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ECEN 5803 Mastering Embedded System Architecture

Project 1 Module 1

Question 1 : Starting with the results from Lab_Exercise_1 in the Homework 2-Practical, create another Keil project, call it M1-String and replace the string copy and string capitalization assembly language functions with C functions written by your or your partner. Compile and run this project. Compare the memory usage between the assembly language function project and the C function project – which uses less memory?

- **Memory Usage for Assembly Code :**

Section	Size (Bytes)
Code	1392
RO-data	436
RW-data	40
ZI-data	1632

Table 1 : Memory usage of a assembly code

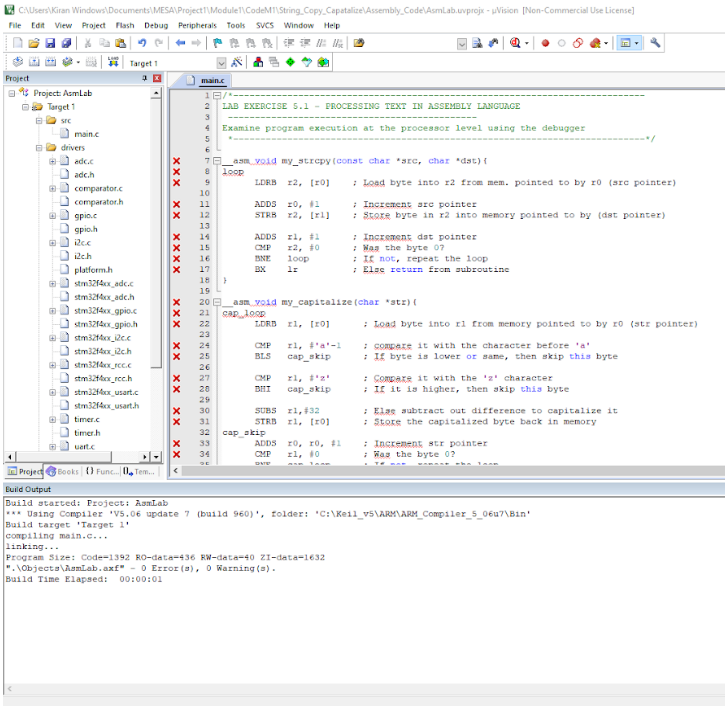


Figure 1 : Compiled Assembly code showing memory usage

- **Memory Usage for C Code :**

Section	Size (Bytes)
Code	1408
RO-data	436
RW-data	40
ZI-data	1632

Table 2 : Memory usage of a C code

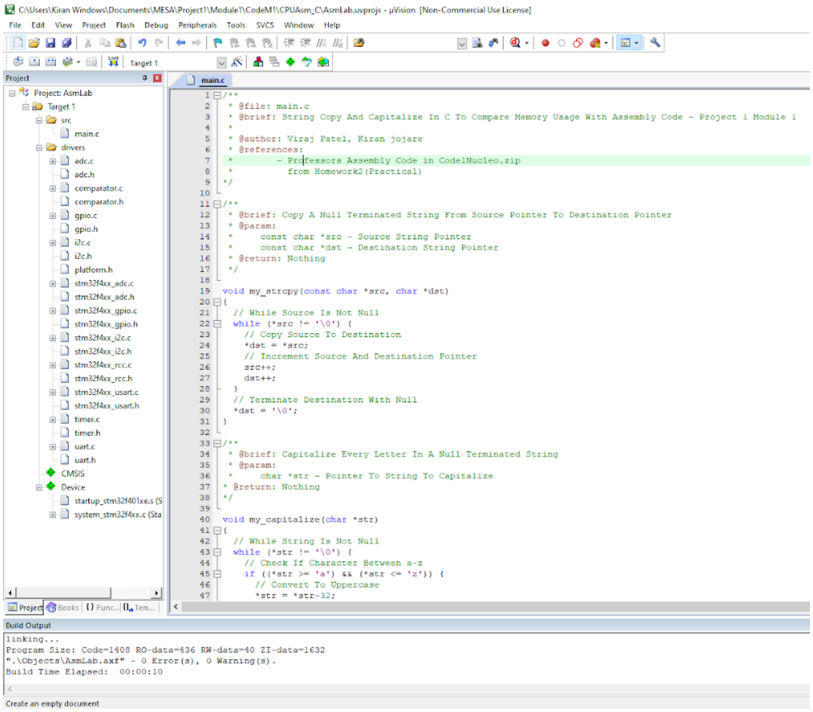


Figure 2 : Compiled C code showing memory usage

- **Size Analysis between Assembly and C Code :**

Looking into the two screenshots with just 16 extra bytes added in the code section, the assembly implementation code size is little less than the C implementation's. The three types of RO, RW, and ZI data memory sections remain unchanged between the two implementations.

This shows that while the assembly fundamental logic optimization concludes in a small space reduction, the overall data structures and constants are unchanged.

Question 2 : Look at the .map file for this project. Explain the memory model of ARM Cortex-M4 with respect to the code memory, data memory, IRQ handlers and peripherals. Explain with the help of a diagram where required.

- **Basic Idea of ARM Cortex-M4 memory model**
  The ARM Cortex M4 is a processor core developed by ARM Holdings organisation for microcontroller use, notably in embedded systems. It features a Memory Model that is suited very well to meet the needs of high-performance, low power devices. Below is a high level overview of the memory model with respect to the mentioned aspects.

  1. Code Memory (Flash):
    - Code memory is a non-volatile and stores the program executable code. It retrieves and retain data even when the power is off.

  2. Data Memory (RAM):
    - Data memory is a volatile and stores data as well as variables that the program uses during execution run. It forgets its content when the power is turned off.

3. Interrupt Vector Table:

- Interrupt vector table contains the addresses of Interrupt Service Routines (ISR) or IRQ Handlers. Each of these IRQ's corresponding to a specific interrupt or exception. It allows the processor to handle requests from peripherals efficiently.

4. Peripherals:

- Peripherals are the components like timers, communication ports like USART, and ADCs, enabling interaction with the outside world or performing certain tasks. They are used and controlled through memory mapped Special Function Registers(SFR).

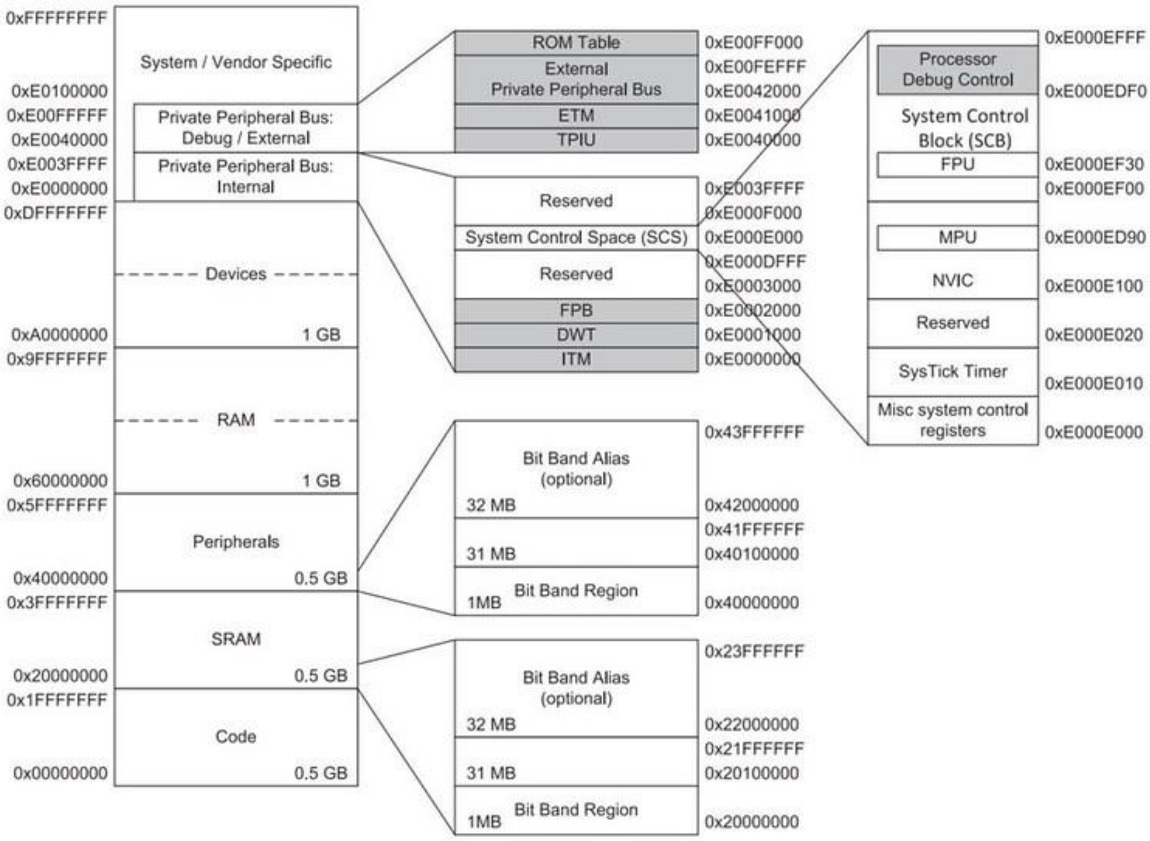


Figure 3 : Memory Map Model From ARM Official Website

- **Our .map Analysis:**

Code Memory :

The code memory in embedded systems is where the executable code is stored. For the ARM Cortex-M4, which, this means that code and data coexist in the same memory space. This specific memory, often known as flash memory, is non-volatile, meaning it retains its data even without power. According to our .map file as seen in figure 4, this memory region is designated as the Load Region LR_IROM1 with a base address of 0x08000000 and a size of 0x0000075c. Within this, the Execution Region ER_IROM1, where the code actually runs, has the same base address, and a slightly smaller size of 0x00000734. The maximum allowable size for this region is 0x00080000.

```
main.c    AsmLab.map
==============================================================================

Memory Map of the image

  Image Entry point : 0x08000195

  Load Region LR_IROM1 (Base: 0x08000000, Size: 0x0000075c, Max: 0x00080000, ABSOLUTE)

    Execution Region ER_IROM1 (Exec base: 0x08000000, Load base: 0x08000000, Size: 0x00000734, Max: 0x00080000, ABSOLUTE)

    Exec Addr    Load Addr    Size         Type   Attr      Idx    E Section Name        Object

    0x08000000   0x08000000   0x00000194   Data   RO         1612    RESET               startup_stm32f401xe.o
    0x08000194   0x08000194   0x00000008   Code   RO         1714  * !!!main             c_w.l(__main.o)
    0x0800019c   0x0800019c   0x00000034   Code   RO         1944    !!!scatter          c_w.l(__scatter.o)
    0x080001d0   0x080001d0   0x0000001a   Code   RO         1946    !!handler_copy      c_w.l(__scatter_copy.o)
    0x080001ea   0x080001ea   0x00000002   PAD
    0x080001ec   0x080001ec   0x0000001c   Code   RO         1948    !!handler_zi        c_w.l(__scatter_zi.o)
    0x08000208   0x08000208   0x00000002   Code   RO         1881    .ARM.Collect$$libinit$$00000000  c_w.l(libinit.o)
    0x0800020a   0x0800020a   0x00000004   Code   RO         1768    .ARM.Collect$$libinit$$00000001  c_w.l(libinit2.o)
    0x0800020e   0x0800020e   0x00000000   Code   RO         1771    .ARM.Collect$$libinit$$00000004  c_w.l(libinit2.o)
```

Figure 4 : Code memory from .map file

Data Memory:

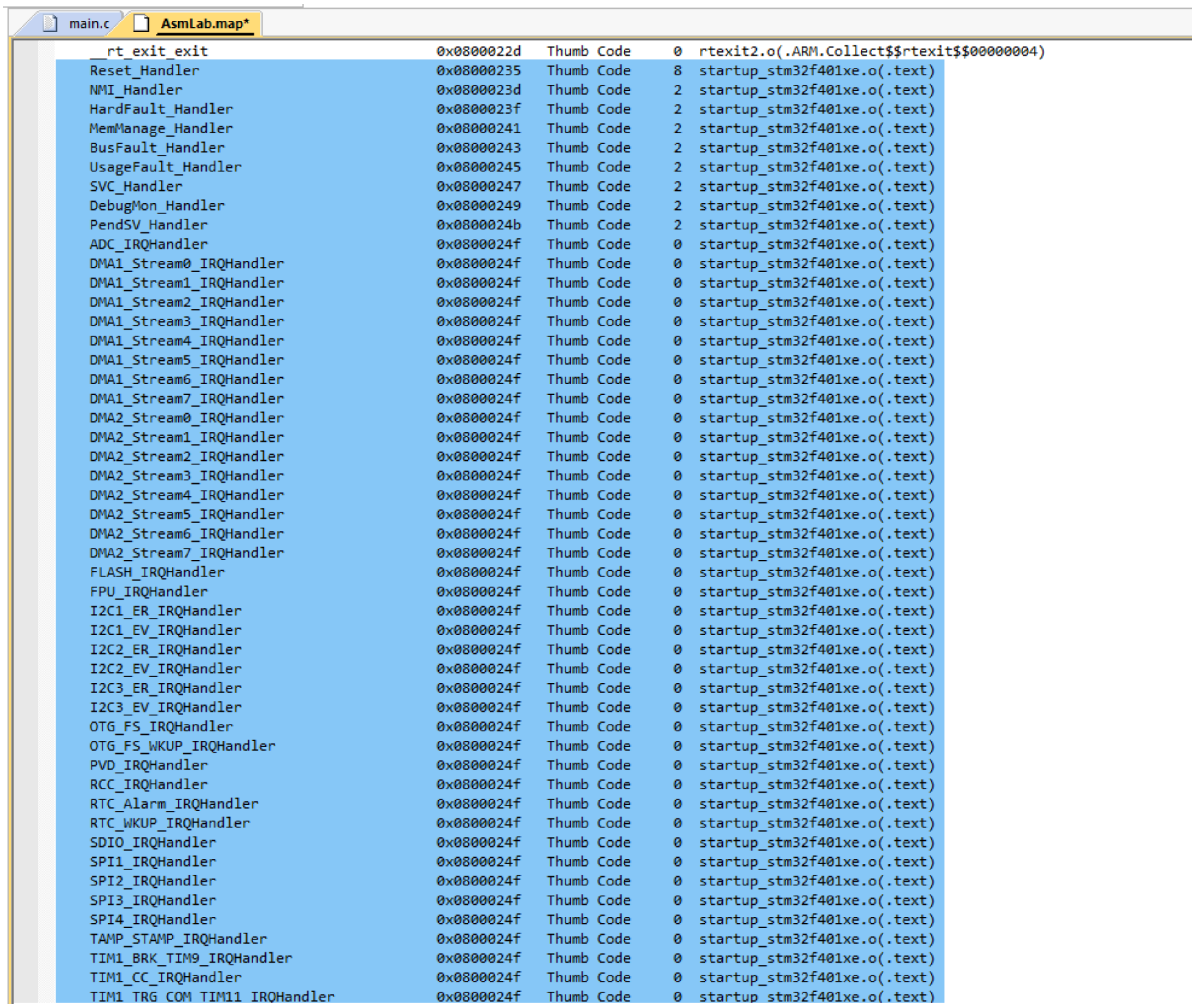
The data memory in embedded systems is used to store variables and run-time data. Within the context of the Cortex-M4, this memory region is predominantly comprised of Random Access Memory (RAM). According to the .map file, the data memory region is denoted by the Execution Region RW_IRAM1. The base address for this region is 0x20000000. The size of RW_IRAM1, as specified in the .map file screenshot in figure 5 , is 0x00000688. This memory also accommodates individual sections like .data for initialized variables and .bss for uninitialized ones. Additionally, dedicated sections for HEAP and STACK are present, which are integral for dynamic memory allocation and function call management respectively.

```
    Execution Region RW_IRAM1 (Exec base: 0x20000000, Load base: 0x08000734, Size: 0x00000688, Max: 0x00018000, ABSOLUTE)

    Exec Addr    Load Addr    Size         Type   Attr      Idx    E Section Name        Object

    0x20000000   0x08000734   0x0000001c   Data   RW          247    .data               gpio.o
    0x2000001c   0x08000750   0x00000008   Data   RW         1479    .data               timer.o
    0x20000024   0x08000758   0x00000004   Data   RW         1544    .data               uart.o
    0x20000028        -       0x00000060   Zero   RW         1821    .bss                c_w.l(libspace.o)
    0x20000088        -       0x00000200   Zero   RW         1611    HEAP                startup_stm32f401xe.o
    0x20000288        -       0x00000400   Zero   RW         1610    STACK               startup_stm32f401xe.o


==============================================================================
```

Figure 5 : data memory section from .map file

IRQ Handlers:

Interrupt Request (IRQ) handlers are responsible for dealing with events or signals from peripherals or internal system components that need immediate attention. In the context of the Cortex-M architecture, these handlers are typically part of the vector table at the beginning of the code memory. In the .map file for the STM32F401xE microcontroller, the IRQ handlers are functions designed to address specific system or peripheral events. Looking at .map file in screenshot below in figure 6, we can see that IRQ for each handers has been assigned a specific address. Many share the address 0x0800024f, suggesting they're aliased to a default function in the absence of specific implementations.



```
main.c    AsmLab.map*
    __rt_exit_exit                  0x0800022d   Thumb Code    0  rtexit2.o(.ARM.Collect$$rtexit$$00000004)
    Reset_Handler                   0x08000235   Thumb Code    8  startup_stm32f401xe.o(.text)
    NMI_Handler                     0x0800023d   Thumb Code    2  startup_stm32f401xe.o(.text)
    HardFault_Handler               0x0800023f   Thumb Code    2  startup_stm32f401xe.o(.text)
    MemManage_Handler               0x08000241   Thumb Code    2  startup_stm32f401xe.o(.text)
    BusFault_Handler                0x08000243   Thumb Code    2  startup_stm32f401xe.o(.text)
    UsageFault_Handler              0x08000245   Thumb Code    2  startup_stm32f401xe.o(.text)
    SVC_Handler                     0x08000247   Thumb Code    2  startup_stm32f401xe.o(.text)
    DebugMon_Handler                0x08000249   Thumb Code    2  startup_stm32f401xe.o(.text)
    PendSV_Handler                  0x0800024b   Thumb Code    2  startup_stm32f401xe.o(.text)
    ADC_IRQHandler                  0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA1_Stream0_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA1_Stream1_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA1_Stream2_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA1_Stream3_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA1_Stream4_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA1_Stream5_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA1_Stream6_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA1_Stream7_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA2_Stream0_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA2_Stream1_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA2_Stream2_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA2_Stream3_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA2_Stream4_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA2_Stream5_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA2_Stream6_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    DMA2_Stream7_IRQHandler         0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    FLASH_IRQHandler                0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    FPU_IRQHandler                  0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    I2C1_ER_IRQHandler              0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    I2C1_EV_IRQHandler              0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    I2C2_ER_IRQHandler              0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    I2C2_EV_IRQHandler              0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    I2C3_ER_IRQHandler              0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    I2C3_EV_IRQHandler              0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    OTG_FS_IRQHandler               0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    OTG_FS_WKUP_IRQHandler          0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    PVD_IRQHandler                  0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    RCC_IRQHandler                  0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    RTC_Alarm_IRQHandler            0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    RTC_WKUP_IRQHandler             0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    SDIO_IRQHandler                 0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    SPI1_IRQHandler                 0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    SPI2_IRQHandler                 0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    SPI3_IRQHandler                 0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    SPI4_IRQHandler                 0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    TAMP_STAMP_IRQHandler           0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    TIM1_BRK_TIM9_IRQHandler        0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    TIM1_CC_IRQHandler              0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
    TIM1_TRG_COM_TIM11_IRQHandler   0x0800024f   Thumb Code    0  startup_stm32f401xe.o(.text)
```

Figure 6 : IRQ's from .map file

Peripherals:

Peripherals represent the various hardware components integrated into the microcontroller, such as GPIOs, UARTs, ADCs, and timers. The memory associated with peripherals is usually mapped to a specific region in memory and is often called the peripheral memory space. In our .map file of microcontroller projects, peripheral-related data doesn't have explicit sections named after the peripherals. Instead, they can be found in the symbol table with names resembling peripheral functions, in memory sections detailing memory-mapped I/O, or via cross-references linking object files to symbols. The absence of peripherals could be because they are not initialised or used in main.c code.

References :

- Arm Developer. (n.d.). Architectural Overview. Retrieved September 25, 2023, from https://developer.arm.com/documentation/den0001/latest/

- MikroE. (n.d.). Memory Organization. Retrieved September 25, 2023, from http://download.mikroe.com/documents/compilers/mikroc/arm/help/memory_organization.htm

Question 3 :

1. Testing Approximate square root with bisection method without Q16.16 format code with these inputs: 2, 4, 22, and 121.
2. Estimate the number of CPU cycles used for this calculation.
3. Auto-generate documentation using Doxygen. Provide either an HTML directory or PDF file documenting your codebase.

- Testing input: 2
  Result as seen in R0 register = 0x00000001

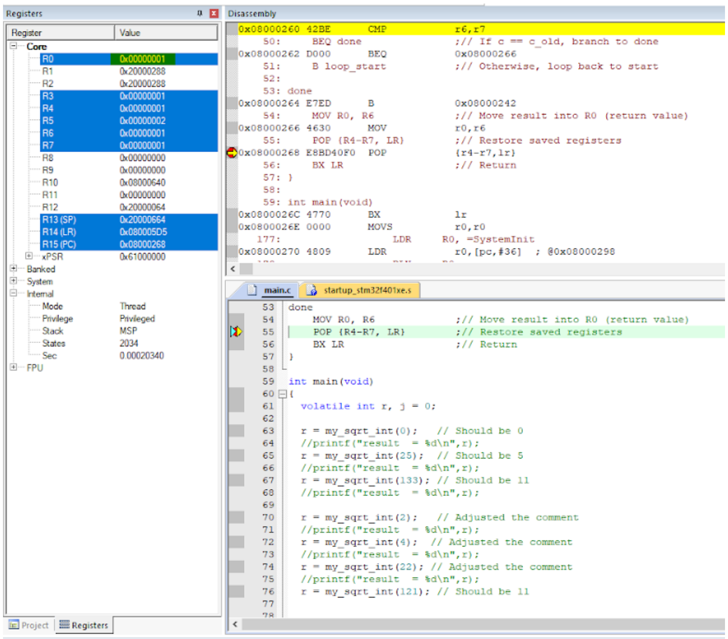


Figure 7 : Result of normal code output with input 2

- Testing input: 4
  Result as seen in R0 register = 0x00000002

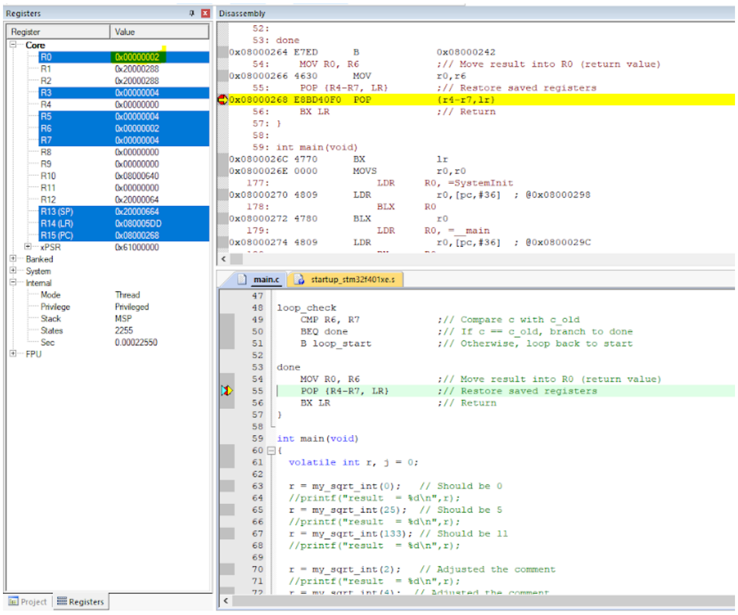


Figure 8 : Result of normal code output with input 4

- Testing input: 22
  Result as seen in R0 register = 0x00000004

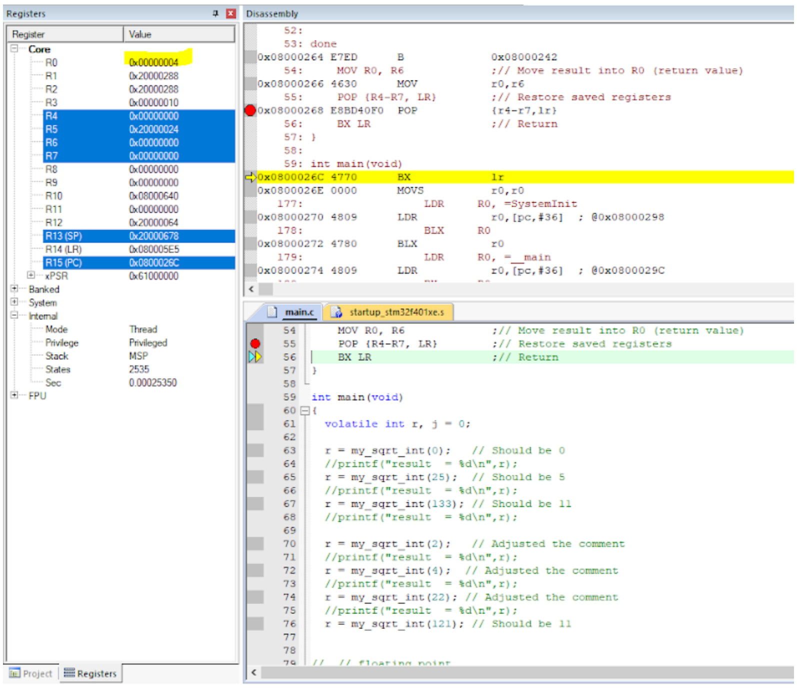


Figure 9 : Result of normal code output with input 22

- Testing input: 121
  Result as seen in R0 register = 0x0000000B

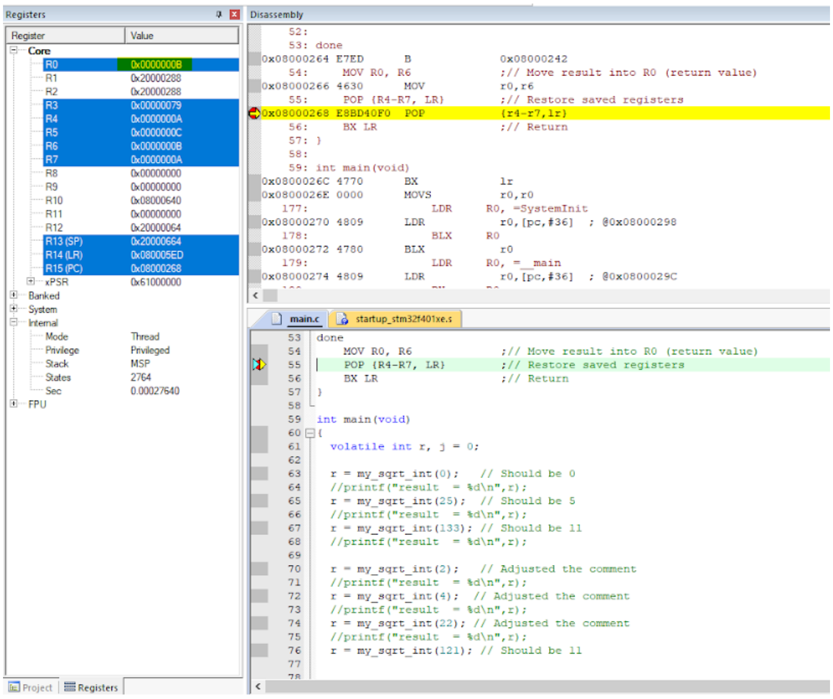


Figure 10 : Result of normal code output with input 121

- CPU Cycle
  After going through the code computing CPU cycles for each instruction the final CPU cycle time can be computed as follows. Assuming that branching is not taken and I being number of iterations.

  Total Cycles = 11 (Setup) + [8 + (2 (for either Update A or B)) + 5]*i (i Iterations) + 8 (Clean-up)

  References:
  - Arm Developer. (n.d.). Cortex-M4 Instructions: Instruction Set Summary. Retrieved September 25, 2023, from https://developer.arm.com/documentation/ddi0439/b/Programmers-Model/Instruction-set-summary/Cortex-M4-instructions

Doxygen Documentation :

Refer the attached pdf auto generated from doxygen using “make pdf ” command in latex folder.
Path in Submission: Doxygen Documentation.
For HTML and Latex Refer to Code Project Folders.

Question 4 : (Bonus Question)

1. Testing Approximate square root with bisection method with Q16.16 format code with these inputs: 2.0, 4.0, 22.0, and 121.0.
2. Estimate the number of CPU cycles used for this calculation and also the size of the code in memory.
3. Auto-generate documentation using Doxygen. Provide either an HTML directory or PDF file documenting your codebase.

- Testing input: 2.0
  Result as seen in R0 register = 0x00016A00(1.41 in Q16.16 format)

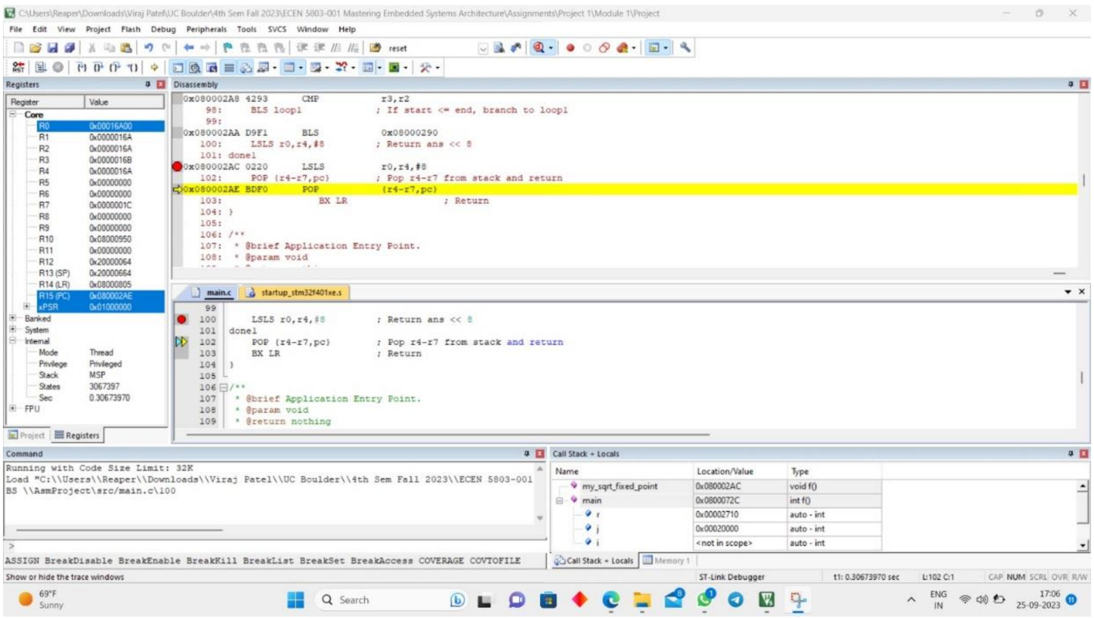


Figure 8 : Bonus Lab output with input 2.0

- Testing input: 4.0
  Result as seen in R0 register = 0x00020000 (2.0 in Q16.16 format)

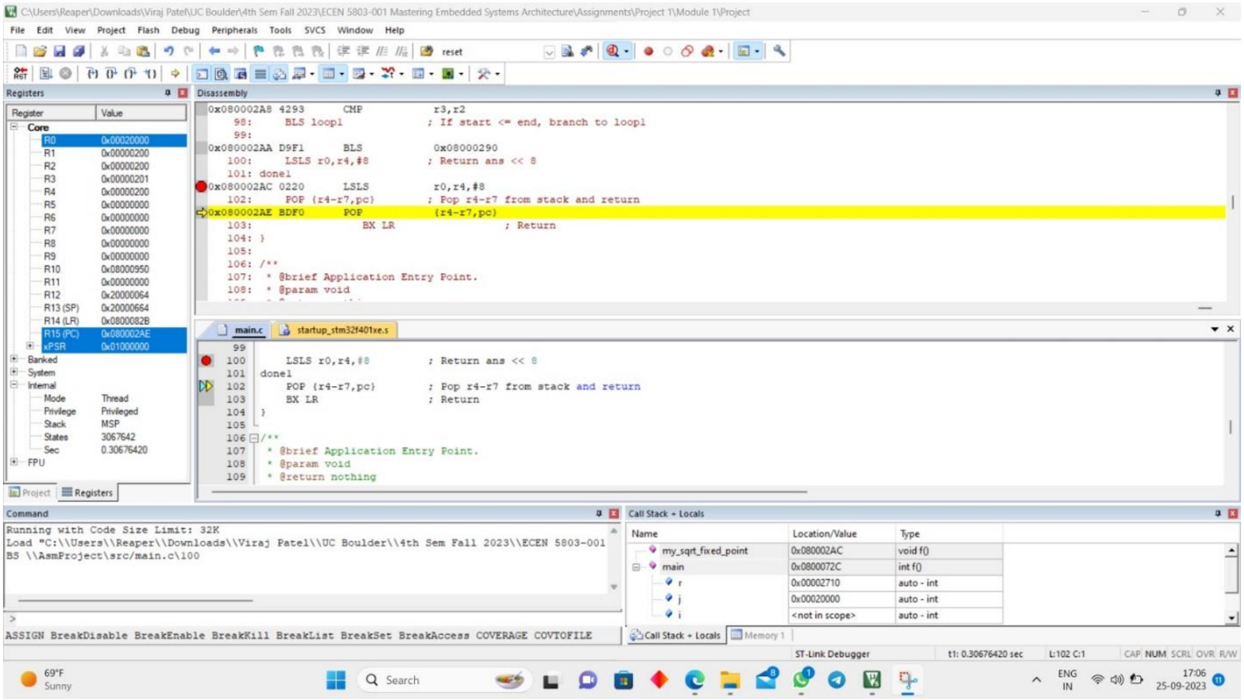


Figure 9 : Bonus Lab output with input 4.0

- Testing input: 22.0
  Result as seen in R0 register = 0x0004B000(4.68 in Q16.16 format)

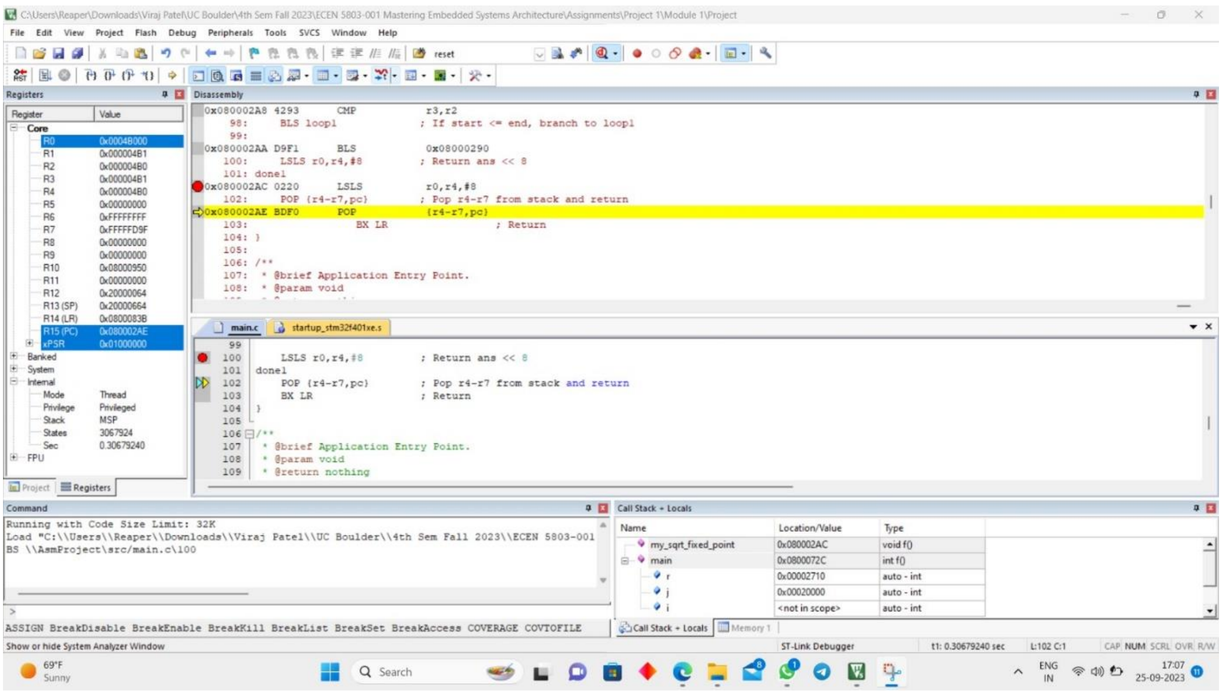


Figure 10 : Bonus Lab output with input 22.0

- Testing input: 121.0
  Result as seen in R0 register = 0x000B0000(11.0 in Q16.16 format

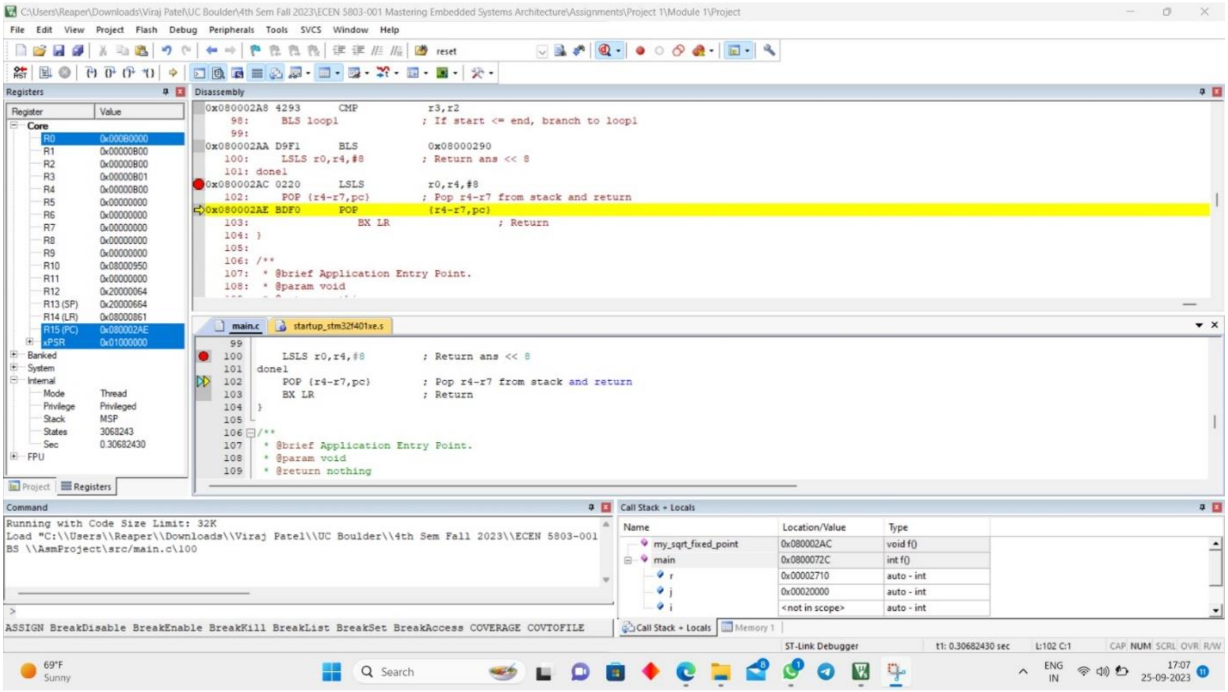


Figure 11 : Bonus Lab output with input 121.0

- CPU Cycle
  After going through the code computing CPU cycles for each instruction the final CPU cycle time can be computed as follows. Assuming that branching is not taken and I being number of iterations.

  Total Cycles = 12 (Setup) + [9 + 1 (cond_less_equal if branched) + 3]*i (i Iterations) + 6 (Clean-up)

- **Memory Usage for Bonus Lab Code :**

Section	Size (Bytes)
Code	1948
RO-data	436
RW-data	36
ZI-data	1636

Doxygen Documentation :

Refer the attached pdf auto generated from doxygen using "make pdf " command in latex folder.
Path in Submission: Doxygen Documentation (Folder)
For HTML and Latex Refer to Code Project Folders.

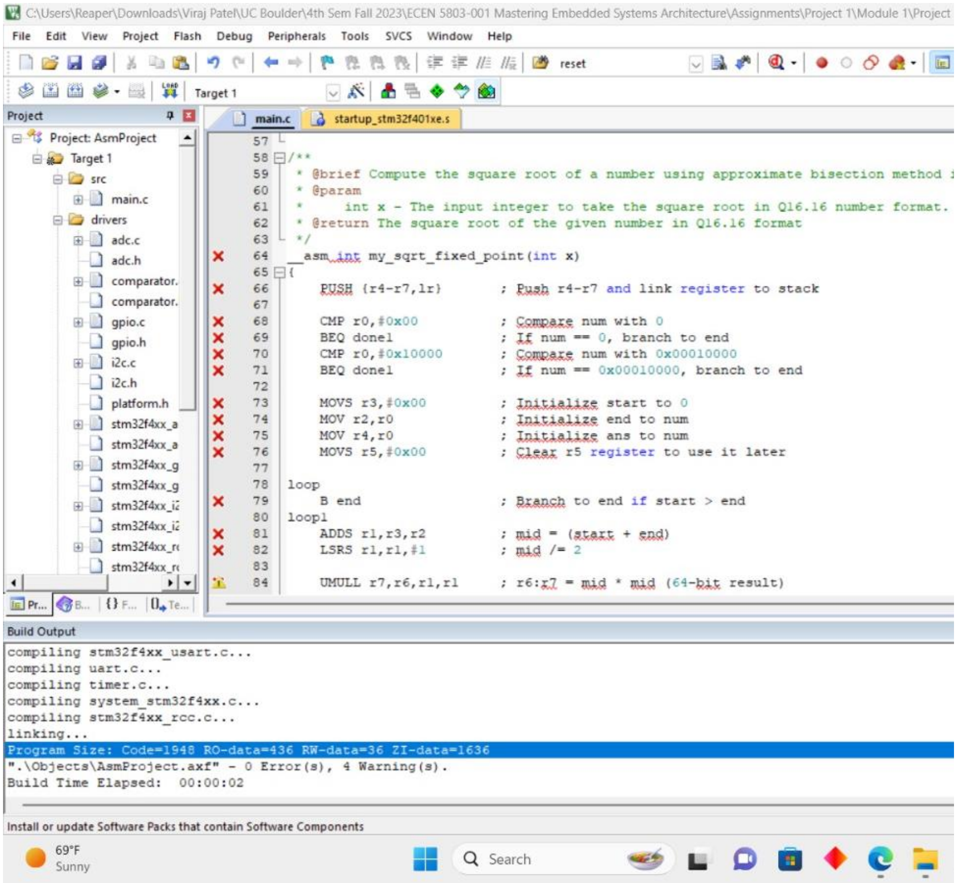


Figure 12 : Bonus Lab Size of Memory

References:

- Arm Developer. (n.d.). Cortex-M4 Instructions: Instruction Set Summary. Retrieved September 25, 2023, from https://developer.arm.com/documentation/ddi0439/b/Programmers-Model/Instruction-set-summary/Cortex-M4-instructions

Code :

Square Root approximation :

```
/**
 * @file main.c
 * @brief Square Root Approximation using Integer Approach - Project 1 Module 1
 *
 * @author Viraj Patel, Kiran jojare
 * @see <a href="https://developer.arm.com/documentation/ddi0439/b/Programmers-Model/Instruction-set-
summary/Cortex-M4-instructions?lang=en">ARM Cortex-M4 Instructions</a>
 * @see PDF obtained from professor "Approximate Square Root Bisection Method"
 */

// include standard header files
#include <string.h>
#include <assert.h>

/**
 * @brief Compute the integer square root of a number using approximate bisection method.
 * @param
 *     int x - The input integer to take the square root.
 * @return The integer square root of the given number.
 */
__asm int my_sqrt_int(int x)
{
    PUSH {R4-R8, LR}       ; Save registers that will be used in the subroutine
    MOV R4, #0             ; Initialize a = 0
    LDR R5, =0x4000        ; Initialize b = 2^16
    MOV R6, #-1            ; Initialize c = -1
               MOV R8, #0             ; Initialize done = 0
loop_start
    MOV R7, R6             ; c_old <- c
    ADD R6, R4, R5         ; R6 = a + b
    ASR R6, R6, #1         ; c <- (a+b)/2
    MUL R3, R6, R6         ; R3 = c*c
    CMP R3, R0             ; Compare c*c with x
    BEQ done               ; If c*c == x, branch to done
    BLT update_a           ; If c*c < x, branch to update_a
    B update_b             ; Otherwise, branch to update_b

update_a
    MOV R4, R6             ; a <- c
    B loop_check                                  ; jump to loop_check

update_b
    MOV R5, R6             ; b <- c
    B loop_check           ; jump to loop_check

loop_check
    CMP R6, R7             ; Compare c with c_old
    BEQ done               ; If c == c_old, branch to done
               CMP R8, #1             ; Compare done with 1
               BEQ done               ; If done == 1, branch to done
    B loop_start           ; Otherwise, loop back to start

done
    MOV R0, R6             ; Move result into R0 (return value)
    POP {R4-R8, LR}        ; Restore saved registers
    BX LR                  ; Return
}

/**
 * @brief Compute the square root of a number using approximate bisection method in Q16.16 number
format
 * @param
 *     int x - The input integer to take the square root in Q16.16 number format.
 * @return The square root of the given number in Q16.16 format
 */
__asm int my_sqrt_fixed_point(int x)
{
    PUSH {r4-r7,lr}       ; Push r4-r7 and link register to stack

    CMP r0,#0x00          ; Compare num with 0
    BEQ done1             ; If num == 0, branch to end
```

```
    CMP r0,#0x10000       ; Compare num with 0x00010000
    BEQ done1             ; If num == 0x00010000, branch to end

    MOVS r3,#0x00         ; Initialize start to 0
    MOV r2,r0             ; Initialize end to num
    MOV r4,r0             ; Initialize ans to num
    MOVS r5,#0x00         ; Clear r5 register to use it later

loop
    B end                 ; Branch to end if start > end
loop1
    ADDS r1,r3,r2         ; mid = (start + end)
    LSRS r1,r1,#1         ; mid /= 2

    UMULL r7,r6,r1,r1     ; r6:r7 = mid * mid
    SUBS r7,r0,r7         ; Subtract result from num
    SBCS r6,r5,r6         ; Subtract with carry the result from 0
    BCC cond_less_equal   ; If unsigned lower or same, branch to cond_less_equal

    ADDS r3,r1,#1         ; start = mid + 1
    MOV r4,r1             ; ans = mid
    B loop

cond_less_equal
    SUBS r2,r1,#1         ; end = mid - 1

end
    CMP r3,r2             ; Compare start with end
    BLS loop1             ; If start <= end, branch to loop1

    LSLS r0,r4,#8         ; Return ans << 8
done1
    POP {r4-r7,pc}        ; Pop r4-r7 from stack and return
              BX LR                 ; Return
}

/**
 * @brief Application Entry Point.
 * @param void
 * @return nothing
 */
int main(void)
{
       volatile int r, j = 0;

       // Assert that my_sqrt_int returns the correct value for each test input
       r = my_sqrt_int(0);
       assert(r == 0); // assert that the square root of 0 is 0

       r = my_sqrt_int(25);
       assert(r == 5); // assert that the square root of 25 is 5

       r = my_sqrt_int(133);
       assert(r == 11); // assert that the square root of 133 is 11

       // Testing requested from lab exercise question
       // 3. Test your code with these inputs: 2, 4, 22, and 121. Record the results

       r = my_sqrt_int(2);
       assert(r == 1); // assert that the square root of 2 is 1

       r = my_sqrt_int(4);
       assert(r == 2); // assert that the square root of 4 is 2

       r = my_sqrt_int(22);
       assert(r == 4); // assert that the square root of 22 is 4

       r = my_sqrt_int(121);
       assert(r == 11); // assert that the square root of 121 is 11

       // Iterate from 0 to 9999 and compute square root of 'i' using 'my_sqrt_int', then accumulate
the results in 'j'.
       for (int i = 0; i < 10000; i++) {
                      r = my_sqrt_int(i);
                      j += r;
       }
       // Assert that the accumulated result 'j' is 661650
```

```
        assert(j == 661650);

        // Testing requested from bonus lab exercise question
        // 1. Test your code with these inputs: 2.0, 4.0, 22.0, and 121.0. Record the results
        r = my_sqrt_fixed_point(0x00020000);    // 2.0 in Q16.16 format
        assert(r == 0x00016a00);    // assert that square root of 2.0 is 1.41 in Q16.16 format

        r = my_sqrt_fixed_point(0x00040000);    // 4.0 in Q16.16 format
        assert(r == 0x00020000);    // assert that square root of 4.0 is 2.0 in Q16.16 format

        r = my_sqrt_fixed_point(0x00160000);    // 22.0 in Q16.16 format
        assert(r == 0x0004b000);    // assert that square root of 22.0 is 4.68 in Q16.16 format

        r = my_sqrt_fixed_point(0x00790000);    // 121.0 in Q16.16 format
        assert(r == 0x000b0000);    // assert that square root of 121.0 is 11.0 in Q16.16 format

        // Code execution ends here
        while(1);
}
```

Code :

String Capitalize and Copy (C Code):

```
/**
 * @file: main.c
 * @brief: String Copy And Capitalize In C To Compare Memory Usage With Assembly Code - Project 1
Module 1
 *
 * @author: Viraj Patel, Kiran jojare
 * @references:
 *        - Professors Assembly Code in Code1Nucleo.zip
 *          from Homework2(Practical)
*/

/**
 * @brief: Copy A Null Terminated String From Source Pointer To Destination Pointer
 * @param:
 *     const char *src - Source String Pointer
 *     const char *dst - Destination String Pointer
 * @return: Nothing
 */

void my_strcpy(const char *src, char *dst)
{
        // While Source Is Not Null
        while (*src != '\0') {
                // Copy Source To Destination
                *dst = *src;
                // Increment Source And Destination Pointer
                src++;
                dst++;
        }
        // Terminate Destination With Null
        *dst = '\0';
}

/**
 * @brief: Capitalize Every Letter In A Null Terminated String
 * @param:
 *     char *str - Pointer To String To Capitalize
* @return: Nothing
*/

void my_capitalize(char *str)
{
        // While String Is Not Null
        while (*str != '\0') {
                // Check If Character Between a-z
                if ((*str >= 'a') && (*str <= 'z')) {
                        // Convert To Uppercase
                        *str = *str-32;
                }
                // Increment String Pointer
                str++;
        }
}

int main(void)
{
        const char a[] = "Hello world!";
        char b[20];

        my_strcpy(a, b);
        my_capitalize(b);

        while (1);
}

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```

Code :

String Capitalize and Copy (Assembly Code):

```
/*----------------------------------------------------------------------------
LAB EXERCISE 5.1 - PROCESSING TEXT IN ASSEMBLY LANGUAGE
 ----------------------------------------------
Examine program execution at the processor level using the debugger

 * @file: main.c
 * @brief: String Copy And Capitalize In Assembly - Project 1 Module 1
 *
 * @author: Viraj Patel, Kiran jojare
 * @references:
 *        - Professors Assembly Code in Code1Nucleo.zip
 *          from Homework2(Practical)
 *----------------------------------------------------------------------------*/

/**
 * @brief: Copy A Null Terminated String From Source Pointer To Destination Pointer
 * @param:
 *     const char *src - Source String Pointer
 *     char *dst - Destination String Pointer
 * @return: Nothing
 */
__asm void my_strcpy(const char *src, char *dst){
loop
      LDRB  r2, [r0]    ; Load byte into r2 from mem. pointed to by r0 (src pointer)

      ADDS  r0, #1      ; Increment src pointer
      STRB  r2, [r1]    ; Store byte in r2 into memory pointed to by (dst pointer)

      ADDS  r1, #1      ; Increment dst pointer
      CMP   r2, #0      ; Was the byte 0?
      BNE   loop        ; If not, repeat the loop
      BX    lr          ; Else return from subroutine
}

/**
 * @brief: Capitalize Lowercase Letters In A Null Terminated String
 * @param:
 *     char *str - String Pointer
 * @return: Nothing
 */
__asm void my_capitalize(char *str){
cap_loop
      LDRB  r1, [r0]      ; Load byte into r1 from memory pointed to by r0 (str pointer)

      CMP   r1, #'a'-1    ; compare it with the character before 'a'
      BLS   cap_skip      ; If byte is lower or same, then skip this byte

      CMP   r1, #'z'      ; Compare it with the 'z' character
      BHI   cap_skip      ; If it is higher, then skip this byte

      SUBS  r1,#32        ; Else subtract out difference to capitalize it
      STRB  r1, [r0]      ; Store the capitalized byte back in memory
cap_skip
      ADDS  r0, r0, #1    ; Increment str pointer
      CMP   r1, #0        ; Was the byte 0?
      BNE   cap_loop      ; If not, repeat the loop
      BX    lr            ; Else return from subroutine
}

/*----------------------------------------------------------------------------
 MAIN function
 *----------------------------------------------------------------------------*/
int main(void){
       const char a[] = "Hello world!";
  char b[20];
  my_strcpy(a, b);
  my_capitalize(b);
  while (1);
}
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```