Buer Loader Analysis, a Rusted malware program

tehtris.com/en/blog/buer-loader-analysis-a-rusted-malware-program

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Malware analysis is part of the CTI team's daily routine. This article presents the analysis of a Rust strain of Buer Loader from the reception of the samples to the writing of a stage2* extraction script. Despite several protection mechanisms, it was possible to extract all the samples in different ways. TEHTRIS provides the code for such an extraction.

Summary

Introduction

The Rust language [1] is more and more used [2] by developers. Indeed, the philosophy of this language is to maximize security while offering performances close to C++ in a pleasant syntax. Many ambitious projects like Kerla [3] aim at offering an operating system that is compatible with any Linux binary, without modification. This gives Rust a lot of credibility and explains its adoption by developers. From a low-level point of view, this language generates a more complex binary code to sign and analyze compared to C by offering more instructions and adding obfuscation at low cost, which is of interest to malware authors.

If still few adopt it, it is however not surprising to note that this language is starting to make a name for itself in the malware bestiary, as shown by Buer Loader [3] which includes variants developed in this language.

If this malware program has already been analyzed [3], it remains interesting to study its “stage1*” to identify the protection mechanisms and the evolutions concerning its obfuscation over time. Indeed, sandbox bypass techniques [5] and memory loading of offended binaries [6] by an unknown mechanism have been observed. This was enough to trigger the interest of a retro-analysis of the loader in question.

The goal is to characterize and extract the main load of the malware that was specifically spotted in computing environments between July and August 2021.

An emulation-based extraction method was presented at the Hack-It-N conference in December 2021. A replay of the presentation is available on Youtube [16].

Analysis

The retrieved samples work on the same model, i.e. a base in Rust loading in memory a stage2, itself written in Rust. Here is the list of these samples:

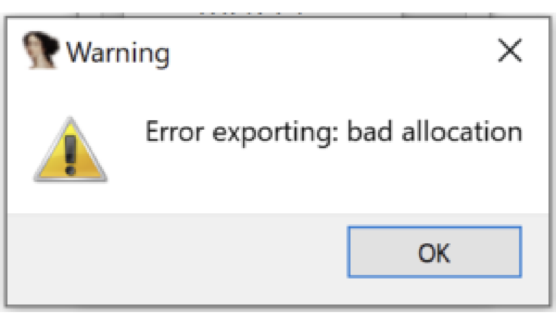
Sha256	Compile time	Size
001405ded84e227092bafe165117888d423719d7d75554025ec410d1d6558925	2021-07-28 17:59:19	3.4 MB
4421dbc01ddc5ed959419fe2a3a0f1c7b48f92b880273b481eb249cd17d59b91	2021-08-11 15:35:55	6.6 MB
52d8316b0765c147558aecbda686d076783f3a08b2741b8c9e3e717cc56e8a92	2021-07-19 13:57:22	7.3 MB
580d55f1e51465b697d46e67561f3161d4534a73e8aa47e18b9bae344d46bcf4	2021-07-19 13:57:22	7.3 MB
578dc62dfa0203080da262676f28c679114d6b1c90a4ab6c07b736d9ce64e43e	2021-07-15 16:28:54	7.1 MB
5ac6766680c8c06a4b0b4e6a929ec4f5404fca75aa774f3eb986f81b1b30622b	2021-08-05 14:47:25	4.9 MB

64dd547546394e1d431a25a671892c7aca9cf57ed0733a7435028792ad42f4a7	2021-08-16 18:54:29	4.1 MB
88689636f4b2287701b63f42c12e7e2387bf4c3ecc45eeb8a61ea707126bad9b	2021-08-03 15:46:42	3.3 MB
afb5cbe324865253c7a9dcadbe66c66746ea360f0cd184a2f4e1bbf104533ccd	2021-06-25 17:49:48	7.1 MB
c425264f34fa8574c7e4321020eb374b9364a094cda9647e557b97d5e2b8c17b	2021-08-16 18:54:29	4.1 MB
d3a486d3b032834b1203adefd25d0bf0b36fae7f9e72071c21ccc266e1e1f893	2021-07-19 14:14:54	4.3 MB

The compilation dates seem consistent with each other. Indeed, they match approximately the submission dates on Virus Total [15] (with a small delay). The binaries are stripped (i.e. symbols unnecessary for the binary to work have been removed, especially function names and debugging symbols) but still contain information about the used source code:

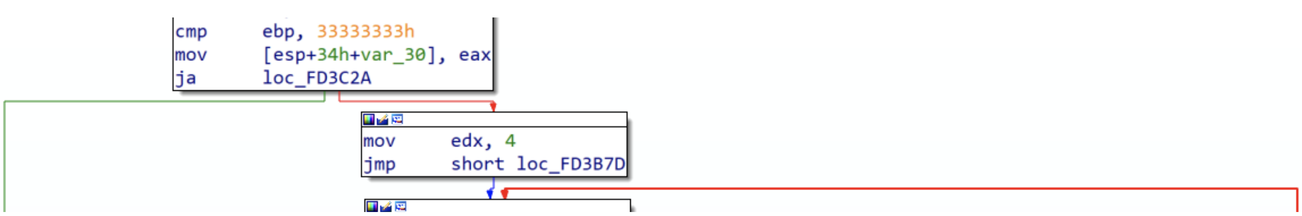
```
user@user-virtual-machine:/dev/shm$ strings 88689636f4b2287701b63f42c12e7e2387bf4c3ecc45eeb8a61ea707126bad9b.exe | grep '^src.*rs$'
src\defence.rs
src\main.rs
```

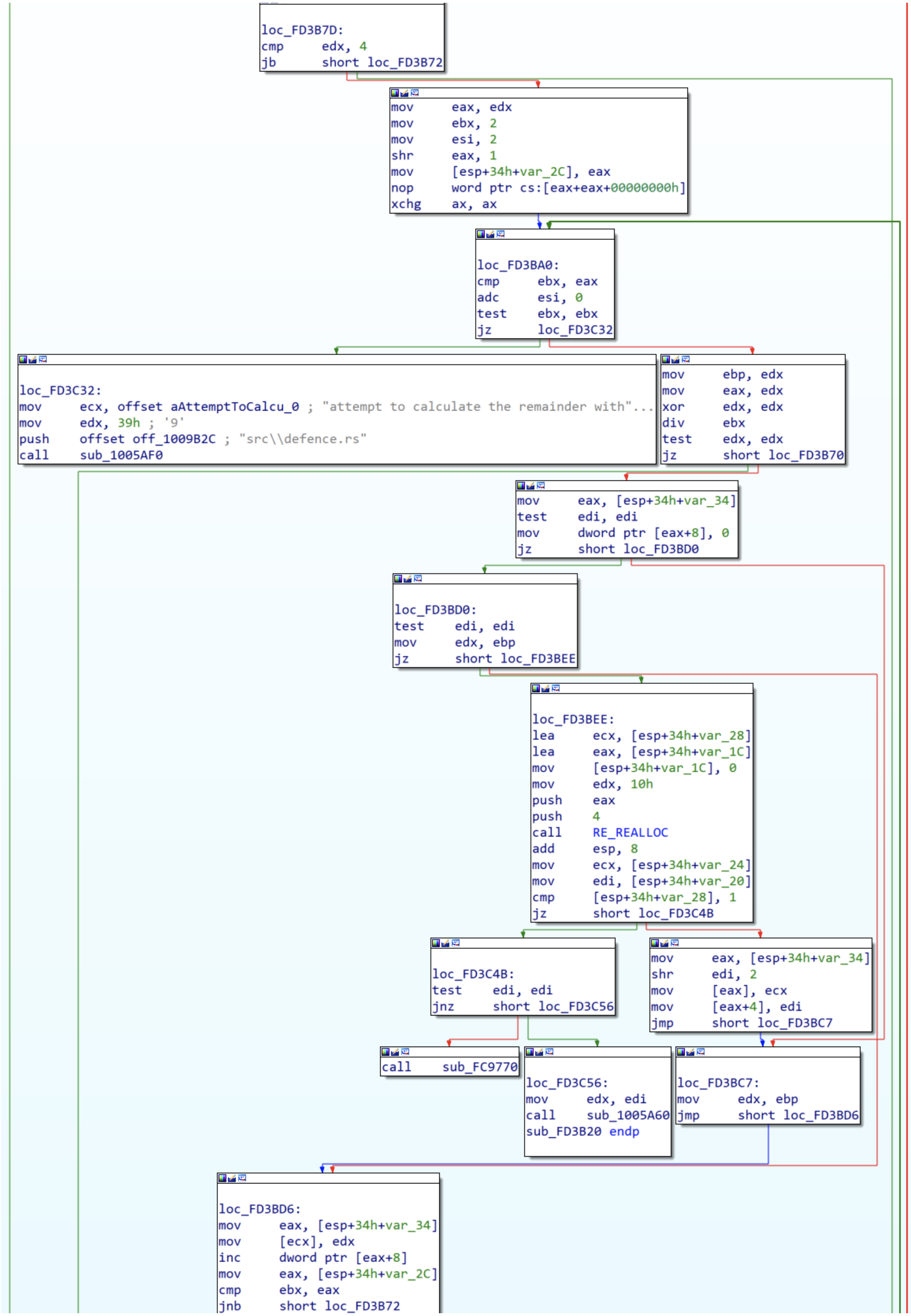
Unfortunately, BinDiff [7] is not able to compare binaries. The control flow is too complex for it. Therefore, the code comparisons were done manually by our experts.

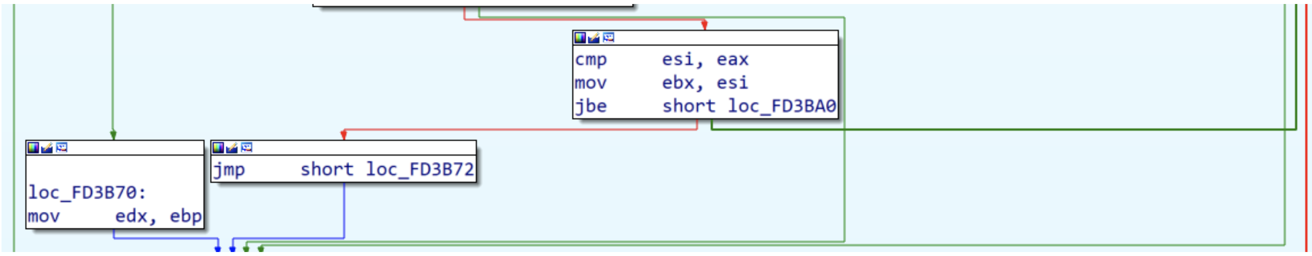


BinDiff error

Our analysis determined that there seem to be only 2 source files outside of the open source (mainly cryptographic) libraries used. A first anti-sandbox technique consists in wasting time by performing an unnecessary loop. The order of magnitude of the time needed (and lost) is about one minute with a 100% occupied CPU.




loc_FD3B7D:
cmp edx, 4
jb short loc_FD3B72
mov eax, edx
mov ebx, 2
mov esi, 2
shr eax, 1
mov [esp+34h+var_2C], eax
nop word ptr cs:[eax+eax+00000000h]
xchg ax, ax
loc_FD3BA0:
cmp ebx, eax
adc esi, 0
test ebx, ebx
jz loc_FD3C32
loc_FD3C32:
mov ecx, offset aAttemptToCalcu_0 ; "attempt to calculate the remainder with"...
mov edx, 39h ; '9'
push offset off_1009B2C ; "src\\defence.rs"
call sub_1005AF0
mov ebp, edx
mov eax, edx
xor edx, edx
div ebx
test edx, edx
jz short loc_FD3B70
mov eax, [esp+34h+var_34]
test edi, edi
mov dword ptr [eax+8], 0
jz short loc_FD3BD0
loc_FD3BD0:
test edi, edi
mov edx, ebp
jz short loc_FD3BEE
loc_FD3BEE:
lea ecx, [esp+34h+var_28]
lea eax, [esp+34h+var_1C]
mov [esp+34h+var_1C], 0
mov edx, 10h
push eax
push 4
call RE_REALLOC
add esp, 8
mov ecx, [esp+34h+var_24]
mov edi, [esp+34h+var_20]
cmp [esp+34h+var_28], 1
jz short loc_FD3C4B
loc_FD3C4B:
test edi, edi
jnz short loc_FD3C56
mov eax, [esp+34h+var_34]
shr edi, 2
mov [eax], ecx
mov [eax+4], edi
jmp short loc_FD3BC7
call sub_FC9770
loc_FD3C56:
mov edx, edi
call sub_1005A60
sub_FD3B20 endp
loc_FD3BC7:
mov edx, ebp
jmp short loc_FD3BD6
loc_FD3BD6:
mov eax, [esp+34h+var_34]
mov [ecx], edx
inc dword ptr [eax+8]
mov eax, [esp+34h+var_2C]
cmp ebx, eax
jnb short loc_FD3B72



Anti-sandbox by waste of time

After passing through this loop, we arrive at the decryption function of stage2. This one contains a large number of successive calls to useless functions, among which we find:

- **GetCommandLineA;**
- **GetCurrentProcess;**
- **GetEnvironmentStrings;**
- **GetLastError;**
- **GetProcessHeap;**
- **GetTickCount;**

It is probably a saturation mechanism using calls (call to a Windows library) and not taking any argument to override possible sandboxes, which complicates code emulation. It seems that a script generates all the calls. This technique also has the advantage of adding a credible call/instruction ratio compared to a legitimate program. Counting the calls sometimes allows to find decryption or unpacking routines:

```
sub_401000 proc near
push    esi
mov     esi, ecx
call    GetTickCount
call    GetEnvironmentStrings
call    GetCurrentProcess
call    GetCommandLineA
call    GetLastError
call    GetCurrentProcess
call    GetLastError
call    GetVersion
call    GetCurrentProcess
call    GetProcessHeap
call    GetEnvironmentStrings
call    GetCurrentProcess
call    GetCommandLineA
```

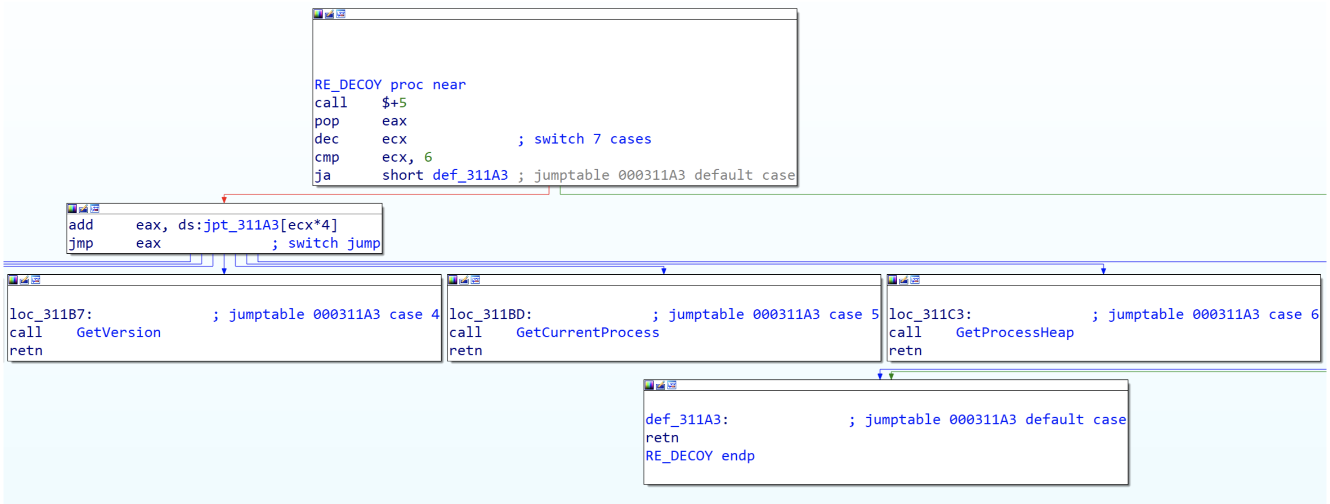
```
call    GetLastError
call    GetVersion
call    GetEnvironmentStrings
call    GetTickCount
call    GetTickCount
call    GetCurrentProcess
call    GetTickCount
call    GetLastError
call    GetCurrentProcess
call    GetCommandLineA
call    GetVersion
call    GetCommandLineA
call    GetProcessHeap
call    GetTickCount
call    GetProcessHeap
call    GetCommandLineA
call    GetCommandLineA
call    GetEnvironmentStrings
call    GetTickCount
call    GetCommandLineA
call    GetLastError
call    GetLastError
call    GetVersion
call    GetCurrentProcess
call    GetTickCount
call    GetTickCount
call    GetTickCount
call    GetLastError
call    GetProcessHeap
call    GetEnvironmentStrings
call    GetCurrentProcess
call    GetProcessHeap
```

Decoys variant 1

```
call    GetTickCount
call    GetTickCount
call    GetEnvironmentStrings
call    GetProcessHeap
call    GetCurrentProcess
call    GetCurrentProcess
```

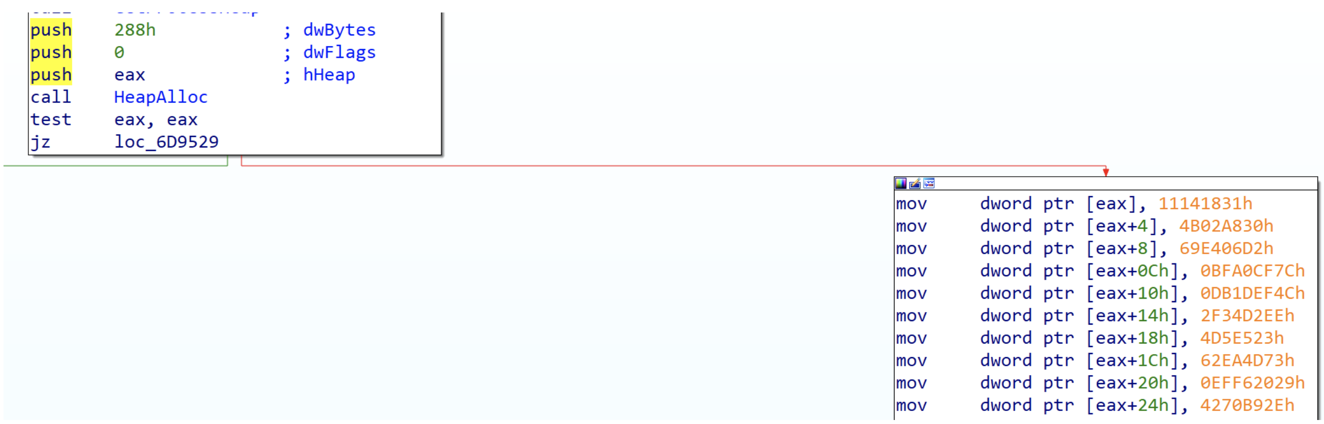
```
push    ebx
push    edi
push    esi
sub     esp, 18h
mov     esi, [esp+24h+arg_0]
lea     edi, [esp+24h+var_18]
mov     ecx, edi
call    sub_31080
mov     ebx, esp
mov     ecx, ebx        ; int
call    sub_311F0
mov     ecx, edi
mov     edx, ebx
call    sub_31110
mov     ecx, ebx
call    sub_31000
mov     ebx, esp
mov     ecx, ebx        ; int
call    sub_35C90
mov     ecx, edi
mov     edx, ebx
call    sub_31110
mov     ecx, ebx
call    sub_31000
mov     ebx, esp
mov     ecx, ebx        ; int
call    sub_36CC0
mov     ecx, edi
mov     edx, ebx
call    sub_31110
mov     ecx, ebx
call    sub_31000
```

```
push    esi
sub     esp, 0AACh
mov     esi, ecx
mov     ecx, 1
call    RE_DECOY
mov     ecx, 3
call    RE_DECOY
mov     ecx, 2
call    RE_DECOY
mov     ecx, 2
call    RE_DECOY
mov     ecx, 7
call    RE_DECOY
mov     ecx, 2
call    RE_DECOY
mov     ecx, 7
call    RE_DECOY
mov     ecx, 2
call    RE_DECOY
mov     ecx, 4
call    RE_DECOY
mov     ecx, 6
call    RE_DECOY
```



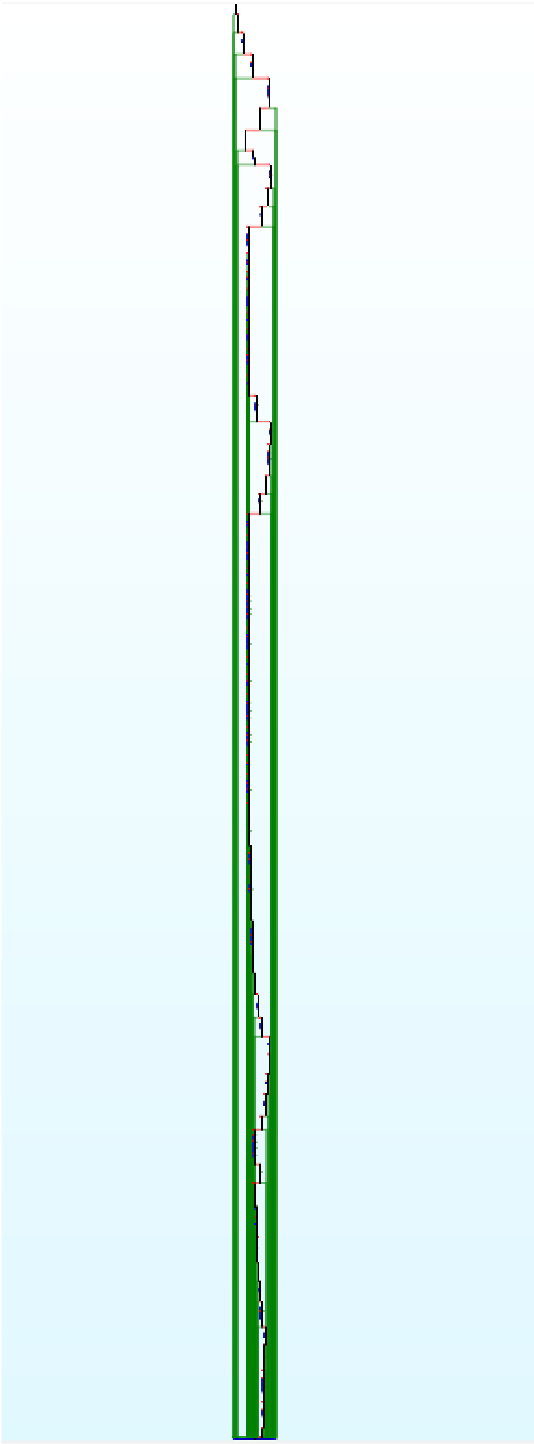
Decoys variant 2

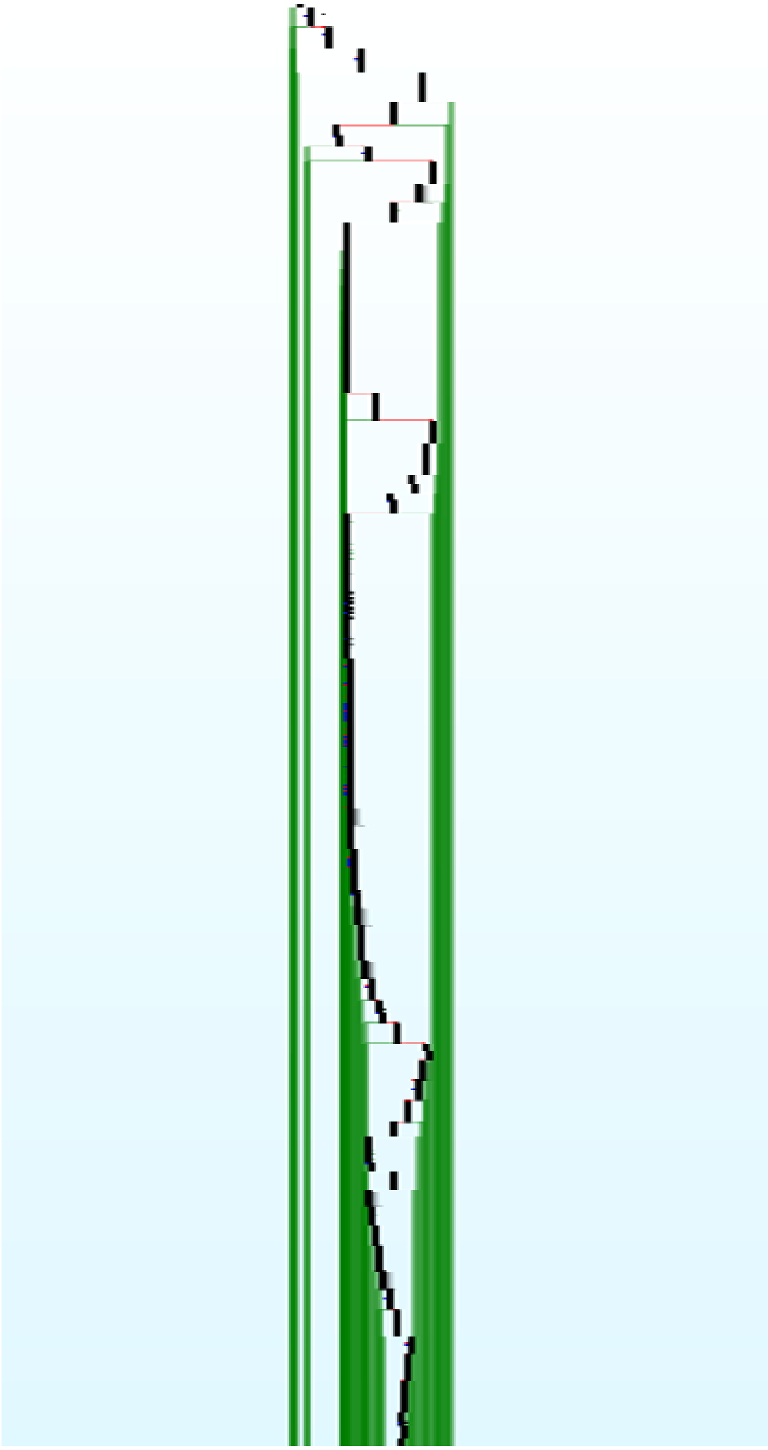
These calls are repeated throughout the desobfuscation routine. The data are successively pushed on the stack, then in the heap with the help of kernel32 !HeapAlloc, in the form of DWORD:



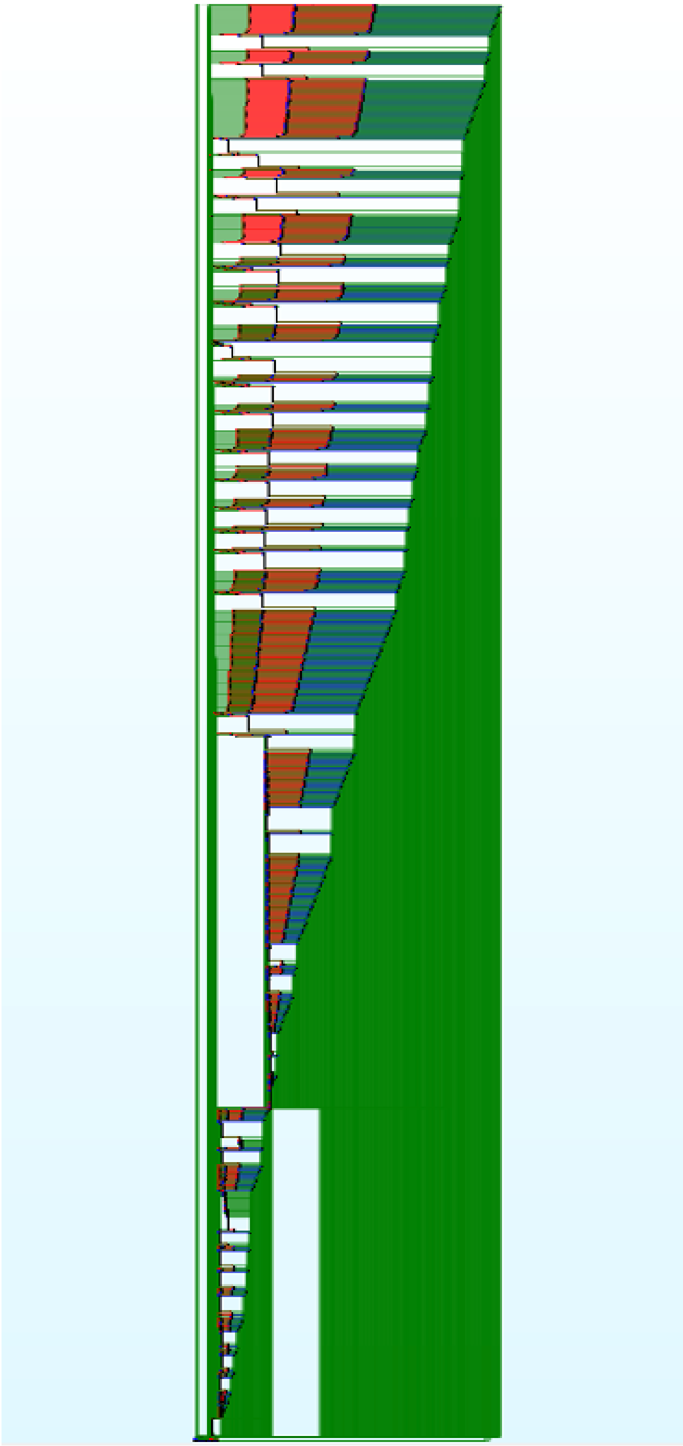
Stage2 buffer reconstruction

The call graph is very different across samples, reinforcing our hypothesis that the code is generated from a script. The mix of calls and desobfuscation involves a special effort to blend in a behavior that appears to be legitimate.


Control flow Variant1

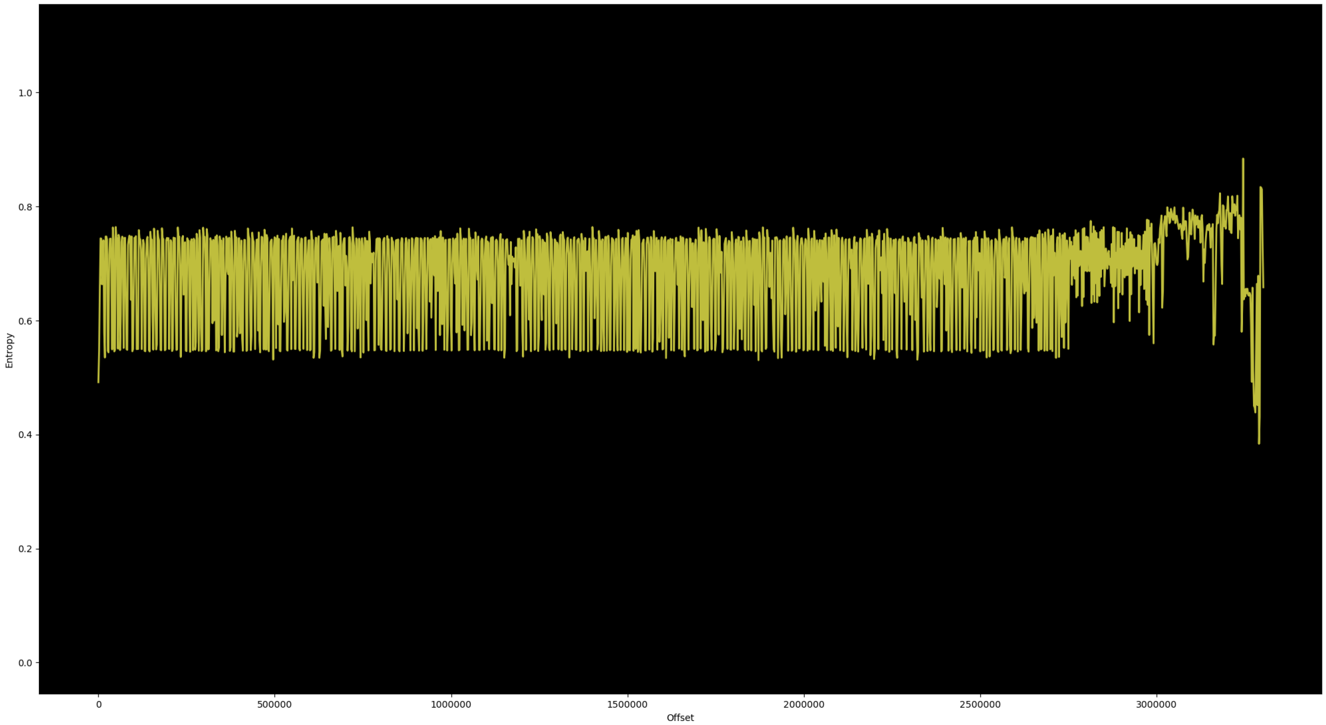


Control flow Variant2



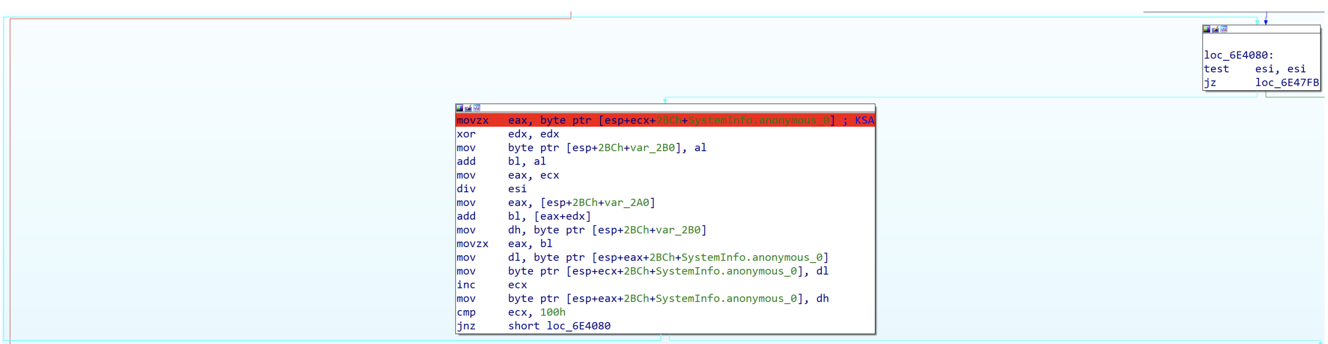
Control flow Variant3

This technique allows to include binary data by limiting the entropy between 0.5 and 0.8, very close to what one would expect from legitimate instructions.

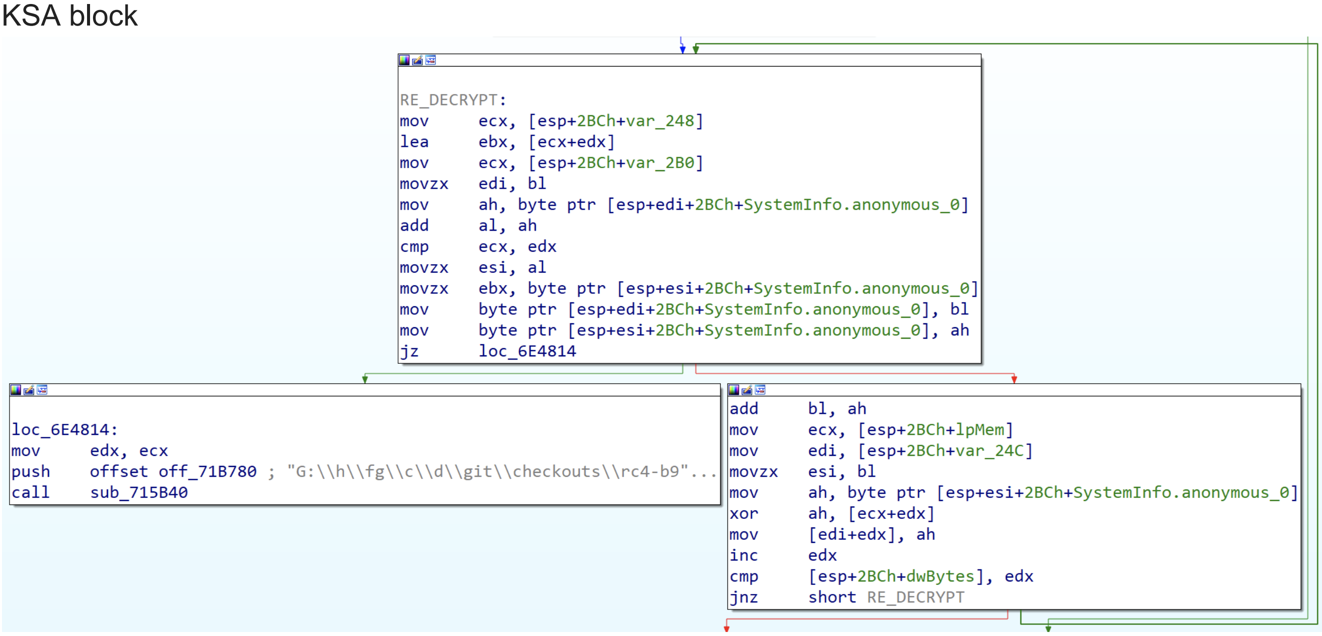


Entropy of the malware program

This data, once reconstituted, is placed in a buffer which is decrypted. We then recognize a Key Schedule type mechanism, followed by a generator reminiscent of RC4:



KSA block



RC4 Random generator

The Rust paradigm makes these decryption routines difficult to identify. Tools such as findcrypt [8] do not detect them. The following check identifies the entire desobfuscation chain:

```
>>> magic.from_buffer(ARC4.new(b"DQOQHMLGYU").decrypt(binascii.unhexlify('31 18 14 11 30 A8 02 4B D2 06 E4 69 7C CF A0 BF 4C EF 1D DB EE D2 34 2F 23
 E5 D5 04 73 4D EA 62 29 20 F6 EF 2E B9 70 42 7D 0E 15 89 B6 71 7B 4D'.replace(' ', ''))))
'LZMA compressed data, non-streamed, size 1249792'
```

Decryption in python

The decompression is performed by the version 0.1.3 of the lzma-rs library [9], and the decryption keys are easily visible in the code. The following script allows its extraction:

```python
def get_rc4_key() -> Tuple[int, bytes]:
    """Extract RC4 key. Return tuple: keyoffset VA, keyval"""
    try:
        segstart, seglen = [(idc.get_segm_start(x), idc.get_segm_end(x) - idc.get_segm_start(x)) for x in idautils.Segments() if idc.get_segm_name(x) == ".rdata"][0]
        keyoffset = re.search(rb'[A-Z]{10}capacity overflow', idc.get_bytes(segstart, seglen)).start() + segstart
        return keyoffset, idc.get_bytes(keyoffset, 10)
    except (KeyError, AttributeError):
        return 0, b''
```

Key extraction script

The list of RC4 keys for the samples is as follows:

- **YDVHHCYTCH ;**
- **DQOQHMLGYU ;**
- **BWSCVQZXOB ;**
- **SIMHIDVSCR ;**
- **RGZPMAAQRP ;**
- **YVMOOVSIOF ;**
- **KSQKGUUTXZ ;**
- **EUWPUQYDTT ;**
- **KHBXNNHKNN ;**

Unfortunately, the number of keys is insufficient to evaluate the quality of the PRNG [10]. Note that the charset is very small, which does not matter since the key is in plain text in the ".rdata" section. Given the extremely variable and complex call graph, writing a generic data extraction script that works for all samples is tedious. Now that we know the key (cf. previous extraction script), we need to find the encrypted data. These, once desobfuscated, have a header with invariant data:

```
04066000  00 E0 0C 06 9C 00 89 00 00 00 00 00 00 00 00 00  .à..............
04066010  00 40 0B 00 00 B0 0B 00 2E F5 39 D8 00 00 00 04  .@...°...õ9Ø....
04066020  31 18 14 11 30 A8 02 4B D2 06 E4 69 7C CF A0 BF  1...0¨.KÒ.äi|Ï ¿

041D3000  9C 00 A8 00 9C 00 A8 00 00 00 00 00 00 00 00 00  ..¨...¨.........
041D3010  00 B0 0A 00 00 F0 0A 00 0A 16 96 88 00 00 00 04  .°...ð..........
041D3020  B5 8D 1E 7E 5C 88 FD 56 EB 48 30 D1 72 BD DC A5  µ..~\.ýVëH0Ñr½Ü¥

07301000  9C 00 C1 00 9C 00 C1 00 00 00 00 00 00 00 00 00  ..Á...Á.........
07301010  00 80 0F 00 00 A0 0F 00 06 27 1B 75 00 00 00 04  ..... ...'.u....
07301020  52 C6 F3 9E 73 9F B4 1A F0 45 43 78 FB FB A1 9B  RÆó.s.´.ðECxûû¡.
```

3 blocks of encrypted buffer header

The following script then allows to find the extracted data in memory, provided that the program has performed the decryption phase by carrying out an Egg-hunting search:

```python
def find_segment() -> bytes:
    """Go throw all the segments until we find encrypted data"""
    for segment in idautils.Segments():
        seglen = idc.get_segm_end(segment) - idc.get_segm_start(segment)
        if idc.get_segm_name(segment).startswith("debug") and seglen > 1024 * 100:
            header = idc.get_bytes(idc.get_segm_start(segment), 32)
            if header[8:16] == b"\x00" * 8 and header[28:] == b"\x00\x00\x00\x04":
                data = idc.get_bytes(idc.get_segm_start(segment) + 32, seglen - 32)
                return data
    return b""
```

Encrypted data recovery script

The only thing missing to automate the extraction is to find an address or to set a breakpoint, which is done in a fairly logical way by finding the references to the RC4 key:

```python
def go_to_decrypt(offset: int) -> bool:
    """Run the debugger until we reach an offset where the key has been decrypted"""
    try:
        reference = [x.frm for x in idautils.XrefsTo(offset)][0]
    except AttributeError:
        return False
    print(f'Found reference: {hex(reference)}')
    if not ida_dbg.dbg_is_loaded():
        print("No debugger selected. Please select a debugger and restart script")
        return False
    ida_dbg.exit_process()
    print("Have a cofee, it will take some time")
    ida_dbg.run_to(reference)
    ida_dbg.wait_for_next_event(ida_dbg.WFNE_SUSP, -1)
    return True
```

Malware launching script

And the script works on the first try for all samples. The source code of the tool is available on the TEHTRIS github [19].

An alternative method was presented at the Hack-it-N conference [16]. It consists in extracting the stage2 by emulation using the unicorn lib [17]. The source code is available on the TEHTRIS github [18].

The extraction of stage2 from the studied samples gives the following list:

Sha256	**Stage1 compile time**	**Stage 2 compile time**
edc3b5f8d45d7a1cceee144e57fc5ddfaf8c0c7407a1514d2f3bab4f3c9f18b8	2021-07-28 17:59:19	2021-07-28 17:39:31
d7ec38c0e89a749a7727e5644328835b50e19302e9f3a4688809403ebcbd03d2	2021-08-11 15:35:55	2021-08-11 15:30:38

6578db32dc78ef7f41213557cf894d03b97ed6974ae7a72bec9b7c7ac08c4ba9	2021-07-19 13:57:22	2021-07-19 13:44:11
d48d91451b9594eadc0d1ef6e379bbce9a6033bd337e06d46613a70187c9c5ef	2021-07-15 16:28:54	2021-07-15 16:20:18
54109b12cbbd223f5ad79a9f87bfe50ef05a80e5551a3c1931748c3698900496	2021-08-05 14:47:25	2021-08-05 14:38:43
2d8a2bcc45daedd343eadb4222885d12a221bebbf7f1d98f92cb233df0a4c1d4	2021-08-16 18:54:29	2021-08-16 18:45:22
16feaed6222ce4a1941ae0c32eabaf0ecf68c33c49544f71d431d1b70c4247fd	2021-08-03 15:46:42	2021-08-03 15:38:18
7af554fb260817350d33b801d9f0b8a638b831992f4b1b31c2bbdab875b211df	2021-06-25 17:49:48	2021-06-25 17:43:23
2d8a2bcc45daedd343eadb4222885d12a221bebbf7f1d98f92cb233df0a4c1d4	2021-08-16 18:54:29	2021-08-16 18:45:22
039d63a07372e6e17f9779ccffbafbf9a06a9402ade58fbec3b0b2f8d2038175	2021-07-19 13:57:22	2021-07-19 13:46:46

The timestamps seem coherent between themselves and we note that the compilation dates correspond with a gap of 5 to 10 minutes, suggesting a manual packing step.

We note that stage2 verifies the presence of a virtual machine by testing the presence of the following executables:

> vboxservice.exe ;
> vboxtray.exe ;
> vmtoolsd.exe ;
> vmwaretray.exe ;
> vmwareuser.exe ;
> vmacthlp.exe ;
> vmsrvc.exe ;
> vmusrvc.exe ;

> prl_cc.exe ;
> prl_tools.exe ;
> xenservice.exe ;
> qemu-ga.exe ;
> windanr.exe.

Once the desobfuscation step is done, the binary is no longer obfuscated and easily delivers its secrets. For example C2 [11]:

```
user@GIT:/mnt/hgfs/share/tocheck/buer/unknownrust/stage_2$ grep -raPo 'https?://\S([a-z0-9]+\.com)' | grep -v github
d3a486d3b032834b1203adefd25d0bf0b36fae7f9e72071c21ccc266e1e1f893_stage_2.exe:https://karbotza.com
c425264f34fa8574c7e4321020eb374b9364a094cda9647e557b97d5e2b8c17b_stage_2.exe:https://awmelisers.com
578dc62dfa0203080da262676f28c679114d6b1c90a4ab6c07b736d9ce64e43e_stage_2.exe:https://lebatyo.com
52d8316b0765c147558aecbda686d076783f3a08b2741b8c9e3e717cc56e8a92_stage_2.exe:https://gyuntae.com
64dd547546394e1d431a25a671892c7aca9cf57ed0733a7435028792ad42f4a7_stage_2.exe:https://awmelisers.com
88689636f4b2287701b63f42c12e7e2387bf4c3ecc45eeb8a61ea707126bad9b_stage_2.exe:https://cerionetya.com
4421dbc01ddc5ed959419fe2a3a0f1c7b48f92b880273b481eb249cd17d59b91_stage_2.exe:https://botesauke.com
afb5cbe324865253c7a9dcadbe66c66746ea360f0cd184a2f4e1bbf104533ccd_stage_2.exe:https://usergtarca.com
5ac6766680c8c06a4b0b4e6a929ec4f5404fca75aa774f3eb986f81b1b30622b_stage_2.exe:https://bostauherde.com
001405ded84e227092bafe165117888d423719d7d75554025ec410d1d6558925_stage_2.exe:https://vesupyny.com
```

List of C2 URLs

Or encrypts list of files constituting the source code:

```
user@GIT:/mnt/hgfs/share/git/gitlab/cti_sbx_src$ grep -aPo 'src\\(modules\\|client|\\collections||net\\|windows\\)?[a-z-0-9]+\.rs' /mnt/hgfs/share/tocheck/buer/unknownrust/stage_2/*exe | cut -d: -f2 |sort | uniq
src\aead.rs
src\agreement.rs
src\arrayvec.rs
src\body.rs
src\calendar.rs
src\check.rs
src\cipher.rs
src\cryptoutil.rs
src\dbghelp.rs
src\decoder.rs
src\decode.rs
src\decompose.rs
src\de.rs
src\digest.rs
src\encode.rs
src\env.rs
src\error.rs
src\fmt.rs
src\guts.rs
src\header.rs
src\hkdf.rs
src\hmac.rs
src\host.rs
src\legacy.rs
src\lib.rs
src\limb.rs
src\main.rs
src\modules\c2.rs
src\modules\defence.rs
src\modules\enc.rs
src\modules\identity.rs
src\modules\map.rs
src\name.rs
src\net\addr.rs
src\net\ip.rs
src\net\parser.rs
src\once.rs
src\panicking.rs
src\parser.rs
src\path.rs
src\pool.rs
src\prf.rs
src\punycode.rs
src\rand.rs
src\read.rs
src\request.rs
src\response.rs
src\ser.rs
src\session.rs
src\sha2.rs
src\slice.rs
src\stream.rs
src\string.rs
src\str.rs
src\suites.rs
src\testserver.rs
src\ticketer.rs
src\time.rs
src\ucstring.rs
src\ucstr.rs
src\unit.rs
src\uts46.rs
src\v0.rs
src\vecbuf.rs
src\verify.rs
src\windows\mod.rs
src\windows.rs
src\windows\winapi.rs
```

Source code metadata

The analysis of the stage2 has already been done, however, and we will not describe it here.

Conclusion

Evading automated malware detection systems is a balancing act between binary entropy, hiding encryption functions, slowing down the analysis time, obtaining a consistent call/instruction ratio…

The use of Rust adds a machine code overlay which is however much less than what a Go [12], delphi [13], cython [14], etc. compiler would do, making a manual analysis quite reasonable.

However, these techniques are no match for a reverser or a well-configured sandbox. The manual analysis of the most known and least traceable threats is a plus in the continuous improvement of our sandbox and EDR products. It is very likely that in the future, more and more malware programs will be developed in Rust.

* The use of stageN consists in separating the malware program into several specialized sub-parts in order to escape antivirus detection. In this case, stage1 is the malware program as sent to victims and stage2 is the payload encapsulated in stage1.

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