# Abstract

In this phase, we found some errors and modified the assembly code slightly. After that, we confirmed that the result is correctly displayed on the console through QtSpim, and calculated instruction count in manually and calculated it in QtSpim. Finally, we compared the two to confirm the error.

# Assembly Code (modified compared to phase2)

[tsp.s]

# SWE3005 Computer Architectures

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# 2019 Spring Course Project

# TSP on MIPS

# Phase 2: Manually compile into MIPS

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.data

ans:

  .double 1000000.0

arr:  # array for distance

  .double 0.000000  # row 1

  .double 10.000000

  .double 4.472136

  .double 9.219544

  .double 3.162278

  .double 9.848858

  .double 3.605551

  .double 10.000000 # row 2

  .double 0.000000

  .double 6.324555

  .double 2.236068

  .double 7.615773

  .double 2.236068

  .double 6.708204

  .double 4.472136  # row 3

  .double 6.324555

  .double 0.000000

  .double 5.000000

  .double 1.414214

  .double 7.000000

  .double 1.000000

  .double 9.219544  # row 4

  .double 2.236068

  .double 5.000000

  .double 0.000000

  .double 6.403124

  .double 4.242641

  .double 5.656854

  .double 3.162278  # row 5

  .double 7.615773

  .double 1.414214

  .double 6.403124

  .double 0.000000

  .double 8.062258

  .double 1.000000

  .double 9.848858  # row 6

  .double 2.236068

  .double 7.000000

  .double 4.242641

  .double 8.062258

  .double 0.000000

  .double 7.071068

  .double 3.605551  # row 7

  .double 6.708204

  .double 1.000000

  .double 5.656854

  .double 1.000000

  .double 7.071068

  .double 0.000000

visit:      .space 28 # int visit[7];

shortest\_path:  .space 28 # int shortest\_path[7];

current\_path: .space 28 # int current\_path[7];

space:      .asciiz " "

newline:    .asciiz "\n"

.text

main:

  li    $t0, 1

  la    $t1, shortest\_path

  sw    $t0, 0($t1)     # shortest\_path[0] = 1

  la    $t2, current\_path

  sw    $t0, 0($t2)     # current\_path[0] = 1

  li    $a0, 0

  li    $a1, 0

  mfc1  $zero, $f14

  jal   dfs   # call dfs

  nop

  ldc1  $f12, ans

  li    $v0, 3

  syscall

  nop

  la    $a0, newline

  li    $v0, 4

  syscall

  nop

  jal   print\_path

  nop

  li    $v0, 10   # terminate program

syscall

print\_path:

  la    $s1, shortest\_path

  li    $t3, 0    # i = 0

  L1:

    beq   $t3, 7, print\_path\_dfs\_end  # if i >= 7 then print\_path\_dfs\_end

    sll   $t4, $t3, 2   # i \* 4 (offset)

    add   $t4, $s1, $t4 # arr[i]

    lw    $a0, 0($t4)   # $a0 = arr[i]

    li    $v0, 1      # print integer

    syscall

    nop

    la    $a0, space    # print space

    li    $v0, 4

    syscall

    nop

    addiu $t3, $t3, 1   # i++

    j   L1        # branch to L1

    nop

  print\_path\_dfs\_end:

    la    $a0, newline  # print newline (not really useful for here)

    li    $v0, 4

    syscall

    nop

    jr    $ra       # jump to $ra

    nop

save\_path:

  li    $t3, 0  # i

  L3:

    bge   $t3, 7, save\_path\_end

    sll   $t4, $t3, 2

    la    $s3, current\_path # $s3 = cur

    add   $s3, $s3, $t4   # current\_path[i]

    lw    $s1, 0($s3)     # $s1 = current\_path[i]

    la    $s3, shortest\_path

    add   $s3, $s3, $t4

    sw    $s1, 0($s3)

    addiu $t3, $t3, 1   # i++

    b   L3        # branch to L3

    nop

  save\_path\_end:

    jr    $ra

    nop

dfs: # $a0 - n, $a1 - depth, $f14 - sum, $s4 - i

  beq   $a1, 6, dfs\_end # if depth == 6 then end

  nop

  li    $s4, 0  # $s4 is i index

  L2: # for loop

    addi  $s4, $s4, 1     # ++i

    bgt   $s4, 6, save\_end  # if i > 6 then end recursive call

    nop

    sll   $t3, $s4, 2     # index processing

    la    $s1, visit      # load visit address

    add   $s7, $t3, $s1   # $s7 = address of visit[i]

    lw    $t5, 0($s7)     # $t5 = visit[i]

    beq   $t5, 1, L2      # if visit[i] == 1 continue;

    nop

    la    $t0, arr      # $t0 = &arr

    mul   $t1, $a0, 7     # col processing; $t1 = n \* 7

    add   $t1, $t1, $s4   # row proceesing; $ti = n \* 7 + i

    mul   $t1, $t1, 8     # address processing; size of double

    add   $t0, $t0, $t1   # $t0 = &arr[n][i]

    l.d   $f4, 0($t0)     # $f4 = arr[n][i]

    add.d $f0, $f4, $f14    # $f0 = sum + arr[n][i]

    ldc1  $f2, ans      # $f2 = ans

    c.lt.d  $f2, $f0      # if sum + arr[n][i] > ans then L2 (inverse condition)

    bc1t  L2

    nop

    li    $t5, 1        # $t5 = 1

    sw    $t5, 0($s7)     # visit[i] = 1

    addi  $t6, $s4, 1     # city num (i + 1)

    addi  $t7, $a1, 1     # depth+1

    mul   $t8, $t7, 4     # [depth+1]

    la    $s2, current\_path

    add   $s2, $t8, $s2   # $s2 = current\_path[depth+1]

    sw    $t6, 0($s2)     # current\_path[i] = cities[i].num

    # caller saved register

    addi  $sp, $sp, -48

    sw    $ra, 40($sp)

    sw    $a0, 32($sp)

    sw    $a1, 24($sp)

    s.d   $f14, 16($sp) # 8 byte double

    sw    $s7, 8($sp)   # &visit[i] of caller

    sw    $s4, 0($sp)   # i index

    # save next argument

    move  $a0, $s4    # n = i

    move  $a1, $t7    # depth = depth+1

    mov.d $f14, $f0   # move $f0(sum+arr[n][i]) to $f14

    jal   dfs   # recursive call

    nop

    lw    $s4, 0($sp)

    lw    $s7, 8($sp)

    l.d   $f14, 16($sp)

    lw    $a1, 24($sp)

    lw    $a0, 32($sp)

    lw    $ra, 40($sp)

    addi  $sp, $sp, 48

    sw    $zero, 0($s7)   # visit[i] = 0

    j   L2          # jump to L2

    nop

  dfs\_end:

    la    $t0, arr

    mul   $t1, $a0, 7

    mul   $t1, $t1, 8

    add   $t0, $t0, $t1   # $t0 = &arr[n][0]

    ldc1  $f4, 0($t0)     # $f4 = arr[n][0]

    add.d $f8, $f14, $f4    # sum += arr[n][0]

    la    $t9, ans      # $t9 = &ans

    l.d   $f6, 0($t9)     # $f6 = ans

    c.le.d  $f8, $f6      # if sum <= ans

    bc1t  save        # then goto save

    nop

    b save\_end

  save:

    s.d   $f8, 0($t9)   # ans = sum

    addi  $sp, -8

    sw    $ra, 0($sp)

    jal   save\_path

    lw    $ra, 0($sp)

    addi  $sp, 8

    nop

  save\_end:

    jr    $ra

    nop

# Execution Time Estimate at Instruction Count by hand

We assumeed the worst case (O(n!)) and calculated the instruction count.

At main: we have 18 instructions except ‘nop’ instruction. We always didn’t count ‘nop’ instruction.

At print\_path: we have 2 + 11 \* 7 + 4 = 83 instructions.

At save\_path: we have 1 + 10 \* 7 + 1 = 72 instructions.

At dfs: we have (45 (by backtracking) + 18 (dfs\_end & save) + 72 (save\_path)) \* 720 (=6!) = 97200

Total: 97300 instructions (save\_path is included in dfs).

# Execution Time and Result at Instruction Count by SPIM

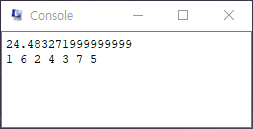


Figure 1 QtSpim Console Output Result (tsp.s)

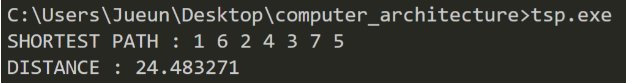


Figure 2 Output result of Phase 1 (tsp.c)

The measured execution time obtained from QtSpim simulator is 64600 instructions. The console output of the QtSpim (Figure 1) means the distance of the shortest tour and the ordered node numbers of the shortest route, respectively.

We could also confirm the answer gave from the assembly program which manually compiled by our hand is the same as the answer of the C program (Figure 2). The tsp.s can run on the QtSpim simulator like the C program tsp.c can run on the desktop computer.

Note that when the estimated execution time 97300 was computed, the pruned explore route taken by backtracking was not considered. The backtracking condition was if the next distance of current exploring route is not shorter than the current shortest distance then the following examination does not have to be done for this route. Using this way, we can get the actual execution time with the pruning which is only 2/3 of the estimated execution time.

# Conclusion

We adopted the DFS algorithm which uses pruning to deal with the TSP in this project. The high-level language program is coded using C, and then we manually compiled the C program into MIPS assembly. We first estimate the execution time of assembly code program in terms of the number of instructions executed. Finally, we compared the real execution time get from simulation over the QtSpim simulator with the estimated time and found the algorithm improvement. Pruning reduced the unnecessary path, reducing the instruction by 2/3.