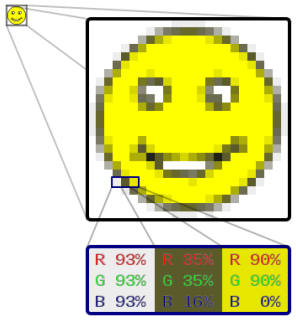
Lab 5: Functions and Graphics



Due Friday 5 June 2020, 11:59 PM

Minimum Submission Requirements

- Ensure that your Lab5 folder contains the following files (note the capitalization convention):
  - Lab5.asm
  - README.txt
  - It is ok if you also have lab5_s20_test.asm, but we will not require or check it.
- Commit and push your repository
- Complete the Google Form with the correct commit ID of your final submission

Lab Objective

In this lab, you will implement functions that perform some primitive graphics operations on a small simulated display. These functions will clear the entire display to a color, display a filled colored circle and display an unfilled colored circle using a memory-mapped bitmap graphics display in MARS. To do this you will utilize:

1. Arrays
2. Memory-mapped Input/Output (IO)
3. Subroutines (a.k.a. Functions or Procedures)
4. Macros
5. The MIPS Stack (for arguments and subroutine call state)

Lab Preparation

1. Read some background on Raster graphics

2. Introduction To MIPS Assembly Language Programming
   chapters 5, 6; sections 8.1, 8.2

3. Macros

4. Procedures
   watch videos 2.7 - 2.12

5. Functions
   watch video tutorials 15 – 18

6. Read up on Draw a circle without floating point arithmetic (don’t worry -- we give you the pseudocode!)

7. Read up on Bresenham's circle drawing algorithm (don’t worry -- we give you the pseudocode!)

Specification

You will need to implement a set of specific subroutines indicated in these lab instructions. You are required to start with the skeleton code provided (lab5_s20_template.asm) and **may not change the function names or arguments at all.** Please rename the file to Lab5.asm and start with it. To receive any credit for your subroutines, **Lab5.asm must assemble** both **on its own** and with the test file. On its own, the template file shouldn't print or draw anything -- it is just a set of subroutines.

A test file (lab5_s20_test.asm) tests each one of your subroutines and includes (at the very end) your subroutines from Lab5.asm (based on the above template file). You should modify the test to include Lab5.asm instead of lab5_s20_template.asm. Don't put the functions in this the test, they go in Lab5.asm. **We will not use your test file!** In order for your subroutines to function properly, **you must use** the instructions **JAL and JR** to enter and exit subroutines. You must save and restore registers as required in MIPS. Our test file will look very much like this one, so you should ensure that your functions work with it!

Functionality

The functionality of your program will support the following:

1. All pixels should be in the range x in [0,128) and y in [0,128) (the parenthesis means not including 128).
2. Pixels start from (0,0) in the upper left to (127,127) in the lower right.
3. Pixel values are referenced in a single word using the upper and lower half of the word. So, for example, 0x00XX00YY) where XX and YY can be 0x00 to 0x7F.
4. All colors should be RGB using a single 32-bit word where the top byte is zero. So, for example, 0x00RRGGBB where RR, GG, and BB can be 0x00 to 0xFF.
5. Clear the entire bitmap display to a color c.
6. Draw a circle with center at (xc, yc) and radius r filled of a given color c.
7. Draw a circumference with center at (xc, yc) and radius r of a given color c.

Macro Descriptions

You are required to use these macro definitions without modification. These macros should be in the Lab5.asm file. You may use additional macros if you like but be sure to include them in Lab5.asm.

getCoordinates(%input %x %y): Macro that takes as input coordinates in the format (0x00XX00YY) and returns 0x000000XX in %x and returns 0x000000YY in %y. Do not use any registers other than the input registers to write this macro.

formatCoordinates(%output %x %y): Macro that takes Coordinates in (%x,%y) where %x = 0x000000XX and %y= 0x000000YY and returns %output = (0x00XX00YY). Do not use any registers other than the input registers to write this macro.

push(%reg): Macro that stores the value in %reg on the stack and moves the stack pointer. The only register that is altered in this macro is $sp.

pop(%reg): Macro takes the value on the top of the stack and loads it into %reg then moves the stack pointer. The only registers altered are %reg and $sp.

Subroutine Descriptions

These subroutines should be in the Lab5.asm file. You may use additional functions if you like, but they should be included in Lab5.asm as well.

It is important that these subroutines do **NOT** display any text to the screen using syscalls. If so, this will interfere with the grading script and result in point deductions. **You may print strings and characters in the lab5_s20_test.asm file, but not in Lab5.asm!**

We recommend that you try to implement these functions in roughly the given order. This order "builds up" so you get an understanding of memory-mapped IO, the bitmap display, and how functions work.

clear_bitmap: Given a color, this function will fill the bitmap display with that color. **It is not required that this call any other functions, but you may want to use draw_pixel.**

Inputs:
$a0 = Color
Outputs:
No register outputs
Side-Effects:
Colors the Bitmap display (all RGB pixels from 0xFFFF0000 to 0xFFFFFFFC) all the same color. (Question for yourself, why 0xFFFFFFFC and not 0xFFFFFFFF?)

draw_pixel: Given a coordinate in $a0, this function will color a pixel in the image according to the RGB value given by register $a1. This works by storing the RGB value in the appropriate location of the row-major bitmap array starting at address 0xFFFF0000.

You should do some error checking to ensure the pixel is within range. If the XX or YY values "overflow" and are more than 8-bits, you could have segmentation fault errors when storing to the memory-map. We will not be grading this error checking, but **it will save you time debugging**!

Inputs:
$a0 = coordinates of pixel in format (0x00XX00YY)
$a1 = color of bitmap in format (0x00RRGGBB)
Outputs:
No register outputs
Side-effects:
Draws a pixel in the Bitmap Display

get_pixel: Given a coordinate, returns the color of that pixel. This is used for some "spot checks" in our test code.

Inputs:
$a0 = coordinates of pixel in format (0x00XX00YY)
Outputs:
$v0 = color of the pixel at that coordinate in format (0x00RRGGBB)

Side-effects:
None

draw_solid_circle: Given the coordinates of the center (xc, yc) and the radius r draws a filled circle of a desired color. The algorithm (given bellow) test each point of the circumscribed square and plot it if the point lies **inside** the circle (x – xc)^2 + (y – yc)^2 = r^2. **This function should use draw_pixel.**

Inputs:
$a0 = coordinates of the circle center in format (0x00XX00YY)
$a1 = radius of the circle
$a2 = color in format (0x00RRGGBB)

Outputs:
No register Outputs

Side-effects:
Draws a filled circle in the Bitmap Display.

```
draw_solid_circle(int xc, int yc, int r)
    xmin = xc-r
    xmax = xc+r
    ymin = yc-r
    ymax = yc+r
    for (i = xmin; i <= xmax; i++)
        for (j = ymin; j <= ymax; j++)
            a = (i – xc)*(i – xc) + (j – yc)*(j – yc)
            if (a < r*r )
                draw_pixel(x,y)
```

A couple notes:

1. You should accurately follow this algorithm and not “improve” it at all. If you do, you may introduce pixel errors that can cause point deductions.
2. You can assume that the center coordinates and radius are “correct” (in bounds) and do not have to do error checking.
3. Pay attention to the inequalities (for example, <= is not the same as <).
4. This computation should not use floating point numbers. It is all two’s complement (signed) integers.

draw_solid_circle: Given the coordinates of the center (xc, yc) and the radius r, uses draw_circle_pixels and Bresenham's circle drawing algorithm (given below), to draw the circumference with the specified color line. **This function should use draw_circle_pixels.**

Inputs:

$a0 = coordinates of circle center in format (0x00XX00YY)
$a1 = radius of the circle
$a2 = color of line format (0x00RRGGBB)

Outputs:

No register Outputs

Side-effects:

Draws a circumference in the Bitmap Display.

```
draw_circle(xc, yc, r)
    x = 0
    y = r
    d = 3 - 2 * r
    draw_circle_pixels(xc, yc, x, y)
    while (y >= x)
        x=x+1
        if (d > 0)
            y=y-1
            d = d + 4 * (x - y) + 10
        else
            d = d + 4 * x + 6
        draw_circle_pixels(xc, yc, x, y)
```

A couple notes:

1. You should accurately follow this algorithm and not "improve" it at all. If you do, you may introduce pixel errors that can cause point deductions.
2. You can assume that the center coordinates and radius are "correct" (in bounds) and do not have to do error checking.
3. Pay attention to the inequalities (for example, >= is not the same as >).
4. This computation should not use floating point numbers. It is all two's complement (signed) integers.
5. Remember that multiplication by a power of 2 can be done with a shift operation.

draw_circle_pixels: Given the coordinates of the center (xc, yc) and the (x, y) values from the Bresenham's circle drawing algorithm, plots the circumference points. **This function should use draw_pixel.**

Inputs:

$a0 = coordinates of circle center in format (0x00XX00YY)
$a1 = color in format (0x00RRGGBB)
$a2 = current x value from the Bresenham's circle algorithm
$a3 = current y value from the Bresenham's circle algorithm

Outputs:

No register Outputs

Side-effects:

Draws the points of the circumference using the circle's symmetry.

```
draw_circle_pixels(xc, yc, x, y)
    draw_pixel(xc+x, yc+y)
    draw_pixel(xc-x, yc+y)
    draw_pixel(xc+x, yc-y)
    draw_pixel(xc-x, yc-y)
    draw_pixel(xc+y, yc+x)
    draw_pixel(xc-y, yc+x)
    draw_pixel(xc+y, yc-x)
    draw_pixel(xc-y, yc-x)
```

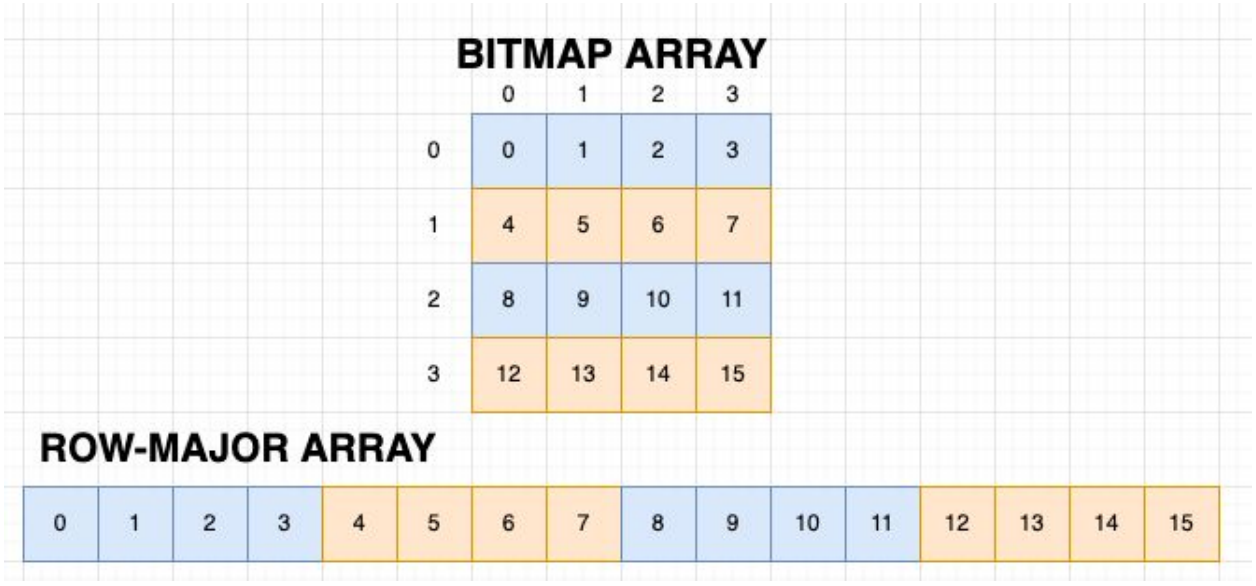
A couple notes:

1. You should accurately follow this algorithm and not "improve" it at all. If you do, you may introduce pixel errors that can cause point deductions.
2. You can assume that the center coordinates are "correct" (in bounds) and do not have to do error checking.
3. This computation should not use floating point numbers. It is all two's complement (signed) integers.

Test Output

The test output for this lab is visual and requires you to use the MARS Bitmap Display tool (in Mars select Bitmap Display from the Tools menu). You should modify the settings of the bitmap display to be 128 x 128 pixels and to have a base address of the memory map (0xffff_0000) as shown here:

Press “Connect to MIPS” to use this in your program.



The bitmap display is a grid of 128 x 128 pixels that displays a color based off the value written to the address corresponding to that pixel. In the example above, you can see how the coordinates of the pixel relate to the array in memory for a 4 x 4 pixel bitmap. For example if you wanted to color the pixel at row 2, column 3 (2,3)

you would take the base address of the of the first pixel and offset that by +11 which is (2 * row_size) + 3 to locate the correct pixel to color.
We will be grading your solution by dumping the memory-mapped IO segment as hexadecimal ASCII and comparing with the correct results. **You will miss all the points if you do not use the above size and base address configuration! In addition, your Lab5.asm should not display any text using syscalls as this will interfere with the grading output.** If you want, you can also display the memory-mapped segment using a command line argument like this:

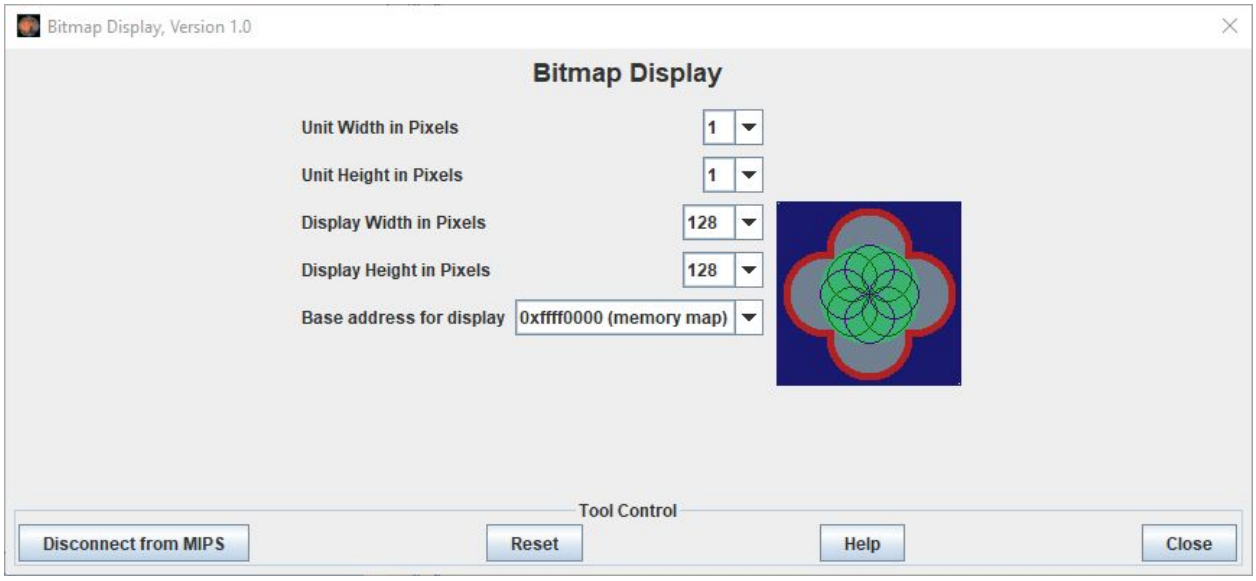
```
java -jar Mars4_5.jar nc 0xffff0000-0xfffffffc lab5_s20_test.asm
```

Sample Input/Outputs

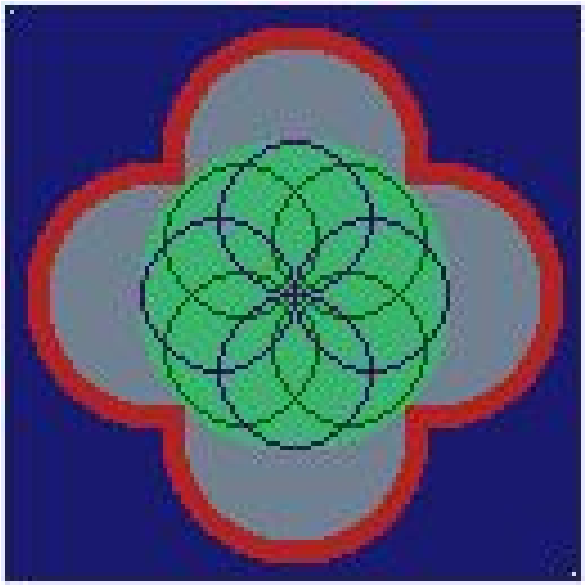
You are expected to read through and understand how the provided lab5_s20_test.asm file works. The test file will print to the console the state of the S registers before and after calling a subroutine, provide inputs, and test certain pixels to make sure that it's drawn in the correct place. This is what the output of your completed lab should look like:

```
--------------------------------
Clear_Bitmap Test:
Paints entire bitmap a midnight blue color

S registers before: 0xfeedbabe 0xc0ffeeee 0xbabedade 0xfeed0dad 0x00000000 0xcafecafe 0xbad00dad 0xdad00b0d
S registers after:  0xfeedbabe 0xc0ffeeee 0xbabedade 0xfeed0dad 0x00000000 0xcafecafe 0xbad00dad 0xdad00b0d

--------------------------------
Pixel Test:
Draws single orange pixel at (1,1) and yellow pixel at (126,126)

S registers before: 0xfeedbabe 0xc0ffeeee 0xbabedade 0xfeed0dad 0x00000000 0xcafecafe 0xbad00dad 0xdad00b0d
Get_pixel($a0 = 0x00400040) should return: 0x00191970
Your get_pixel($a0 = 0x00400040) returns:  0x00191970
Get_pixel($a0 = 0x00010001) should return: 0x0000ffff
Your get_pixel($a0 = 0x00010001) returns:  0x0000ffff
Get_pixel($a0 = 0x007e007e) should return: 0x00ffff00
Your get_pixel($a0 = 0x007e007e) returns:  0x00ffff00
S registers after:  0xfeedbabe 0xc0ffeeee 0xbabedade 0xfeed0dad 0x00000000 0xcafecafe 0xbad00dad 0xdad00b0d

--------------------------------
Solid Circle Test:
Creates a pattern using 9 solid circles

S registers before: 0xfeedbabe 0xc0ffeeee 0xbabedade 0xfeed0dad 0x00000000 0xcafecafe 0xbad00dad 0xdad00b0d
Get_pixel($a0 = 0x00240024) should return: 0x00b22222
Your get_pixel($a0 = 0x00240024) returns:  0x00b22222
Get_pixel($a0 = 0x00400010) should return: 0x00708090
Your get_pixel($a0 = 0x00400010) returns:  0x00708090
Get_pixel($a0 = 0x00400040) should return: 0x003cb371
Your get_pixel($a0 = 0x00400040) returns:  0x003cb371
S registers after:  0xfeedbabe 0xc0ffeeee 0xbabedade 0xfeed0dad 0x00000000 0xcafecafe 0xbad00dad 0xdad00b0d

--------------------------------
Bresenham's Circle Test:
Creates a pattern using 8 circunferences

S registers before: 0xfeedbabe 0xc0ffeeee 0xbabedade 0xfeed0dad 0x00000000 0xcafecafe 0xbad00dad 0xdad00b0d
Get_pixel($a0 = 0x00400057) should return: 0x00006400
Your get_pixel($a0 = 0x00400057) returns:  0x00006400
Get_pixel($a0 = 0x0040001E) should return: 0x004b0082
Your get_pixel($a0 = 0x0040001E) returns:  0x004b0082
S registers after:  0xfeedbabe 0xc0ffeeee 0xbabedade 0xfeed0dad 0x00000000 0xcafecafe 0xbad00dad 0xdad00b0d
-- program is finished running --
```

The entire bitmap display tool will look like this:



And the details of bitmap should display the following exactly:



Please note the following:

- The pixels draw “on top of” each other so the order of the drawn shapes matters. For example, the red circles are drawn before the gray circles, so they are “under” them.

This output of the tests are available in this file lab5_s20_test.hex if you wish to compare. You can compare files online using a “diff” utility like Diffchecker or the bash “diff” command.

For full credit, **your output should match ours exactly**.

Pseudocode

You should write pseudocode that outlines each function. Your pseudocode will appear at the start of each function in Lab5.asm. Guidelines on developing pseudocode can be found here: https://www.geeksforgeeks.org/how-to-write-a-pseudo-code/

You may modify your pseudocode as you develop your program. **Your pseudocode must also be present in your final submission**.

Automation

Note that part of our grading script is automated, so **it is imperative that your program’s output matches the specification exactly**. Output that deviates from the spec will cause point deduction.

You should not use a label called “main” anywhere in Lab5.asm. If you do, it will fail to work with our test cases and your assignment will not be graded.

Files

You do not need to include lab5_s20_test.asm in your repo, but you may if you like. We will be using our own version.

Lab5.asm

This file contains your pseudocode and assembly code for all of the functions and macros. It should use the template with the prototype definitions of the functions given. It should assemble on its own and with the test file that we gave you. Do not modify these! Follow the code documentation guidelines here. By itself, this file should not actually do anything but define the functions.

README.txt

This file must be a plain text (.txt) file. It should contain your first and last name (as it appears on Canvas) and your CruzID. Instructions for the README can be found here.

Google Form

You are required to answer questions about the lab in this Google Form. Answers, excluding the ones asking about resources used and collaboration should total at the very least 150 words.

Syscalls

You may use syscalls in the lab5_s20_test.asm file, but you should not use any syscalls in Lab5.asm. We inserted an exit syscall in the template to prevent it from running on its own and you can leave that there, but do not add any more.

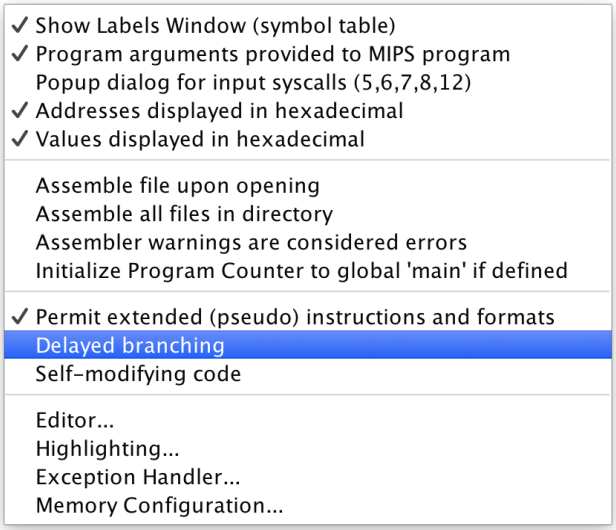
Note

It is important that you **do not hard-code** the values for any of the **addresses** in your program -- except for the memory-mapped IO segment at 0xFFFF0000. We will be testing the functions with different values than those provided in lab5_s20_test.asm, so do not hard code the output!

Other Requirements

Turn Off Delayed Branching

From the settings menu, **make sure Delayed branching is unchecked**

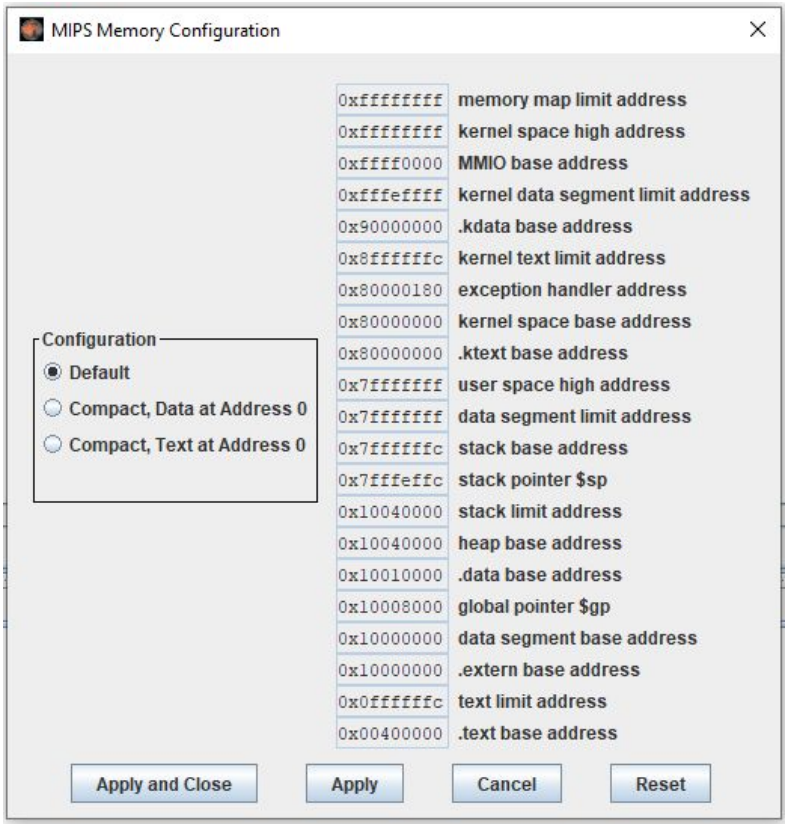


Checking this option will insert a "delay slot" which makes the next instruction after a branch execute, no matter the outcome of the branch. To avoid having your program behave in unpredictable ways, make sure Delayed branching is turned off. In addition, add a NOP instruction after each branch instruction. The NOP instruction guarantees that your program will function properly even if you forgot to turn off delayed branching. For example:

```
      LI   $t1 2

LOOP: NOP
      ADDI $t0 $t0 1
      BLT  $t0 $t1 LOOP
      NOP                    # nop added after the branch instruction
      ADD  $t3 $t5 $t6
```

MIPS Memory Configuration

To find the program arguments more easily in memory, you may choose to develop your program using a compact memory configuration (Settings -> Memory Configuration). However, your program **MUST** function properly using the **Default** memory configuration. You should not run into issues as long as you **do not hard-code any memory addresses** in your program. Make sure to test your program thoroughly using the **Default** memory configuration.



A Note About Academic Integrity

Please review the syllabus and look at the examples in the first lecture for acceptable and unacceptable collaboration. **You should be doing this assignment completely by yourself!**

Grading Rubric (100 points total)

12 pt assembles without errors
80 pt output matches the specification
   15 pt draw_pixel and get_pixel
   25 pt draw a filled circle of the specified radius, center coordinates and color
   25 pt draw a circumference with the specified radius, center coordinates and color
   15 pt caller save registers saved/restored
Note: credit for this section **only** if program assembles without errors

8 pt documentation
   4 pt README file complete
   4 pt Google form complete with at least 150 words

-50 pt if program only runs in a specific memory configuration or memory addresses are hard coded

-25 pt incorrect naming convention

-100 pt no Google form submitted or incorrect commit ID