CPE 325: Intro to Embedded Computer System

Lab010

Software Reverse Engineering

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Introduction

This lab covers how to use different utilities to reverse engineer different types of software. Here we are reversing a .out and .txt file to see what these programs do. The purpose of the .out file is to reverse the usernames and passwords based on command line executables such as readelf.exe which summarizes the content in the .out file. The second .txt file is used to reverse hex data and figure out how the code works based on using similar utilities such as Naken.

Theory

Theory Discussed in the lab demo video.

Results & Observation

-- 1 --

- Do you think Figure 14 belongs to the same microcontroller as in Figure 13?

i. I would say that these devices are different simply due to the starting addresses of the different section headers. For example, figure 13 has the .data section at address 2400 and figure 14 the same section starts at address 1100.

- Where do you find this information about register addresses?

i. To find information about register addresses, you need to look up the msp430 .cmd file under:

D:\CCS\CCS10.1.0.00010_win64\ccs\ccs_base\msp430\include\lnk_msp430f5529.cmd <- This will vary, find where you CCS is installed. Then you need to ctrl+f to find the address. Note that the device you are on the registers will change.

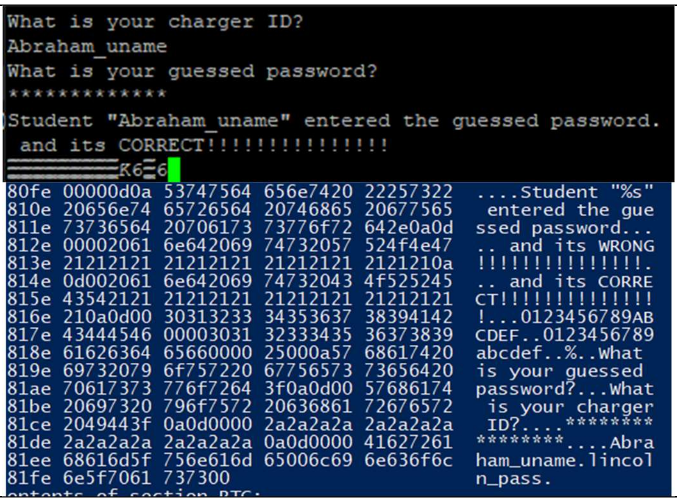
- Similarly, the next instruction ANDs content of 0x0223 with 127. Can you guess what this statement does?

i. This command **ands** the last bits of 0x0223 (most likely the port of the LED) with #127 to most likely turn the LED on port 0x0223 off. In the .cmd file 0x0223 is PBOUT_H.

- The next instruction moves 0x4432 to R0 (PC). The means the PC points to 0x4432. Where command is executed after this?

- The command **xor.b #1, &0x0202 ;0xff80** will be executed. This toggles the other LED. So this code when one LED turns off, the other one is toggled. 0x0202 is PAOUT.

-- 2 --



```
What is your charger ID?
Abraham_uname
What is your guessed password?
*************
Student "Abraham_uname" entered the guessed password.
 and its CORRECT!!!!!!!!!!!!!!!
K6 6
80fe 00000d0a 53747564 656e7420 22257322  ....Student "%s"
810e 20656e74 65726564 20746865 20677565   entered the gue
811e 73736564 20706173 73776f72 642e0a0d  ssed password...
812e 00002061 6e642069 74732057 524f4e47  .. and its WRONG
813e 21212121 21212121 21212121 2121210a  !!!!!!!!!!!!!!!.
814e 0d002061 6e642069 74732043 4f525245  .. and its CORRE
815e 43542121 21212121 21212121 21212121  CT!!!!!!!!!!!!!!
816e 210a0d00 30313233 34353637 38394142  !...0123456789AB
817e 43444546 00003031 32333435 36373839  CDEF..0123456789
818e 61626364 65660000 25000a57 68617420  abcdef..%..What
819e 69732079 6f757220 67756573 73656420  is your guessed
81ae 70617373 776f7264 3f0a0d00 57686174  password?...What
81be 20697320 796f7572 20636861 72676572   is your charger
81ce 2049443f 0a0d0000 2a2a2a2a 2a2a2a2a   ID?....********
81de 2a2a2a2a 2a2a2a2a 0a0d0000 41627261  ********....Abra
81ee 68616d5f 756e616d 65006c69 6e636f6c  ham_uname.lincol
81fe 6e5f7061 737300                      n_pass.
```

Username: Abraham_uname | Password: lincoln_pass

Command to run: .**msp430-elf-objdump.exe -s crack_me.out**

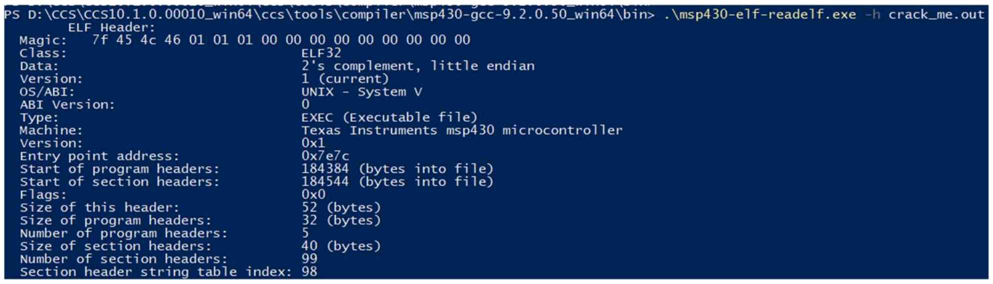
- This command will output all of the different sections and their data in strings and in hex along with their addresses.

--- 3 ---

a. What is the magic number used? [1 pts] **b**. What is the class of this .out file? [1 pts] **c**. What machine was this file built for? [1 pts] **d**. What is the size of the header? [1 pts] **e**. How many section headers are there? [6 pts]

- Run with **.\msp430-elf-readelf.exe -h crack_me.out** in Windows Powershell.

a. 7f 45 4c 46 01 01 01 00 00 00 00 00 00 00 00 00
b. ELF32
c. Texas Instruments msp430 microcontroller
d. 52 (bytes)
e. 99 Section headers.
f. Command line source:



```
PS D:\CCS\CCS10.1.0.00010_win64\ccs\tools\compiler\msp430-gcc-9.2.0.50_win64\bin> .\msp430-elf-readelf.exe -h crack_me.out
        ELF Header:
  Magic:   7f 45 4c 46 01 01 01 00 00 00 00 00 00 00 00 00
  Class:                             ELF32
  Data:                              2's complement, little endian
  Version:                           1 (current)
  OS/ABI:                            UNIX - System V
  ABI Version:                       0
  Type:                              EXEC (Executable file)
  Machine:                           Texas Instruments msp430 microcontroller
  Version:                           0x1
  Entry point address:               0x7e7c
  Start of program headers:          184384 (bytes into file)
  Start of section headers:          184544 (bytes into file)
  Flags:                             0x0
  Size of this header:               52 (bytes)
  Size of program headers:           32 (bytes)
  Number of program headers:         5
  Size of section headers:           40 (bytes)
  Number of section headers:         99
  Section header string table index: 98
```

-- 4 --

a. **Flasher output [10 pts]:**

```
PS D:\CCS\CCS10.1.0.00010_win64\ccs\tools\compiler\msp430-gcc-9.2.0.50_win64\bin>
D:\CCS\Flasher\MSP430Flasher.exe -n MSP430F5529 -w reverse_me.txt -v -z [Vcc]
* -----/|-------------------------------------------------------------------- *
*    / |__                                                   *
*   /_  /   MSP Flasher v1.3.20                              *
*     | /                                                    *
* -----|/-------------------------------------------------------------------- *
*
* Evaluating triggers...done
* Checking for available FET debuggers:
* Found USB FET @ COM3 <- Selected
* Initializing interface @ COM3...done
* Checking firmware compatibility:
* FET firmware is up to date.
* Reading FW version...
* Debugger does not support target voltages other than 3000 mV!
* Setting VCC to 3000 mV...done
* Accessing device...done
* Reading device information...done
* Loading file into device...done
* Verifying memory (reverse_me.txt)...done
*
* ----------------------------------------------------------------------------
* Arguments   : -n MSP430F5529 -w reverse_me.txt -v -z [Vcc]
* ----------------------------------------------------------------------------
* Driver      : loaded
* Dll Version : 31400000
* FwVersion   : 31200000
* Interface   : TIUSB
* HwVersion   : E 3.0
* JTAG Mode   : AUTO
* Device      : MSP430F5529
* EEM         : Level 7, ClockCntrl 2
* Erase Mode  : ERASE_ALL
* Prog.File   : reverse_me.txt
* Verified    : TRUE
* BSL Unlock  : FALSE
* InfoA Access: FALSE
* VCC ON      : 3000 mV
* ----------------------------------------------------------------------------
* Starting target code execution...done
* Disconnecting from device...done
*
* ----------------------------------------------------------------------------
* Driver      : closed (No error)
* ----------------------------------------------------------------------------
*/
PS D:\CCS\CCS10.1.0.00010_win64\ccs\tools\compiler\msp430-gcc-9.2.0.50_win64\bin>
```

b. **Guess from observation on the board what the program does? [5 pts]**
   i. This code blinks both LED’s infinitely when you press switch 1 (Port 2.1 that is).

c. **Using the naken utility and the steps shown in Section 5.2 of the tutorial, reverse engineer the hex file to assembly code. [5 pts]**

```
            PS D:\CCS\CCS10.1.0.00010_win64\ccs\tools\compiler\msp430-gcc-
            9.2.0.50_win64\bin> D:\CCS\Flasher\MSP430Flasher.exe -r [reverse_me.txt, MAIN]
            * -----/|--------------------------------------------------------------- *
            *     / |__                                                    *
            *    /_  /   MSP Flasher v1.3.20                                        *
            *      | /                                                   *
            * -----|/--------------------------------------------------------------- *
            *
            * Evaluating triggers...done
            * Checking for available FET debuggers:
            * Found USB FET @ COM3 <- Selected
            * Initializing interface @ COM3...done
            * Checking firmware compatibility:
            * FET firmware is up to date.
            * Reading FW version...done
            * Setting VCC to 3000 mV...done
            * Accessing device...done
            * Reading device information...done
            * Dumping memory from MAIN into reverse_me.txt...done
            *
            * -----------------------------------------------------------------------
            * Arguments   : -r [reverse_me.txt MAIN]
            * -----------------------------------------------------------------------
            * Driver      : loaded
            * Dll Version : 31400000
            * FwVersion   : 31200000
            * Interface   : TIUSB
            * HwVersion   : E 3.0
            * JTAG Mode   : AUTO
            * Device      : MSP430F5529
            * EEM         : Level 7, ClockCntrl 2
            * Read File   : reverse_me.txt (memory segment = MAIN)
            * VCC OFF
            * -----------------------------------------------------------------------
            * Powering down...done
            * Disconnecting from device...done
            *
            * -----------------------------------------------------------------------
            * Driver      : closed (No error)
            * -----------------------------------------------------------------------
            */
 PS D:\CCS\CCS10.1.0.00010_win64\ccs\tools\compiler\msp430-gcc-9.2.0.50_win64\bin>
```

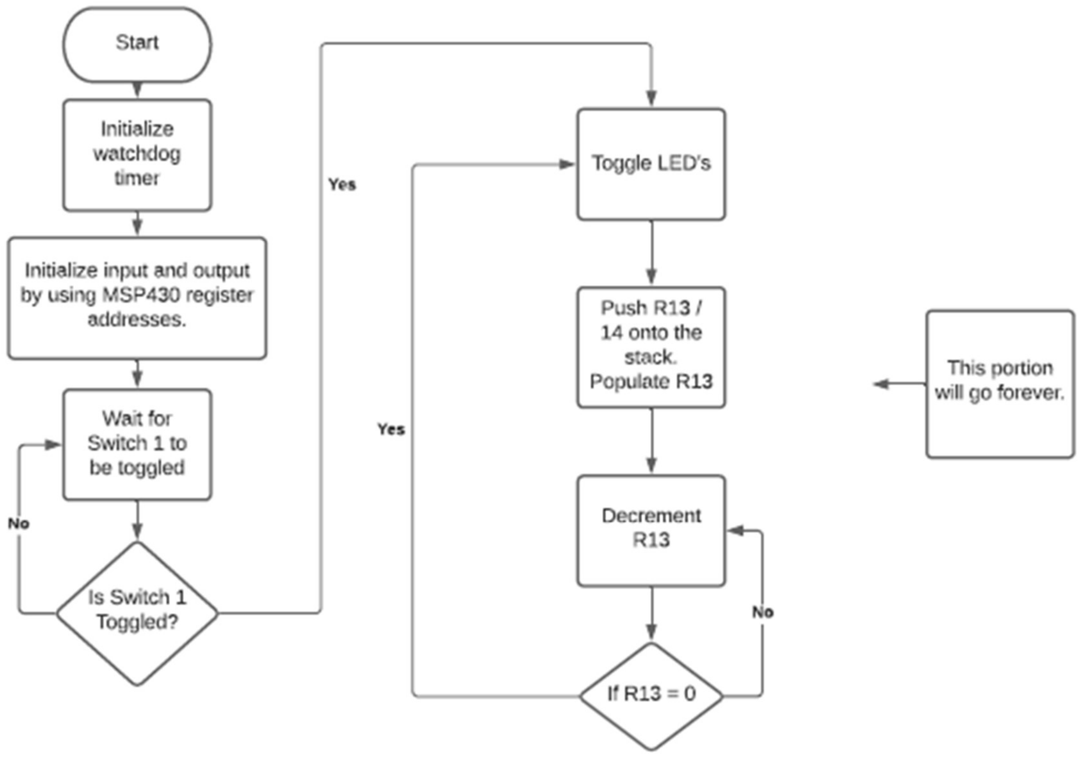
d. **Comment on each line of the assembly code generated from Q4c above to describe what each line is doing. [20 pts]**

```
Addr    Opcode Instruction                          Cycles
------- ------ ----------------------------------   ------
0x4400: 0x40b2 mov.w #0x5a80, &0x015c               5      //  Setting the watchdog timer
0x4402: 0x5a80
0x4404: 0x015c
0x4406: 0xd3d2 bis.b #1, &0x0204                    4      //  Setting PADIR
0x4408: 0x0204
0x440a: 0xd0f2 bis.b #0x80, &0x0225                 5      //  Setting PBDIR_H
0x440c: 0x0080
0x440e: 0x0225
0x4410: 0xc3e2 bic.b #2, &0x0204                    4      //  Clearing PADIR
0x4412: 0x0204
0x4414: 0xd3e2 bis.b #2, &0x0202                    4      //  Setting output direction P2.2 for PAOUT
0x4416: 0x0202
0x4418: 0xd3e2 bis.b #2, &0x0206                    4      //  Setting PAREN
0x441a: 0x0206
0x441c: 0xc3e2 bic.b #2, &0x0205                    4      //  Clearing PADIR_H
0x441e: 0x0205
0x4420: 0xd3e2 bis.b #2, &0x0203                    4      //  Setting PAOUT_H
0x4422: 0x0203
0x4424: 0xd3e2 bis.b #2, &0x0207                    4      //  Setting PAREN_H
0x4426: 0x0207
// What's about to happen below is the auto generation waiting for an input, but it does it I think 3 times. As in it waits for input 3 times, maybe debouncing? Not sure.
0x4428: 0xb3e2 bit.b #2, &0x0200                    4      //  Anding with PAIN, a test. Most likely for the button press.
0x442a: 0x0200
0x442c: 0x23fd jne 0x4428  (offset: -6)             2      //  And then if the switch has not been pressed, wait for the button to be pressed.
0x442e: 0x120d push.w r13                           3      //  If the button is pressed, push R13 onto the stack
0x4430: 0x403d mov.w #0x031d, r13                   2      //  Populate a large value
0x4432: 0x031d
0x4434: 0x831d sub.w #1, r13                        1      //  Sub R13
0x4436: 0x23fe jne 0x4434  (offset: -4)             2      //  Loop until 0
0x4438: 0x413d pop.w r13   --  mov.w @SP+, r13      2      //  Then pop R13
0x443a: 0x3c00 jmp 0x443c  (offset: 0)              2      //  And jump to 443c, which is next line? This is funny how it generates.
0x443c: 0xb3e2 bit.b #2, &0x0200                    4      //  Same thing as 0x4428. It waits for a button to be pressed or some tinput.
0x443e: 0x0200
0x4440: 0x23f3 jne 0x4428  (offset: -26)            2      //  If it is not set jump to 4428 to restart (loop).
0x4442: 0xb3e2 bit.b #2, &0x0201                    4      //  Test the input high value
0x4444: 0x0201
0x4446: 0x23fd jne 0x4442  (offset: -6)             2      //  If it is not set go back to 4442 ti wait for the high value to be set.
0x4448: 0x120d push.w r13                           3      //  Push r13
0x444a: 0x403d mov.w #0x031d, r13                   2      //  Populate a value
0x444c: 0x031d
0x444e: 0x831d sub.w #1, r13                        1      //  Sub 1
0x4450: 0x23fe jne 0x444e  (offset: -4)             2      //  Until 0, loop.
0x4452: 0x413d pop.w r13   --  mov.w @SP+, r13      2      //  Pop R13 and push it onto the stack.
0x4454: 0x3c00 jmp 0x4456  (offset: 0)              2      //  Jump to next line lol
0x4456: 0xb3e2 bit.b #2, &0x0201                    4      //  Test the high state of the input again
0x4458: 0x0201
0x445a: 0x23f3 jne 0x4442  (offset: -26)            2      //  The following code below is a loop to toggle the LED's by decrementing
0x445c: 0xe3d2 xor.b #1, &0x0202                    4      //  the register values and then toggling when they're 0.
0x445e: 0x0202
0x4460: 0xe0f2 xor.b #0x80, &0x0223                 5      //  Toggle the LED
0x4462: 0x0080
0x4464: 0x0223
0x4466: 0x120d push.w r13                           3      //  Push R13 and R14 onto the stack.
0x4468: 0x120e push.w r14                           3      //
0x446a: 0x403d mov.w #0x2844, r13                   2      //  Move 2844 into R13 to reset its value.
0x446c: 0x2844
0x446e: 0x431e mov.w #1, r14                        1      //  Move #1 into register R14
0x4470: 0x831d sub.w #1, r13                        1      //  Take 1 off of register R13
0x4472: 0x730e subc.w #0, r14                       1      //  Subtract with carray off of R14
0x4474: 0x23fd jne 0x4470  (offset: -6)             2      //  If the Z flag is not set, keep decrementing.
0x4476: 0x930d cmp.w #0, r13                        1      //  Compare 0 to R13.
0x4478: 0x23fb jne 0x4470  (offset: -10)            2      //  If the Z flag is not set, keep decrementing
0x447a: 0x413e pop.w r14   --  mov.w @SP+, r14      2      //  If they are 0, pop R14 and R13 off of the stack
0x447c: 0x413d pop.w r13   --  mov.w @SP+, r13      2      //  Increment the stack pointer and put it into R13 and R14 presumably to restart.
0x447e: 0x3c00 jmp 0x4480  (offset: 0)              2      //  Jump to 4480? Weird...
0x4480: 0x4303 nop   --  mov.w #0, CG               1      //  No operation, move 0 into CG?
0x4482: 0x3fec jmp 0x445c  (offset: -40)            2      //  Jump to 445c.
0x4484: 0x4303 nop   --  mov.w #0, CG               1      //  Move 0 into CG?
0x4486: 0x4031 mov.w #0x4400, SP                    2      //  Go back to start of program.
0x4488: 0x4400
0x448a: 0x12b0 call #0x44a0                         5      //  Weird... Just goes to next line.
0x448c: 0x44a0
0x448e: 0x430c mov.w #0, r12                        1      //  Move 0 into R12
0x4490: 0x12b0 call #0x4400                         5      //  Restart program
0x4492: 0x4400
0x4494: 0x431c mov.w #1, r12                        1      //  Move 1 into R12
0x4496: 0x12b0 call #0x449a                         5      //  Goes to next line...
0x4498: 0x449a
// Maybe what's going on here is the program is just infinite looping as an interrupt. It's a little obscure.
0x449a: 0x4303 nop   --  mov.w #0, CG               1      //  No operation
0x449c: 0x3fff jmp 0x449c  (offset: -2)             2      //  jmp to next line
0x449e: 0x4303 nop   --  mov.w #0, CG               1      //  no operation
0x44a0: 0x431c mov.w #1, r12                        1      //  Move 1 into r12, Already done though???
0x44a2: 0x4130 ret   --  mov.w @SP+, PC             3      //  Return from interrupt
0x44a4: 0xd032 bis.w #0x0010, SR                    2      //  Set 10 as the status register
0x44a6: 0x0010
```

```
0x44a8: 0x3ffd jmp 0x44a4  (offset: -6)        2       //  Jump to 44a4
0x44aa: 0x4303 nop   --  mov.w #0, CG          1       //  No operation wait for end of program
```

e. Describe what the program is doing in a neat flowchart. You can also write a paragraph to describe in addition to the flowchart. [10 pts]

Flow Charts:



Start
Initialize watchdog timer
Initialize input and output by using MSP430 register addresses.
Wait for Switch 1 to be toggled
Is Switch 1 Toggled?
No
Yes
Toggle LED's
Push R13 / 14 onto the stack. Populate R13
Decrement R13
If R13 = 0
No
Yes
This portion will go forever.

Essentially what this code does is it waits around for a user to press the switch on P2.1, and once it is pressed it infinitely blinks the LEDs at about 1 hz. The way it blinks them is by toggling every time register R13 goes from #2844-0, and then repopulates R13 with that same number to start the process all over again. From what I can see, it does this infinitely or until someone stops the program all together. It does not look like the switches do anything after they are pressed initially.

Observations:

Reverse engineering is very useful, and somewhat scary. It was relatively simple to find those usernames and passwords. I am not sure if these files had any robustness coded in but if not it makes you wonder how secure your passwords are.

Conclusion

This lab was by far my favorite, maybe I have a thing for reverse engineering. Anyways, I found this lab to be very informative and challenging enough to keep me interested. I did not face many issues other than just not reading the instructions fully, but at least I know how to do it now. Getting the LED's to blink was troubling but once I figured out I was not supposed to use CCS it all went smoothly. I also accidentally created code for the crack_me.out file and it was extremely long…

https://drive.google.com/file/d/1CyaT0a_dhD_gGi7_y66G_6Zomp3HXL1r/view?usp=sharin

Appendix

No code was specifically written for this assignment, but I will compile the different command line operations here.

msp430-elf-readelf.exe –help

msp430-elf-objdump.exe –help

msp430-elf-strings.exe –help

msp430-elf-readelf.exe -h crack_me.out

- Determines type of machine code, data representation, entry points and more.

msp430-elf-readelf.exe --section-headers crack_me.out

- Displays information about all sections.

msp430-elf-objdump.exe -h crack_me.out

- Not sure exactly what this one does.

msp430-elf-readelf.exe --symbols crack_me.out

- Displays all symbols in the ELF file.

msp430-elf-readelf.exe --program-headers crack_me.out

- Displays all segments that are loadable into the memory.

msp430-elf-objdump.exe -S crack_me.out

- Dumps source code together with disassembly.

msp430-elf-objdump.exe -d crack_me.out

- Does not assume that source code is present.