THE FLARE ON CHALLENGE SOLUTIONS: PART 1 OF 2

November 17, 2014 | by Richard Wartell, Mike Sikorski

In July, the FireEye Labs Advanced Reverse Engineering (FLARE) team created and released the first FLARE On Challenge to the community. A total of 7,140 people participated and showed off their skills, and 226 people completed the challenge. Everyone who finished the challenge received a challenge coin to commemorate their success.

The coveted challenge coin

We are releasing the challenge solutions to help those who didn't finish improve their skills. There are many different ways to complete each challenge, so we waited to see what solutions people devised. We found the following solutions posted online and recommend taking a look at these as well to see how the later challenges can be solved in different ways.

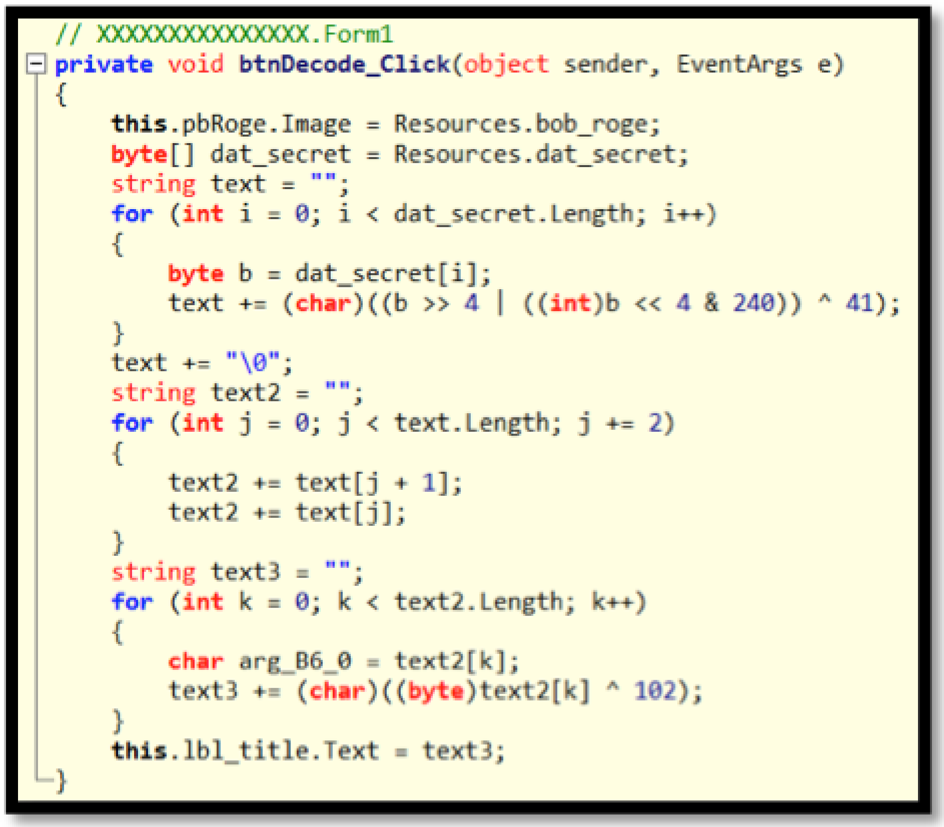
http://www.ghettoforensics.com/2014/09/a-walkthrough-for-flare-re-challenges.html

to find a key in the form of an email address that allows you unlock the next challenge. The archive of challenges have been posted to the challenge website.

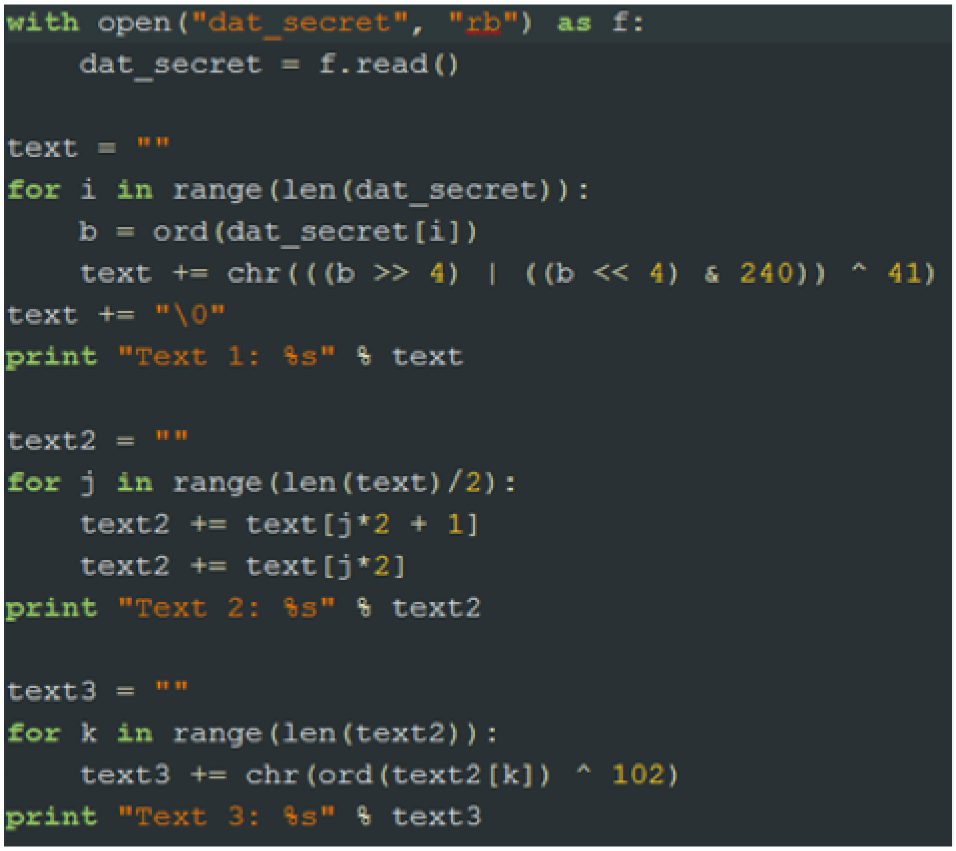
Stay tuned for Part 2 where we show two different and interesting ways of solving Challenge 6.

Challenge 1: Bob Doge

The first challenge starts out pretty easy. When we drop the binary into CFF Explorer (or equivalent PE tool), it informs us that we’re dealing with a PE 32-bit .NET Assembly, so we can run it in an x86 Windows VM and see what happens. A decode button appears to have two functions: transforming Bob Ross into Bob Doge, and converting the top label into some unprintable strings. We drop the binary into ILSpy (or equivalent .NET decompiler) to get an idea what this decode button is doing. The decompiled code is shown in the top of Figure 1.



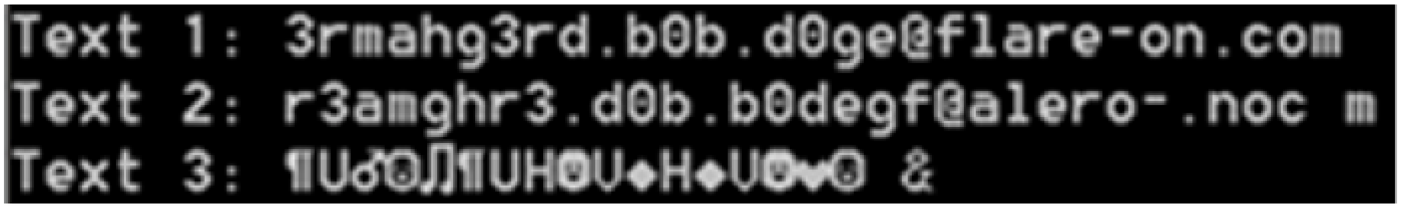
```
// XXXXXXXXXXXXXXX.Form1
private void btnDecode_Click(object sender, EventArgs e)
{
    this.pbRoge.Image = Resources.bob_roge;
    byte[] dat_secret = Resources.dat_secret;
    string text = "";
    for (int i = 0; i < dat_secret.Length; i++)
    {
        byte b = dat_secret[i];
        text += (char)((b >> 4 | ((int)b << 4 & 240)) ^ 41);
    }
    text += "\0";
    string text2 = "";
    for (int j = 0; j < text.Length; j += 2)
    {
        text2 += text[j + 1];
        text2 += text[j];
    }
    string text3 = "";
    for (int k = 0; k < text2.Length; k++)
    {
        char arg_B6_0 = text2[k];
        text3 += (char)((byte)text2[k] ^ 102);
    }
    this.lbl_title.Text = text3;
}
```



```
with open("dat_secret", "rb") as f:
    dat_secret = f.read()

text = ""
for i in range(len(dat_secret)):
    b = ord(dat_secret[i])
    text += chr(((b >> 4) | ((b << 4) & 240)) ^ 41)
text += "\0"
print "Text 1: %s" % text

text2 = ""
for j in range(len(text)/2):
    text2 += text[j*2 + 1]
    text2 += text[j*2]
print "Text 2: %s" % text2

text3 = ""
for k in range(len(text2)):
    text3 += chr(ord(text2[k]) ^ 102)
print "Text 3: %s" % text3
```

Figure 1: Decode button code in ILSpy (top) and re-implemented in Python (bottom)

The button changes the image to Bob Doge, and encodes a resource string twice and sets the label text to the result. If we save out the resource that is being manipulated, we can play around with it. The Python code in the right side of Figure 1 is the decode button re-implement to help us figure out what we are dealing with. When this Python code is run, the following is printed out showing the solution to Challenge 1 as “Text 1” in the output.



```
Text 1: 3rmahg3rd.b0b.d0ge@flare-on.com
Text 2: r3amghr3.d0b.b0degf@alero-.noc m
Text 3: ¶U♂☺♫¶UH☺U♦H♦U☺♥☺ &
```

Figure 2: Challenge 1 result

Challenge 2: Javascrap

The next challenge (to the bane of some of our players) is not a Windows PE file. Instead we have a version of

Why would a PNG image be loaded as a PHP script? When we open this image with an image viewer, the banner comes up so it is definitely an image. Since we know that the image is being loaded as a PHP script, we search for *php* inside of the image file and find the following:

```
19C0 AE 42 60 82 3C 3F 70 68 70 20 24 74 65 72 6D 73 .B`.<?php $terms
 19D0 3D 61 72 72 61 79 28 22 4D 22 2C 20 22 5A 22 2C =array("M", "Z",
 19E0 20 22 5D 22 2C 20 22 70 22 2C 20 22 5C 5C 22 2C "]", "p", "\\",
 19F0 20 22 77 22 2C 20 22 66 22 2C 20 22 31 22 2C 20 "w", "f", "1",
 1A00 22 76 22 2C 20 22 3C 22 2C 20 22 61 22 2C 20 22 "v", "<", "a", "
 1A10 51 22 2C 20 22 7A 22 2C 20 22 20 22 2C 20 22 73 Q", "z", " ", "s
...
```

Pulling this out of the image leaves us with:

```
<?php
 $terms=array("M", "Z", "]", "p", "\\", "w", "f", "1", "v",...
 $order=array(59, 71, 73, 13, 35, 10, 20, 81, 76, 10, 28, 63, 12,...
 $do_me="";
 for($i=0;$i<count($order);$i++)
 {
 $do_me=$do_me.$terms[$order[$i]];
}
 eval($do_me);
 ?>
```

So we have an array of characters, and then an array of indexes into the array of characters being used to build a string that gets evaluated. If we replace that *eval* with a call to *echo*, we can see the following strings in the display:

```
$_ = 'aWYoaXNzZXQoJF9QT1NUWyJcOTdcNDlcNDlcNjhceDRGXDg0XDExNlx4Nj
```

```
eval($___($__));
```

This reveals more obfuscation! Applying the same trick again results in the following lines of code:

```
$code=base64_decode($_);

eval($code);
```

So from this, we decide we should base64 decode the $_ string and, lo and behold, we have our key.

```
If(isset($_POST[\97\49\49\68\x4F\84\116\x68\97\x74\x74\x44\x4F\x54...

 {

 eval(base64_decode($_POST["\97\49\x31\68\x4F\x54\116\104\x61\116...

 }
```

This is a string that is made out of mixing hexadecimal and ordinals. By writing a quick decoder for this conversion we get *a11DOTthatDOTjava5crapATflareDASHonDOTcom*. We then replace "DOT", "AT", and "DASH" with the corresponding character and get the key: *a11.that.java5crap@flare-on.com*.

Challenge 3: Shellolololol

Challenge 3 is an x86 PE file. We drop the binary into IDA Pro to see what it shows us:

```
push   eax

 call   __getmainargs

 add     esp, 14h

 mov     eax, [ebp+var_24]

 push   eax

 mov     eax, [ebp+var_20]

 push   eax

 mov     eax, [ebp+var_1C]

 push   eax

 call   sub_401000
```

```
 push   eax

 call   exit
```

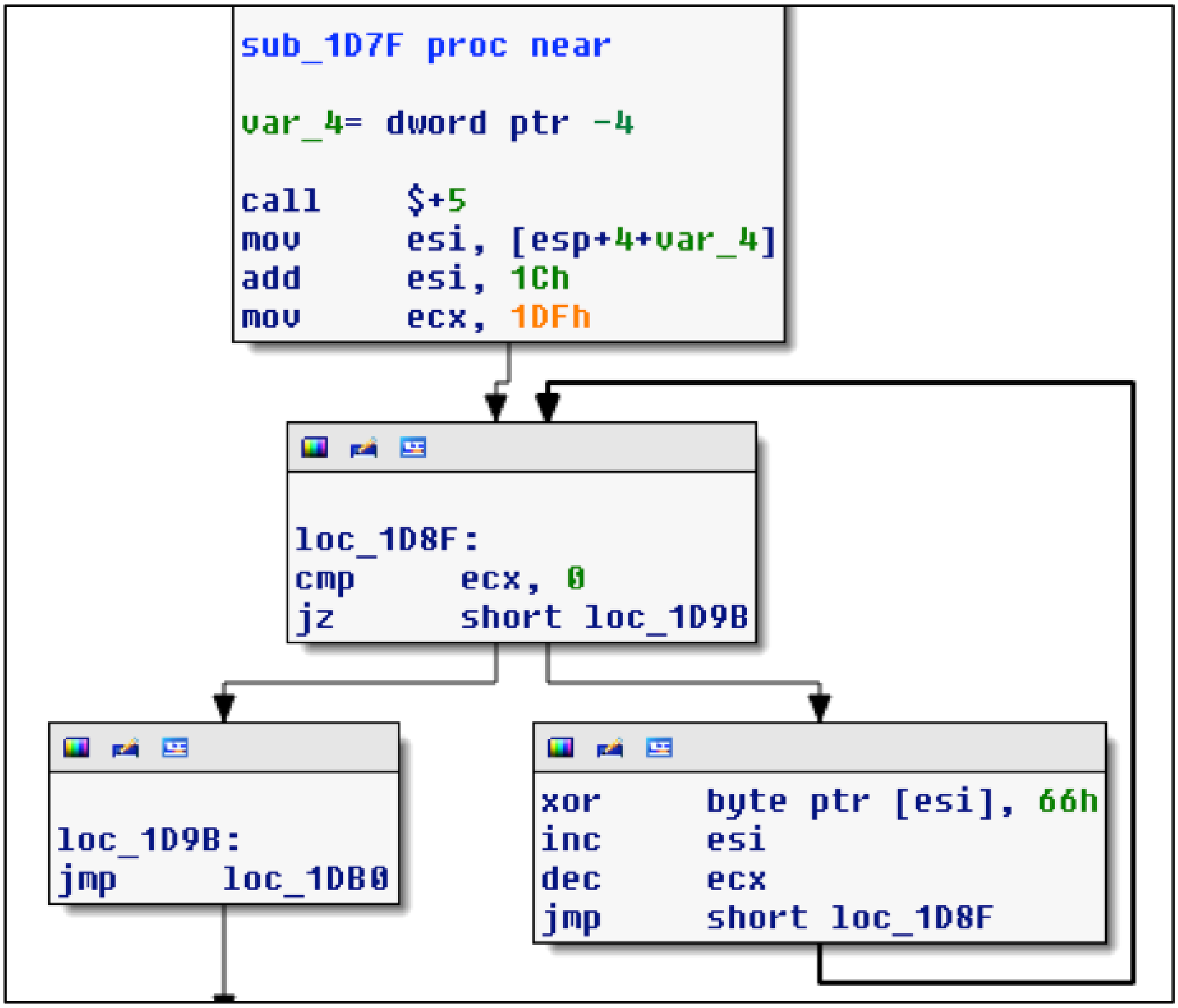
The function *sub_401000* looks interesting to us since all of the other functions called before it have symbols associated with them, and 0×401000 is the beginning of the code section, commonly where the beginning of any user-written code exists.

```
push   ebp
 mov     ebp, esp
 sub     esp, 204h
 nop
 mov     eax, 0E8h
 mov     [ebp+var_201], al
 mov     eax, 0
 mov     [ebp+var_200], al
 mov     eax, 0
 mov     [ebp+var_1FF], al
 mov     eax, 0
 mov     [ebp+var_1FE], al
 mov     eax, 0
 mov     [ebp+var_1FD], al
 mov     eax, 8Bh
```

After just a cursory look, we see single bytes being moved onto the stack one at a time. After we get past all of the bytes being moved onto the stack, we see the following:

```
lea     eax, [ebp+var_201]
 call   eax
 mov     eax, 0
 jmp   $+5
```

We set a breakpoint at the *call eax* above and let the code run to catch the program before it calls into the shellcode. Now we can dump the stack memory to a file and analyze it in IDA Pro as shown in Figure 3. All of the following analysis could be done in the debugger, but we decided to show the steps in IDA Pro.



```
sub_1D7F proc near

var_4= dword ptr -4

call    $+5
mov     esi, [esp+4+var_4]
add     esi, 1Ch
mov     ecx, 1DFh

loc_1D8F:
cmp     ecx, 0
jz      short loc_1D9B

loc_1D9B:
jmp     loc_1DB0

xor     byte ptr [esi], 66h
inc     esi
dec     ecx
jmp     short loc_1D8F
```

Figure 3: 0×66 decoding loop

Figure 3 shows a loop decoding everything after the *jmp* instruction by XORing each byte with 0×66. We decided to write a script to do the decoding for us rather than running it and dumping it in the debugger again.

import idaapi

 loc = 0x1DA0

When we run this script we get the following decoded string:

00001DA0 aAndSoItBegins db 'and so it begins',0

Additional code that has also been decoded, showing another decoding loop:

```
00001DB0          push   'su'
00001DB5          push   'ruas'
00001DBA          push   'apon'
00001DBF          mov    ebx, esp
00001DC1          call   $+5
00001DC6          mov    esi, [esp]
00001DC9          add    esi, 2Dh ; '-'
00001DCC          mov    ecx, esi
00001DCE          add    ecx, 18Ch
00001DD4          mov    eax, ebx
00001DD6          add    eax, 0Ah
00001DD9
00001DD9 loc_1DD9:
00001DD9          cmp    eax, ebx
00001DDB          jnz    short loc_1DE2
00001DDD          mov    ebx, esp
00001DDF          add    ebx, 4
00001DE2
00001DE2 loc_1DE2:
00001DE2          cmp    esi, ecx
00001DE4          jz     short loc_1DEE
00001DE6          mov    dl, [ebx]
```

```
00001DEB          inc    esi
00001DEC          jmp    short loc_1DD9
```

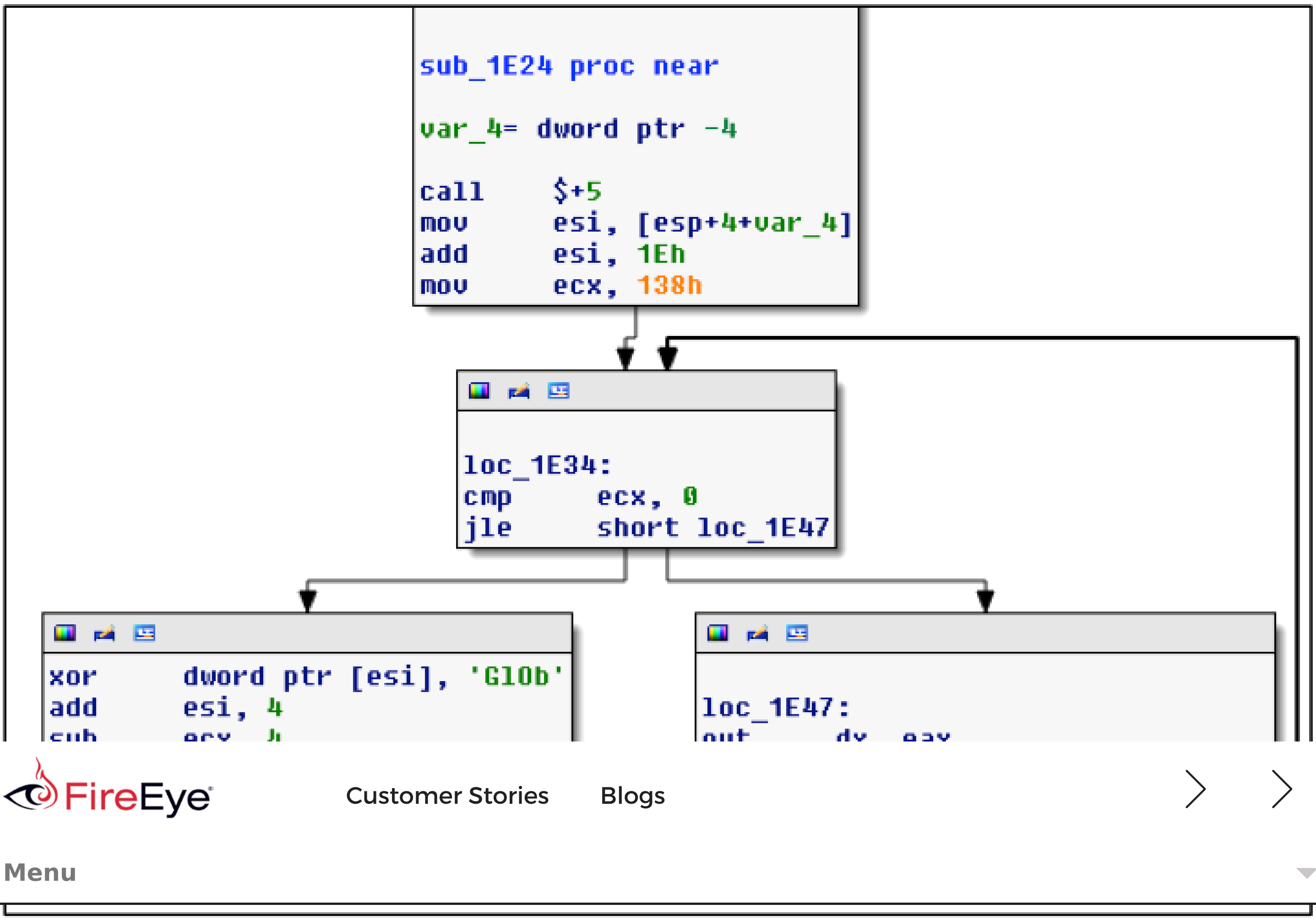
This time the encoding is a multi-byte XOR, so we write another script:

```
import idaapi

 loc = 0x1DF3

 key = “nopasaurus”

 for i in range(0x18C):

 idaapi.patch_byte(loc+i,idaapi.get_byte(loc+i)^ord(key[i%len(key)]))
```

Scripts like this are often needed when reversing malware to decode strings used by the program. After this script executes it seems we’ve gotten further because we have another string that has been decoded:

```
00001DF3 aGetReadyToGetN db 'get ready to get nop',27h,'ed so damn    hard in the paint
```

And following this we now have more code as shown in Figure 4.



```
sub_1E24 proc near

var_4= dword ptr -4

call    $+5
mov     esi, [esp+4+var_4]
add     esi, 1Eh
mov     ecx, 138h

loc_1E34:
cmp     ecx, 0
jle     short loc_1E47

xor     dword ptr [esi], 'GlOb'
add     esi, 4

loc_1E47:
```

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Figure 4: GlOb decoding loop

What a surprise: another deccoding loop. By now, we've gotten pretty decent at writing these scripts, so here's another one:

```
import idaapi

 loc = 0x1E47

 key = "bOlG"

 for i in range(0x138):

 idaapi.patch_byte(loc+i,idaapi.get_byte(loc+i)^ord(key[i%len(key)]))
```

After this one executes we have more code to look at. This is the last decoding step using the key of "*omg is it almost over?!?*" This time the script looks like:

```
import idaapi

 loc = 0x1EA9

 key = "omg is it almost over?!?"

 for i in range(0xD6):

 idaapi.patch_byte(loc+i,idaapi.get_byte(loc+i)^ord(key[i%len(key)]))
```

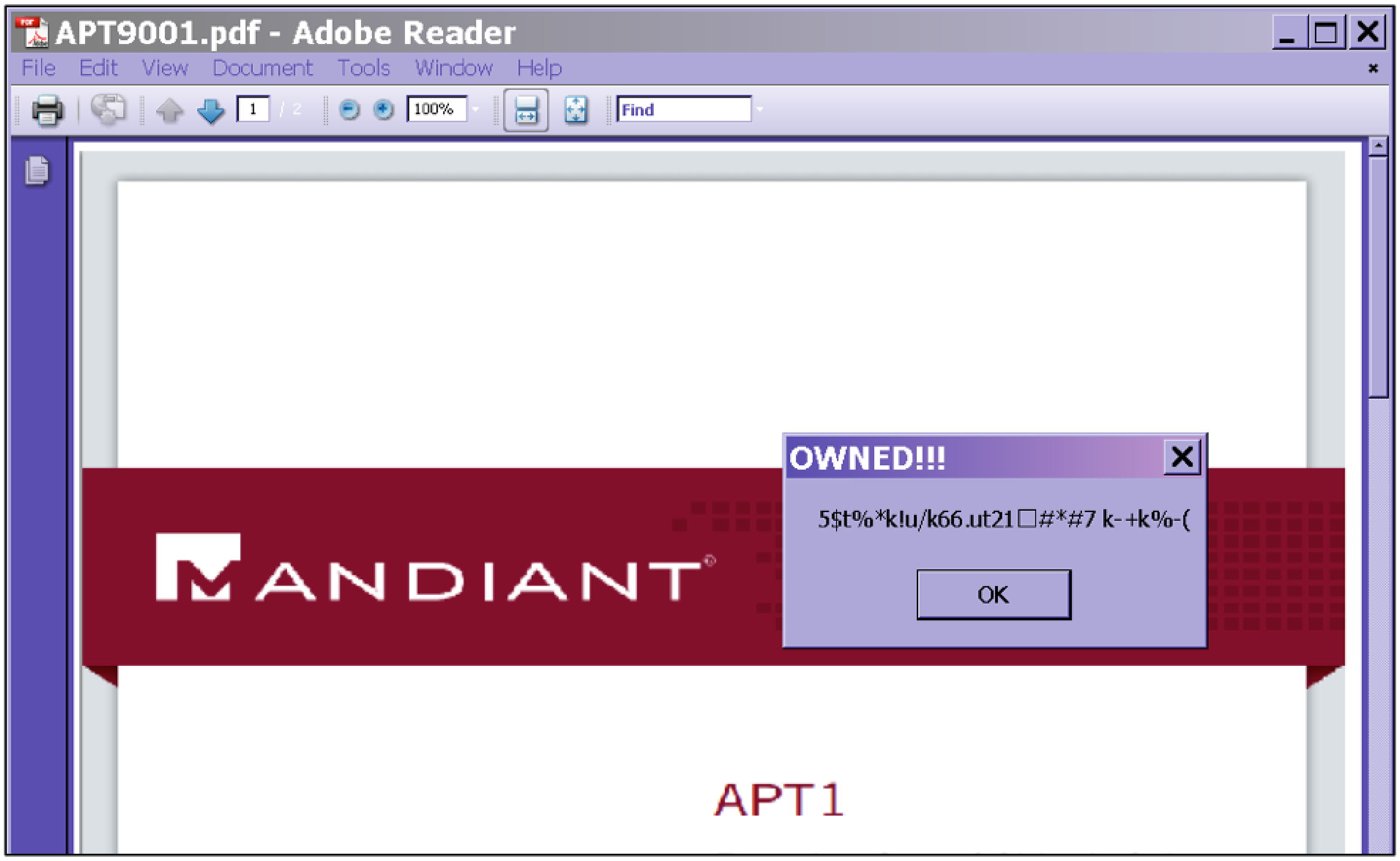
And we have our next key.

```
00001EA9 aSuch_5h3110101 db 'such.5h311010101@flare-on.com
```

We could have come to the same conclusion by stepping through the whole binary in a debugger. But we wanted to have a bit of fun in IDA Pro scripting!

Challenge 4: Sploitastic

Challenge 4 requires that we examine a PDF. Let's see what happens when we open this in an unpatched version of Adobe Reader that is highly exploitable, like 9.0 as shown in Figure 5.


APT9001.pdf - Adobe Reader
File Edit View Document Tools Window Help
100%
Find
MANDIANT
APT1

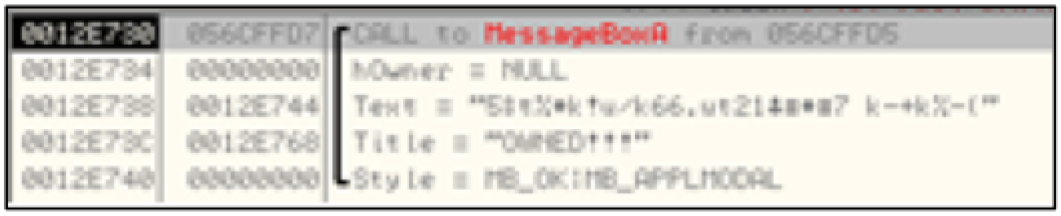
OWNED!!!

5$t%*k!u/k66.ut21□#*#7 k-+k%-(

OK

Figure 5: Malicious PDF

It looks like the malicious PDF popped open a message box, so we set a breakpoint on *MessageBoxA* and *MessageBoxW*. Figure 6 shows the arguments on the stack when this breakpoint hits.



```
0012E730  056CFFD7  CALL to MessageBoxA from 056CFFD5
0012E734  00000000  hOwner = NULL
0012E738  0012E744  Text = "5$t%*k!u/k66.ut21‡■*■7 k-+k%-("
0012E73C  0012E768  Title = "OWNED!!!"
0012E740  00000000  Style = MB_OK|MB_APPLMODAL
```

Figure 6: MessageBoxA arguments

From the strings that are on the stack, we know that we are in the correct call to *MessageBoxA*. So if we trace back to the address that made this call, we find the following shellcode block:

```
00000000 E8 00 00 00 00 8B 14 24 81 72 0B 16 A3 FB 32 68 .......$.r....2h
```

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```
00000040 D2 A3 98 37 81 72 47 82 8A 62 3B 68 EF A4 11 4B ...7.rG..b;h...K

00000050 81 72 53 D6 47 C0 CC 68 BE 69 A4 FF 81 72 5F A3 .rS.G..h.i...r_.
```

```
00000060 CA 54 31 68 D4 AB 65 52 8B CC 57 53 51 57 8B F1 .T1h..eR..WSQW..

00000070 89 F7 83 C7 1E 39 FE 7D 0B 81 36 42 45 45 46 83 .....9.}..6BEEF.

00000080 C6 04 EB F1 FF D0 68 65 73 73 01 8B DF 88 5C 24 ......hess....\$

00000090 03 68 50 72 6F 63 68 45 78 69 74 54 FF 74 24 40 .hProchExitT.t$@
```

Examining this in IDA shows the following:

```
00000359    call   $+5
0000035E    mov    edx, [esp]
00000361    xor    dword ptr [edx+0Bh], 32FBA316h
00000368    push   32BECE79h
0000036D    xor    dword ptr [edx+17h], 48CF45AEh
00000374    push   2BE12BC1h
00000379    xor    dword ptr [edx+23h], 0D29F3610h
00000380    push   0FFFA4471h
00000385    xor    dword ptr [edx+2Fh], 0CA9A9F7h
0000038C    push   60CFE984h
00000391    xor    dword ptr [edx+3Bh], 43A993BEh
00000398    push   3798A3D2h
0000039D    xor    dword ptr [edx+47h], 3B628A82h
000003A4    push   4B11A4EFh
000003A9    xor    dword ptr [edx+53h], 0CCC047D6h
000003B0    push   0FFA469BEh
000003B5    xor    dword ptr [edx+5Fh], 3154CAA3h
000003BC    push   5265ABD4h
```

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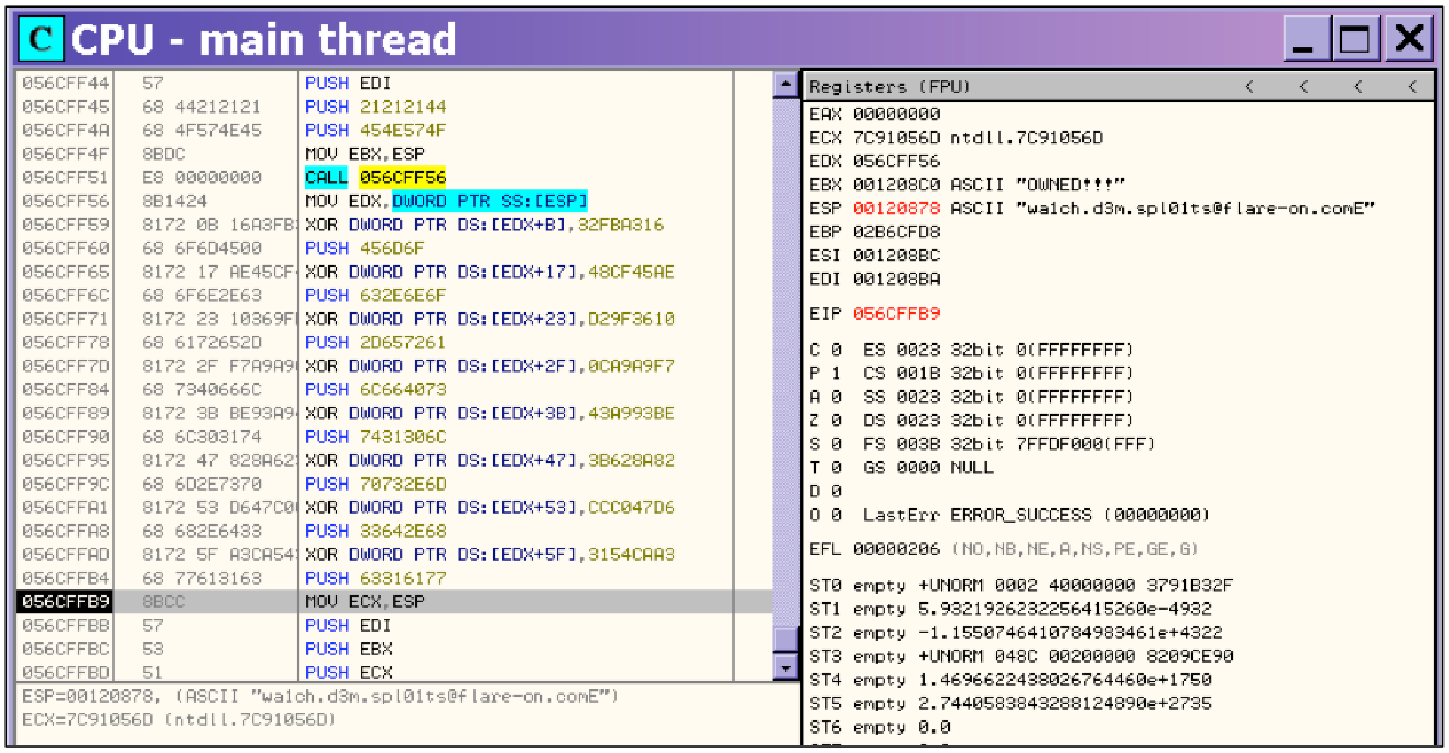
```
000003C4    push   ebx
000003C5    push   ecx
000003C6    push   edi
```

So it looks like we have strings that are being encoded on the stack in some way. Since our breakpoint hit after this code has already run, we can go back and force the debugger to execute this code again to see what is revealed on the stack.


CPU - main thread

```
056CFF44  57             PUSH EDI
056CFF45  68 44212121    PUSH 21212144
056CFF4A  68 4F574E45    PUSH 454E574F
056CFF4F  8BDC           MOV EBX,ESP
056CFF51  E8 00000000    CALL 056CFF56
056CFF56  8B1424         MOV EDX,DWORD PTR SS:[ESP]
056CFF59  8172 0B 16A3FB XOR DWORD PTR DS:[EDX+B],32FBA316
056CFF60  68 6F6D4500    PUSH 456D6F
056CFF65  8172 17 AE45CF XOR DWORD PTR DS:[EDX+17],48CF45AE
056CFF6C  68 6F6E2E63    PUSH 632E6E6F
056CFF71  8172 23 10369F XOR DWORD PTR DS:[EDX+23],D29F3610
056CFF78  68 6172652D    PUSH 2D657261
056CFF7D  8172 2F F7A9A9 XOR DWORD PTR DS:[EDX+2F],0CA9A9F7
056CFF84  68 7340666C    PUSH 6C664073
056CFF89  8172 3B BE93A9 XOR DWORD PTR DS:[EDX+3B],43A993BE
056CFF90  68 6C303174    PUSH 7431306C
056CFF95  8172 47 828A62 XOR DWORD PTR DS:[EDX+47],3B628A82
056CFF9C  68 6D2E7370    PUSH 70732E6D
056CFFA1  8172 53 D647C0 XOR DWORD PTR DS:[EDX+53],CCC047D6
056CFFA8  68 682E6433    PUSH 33642E68
056CFFAD  8172 5F A3CA54 XOR DWORD PTR DS:[EDX+5F],3154CAA3
056CFFB4  68 77613163    PUSH 63316177
056CFFB9  8BCC           MOV ECX,ESP
056CFFBB  57             PUSH EDI
056CFFBC  53             PUSH EBX
056CFFBD  51             PUSH ECX
ESP=00120878, (ASCII "wa1ch.d3m.spl01ts@flare-on.comE")
ECX=7C91056D (ntdll.7C91056D)
```

```
Registers (FPU)
EAX 00000000
ECX 7C91056D ntdll.7C91056D
EDX 056CFF56
EBX 001208C0 ASCII "OWNED!!!"
ESP 00120878 ASCII "wa1ch.d3m.spl01ts@flare-on.comE"
EBP 02B6CFD8
ESI 001208BC
EDI 001208BA

EIP 056CFFB9

C 0  ES 0023 32bit 0(FFFFFFFF)
P 1  CS 001B 32bit 0(FFFFFFFF)
A 0  SS 0023 32bit 0(FFFFFFFF)
Z 0  DS 0023 32bit 0(FFFFFFFF)
S 0  FS 003B 32bit 7FFDF000(FFF)
T 0  GS 0000 NULL
D 0
O 0  LastErr ERROR_SUCCESS (00000000)

EFL 00000206 (NO,NB,NE,A,NS,PE,GE,G)

ST0 empty +UNORM 0002 40000000 3791B32F
ST1 empty 5.9321926232256415260e-4932
ST2 empty -1.1550746410784983461e+4322
ST3 empty +UNORM 048C 00200000 8209CE90
ST4 empty 1.4696622438026764460e+1750
ST5 empty 2.7440583843288124890e+2735
ST6 empty 0.0
```

Figure 7: Breakpoint to reveal the key

And there it is in Figure 7 as referenced by ESP. So we've found the next key.

Challenge 5: 5get_it

Challenge 5 is a Windows PE DLL, so we drop it into IDA Pro and started jumping around the functions to see if anything interesting pops out. After bouncing around a bit, we stumble upon this huge function starting at *0×10001240*. This function takes no arguments and appears to build a giant stack string. Since it takes no arguments, we tried setting eip to the entry of the function in a debugger and running it, which reveals the image shown in Figure 8.

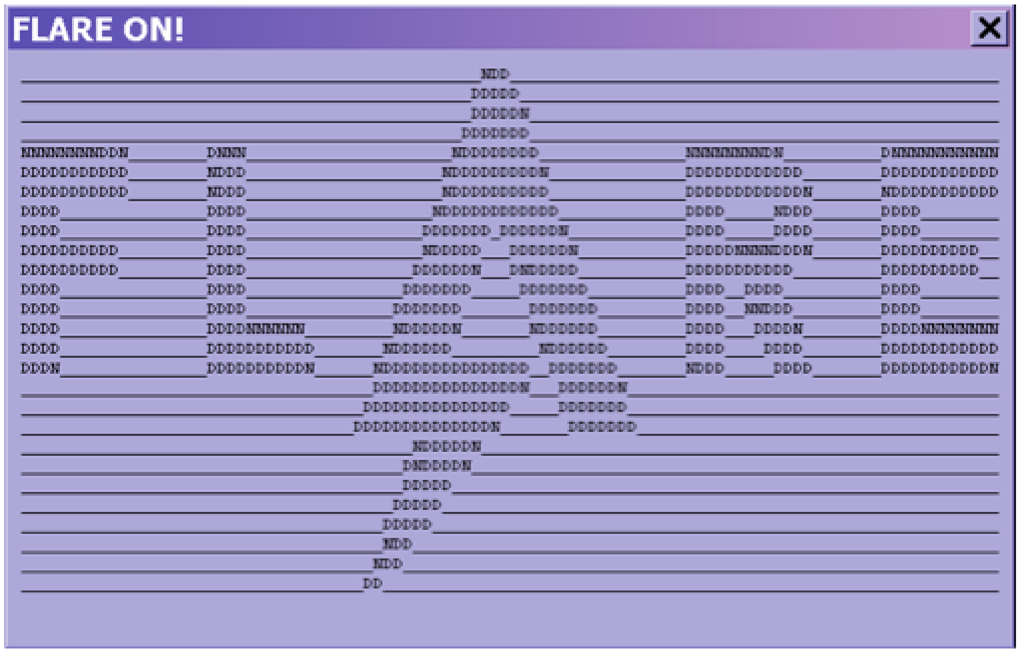
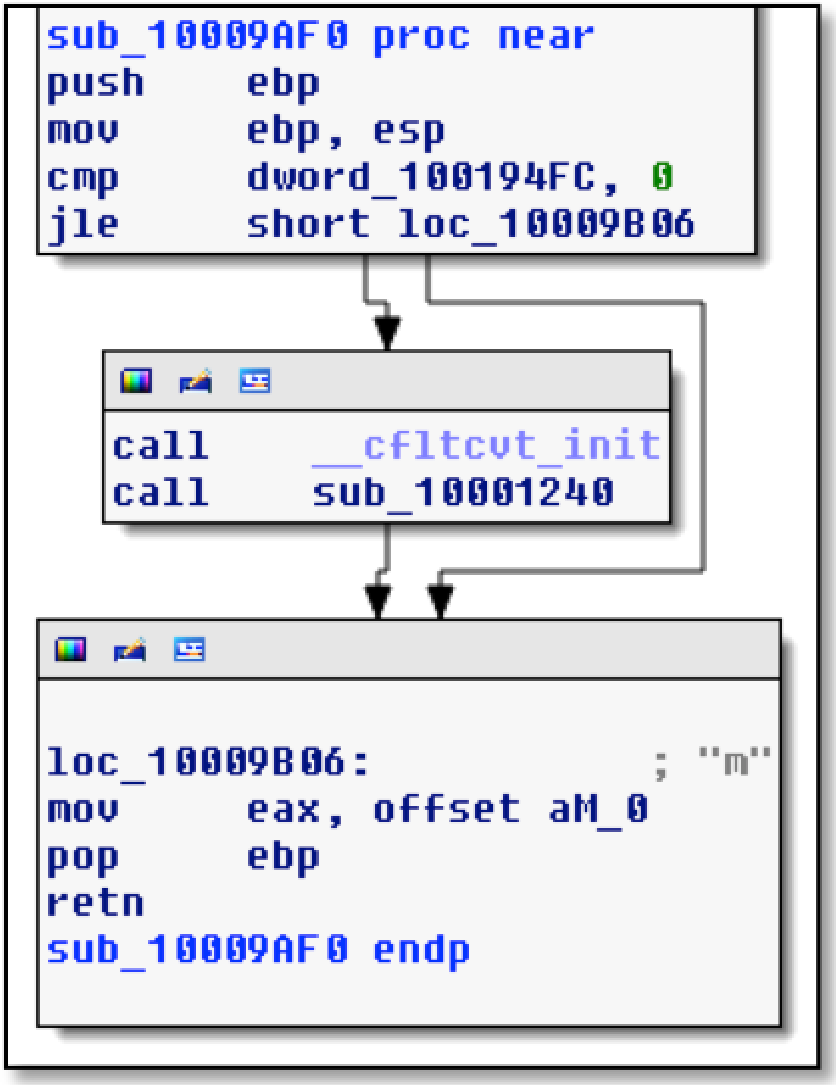


Figure 8: Challenge 5 message box

Interesting, but it doesn't seem to contain the key. Checking the cross references to this function leads us to the function shown in Figure 9.



```
sub_10009AF0 proc near
push    ebp
mov     ebp, esp
cmp     dword_100194FC, 0
jle     short loc_10009B06

call    __cfltcvt_init
call    sub_10001240

loc_10009B06:                ; "m"
mov     eax, offset aM_0
pop     ebp
retn
sub_10009AF0 endp
```

Figure 9: Subroutine that calls the message box function

That doesn't tell us much by itself. We see this function checks a global variable to determine whether to open a *MessageBox*, and then the letter "m" is returned. Cross references to this function show a function whose graph is shown in Figure 10.

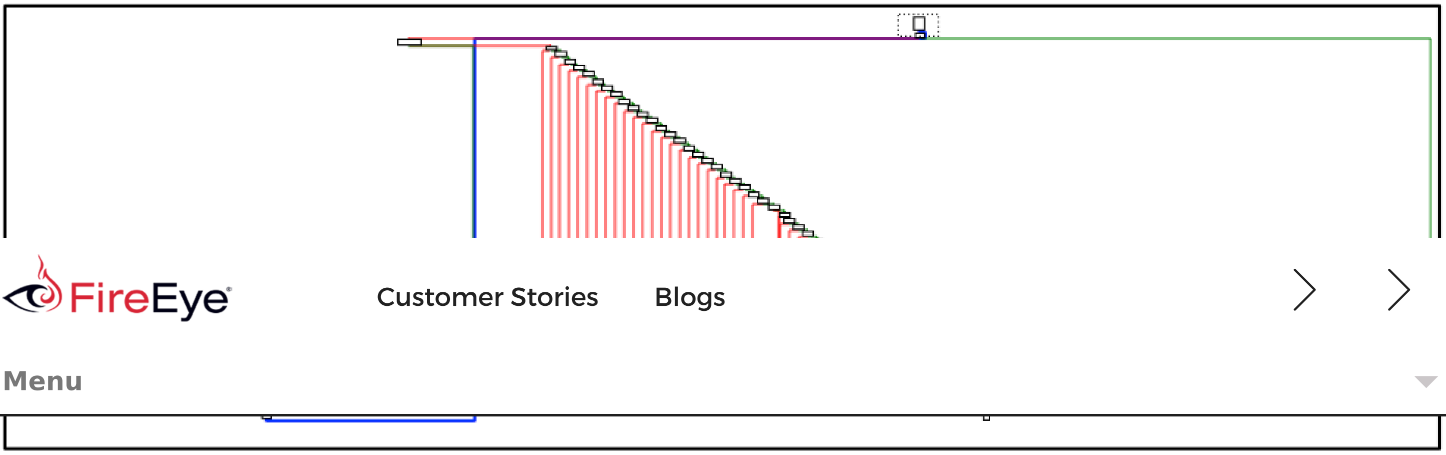
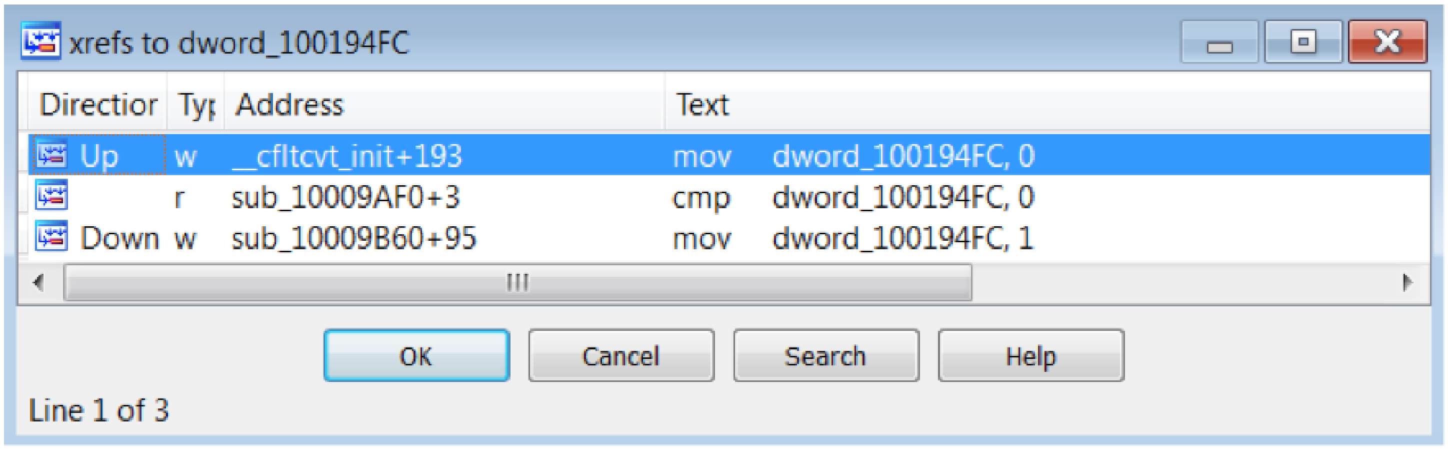


Figure 10: "if" statement control function

This function is huge and contains some sort of if/else statement. At the top of it we see the following bit of code.

```
10009ECD      movsx   edx, [ebp+var_4]
 10009ED1      cmp     edx, 0DEh
 10009ED7      jg      loc_1000A3A4
 10009EDD     movsx   eax, [ebp+var_4]
 10009EE1      push   eax
 10009EE2      call   ds:GetAsyncKeyState
 10009EE8      movsx   ecx, ax
 10009EEB      cmp     ecx, 0FFFF8001h
 10009EF1      jnz     loc_1000A39F
```

An if/else statement based on *GetAsyncKeyState* sounds like we are dealing with a keylogger. It appears that pressing the "m" key causes a specific global variable to be set, which later causes the program to pop up a message box. So what is this global variable, *dword_100194FC*, and what sets it? Cross references to this are shown in Figure 11.


xrefs to dword_100194FC

Directior	Typ	Address	Text
Up	w	__cfltcvt_init+193	mov dword_100194FC, 0
	r	sub_10009AF0+3	cmp dword_100194FC, 0
Down	w	sub_10009B60+95	mov dword_100194FC, 1

Figure 11: Cross references to dword_100184FC

The global variable is initialized to zero, and then some other function sets it to one. The function that sets it is *sub_10009B60* and is shown in Figure 12.

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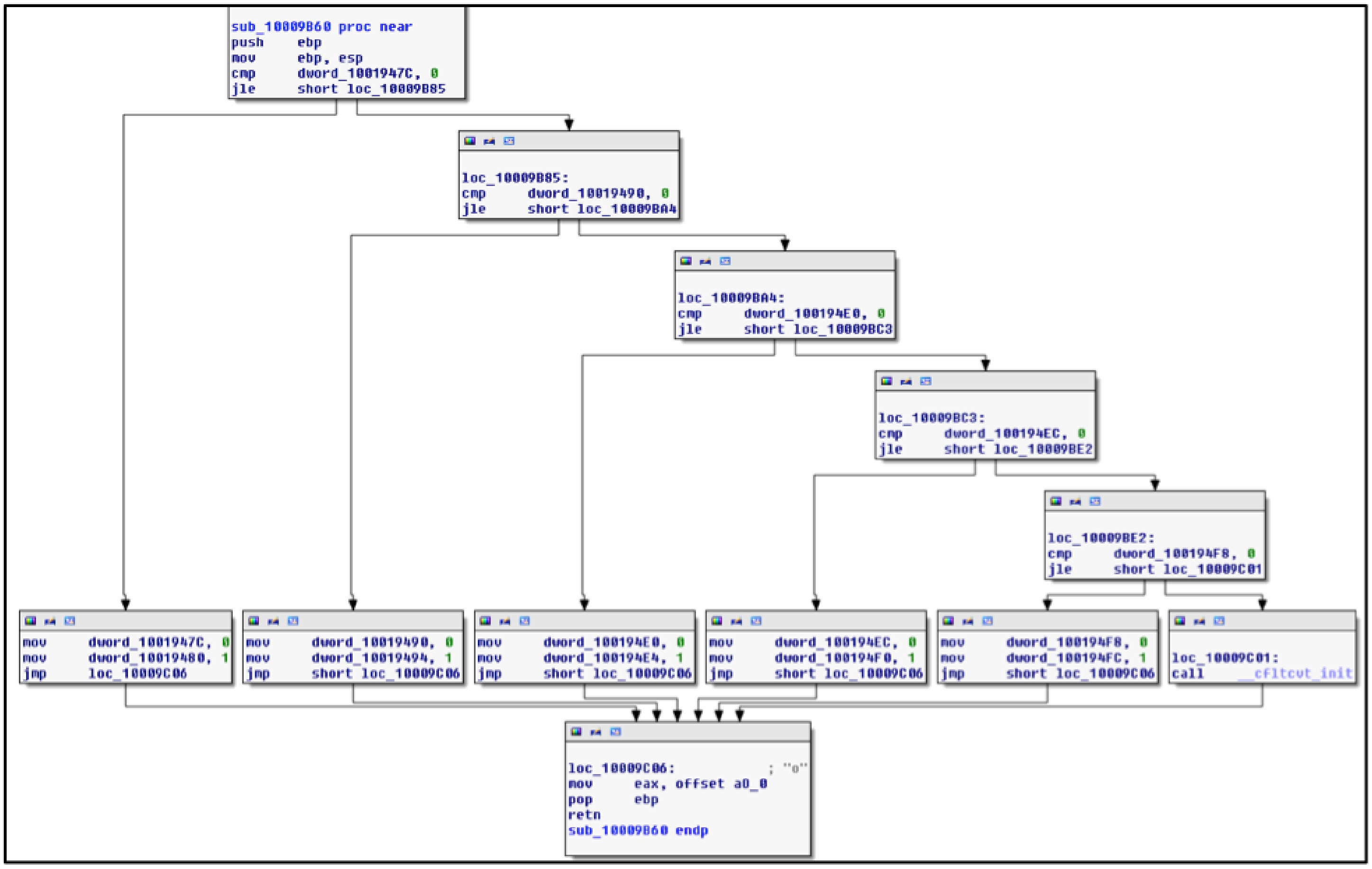

```
sub_10009B60 proc near
push    ebp
mov     ebp, esp
cmp     dword_1001947C, 0
jle     short loc_10009B85
```

```
loc_10009B85:
cmp     dword_10019490, 0
jle     short loc_10009BA4
```

```
loc_10009BA4:
cmp     dword_100194E0, 0
jle     short loc_10009BC3
```

```
loc_10009BC3:
cmp     dword_100194EC, 0
jle     short loc_10009BE2
```

```
loc_10009BE2:
cmp     dword_100194F8, 0
jle     short loc_10009C01
```

```
mov     dword_1001947C, 0
mov     dword_10019480, 1
jmp     loc_10009C06
```

```
mov     dword_10019490, 0
mov     dword_10019494, 1
jmp     short loc_10009C06
```

```
mov     dword_100194E0, 0
mov     dword_100194E4, 1
jmp     short loc_10009C06
```

```
mov     dword_100194EC, 0
mov     dword_100194F0, 1
jmp     short loc_10009C06
```

```
mov     dword_100194F8, 0
mov     dword_100194FC, 1
jmp     short loc_10009C06
```

```
loc_10009C01:
call    __cfltcvt_init
```

```
loc_10009C06:                   ; "o"
mov     eax, offset aO_0
pop     ebp
retn
sub_10009B60 endp
```

Figure 12: "o" keystroke function

This appears to be the function that handles the keystrokes for the "o" key. The last condition checks if *dword_100194F8* is set, and if so then set *dword_100194FC* to 1. Those global variables are in sequence, so from here we play on a hunch and look at the memory addresses of the global variables and start naming them as follows:

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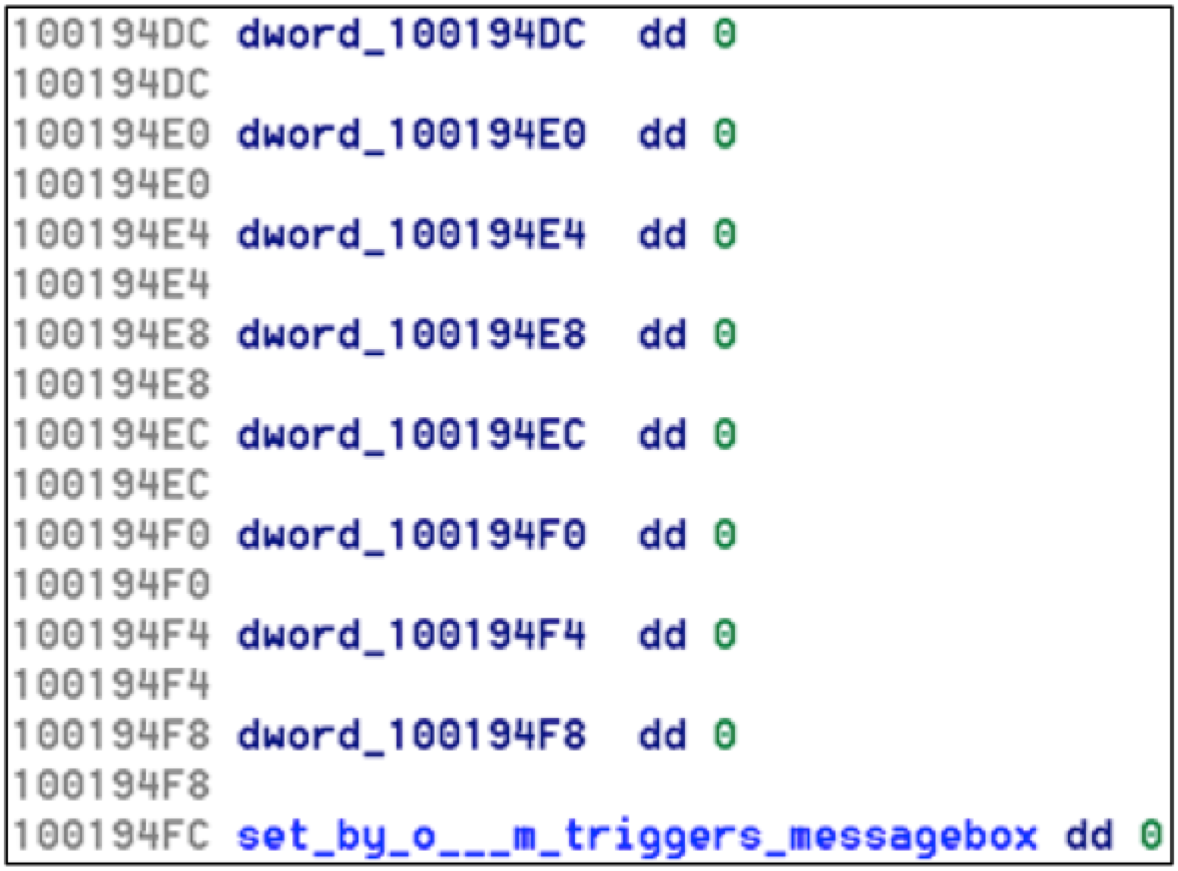
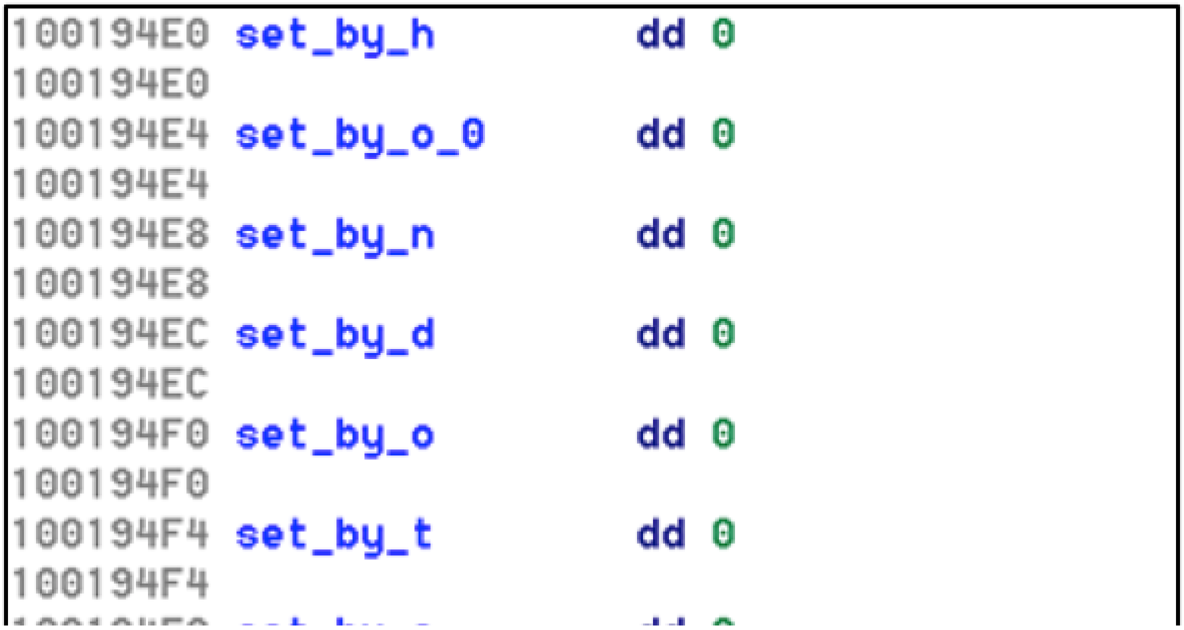


```
100194DC dword_100194DC  dd 0
100194DC
100194E0 dword_100194E0  dd 0
100194E0
100194E4 dword_100194E4  dd 0
100194E4
100194E8 dword_100194E8  dd 0
100194E8
100194EC dword_100194EC  dd 0
100194EC
100194F0 dword_100194F0  dd 0
100194F0
100194F4 dword_100194F4  dd 0
100194F4
100194F8 dword_100194F8  dd 0
100194F8
100194FC set_by_o___m_triggers_messagebox dd 0
```

As we start doing this, a pattern starts to emerge:



```
100194E0 set_by_h        dd 0
100194E0
100194E4 set_by_o_0      dd 0
100194E4
100194E8 set_by_n        dd 0
100194E8
100194EC set_by_d        dd 0
100194EC
100194F0 set_by_o        dd 0
100194F0
100194F4 set_by_t        dd 0
100194F4
```

We notice that the pattern "dotcom" emerge so we can do this for the rest of the global variables (which are a series of global variables controlling a state machine based on key strokes) and we get the final key: *l0gging.Ur.5tr0ke5@flare-on.com.*

This entry was posted on Mon Nov 17 19:14:00 EST 2014 and filed under Exploits, Mike Sikorski, Richard Wartell and Threat Research.

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