffffdda 7ffffdc2 . . . . . .
[7ffff7b0] 7ffffdaa 7ffffd73 7ffffd32 7ffffd24 . . . . s . . . 2 . . . $ . . .
[7ffff7c0] 7ffffb7e 7ffffb37 7ffffb1a 7ffffad3 ~ . . . 7 . . . . . .
[7ffff7d0] 7ffffac0 7ffffaa8 7ffffa8d 7ffffa6f . . . . . o . . .
[7ffff7e0] 7ffffa46 7ffffa28 7ffff9bd 7ffff9a6 F . . . (. . . . . .
[7ffff7f0] 7ffff995 7ffff981 7ffff972 7ffff95c . . . . . r . . . \ . . .
[7ffff800] 7ffff935 7ffff90f 7ffff8fa 7ffff8d6 5 . . . . . .
[7ffff810] 7ffff8c7 7ffff8ac 7ffff872 7ffff860 . . . . . r . . . ` . . .
[7ffff820] 00000000 2f3a4300 72657355 6e612f73 . . . . . C : / U s e r s / a n
[7ffff830] 2f696861 75636f44 746e656d 65522f73 a h i / D o c u m e n t s / R e
[7ffff840] 342f6f70 412f3034 67697373 6e656d6e p o / 4 4 0 / A s s i g n m e n
[7ffff850] 702f3174 31747261 2d34715f 00732e36 t l / p a r t l _ q 4 - 6 . s .
[7ffff860] 646e6977 433d7269 49575c3a 574f444e w i n d i r = C : \ W I N D O W
[7ffff870] 42560053 4d5f584f 495f4953 4154534e S . V B O X _ M S I _ I N S T A
[7ffff880] 505f4c4c 3d485441 505c3a43 72676f72 L L _ P A T H = C : \ P r o g r
[7ffff890] 46206d61 73656c69 61724f5c 5c656c63 a m _ F i l e s \ O r a c l e \
[7ffff8a0] 74726956 426c6175 005c786f 52455355 V i r t u a l B o x \ . U S E R
[7ffff8b0] 464f5250 3d454c49 555c3a43 73726573 P R O F I L E = C : \ U s e r s
[7ffff8c0] 616e615c 55006968 4e524553 3d454d41 \ a n a h i . U S E R N A M E =
[7ffff8d0] 68616e61 53550069 4f445245 4e49414d a n a h i . U S E R D O M A I N
[7ffff8e0] 414f525f 474e494d 464f5250 3d454c49 _ R O A M I N G P R O F I L E =
[7ffff8f0] 48414e41 502d4449 53550043 4f445245 A N A H I D - P C . U S E R D O
[7ffff900] 4e49414d 414e413d 2d444948 54004350 M A I N = A N A H I D - P C . T
[7ffff910] 433d504d 73555c3a 5c737265 68616e61 M P = C : \ U s e r s \ a n a h
[7ffff920] 70415c69 74614470 6f4c5c61 5c6c6163 i \ A p p D a t a \ L o c a l \
[7ffff930] 706d6554 4d455400 3a433d50 6573555c T e m p . T E M P = C : \ U s e

- **c:** the value of f(2023) is stored in R14 [t6] = 24545038

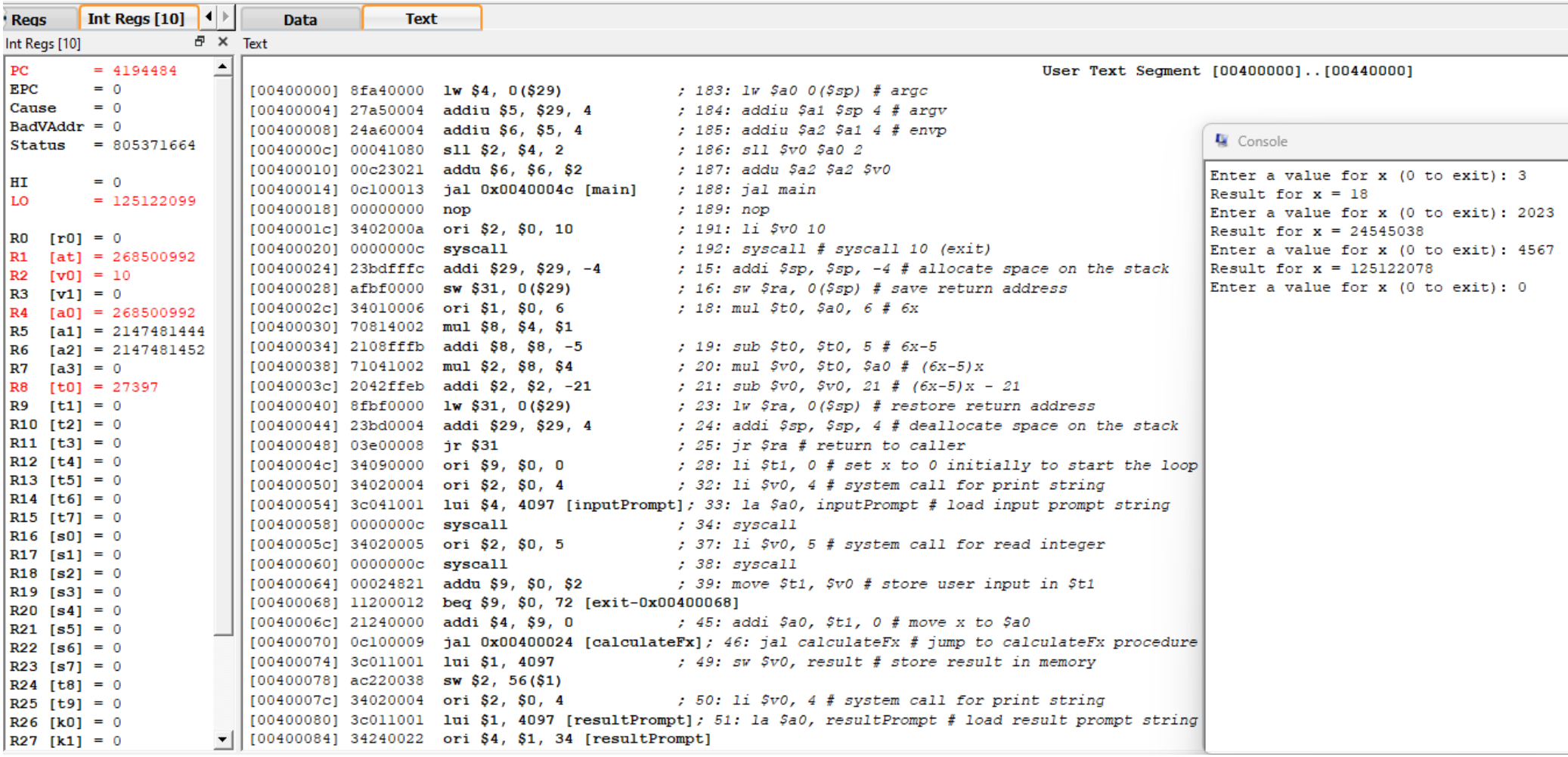


- **d:** the value of f(2023) is stored in R14 [t6] = 24545038

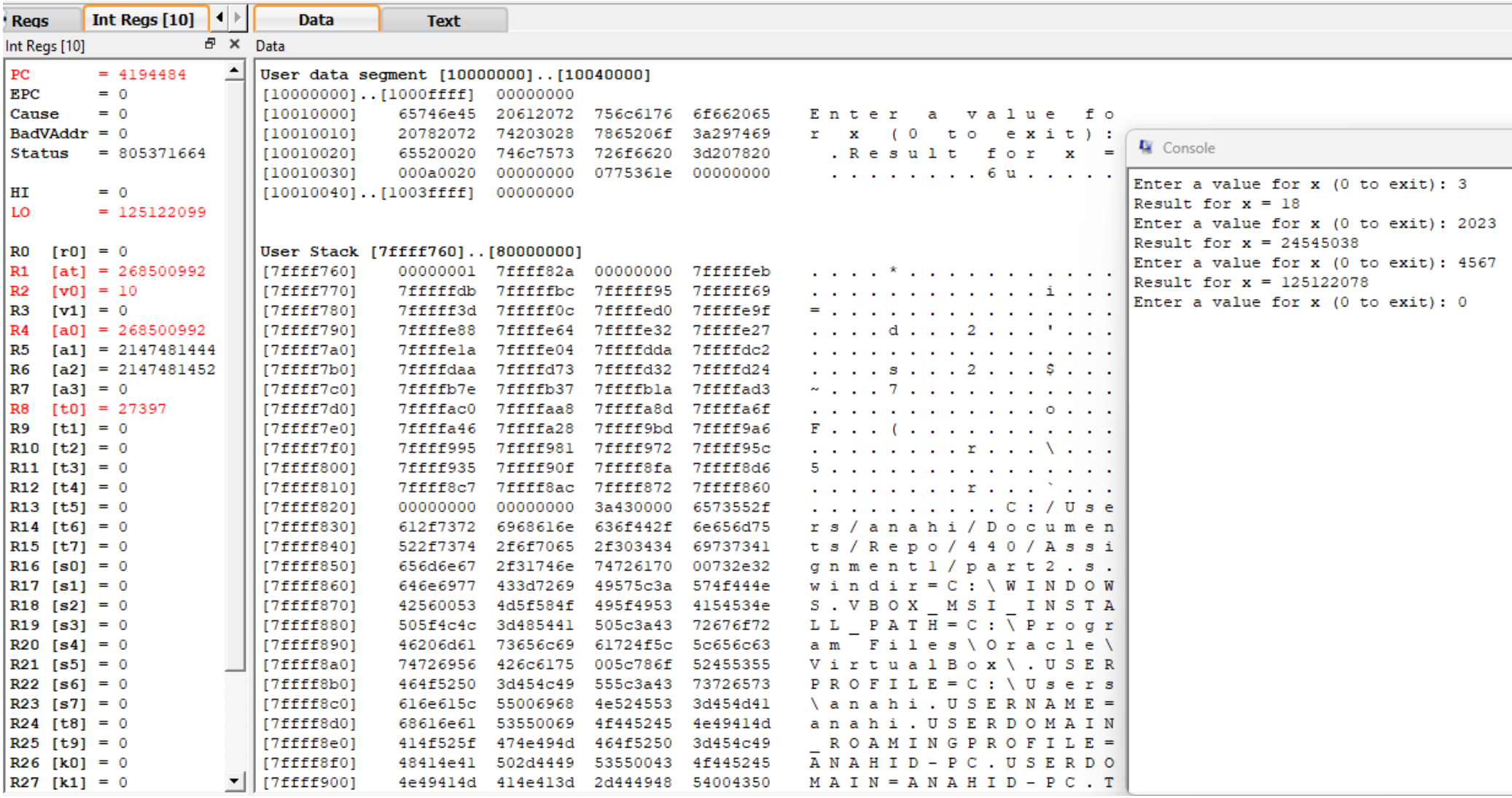

FP Regs
Int Regs [10]
Data
Text
Int Regs [10]
Data
PC = 4194440
EPC = 0
Cause = 0
BadVAddr = 0
Status = 805371664
HI = 0
LO = 24545059
R0 [r0] = 0
R1 [at] = 268500992
R2 [v0] = 10
R3 [v1] = 0
R4 [a0] = 1
R5 [a1] = 2147481444
R6 [a2] = 2147481452
R7 [a3] = 0
R8 [t0] = 3
R9 [t1] = -21
R10 [t2] = 24545038
R11 [t3] = 0
R12 [t4] = 2023
R13 [t5] = 18
R14 [t6] = 24545038
R15 [t7] = 0
R16 [s0] = 0
R17 [s1] = 0
R18 [s2] = 0
R19 [s3] = 0
R20 [s4] = 0
R21 [s5] = 0
R22 [s6] = 0
R23 [s7] = 0
R24 [t8] = 0
R25 [t9] = 0
R26 [k0] = 0
R27 [k1] = 0
[7ffff7b0] 7ffffdaa 7ffffd73 7ffffd32 7ffffd24 . . . . s . . . 2 . . . $ . . .
[7ffff7c0] 7ffffb7e 7ffffb37 7ffffb1a 7ffffad3 ~ . . . 7 . . . . . .
[7ffff7d0] 7ffffac0 7ffffaa8 7ffffa8d 7ffffa6f . . . . . o . . .
[7ffff7e0] 7ffffa46 7ffffa28 7ffff9bd 7ffff9a6 F . . . (. . . . . .
[7ffff7f0] 7ffff995 7ffff981 7ffff972 7ffff95c . . . . . r . . . \ . . .
[7ffff800] 7ffff935 7ffff90f 7ffff8fa 7ffff8d6 5 . . . . . .
[7ffff810] 7ffff8c7 7ffff8ac 7ffff872 7ffff860 . . . . . r . . . ` . . .
[7ffff820] 00000000 2f3a4300 72657355 6e612f73 . . . . . C : / U s e r s / a n
[7ffff830] 2f696861 75636f44 746e656d 65522f73 a h i / D o c u m e n t s / R e
[7ffff840] 342f6f70 412f3034 67697373 6e656d6e p o / 4 4 0 / A s s i g n m e n
[7ffff850] 702f3174 31747261 2d34715f 00732e36 t l / p a r t 1 _ q 4 - 6 . s .
[7ffff860] 646e6977 433d7269 49575c3a 574f444e w i n d i r = C : \ W I N D O W
[7ffff870] 42560053 4d5f584f 495f4953 4154534e S . V B O X _ M S I _ I N S T A
[7ffff880] 505f4c4c 3d485441 505c3a43 72676f72 L L _ P A T H = C : \ P r o g r
[7ffff890] 46206d61 73656c69 61724f5c 5c656c63 a m _ F i l e s \ O r a c l e \
[7ffff8a0] 74726956 426c6175 005c786f 52455355 V i r t u a l B o x \ . U S E R
[7ffff8b0] 464f5250 3d454c49 555c3a43 73726573 P R O F I L E = C : \ U s e r s
[7ffff8c0] 616e615c 55006968 4e524553 3d454d41 \ a n a h i . U S E R N A M E =
[7ffff8d0] 68616e61 53550069 4f445245 4e49414d a n a h i . U S E R D O M A I N
[7ffff8e0] 414f525f 474e494d 464f5250 3d454c49 _ R O A M I N G P R O F I L E =
[7ffff8f0] 48414e41 502d4449 53550043 4f445245 A N A H I D - P C . U S E R D O
[7ffff900] 4e49414d 414e413d 2d444948 54004350 M A I N = A N A H I D - P C . T
[7ffff910] 433d504d 73555c3a 5c737265 68616e61 M P = C : \ U s e r s \ a n a h
[7ffff920] 70415c69 74614470 6f4c5c61 5c6c6163 i \ A p p D a t a \ L o c a l \
[7ffff930] 706d6554 4d455400 3a433d50 6573555c T e m p . T E M P = C : \ U s e
[7ffff940] 615c7372 6968616e 7070415c 61746144 r s \ a n a h i \ A p p D a t a
[7ffff950] 636f4c5c 545c6c61 00706d65 74737953 \ L o c a l \ T e m p . S y s t
[7ffff960] 6f526d65 433d746f 49575c3a 574f444e e m R o o t = C : \ W I N D O W
[7ffff970] 79530053 6d657473 76697244 3a433d65 S . S y s t e m D r i v e = C :
[7ffff980] 53455300 4e4f4953 454d414e 6e6f433d . S E S S I O N N A M E = C o n
[7ffff990] 656c6f73 736c5200 50637653 3d74726f s o l e . R l s S v c P o r t =
[7ffff9a0] 31313232 55500032 43494c42 5c3a433d 2 2 1 1 2 . P U B L I C = C : \
[7ffff9b0] 72657355 75505c73 63696c62 4d535000 U s e r s \ P u b l i c . P S M
[7ffff9c0] 6c75646f 74615065 3a433d68 6f72505c o d u l e P a t h = C : \ P r o
[7ffff9d0] 6d617267 6c694620 575c7365 6f646e69 g r a m _ F i l e s \ W i n d o
[7ffff9e0] 6f507377 53726577 6c6c6568 646f4d5c w s P o w e r S h e l l \ M o d
[7ffff9f0] 73656c75 5c3a433b 444e4957 5c53574f u l e s ; C : \ W I N D O W S \

Part 2 – MIPS Procedure Call. Relevant assembly file: part2.s

- **Q3:**
  - **a:**

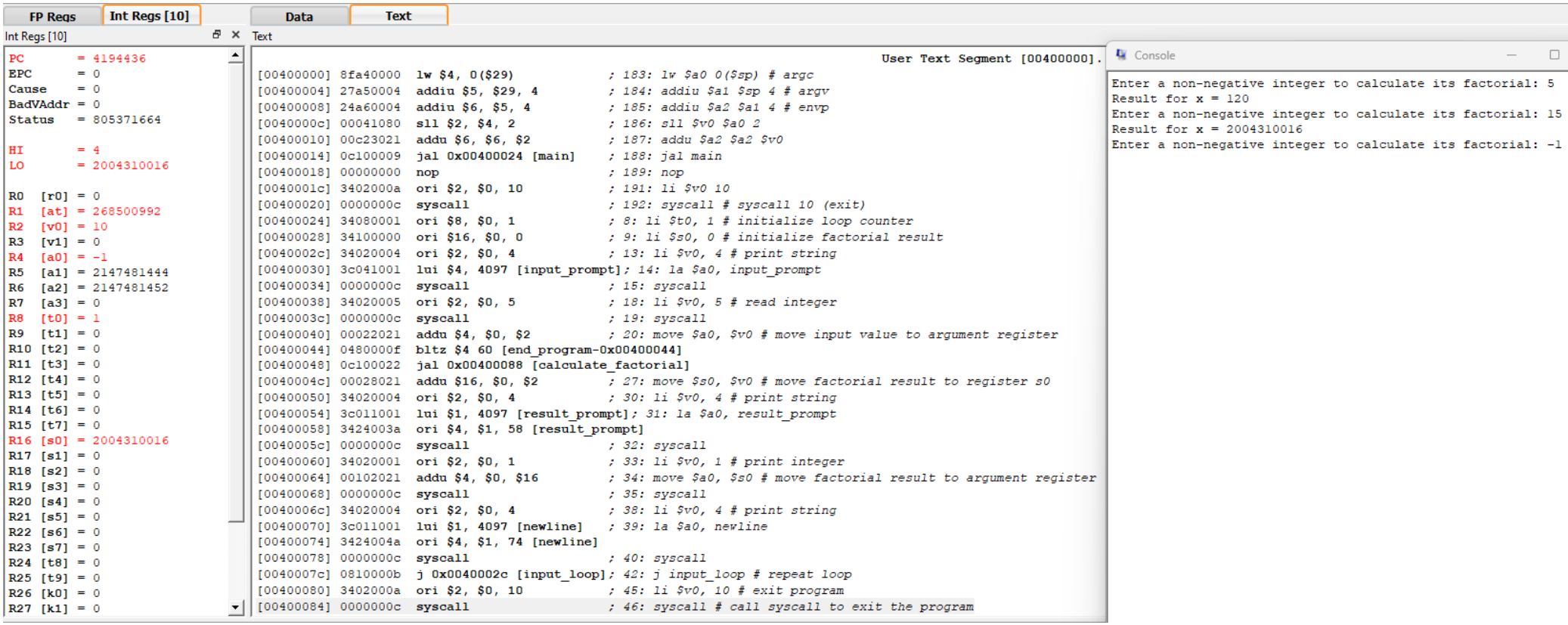


  - **b:**

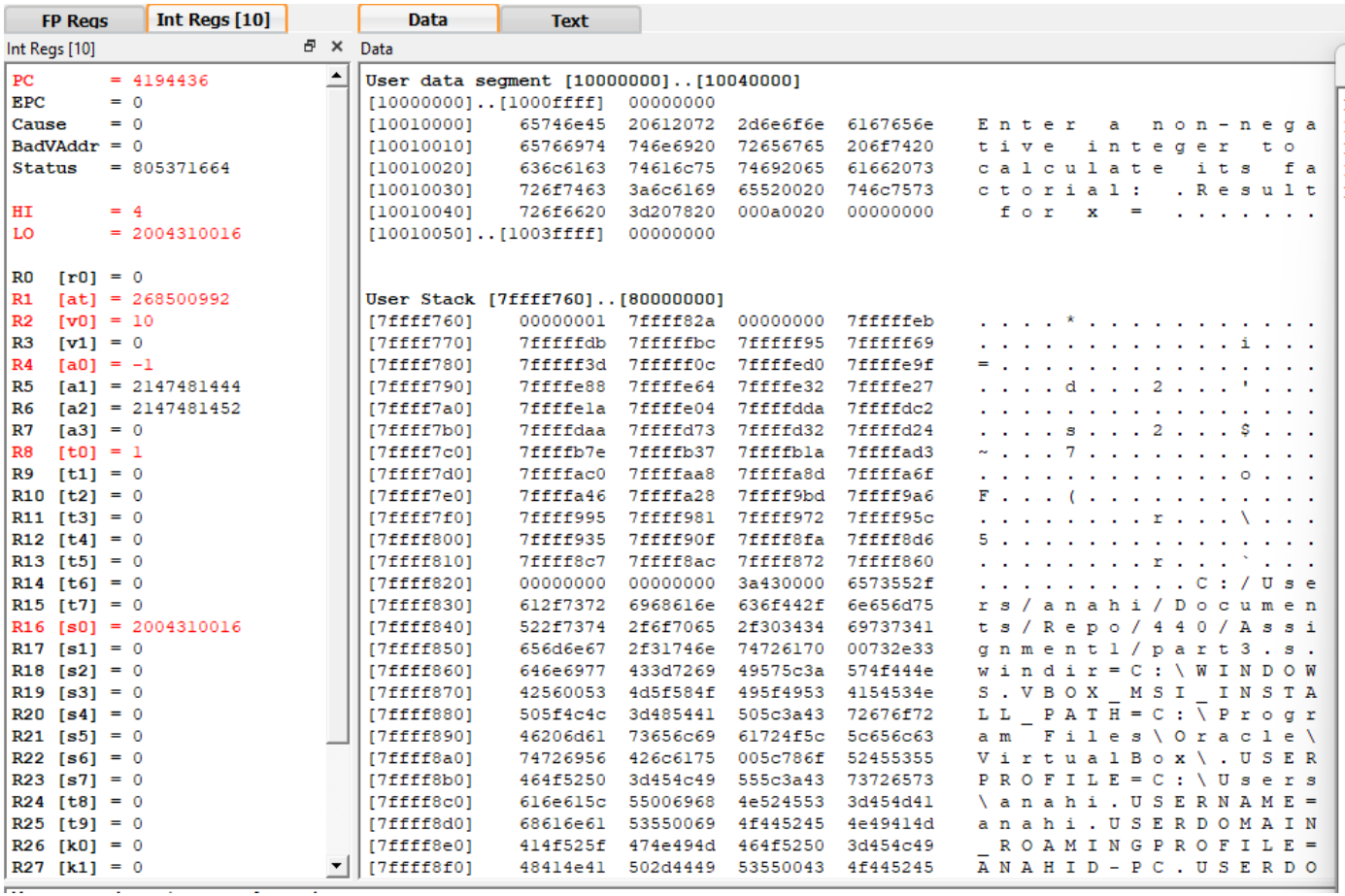


Part 3 - MIPS Procedure Call Recursive. **Relevant assembly file: part3.s**

- **Q4**
  - **a:**


FP Regs
Int Regs [10]
Data
Text
Int Regs [10]
PC = 4194436
EPC = 0
Cause = 0
BadVAddr = 0
Status = 805371664
HI = 4
LO = 2004310016
R0 [r0] = 0
R1 [at] = 268500992
R2 [v0] = 10
R3 [v1] = 0
R4 [a0] = -1
R5 [a1] = 2147481444
R6 [a2] = 2147481452
R7 [a3] = 0
R8 [t0] = 1
R9 [t1] = 0
R10 [t2] = 0
R11 [t3] = 0
R12 [t4] = 0
R13 [t5] = 0
R14 [t6] = 0
R15 [t7] = 0
R16 [s0] = 2004310016
R17 [s1] = 0
R18 [s2] = 0
R19 [s3] = 0
R20 [s4] = 0
R21 [s5] = 0
R22 [s6] = 0
R23 [s7] = 0
R24 [t8] = 0
R25 [t9] = 0
R26 [k0] = 0
R27 [k1] = 0
Text
User Text Segment [00400000].
[00400000] 8fa40000 lw $4, 0($29) ; 183: lw $a0 0($sp) # argc
[00400004] 27a50004 addiu $5, $29, 4 ; 184: addiu $a1 $sp 4 # argv
[00400008] 24a60004 addiu $6, $5, 4 ; 185: addiu $a2 $a1 4 # envp
[0040000c] 00041080 sll $2, $4, 2 ; 186: sll $v0 $a0 2
[00400010] 00c23021 addu $6, $6, $2 ; 187: addu $a2 $a2 $v0
[00400014] 0c100009 jal 0x00400024 [main] ; 188: jal main
[00400018] 00000000 nop ; 189: nop
[0040001c] 3402000a ori $2, $0, 10 ; 191: li $v0 10
[00400020] 0000000c syscall ; 192: syscall # syscall 10 (exit)
[00400024] 34080001 ori $8, $0, 1 ; 8: li $t0, 1 # initialize loop counter
[00400028] 34100000 ori $16, $0, 0 ; 9: li $s0, 0 # initialize factorial result
[0040002c] 34020004 ori $2, $0, 4 ; 13: li $v0, 4 # print string
[00400030] 3c041001 lui $4, 4097 [input_prompt] ; 14: la $a0, input_prompt
[00400034] 0000000c syscall ; 15: syscall
[00400038] 34020005 ori $2, $0, 5 ; 18: li $v0, 5 # read integer
[0040003c] 0000000c syscall ; 19: syscall
[00400040] 00022021 addu $4, $0, $2 ; 20: move $a0, $v0 # move input value to argument register
[00400044] 0480000f bltz $4 60 [end_program-0x00400044]
[00400048] 0c100022 jal 0x00400088 [calculate_factorial]
[0040004c] 00028021 addu $16, $0, $2 ; 27: move $s0, $v0 # move factorial result to register s0
[00400050] 34020004 ori $2, $0, 4 ; 30: li $v0, 4 # print string
[00400054] 3c011001 lui $1, 4097 [result_prompt] ; 31: la $a0, result_prompt
[00400058] 3424003a ori $4, $1, 58 [result_prompt]
[0040005c] 0000000c syscall ; 32: syscall
[00400060] 34020001 ori $2, $0, 1 ; 33: li $v0, 1 # print integer
[00400064] 00102021 addu $4, $0, $16 ; 34: move $a0, $s0 # move factorial result to argument register
[00400068] 0000000c syscall ; 35: syscall
[0040006c] 34020004 ori $2, $0, 4 ; 38: li $v0, 4 # print string
[00400070] 3c011001 lui $1, 4097 [newline] ; 39: la $a0, newline
[00400074] 3424004a ori $4, $1, 74 [newline]
[00400078] 0000000c syscall ; 40: syscall
[0040007c] 0810000b j 0x0040002c [input_loop] ; 42: j input_loop # repeat loop
[00400080] 3402000a ori $2, $0, 10 ; 45: li $v0, 10 # exit program
[00400084] 0000000c syscall ; 46: syscall # call syscall to exit the program
Console
Enter a non-negative integer to calculate its factorial: 5
Result for x = 120
Enter a non-negative integer to calculate its factorial: 15
Result for x = 2004310016
Enter a non-negative integer to calculate its factorial: -1

- **b:**



Part 4 - Implementing MIPS Assembly Pseudocode. Relevant assembly file: part4.s

- **Q1:** this is my implementation

```
lw $t0, A      # $t0 = Memory[$rs]
lw $t1, B      # $t1 = Memory[$rt]
add $t2, $t0, $t1  # $t2 = $t0 + $t1
sw $t2, C      # Memory[$rd] = $t2
```

1. In the first step of this implementation, the data is loaded from the memory location specified by $rs into register $t0 using the "lw" (load word) instruction. The address of the first memory location to be added is stored in $rs.

2. The second step loads the data from the memory location specified by $rt into register $t1 using the "lw" instruction. The address of the second memory location to be added is stored in $rt.
3. The third step uses the "add" instruction to add the contents of $t0 and $t1 and store the result in $t2. The "add" instruction adds the values in $t0 and $t1 and stores the result in $t2.
4. Finally, in the fourth step, the "sw" (store word) instruction is used to store the contents of $t2 into the memory location specified by $rd. The address of the memory location where the result of the addition should be stored is stored in $rd, and the "sw" instruction stores the contents of $t2 into that memory location.

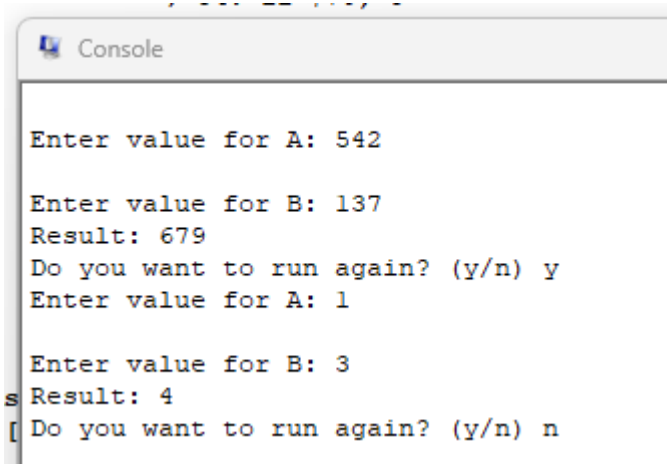
- **Q3:**

```
.data
A: .word 0
B: .word 0
C: .word 0
newline: .asciiz "\n"
prompt: .asciiz "Do you want to run again? (y/n) "
msg_A: .asciiz "Enter value for A: "
msg_B: .asciiz "Enter value for B: "
msg_result: .asciiz "Result: "

.text
main:
   # Prompt user to enter A and B values
   li $v0, 4
   la $a0, newline
   syscall

   li $v0, 4
   la $a0, msg_A
   syscall

   li $v0, 5
   syscall
   sw $v0, A
```

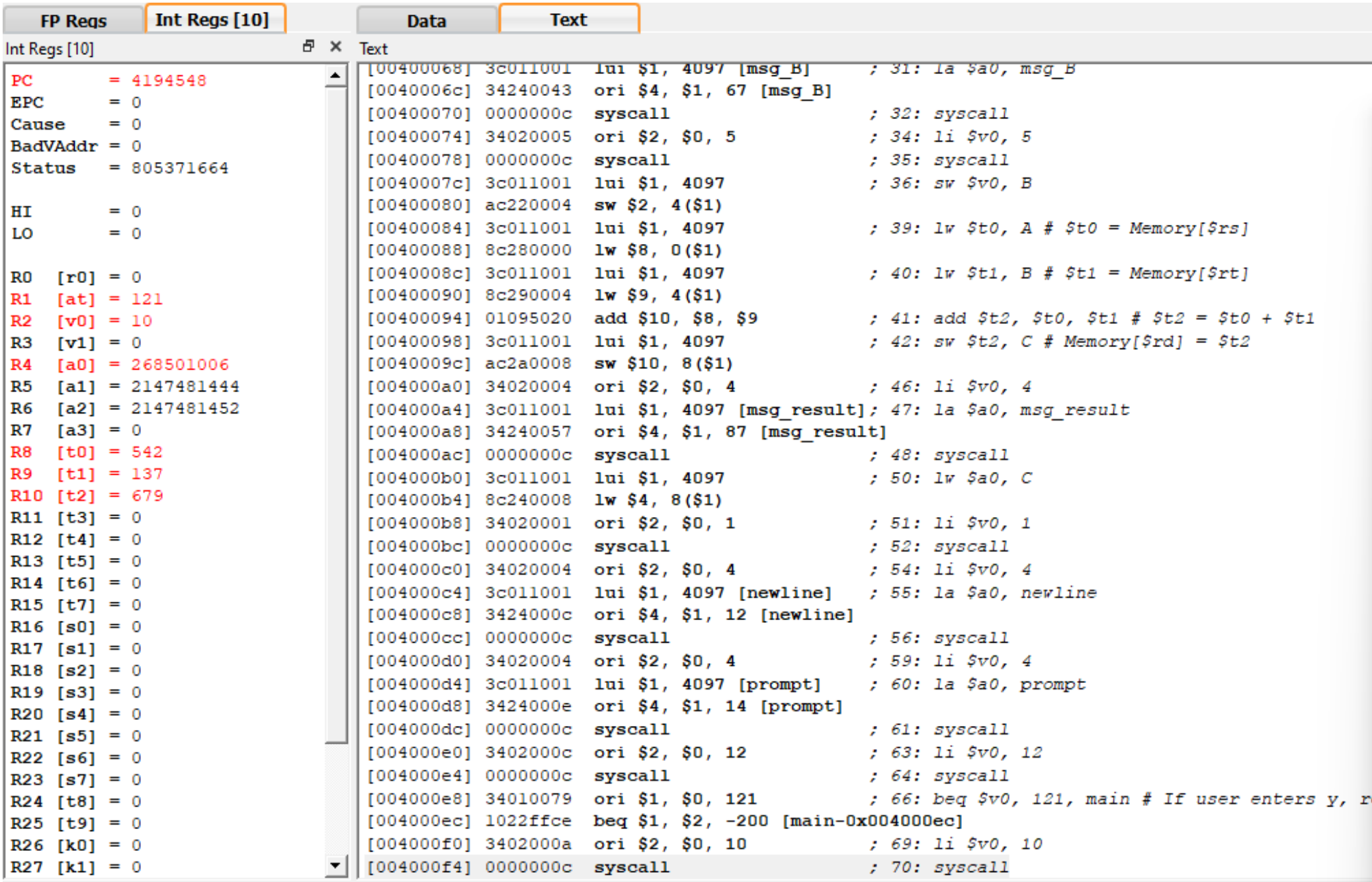
```
li $v0, 4
la $a0, newline
syscall

li $v0, 4
la $a0, msg_B
syscall

li $v0, 5
syscall
sw $v0, B

# begin my pseudo-code implementation for addmem $rd, $rs, $rt
lw $t0, A      # $t0 = Memory[$rs]
lw $t1, B      # $t1 = Memory[$rt]
add $t2, $t0, $t1  # $t2 = $t0 + $t1
sw $t2, C      # Memory[$rd] = $t2
# end of my pseudo-code

# Display result on console screen
li $v0, 4
la $a0, msg_result
syscall

lw $a0, C
li $v0, 1
syscall

li $v0, 4
la $a0, newline
syscall
```

```
# Ask user to rerun or not
li $v0, 4
la $a0, prompt
syscall

li $v0, 12
syscall

beq $v0, 121, main  # If user enters y, rerun program

# Exit program if user enters n
li $v0, 10
syscall
```

- **Q4:**



- **Q5:**
  - **a:**


FP Regs
Int Regs [10]
Data
Text
Int Regs [10]
PC = 4194548
EPC = 0
Cause = 0
BadVAddr = 0
Status = 805371664
HI = 0
LO = 0
R0 [r0] = 0
R1 [at] = 121
R2 [v0] = 10
R3 [v1] = 0
R4 [a0] = 268501006
R5 [a1] = 2147481444
R6 [a2] = 2147481452
R7 [a3] = 0
R8 [t0] = 542
R9 [t1] = 137
R10 [t2] = 679
R11 [t3] = 0
R12 [t4] = 0
R13 [t5] = 0
R14 [t6] = 0
R15 [t7] = 0
R16 [s0] = 0
R17 [s1] = 0
R18 [s2] = 0
R19 [s3] = 0
R20 [s4] = 0
R21 [s5] = 0
R22 [s6] = 0
R23 [s7] = 0
R24 [t8] = 0
R25 [t9] = 0
R26 [k0] = 0
R27 [k1] = 0
Text
[00400068] 3c011001 lui $1, 4097 [msg_B] ; 31: la $a0, msg_B
[0040006c] 34240043 ori $4, $1, 67 [msg_B]
[00400070] 0000000c syscall ; 32: syscall
[00400074] 34020005 ori $2, $0, 5 ; 34: li $v0, 5
[00400078] 0000000c syscall ; 35: syscall
[0040007c] 3c011001 lui $1, 4097 ; 36: sw $v0, B
[00400080] ac220004 sw $2, 4($1)
[00400084] 3c011001 lui $1, 4097 ; 39: lw $t0, A # $t0 = Memory[$rs]
[00400088] 8c280000 lw $8, 0($1)
[0040008c] 3c011001 lui $1, 4097 ; 40: lw $t1, B # $t1 = Memory[$rt]
[00400090] 8c290004 lw $9, 4($1)
[00400094] 01095020 add $10, $8, $9 ; 41: add $t2, $t0, $t1 # $t2 = $t0 + $t1
[00400098] 3c011001 lui $1, 4097 ; 42: sw $t2, C # Memory[$rd] = $t2
[0040009c] ac2a0008 sw $10, 8($1)
[004000a0] 34020004 ori $2, $0, 4 ; 46: li $v0, 4
[004000a4] 3c011001 lui $1, 4097 [msg_result] ; 47: la $a0, msg_result
[004000a8] 34240057 ori $4, $1, 87 [msg_result]
[004000ac] 0000000c syscall ; 48: syscall
[004000b0] 3c011001 lui $1, 4097 ; 50: lw $a0, C
[004000b4] 8c240008 lw $4, 8($1)
[004000b8] 34020001 ori $2, $0, 1 ; 51: li $v0, 1
[004000bc] 0000000c syscall ; 52: syscall
[004000c0] 34020004 ori $2, $0, 4 ; 54: li $v0, 4
[004000c4] 3c011001 lui $1, 4097 [newline] ; 55: la $a0, newline
[004000c8] 3424000c ori $4, $1, 12 [newline]
[004000cc] 0000000c syscall ; 56: syscall
[004000d0] 34020004 ori $2, $0, 4 ; 59: li $v0, 4
[004000d4] 3c011001 lui $1, 4097 [prompt] ; 60: la $a0, prompt
[004000d8] 3424000e ori $4, $1, 14 [prompt]
[004000dc] 0000000c syscall ; 61: syscall
[004000e0] 3402000c ori $2, $0, 12 ; 63: li $v0, 12
[004000e4] 0000000c syscall ; 64: syscall
[004000e8] 34010079 ori $1, $0, 121 ; 66: beq $v0, 121, main # If user enters y, r
[004000ec] 1022ffce beq $1, $2, -200 [main-0x004000ec]
[004000f0] 3402000a ori $2, $0, 10 ; 69: li $v0, 10
[004000f4] 0000000c syscall ; 70: syscall

- **b:**

FP Regs | Int Regs [10] | Data | Text

Int Regs [10]

```
PC       = 4194548
EPC      = 0
Cause    = 0
BadVAddr = 0
Status   = 805371664

HI       = 0
LO       = 0

R0  [r0] = 0
R1  [at] = 121
R2  [v0] = 10
R3  [v1] = 0
R4  [a0] = 268501006
R5  [a1] = 2147481444
R6  [a2] = 2147481452
R7  [a3] = 0
R8  [t0] = 542
R9  [t1] = 137
R10 [t2] = 679
R11 [t3] = 0
R12 [t4] = 0
R13 [t5] = 0
R14 [t6] = 0
R15 [t7] = 0
R16 [s0] = 0
R17 [s1] = 0
R18 [s2] = 0
R19 [s3] = 0
R20 [s4] = 0
R21 [s5] = 0
R22 [s6] = 0
R23 [s7] = 0
R24 [t8] = 0
R25 [t9] = 0
R26 [k0] = 0
R27 [k1] = 0
```

Data

```
User data segment [10000000]..[10040000]
[10000000]..[1000ffff]  00000000
[10010000]    0000021e  00000089  000002a7  6f44000a    . . . . . D o
[10010010]    756f7920  6e617720  6f742074  6e757220      y o u   w a n t   t o   r u n
[10010020]    61676120  203f6e69  6e2f7928  45002029      a g a i n ?   ( y / n )   . E
[10010030]    7265746e  6c617620  66206575  4120726f    n t e r   v a l u e   f o r   A
[10010040]    4500203a  7265746e  6c617620  66206575    :   . E n t e r   v a l u e   f
[10010050]    4220726f  5200203a  6c757365  00203a74    o r   B :   . R e s u l t :   .
[10010060]..[1003ffff]  00000000


User Stack [7ffff760]..[80000000]
[7ffff760]    00000001  7ffff82a  00000000  7fffffeb    . . . . * . . . . . . . . . .
[7ffff770]    7fffffdb  7fffffbc  7fffff95  7fffff69    . . . . . . . . . . . . . i . . .
[7ffff780]    7fffff3d  7fffff0c  7ffffed0  7ffffe9f    = . . . . . . . . . . . . . . . .
[7ffff790]    7ffffe88  7ffffe64  7ffffe32  7ffffe27    . . . . d . . . 2 . . . ' . . .
[7ffff7a0]    7ffffe1a  7ffffe04  7ffffdda  7ffffdc2    . . . . . . . . . . . . . . . .
[7ffff7b0]    7ffffdaa  7ffffd73  7ffffd32  7ffffd24    . . . . s . . . 2 . . . $ . . .
[7ffff7c0]    7ffffb7e  7ffffb37  7ffffb1a  7ffffad3    ~ . . . 7 . . . . . . . . . . .
[7ffff7d0]    7ffffac0  7ffffaa8  7ffffa8d  7ffffa6f    . . . . . . . . . . . . . o . . .
[7ffff7e0]    7ffffa46  7ffffa28  7ffff9bd  7ffff9a6    F . . . ( . . . . . . . . . . .
[7ffff7f0]    7ffff995  7ffff981  7ffff972  7ffff95c    . . . . . . . . r . . . \ . . .
[7ffff800]    7ffff935  7ffff90f  7ffff8fa  7ffff8d6    5 . . . . . . . . . . . . . . .
[7ffff810]    7ffff8c7  7ffff8ac  7ffff872  7ffff860    . . . . . . . . r . . . ` . . .
[7ffff820]    00000000  00000000  3a430000  6573552f    . . . . . . . . . . C : / U s e
[7ffff830]    612f7372  6968616e  636f442f  6e656d75    r s / a n a h i / D o c u m e n
[7ffff840]    522f7374  2f6f7065  2f303434  69737341    t s / R e p o / 4 4 0 / A s s i
[7ffff850]    656d6e67  2f31746e  74726170  00732e34    g n m e n t l / p a r t 4 . s .
[7ffff860]    646e6977  433d7269  49575c3a  574f444e    w i n d i r = C : \ W I N D O W
[7ffff870]    42560053  4d5f584f  495f4953  4154534e    S . V B O X _ M S I _ I N S T A
[7ffff880]    505f4c4c  3d485441  505c3a43  72676f72    L L _ P A T H = C : \ P r o g r
[7ffff890]    46206d61  73656c69  61724f5c  5c656c63    a m   F i l e s \ O r a c l e \
[7ffff8a0]    74726956  426c6175  005c786f  52455355    V i r t u a l B o x \ . U S E R
[7ffff8b0]    464f5250  3d454c49  555c3a43  73726573    P R O F I L E = C : \ U s e r s
[7ffff8c0]    616e615c  55006968  4e524553  3d454d41    \ a n a h i . U S E R N A M E =
[7ffff8d0]    68616e61  53550069  4f445245  4e49414d    a n a h i . U S E R D O M A I N
[7ffff8e0]    414f525f  474e494d  464f5250  3d454c49    _ R O A M I N G P R O F I L E =
```