Lab 3: Microprocessor System Design

Programming in ARM assembly language

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Abstract

This lab is an introduction to Keil MDK integrated development environment and programming in ARM assembly language.

Introduction

We used the Keil ARM simulator to create new projects, assemble and debug programs. We also designed an algorithm that counts the number of 1's in a 32-bit number.

Material Used

Keil MDK version 4.7

Procedure

Part I: Using the Keil ARM Simulator

We created a new project by watching a tutorial youtube video and downloaded the startup.s file found on canvas.

Part II: Writing your first Assembly Program

Given a code that adds two numbers, we copied the code to keil editor and debug the code and watched the changes in the registers.

1. Explain what these lines mean

    AREA: instructs the assembler to assemble a new code

    |.text|: Name of the area used for codes produced by C compiler

    CODE: machine instructions

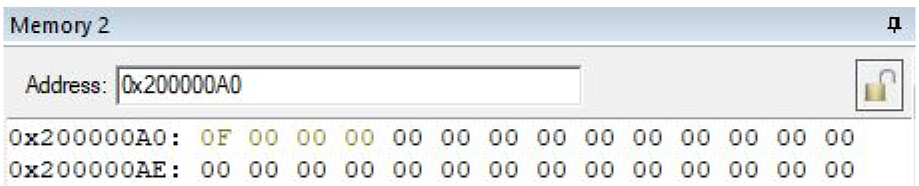
    READONLY: what is stored cannot be changed

    ALIGN = 2: adjust location counter to word boundary, in this case is 2^2-byte boundary (16-bits)

    THUMB: particular set of instruction (library)

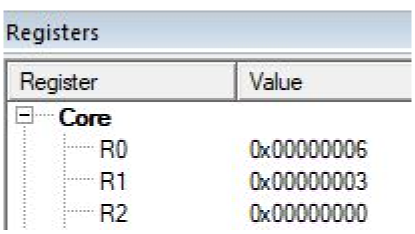
2. What is the value of R0, R1, R2, and PC at the start and at the end of the program?
Start: R0 = 0x0000000, R1 = 0x0000000, R2 = 0x0000000, PC = 0x0000026C
End: R0 = 0x0000004, R1 = 0x0000005, R2 = 0x0000009, PC = 0x000002A4
3. Explain the S B S line of code
Means branch to the line labeled S and is used to create an infinite loop which ends the program.

4. Expand the program to solve 4+5+9-3 and save the result in the 40th word in memory. Take a screenshot of the memory for your lab report.

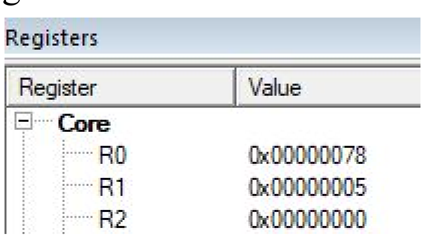


Part II: Tracing an Assembly Program
Given a new set of code to debug and watch the changes in the registers.

1. What is the value in R0 after the program ends? R0 = 0x00000006



2. If the value initially placed in R0 is equal to 5, what is the value in R0 when the program ends? R0 = 0x00000078



3. What does this program do?

    Calculates the factorial of a number, in this case 3! and 5!

4. If you replace the instructions at lines 2 and 10 in Figure 2 with PUSH {R0, R1} and POP {R1, R2} respectively, how will the program behave and why?

    The factorial function is a non-leaf function and therefore it must save values in the preserved registers (R0,LR) in the PUSH instruction and restore it in POP because it will be modified as the code runs. Replacing with PUSH{R0,R1} and POP{R1,R2}means that LR is not saved. Saving R1 does not help because R1 is not used, R2 is restored but was not saved in the first place. The program is stuck in an endless loop and sets R0 = 0.

5. Repeat 4 with the following instructions modifications:

    a. Replace the instructions at lines 2 and 10 in Figure 2 with PUSH {R3, LR} and POP {R3, LR} respectively.

    R3 is not used so it does not have to be saved or restored. The program does not work because the value of preserved register R0 was not saved hence cannot be restored, causing R0 = 0.

    b. Replace the instructions at lines 2 and 10 in Figure 2 with PUSH {LR} and POP {LR} respectively.

    Stores/restores the value of LR(return address) on to the stack but does not save/restore R0 (return value) so the program returns R0 = 0

    c. Delete the instruction at line 6.

    Removing ADD SP,SP, #8 the stack pointer goes to the memory address rather than the immediate values. So, it jumps straight to the last step and the program has the same end result.

Part III: Coding in Assembly Language

We designed an algorithm for counting the number of 1’s in a 32-bit number.

1. A pseudocode or a flow chart of your design steps

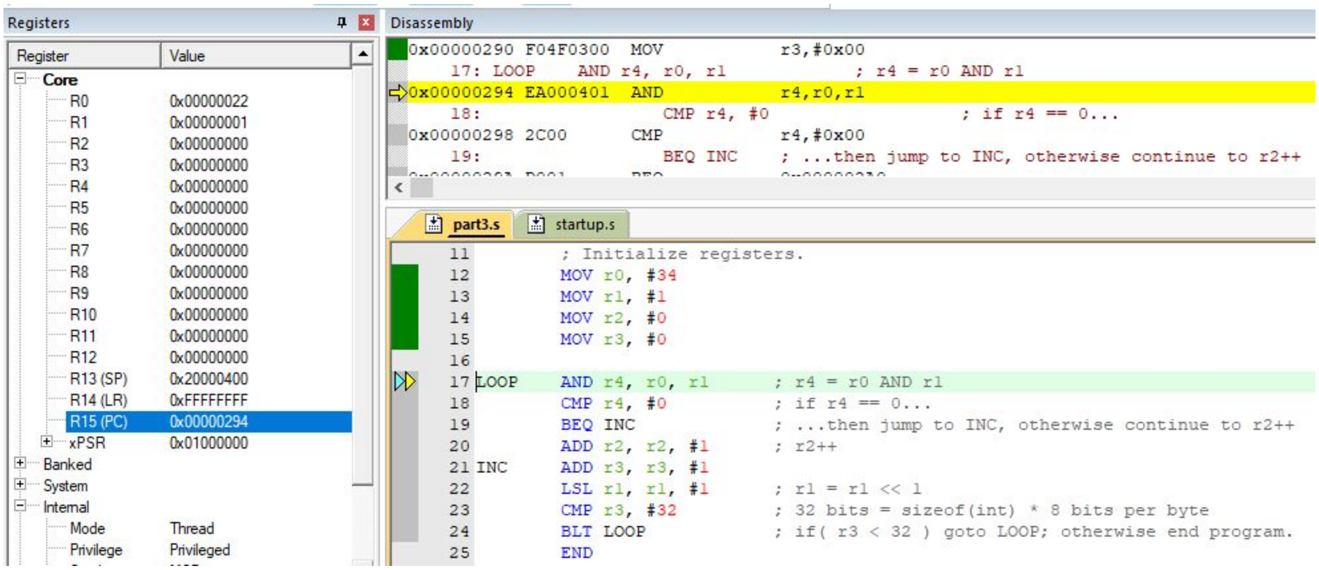
```
int number = -1; //can be any number
int mask = 1;
int onecounter = 0;
for (int i = 0; i < sizeof(int) * 8; i++)//goes to 32-bits
if (mask & number)
Onecounter++;
mask <<= 1; //shift masking number to the left once
```

2. Implement your algorithm using ARM assembly in the Keil IDE. Provide screenshots of the registers and/or memory locations used by the program.

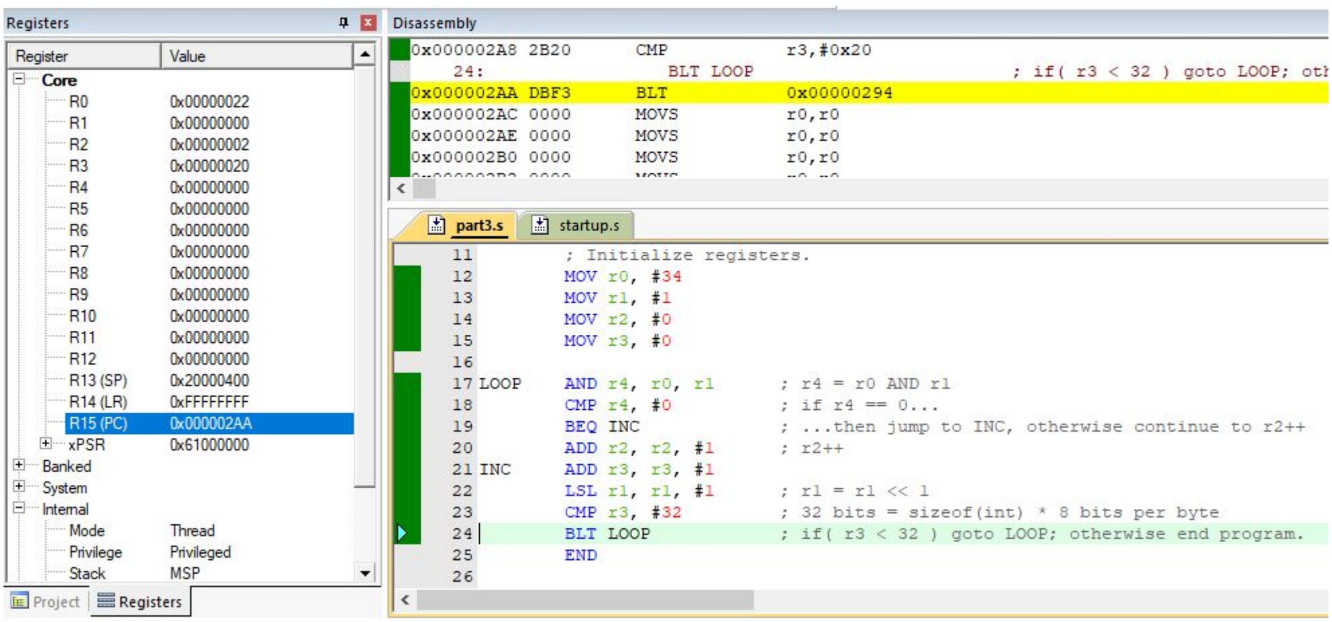
code:

```
AREA |.text|,CODE,READONLY,ALIGN=2
    THUMB
    EXPORT Start
Start
        ; R0 = number
        ; R1 = mask
        ; R2 = counter of ones (Output of the program)
        ; R3 = loop counter
        ; R4 = AND result

        ; Initialize registers.
        MOV r0, #34
        MOV r1, #1
        MOV r2, #0
        MOV r3, #0

LOOP    AND r4, r0, r1      ; r4 = r0 AND r1
        CMP r4, #0          ; if r4 == 0...
        BEQ INC             ; ...then jump to INC, otherwise continue to r2++
        ADD r2, r2, #1      ; r2++
INC     ADD r3, r3, #1
        LSL r1, r1, #1      ; r1 = r1 << 1
        CMP r3, #32         ; 32 bits = sizeof(int) * 8 bits per byte
        BLT LOOP            ; if( r3 < 32 ) goto LOOP; otherwise end program.
        END
```

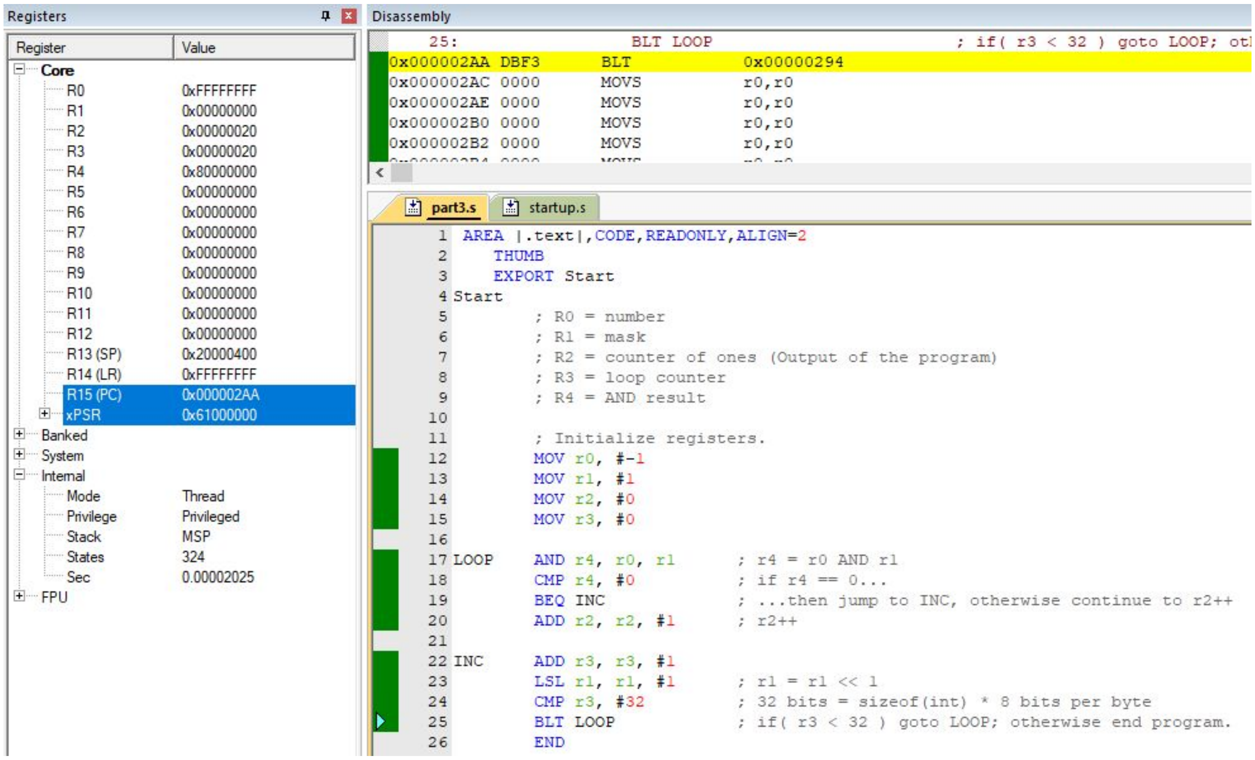
Initializing variable: R0 = 0x00000022 0r 34 (decimal)



Setting R0 = 34, the program runs 20 times (32 decimal) the computed number of 1's in 34(decimal) 0r 0x22 was 2 stored in R2.



Setting R0 = -1, the program runs 20 times (32 decimal) the computed number of 1’s in -1(decimal) 0r 0xF was 20 stored in R2.



Conclusion

This lab has successfully introduced me to Keil MDK integrated development environment. I was able to create new projects, debug code and implement new algorithm that counter the number 1’s in a 32-bit number in ARM assembly language.

Bibliography

Badr: Explanation
Tutorial: https://youtu.be/NwyPuKM1qvw