CS 8803: Compilers: theory and practice

Project Phase 2: Back end Testing and output report Team: Gang Liao, Rachna Saxena

This document describes the assembly code output of Tiger language programs. In the second phase of project, back end components like naive register allocation, control flow graph, intra block allocation, and whole function register allocation using Briggs algorithm using live range analysis is implemented. It also implements instruction selection and code generation. Bonus 2 i.e. function calls are also part of this implementation.

This report contains test case results for generated assembly code executed on SPIM, MIPS based simulator. spim-keepstats is used to generate execution level details.

Test cases Output: All outputs are present in the directory testcases2. Below table describes the purpose and result of different each test cases.

Test case	Test Scenario	Status	Comments
Float.tiger	Tests for floating point parameter to a function and float addition	Pass	
Float_arr.tiger	Tests for floating point array element passed as parameter to a function and float addition	Pass	
Func.tiger	Test for function call, argument passing	Pass	
Func_ret.tiger	Test for function call, argument passing and return value implementation	Pass	
Test1.tiger	Type and variable declaration, for loop, array usage	Pass	
Test2.tiger	Type declaration, function definition, function call	Pass	
Test3.tiger	Variable declaration (float type), function definition, function call	Pass	
Test5.tiger	Variable declaration, if-then-else statement	Pass	
factorial.tiger	Calculate and print factorial of a number	Pass	

Float.tiger:

Float.tiger.naive.s:

```
FP Regs Int Regs [16]
                                                                                                                                                                                                                                                                                    Data
                                                                                                                                                                                                                                       A ×
      Int Regs [16]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               User Text Segment [00400000]..[00440000]; 183: 1v $a0 0($xp) # argc; 184: addiu $a1 $xp 4 # argv; 185: addiu $a2 $a1 4 # envp; 185: addiu $a2 $a1 4 # envp; 186: 311 $v0 $a0 2; 187: addu $a2 $a2 $v0
                                                                                                                                                                                                                                                                 [0040000] 8fa40000 lw $4, 0($29)
[00400004] 27a50004 addin $5, $29, 4
[00400008] 24a60004 addin $6, $5, 4
[00400000] 00041080 sil $2, $4, 2
[00400010] 00c23021 addu $6, $6, $2
      EPC
     Cause = 0
BadVAddr = 0
Status = 3000ff10
      HI
LO
                                                = 0
= 0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                ; 188: jal main
; 189: nop
; 191: li $v0 10
                                                                                                                                                                                                                                                                   [00400014] 0c100062
                                                                                                                                                                                                                                                                                                                                                                             jal 0x00400188 [main]
R0 [r0] = 0

R1 [at] = 10010000

R2 [v0] = a

R3 [v1] = 0

R4 [a0] = 1

R5 [a1] = 7ffff23c

R6 [a2] = 7ffff244

R7 [a3] = 0

R10 [t2] = 0

R11 [t3] = 0

R12 [t4] = 0

R13 [t5] = 0

R14 [t6] = 0

R15 [t7] = 0

R15 [t7] = 0

R16 [s0] = 0

R17 [s1] = 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] = 10010000

R26 [k0] = 0

R27 [k1] = 0
                                                                                                                                                                                                                                                                   [00400018] 00000000
                                                                                                                                                                                                                                                                                                                          3402000a
                                                                                                                                                                                                                                                                                                                                                                              ori $2, $0, 10
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              ; 191: 11 $v0 10
; 192: syscall # syscall
; 199: sv $s0, -4($sp)
; 200: sv $s1, -8($sp)
; 201: sv $s2, -12($sp)
; 202: sv $s3, -16($sp)
; 203: sv $s4, -20($sp)
; 204: sv $s5, -24($sp)
; 205: sv $s6, -28($sp)
; 206: sv $s7, -32($sp)
; 207: addi $sp, $sp, -4;
; 208: sv $ra, -4($sp)
; 209: addi $sp, $sp, -4;
; 209: addi $sp, $sp, -4;
; 210: li $v0, 1
; 211: syscall
                                                                                                                                                                                                                                                                 [00400020] 00000000
[00400024] afbifffs
[00400022] afbifffs
[00400022] afbifffs
[00400030] afbifffs
[00400030] afbiffes
[00400030] afbiffes
[00400040] afbiffes
[00400040] afbiffes
[00400040] afbifffs
[00400040] afbifffs
                                                                                                                                                                                                                                                                                                                                                                         syscall

sw $16, -4 ($29)

sw $17, -8 ($29)

sw $18, -12 ($29)

sw $18, -12 ($29)

sw $20, -20 ($29)

sw $21, -24 ($29)

sw $21, -24 ($29)

sw $22, -28 ($29)

sw $23, -32 ($29)

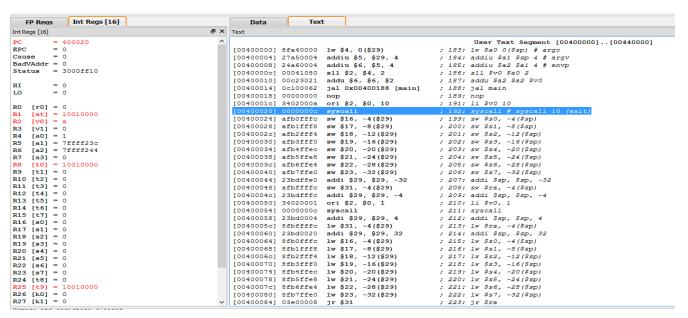
add1 $29, $29, -32

sw $31, -4 ($29)

add1 $29, $29, -4

ori $2, $0, 1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             , 210: 1i $v0, 1
; 211: syscall
; 212: addi $sp, $sp, 4
; 213: lv $ra, -4($sp)
; 214: addi $sp, $sp, 3;
; 215: lv $so, -4($sp)
; 216: lv $s1, -8($sp)
; 217: lv $s2, -12($sp)
; 218: lv $s3, -16($sp)
; 219: lv $s4, -20($sp)
; 220: lv $s5, -24($sp)
; 221: lv $s6, -28($sp)
; 222: lv $s7, -32($sp)
; 223: jr $ra
                                                                                                                                                                                                                                                                   [00400050] 34020001
                                                                                                                                                                                                                                                                                                                                                                             ori $2, $0, 1
syscall
                                                                                                                                                                                                                                                                                                                                                                         syscall
addi $29, $29, 4
lw $31, -4($29)
addi $29, $29, 32
lw $16, -4($29)
lw $17, -8($29)
lw $18, -12($29)
lw $19, -16($29)
lw $20, -20($29)
lw $21, -24($29)
lw $22, -28($29)
lw $22, -32($29)
jr $31
                                                                                                                                                                                                                                                                   [004000541 0000000c
                                                                                                                                                                                                                                                                    [00400058] 23bd0004
                                                                                                                                                                                                                                                                  [00400058] 23bd0004
[0040005c] 8fbffffc
[00400060] 23bd0020
[00400064] 8fb0fffc
[00400068] 8fb1fff8
[0040006c] 8fb2fff4
                                                                                                                                                                                                                                                                   [00400070] 8fb3fff0
[00400074] 8fb4ffec
                                                                                                                                                                                                                                                   [00400074] 8fb5ffe8
[0040007c] 8fb6ffe4
[00400080] 8fb7ffe0
[00400084] 03e00008
```

Float.tiger.cfg.s:



Code/Files	Instructions	Read	Write	Branches	Other
Float.tiger.naive.s	132	29	28	5	70
Float.tiger.cfg.s	134	29	28	5	72

Float arr.tiger:

Float arr.tiger.naive.s

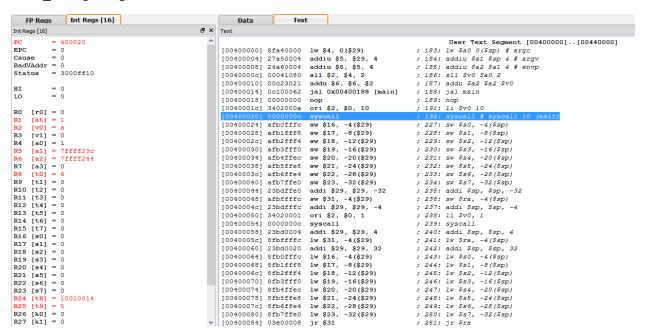
```
FP Regs Int Regs [16]
                                                                                       Text
                                                                     Data
                                                          ₽ × Text
Int Regs [16]
            = 400020
                                                                                                                                       User Text Segment [00400000]..[00440000]
EPC
                                                                 [00400000] 8fa40000 lw $4, 0($29)
                                                                                                                             ; 183: lw $a0 0($sp) # argc
                                                                                           addiu $5, $29, 4
addiu $6, $5, 4
Cause
           = 0
                                                                 [00400004] 27a50004
                                                                                                                             ; 184: addiu $a1 $sp 4 # argv
BadVAddr = 0
Status = 3000ff10
                                                                 [00400008] 24a60004
                                                                                                                             ; 185: addiu $a2 $a1 4 # envp
                                                                                           sl1 $2, $4, 2
addu $6, $6, $2
                                                                 [0040000c] 00041080
                                                                                                                             ; 186: sll $v0 $a0 2
                                                                 [00400010] 00c23021
                                                                                                                             ; 187: addu $a2 $a2 $v0
                                                                 [00400014] 0c100062
[00400018] 00000000
                                                                                            jal 0x00400188 [main]
                                                                                                                             ; 188: jal main
           = 0
LO
                                                                                           nop
                                                                                                                             ; 189: nop
                                                                 [0040001c] 3402000a ori $2, $0, 10
                                                                                                                               191: li $v0 10
R1
     [at] = 1
[v0] = a
                                                                 [00400024] afb0fffc sw $16, -4($29)
                                                                                                                              ; 219: sw $s0, -4($sp)
                                                                 [00400028] afb1fff8
                                                                                                                             ; 220: sw $s1, -8($sp)
                                                                                           sw $17, -8($29)
                                                                 [0040002c] afb2fff4 sw $18, -12($29)
[00400030] afb3fff0 sw $19, -16($29)
                                                                                                                             ; 221: sw $s2, -12($sp)
R4
     [a0] = 1
                                                                                                                             ; 222: sw $s3, -16($sp)
                                                                 [00400034] afb4ffec
[00400038] afb5ffe8
                                                                                                                             ; 223: sw $s4, -20($sp)
; 224: sw $s5, -24($sp)
                                                                                           sw $20, -20($29)
     [a3] = 0
                                                                                           sw $21, -24($29)
R7
                                                                [00400035] alb511e8
[0040003c] afb6ffe4
[00400040] afb7ffe0
[00400044] 23bdffe0
[00400048] afbffffc
     [t0] = 10010030
[t1] = 10010034
                                                                                           sw $22, -28($29)
sw $23, -32($29)
                                                                                                                             ; 225: sw $s6, -28($sp)
; 226: sw $s7, -32($sp)
                                                                                           addi $29, $29, -32
sw $31, -4($29)
                                                                                                                             ; 227: addi $sp, $sp, -32
; 228: sw $ra, -4($sp)
R10 [t2]
R11 [t3] = 0
R12 [t4] = 10010034
R13 [t5] = 1
                                                                 [0040004c] 23bdfffc
[00400050] 34020001
                                                                                           addi $29, $29, -4
                                                                                                                             ; 229: addi $sp, $sp, -4
                                                                                           ori $2, $0, 1
                                                                                                                             ; 230: li $v0, 1
R14 [t6]
                                                                                           syscall
addi $29, $29, 4
                                                                 [00400054] 0000000c
                                                                                                                             ; 231: syscall
R15 [t7] = 0
                                                                 [00400058] 23bd0004
                                                                                                                             ; 232: addi $sp, $sp, 4
R16 [s0] = 0
                                                                [0040005c] 8fbffffc lw $31, -4($29)

[0040006c] 23bd0020 addi $29, $29, 32

[004006d] 8fbbfffc lw $16, -4($29)

[00400068] 8fbfffs lw $17, -8($29)
                                                                                                                             ; 233: lw $ra, -4($sp)
; 234: addi $sp, $sp, 32
R17 [s1]
R18 [s2]
                                                                                                                             ; 235: lw $s0, -4($sp)
; 236: lw $s1, -8($sp)
R19 [s3]
R20 [s4]
                                                                 [0040006c] 8fb2fff4
                                                                                           lw $18, -12($29)
                                                                                                                             ; 237: lw $s2, -12($sp)
R21 [s5]
                                                                 [00400070] 8fb3fff0
                                                                                           lw $19, -16($29)
                                                                                                                             ; 238: lw $s3, -16($sp)
R22 [s6] = 0
R23 [s7]
                                                                 [004000741 8fb4ffec
                                                                                           1w $20. -20($29)
                                                                                                                             : 239: lw $s4, -20($sp)
                                                                 [00400078] 8fb5ffe8
                                                                                           lw $21, -24($29)
                                                                                                                             ; 240: lw $s5, -24($sp)
R24 [t8]
R25 [t9] = 0
                                                                 [0040007c] 8fb6ffe4 lw $22, -28($29)
                                                                                                                             ; 241: lw $s6, -28($sp)
                                                                 [00400080] 8fb7ffe0 lw $23, -32($29)
                                                                                                                             ; 242: lw $s7, -32($sp)
R27 [k1]
                                                                [00400084] 03e00008 jr $31
                                                                                                                             ; 243: jr $ra
```

Float arr.tiger.cfg.s

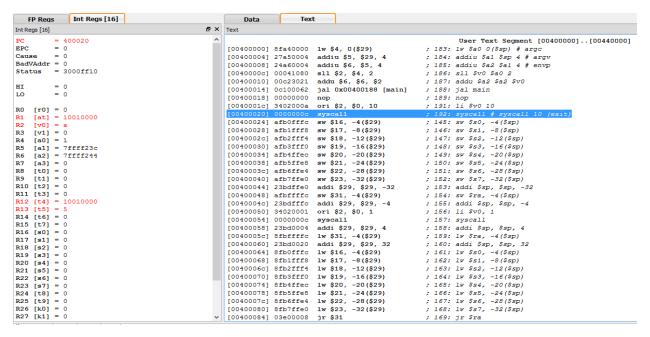


Code/Files	Instructions	Read	Write	Branches	Other
Float_arr.tiger.naive.s	691	159	131	28	373
Float_arr.tiger.cfg.s	680	148	131	28	373

There is 6.92% improved in number of operations. There is 1.62% improvement in the number of instructions in cfg implementation.

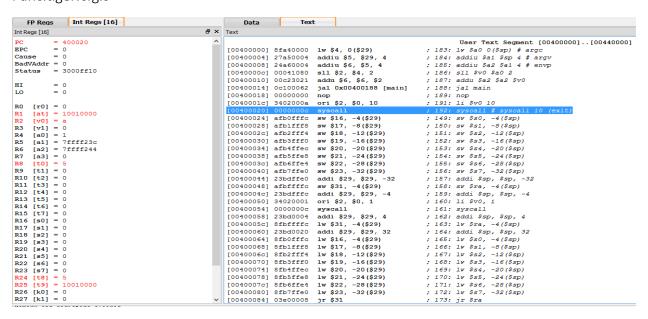
func.tiger:

func.tiger.naive.s



Console output: 5

Func.tiger.cfg.s



Console output: 5

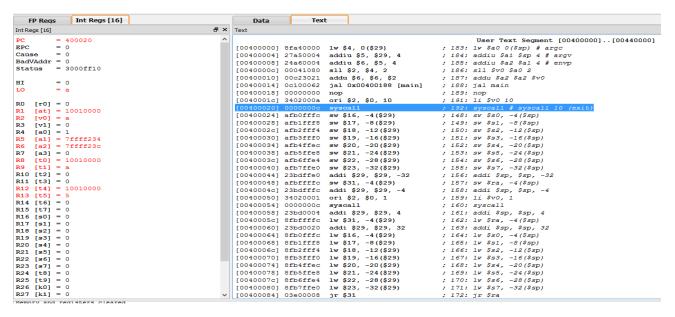
Code/Files	Instructions	Read	Write	Branches	Other	l
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func.tiger.naive.s	153	50	48	7	48
func.tiger.cfg.s	157	50	49	7	51

In this case, there is 2.04% improvement in the number of write operations.

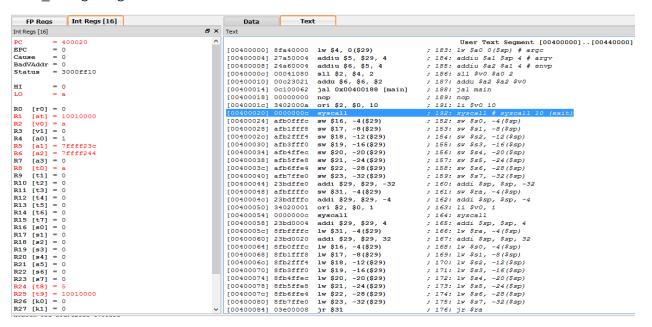
Func_ret.tiger:

Func_ret.tiger.naive.s



Console output: 10

Func ret.tiger.cfg.s



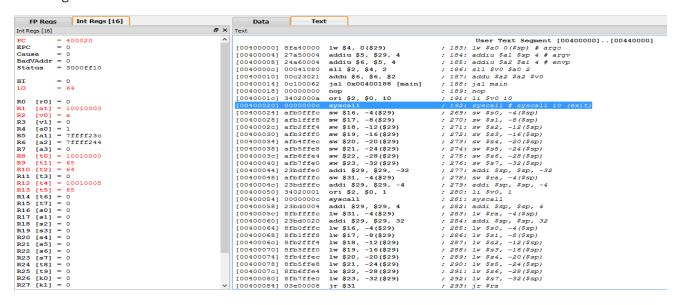
Console output: 10

Code/Files	Instructions	Read	Write	Branches	Other
Func_ret.tiger.naive.s	169	53	50	7	59
Func_ret.tiger.cfg.s	170	52	50	7	61

In this case, there is 1.92% improvement in the number of read operation in the cfg implementation.

Test1.tiger:

Test1.tiger.naive.s



Console output: 10000

Test1.tiger.cfg.s

```
FP Regs Int Regs [16]
                                                                                                                                                                                                                                                              Data
                                                                                                                                                                                                                     ₽ × Text
   Int Regs [16]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                      User Text Segment [00400000]..[00440000]; 183: 1v $a0 O($sp) # argc; 184: addiu $a1 $sp 4 # argv; 185: addiu $a2 $a1 4 # envp; 186: sil $v0 $a0 2; 187: addu $a2 $a2 $v0; 188: ial main
                                               = 400020
                                                                                                                                                                                                                                             [00400000] 8fa40000 lw $4, 0($29)
[00400004] 27a50004 addiu $5, $29, 4
[00400008] 24a60004 addiu $6, $5, 4
[00400006] 00041080 sll $2, $4, 2
[00400010] 00c23021 addu $6, $6, $2
    EPC
    Cause
BadVAddr = 0
c+atus = 3000ff10
    HI
LO
; 188: jal main
; 189: nop
; 191: li $v0 10
                                                                                                                                                                                                                                                                                                                                                jal 0x00400188 [main]
                                                                                                                                                                                                                                              [00400014] 0c100062
                                                                                                                                                                                                                                                                                                                                                nop
ori $2, $0, 10
                                                                                                                                                                                                                                              [00400018] 00000000
                                                                                                                                                                                                                                                [0040001c] 3402000a
                                                                                                                                                                                                                                                                                                                                                                                                                                                                    ; 191: Li Svo 10
; 192: Syscall # Syscall
; 277: Sv $s0, -4($sp)
; 278: sv $s1, -8($sp)
; 278: sv $s2, -12($sp)
; 293: sv $s2, -12($sp)
; 280: sv $s3, -16($sp)
; 281: sv $s4, -20($sp)
; 282: sv $s5, -24($sp)
; 282: sv $s5, -24($sp)
; 283: sv $s6, -28($sp)
; 285: addi $sp, $sp, -32
; 286: sv $ra, -4($sp)
; 287: addi $sp, $sp, -4
; 288: li $v0, 1
; 289: syscall
; 299: syscall
; 290: ddi $sp, $sp, 4
; 291: lv $ra, -4($sp)
; 292: addi $sp, $sp, 4
; 291: lv $ra, -4($sp)
; 292: addi $sp, $sp, 4
; 291: lv $s1, -8($sp)
; 292: lv $s3, -16($sp)
; 292: lv $s3, -16($sp)
; 293: lv $s5, -24($sp)
; 293: lv $s5, -24($sp)
; 293: lv $s5, -24($sp)
; 293: lv $s6, -24($sp)
; 293: lv $s6, -24($sp)
; 293: lv $s6, -24($sp)
; 300: lv $s7, -92($sp)
; 301: jr $ra
                                                                                                                                                                                                                                                                                                                                            SYSCALL

SW $16, -4($29)

sw $17, -8($29)

sw $17, -8($29)

sw $18, -12($29)

sw $20, -20($29)

sw $20, -20($29)

sw $22, -28($29)

sw $22, -28($29)

addi $29, $29, -32

sw $31, -4($29)

addi $29, $29, -4

ori $2, $0, 1

syscall

addi $29, $29, 4

hw $31, -4($29)
                                                                                                                                                                                                                                             [00400020] 0000000c
[00400024] afb0fffc
[00400028] afb1fff8
[0040002c] afb2fff4
[00400030] afb3fff0
[00400034] afb4ffec
                                                                                                                                                                                                                                            [00400034] afb4ffee
[0040003c] afb5ffe8
[0040003c] afb6ffe4
[0040004c] afb7ffe0
[0040004d] 23bdffe0
[0040004d] 23bdfffe
[0040005d] 34020001
[0040005d] 30400000
[0040005d] 32bd0004
                                                                                                                                                                                                                                                                                                                                             addi $29, $29, 4
w $31, -4($29)
addi $29, $29, 32
lw $16, -4($29)
lw $17, -8($29)
lw $18, -12($29)
lw $18, -12($29)
lw $20, -20($29)
lw $20, -20($29)
lw $22, -24($29)
lw $22, -28($29)
                                                                                                                                                                                                                                              [0040005c] 8fbffffc
[00400060] 23bd0020
                                                                                                                                                                                                                                              [00400064] 8fb0fffc
[00400068] 8fb1fff8
[0040006c] 8fb2fff4
[00400070] 8fb3fff0
                                                                                                                                                                                                                                            [00400074] 8fb4ffec
[00400078] 8fb5ffe8
[0040007c] 8fb6ffe4
[00400080] 8fb7ffe0
[00400084] 03e00008
                                            = a
= 10010010
    R26 [k0] = 0

R27 [k1] = 0
                                                                                                                                                                                                                                                                                                                                               lw $23, -32($29)
```

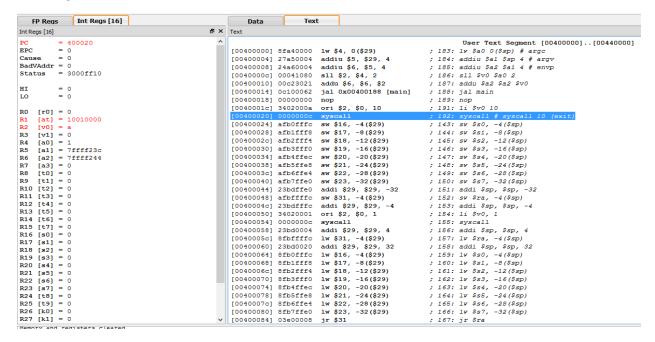
Console output: 10000

Code/Files	Instructions	Read	Write	Branches	Other
Test1.tiger.naive.s	7296	1350	837	207	4902
Test1.tiger.cfg.s	7016	1053	838	207	4918

There is 0.12% improvement in the write performance in the improved implementation. There is 3.99% improvement in the number of instructions.

Test2.tiger:

Test2.tiger.naive.s



Console output: 5

Test2.tiger.cfg.s

```
FP Regs Int Regs [16]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 Data
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  Text
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               ₫ × Text
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             User Text Segment [00400000]..[00440000]
; 183: lv $a0 O($sp) # argc
; 184: addiu $a1 $sp 4 # argv
; 185: addiu $a2 $a1 4 # envp
         PC
EPC
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     [00400000] 8fa40000 lw $4, 0 ($29)
[00400004] 27a50004 addiu $5, $29, 4
[00400008] 24a60004 addiu $6, $5, 44
[00400006] 00041080 all $2, $4, 2
[00400010] 00023021 addu $6, $6, $2
[00400014] 00100062 jal 0x00400188 [
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       ; 186: sll $v0 $a0 2
; 187: addu $a2 $a2 $v0
         HI
LO
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           jal 0x00400188 [main]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       ; 188: jal main
LO = 0

R0 [r0] = 0

R1 [at] = 10010000

R2 [v0] = a

R3 [v1] = 0

R4 [a0] = 1

R5 [a1] = 7ffff23c

R6 [a2] = 7ffff244

R7 [a3] = 0

R8 [t1] = 0

R9 [t1] = 0

R1 [t2] = 0

R1 [t3] = 0

R1 [t3] = 0

R1 [t5] = 0

R2 [t5] = 0

R2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        [00400018] 00000000
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          189: nop
191: li $v0 10
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           [0040001c] 3402000a
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        ori $2,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      $0, 10
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 103403023 | 00030000 | 103400021 | afb0fffc | 100400022 | afb1fffs | 100400032 | afb1fffs | 100400032 | afb3fffc | 100400033 | afb3fffc | 100400033 | afb3ffs | 100400032 | afb6ffes | 100400040 | afb7ffc | 100400040 | afb7ffc | 100400040 | afbfffc | 100400040 | afbfffc | 100400040 | afbfffc | 100400040 | afbfffc | 100400050 | afbfffc | 100400050 | afbfffc | 100400050 | afbfffc | 100400050 | afbfffc | 100400060 | afbfffc | 100400060 | afbfffc | 100400060 | afbfffc | 100400060 | afbfffc | 100400070 | afbfffc | 100400080 | afbffc | 10040080 | a
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          192: syscall & syscall | 192: syscall & syscall | 147: sv $s0, -4($sp) | 148: sv $s1, -8($sp) | 148: sv $s1, -8($sp) | 149: sv $s2, -12($sp) | 150: sv $s2, -12($sp) | 150: sv $s2, -12($sp) | 151: sv $s4, -20($sp) | 152: sv $s5, -24($sp) | 153: sv $s6, -28($sp) | 154: sv $s7, -32($sp) | 155: addi $sp, $sp, -4 | 156: sv $s1, -4($sp) | 157: addi $sp, $sp, -4 | 158: li $v0, 1 | 157: addi $sp, $sp, -4 | 158: li $v0, 1 | 159: syscall | 160: addi $sp, $sp, 4 | 161: lv $s1, -4($sp) | 162: addi $sp, $sp, 32 | 163: lv $s0, -4($sp) | 166: lv $s2, -12($sp) | 166: lv $s4, -20($sp) | 169: lv $s6, -24($sp) | 169: lv $s6, -24($sp) | 169: lv $s6, -24($sp) | 170: lv $s7, -32($sp) | 171: jr $ra
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        [00400024] afb0fffc sw $16, -4($29)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    ; 147: sw $s0, -4($sp)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 sw $16, -4 ($29)

sw $17, -8 ($29)

sw $18, -12 ($29)

sw $18, -12 ($29)

sw $20, -20 ($29)

sw $21, -24 ($29)

sw $22, -28 ($29)

sw $23, -32 ($29)

addi $29, $29, -32

sw $31, -4 ($29)

addi $29, $29, -4

ori $2, $0, 1

syscall

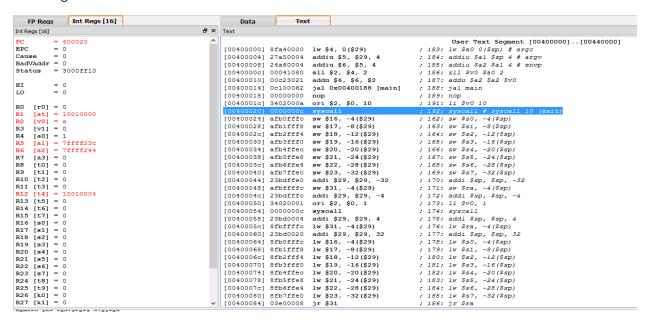
addi $29, $29, 4
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 syscall addi $29, 4 1 w $31, -4 ($29) addi $29, $29, 32 1 w $16, -4 ($29) 1 w $17, -8 ($29) 1 w $16, -12 ($29) 1 w $20, -20 ($29) 1 w $21, -24 ($29) 1 w $22, -28 ($29) 1 w $22, -38 ($29) 1 r $31
```

Console output: 5

Code/Files	Instructions	Read	Write	Branches	Other
Test2.tiger.naive.s	149	49	47	7	46
Test2.tiger.cfg.s	151	49	47	7	48

Test3.tiger

Test3.tiger.naive.s



Console output: 5

Test3.tiger.cfg.s

```
FP Regs
                                                                                                                            Int Regs [16]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                Data
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             Text
                                            Int Regs [16]
                                          PC = 400020

EPC = 0

Cause = 0

BadVAddr = 0

Status = 3000ff10
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               User Text Segment [00400000]..[00440000]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            User Text Segment [004; 183:14 $a0 0($sp) # argc; 184: addiu $a1 $sp 4 # argv; 185: addiu $a2 $a1 4 # envp; 186: sll $v0 $a0 2; 187: addu $a2 $a2 $v0; 188: jal main
                                                                                                                                                                                                                                                                                                                                                                                                                                                                  [00400000] 8fa40000
[00400004] 27a50004
[00400008] 24a60004
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       lw $4, 0($29)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       lw $4, 0($29)
addiu $5, $29, 4
addiu $6, $5, 4
sll $2, $4, 2
addu $6, $6, $2
jal 0x00400188 [main]
                                                                                                                                                                                                                                                                                                                                                                                                                                                                  [00400006] 24460004
[0040000c] 00041080
[00400010] 00c23021
[00400014] 0c100062
                                                                                                                  = 0
= 0
                                            ΗI
                                            LO
[r0] = 0
[at] = 1001000
[v0] = a
[v1] = 0
[a0] = 1
[a1] = 7ffff23c
6 [a2] = 7ffff244
7 [a3] = 0
[b [t0] = 0
R9 [t1] = 0
R11 [t3] = 0
R12 [t4] = 0
R13 [t5] = 0
R14 [t6] = 0
R15 [t7] = 0
R16 [s0] = 0
R17 [s1] = 0
R19 [s3] = 0
R20 [s4] = 0
R21 [s5] = 0
R22 [s6] = 0
R24 [t8] = 0
R25 [t9] = 1/
R26 [k0] = 0
R27 [k1] = 0
R26 [k0] = 0
R27 [k1] = 0
R27 [k1] = 0
R28 [k0] = 0
R29 [k1] = 0
R29 [k1] = 0
R29 [k1] = 0
R20 [k2] = 1/
R20 [k2] = 1/
R21 [k2] = 0
R22 [k2] = 1/
R22 [k3] = 0
R25 [k2] = 1/
R26 [k0] = 0
R27 [k1] = 0
R28 [k1] =
                                                                                                                                                                                                                                                                                                                                                                                                                                                                  [00400018] 00000000
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            nop
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           189: nop
                                                                                                                                                                                                                                                                                                                                                                                                                                                                      [0040001c] 3402000a
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            ori $2,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             191: li $v0 10
                                                                                                                                                                                                                                                                                                                                                                                                                                                              192: vyscall f syscal

166: sv $s0, -4($sp)

167: sv $s1, -8($sp)

168: sv $s2, -12($sp)

169: sv $s3, -16($sp)

170: sv $s4, -20($sp)

171: sv $s5, -24($sp)

172: sv $s6, -28($sp)

173: sv $s7, -32($sp)

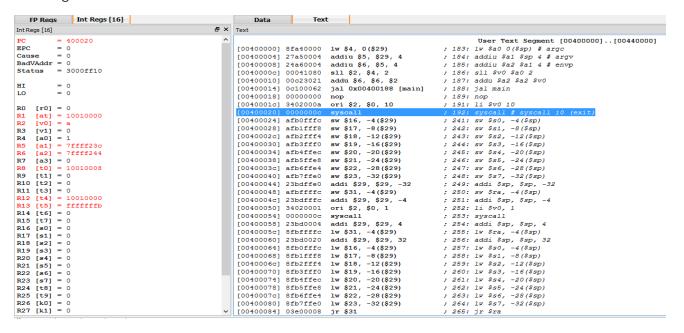
174: add $sp, $sp.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          ; 173: SV $S7, -32($sp)
; 174: addi $sp, $sp, -32
; 175: sv $ra, -4($sp)
; 176: addi $sp, $sp, -4
; 177: li $v0, 1
; 178: syscall
; 179: addi $sp, $sp, 4
; 180: lv $ra, -4($sp)
; 181: addi $sp, $sp, 32
; 182: lv $s0, -4($sp)
; 183: lv $s1, -8($sp)
; 184: lv $s2, -12($sp)
; 185: lv $s5, -16($sp)
; 185: lv $s3, -16($sp)
; 186: lv $s4, -20($sp)
; 187: lv $s5, -24($sp)
; 187: lv $s5, -24($sp)
; 187: lv $s5, -24($sp)
; 189: lv $s5, -32($sp)
; 189: lv $s5, -32($sp)
; 189: lv $s7, -32($sp)
; 189: lv $s7, -32($sp)
; 189: lv $s7, -32($sp)
; 190: jr $ra
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         sw $23, -32($29)
addi $29, $29, -32
sw $31, -4($29)
addi $29, $29, -4
ori $2, $0, 1
syscall
                                                                                                                                                                                                                                                                                                                                                                                                                                                              [00400058] 23bd0004 addi $29, $29, 4 [00400060] 87bffffe lw $31, -4($29) [00400060] 87bffff8 lw $17, -8($29) [00400060] 87bffff8 lw $18, -12($29) [00400061] 87bffff8 lw $19, -16($29) [00400070] 87bfff6 lw $19, -16($29) [00400076] 87bfffec lw $20, -20($29) [00400076] 87bfffec lw $21, -24($29) [00400076] 87bfffe4 lw $22, -28($29) [00400084] 87bfffe6 lw $23, -32($29) [00400084] 03e00008 jr $31
                                                                                                                                                                                                                                                                                                                                                                                                                                                                [004000841 03e00008
```

Console output:5

Code/Files	Instructions	Read	Write	Branches	Other
Test3.tiger.naive.s	166	49	47	7	63
Test3.tiger.cfg.s	172	49	47	7	69

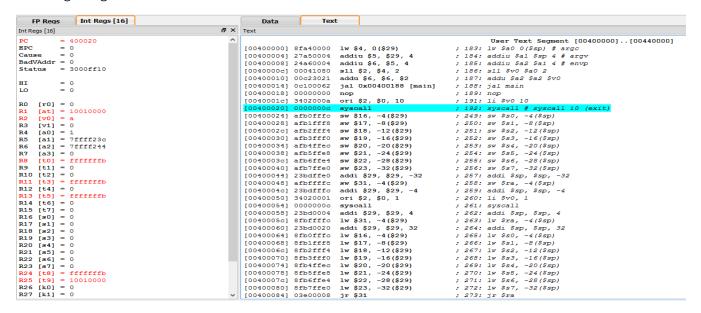
Test5.tiger:

Test5.tiger.naive.s



Console output: -5

Test5.tiger.cfg.s



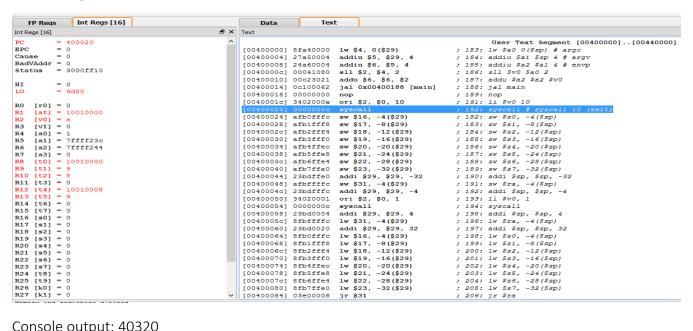
Console output: -5

Code/Files	Instructions	Read	Write	Branches	Other
Test5.tiger.naive.s	175	47	37	6	85
Test5.tiger.cfg.s	177	43	39	6	89

There is 9.3% improvement in the number of instruction in improved implementation.

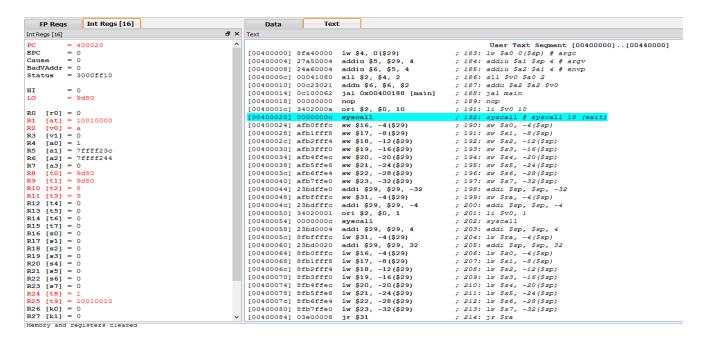
factorial.tiger:

factorial.tiger.naive.s



Console output: 40320

factorial.tiger.cfg.s



Console output: 40320

Code/Files	Instructions	Read	Write	Branches	Other
factorial.tiger.naive.s	402	92	56	21	233
factorial.tiger.cfg.s	408	79	65	21	243

There is 16.46% improvement in the number of read operations in the cfg implementation.