TRƯỜNG ĐẠI HỌC BÁCH KHOA TP.HCM

KHOA KHOA HỌC VÀ KỸ THUẬT MÁY TÍNH

BÁO CÁO BÀI TẬP LỚN KIẾN TRÚC MÁY TÍNH

Đề 6: Sắp xếp chuỗi. Cho một chuỗi số nguyên 20 phần tử. Sử dụng hợp ngữ assembly MIPS, viết thủ tục sắp xếp chuỗi đó theo tứ tự tăng dần theo giải thuật merge sort.

GV hướng dẫn: **Trần Thanh Bình**

Lớp: L05

Nhóm thực hiện :

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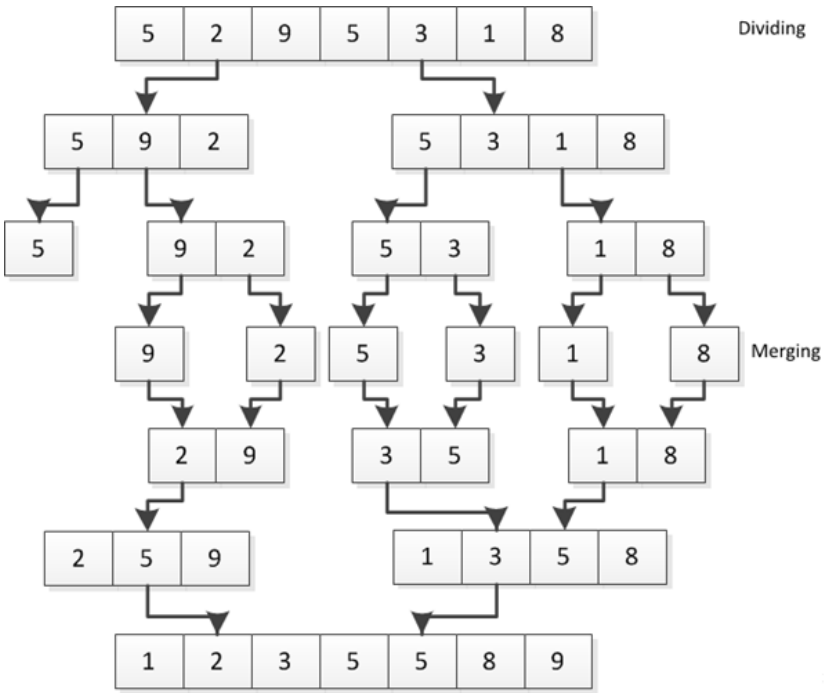
Divide and conquer là một trong số những mẫu thiết kế giải thuật chung được nhiều người biết đến nhất, và **merge sort** là một ứng dụng hay được tạo ra trên nền algorithm này.

Các giải thuật devide and conquer hoạt động theo các bước sau:

- Problem sẽ được chia thành nhiều cụm nhỏ, nên có kích thước bằng nhau.
- Chúng ta sẽ xử lý tuần tử các problem nhỏ, đa số dùng đệ quy.
- Trong một số trường hợp, kết quả của chúng sẽ được gộp để có kết quả.

Giải thuật Merge Sort

Merge sort là một ví dụ của giải thuật divide and conquer này. Sau khi chia đủ nhỏ, merge sort sẽ gộp hai dữ liệu đã sort thành một dữ liệu lớn hơn.



Ưu nhược điểm của Merge sort:

- Ưu: Độ phức tạp tốt hơn so với Insertion Sort, Selection Sort, Interchange Sort
- Nhược: Cần thêm bộ nhớ để chứa một mảng thứ 3

Hàm Merge sort:

```
################### begin merge_sort ##########################
merge_sort:
slt $t6, $a1, $a2
bne $t6, $0, mergesort       # if(a2 <= a1) return
jr $ra
mergesort:
add $s0, $a1, $a2
addi $s0, $s0, -1
div $s0, $s0, 2              # $s0 = ($a1 + $a2 - 1)/2
add $sp, $sp, -16
sw $ra, 12($sp)              # save address $ra
sw $a1, 8($sp)               # save address $a1
sw $a2, 4($sp)               # save address $a2
sw $s0, 0($sp)
move $a2, $s0                # $a2 = $s0
jal merge_sort               # merge_sort(string, a1, a2)
lw $s0, 0($sp)
lw $a2, 4($sp)               # save address $a2
addi $a1, $s0, 1             # $a1 = $s0 + 1
jal merge_sort               # merge_sort(string, a1, a2)
lw $s0, 0($sp)
lw $a2, 4($sp)               # restore $a2
lw $a1, 8($sp)               # restore $a1
jal merge                    # merge(string, a1, s0, a2)
lw $s0, 0($sp)
lw $a2, 4($sp)               # restore $a2
lw $a1, 8($sp)
lw $ra, 12($sp)              # restore $ra
add $sp, $sp, 16
jr $ra
###################### end merge_sort ##########################
```

```
.data
size: .word 20
arr1: .space 40
arr2: .space 40
```

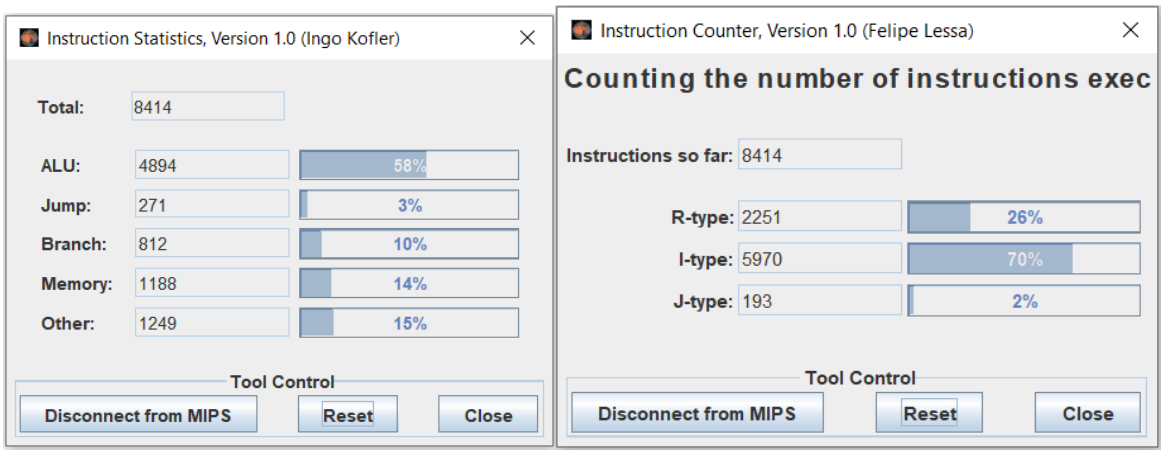
```
######################## begin merge ######################
merge:
sub $s1, $s0, $a1
addi $s1, $s1, 1              # $s1 = $s0 - $a1 + 1
sub $s2, $a2, $s0             # $s2 = $a2 - $s0
mul $a1, $a1, 4
mul $a2, $a2, 4
mul $s0, $s0, 4

la $t1, arr1                  # $t1 <- arr1[size]
la $t2, arr2                  # $t2 <- arr2[size]
```

```
la $s3, string
add $s3, $s3, $a1               # string[a1]
li $t3, 0                       # i = 0
loop_T1:
lw $s4, 0($s3)
sw $s4, 0($t1)                  # arr1[i] = string[a1+i]
addi $t3, $t3, 1                # i++
la $s3, 4($s3)
la $t1, 4($t1)
bne $t3, $s1, loop_T1           # if(i == s1) break
```

```
la $s3, string
add $s3, $s3, $s0             # string[s0]
la $s3, 4($s3)                # string[s0+1]
li $t3, 0                     # i = 0
loop_T2:
lw $s4, 0($s3)
sw $s4, 0($t2)                # arr2[i] = string[s0+1+i]
addi $t3, $t3, 1              # i++
la $s3, 4($s3)
la $t2, 4($t2)
bne $t3, $s2, loop_T2         # if(i == s2) break
```

TEST CASE 1:

.word 18, 9, 11, 20, 10, 8, 13, 19, 17, 7, 6, 12, 5, 16, 4, 15, 3, 2, 1, 14



18 9 11 20 10 8 13 19 17 7 6 12 5 16 4 15 3 2 1 14
9 18 11 20 10 8 13 19 17 7 6 12 5 16 4 15 3 2 1 14
9 18 11 10 20 8 13 19 17 7 6 12 5 16 4 15 3 2 1 14
9 18 10 11 20 8 13 19 17 7 6 12 5 16 4 15 3 2 1 14
9 10 11 18 20 8 13 19 17 7 6 12 5 16 4 15 3 2 1 14
9 10 11 18 20 8 13 19 17 7 6 12 5 16 4 15 3 2 1 14
9 10 11 18 20 8 13 19 7 17 6 12 5 16 4 15 3 2 1 14
9 10 11 18 20 8 13 7 17 19 6 12 5 16 4 15 3 2 1 14
9 10 11 18 20 7 8 13 17 19 6 12 5 16 4 15 3 2 1 14
7 8 9 10 11 13 17 18 19 20 6 12 5 16 4 15 3 2 1 14
7 8 9 10 11 13 17 18 19 20 6 12 5 16 4 15 3 2 1 14
7 8 9 10 11 13 17 18 19 20 6 12 5 4 16 15 3 2 1 14
7 8 9 10 11 13 17 18 19 20 6 12 4 5 16 15 3 2 1 14
7 8 9 10 11 13 17 18 19 20 4 5 6 12 16 15 3 2 1 14
7 8 9 10 11 13 17 18 19 20 4 5 6 12 16 3 15 2 1 14
7 8 9 10 11 13 17 18 19 20 4 5 6 12 16 3 15 2 1 14
7 8 9 10 11 13 17 18 19 20 4 5 6 12 16 3 15 1 2 14
7 8 9 10 11 13 17 18 19 20 4 5 6 12 16 1 2 3 14 15
7 8 9 10 11 13 17 18 19 20 1 2 3 4 5 6 12 14 15 16
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

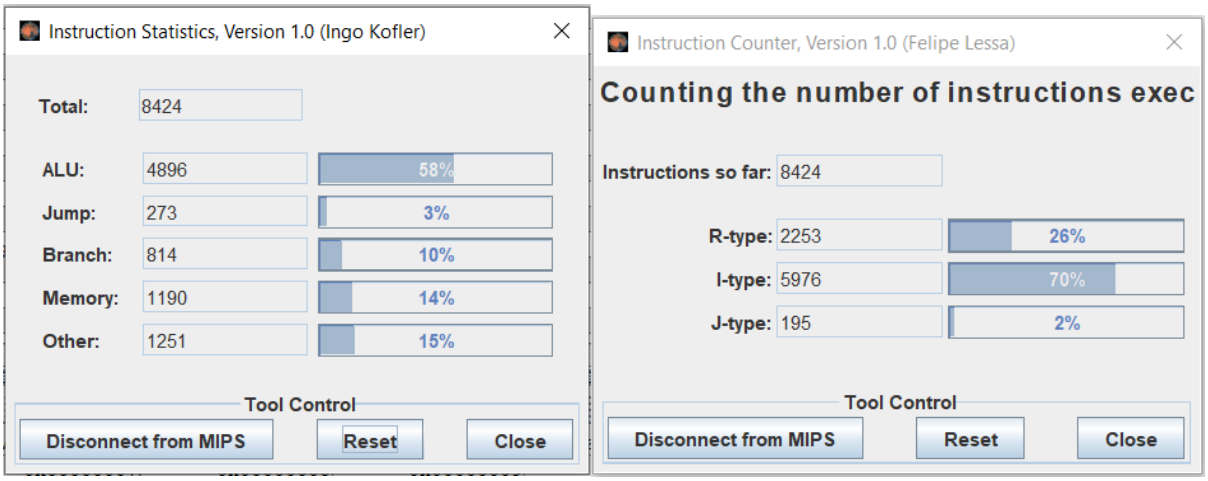
Thời gian thực thi: execution time $= \frac{CPI \times \boldsymbol{Intrustions}}{Clock\ rate}$

$= \frac{1 \times 8414}{2 \times 10^9}$

$= 4.207\ (\mu s)$

TEST CASE 2:

.word -18, 9, 11, 20, -10, 8, 13, -19, 17, 7, -6, 12, 5, -16, 4, 15, -3, 2, 1, -14



-18 9 11 20 -10 8 13 -19 17 7 -6 12 5 -16 4 15 -3 2 1 -14
-18 9 11 20 -10 8 13 -19 17 7 -6 12 5 -16 4 15 -3 2 1 -14
-18 9 11 -10 20 8 13 -19 17 7 -6 12 5 -16 4 15 -3 2 1 -14
-18 9 -10 11 20 8 13 -19 17 7 -6 12 5 -16 4 15 -3 2 1 -14
-18 -10 9 11 20 8 13 -19 17 7 -6 12 5 -16 4 15 -3 2 1 -14
-18 -10 9 11 20 8 13 -19 17 7 -6 12 5 -16 4 15 -3 2 1 -14
-18 -10 9 11 20 8 13 -19 7 17 -6 12 5 -16 4 15 -3 2 1 -14
-18 -10 9 11 20 8 13 -19 7 17 -6 12 5 -16 4 15 -3 2 1 -14
-18 -10 9 11 20 -19 7 8 13 17 -6 12 5 -16 4 15 -3 2 1 -14
-19 -18 -10 7 8 9 11 13 17 20 -6 12 5 -16 4 15 -3 2 1 -14
-19 -18 -10 7 8 9 11 13 17 20 -6 12 5 -16 4 15 -3 2 1 -14
-19 -18 -10 7 8 9 11 13 17 20 -6 12 5 -16 4 15 -3 2 1 -14
-19 -18 -10 7 8 9 11 13 17 20 -6 12 -16 4 5 15 -3 2 1 -14
-19 -18 -10 7 8 9 11 13 17 20 -16 -6 4 5 12 15 -3 2 1 -14
-19 -18 -10 7 8 9 11 13 17 20 -16 -6 4 5 12 -3 15 2 1 -14
-19 -18 -10 7 8 9 11 13 17 20 -16 -6 4 5 12 -3 15 2 -14 1
-19 -18 -10 7 8 9 11 13 17 20 -16 -6 4 5 12 -3 15 -14 1 2
-19 -18 -10 7 8 9 11 13 17 20 -16 -6 4 5 12 -14 -3 1 2 15
-19 -18 -10 7 8 9 11 13 17 20 -16 -14 -6 -3 1 2 4 5 12 15
-19 -18 -16 -14 -10 -6 -3 1 2 4 5 7 8 9 11 12 13 15 17 20

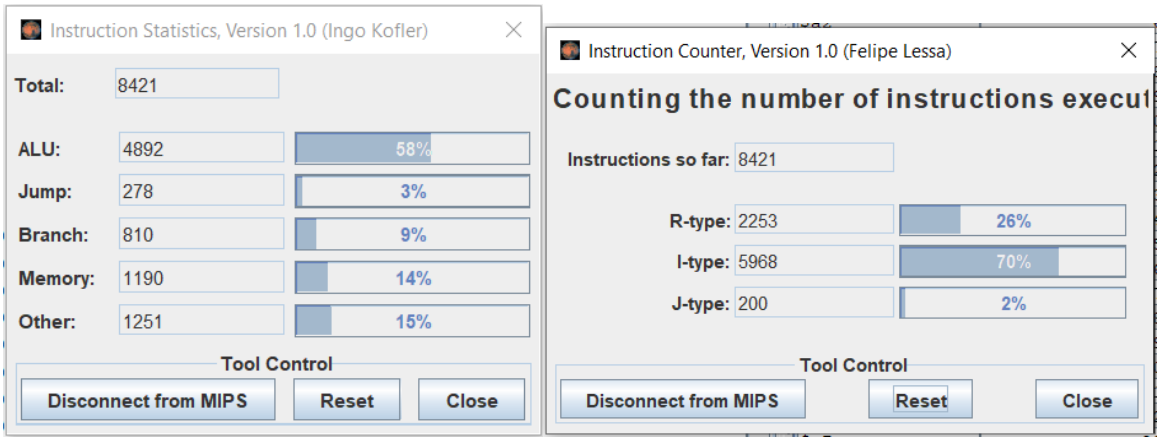
Thời gian thực thi: execution time $= \frac{CPI \times \boldsymbol{Intrustions}}{Clock\ rate}$

$= \frac{1 \times 8424}{2 \times 10^9}$

$= 4.212\ (\mu s)$

TEST CASE 3:

.word 18,9,11,20,-10,8,13,19,17,100,-7,6,-12,5,-16,4,-15,-100,-1,56



18 9 11 20 -10 8 13 19 17 100 -7 6 -12 5 -16 4 -15 -100 -1 56
9 18 11 20 -10 8 13 19 17 100 -7 6 -12 5 -16 4 -15 -100 -1 56
9 18 11 -10 20 8 13 19 17 100 -7 6 -12 5 -16 4 -15 -100 -1 56
9 18 -10 11 20 8 13 19 17 100 -7 6 -12 5 -16 4 -15 -100 -1 56
-10 9 11 18 20 8 13 19 17 100 -7 6 -12 5 -16 4 -15 -100 -1 56
-10 9 11 18 20 8 13 19 17 100 -7 6 -12 5 -16 4 -15 -100 -1 56
-10 9 11 18 20 8 13 19 17 100 -7 6 -12 5 -16 4 -15 -100 -1 56
-10 9 11 18 20 8 13 17 19 100 -7 6 -12 5 -16 4 -15 -100 -1 56
-10 9 11 18 20 8 13 17 19 100 -7 6 -12 5 -16 4 -15 -100 -1 56
-10 8 9 11 13 17 18 19 20 100 -7 6 -12 5 -16 4 -15 -100 -1 56
-10 8 9 11 13 17 18 19 20 100 -7 6 -12 5 -16 4 -15 -100 -1 56
-10 8 9 11 13 17 18 19 20 100 -7 6 -12 -16 5 4 -15 -100 -1 56
-10 8 9 11 13 17 18 19 20 100 -7 6 -16 -12 5 4 -15 -100 -1 56
-10 8 9 11 13 17 18 19 20 100 -16 -12 -7 5 6 4 -15 -100 -1 56
-10 8 9 11 13 17 18 19 20 100 -16 -12 -7 5 6 -15 4 -100 -1 56
-10 8 9 11 13 17 18 19 20 100 -16 -12 -7 5 6 -15 4 -100 -1 56
-10 8 9 11 13 17 18 19 20 100 -16 -12 -7 5 6 -15 4 -100 -1 56
-10 8 9 11 13 17 18 19 20 100 -16 -12 -7 5 6 -100 -15 -1 4 56
-10 8 9 11 13 17 18 19 20 100 -100 -16 -15 -12 -7 -1 4 5 6 56
-100 -16 -15 -12 -10 -7 -1 4 5 6 8 9 11 13 17 18 19 20 56 100

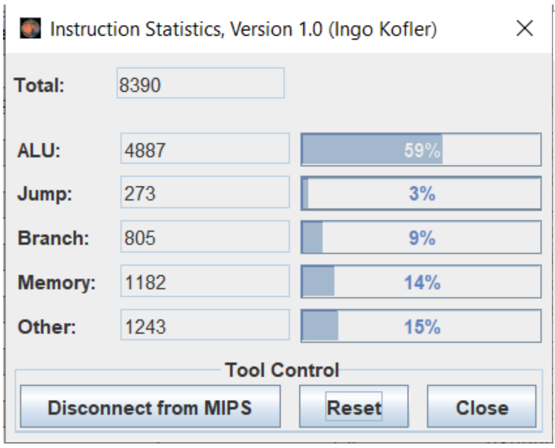
Thời gian thực thi: execution time $= \frac{CPI \times \boldsymbol{Intrustions}}{Clock\ rate}$

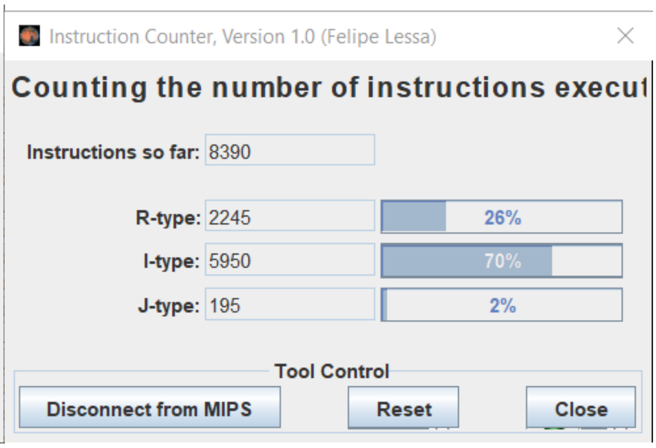
$= \frac{1 \times 8421}{2 \times 10^9}$

$= 4.2105\ (\mu s)$

TEST CASE 4:

.word 69,-8,7,35,68,19,23,45,58,-98,-13,44,66,16,22,3,-34,24,56,29





69	-8	7	35	68	19	23	45	58	-98	-13	44	66	16	22	3	-34	24	56	29
-8	69	7	35	68	19	23	45	58	-98	-13	44	66	16	22	3	-34	24	56	29
-8	69	7	35	68	19	23	45	58	-98	-13	44	66	16	22	3	-34	24	56	29
-8	69	7	35	68	19	23	45	58	-98	-13	44	66	16	22	3	-34	24	56	29
-8	7	35	68	69	19	23	45	58	-98	-13	44	66	16	22	3	-34	24	56	29
-8	7	35	68	69	19	23	45	58	-98	-13	44	66	16	22	3	-34	24	56	29
-8	7	35	68	69	19	23	45	-98	58	-13	44	66	16	22	3	-34	24	56	29
-8	7	35	68	69	19	23	-98	45	58	-13	44	66	16	22	3	-34	24	56	29
-8	7	35	68	69	-98	19	23	45	58	-13	44	66	16	22	3	-34	24	56	29
-98	-8	7	19	23	35	45	58	68	69	-13	44	66	16	22	3	-34	24	56	29
-98	-8	7	19	23	35	45	58	68	69	-13	44	66	16	22	3	-34	24	56	29
-98	-8	7	19	23	35	45	58	68	69	-13	44	66	16	22	3	-34	24	56	29
-98	-8	7	19	23	35	45	58	68	69	-13	44	16	22	66	3	-34	24	56	29
-98	-8	7	19	23	35	45	58	68	69	-13	16	22	44	66	3	-34	24	56	29
-98	-8	7	19	23	35	45	58	68	69	-13	16	22	44	66	-34	3	24	56	29
-98	-8	7	19	23	35	45	58	68	69	-13	16	22	44	66	-34	3	24	29	56
-98	-8	7	19	23	35	45	58	68	69	-13	16	22	44	66	-34	3	24	29	56
-98	-8	7	19	23	35	45	58	68	69	-13	16	22	44	66	-34	3	24	29	56
-98	-8	7	19	23	35	45	58	68	69	-34	-13	3	16	22	24	29	44	56	66
-98	-34	-13	-8	3	7	16	19	22	23	24	29	35	44	45	56	58	66	68	69

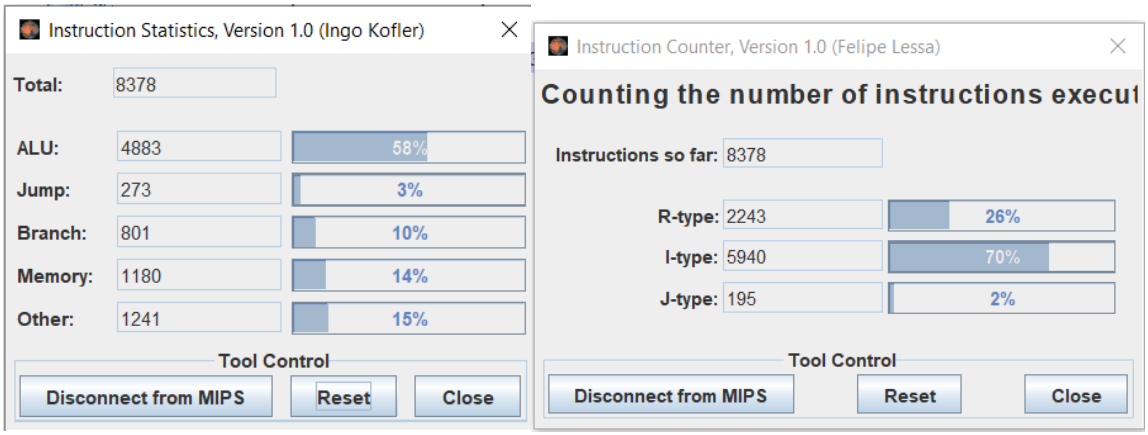
Thời gian thực thi: $\text{execution time} = \dfrac{CPI \times Intrustions}{Clock\ rate}$

$$= \frac{1 \times 8390}{2 \times 10^9}$$

$$= 4.195\ (\mu s)$$

TEST CASE 5:

.word 564,267,-754,256,237,-872,21,-45,26,28,36,-75,16,186,-257,287,-999,127,-753,666



564 267 -754 256 237 -872 21 -45 26 28 36 -75 16 186 -257 287 -999 127 -753 666
267 564 -754 256 237 -872 21 -45 26 28 36 -75 16 186 -257 287 -999 127 -753 666
267 564 -754 237 256 -872 21 -45 26 28 36 -75 16 186 -257 287 -999 127 -753 666
267 564 -754 237 256 -872 21 -45 26 28 36 -75 16 186 -257 287 -999 127 -753 666
-754 237 256 267 564 -872 21 -45 26 28 36 -75 16 186 -257 287 -999 127 -753 666
-754 237 256 267 564 -872 21 -45 26 28 36 -75 16 186 -257 287 -999 127 -753 666
-754 237 256 267 564 -872 21 -45 26 28 36 -75 16 186 -257 287 -999 127 -753 666
-754 237 256 267 564 -872 21 -45 26 28 36 -75 16 186 -257 287 -999 127 -753 666
-754 237 256 267 564 -872 -45 21 26 28 36 -75 16 186 -257 287 -999 127 -753 666
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-872 -754 -45 21 26 28 237 256 267 564 -257 -75 16 36 186 287 -999 127 -753 666
-872 -754 -45 21 26 28 237 256 267 564 -257 -75 16 36 186 -999 287 127 -753 666
-872 -754 -45 21 26 28 237 256 267 564 -257 -75 16 36 186 -999 287 127 -753 666
-872 -754 -45 21 26 28 237 256 267 564 -257 -75 16 36 186 -999 287 -753 127 666
-872 -754 -45 21 26 28 237 256 267 564 -257 -75 16 36 186 -999 -753 127 287 666
-872 -754 -45 21 26 28 237 256 267 564 -999 -753 -257 -75 16 36 127 186 287 666
-999 -872 -754 -753 -257 -75 -45 16 21 26 28 36 127 186 237 256 267 287 564 666

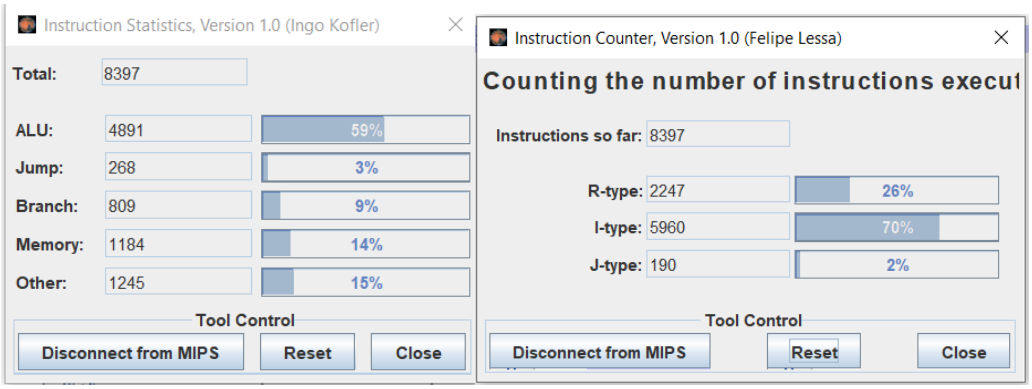
Thời gian thực thi: execution time $= \frac{CPI \times \boldsymbol{Intrustions}}{Clock\ rate}$

$= \frac{1 \times 8378}{2 \times 10^9}$

$= 4.189\ (\mu s)$

TEST CASE 6:

.word 1234, -4, 20, 235, -940, 9848, -30, -2, -2344, 98, 22, 50, 200, 111, 1, 0, 10, 14, -29, -30



1234 -4 20 235 -940 9848 -30 -2 -2344 98 22 50 200 111 1 0 10 14 -29 -30
-4 1234 20 235 -940 9848 -30 -2 -2344 98 22 50 200 111 1 0 10 14 -29 -30
-4 1234 20 -940 235 9848 -30 -2 -2344 98 22 50 200 111 1 0 10 14 -29 -30
-4 1234 -940 20 235 9848 -30 -2 -2344 98 22 50 200 111 1 0 10 14 -29 -30
-940 -4 20 235 1234 9848 -30 -2 -2344 98 22 50 200 111 1 0 10 14 -29 -30
-940 -4 20 235 1234 -30 9848 -2 -2344 98 22 50 200 111 1 0 10 14 -29 -30
-940 -4 20 235 1234 -30 9848 -2 -2344 98 22 50 200 111 1 0 10 14 -29 -30
-940 -4 20 235 1234 -30 9848 -2344 -2 98 22 50 200 111 1 0 10 14 -29 -30
-940 -4 20 235 1234 -2344 -30 -2 98 9848 22 50 200 111 1 0 10 14 -29 -30
-2344 -940 -30 -4 -2 20 98 235 1234 9848 22 50 200 111 1 0 10 14 -29 -30
-2344 -940 -30 -4 -2 20 98 235 1234 9848 22 50 200 111 1 0 10 14 -29 -30
-2344 -940 -30 -4 -2 20 98 235 1234 9848 22 50 200 1 111 0 10 14 -29 -30
-2344 -940 -30 -4 -2 20 98 235 1234 9848 22 50 1 111 200 0 10 14 -29 -30
-2344 -940 -30 -4 -2 20 98 235 1234 9848 1 22 50 111 200 0 10 14 -29 -30
-2344 -940 -30 -4 -2 20 98 235 1234 9848 1 22 50 111 200 0 10 14 -29 -30
-2344 -940 -30 -4 -2 20 98 235 1234 9848 1 22 50 111 200 0 10 14 -30 -29
-2344 -940 -30 -4 -2 20 98 235 1234 9848 1 22 50 111 200 0 10 -30 -29 14
-2344 -940 -30 -4 -2 20 98 235 1234 9848 1 22 50 111 200 -30 -29 0 10 14
-2344 -940 -30 -4 -2 20 98 235 1234 9848 -30 -29 0 1 10 14 22 50 111 200
-2344 -940 -30 -30 -29 -4 -2 0 1 10 14 20 22 50 98 111 200 235 1234 9848

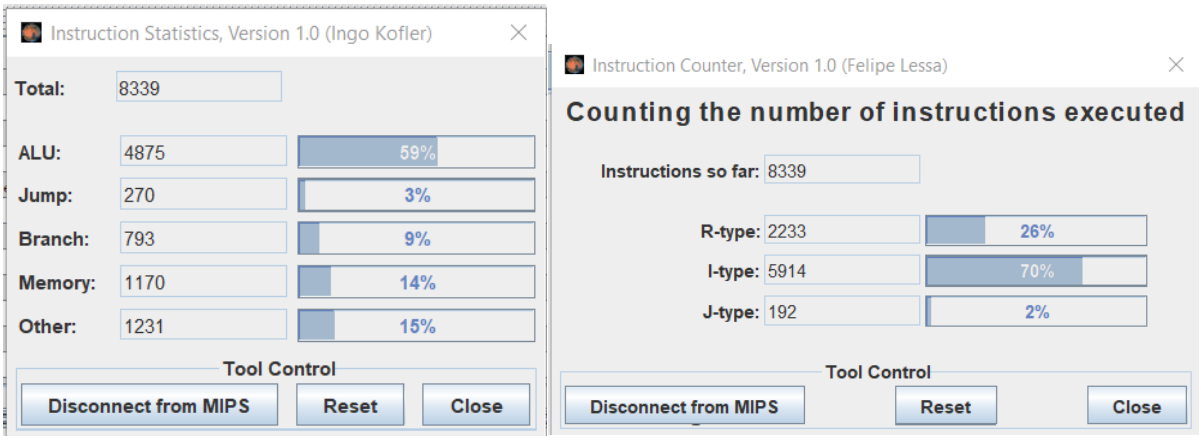
Thời gian thực thi:execution time $= \frac{CPI \times \boldsymbol{Intrustions}}{Clock\ rate}$

$= \frac{1 \times 8397}{2 \times 10^9}$

$= 4.1985\ (\mu s)$

TEST CASE 7:

.word 6, 7, 30, 450, 10, -49, -20, -154, -235, -390, -22, -456, -40, 29, 0, -23, 45, 290, 39, 99



6 7 30 450 10 -49 -20 -154 -235 -390 -22 -456 -40 29 0 -23 45 290 39 99
6 7 30 450 10 -49 -20 -154 -235 -390 -22 -456 -40 29 0 -23 45 290 39 99
6 7 30 10 450 -49 -20 -154 -235 -390 -22 -456 -40 29 0 -23 45 290 39 99
6 7 10 30 450 -49 -20 -154 -235 -390 -22 -456 -40 29 0 -23 45 290 39 99
6 7 10 30 450 -49 -20 -154 -235 -390 -22 -456 -40 29 0 -23 45 290 39 99
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6 7 10 30 450 -49 -20 -390 -235 -154 -22 -456 -40 29 0 -23 45 290 39 99
6 7 10 30 450 -390 -235 -154 -49 -20 -22 -456 -40 29 0 -23 45 290 39 99
-390 -235 -154 -49 -20 6 7 10 30 450 -22 -456 -40 29 0 -23 45 290 39 99
-390 -235 -154 -49 -20 6 7 10 30 450 -456 -22 -40 29 0 -23 45 290 39 99
-390 -235 -154 -49 -20 6 7 10 30 450 -456 -22 -40 0 29 -23 45 290 39 99
-390 -235 -154 -49 -20 6 7 10 30 450 -456 -22 -40 0 29 -23 45 290 39 99
-390 -235 -154 -49 -20 6 7 10 30 450 -456 -40 -22 0 29 -23 45 290 39 99
-390 -235 -154 -49 -20 6 7 10 30 450 -456 -40 -22 0 29 -23 45 290 39 99
-390 -235 -154 -49 -20 6 7 10 30 450 -456 -40 -22 0 29 -23 45 290 39 99
-390 -235 -154 -49 -20 6 7 10 30 450 -456 -40 -22 0 29 -23 45 39 99 290
-390 -235 -154 -49 -20 6 7 10 30 450 -456 -40 -22 0 29 -23 39 45 99 290
-390 -235 -154 -49 -20 6 7 10 30 450 -456 -40 -23 -22 0 29 39 45 99 290
-456 -390 -235 -154 -49 -40 -23 -22 -20 0 6 7 10 29 30 39 45 99 290 450

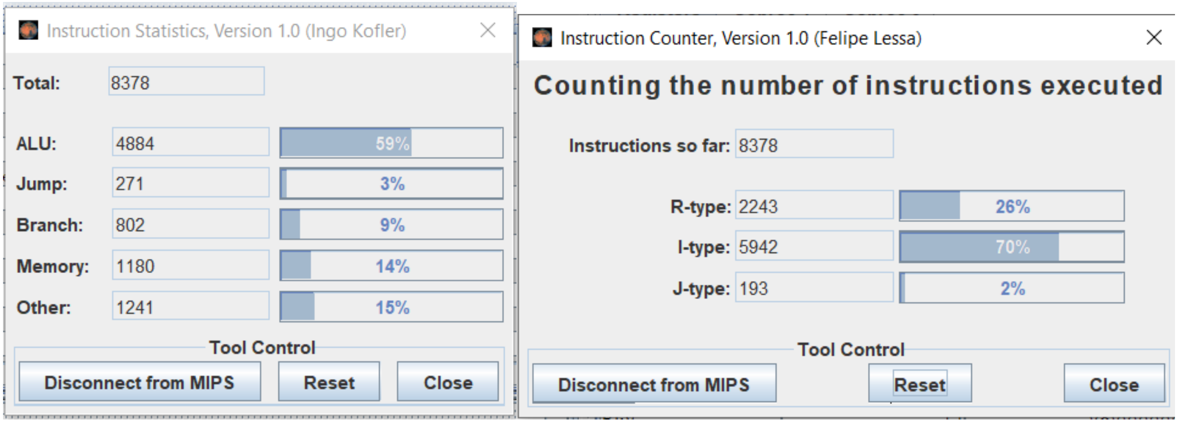
Thời gian thực thi:execution time $= \frac{CPI \times \boldsymbol{Intrustions}}{Clock\ rate}$

$= \frac{1 \times 8339}{2 \times 10^9}$

$= 4.1695\ (\mu s)$

TEST CASE 8:

.word -1000, 1000, 500, -500, 20, -20, 50, -50, 999, -999, 0, 1, 2, 3, 4, 5 -10, -11, -11, -12



-1000	1000	500	-500	20	-20	50	-50	999	-999	0	1	2	3	4	5	-10	-11	-11	-12
-1000	1000	500	-500	20	-20	50	-50	999	-999	0	1	2	3	4	5	-10	-11	-11	-12
-1000	1000	500	-500	20	-20	50	-50	999	-999	0	1	2	3	4	5	-10	-11	-11	-12
-1000	1000	-500	20	500	-20	50	-50	999	-999	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-500	20	500	1000	-20	50	-50	999	-999	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-500	20	500	1000	-20	50	-50	999	-999	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-500	20	500	1000	-20	50	-50	-999	999	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-500	20	500	1000	-20	50	-999	-50	999	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-500	20	500	1000	-999	-50	-20	50	999	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-999	-500	-50	-20	20	50	500	999	1000	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-999	-500	-50	-20	20	50	500	999	1000	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-999	-500	-50	-20	20	50	500	999	1000	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-999	-500	-50	-20	20	50	500	999	1000	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-999	-500	-50	-20	20	50	500	999	1000	0	1	2	3	4	5	-10	-11	-11	-12
-1000	-999	-500	-50	-20	20	50	500	999	1000	0	1	2	3	4	-10	5	-11	-11	-12
-1000	-999	-500	-50	-20	20	50	500	999	1000	0	1	2	3	4	-10	5	-11	-12	-11
-1000	-999	-500	-50	-20	20	50	500	999	1000	0	1	2	3	4	-10	5	-12	-11	-11
-1000	-999	-500	-50	-20	20	50	500	999	1000	0	1	2	3	4	-12	-11	-11	-10	5
-1000	-999	-500	-50	-20	20	50	500	999	1000	-12	-11	-11	-10	0	1	2	3	4	5
-1000	-999	-500	-50	-20	-12	-11	-11	-10	0	1	2	3	4	5	20	50	500	999	1000

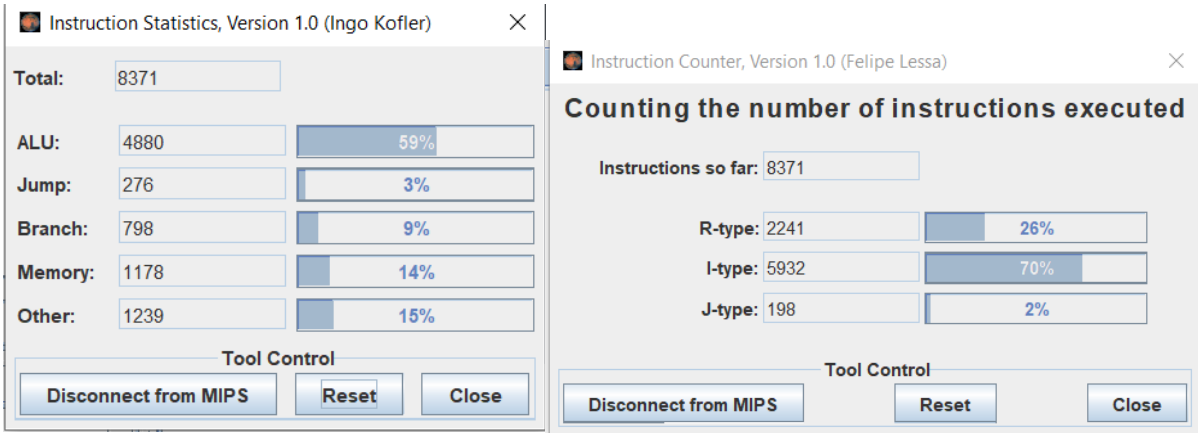
Thời gian thực thi: $\text{execution time} = \dfrac{CPI \times \textbf{Intrustions}}{Clock\ rate}$

$$= \frac{1 \times 8378}{2 \times 10^9}$$

$$= 4.189\ (\mu s)$$

TEST CASE 9:

.word 10, 10, 4, 100, 409, -30, -10, 0, 349, 03, -320, 904, 49, -30, 49, -403, -439, 39, 25, 30



10 10 4 100 409 -30 -10 0 349 3 -320 904 49 -30 49 -403 -439 39 25 30
10 10 4 100 409 -30 -10 0 349 3 -320 904 49 -30 49 -403 -439 39 25 30
10 10 4 100 409 -30 -10 0 349 3 -320 904 49 -30 49 -403 -439 39 25 30
10 10 4 100 409 -30 -10 0 349 3 -320 904 49 -30 49 -403 -439 39 25 30
4 10 10 100 409 -30 -10 0 349 3 -320 904 49 -30 49 -403 -439 39 25 30
4 10 10 100 409 -30 -10 0 349 3 -320 904 49 -30 49 -403 -439 39 25 30
4 10 10 100 409 -30 -10 0 3 349 -320 904 49 -30 49 -403 -439 39 25 30
4 10 10 100 409 -30 -10 0 3 349 -320 904 49 -30 49 -403 -439 39 25 30
4 10 10 100 409 -30 -10 0 3 349 -320 904 49 -30 49 -403 -439 39 25 30
-30 -10 0 3 4 10 10 100 349 409 -320 904 49 -30 49 -403 -439 39 25 30
-30 -10 0 3 4 10 10 100 349 409 -320 904 49 -30 49 -403 -439 39 25 30
-30 -10 0 3 4 10 10 100 349 409 -320 904 49 -30 49 -403 -439 39 25 30
-30 -10 0 3 4 10 10 100 349 409 -320 904 -30 49 49 -403 -439 39 25 30
-30 -10 0 3 4 10 10 100 349 409 -320 -30 49 49 904 -403 -439 39 25 30
-30 -10 0 3 4 10 10 100 349 409 -320 -30 49 49 904 -439 -403 39 25 30
-30 -10 0 3 4 10 10 100 349 409 -320 -30 49 49 904 -439 -403 39 25 30
-30 -10 0 3 4 10 10 100 349 409 -320 -30 49 49 904 -439 -403 25 30 39
-30 -10 0 3 4 10 10 100 349 409 -320 -30 49 49 904 -439 -403 25 30 39
-30 -10 0 3 4 10 10 100 349 409 -439 -403 -320 -30 25 30 39 49 49 904
-439 -403 -320 -30 -30 -10 0 3 4 10 10 25 30 39 49 49 100 349 409 904

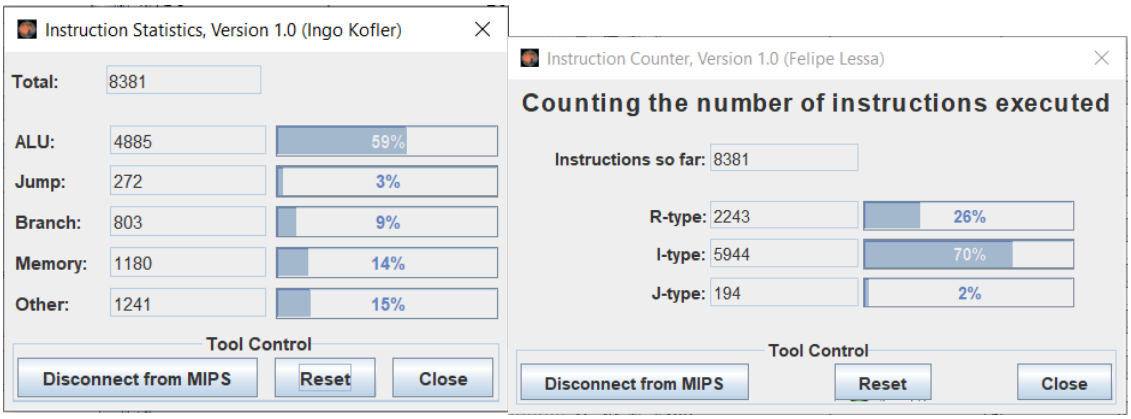
Thời gian thực thi: execution time $= \frac{CPI \times \boldsymbol{Intrustions}}{Clock\ rate}$

$= \frac{1 \times 8371}{2 \times 10^9}$

$= 4.1855\ (\mu s)$

TEST CASE 10:

.word 0, 3495, 349, 02, -239, -23, -435, -3490, -2, -23, 10, 45, 35, 354, 390, 329, 109, 303, 490, 320



0 3495 349 2 -239 -23 -435 -3490 -2 -23 10 45 35 354 390 329 109 303 490 320
0 3495 349 2 -239 -23 -435 -3490 -2 -23 10 45 35 354 390 329 109 303 490 320
0 3495 349 -239 2 -23 -435 -3490 -2 -23 10 45 35 354 390 329 109 303 490 320
0 3495 -239 2 349 -23 -435 -3490 -2 -23 10 45 35 354 390 329 109 303 490 320
-239 0 2 349 3495 -23 -435 -3490 -2 -23 10 45 35 354 390 329 109 303 490 320
-239 0 2 349 3495 -435 -23 -3490 -2 -23 10 45 35 354 390 329 109 303 490 320
-239 0 2 349 3495 -435 -23 -3490 -23 -2 10 45 35 354 390 329 109 303 490 320
-239 0 2 349 3495 -435 -23 -3490 -23 -2 10 45 35 354 390 329 109 303 490 320
-239 0 2 349 3495 -3490 -435 -23 -23 -2 10 45 35 354 390 329 109 303 490 320
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 45 35 354 390 329 109 303 490 320
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 45 35 354 390 329 109 303 490 320
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 45 35 354 390 329 109 303 490 320
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 45 35 354 390 329 109 303 490 320
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 35 45 354 390 329 109 303 490 320
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 35 45 354 390 109 329 303 490 320
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 35 45 354 390 109 329 303 320 490
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 35 45 354 390 109 329 303 320 490
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 35 45 354 390 109 303 320 329 490
-3490 -435 -239 -23 -23 -2 0 2 349 3495 10 35 45 109 303 320 329 354 390 490
-3490 -435 -239 -23 -23 -2 0 2 10 35 45 109 303 320 329 349 354 390 490 3495

Thời gian thực thi: execution time $= \frac{CPI \times \boldsymbol{Intrustions}}{Clock\ rate}$

$= \frac{1 \times 8381}{2 \times 10^9}$

$= 4.1905\ (\mu s)$