MalwareByte Challenge 2

Challenge's write-up

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1 Introduction

Malwarebyte published on April 27th a new reverse engineering challenge, an executable mixing malware behavior with a traditional crackme look. It came in the form of a Windows executable.

Figure 1: Challenge's icon

This document describes the solving step of the challenge.

2 Lightweight analysis of "mb_crackme_2.exe"

As we would do with any real malware, we start by performing some basic information gathering on the provided executable. Even if the static and dynamic approaches gave us similar conclusions on the executable's nature (see 2.4), the different methods have been described nonetheless in the following sections.

2.1 Basic static information gathering

Using **Exeinfo PE**, a maintained successor of the renowned (but outdated) **PEiD** software, gives us some basic information about the binary:

- The program is a **32 bits Portable Executable** (PE), meant to be run in console (no GUI);
- It *seems* to be compiled from C++ using Microsoft Visual C++ 8;
- No obvious sign of packing is detected by the tool.

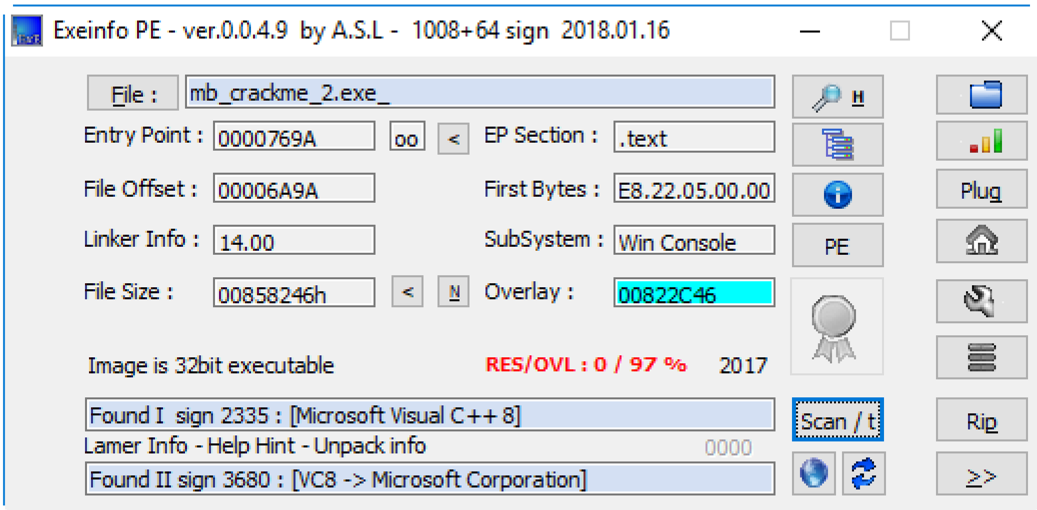


Figure 2 : Output of Exeinfo PE

Looking for **printable strings** in the binary already gives us some hints about the executable's nature:

```
$ strings -n 10 mb_crackme_2.exe_
[...]
pyi-windows-manifest-filename
[...]
Py_IgnoreEnvironmentFlag
Failed to get address for Py_IgnoreEnvironmentFlag
Py_NoSiteFlag
Failed to get address for Py_NoSiteFlag
Py_NoUserSiteDirectory
[...]
mpyimod01_os_path
mpyimod02_archive
mpyimod03_importers
spyiboot01_bootstrap
spyi_rth__tkinter
bCrypto.Cipher._AES.pyd
bCrypto.Hash._SHA256.pyd
bCrypto.Random.OSRNG.winrandom.pyd
bCrypto.Util._counter.pyd
bMicrosoft.VC90.CRT.manifest
bPIL._imaging.pyd
bPIL._imagingtk.pyd
[...]
opyi-windows-manifest-filename another.exe.manifest
[...]
zout00-PYZ.pyz
python27.dll
```

Many references to **Python libraries**, **PYZ archives** and **"pyi" substring** indicates the use of the **PyInstaller** utility to build a PE executable from a Python script.

2.2 Basic dynamic information gathering

Running the executable (in a sandboxed environment) gives us the following message:

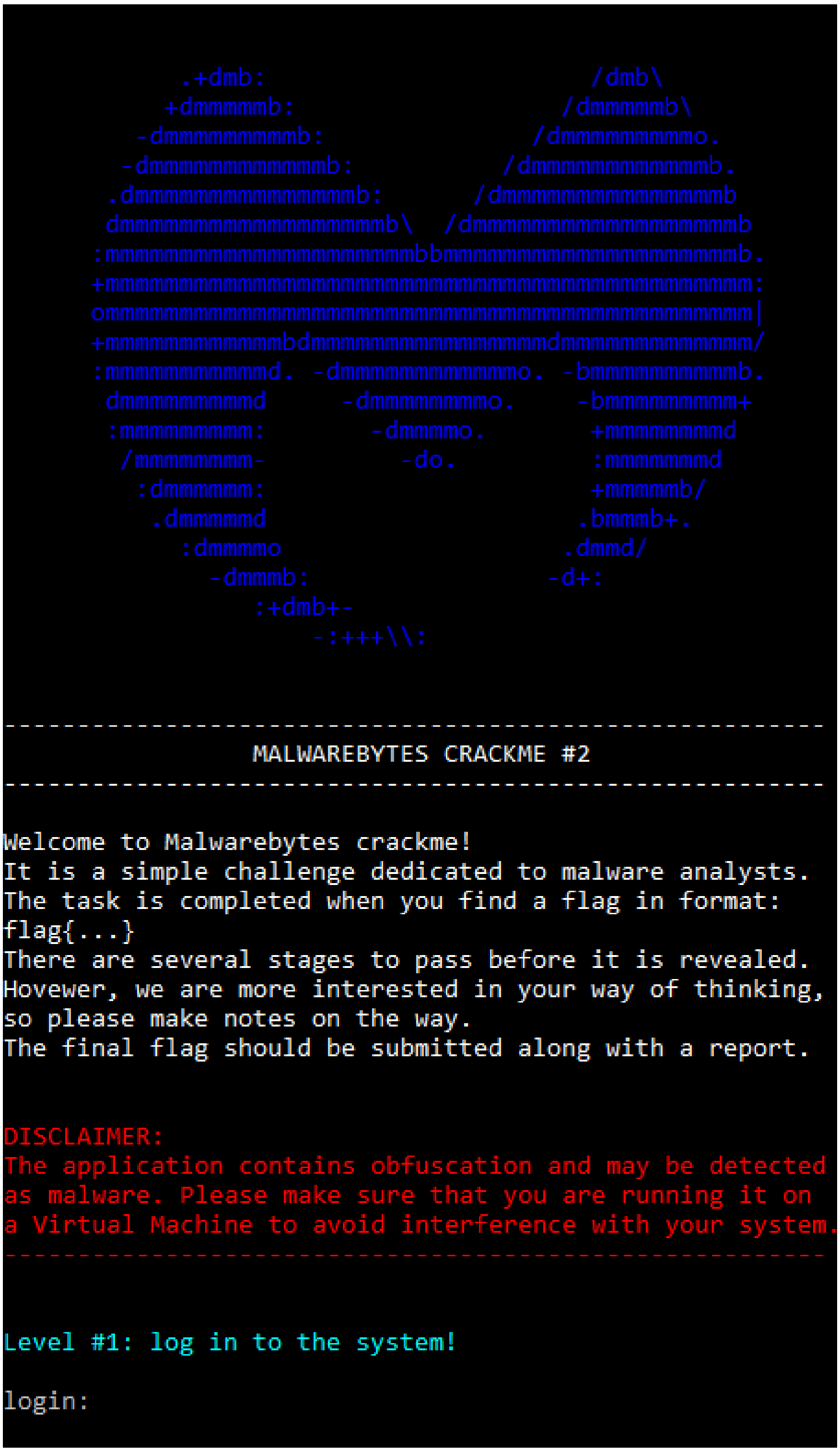
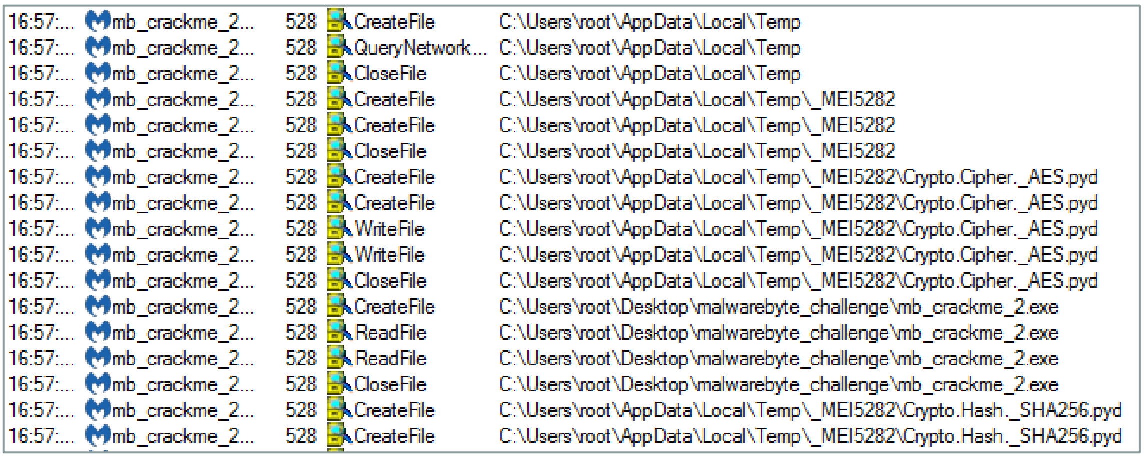


Figure 3 : Malware's login screen

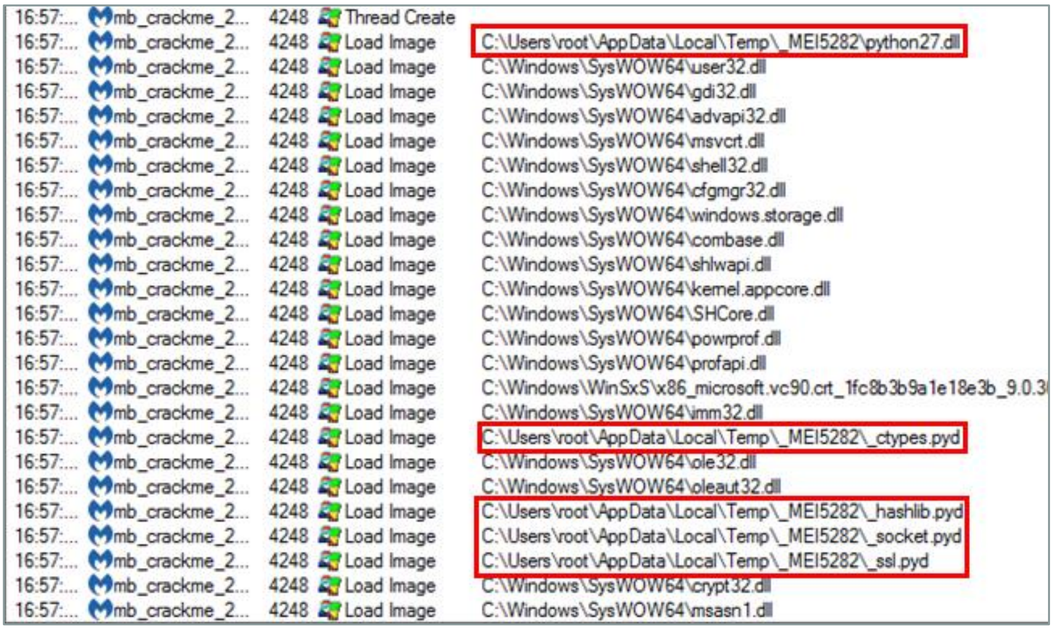
Using **Process Monitor**, from SysInternals Tools Suite[1], allows us to quickly get a glimpse of the actions performed by the executable:



16:57:...	mb_crackme_2...	528	CreateFile	C:\Users\root\AppData\Local\Temp
16:57:...	mb_crackme_2...	528	QueryNetwork...	C:\Users\root\AppData\Local\Temp
16:57:...	mb_crackme_2...	528	CloseFile	C:\Users\root\AppData\Local\Temp
16:57:...	mb_crackme_2...	528	CreateFile	C:\Users\root\AppData\Local\Temp_MEI5282
16:57:...	mb_crackme_2...	528	CreateFile	C:\Users\root\AppData\Local\Temp_MEI5282
16:57:...	mb_crackme_2...	528	CloseFile	C:\Users\root\AppData\Local\Temp_MEI5282
16:57:...	mb_crackme_2...	528	CreateFile	C:\Users\root\AppData\Local\Temp_MEI5282\Crypto.Cipher._AES.pyd
16:57:...	mb_crackme_2...	528	CreateFile	C:\Users\root\AppData\Local\Temp_MEI5282\Crypto.Cipher._AES.pyd
16:57:...	mb_crackme_2...	528	WriteFile	C:\Users\root\AppData\Local\Temp_MEI5282\Crypto.Cipher._AES.pyd
16:57:...	mb_crackme_2...	528	WriteFile	C:\Users\root\AppData\Local\Temp_MEI5282\Crypto.Cipher._AES.pyd
16:57:...	mb_crackme_2...	528	CloseFile	C:\Users\root\AppData\Local\Temp_MEI5282\Crypto.Cipher._AES.pyd
16:57:...	mb_crackme_2...	528	CreateFile	C:\Users\root\Desktop\malwarebyte_challenge\mb_crackme_2.exe
16:57:...	mb_crackme_2...	528	ReadFile	C:\Users\root\Desktop\malwarebyte_challenge\mb_crackme_2.exe
16:57:...	mb_crackme_2...	528	ReadFile	C:\Users\root\Desktop\malwarebyte_challenge\mb_crackme_2.exe
16:57:...	mb_crackme_2...	528	CloseFile	C:\Users\root\Desktop\malwarebyte_challenge\mb_crackme_2.exe
16:57:...	mb_crackme_2...	528	CreateFile	C:\Users\root\AppData\Local\Temp_MEI5282\Crypto.Hash._SHA256.pyd
16:57:...	mb_crackme_2...	528	CreateFile	C:\Users\root\AppData\Local\Temp_MEI5282\Crypto.Hash._SHA256.pyd

Figure 4 : Files operations performed by the malware

A temporary directory named "**_MEI5282**" is created under user's **"%temp%"** directory, and filled with **Python-related resources**. In particular, "**python27.dll**" and "***.pyd**" libraries are written and later loaded by the executable.



16:57:...	mb_crackme_2...	4248	Thread Create	
16:57:...	mb_crackme_2...	4248	Load Image	C:\Users\root\AppData\Local\Temp_MEI5282\python27.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\user32.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\gdi32.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\advapi32.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\msvcrt.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\shell32.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\cfgmgr32.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\windows.storage.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\combase.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\shlwapi.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\kernel.appcore.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\SHCore.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\powrprof.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\profapi.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\WinSxS\x86_microsoft.vc90.crt_1fc8b3b9a1e18e3b_9.0.3
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\imm32.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Users\root\AppData\Local\Temp_MEI5282_ctypes.pyd
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\ole32.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\oleaut32.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Users\root\AppData\Local\Temp_MEI5282_hashlib.pyd
16:57:...	mb_crackme_2...	4248	Load Image	C:\Users\root\AppData\Local\Temp_MEI5282_socket.pyd
16:57:...	mb_crackme_2...	4248	Load Image	C:\Users\root\AppData\Local\Temp_MEI5282_ssl.pyd
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\crypt32.dll
16:57:...	mb_crackme_2...	4248	Load Image	C:\Windows\SysWOW64\msasn1.dll

Figure 5 : Libraries loaded by the malware

This behavior is typical of executables generated by PyInstaller.

[1] https://docs.microsoft.com/en-us/sysinternals/

2.3 Error-handling analysis

Without tools, it is often possible to quickly get information about a binary's internals by **testing its error handling**. For example, inserting an **EOF** (End-Of-File) signal in the terminal ("Ctrl+Z + Return" on Windows Command Prompt) makes the program crash, printing the following information:

```
Level #1: log in to the system!

login: ^Z
Traceback (most recent call last):
  File "another.py", line 323, in <module>
  File "another.py", line 295, in main
  File "another.py", line 265, in stage1_login
EOFError: EOF when reading a line
[3972] Failed to execute script another
```

Figure 6 : Python stack-trace printed after a crash

This allows us to identify the presence of a Python program embedded inside the executable and gives us the name of the main script: **another.py**. The error message "[$PID] Failed to execute script $scriptName" is typical of **PyInstaller**-produced programs.

2.4 Python files extraction and decompilation

Every lightweight analysis presented in 2.1, 2.2 and 2.3 points out that the executable has been built using **PyInstaller**.

The **PyInstaller Extractor**[2] program can be used to extract python-compiled resources from the executable.

```
$ python pyinstxtractor.py mb_crackme_2.exe
[*] Processing mb_crackme_2.exe
[*] Pyinstaller version: 2.1+
[*] Python version: 27
[*] Length of package: 8531014 bytes
[*] Found 931 files in CArchive
[*] Beginning extraction...please standby
[+] Possible entry point: pyiboot01_bootstrap
[+] Possible entry point: pyi_rth__tkinter
[+] Possible entry point: another
[*] Found 440 files in PYZ archive
[*] Successfully extracted pyinstaller archive: mb_crackme_2.exe

You can now use a python decompiler on the pyc files within the extracted directory
```

As previously seen, the most interesting file is "**another**", as it should contain the "main" function (cf. Figure 6).

_ssl.pyd	30/04/2018 17:16	Fichier PYD	1 378 Ko
_testcapi.pyd	30/04/2018 17:16	Fichier PYD	41 Ko
_tkinter.pyd	30/04/2018 17:16	Fichier PYD	40 Ko
another	30/04/2018 17:16	Fichier	12 Ko
another.exe.manifest	30/04/2018 17:16	Fichier MANIFEST	1 Ko
bz2.pyd	30/04/2018 17:16	Fichier PYD	70 Ko

[2] https://0xec.blogspot.fr/2017/11/pyinstaller-extractor-updated-to-v19.html

A quick Internet search[3] informs us that in a PYZ archive, the main file is in fact a ***.pyc file** (Python bytecode) whose **first 8 bytes**, containing its signature, **have been removed.** Looking the hex dump of **another *.pyc file** of the archive confirms this statement and gives us the correct signature for Python 2.7 bytecode files (in purple).

```
$ hexdump -C another | head -n 3
00000000  63 00 00 00 00 00 00 00  00 03 00 00 00 40 00 00  |c............@..|
00000010  00 73 03 02 00 00 64 00  00 5a 00 00 64 01 00 5a  |.s....d..Z..d..Z|
00000020  01 00 64 02 00 5a 02 00  64 03 00 64 04 00 6c 03  |..d..Z..d..d..l.|

$ hexdump -C out00-PYZ.pyz_extracted/cmd.pyc | head -n 3
00000000  03 f3 0d 0a 00 00 00 00  63 00 00 00 00 00 00 00  |.ó......c.......|
00000010  00 03 00 00 00 40 00 00  00 73 4c 00 00 00 64 00  |.....@...sL...d.|
00000020  00 5a 00 00 64 01 00 64  02 00 6c 01 00 5a 01 00  |.Z..d..d..l..Z..|
```

Restoring the file's signature produces a correct Python bytecode file.

```
$ cat <(printf "\x03\xf3\x0d\x0a\x00\x00\x00\x00") another > another.pyc
$ file another.pyc
another.pyc: python 2.7 byte-compiled
```

Using the **uncompyle6** [4] decompilation tool, we can easily recover the original source code of **another.py**.

```
$ uncompyle6 another.pyc > another.py
```

[3] https://hshrzd.wordpress.com/2018/01/26/solving-a-pyinstaller-compiled-crackme/ from (one of) the chalenge's author(s), @hasherezade
[4] https://github.com/rocky/python-uncompyle6

3 Stage 1: login

Looking at the **main()** function of **another.py**, we see that the first operations are performed by the **stage1_login()** function.

```
def main():
    key = stage1_login()
    if not check_if_next(key):
        return
    else:
        content = decode_and_fetch_url(key)
        if content is None:
            print 'Could not fetch the content'
            return -1
        decdata = get_encoded_data(content)
        if not is_valid_payl(decdata):
            return -3
        print colorama.Style.BRIGHT + colorama.Fore.CYAN
        print 'Level #2: Find the secret console...'
        print colorama.Style.RESET_ALL
        #load_level2(decdata, len(decdata))
        dump_shellcode(decdata, len(decdata))
        user32_dll.MessageBoxA(None, 'You did it, level up!', 'Congrats!', 0)
        try:
            if decode_pasted() == True:
                user32_dll.MessageBoxA(None, 'Congratulations! Now save your flag
and send it to Malwarebytes!', 'You solved it!', 0)
                return 0
            user32_dll.MessageBoxA(None, 'See you later!', 'Game over', 0)
        except:
            print 'Error decoding the flag'

        return
```

Figure 7: main() function

```
def stage1_login():
    show_banner()
    print colorama.Style.BRIGHT + colorama.Fore.CYAN
    print 'Level #1: log in to the system!'
    print colorama.Style.RESET_ALL
    login = raw_input('login: ')
    password = getpass.getpass()
    if not (check_login(login) and check_password(password)):
        print 'Login failed. Wrong combination username/password'
        return None
    else:
        PIN = raw_input('PIN: ')
        try:
            key = get_url_key(int(PIN))
        except:
            print 'Login failed. The PIN is incorrect'
            return None

        if not check_key(key):
            print 'Login failed. The PIN is incorrect'
            return None
        return key
```

Figure 8: stage1_login() function

Three user inputs are successively checked: the user's **login**, **password** and **PIN code**.

3.1.1 Finding the login

The **check_login()** function's code is completely transparent:

```
def check_login(login):
    if login == 'hackerman':
        return True
    return False
```

Figure 9: check_login() function

We now have found the login, let's search for the password.

Figure 10: Expected login :)

3.1.2 Finding the password

The **check_password()** function hashes user's input using the **MD5** hash function, and compares the result with an hardcoded string:

```
def check_password(password):
    my_md5 = hashlib.md5(password).hexdigest()
    if my_md5 == '42f749ade7f9e195bf475f37a44cafcb':
        return True
    return False
```

Figure 11: check_password() function

A quick Internet search of this string gives us the corresponding cleartext password: **Password123**.

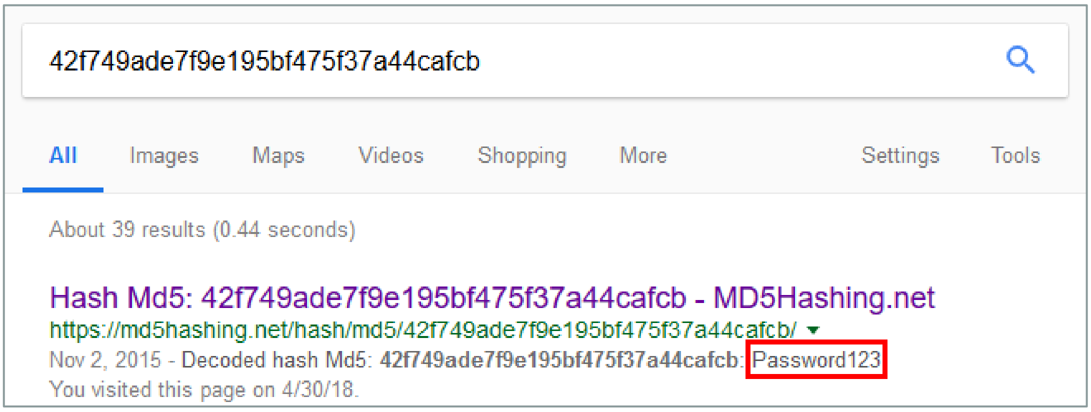


Figure 12 : Finding the password on a search engine

3.1.3 Finding the PIN code

The PIN code is read from standard input, converted into an **integer** (cf. **stage1_login()** function), and passed to the **get_url_key()** function:

```
def get_url_key(my_seed):
    random.seed(my_seed)
    key = ''
    for I in xrange(0, 32):
        id = random.randint(0, 9)
        key += str(id)

    return key
```

Figure 13: get_url_key() function

This function **derives a pseudo-random 32 digits key** from the PIN code, using it as a **seed for Python's PRNG**. The generated key is then verified using the **check_key()** function, where its MD5 sum is checked against another hardcoded value.

```
def check_key(key):
    my_md5 = hashlib.md5(key).hexdigest()
    if my_md5 == 'fb4b322c518e9f6a52af906e32aee955':
        return True
    return False
```

Figure 14: check_key() function

The key space is obviously **too large to be brute-forced**, as a 32-digits string corresponds to 10^{32} ($\sim 2^{106}$) possible combinations. However, we can **brute-force the PIN code**, being an integer, using the following code:

```
from another import get_url_key, check_key

PIN = 0
while True:
    key = get_url_key(PIN)
    if check_key(key):
        print PIN
        break
    PIN += 1
```

Figure 15: PIN bruteforcing code

The solution is obtained in a few milliseconds:

```
$ python bruteforcePIN.py
9667
```

3.1.4 Testing credentials

Using the credentials found in the previous step completes the first stage of the challenge.

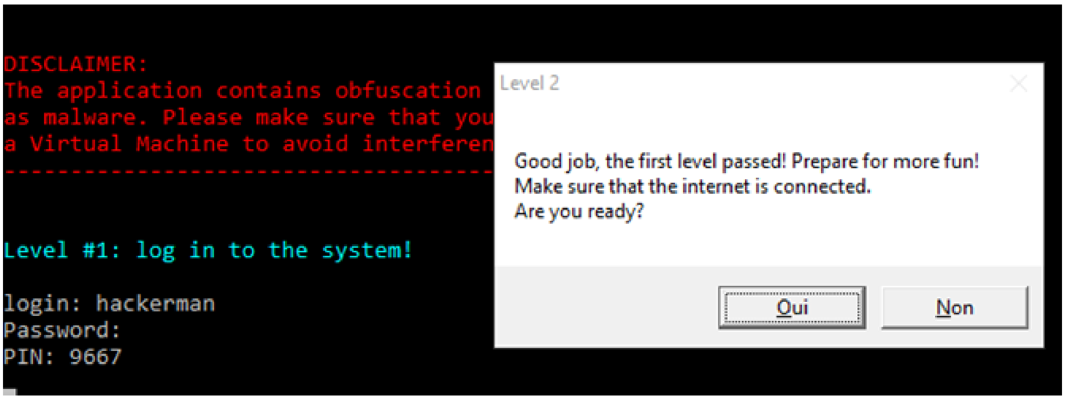


Figure 16: Validating stage 1

Clicking "Yes" make the executable pause after printing the following message in the console:

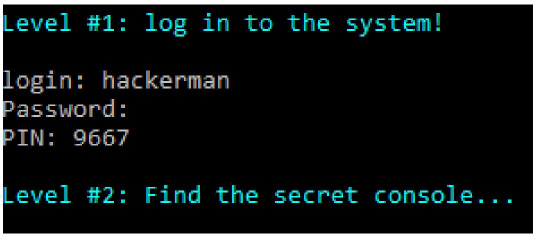


Figure 17: Waiting for us to find a "secret console"

Let's find that secret console!

4 Stage 2: the secret console

4.1 Payload download and decoding

Continuing our analysis of the **main()** function, the next function to be called after credentials verification is **decode_and_fetch_url()**, with the previously calculated 32-digits key given as argument:

```
def decode_and_fetch_url(key):
    try:
        encrypted_url =
'\xa6\xfa\x8f0\xba\x7f\x9d\xe2c\x81`\xf5\xd5\xf6\x07\x85\xfe[hr\xd6\x80?U\x90\x89)\
xd1\xe9\xf0<\xfe'
        aes = AESCipher(bytearray(key))
        output = aes.decrypt(encrypted_url)
        full_url = output
        content = fetch_url(full_url)
    except:
        return None

    return content
```

Figure 18: decode_and_fetch_url() function

A URL is decrypted using an **AES cipher** and the 32-digits key. The resource at this URL is then **downloaded** and its content returned by the function.

To simply get the decrypted URL, we **add some logging instructions** to the original code of **another.py**, which can be run independently of mb_crackme_2.exe (given that the required dependencies are present on our machine).

```
[...]
        full_url = output
        print "DEBUG : URL fetched is : %s " % full_url #added from original code
        content = fetch_url(full_url)
 [...]
```

The result execution is the following:

```
login: hackerman
Password:
PIN: 9667
DEBUG : URL fetched is : https://i.imgur.com/dTHXed7.png
```

The decrypted URL hosts the PNG image displayed bellow:

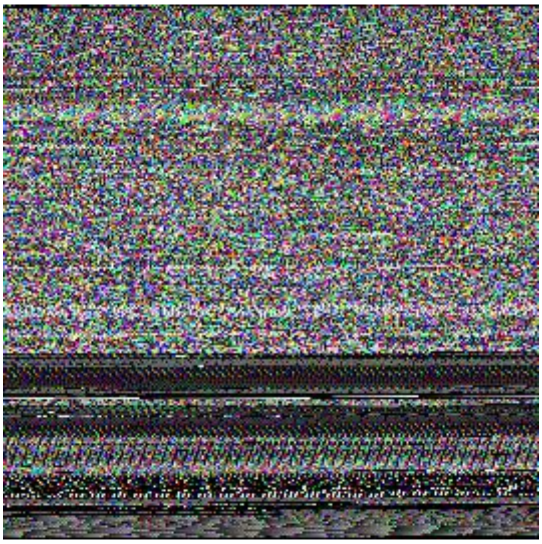


Figure 19: Image downloaded by the executable

The "malware" then read the **Red, Green and Blue components of each image's pixel**, interprets them as **bytes** and constructs a buffer from their concatenation.

```
def get_encoded_data(bytes):
    imo = Image.open(io.BytesIO(bytes))
    rawdata = list(imo.getdata())
    tsdata = ''
    for x in rawdata:
        for z in x:
            tsdata += chr(z)

    del rawdata
    return tsdata
```

Figure 20: get_encode_data() function

This technique is **sometimes used by real malware to download malicious code** without raising suspicion of traffic-analysis tools, hiding the real nature of the downloaded resource.

Using the "Extract data…" function of the **Stegsolve** tool[5] allows to quickly preview the data encoded in the image, which appears to be a PE file (and more specifically, a DLL):

[5] https://www.wechall.net/forum/show/thread/527/Stegsolve_1.3/page-1

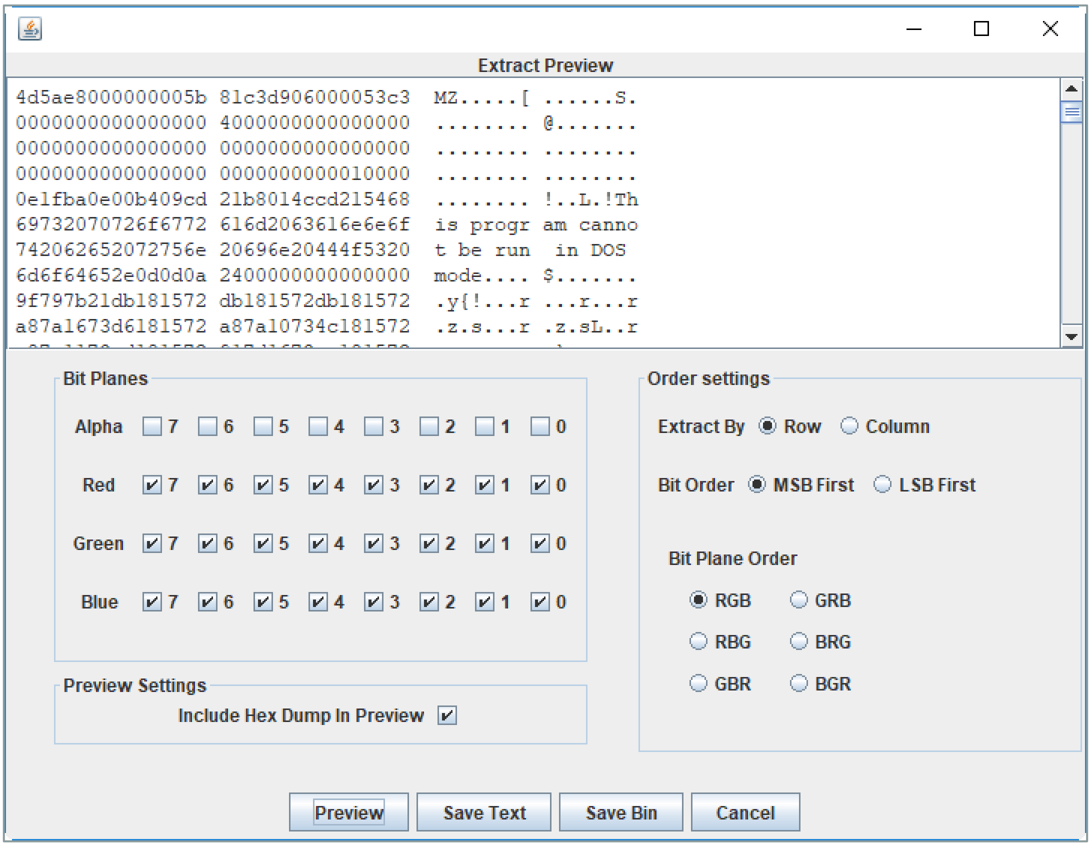


Figure 21 : Output of the Stegsolve tool

The function **is_valid_payl()** is then used to check whether the decoded payload is correct:

```
def is_valid_payl(content):
    if get_word(content) != 23117:
        return False
    next_offset = get_dword(content[60:])
    next_hdr = content[next_offset:]
    if get_dword(next_hdr) != 17744:
        return False
    return True
```

The **23117** and **17744** constants represent the "**MZ**" and "**PE**" magic bytes present in the headers of a PE.

```
>>> import struct
>>> struct.pack("<H", 23117)
'MZ'
>>> struct.pack("<H", 17744)
'PE'
```

The decoded file is then passed to the **load_level2()** function, which is a wrapper around **prepare_stage()**.

```
def load_level2(rawbytes, bytesread):
    try:
        if prepare_stage(rawbytes, bytesread):
            return True
    except:
        return False
```

Figure 22: load_level2() function

```
def prepare_stage(content, content_size):
    with open("dumped_pe.dll", "wb") as f:
        f.write(content[:content_size])
        print "DEBUG : File dumped in dumped_pe.dll"
    virtual_buf = kernel_dll.VirtualAlloc(0, content_size, 12288, 64)
    if virtual_buf == 0:
        return False
    res = memmove(virtual_buf, content, content_size)
    if res == 0:
        return False
    MR = WINFUNCTYPE(c_uint)(virtual_buf + 2)
    MR()
    return True
```

Figure 23: prepare_stage() function

This function starts by allocating enough space to store the downloaded code, using the **VirtualAlloc API function call**. The allocated space is **readable**, **writable** and **executable**, as the provided arguments reveal (12288 being equal to "MEM_COMMIT | MEM_RESERVE", and 64 to PAGE_EXECUTE_READWRITE).

The downloaded code is then written in the allocated space using the **memmove** function, and **executed**.

To get a **clean dump of the downloaded code** (once decrypted), we add a piece of code in the **prepare_stage()** function, as follows:

```
def prepare_stage(content, content_size):
    with open("dumped_pe.dll", "wb") as f:
        f.write(content[:content_size])
        print "DEBUG : File dumped in dumped_pe.dll"
    virtual_buf = kernel_dll.VirtualAlloc(0, content_size, 12288, 64)
    if virtual_buf == 0:
        return False
    res = memmove(virtual_buf, content, content_size)
    if res == 0:
        return False
    MR = WINFUNCTYPE(c_uint)(virtual_buf + 2)
    MR()
    return True
```

After re-executing the program, we observe that the obtained file is indeed a **valid 32 bits Windows DLL**:

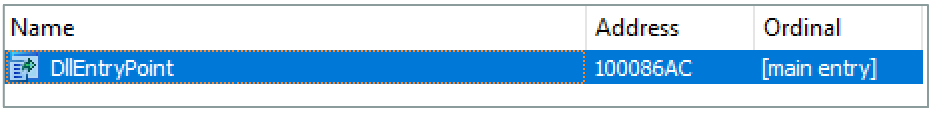
```
$ file dumped_pe.dll
dumped_file.ext: PE32 executable (DLL) (console) Intel 80386, for MS Windows
```

Time for us to open our favorite disassembler[6]!

[6] In my case, IDA ☺

4.2 Downloaded DLL's reverse-engineering

The list of **exported functions** being empty (except for the **DllEntryPoint** function), we start our analysis at the entry point of the DLL.



Name	Address	Ordinal
DllEntryPoint	100086AC	[main entry]

Figure 24: Exports list

4.2.1 Entry point

Our first goal is to search for the **DllMain()** function from the entry point. If the reverser is not used to analyze Windows DLLs, a simple way to start the analysis would be to open **any random non-stripped 32bit DLL**, which (with a little luck) would be **compiled with the same compiler** (Visual C++ ~7.10 here), and which would have a **similar CFG structure** for the DllEntryPoint function.

An example of CFG comparisons between the analyzed DLL (left) and another non-stripped 32bit DLL (right) is presented below:

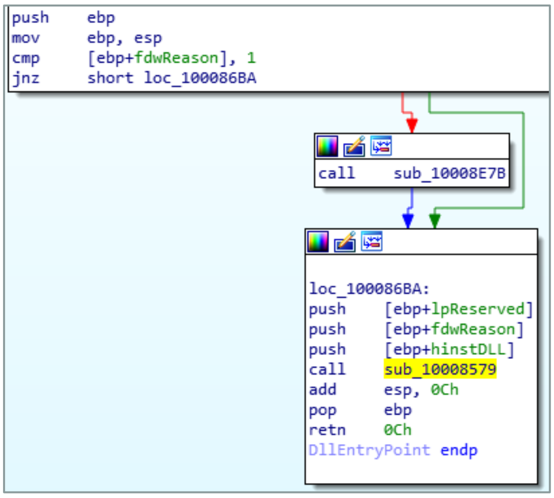


Figure 25: DllEntryPoint function in our DLL

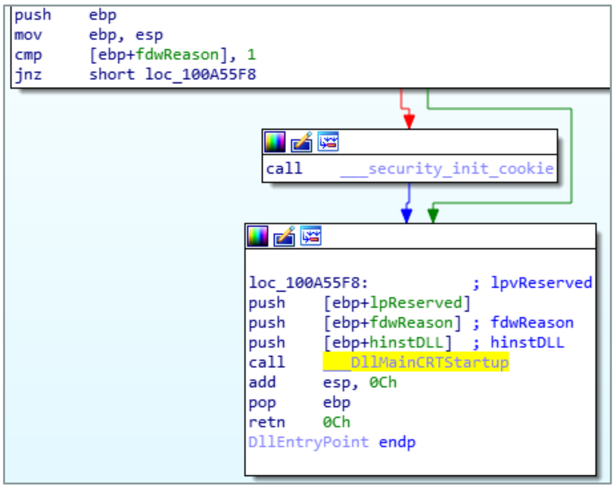


Figure 26: DllEntryPoint function in another non-stripped DLL

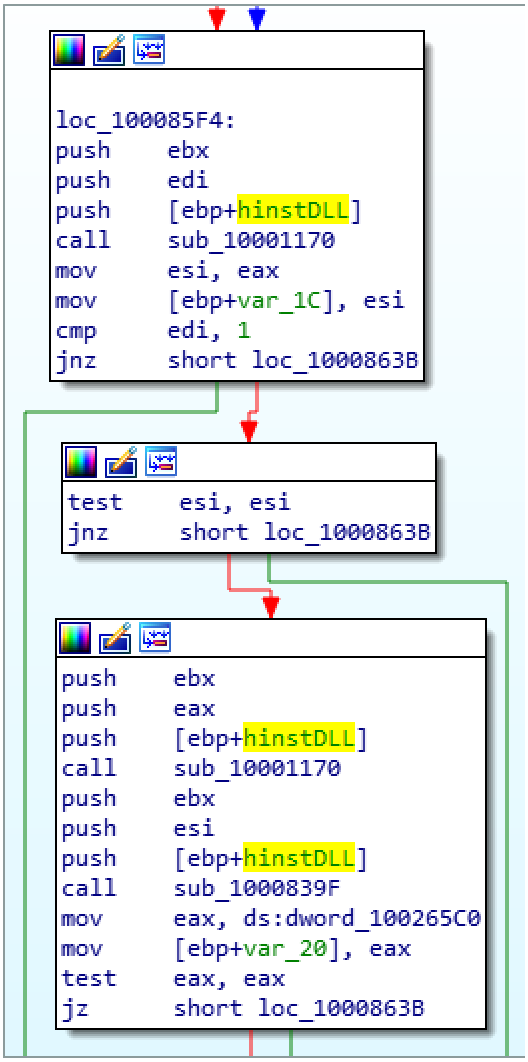


Figure 27: DllMainCTRStartup (0x10008579) function in our DLL

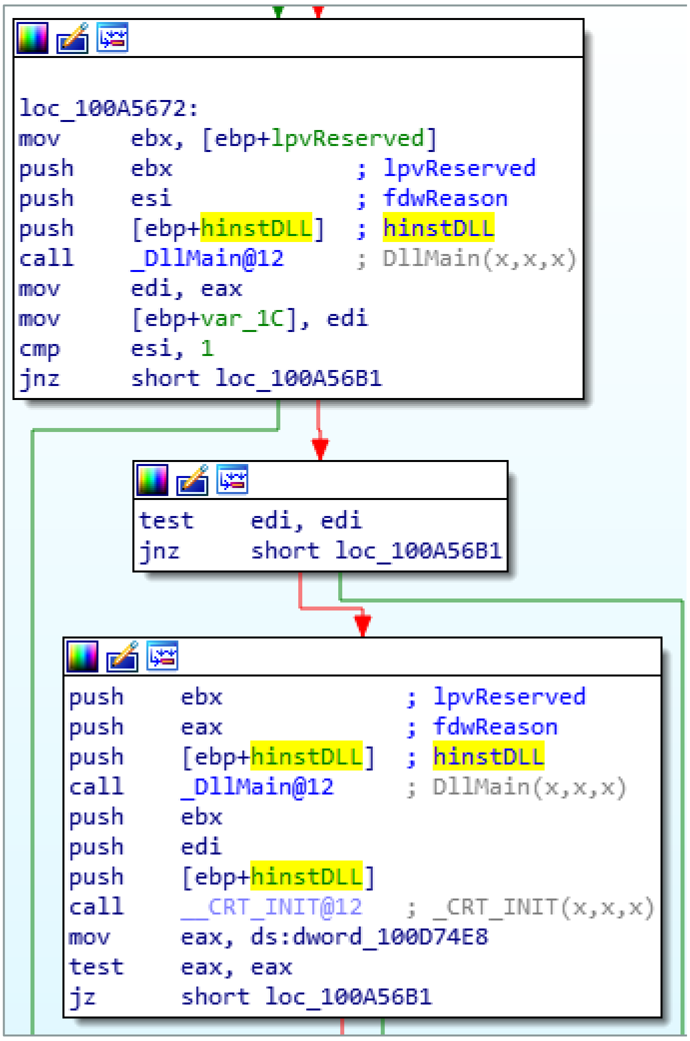


Figure 28: DllMainCTRStartup function in another non-stripped DLL

This technique allows us to **quickly find the DllMain** function in our DLL, here being located at 0x10001170.

4.2.2 DllMain (0x10001170)

The function starts by checking if it has been called during the **first load of the DLL by a process**, by comparing the value of the **fdwReason** argument[7] against the DLL_PROCESS_ATTACH constant.

The **DllMain()** function then registers two exception handlers using the **AddVectoredExceptionHandler**[8] API call. The handlers are named "**Handler_0**" and "**Handler_1**" in the screenshot below:

[7] cf. https://msdn.microsoft.com/en-us/library/windows/desktop/ms682583(v=vs.85).aspx for more info on DLL loading
[8] https://msdn.microsoft.com/en-us/library/windows/desktop/ms679274(v=vs.85).aspx

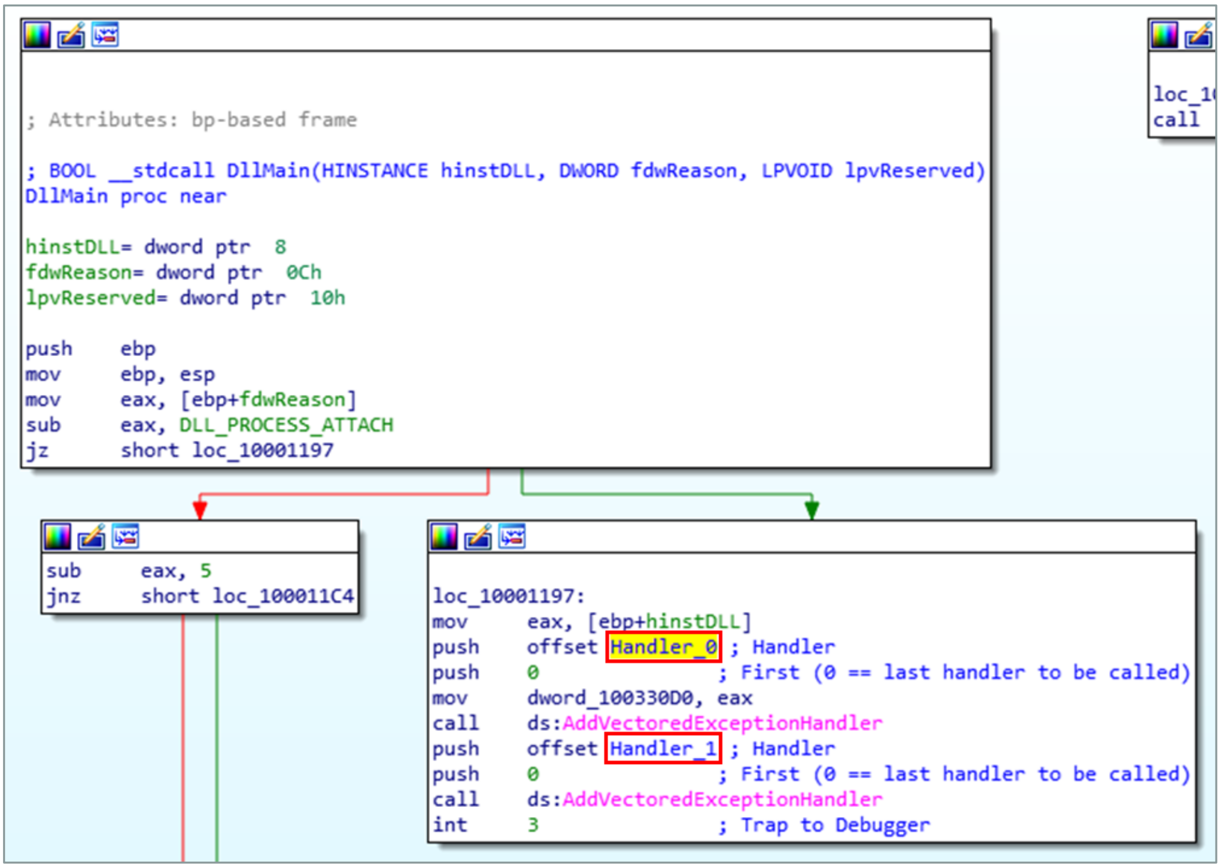


Figure 29: DllMain() function

An exception is then **manually raised** using the "**int 3**" interruption instruction, triggering the execution of **Handler_0**.

4.2.3 Interlude: debugging a DLL in IDA Pro

To make the reverse-engineering of some functions easier, debugging the code to observe functions inputs and outputs can be an effective method.

One simple way to **debug a DLL inside IDA** is to load the file as usual, then go to "Debugger ->Process options..." and modify the following value:

- Application:
  - On a **64 bits** version of Windows:
    - "C:\Windows\SysWOW64\rundll32.exe" to **debug a 32 bits library**
    - "C:\Windows\System32\rundll32.exe" to **debug a 64 bits library**
  - On a **32 bits** version of Windows:
    - "C:\Windows\System32\rundll32.exe" to debug a **32 bits library**
    - Obviously, you cannot run (therefore debug) a 64 bits library on a 32 bits version of Windows
- Parameters:
  - "PATH_OF_YOUR_DLL",functionToCall [function parameters if any][9]

[9] https://support.microsoft.com/en-us/help/164787/info-windows-rundll-and-rundll32-interface

Note: The file extension must be **"*.dll"** for rundll32.exe to accept it.

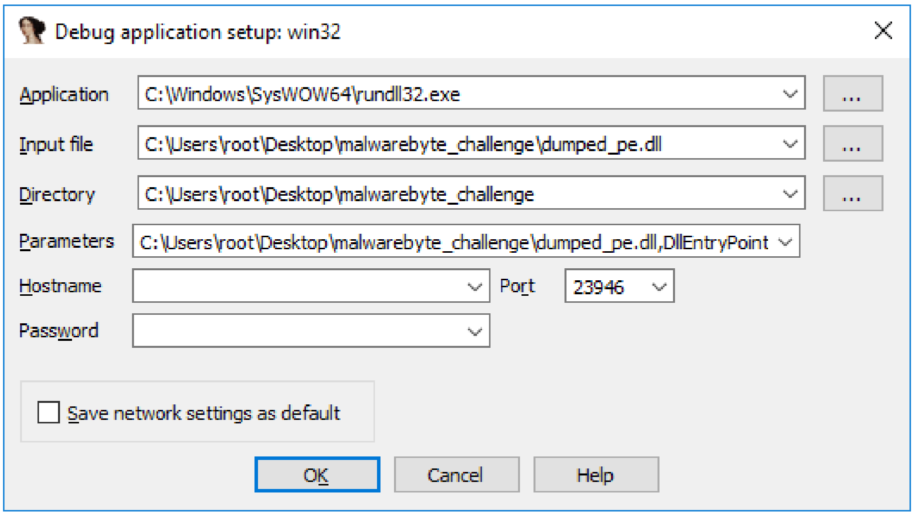


Figure 30: IDA "Process options..." menu

To test the configuration, just **place a breakpoint** at the entry point of the DLL:

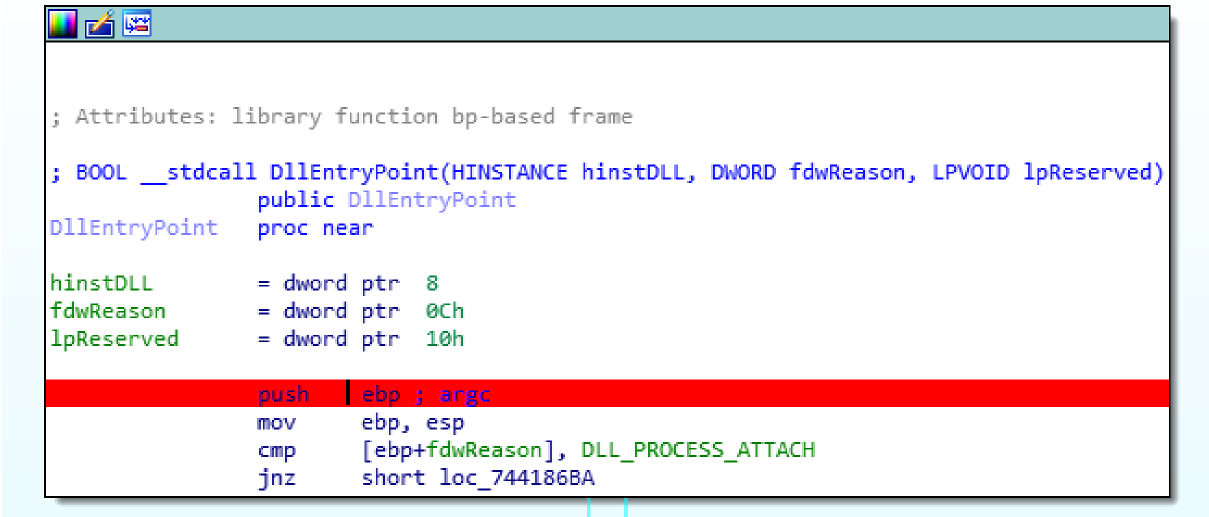


Figure 31: Placing a breakpoint at entry point

Run your debugger (F9). If configured correctly, your **debugger should break at the DLL entry point**, allowing you to debug any DLL function

4.2.4 Handler_0 (0x10001260)

Looking at the **Handler_0**'s CFG (given below), we see that the function calls two unknown functions (0x100092C0 and 0x1000E61D). To quickly identify these functions, let's **debug the DLL**, and look at the functions inputs/outputs:

sub_100092C0

```
push    104h
mov     esi, eax
lea     eax, [ebp+Value]
push    0
push    eax
call    sub_100092C0
```

Figure 32: function sub_100092C0() call

The function seems to take 3 arguments:

- A **buffer** (here named "Value");
- A **value** (here 0);
- The **size of the buffer** (here 0x104).

We look at the **buffer's content** before and after the function call:

```
debug006:000CECF4 db    0
debug006:000CECF5 db    0
debug006:000CECF6 db    0
debug006:000CECF7 db    0
debug006:000CECF8 db 0E0h ; à
debug006:000CECF9 db 0DEh ; Þ
debug006:000CECFA db  0Ah
debug006:000CECFB db    1
debug006:000CECFC db    0
debug006:000CECFD db    0
debug006:000CECFE db    0
```

Figure 33: "Value" buffer before function sub_100092C0()'s call

```
debug006:000CECF4 db    0
debug006:000CECF5 db    0
debug006:000CECF6 db    0
debug006:000CECF7 db    0
debug006:000CECF8 db    0
debug006:000CECF9 db    0
debug006:000CECFA db    0
debug006:000CECFB db    0
debug006:000CECFC db    0
debug006:000CECFD db    0
debug006:000CECFE db    0
```

Figure 34: "Value" buffer after function sub_100092C0()'s call

The function prototype and its side effects **correspond to the memset** function.

sub_1000E61D

```
push    0Ah
push    104h
lea     eax, [ebp+Value]
push    eax
push    esi             ; PID
call    sub_1000E61D
```

Figure 35: function sub_1000E61D() call

The function seems to take 4 arguments:

- An **integer** (here the PID of the process);
- A **buffer** (here named "Value");
- The **size of the buffer** (here 0x104);
- A **value** (here 0xA, or 10).

Looking at the provided **buffer's content** after the function call, we see that the representation in base 10 of the first integer passed in parameter is written in the provided buffer.

```
debug006:000CECF4 db  35h ; 5
debug006:000CECF5 db  34h ; 4
debug006:000CECF6 db  34h ; 4
debug006:000CECF7 db  34h ; 4
debug006:000CECF8 db    0
debug006:000CECF9 db    0
debug006:000CECFA db    0
debug006:000CECFB db    0
debug006:000CECFC db    0
debug006:000CECFD db    0
debug006:000CECFE db    0
```

Figure 36: "Value" buffer after function sub_1000E61D() call

The function prototype and its side effects correspond to the **_itoa_s** function[10].

Handler_0 whole CFG and pseudo-code

Here is the graph of the Handler_0 function:

```
; Attributes: bp-based frame

; LONG __stdcall Handler_0(struct _EXCEPTION_POINTERS *ExceptionInfo)
Handler_0 proc near

pid_str_buffer= __m128i ptr -108h
var_4= dword ptr -4
ExceptionInfo= dword ptr  8

push    ebp
mov     ebp, esp
sub     esp, 108h
mov     eax, ___security_cookie
xor     eax, ebp
mov     [ebp+var_4], eax
push    esi
call    ds:GetCurrentProcessId ; get current PID
push    104h            ; count
mov     esi, eax
lea     eax, [ebp+pid_str_buffer]
push    0               ; c
push    eax             ; dest
call    memset
add     esp, 0Ch
push    offset ModuleName ; "python27.dll"
call    ds:GetModuleHandleA
test    eax, eax
jz      short loc_100012B8 ; checks if python.dll is loaded
```

[10] https://msdn.microsoft.com/fr-fr/library/0we9x30h.aspx

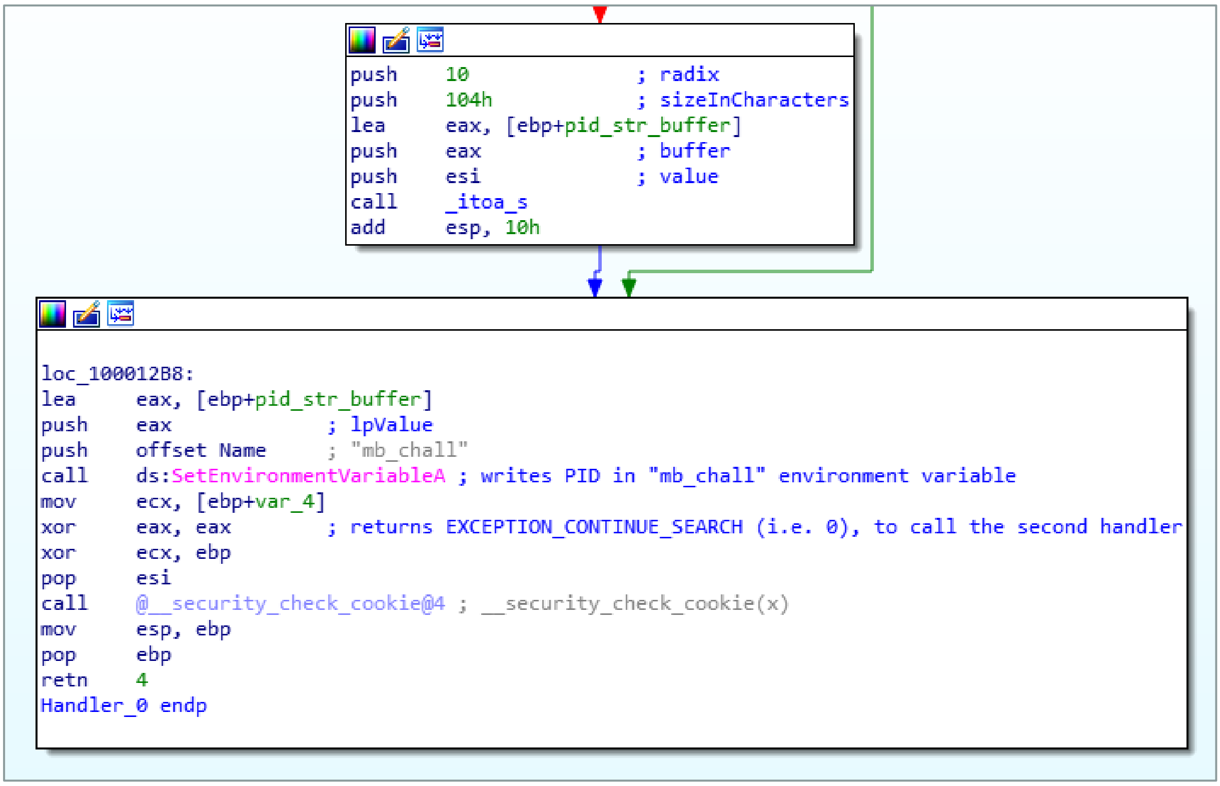


Figure 37: CFG of function Handler_0()

This corresponds to the following pseudo code:

```
if isloaded("python.dll"):
   pid = getpid()
else:
   pid = 0
setEnvironmentVariable("mb_chall", str(pid))
return EXCEPTION_CONTINUE_SEARCH
```

The function checks the presence of the **python27.dll** library (normally loaded by the main program mb_crackme_2.exe) in the process address space, and sets the "mb_chall" environment variable consequently.

This may be seen as an "**anti-debug**" trick, because running the DLL independently in a debugger makes the execution follow a different path.

4.2.5 Handler_1 (0x100011D0)

The code of this handler is quite self-explanatory, being similar to the previous handler's code:

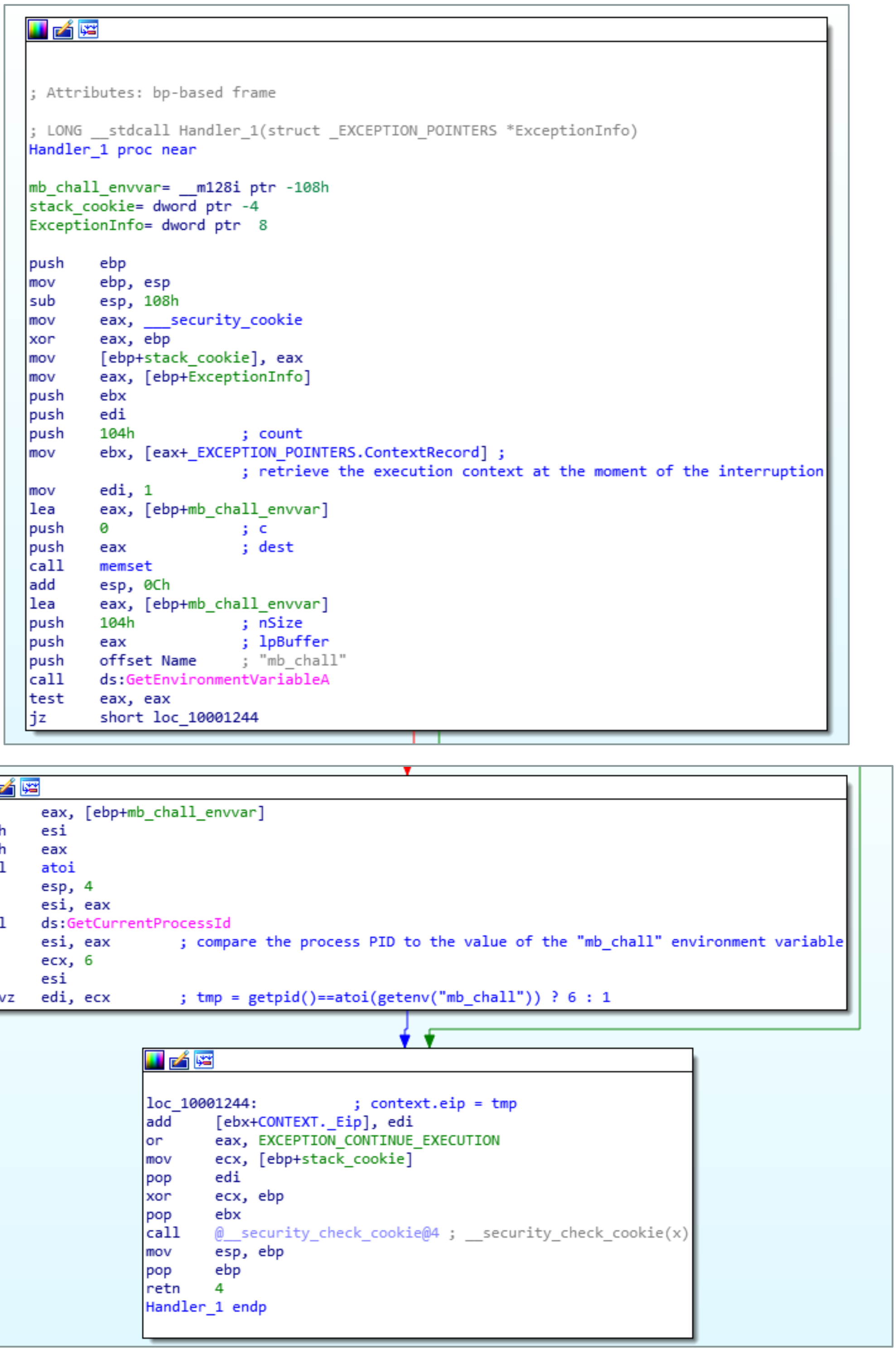


Figure 38: CFG of function Handler_1()

Once again, this corresponds to the following **pseudo code**:

```
if getpid() == int(getenv("mb_chall"):
   tmp = 6
else:
   tmp = 1
exceptionInfo->Context._Eip += tmp
return EXCEPTION_CONTINUE_EXECUTION
```

After this handler, **execution restarts at the address of original interruption** (“**int 3**”) **+1 or +6** (as presented in the pseudo-code above), whether performed checks pass or not.

```
.text:100011AC                  push    offset Handler_1 ; Handler
.text:100011B1                  push    0               ; First (0 == last handler to be called)
.text:100011B3                  call    ds:AddVectoredExceptionHandler
.text:100011B9                  int     3               ; Trap to Debugger
.text:100011BA ; ---------------------------------------------------------------------------
.text:100011BA
.text:100011BA loc_100011BA:                            ; @interruption + 1
.text:100011BA                  call    fail
.text:100011BF ; ---------------------------------------------------------------------------
.text:100011BF                  call    not_fail        ; @interruption + 6
```

Figure 39: Execution restart location after interruption

We thus continue the analysis at the **not_fail** function (0x100010D0).

4.2.6 not_fail (0x100010D0)

The function only **starts a thread** and wait for it to terminate.

```
not_fail proc near
push    offset MainThread ; lpStartAddress
call    CreateThreadWrapper
add     esp, 4
push    0FFFFFFFFh      ; dwMilliseconds
push    eax             ; hHandle
call    ds:WaitForSingleObject
retn
not_fail endp
```

Figure 40: CFG of not_fail() function

The created thread executes the **MainThread** (0x10001110) function, where our analysis continues.

4.2.7 MainThread (0x10001110)

The function loops and call the **EnumWindows**[11] API every second, which in turn calls the provided callback function (**EnumWindowsCallback**) on every window present on the desktop.

[11] https://msdn.microsoft.com/fr-fr/library/windows/desktop/ms633497(v=vs.85).aspx

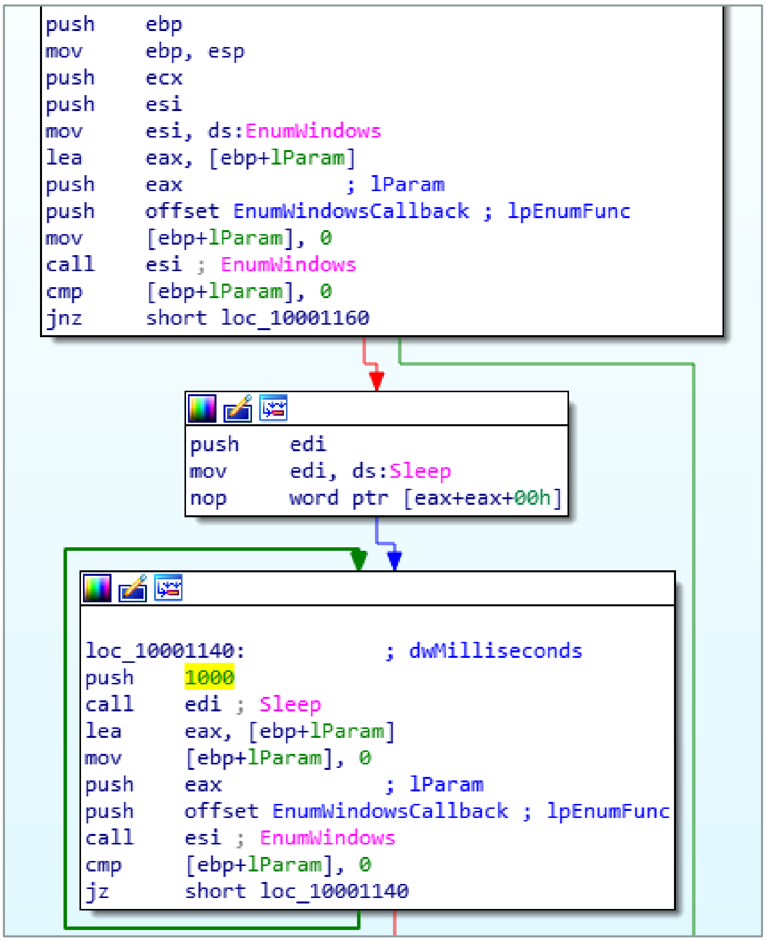


Figure 41: CFG of MainThread() function

4.2.8 EnumWindowsCallback function (0x10005750)

The function, called on each window, uses the **SendMessageA**[12] API with the **WM_GETTEXT** message to **retrieve the window's title**.

```
lea     eax, [ebp+window_text_buffer]
push    0
push    eax
call    memset
add     esp, 0Ch
lea     eax, [ebp+window_text_buffer]
push    eax                 ; lParam
push    104h                ; wParam
push    WM_GETTEXT          ; Msg
push    edi                 ; hWnd
call    ds:SendMessageA
```

Figure 42: SendMessageA() call in MainThread() function

After being converted to **C++ std::string**, the substrings "**Notepad**" and "**secret_console**" are searched in the window's title.

[12] https://msdn.microsoft.com/en-us/library/windows/desktop/ms632627(v=vs.85).aspx

```
sub     ecx, edx
lea     eax, [ebp+window_text_buffer]
push    ecx
push    eax
lea     ecx, [ebp+string_window_text]
call    string_constructor
push    0
push    offset aNotepad ; "Notepad"
lea     ecx, [ebp+string_window_text]
;   try {
mov     dword ptr [ebp+new_title_buffer+3Ch], 0
call    string_find
cmp     eax, 0FFFFFFFFh
jz      short loc_100058B9
```

```
push    0
push    offset aSecretConsole ; "secret_console"
lea     ecx, [ebp+string_window_text]
call    string_find
cmp     eax, 0FFFFFFFFh
jz      short loc_100058B9
```

Figure 43: Strings "**Notepad**" and "**secret_console**" are searched in window title

If the **substrings are both present**, the window's title is **replaced by the hardcoded string "Secret Console is waiting for the commands..."**, using the **SendMessageA** API along with the WM_SETTEXT message. The window is **placed to the foreground**, using the **ShowWindow** API call.

```
lea     eax, [ebp+new_title_buffer]
push    eax             ; lParam
push    esi             ; wParam
push    WM_SETTEXT      ; Msg
push    edi             ; hWnd
call    ds:SendMessageA
push    SW_SHOW         ; nCmdShow
push    edi             ; hWnd
call    ds:ShowWindow
```

Figure 44: Modification of the window title using SendMessageA()

The **PID** of the process corresponding to the window is then **written in the "malware"'s console**, and **sub-windows of this window are enumerated**, using the EnumChildWindows[13] API.The function **EnumChildWindowsCallback** (0x100034C0) is thus called on every sub-window.

[13] https://msdn.microsoft.com/fr-fr/library/windows/desktop/ms633494(v=vs.85).aspx

```
lea     eax, [ebp+dwProcessId]
mov     [ebp+dwProcessId], 0
push    eax             ; lpdwProcessId
push    edi             ; hWnd
call    ds:GetWindowThreadProcessId
push    offset aWaitingForTheC ; ": waiting for the command"
push    [ebp+dwProcessId]
mov     ecx, offset ios_base_struct
call    string_from_int
push    eax
call    string_concat
push    eax
call    print_console
add     esp, 0Ch
push    [ebp+lParam]    ; lParam
push    offset EnumChildWindowsCallback ; lpEnumFunc
push    edi             ; hWndParent
call    ds:EnumChildWindows
```

Figure 45: EnumChildWindows() function call

4.2.9 EnumChildWindowsCallback function (0x100034C0)

This function gets the content of the sub-window using the **SendMessageA** API call:

```
lea     eax, [ebp+window_text_buffer]
push    eax             ; lParam
push    104h            ; wParam
push    WM_GETTEXT      ; Msg
push    esi             ; hWnd
call    ds:SendMessageA ; get the content of the sub-window
lea     ecx, [ebp+window_text_buffer]
mov     [ebp+var_11C], 0
mov     [ebp+var_118], 0Fh
lea     edx, [ecx+1]
mov     byte ptr [ebp+window_text_buffer_], 0
```

Figure 46: SendMessageA() call in EnumChildWindowsCallback() function

The substring "**dump_the_key**" is then **searched in the retrieved content**:

```
sub     ecx, edx
lea     eax, [ebp+window_text_buffer]
push    ecx
push    eax
lea     ecx, [ebp+window_text_buffer_]
call    string_constructor
push    0
push    offset aDumpTheKey ; "dump_the_key"
lea     ecx, [ebp+window_text_buffer_]
;   try {
mov     [ebp+var_4], 0
call    string_find
cmp     eax, 0FFFFFFFFh
jz      loc_1000368B
```

Figure 47: String "dump_the_key" is searched in window content

If this string is found, this function **calls a decryption routine decrypt_buffer()** (0x100016F0) on a buffer (**encrypted_buff**), using the string **"dump_the_key"** as argument.

```
push    269h
push    offset encrypted_buff
push    offset aDumpTheKey ; "dump_the_key"
lea     ecx, [ebp+var_144]
;   } // starts at 1000356C
;   try {
mov     byte ptr [ebp+var_4], 1
call    decrypt_buffer
push    offset LibFileName ; "actxprxy.dll"
decrypted_buffer = edi
mov     decrypted_buffer, eax
```

Figure 48: Decrypting a hardcoded buffer using "dump_the_key" as the key

Then, the "malware" loads the **actxprxy.dll** library into the process memory space. The first **4096 bytes** (i.e. the first memory page) of the library is made **writable** using the **VirtualProtect** API call, and **the decrypted payload is written at this location**.

```
call    ds:LoadLibraryA ; loads "actxprxy.dll" in process address space
actxprxy_dll_addr = esi
mov     actxprxy_dll_addr, eax
test    actxprxy_dll_addr, actxprxy_dll_addr
jz      short loc_1000364C

lea     eax, [ebp+flOldProtect]
mov     [ebp+flOldProtect], 0
push    eax                 ; lpflOldProtect
push    PAGE_READWRITE      ; flNewProtect
push    4096                ; dwSize
push    actxprxy_dll_addr   ; lpAddress
call    ds:VirtualProtect ; makes actxprxy.dll first memory page writable
test    eax, eax
jz      short loc_1000364C

push    269h                ; num
push    decrypted_buffer ; src
push    actxprxy_dll_addr ; dst
call    memcpy              ; copy decrypted buffer at the start of "actxprxy.dll" address space
add     esp, 0Ch
```

Figure 49: Loading a library and writing the decrypted_buffer at its location

Since the **actxprxy.dll** library is not used anywhere in the analyzed DLL after being re-written, it may be seen as a **covert communication channel** between the analyzed DLL and the main program **mb_crackme_2.exe**.

After this, the function **clears every allocated memory** and **exits**. The **created thread** (see 4.2.6) therefore also **exits**, and the **DllEntryPoint** function call terminates, giving the control **back to the main python script**.

4.3 Triggering the secret console

As seen in the DLL analysis, to trigger the required conditions, a file named "**secret_console – Notepad**" is opened in a text editor. As such, the window title **contains the mentioned substrings**:

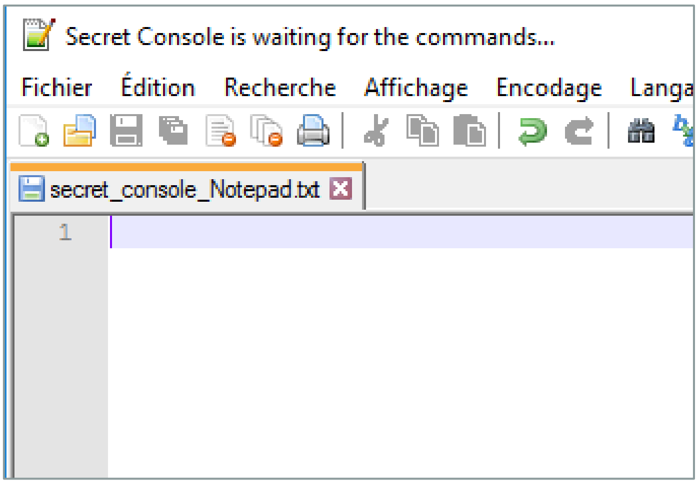


Figure 50: Opening a file named "secret_console_Notepad.txt" on Notepad++

As expected, **the title of the window is changed to "Secret Console is waiting for the commands…"** by the malware. Writing "dump_the_key" in the window **validates the second stage**.

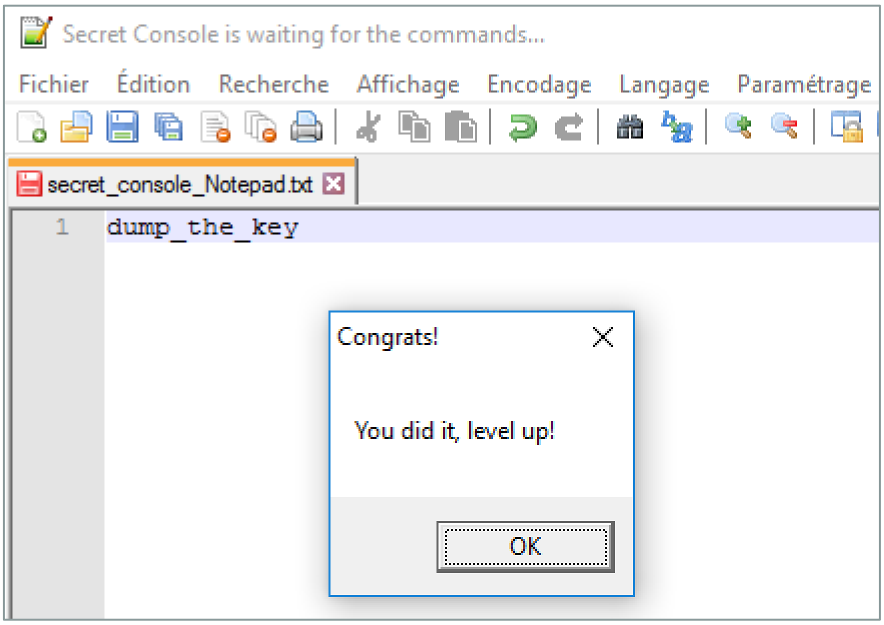


Figure 51: Writing "dump_the_key" in the text editor

5 Stage 3: the colors

After validating the previous step, a message is printed on the console, asking the user to "**guess a color**":

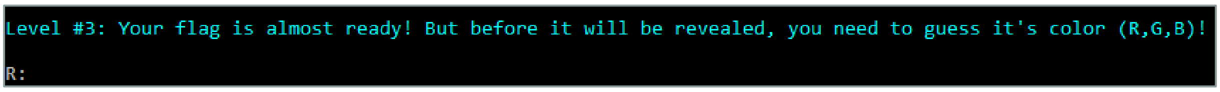


Figure 52: Level 3 message

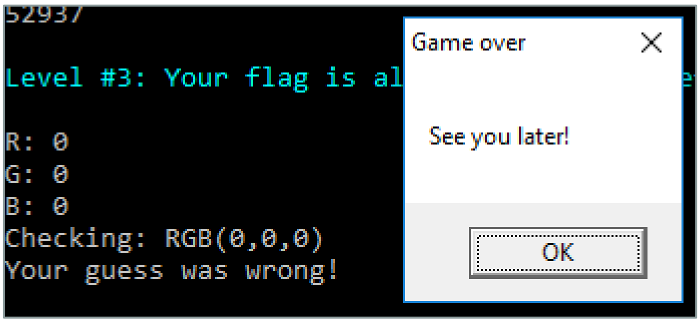


Figure 53: Level 3 failed guess message

The three components (R, G and B) of a specific color, whose values each vary between 0 and 255, need to be entered to validate this step.

5.1 Understanding the code

Looking back at the **another.py**'s **main()** function code, it seems that the corresponding operations are performed inside the **decode_pasted()** function.

```
def main():
   [...]
      load_level2(decdata, len(decdata))
      user32_dll.MessageBoxA(None, 'You did it, level up!', 'Congrats!', 0)
      try:
         if decode_pasted() == True:
            user32_dll.MessageBoxA(None, 'Congratulations! Now save your flag and
send it to Malwarebytes!', 'You solved it!', 0)
            return 0
```

Figure 54: Extract from main() function

```python
def decode_pasted():
    my_proxy = kernel_dll.GetModuleHandleA('actxprxy.dll')
    if my_proxy is None or my_proxy == 0:
        return False
    else:
        char_sum = 0
        arr1 = my_proxy
        str = ''
        while True:
            val = get_char(arr1)
            if val == '\x00':
                break
            char_sum += ord(val)
            str = str + val
            arr1 += 1

        print char_sum
        if char_sum != 52937:
            return False
        colors = level3_colors()
        if colors is None:
            return False
        val_arr = zlib.decompress(base64.b64decode(str))
        final_arr = dexor_data(val_arr, colors)
        try:
            exec final_arr
        except:
            print 'Your guess was wrong!'
            return False

        return True

def dexor_data(data, key):
    maxlen = len(data)
    keylen = len(key)
    decoded = ''
    for i in range(0, maxlen):
        val = chr(ord(data[i]) ^ ord(key[i % keylen]))
        decoded = decoded + val

    return decoded
```

Figure 55: decode_pasted() function

```python
def level3_colors():
    colorama.init()
    print colorama.Style.BRIGHT + colorama.Fore.CYAN
    print "Level #3: Your flag is almost ready! But before it will be revealed, you
need to guess it's color (R,G,B)!"
    print colorama.Style.RESET_ALL
    color_codes = ''
    while True:
        try:
            val_red = int(raw_input('R: '))
            val_green = int(raw_input('G: '))
            val_blue = int(raw_input('B: '))
            color_codes += chr(val_red)
            color_codes += chr(val_green)
            color_codes += chr(val_blue)
            break
        except:
            print 'Invalid color code! Color code must be an integer (0,255)'

    print 'Checking: RGB(%d,%d,%d)' % (val_red, val_green, val_blue)
    return color_codes
```

Figure 56: level3_colors() function

According to the **decode_pasted()** function, the decrypted buffer stored at the start of **actxprxy.dll**'s address space is read and:

- **base64-decoded**;
- **zlib-decompressed;**
- **XOR'ed** against the user-provided **colors** values;
- **Executed** by the Python **exec** function.

To start our cryptanalysis, we modify the **decode_pasted()** function to dump the **val_arr** buffer before the **dexor_data()** operation, and rerun **another.py**, providing all required credentials:

```
[...]
if colors is None:
   return False
val_arr = zlib.decompress(base64.b64decode(str))
with open("val_arr.bin", "wb") as f:
   f.write(val_arr)
   print "val_arr dumped !"
exit()
final_arr = dexor_data(val_arr, colors)
[...]
```

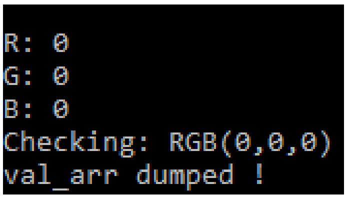


Figure 57: Dumping the xor'ed array

5.2 Decrypting the val_arr buffer

Knowing that the buffer is a **string** passed to the "exec" Python statement after being decrypted, it should **represent a valid Python source code**.

To find the right key, the **naïve solution** would be to run a **brute-force attack on all the possible "(R, G, B)" combinations**, and look for printable solutions. This solution would need to perform 256^3 = 16'777'216 **dexor_data()** calls, which is practically feasible but **inefficient**.

Instead, we perform **3 independent brute-force attacks** on each R, G and B component, therefore performing 256 x 3 = **768 dexor_data()** calls. The 3 brute-force attacks are performed on different "slices" of the **val_arr** string (of each of stride 3). We then **test each combination** of potential values previously found for each component.

For example, if our 3 brute-force attacks indicate that:

- **R** can take values **2** and **37**,
- **G** can take values **77** and **78**,
- and **B** can only take the value **3,**

Then we test the combinations **(2,77, 3)**, **(37,77, 3)**, **(2,78, 3)** and **(37,78, 3)**.

The following code implements our attack:

```
import string
import itertools
from colorama import *
from another import dexor_data

with open("val_arr.bin", "rb") as f:
    val_arr = f.read()

#lists of possible values for R, G and B
potential_solutions = [list(), list(), list()]
for color in range(3): # separate bruteforce on R, G and B
    for xor_value in range(256): #testing all potential values
        valid = True
        for b in val_arr[color::3]: #extracting one every 3 characters, from index
"color" (i.e. extracting all characters xored by the same "color" value)
            if chr(ord(b) ^ xor_value) not in string.printable:
                valid = False
                break
        if valid:
            potential_solutions[color].append(xor_value)

print "Possible values for R, G and B :", potential_solutions

for colors in itertools.product(*potential_solutions):
    print "Testing ", colors
    plaintext = dexor_data(val_arr, map(chr, colors))
    print repr(plaintext)
    if not raw_input("Does it seems right ? [Y/n]\n").startswith("n"):
       print "Executing payload :"
       exec plaintext
       break
```

Executing this code gives us the solution instantly:

```
C:\no_scan\malwarebyte_challenge>python decrypt_val_arr.py
Possible values for R, G and B : [[128, 131], [0], [128]]
Testing  (128, 0, 128)
'def print_flag():\r\n\tflag_hex = ( 0x73, 0x75, 0x72, 0x64, 0x65, 0x61, 0x68, 0x50, 0x20, 0x2D, 0x20, 0x22,0x2E, 0x6
E, 0x65, 0x64, 0x64, 0x69, 0x68, 0x20, 0x79, 0x6C, 0x6C, 0x75, 0x66, 0x65, 0x72, 0x61, 0x63, 0x20, 0x6E, 0x65, 0x65,
0x62, 0x20, 0x73, 0x61, 0x68, 0x20, 0x74, 0x61, 0x68, 0x77, 0x20, 0x73, 0x65, 0x76,\t0x69, 0x65, 0x63, 0x72, 0x65, 0x
70, 0x20, 0x77, 0x65, 0x66, 0x20, 0x61,\t0x20, 0x66, 0x6F, 0x20, 0x65, 0x63, 0x6E, 0x65, 0x67, 0x69, 0x6C, 0x6C,\t0x6
5, 0x74, 0x6E, 0x69, 0x20, 0x65, 0x68, 0x74, 0x20, 0x3B, 0x79, 0x6E,\t0x61, 0x6D, 0x20, 0x73, 0x65, 0x76, 0x69, 0x65,
 0x63, 0x65, 0x64, 0x20,\t0x65, 0x63, 0x6E, 0x61, 0x72, 0x61, 0x65, 0x70, 0x70, 0x61, 0x20, 0x74,\t0x73, 0x72, 0x69,
0x66, 0x20, 0x65, 0x68, 0x74, 0x20, 0x3B, 0x6D, 0x65,\t0x65, 0x73, 0x20, 0x79, 0x65, 0x68, 0x74, 0x20, 0x74, 0x61, 0x
68, 0x77,\t0x20, 0x73, 0x79, 0x61, 0x77, 0x6C, 0x61, 0x20, 0x74, 0x6F, 0x6E, 0x20,0x65, 0x72, 0x61, 0x20, 0x73, 0x67,
 0x6E, 0x69, 0x68, 0x54, 0x22 )\r\n\tflag_str = ""\r\n\tfor i in flag_hex:\r\n\t\tflag_str = chr(i) + flag_str\r\n\ti
nit()\r\n\tprint(Style.BRIGHT + Back.MAGENTA) + "flag{"  + flag_str + "}" + (Style.RESET_ALL)\r\nprint_flag()\r\n'
Does it seems right ? [Y/n]

Executing payload :
flag{"Things are not always what they seem; the first appearance deceives many; the intelligence of a few perceives w
hat has been carefully hidden." - Phaedrus}
```

Figure 58: Decrypting the payload

The final flag appears in the console:

```
flag{"Things are not always what they seem; the first appearance deceives many; the
intelligence of a few perceives what has been carefully hidden." - Phaedrus}
```

6 Conclusion

This challenge was **very interesting to solve**, because apart from being an **original crackme**, it also included various topics that could be found **during a real malware analysis**. These topics included:

- **DLL-rewriting** techniques, here used as a kind of covert communication channel between a DLL and its main process;
- **"Non-obvious" anti-debugging tricks**, like checking the presence of a known library in the process' memory space to identify standalone DLL debugging;
- **Concealed malware downloading**, using « harmless » formats (like PNG) to hide an executable payload from basic traffic analysis;
- **PyInstaller-based malware,** (yes, sometimes malware writers can be lazy).

Thanks MalwareByte for this entertaining challenge!