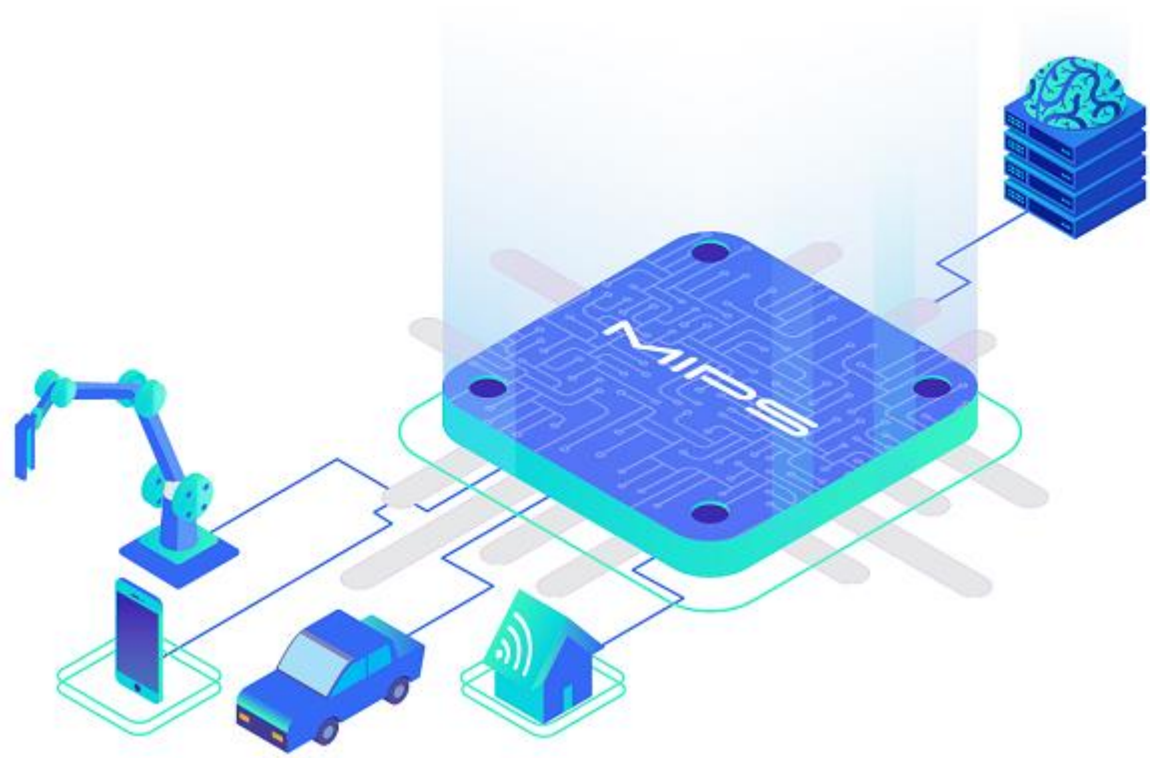
EC-340

COMPUTER ORGANIZATION AND ARCHITECTURE



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a) Assume that you have an array of 10 elements with base address in $s0. Write an assembly program to find the minimum value from the array and swap it with the last element in the array.

-> We will make use of word directives to store array into memory with base address labelled as array. For debugging the code, We will use **la** to store the base address at **$s0** as asked to be assumed in the question. We will store index I in register **$t1** initializing it to 0. And then check if it reaches 10 using **slti**. Through each iteration, we will first multiply index(**$t1**) by 4 by left shifting by 2bits and store that offset value in **$t6**. Calculating respective index's address by adding base + the offset. Then through address we will check if it's the minimum value until now using **slt** and if it is then we will jump to **min** where we will store the value and its index in **$t7** and **$t0** respectively, we will increment at the end of the loop and then jump to loop label where the condition will be checked again.

Once the most minimum value has been found in the array after iterating through the array. Through **beq**, We will jump to **swapmin**. Here we will swap the minimum value with the last value of the array.

Later jumping to **printl.** Looping similarly, we will later print the updated array into the console using **syscall** with respective **$v0** and **$a0** values then jump to done which will jump to **$ra** (return address)

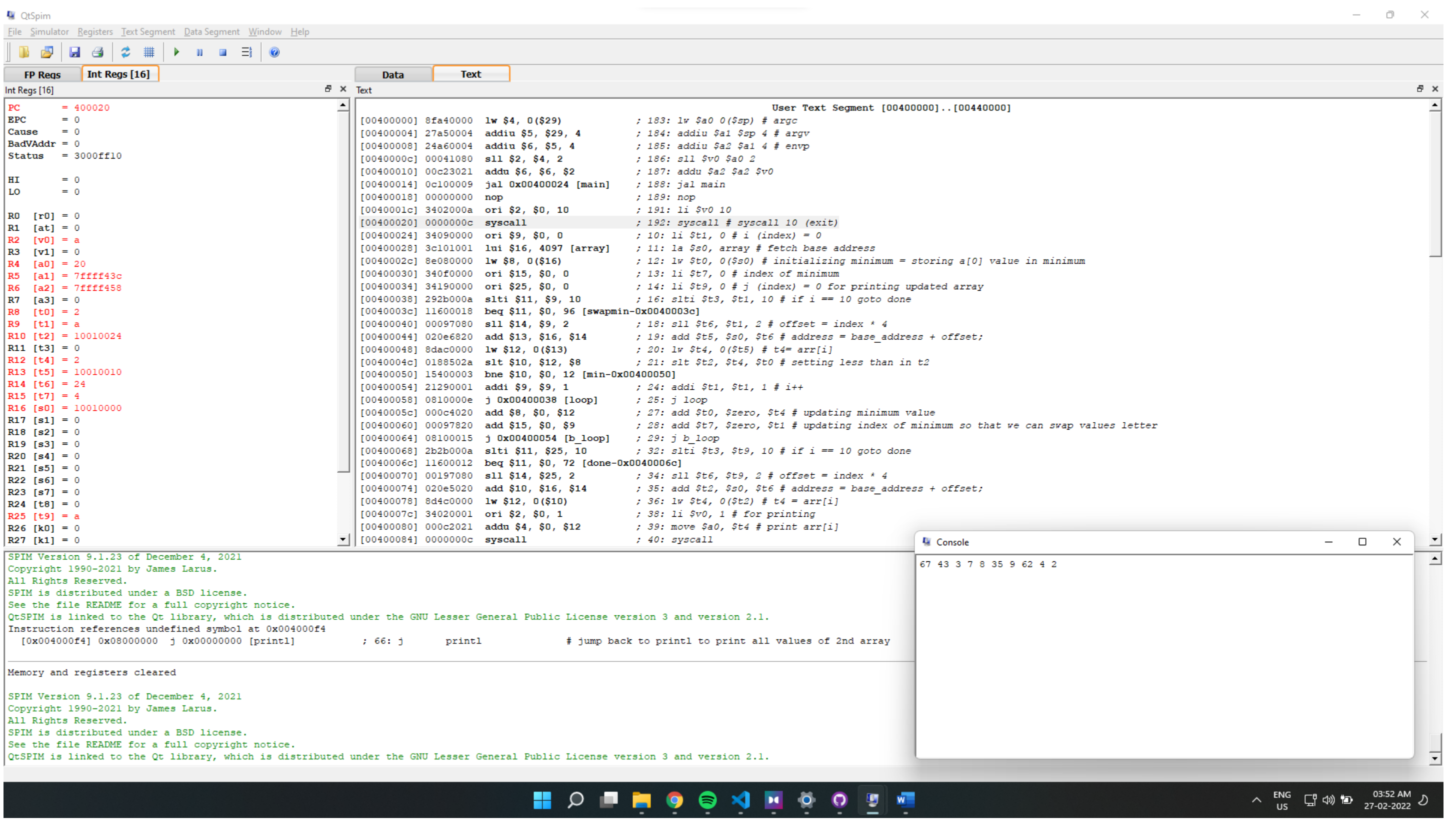
Assembly code:

```
        .data
#  storing required data into memory
array:  .word 67 43 3 7 2 35 9 62 4 8

        .text
        .globl main
main:

        li      $t1, 0              # i (index) = 0
        la      $s0, array          # fetch base address
        # initializing minimum =  storing a[0] value in minimum
        lw      $t0, 0($s0)
        li      $t7, 0              # index of minimum
```

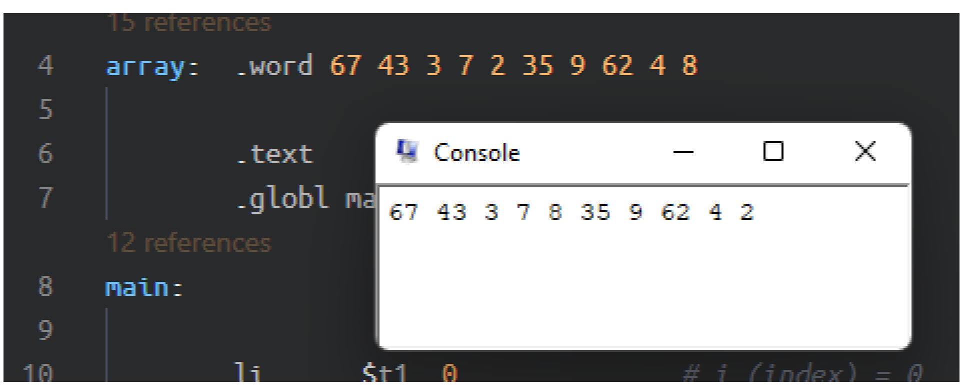
```
        # j (index) = 0 for printing updated array
        li      $t9, 0

loop:   slti    $t3, $t1, 10          # if i == 10 goto done
        beq     $t3, $zero, swapmin
        sll     $t6, $t1, 2          # offset = index * 4
        add     $t5, $s0, $t6        # address = base_address + offset;
        lw      $t4, 0($t5)          # t4= arr[i]
        slt     $t2, $t4, $t0        # setting less than in t2
        # switching to min branch if a[i]<current_min
        bne     $t2, $zero, min
# label b_loop for returning after min has been updated
b_loop: addi    $t1, $t1, 1          # i++
        j       loop
# min updates the minimum value and the index containing it
min:    add     $t0, $zero, $t4      # updating minimum value
        # updating index of minimum so that we can swap values letter
        add     $t7, $zero, $t1
        j      b_loop

# for printing the updated array
printl: slti    $t3, $t9, 10          # if i == 10 goto done
        beq     $t3, $zero, done      # jumping to done if all elements are
printed
        sll     $t6, $t9, 2          # offset = index * 4
        add     $t2, $s0, $t6        # address = base_address + offset;
        lw      $t4, 0($t2)         # t4 = arr[i]

        li      $v0, 1               # for printing
        move    $a0, $t4             # print arr[i]
        syscall

        li      $v0, 11              # print space character
        li      $a0, 32
        syscall

        addi    $t9, $t9, 1          # i++
        # jump back to printl to print all values of 2nd array
        j       printl

# for swapping the minimum and last array
swapmin:
        lw      $t4,  36($s0)      # saving the last value of the array
```

```
        sll     $t6, $t7, 2         # offset = min_index *4
        sw      $t0, 36($s0)         # storing min value in last position
        add     $t5, $s0, $t6        # min_address = base + offset
        # storing the value of last element in the position of minimum value
        sw      $t4, 0($t5)
        j       printl          # to print the updated array


done:
        jr $ra                       # return from main
```

Output:



Console output and input array value:



b) Assume that you have an array of 10 elements with base address in $s0. Assume that the base address of a second array is in $t0. Write an assembly program to copy the elements from the first array to the second.

->

We will make use of word directives to store first and second array labelling them as **firstarray** and **secondarray** respectively. For debugging the code, We will use **la** to store the base addresses at **$s0** and **$t0** respectively as asked to be assumed in the question. We will store index i in register **$t1** initializing it to 0. And then check if it reaches 10 using **slti**.

Through each iteration, we will first multiply index(**$t1**) by 4 by left shifting by 2bits and store that offset value in **$t6**. Calculating respective index's address by adding base + the offset. We will store the element from first array to second array by loading a element with **lw** and storing into second array one with **sw**. we will increment index at the end of the loop and then jump to loop label where the condition will be checked again.

Once the most minimum value has been found in the array after iterating through the array. Through **beq**, we will jump to **swapmin**. Here we will swap the minimum value with the last value of the array.

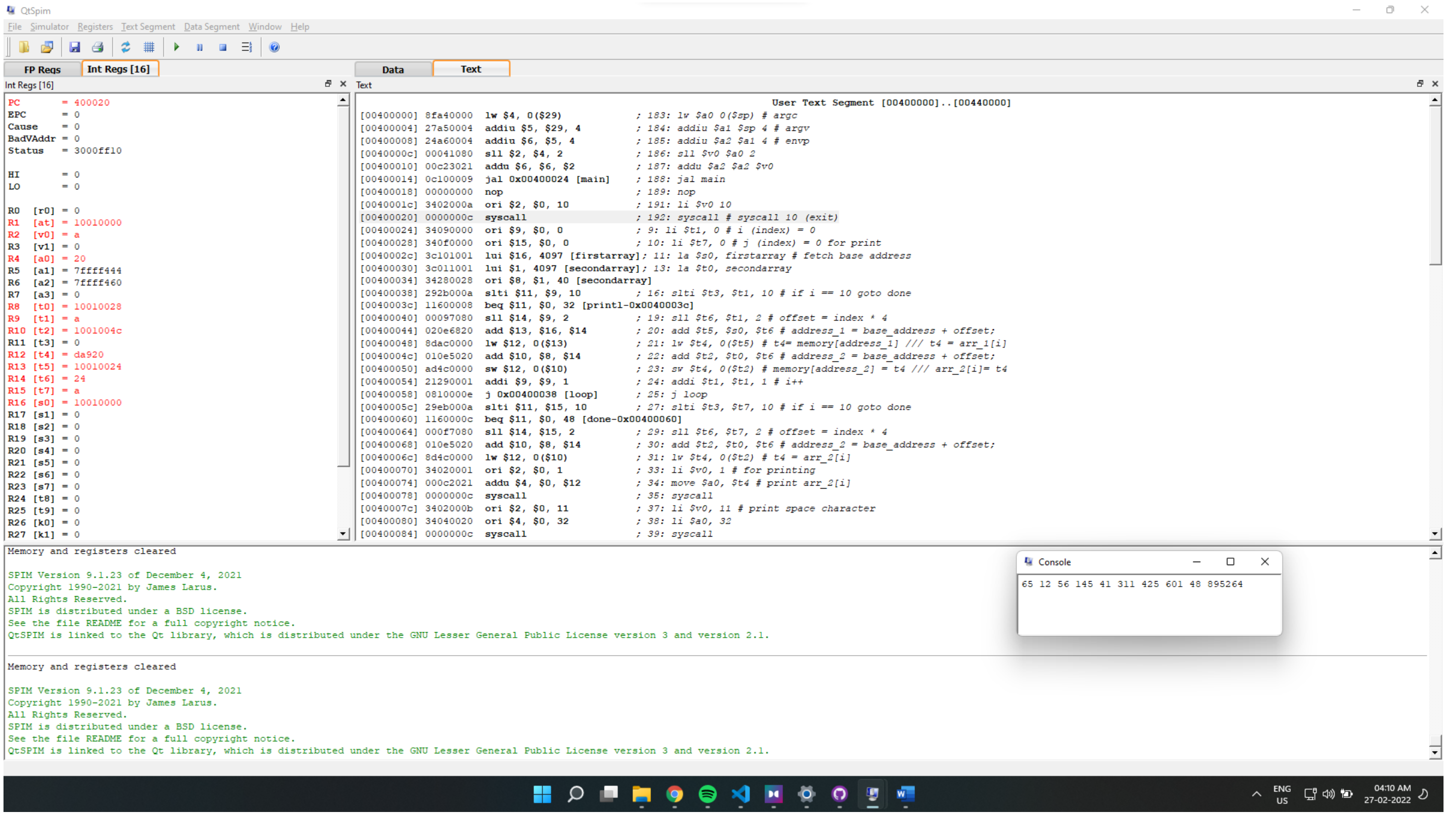
Later jumping to **printl.** Looping similarly, we will later print the updated array into the console using **syscall** with respective **$v0** and **$a0** values then jump to done which will jump to **$ra** (return address)

Assembly Code:

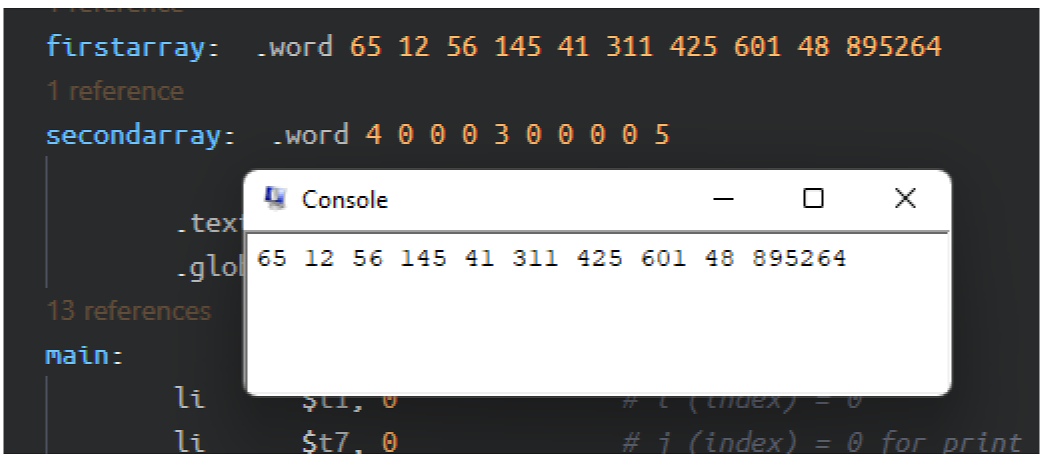
```
        .data
#  storing required data into memory
firstarray:  .word 65 12 56 145 41 311 425 601 48 895264
secondarray:  .word 4 0 0 0 3 0 0 0 0 5

        .text
        .globl main
```

```
main:
        li      $t1, 0                  # i (index) = 0
        li      $t7, 0                  # j (index) = 0 for print
        la      $s0, firstarray         # fetch base address
        # initializing minimum =  storing a[0] value in minimum
        la      $t0, secondarray

# label for looping throughtout the array and copying to second array
loop:   slti    $t3, $t1, 10             # if i == 10 goto done
        # after completition, jump to printl to print 2nd array
        beq     $t3, $zero, printl
        sll     $t6, $t1, 2             # offset = index * 4
        add     $t5, $s0, $t6           # address_1 = base_address + offset;
        lw      $t4, 0($t5)             # t4= memory[address_1]  /// t4 =
arr_1[i]
        add     $t2, $t0, $t6           # address_2 = base_address + offset;
        sw      $t4, 0($t2)            # memory[address_2] = t4 /// arr_2[i]= t4
        addi    $t1, $t1, 1             # i++
        j       loop
# for printing the second array
printl: slti    $t3, $t7, 10             # if i == 10 goto done
        beq     $t3, $zero, done
        sll     $t6, $t7, 2             # offset = index * 4
        add     $t2, $t0, $t6           # address_2 = base_address + offset;
        lw      $t4, 0($t2)            # t4 = arr_2[i]

        li      $v0, 1                  # for printing
        move    $a0, $t4                # print arr_2[i]
        syscall

        li      $v0, 11                 # print space character
        li      $a0, 32
        syscall

        addi    $t7, $t7, 1             # i++
        # jump back to printl to print all values of 2nd array
        j       printl
done:
        jr      $ra                    # return from main
```

Output:



Console output and input array value:



c) Write an assembly program to convert red-green-blue (RGB) values for a set of pixels into a single gray value per pixel. You are given an array called pixels, each element of which is a 32-bit word representing a color value. The lowest 8 bits of each color value denote an unsigned integer representing the BLUE value, the next 8 bits are the GREEN value, the next 8 bits are the RED value, and the most significant 8 bits are all zeroes. gray

value = (red + green + blue) / 3 (integer divide and truncate). Use a separate procedure rgb2gray and print each RGB value and the corresponding gray value on the console.

-> Similar to the codes above, we will store the needed values into memory, here for debugging under .data section using data directives like .asciiz (for strings) and .word.

We will use arguments **$a2** and **$a3** for indexing. Store base address for RGB input array in **$s0** and for output gray array in **$s1** .

Since we will be making a procedure call, we will need to save the return address of the main. For that we will allocate 32 bit space by decrementing stack pointer(**$sp**) by 4(in bytes). And store the return address in it using **lw**.

We will jump to the procedure **rgb2gray** using function jal which will update the **$ra** (return address). Inside the **rgb2gray**. We will loop until index i(stored in **$a3**) reaches 10. We will increment I at every end of the loop.

In the loop, At first we will calculate offset by multiplying index by 4 (left shifting by 2 bits) and storing it in a temporary variable **$t2**. Then for getting the i'th element of the rgb array. we will calculate its respective address by adding base(**$s0**) and offset(**$t2**) and store it in **$t4**. Loading the rgb value in **$t5**. We will use **andi** with immediate **#0xff**, to get the lowest significant byte of it which is the value of **blue** and store it in a temporary variable **$t6**. Later right shifting **$t5** by a byte. We get **Green** value at Lowest significant byte. This can again be separated using **andi**, and then will be added to **$t6**. Repeating the right shift, we will have red value at lowest significant byte. Which will be separated similarly using **andi**. Then added to **$t6**.

We will have all the R, G and B values summed up in **$t6**. We will divide it by 3 using **div** and store the quotient in **$t6** itself. Later to store the value from the temporary register **$t6** into the respective I'th element of gray code's array. by calculating address for the I'th element similar to what we did for RGB array elements. But here we will store the value (using sw) and not load.

After Gray code values of all the 10 RGB code values have been calculated, we will jump to **printl**. Where with the help of **syscall** and similar looping, We will print all the RGB code and its gray code respectively. After the looping it will jump to done which will return to the next address of where the rgb2gray was called. Here, the main's return address is restored in **$ra** return address

From stack pointer and then the space allocated for it is deallocated by incrementing the stack pointer. After it, the main function will return and the program ends.

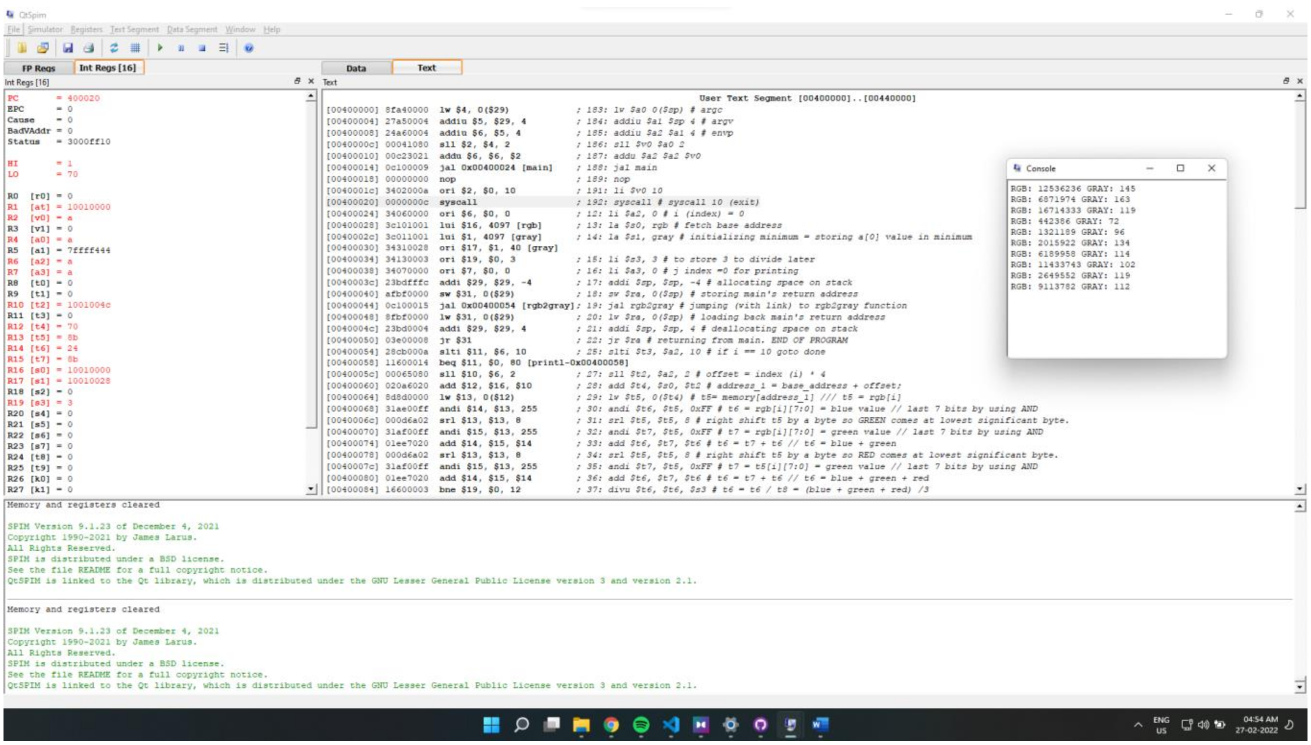
Assembly Code:

```
        .data
#  storing required data into memory
rgb:  .word 0xbf49ac 0x68dba6 0xFF0A5D 0x06c012 0x1428e5 0x1ec2b2
0x5e7386 0xae770f 0x286dd0 0x8b10b6
gray:  .word 4 0 0 0 3 0 0 0 0 5
#  storing strings required to print at the end
trgb:   .asciiz "RGB: "

tgray:  .asciiz " GRAY: "
        .text
        .globl main
main:
        li      $a2, 0                 # i (index) = 0
        la      $s0, rgb     # fetch base address
        # initializing minimum =  storing a[0] value in minimum
        la      $s1, gray
        li      $s3, 3       # to store 3 to divide later
        li      $a3, 0       # j index =0 for printing
        addi    $sp, $sp, -4 # allocating space on stack
        sw      $ra, 0($sp)  # storing main's return address
        jal     rgb2gray     # jumping (with link) to rgb2gray
function
        lw      $ra, 0($sp)  # loading back main's return address
        addi    $sp, $sp, 4  # deallocating space on stack
        jr      $ra          # returning from main. END OF PROGRAM

# procedure(Function) rgb2gray
rgb2gray:   slti    $t3, $a2, 10        # if i == 10 goto done
        beq     $t3, $zero, printl
        sll     $t2, $a2, 2            # offset = index (i) * 4
        # address_1 = base_address + offset;
        add     $t4, $s0, $t2
```

```
        # t5= memory[address_1]  /// t5 = rgb[i]
        lw      $t5, 0($t4)
        # t6 = rgb[i][7:0] = blue value // last 7 bits by using AND
        andi    $t6, $t5, 0xFF
# right shift t5 by 8 so GREEN comes at lowest significant byte.
        srl     $t5, $t5, 8
        # t7 = rgb[i][7:0] = green value  // last 7 bits by using
AND
        andi    $t7, $t5, 0xFF
        # t6 = t7 + t6 // t6 = blue + green
        add     $t6, $t7, $t6
# right shift t5 by 8 so RED comes at lowest significant byte.
        srl     $t5, $t5, 8
        # t7 = t5[i][7:0] = green value  // last 7 bits by using
AND
        andi    $t7, $t5, 0xFF
        # t6 = t7 + t6 // t6 = blue + green + red
        add     $t6, $t7, $t6
        # t6 = t6 / t8 = (blue + green + red) /3
        divu    $t6, $t6, $s3
        # address_2 = base_address + offset;
        add     $t4, $s1, $t2
        #  memory[address_1]= t6  /// gray[i] = t6 = (r+g+b)/3
        sw      $t6, 0($t4)
        addi    $a2, $a2, 1          # i++
        j       rgb2gray

# for printing RGB values and its respective Gray values
printl: slti    $t3, $a3, 10          # if i == 10 goto done
        beq     $t3, $zero, done
        sll     $t6, $a3, 2          # offset = index * 4
        # rgb_address = base_rgb_address + offset;
        add     $t2, $s0, $t6
        lw      $t4, 0($t2)         # t4 = rgb[i]
        li      $v0, 4
        la      $a0, trgb             # printing string "RGB:  "
       syscall
       li      $v0, 1                # for printing
       move    $a0, $t4              # print rgb[i]
       syscall
       li      $v0, 4
       la      $a0, tgray             # printing string " GRAY:  "
       syscall
```

```
        # gray_address = base_gray_address + offset;
        add     $t2, $s1, $t6
        lw      $t4, 0($t2)         # t4 = gray[i]
        li      $v0, 1               # for printing
        move    $a0, $t4             # print gray[i]
        syscall
        li      $v0, 11              # print newline character
        li      $a0, 0x0a
        syscall
        addi    $a3, $a3, 1          # i++
        # jump back to printl to print all values of 2nd array
        j       printl
done:
        jr      $ra   # return from rgb2gray to main
```

Output:



Console output and input array value:

Note: The console displays values in decimal values and not in hex.

```
#  storing required data into memory
12 references
rgb:  .word 0xbf49ac 0x68dba6 0xFF0A5D 0x06c012 0x1428e5 0x1ec2b2 0x5e7386 0xae770f 0x286dd0 0x8b10b6
8 references
gray:  .word 4 0 0 0 3 0 0 0 0 5
#  storing strings required to print at the end
3 references
trgb:   .asciiz "RGB: "

3 references
tgray:  .asciiz " GRAY: "
        .text
        .globl main
16 references
main:
```

```
RGB: 12536236 GRAY: 145
RGB: 6871974 GRAY: 163
RGB: 16714333 GRAY: 119
RGB: 442386 GRAY: 72
RGB: 1321189 GRAY: 96
RGB: 2015922 GRAY: 134
RGB: 6189958 GRAY: 114
RGB: 11433743 GRAY: 102
RGB: 2649552 GRAY: 119
RGB: 9113782 GRAY: 112
```