Practical applications for the Assembly language

Computer Systems Architecture

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Bitdefender

December 21st 2016

Agenda

1. Introduction
2. Assembly snippets in C code
3. Reverse engineering
4. Understanding exploits
5. Malware detection through disassembly
6. MBR and hypervisors

Agenda

Getting from here to there

```c
#include <stdio.h>

const char *msg = "Hello world!";

int main(void){
    printf("%s\n", msg);
    return 0;
}
```

```
55 8B EC A1 20 30 40 00    Uï¤í 0@
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A0 20 40 00 83 C4 08 33    á @ â—▬3
C0 5D C3 68 E8 13 40 00    └]├hè‼@
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55          U       push    ebp
8BEC        ïœ      mov     ebp, esp
A1 20304000 í 0@    mov     eax, [0x403020]
50          P       push    eax
68 E0204000 hα @    push    0x4020e0
FF15 A0204000  §á @ call  (1) [MSVCR100.dll:printf]
83C4 08     â─◘      add     esp, 0x8
33C0        3└      xor     eax, eax
5D          ]       pop     ebp
C3          ├─      ret
```

binary code →

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Assembly and binary code

Important

Computers only understand binary code.

- Assembly is a human-readable form of binary code.
- Assembly can be directly translated to binary **and vice-versa**.

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Compiled vs. interpreted languages:

- A compiled language (C, C++, Pascal, Rust) is translated into Assembly / binary code.
- An interpreted language (Java, Python, C#) requires an interpretor that is also binary.

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Agenda

Assembly snippets in C code

```
unsigned char a=27, b=4;

printf("before: %d (%02x) \n", a, a);

__asm{
    mov CL, b
    ror a, CL
}

printf("after: %d (%02x) \n", a, a);

return 0;
```

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__asm{
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```
push      ebp
mov       ebp, esp
push      ecx
mov       byte [ebp-0x1], 0x1b
mov       byte [ebp-0x2], 0x4
movzx     eax, byte [ebp-0x1]
push      eax
movzx     ecx, byte [ebp-0x1]
push      ecx
push      0x4020d0 ;-> 'before: %d (%02x) '
call  (1) [MSVCR100.dll:printf]
add       esp, 0xc
mov       cl, [ebp-0x2]
ror       byte [ebp-0x1], cl
movzx     edx, byte [ebp-0x1]
push      edx
movzx     eax, byte [ebp-0x1]
push      eax
push      0x4020e4 ;-> 'after: %d (%02x) '
call  (2) [MSVCR100.dll:printf]
add       esp, 0xc
xor       eax, eax
mov       esp, ebp
pop       ebp
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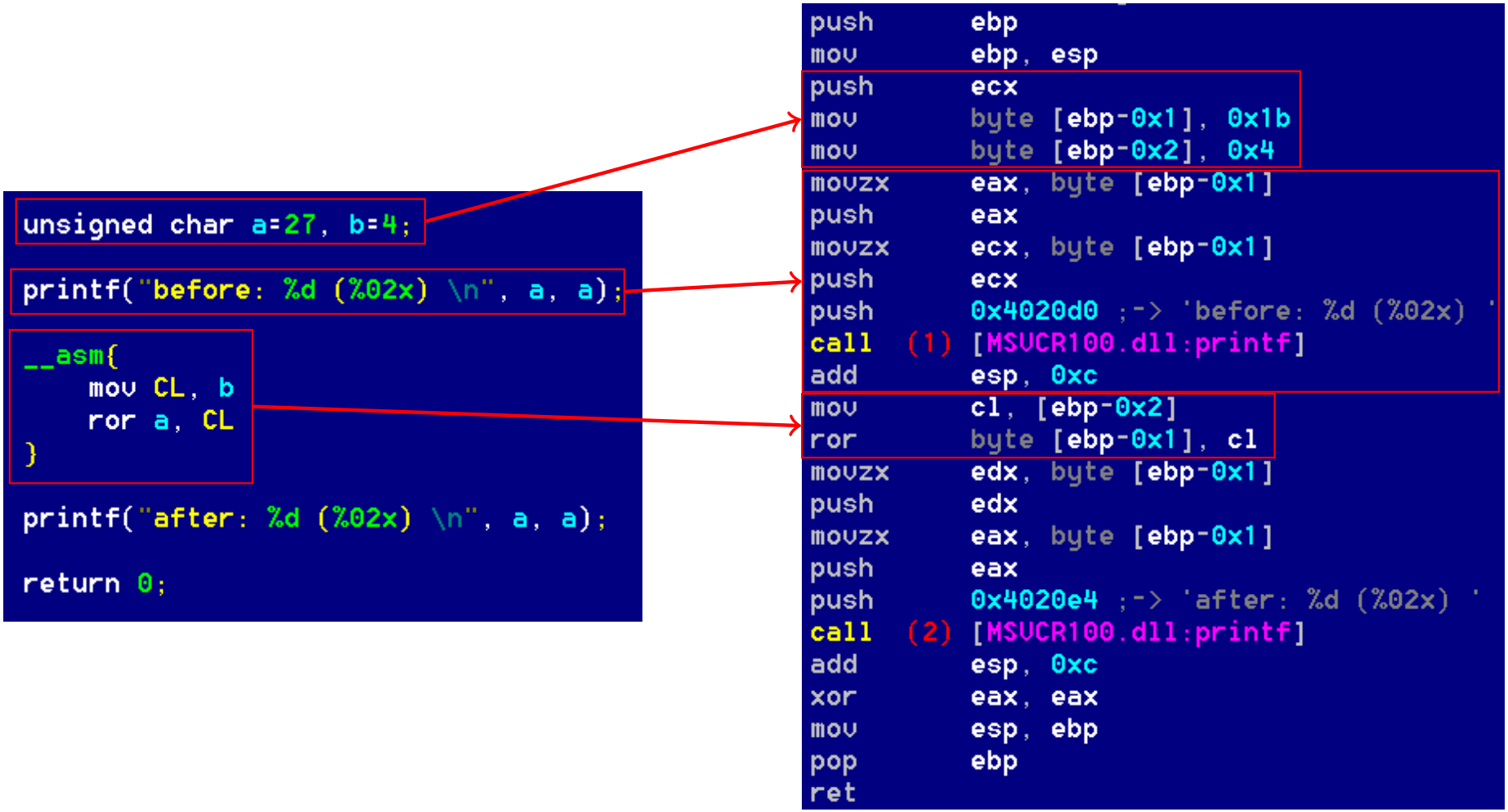
Assembly snippets in C code



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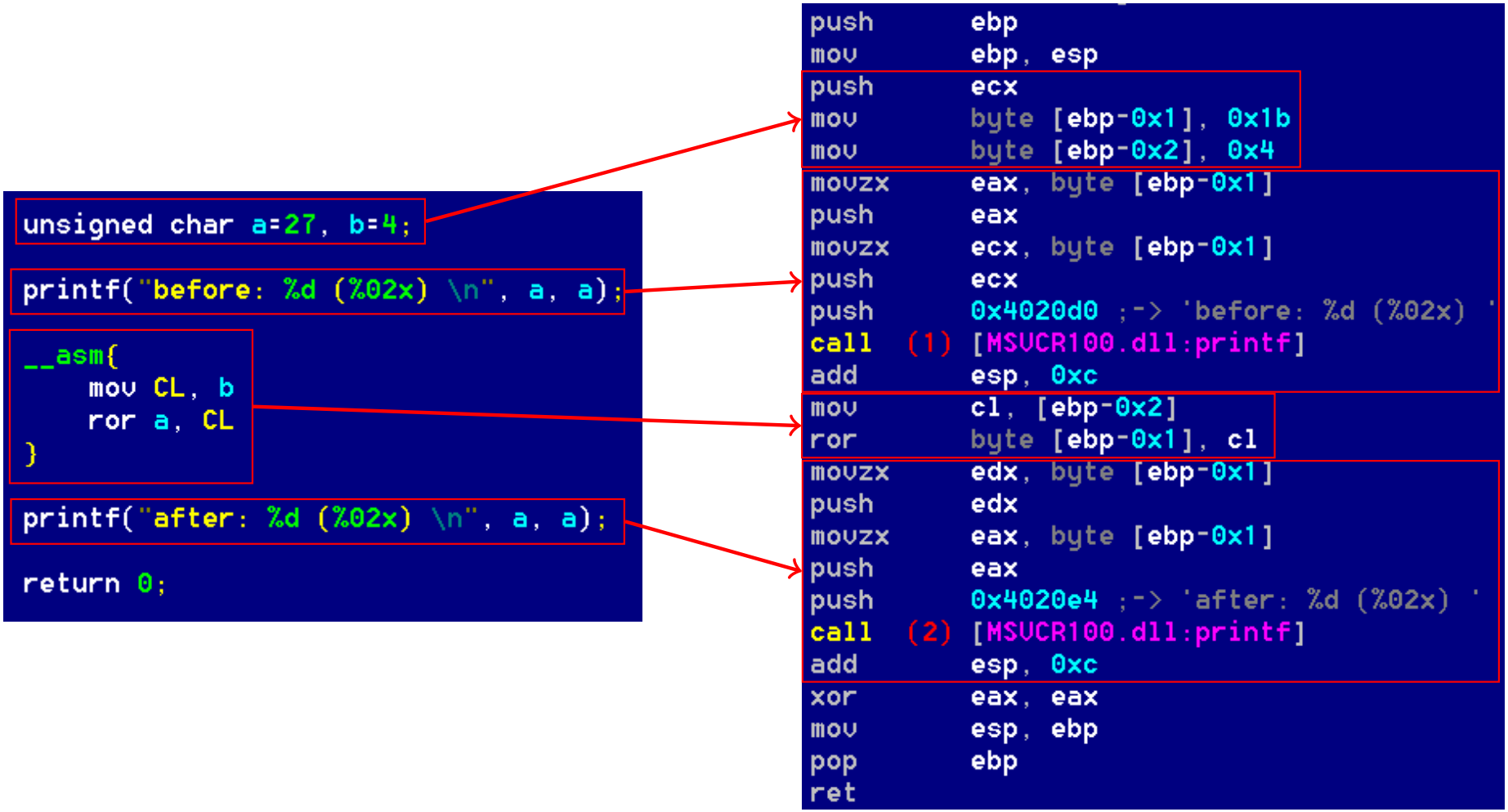

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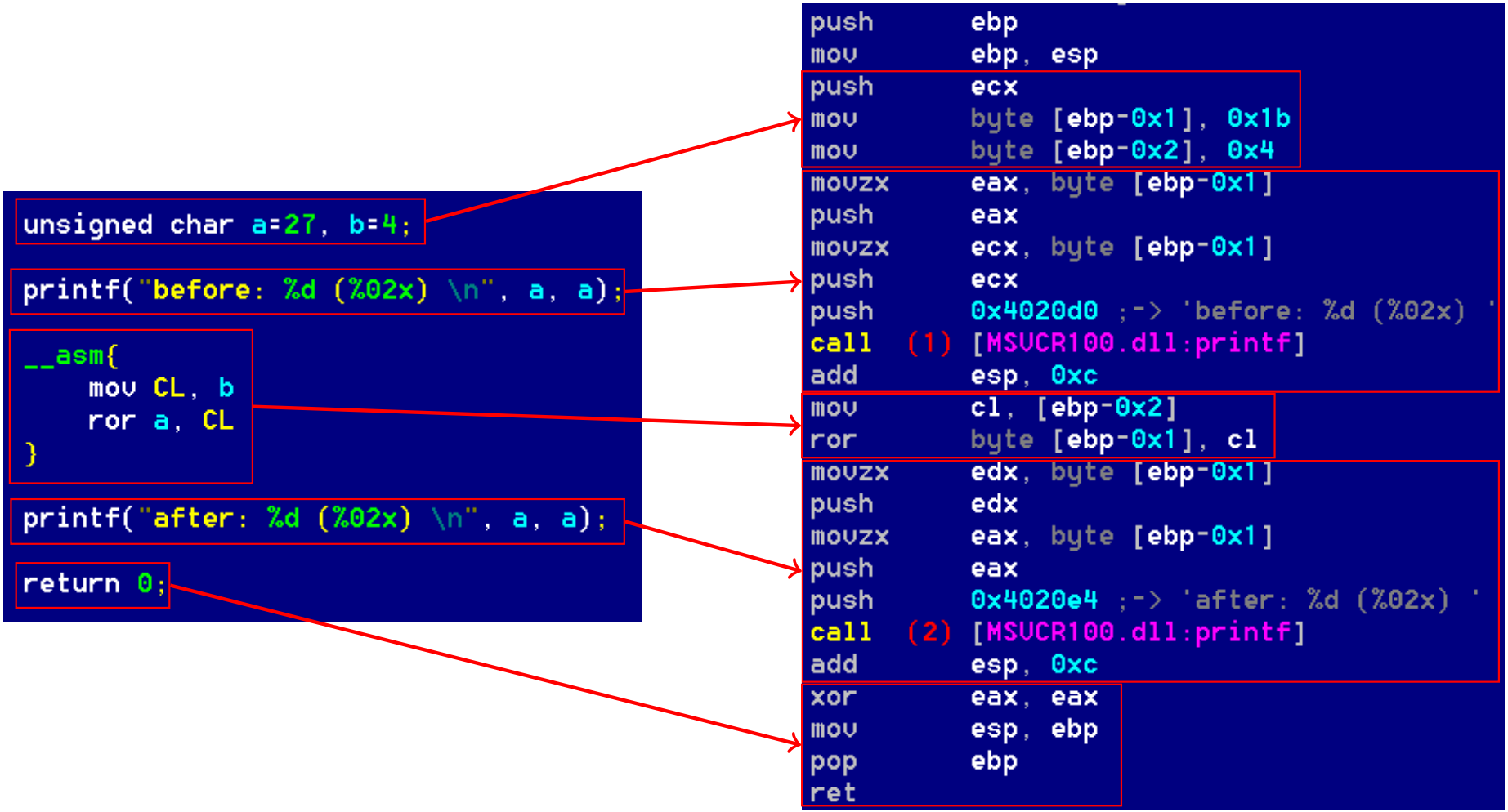

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Reverse engineering

Definition

Analyzing a piece of software in order to understand what it does and how it works.

- static analysis - analyzing the code
- dynamic analysis - analyzing the behavior

Static analysis

Issue: Binary programs have no source code to analyze.

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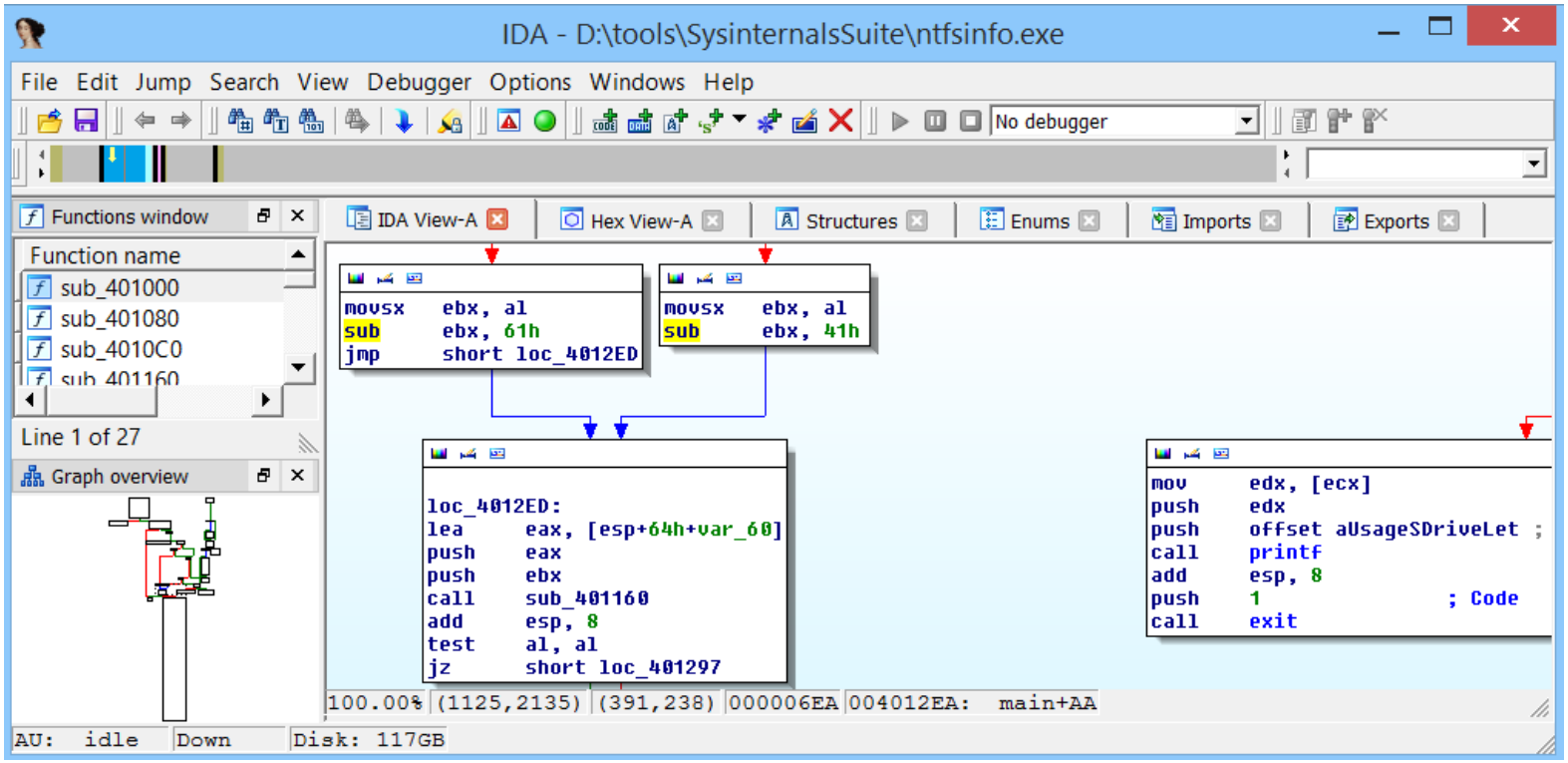
Tool: IDA Pro



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Dynamic analysis

Debugging:

- running Assembly instructions step-by-step *(demo)*

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Hooking functions:

```
; HANDLE __stdcall CreateRemoteThread(HANDLE hProcess, LPSECURITY_ATTRIBUTES lpThreadAttributes
                public CreateRemoteThread
CreateRemoteThread proc near               ; DATA XREF: .rdata:off_6B8E85A8↓o

hProcess        = dword ptr  8
lpThreadAttributes= dword ptr  0Ch
dwStackSize     = dword ptr  10h
lpStartAddress  = dword ptr  14h
lpParameter     = dword ptr  18h
dwCreationFlags = dword ptr  1Ch
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8B FF                   mov     edi, edi
55                      push    ebp
8B EC                   mov     ebp, esp
FF 75 20                push    [ebp+lpThreadId]
8B 45 1C                mov     eax, [ebp+dwCreationFlags]
6A 00                   push    0
25 04 00 01+            and     eax, 10004h
50                      push    eax
FF 75 18                push    [ebp+lpParameter]
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replace with:

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jmp interception
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    push ebp
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    ... logging code ...
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replace with:

```
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```
interception:
    push ebp
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    ... logging code ...

    jmp fn+5
```

Agenda

A closer look at stack frames

```
void func(const char *s){
    char myCopy[8];
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}

int main(void){
    func("12345");
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A closer look at stack frames

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sub     esp, 0x8
mov     eax, [ebp+0x8]
push    eax
lea     ecx, [ebp-0x8]
push    ecx
call    j_MSVCR100.dll:strcpy
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mov     esp, ebp
pop     ebp
ret

push    ebp
mov     ebp, esp
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call    sub_401000
add     esp, 0x4
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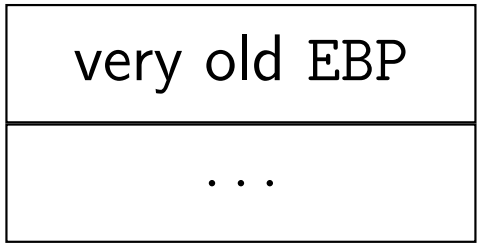

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What happens if we send a 16-bytes string?

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Buffer overflow exploits

- a buffer overflow can be used to override the return address on the stack
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Issue: Data Execution Prevention

- a running program along with its libraries contains many functions
- each function ends with a `ret` instruction

Definition

A group of instructions terminated with `ret` will be called a *gadget*.

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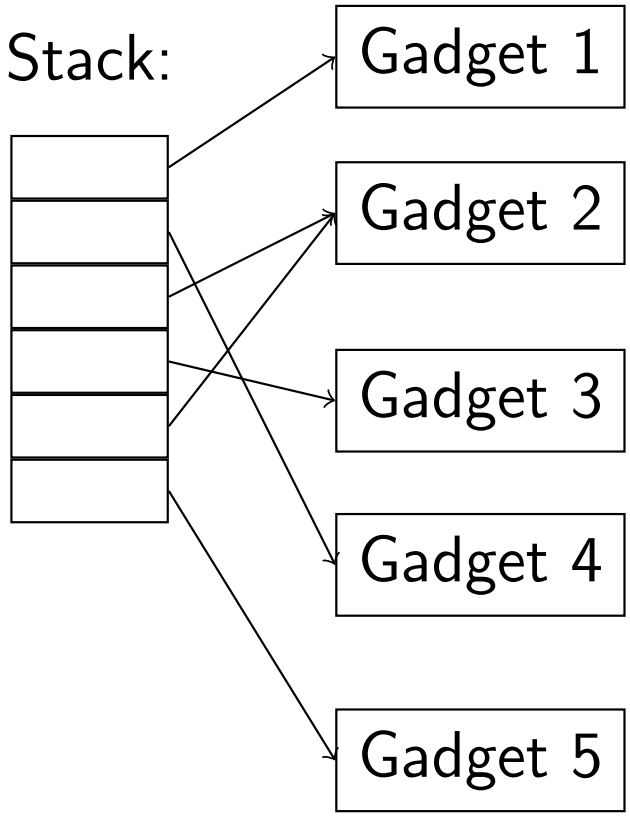

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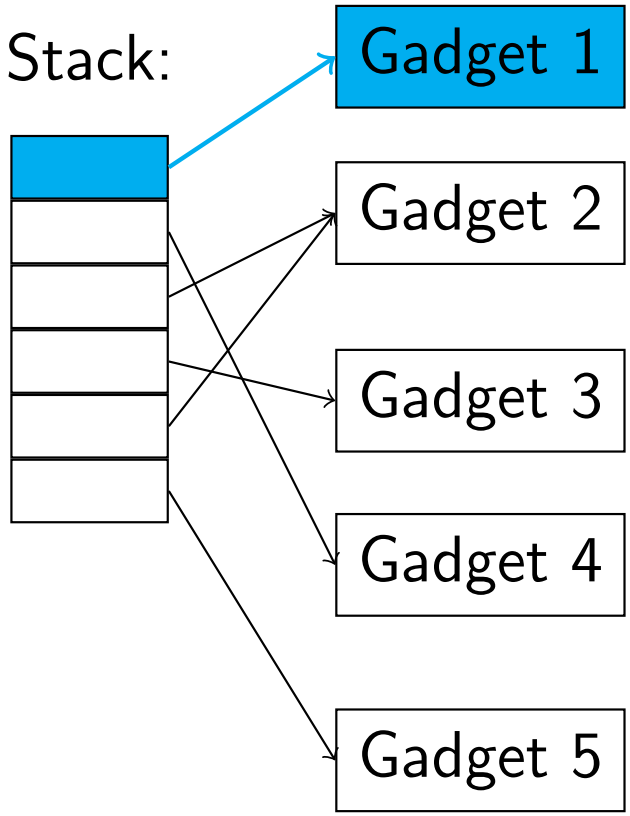

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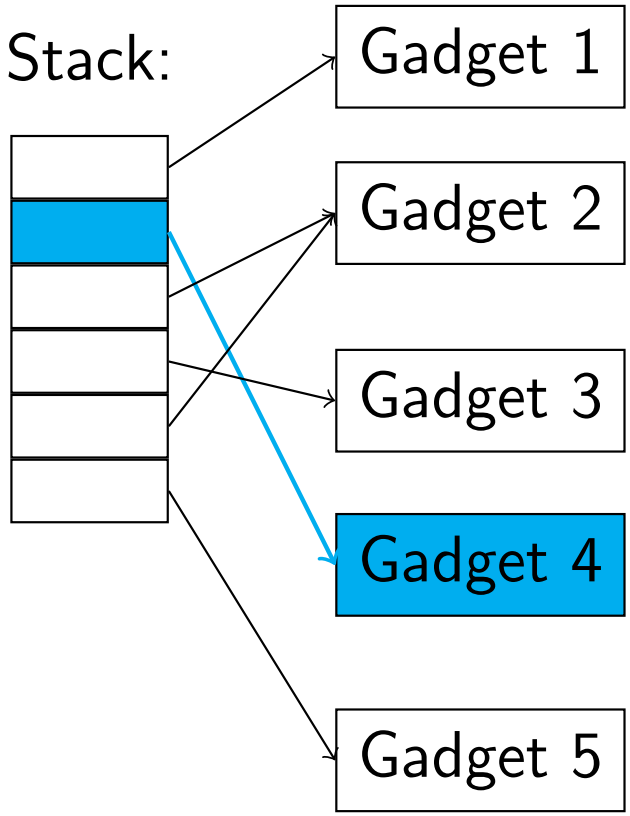

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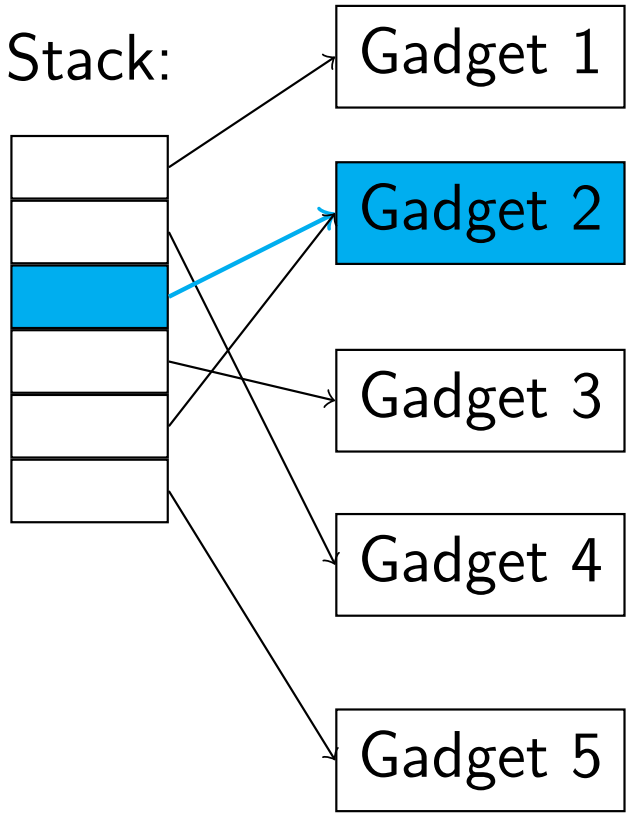

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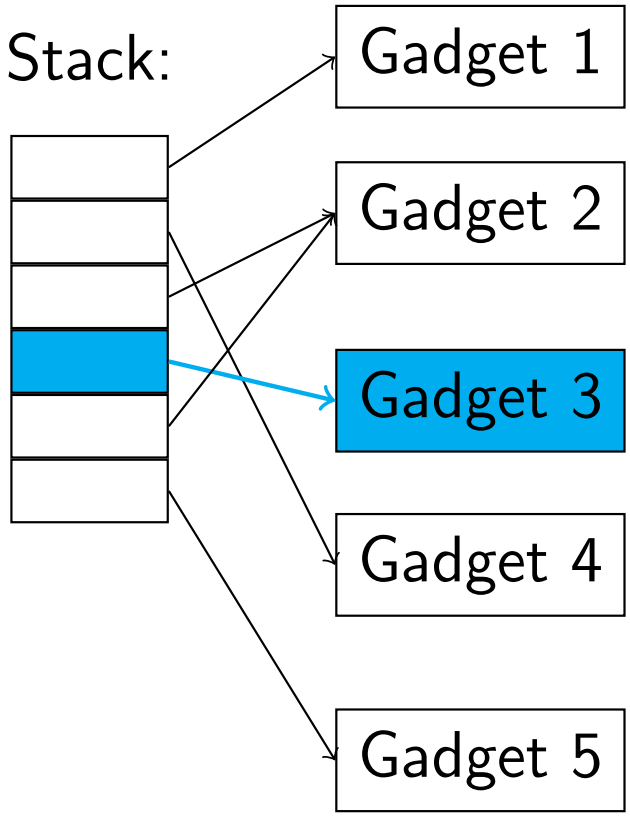
- a running program along with its libraries contains many functions
- each function ends with a `ret` instruction

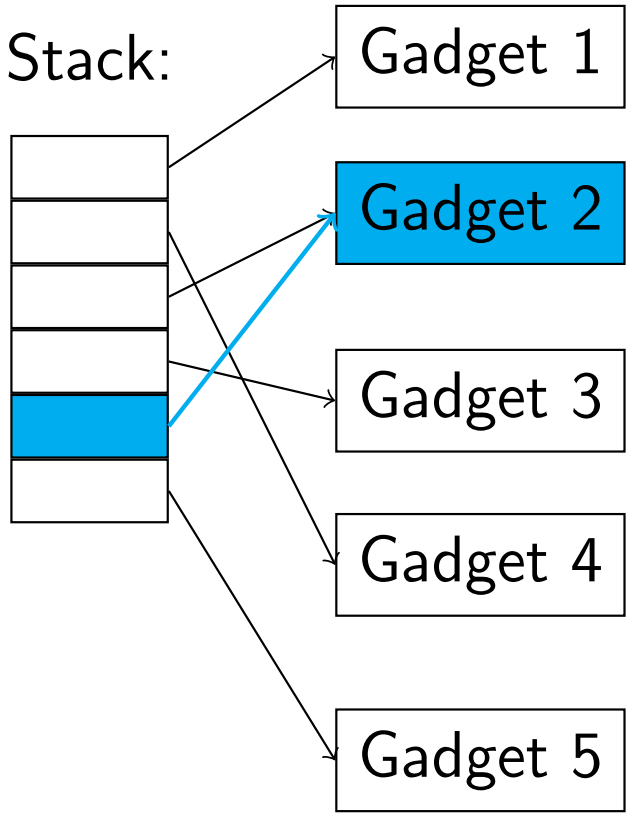


Definition

A group of instructions terminated with `ret` will be called a *gadget*.

We can write meaningful programs by chaining *gadgets*.

- a running program along with its libraries contains many functions
- each function ends with a `ret` instruction

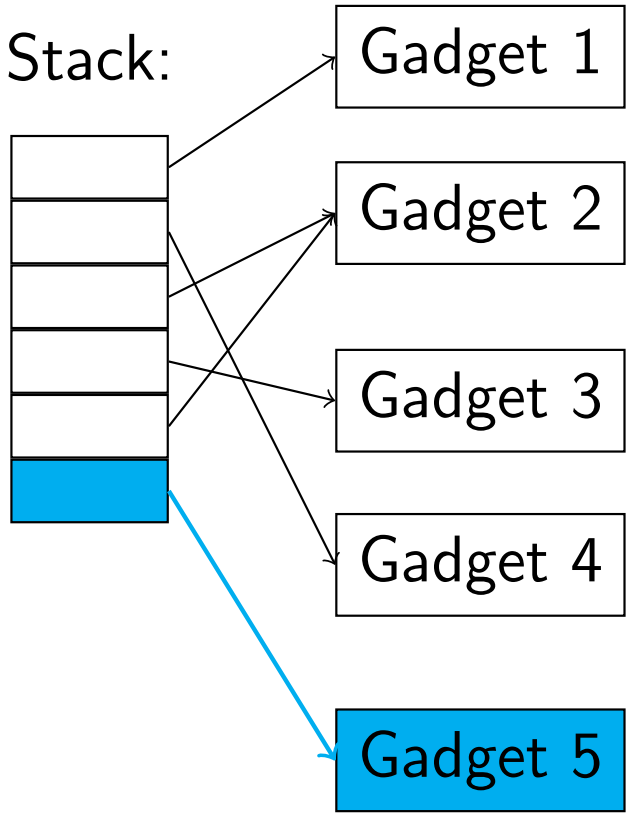


Definition

A group of instructions terminated with `ret` will be called a *gadget*.

We can write meaningful programs by chaining *gadgets*.

- a running program along with its libraries contains many functions
- each function ends with a `ret` instruction



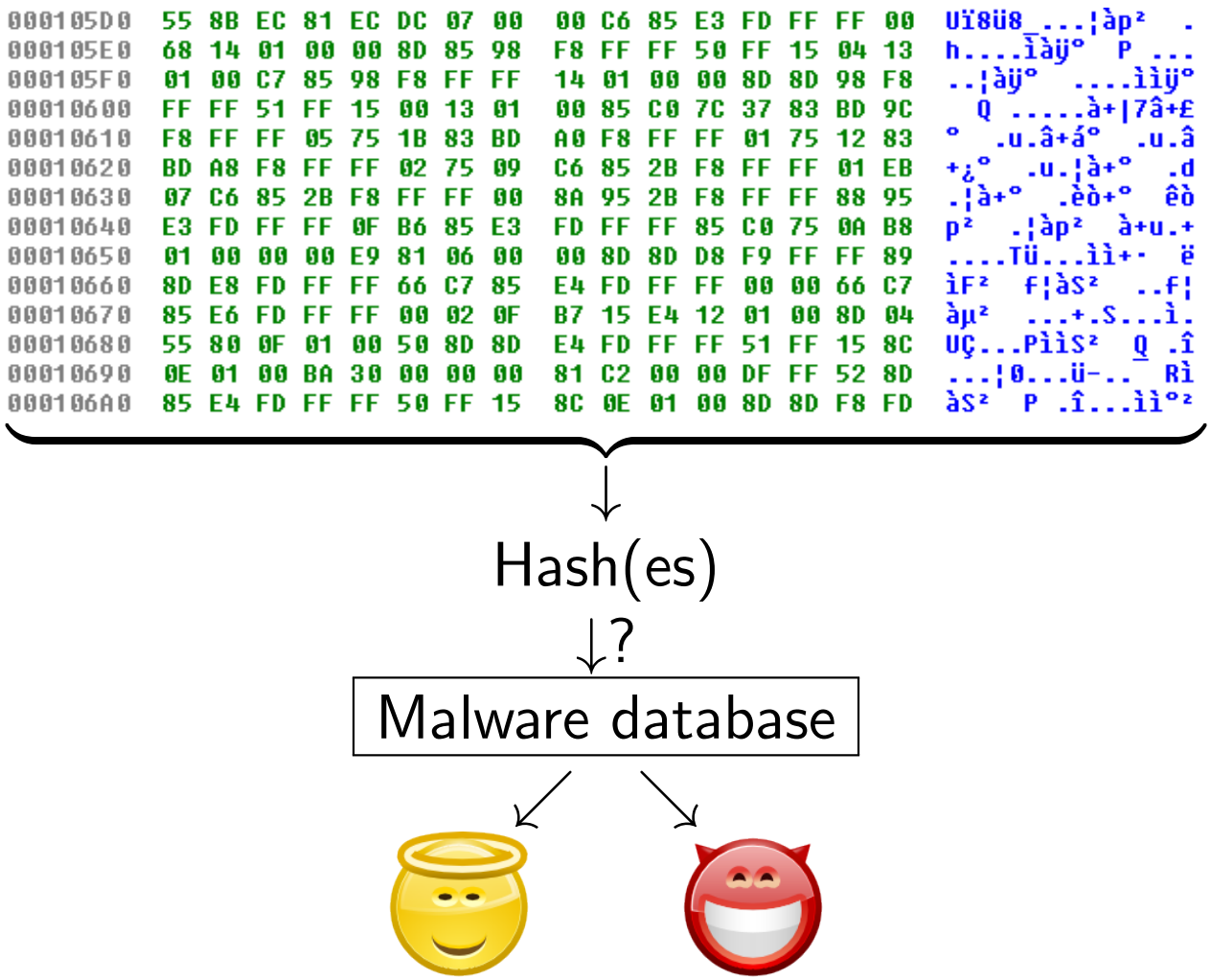
Definition

A group of instructions terminated with `ret` will be called a *gadget*.

We can write meaningful programs by chaining *gadgets*.

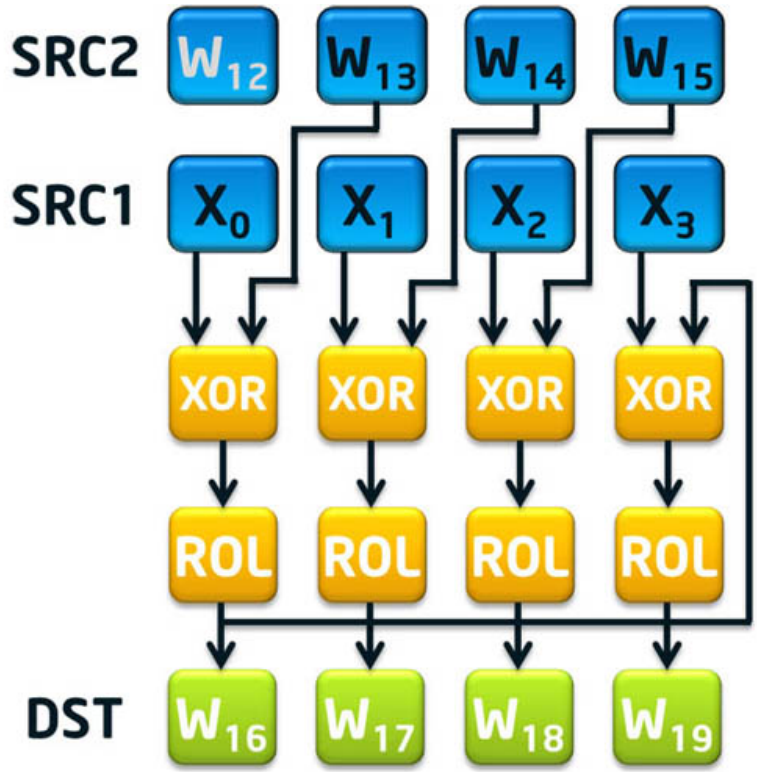
Agenda

Traditional detection mechanism



Hash computation

- hash computations require many bitwise operations
- easier to do in hardware than software
- Intel x86 Assembly provide such operations



SHA1MSG2 instruction

figure from https://software.intel.com

Using OpCode *n*-grams

```
000105D0  55 8B EC 81 EC DC 07 00  00 C6 85 E3 FD FF FF 00  Uï8ü8_...¦àp²  .
000105E0  68 14 01 00 00 8D 85 98  F8 FF FF 50 FF 15 04 13  h....ìàÿ°  P ...
000105F0  01 00 C7 85 98 F8 FF FF  14 01 00 00 8D 8D 98 F8  ..¦àÿ°  ....ììÿ°
00010600  FF FF 51 FF 15 00 13 01  00 85 C0 7C 37 83 BD 9C    Q .....à+|7â+£
00010610  F8 FF FF 05 75 1B 83 BD  A0 F8 FF FF 01 75 12 83  °  .u.â+á°  .u.â
00010620  BD A8 F8 FF FF 02 75 09  C6 85 2B F8 FF FF 01 EB  +¿°  .u.¦à+°  .d
00010630  07 C6 85 2B F8 FF FF 00  8A 95 2B F8 FF FF 88 95  .¦à+°  .èò+°  êò
00010640  E3 FD FF FF 0F B6 85 E3  FD FF FF 85 C0 75 0A B8  p²  .¦àp²  à+u.+
00010650  01 00 00 00 E9 81 06 00  00 8D 8D D8 F9 FF FF 89  ....Tü...ìì+·  ë
00010660  8D E8 FD FF FF 66 C7 85  E4 FD FF FF 00 00 66 C7  ìF²  f¦àS²  ..f¦
00010670  85 E6 FD FF FF 00 02 0F  B7 15 E4 12 01 00 8D 04  àµ²  ...+.S...ì.
00010680  55 80 0F 01 00 50 8D 8D  E4 FD FF FF 51 FF 15 8C  UÇ...PììS²  Q .î
00010690  0E 01 00 BA 30 00 00 00  81 C2 00 00 DF FF 52 8D  ...¦0...ü-..  Rì
000106A0  85 E4 FD FF FF 50 FF 15  8C 0E 01 00 8D 8D F8 FD  àS²  P .î...ìì°²
```

Using OpCode *n*-grams

```
000105D0  55 8B EC 81 EC DC 07 00  00 C6 85 E3 FD FF FF 00  Uï8ü8_...¦àp²  .
000105E0  68 14 01 00 00 8D 85 98  F8 FF FF 50 FF 15 04 13  h....ìàÿ°  P ...
000105F0  01 00 C7 85 98 F8 FF FF  14 01 00 00 8D 8D 98 F8  ..¦àÿ°  ....ììÿ°
00010600  FF FF 51 FF 15 00 13 01  00 85 C0 7C 37 83 BD 9C    Q .....à+|7â+£
00010610  F8 FF FF 05 75 1B 83 BD  A0 F8 FF FF 01 75 12 83  °  .u.â+á°  .u.â
00010620  BD A8 F8 FF FF 02 75 09  C6 85 2B F8 FF FF 01 EB  +¿°  .u.¦à+°  .d
00010630  07 C6 85 2B F8 FF FF 00  8A 95 2B F8 FF FF 88 95  .¦à+°  .èò+°  êò
00010640  E3 FD FF FF 0F B6 85 E3  FD FF FF 85 C0 75 0A B8  p²  .¦àp²  à+u.+
00010650  01 00 00 00 E9 81 06 00  00 8D 8D D8 F9 FF FF 89  ....TÜ...ìì+·  ë
00010660  8D E8 FD FF FF 66 C7 85  E4 FD FF FF 00 00 66 C7  ìF²  f¦àS²  ..f¦
00010670  85 E6 FD FF FF 00 02 0F  B7 15 E4 12 01 00 8D 04  àµ²  ...+.S...ì.
00010680  55 80 0F 01 00 50 8D 8D  E4 FD FF FF 51 FF 15 8C  UÇ...PììS²  Q .î
00010690  0E 01 00 BA 30 00 00 00  81 C2 00 00 DF FF 52 8D  ...¦0...ü-..  Rì
000106A0  85 E4 FD FF FF 50 FF 15  8C 0E 01 00 8D 8D F8 FD  àS²  P .î...ìì°²
```

↓

```
000105D0 55                   push   ebp
000105D1 8B EC                mov    ebp, esp
000105D3 81 EC DC 07 00 00    sub    esp, 7DCh
000105D9 C6 85 E3 FD FF FF+   mov    [ebp+var_21D], 0
000105E0 68 14 01 00 00       push   114h
000105E5 8D 85 98 F8 FF FF    lea    eax, [ebp+var_768]
000105EB 50                   push   eax
000105EC FF 15 04 13 01 00    call   ds:dword_11304
000105F2 C7 85 98 F8 FF FF+   mov    [ebp+var_768], 114h
000105FC 8D 8D 98 F8 FF FF    lea    ecx, [ebp+var_768]
00010602 51                   push   ecx
00010603 FF 15 00 13 01 00    call   ds:dword_11300
00010609 85 C0                test   eax, eax
0001060B 7C 37                jl     short loc_10644
0001060D 83 BD 9C F8 FF FF+   cmp    [ebp+var_764], 5
00010614 75 1B                jnz    short loc_10631
00010616 83 BD A0 F8 FF FF+   cmp    [ebp+var_760], 1
0001061D 75 12                jnz    short loc_10631
0001061F 83 BD A8 F8 FF FF+   cmp    [ebp+var_758], 2
00010626 75 09                jnz    short loc_10631
00010628 C6 85 2B F8 FF FF+   mov    [ebp+var_7D5], 1
0001062F EB 07                jmp    short loc_10638
```

→ push, mov, sub, mov, push, lea, push, call, mov, . . .

→ pmsmplpcmlpctjczczczmJ

Using OpCode *n*-grams

```
000105D0  55 8B EC 81 EC DC 07 00  00 C6 85 E3 FD FF FF 00  Uï8ü8_...¦àp²  .
000105E0  68 14 01 00 00 8D 85 98  F8 FF FF 50 FF 15 04 13  h....ìàÿ°  P ...
000105F0  01 00 C7 85 98 F8 FF FF  14 01 00 00 8D 8D 98 F8  ..¦àÿ°  ....ììÿ°
00010600  FF FF 51 FF 15 00 13 01  00 85 C0 7C 37 83 BD 9C    Q .....à+|7â+£
00010610  F8 FF FF 05 75 1B 83 BD  A0 F8 FF FF 01 75 12 83  °  .u.â+á°  .u.â
00010620  BD A8 F8 FF FF 02 75 09  C6 85 2B F8 FF FF 01 EB  +¿°  .u.¦à+°  .d
00010630  07 C6 85 2B F8 FF FF 00  8A 95 2B F8 FF FF 88 95  .¦à+°  .èò+°  êò
00010640  E3 FD FF FF 0F B6 85 E3  FD FF FF 85 C0 75 0A B8  p²  .¦àp²  à+u.+
00010650  01 00 00 00 E9 81 06 00  00 8D 8D D8 F9 FF FF 89  ....TÜ...ìì+·  ë
00010660  8D E8 FD FF FF 66 C7 85  E4 FD FF FF 00 00 66 C7  ìF²  f¦àS²  ..f¦
00010670  85 E6 FD FF FF 00 02 0F  B7 15 E4 12 01 00 8D 04  àµ²  ...+.S...ì.
00010680  55 80 0F 01 00 50 8D 8D  E4 FD FF FF 51 FF 15 8C  UÇ...PììS²  Q .î
00010690  0E 01 00 BA 30 00 00 00  81 C2 00 00 DF FF 52 8D  ...¦0...ü-..  Rì
000106A0  85 E4 FD FF FF 50 FF 15  8C 0E 01 00 8D 8D F8 FD  àS²  P .î...ìì°²
```

↓

```
000105D0 55                   push   ebp
000105D1 8B EC                mov    ebp, esp
000105D3 81 EC DC 07 00 00    sub    esp, 7DCh
000105D9 C6 85 E3 FD FF FF+   mov    [ebp+var_21D], 0
000105E0 68 14 01 00 00       push   114h
000105E5 8D 85 98 F8 FF FF    lea    eax, [ebp+var_768]
000105EB 50                   push   eax
000105EC FF 15 04 13 01 00    call   ds:dword_11304
000105F2 C7 85 98 F8 FF FF+   mov    [ebp+var_768], 114h
000105FC 8D 8D 98 F8 FF FF    lea    ecx, [ebp+var_768]
00010602 51                   push   ecx
00010603 FF 15 00 13 01 00    call   ds:dword_11300
00010609 85 C0                test   eax, eax
0001060B 7C 37                jl     short loc_10644
0001060D 83 BD 9C F8 FF FF+   cmp    [ebp+var_764], 5
00010614 75 1B                jnz    short loc_10631
00010616 83 BD A0 F8 FF FF+   cmp    [ebp+var_760], 1
0001061D 75 12                jnz    short loc_10631
0001061F 83 BD A8 F8 FF FF+   cmp    [ebp+var_758], 2
00010626 75 09                jnz    short loc_10631
00010628 C6 85 2B F8 FF FF+   mov    [ebp+var_7D5], 1
0001062F EB 07                jmp    short loc_10638
```

→ push, mov, sub, mov, push, lea, push, call, mov, . . .

→ pmsmplpc mlpctjczczczmJ

<pmsmplpc>

Using OpCode *n*-grams

```
000105D0  55 8B EC 81 EC DC 07 00  00 C6 85 E3 FD FF FF 00  Uï8ü8_...¦àp²  .
000105E0  68 14 01 00 00 8D 85 98  F8 FF FF 50 FF 15 04 13  h....ìàÿ°  P ...
000105F0  01 00 C7 85 98 F8 FF FF  14 01 00 00 8D 8D 98 F8  ..¦àÿ°  ....ììÿ°
00010600  FF FF 51 FF 15 00 13 01  00 85 C0 7C 37 83 BD 9C    Q .....à+|7â+£
00010610  F8 FF FF 05 75 1B 83 BD  A0 F8 FF FF 01 75 12 83  °  .u.â+á°  .u.â
00010620  BD A8 F8 FF FF 02 75 09  C6 85 2B F8 FF FF 01 EB  +¿°  .u.¦à+°  .d
00010630  07 C6 85 2B F8 FF FF 00  8A 95 2B F8 FF FF 88 95  .¦à+°  .èò+°  êò
00010640  E3 FD FF FF 0F B6 85 E3  FD FF FF 85 C0 75 0A B8  p²  .¦àp²  à+u.+
00010650  01 00 00 00 E9 81 06 00  00 8D 8D D8 F9 FF FF 89  ....TÜ...ìì+·  ë
00010660  8D E8 FD FF FF 66 C7 85  E4 FD FF FF 00 00 66 C7  ìF²  f¦àS²  ..f¦
00010670  85 E6 FD FF FF 00 02 0F  B7 15 E4 12 01 00 8D 04  àµ²  ...+.S...ì.
00010680  55 80 0F 01 00 50 8D 8D  E4 FD FF FF 51 FF 15 8C  UÇ...PììS²  Q .î
00010690  0E 01 00 BA 30 00 00 00  81 C2 00 00 DF FF 52 8D  ...¦0...ü-..  Rì
000106A0  85 E4 FD FF FF 50 FF 15  8C 0E 01 00 8D 8D F8 FD  àS²  P .î...ìì°²
```

↓

```
000105D0 55                   push   ebp
000105D1 8B EC                mov    ebp, esp
000105D3 81 EC DC 07 00 00    sub    esp, 7DCh
000105D9 C6 85 E3 FD FF FF+   mov    [ebp+var_21D], 0
000105E0 68 14 01 00 00       push   114h
000105E5 8D 85 98 F8 FF FF    lea    eax, [ebp+var_768]
000105EB 50                   push   eax
000105EC FF 15 04 13 01 00    call   ds:dword_11304
000105F2 C7 85 98 F8 FF FF+   mov    [ebp+var_768], 114h
000105FC 8D 8D 98 F8 FF FF    lea    ecx, [ebp+var_768]
00010602 51                   push   ecx
00010603 FF 15 00 13 01 00    call   ds:dword_11300
00010609 85 C0                test   eax, eax
0001060B 7C 37                jl     short loc_10644
0001060D 83 BD 9C F8 FF FF+   cmp    [ebp+var_764], 5
00010614 75 1B                jnz    short loc_10631
00010616 83 BD A0 F8 FF FF+   cmp    [ebp+var_760], 1
0001061D 75 12                jnz    short loc_10631
0001061F 83 BD A8 F8 FF FF+   cmp    [ebp+var_758], 2
00010626 75 09                jnz    short loc_10631
00010628 C6 85 2B F8 FF FF+   mov    [ebp+var_7D5], 1
0001062F EB 07                jmp    short loc_10638
```

→ push, mov, sub, mov, push, lea, push, call, mov, . . .

→ p msmplpcm lpctjczczczmJ

<pmsmplpc>, <msmplpcm>

Using OpCode *n*-grams

```
000105D0  55 8B EC 81 EC DC 07 00  00 C6 85 E3 FD FF FF 00  Uï8ü8_...¦àp²  .
000105E0  68 14 01 00 00 8D 85 98  F8 FF FF 50 FF 15 04 13  h....ìàÿ°  P ...
000105F0  01 00 C7 85 98 F8 FF FF  14 01 00 00 8D 8D 98 F8  ..¦àÿ°  ....ììÿ°
00010600  FF FF 51 FF 15 00 13 01  00 85 C0 7C 37 83 BD 9C    Q .....à+|7â+£
00010610  F8 FF FF 05 75 1B 83 BD  A0 F8 FF FF 01 75 12 83  °  .u.â+á°  .u.â
00010620  BD A8 F8 FF FF 02 75 09  C6 85 2B F8 FF FF 01 EB  +¿°  .u.¦à+°  .d
00010630  07 C6 85 2B F8 FF FF 00  8A 95 2B F8 FF FF 88 95  .¦à+°  .èò+°  êò
00010640  E3 FD FF FF 0F B6 85 E3  FD FF FF 85 C0 75 0A B8  p²  .¦àp²  à+u.+
00010650  01 00 00 00 E9 81 06 00  00 8D 8D D8 F9 FF FF 89  ....Tü...ìì+·  ë
00010660  8D E8 FD FF FF 66 C7 85  E4 FD FF FF 00 00 66 C7  ìF²  f¦àS²  ..f¦
00010670  85 E6 FD FF FF 00 02 0F  B7 15 E4 12 01 00 8D 04  àµ²  ...+.S...ì.
00010680  55 80 0F 01 00 50 8D 8D  E4 FD FF FF 51 FF 15 8C  UÇ...PìiS²  Q .î
00010690  0E 01 00 BA 30 00 00 00  81 C2 00 00 DF FF 52 8D  ...¦0...ü-..  Rì
000106A0  85 E4 FD FF FF 50 FF 15  8C 0E 01 00 8D 8D F8 FD  àS²  P .î...ìì°²
```

↓

```
000105D0 55                   push   ebp
000105D1 8B EC                mov    ebp, esp
000105D3 81 EC DC 07 00 00    sub    esp, 7DCh
000105D9 C6 85 E3 FD FF FF+   mov    [ebp+var_21D], 0
000105E0 68 14 01 00 00       push   114h
000105E5 8D 85 98 F8 FF FF    lea    eax, [ebp+var_768]
000105EB 50                   push   eax
000105EC FF 15 04 13 01 00    call   ds:dword_11304
000105F2 C7 85 98 F8 FF FF+   mov    [ebp+var_768], 114h
000105FC 8D 8D 98 F8 FF FF    lea    ecx, [ebp+var_768]
00010602 51                   push   ecx
00010603 FF 15 00 13 01 00    call   ds:dword_11300
00010609 85 C0                test   eax, eax
0001060B 7C 37                jl     short loc_10644
0001060D 83 BD 9C F8 FF FF+   cmp    [ebp+var_764], 5
00010614 75 1B                jnz    short loc_10631
00010616 83 BD A0 F8 FF FF+   cmp    [ebp+var_760], 1
0001061D 75 12                jnz    short loc_10631
0001061F 83 BD A8 F8 FF FF+   cmp    [ebp+var_758], 2
00010626 75 09                jnz    short loc_10631
00010628 C6 85 2B F8 FF FF+   mov    [ebp+var_7D5], 1
0001062F EB 07                jmp    short loc_10638
```

→ push, mov, sub, mov, push, lea, push, call, mov, . . .

→ pm smplpcml pctjczczczmJ

<pmsmplpc>, <msmplpcm>, <smplpcml>

Using OpCode *n*-grams

```
000105D0  55 8B EC 81 EC DC 07 00  00 C6 85 E3 FD FF FF 00  Uï8ü8_...¦àp²  .
000105E0  68 14 01 00 00 8D 85 98  F8 FF FF 50 FF 15 04 13  h....ìàÿ°  P ...
000105F0  01 00 C7 85 98 F8 FF FF  14 01 00 00 8D 8D 98 F8  ..¦àÿ°  ....ììÿ°
00010600  FF FF 51 FF 15 00 13 01  00 85 C0 7C 37 83 BD 9C    Q .....à+|7â+£
00010610  F8 FF FF 05 75 1B 83 BD  A0 F8 FF FF 01 75 12 83  °  .u.â+á°  .u.â
00010620  BD A8 F8 FF FF 02 75 09  C6 85 2B F8 FF FF 01 EB  +¿°  .u.¦à+°  .d
00010630  07 C6 85 2B F8 FF FF 00  8A 95 2B F8 FF FF 88 95  .¦à+°  .èò+°  êò
00010640  E3 FD FF FF 0F B6 85 E3  FD FF FF 85 C0 75 0A B8  p²  .¦àp²  à+u.+
00010650  01 00 00 00 E9 81 06 00  00 8D 8D D8 F9 FF FF 89  ....Tü...ìì+·  ë
00010660  8D E8 FD FF FF 66 C7 85  E4 FD FF FF 00 00 66 C7  ìF²  f¦àS²  ..f¦
00010670  85 E6 FD FF FF 00 02 0F  B7 15 E4 12 01 00 8D 04  àµ²  ...+.S...ì.
00010680  55 80 0F 01 00 50 8D 8D  E4 FD FF FF 51 FF 15 8C  UÇ...PììS²  Q .î
00010690  0E 01 00 BA 30 00 00 00  81 C2 00 00 DF FF 52 8D  ...¦0...ü-..  Rì
000106A0  85 E4 FD FF FF 50 FF 15  8C 0E 01 00 8D 8D F8 FD  àS²  P .î...ìì°²
```

↓

```
000105D0 55                   push   ebp
000105D1 8B EC                mov    ebp, esp
000105D3 81 EC DC 07 00 00    sub    esp, 7DCh
000105D9 C6 85 E3 FD FF FF+   mov    [ebp+var_21D], 0
000105E0 68 14 01 00 00       push   114h
000105E5 8D 85 98 F8 FF FF    lea    eax, [ebp+var_768]
000105EB 50                   push   eax
000105EC FF 15 04 13 01 00    call   ds:dword_11304
000105F2 C7 85 98 F8 FF FF+   mov    [ebp+var_768], 114h
000105FC 8D 8D 98 F8 FF FF    lea    ecx, [ebp+var_768]
00010602 51                   push   ecx
00010603 FF 15 00 13 01 00    call   ds:dword_11300
00010609 85 C0                test   eax, eax
0001060B 7C 37                jl     short loc_10644
0001060D 83 BD 9C F8 FF FF+   cmp    [ebp+var_764], 5
00010614 75 1B                jnz    short loc_10631
00010616 83 BD A0 F8 FF FF+   cmp    [ebp+var_760], 1
0001061D 75 12                jnz    short loc_10631
0001061F 83 BD A8 F8 FF FF+   cmp    [ebp+var_758], 2
00010626 75 09                jnz    short loc_10631
00010628 C6 85 2B F8 FF FF+   mov    [ebp+var_7D5], 1
0001062F EB 07                jmp    short loc_10638
```

→ push, mov, sub, mov, push, lea, push, call, mov, . . .

→ pms **mplpcmlp** ctjczczczmJ

<pmsmplpc>, <msmplpcm>, <smplpcml>, <mplpcmlp>

Using OpCode *n*-grams

```
000105D0  55 8B EC 81 EC DC 07 00  00 C6 85 E3 FD FF FF 00  Uï8ü8_...¦àp²  .
000105E0  68 14 01 00 00 8D 85 98  F8 FF FF 50 FF 15 04 13  h....ìàÿ°  P ...
000105F0  01 00 C7 85 98 F8 FF FF  14 01 00 00 8D 8D 98 F8  ..¦àÿ°  ....ììÿ°
00010600  FF FF 51 FF 15 00 13 01  00 85 C0 7C 37 83 BD 9C    Q .....à+|7â+£
00010610  F8 FF FF 05 75 1B 83 BD  A0 F8 FF FF 01 75 12 83  °  .u.â+á°  .u.â
00010620  BD A8 F8 FF FF 02 75 09  C6 85 2B F8 FF FF 01 EB  +¿°  .u.¦à+°  .d
00010630  07 C6 85 2B F8 FF FF 00  8A 95 2B F8 FF FF 88 95  .¦à+°  .èò+°  êò
00010640  E3 FD FF FF 0F B6 85 E3  FD FF FF 85 C0 75 0A B8  p²  .¦àp²  à+u.+
00010650  01 00 00 00 E9 81 06 00  00 8D 8D D8 F9 FF FF 89  ....Tü...ìì+·  ë
00010660  8D E8 FD FF FF 66 C7 85  E4 FD FF FF 00 00 66 C7  ìF²  f¦àS²  ..f¦
00010670  85 E6 FD FF FF 00 02 0F  B7 15 E4 12 01 00 8D 04  àµ²  ...+.S...ì.
00010680  55 80 0F 01 00 50 8D 8D  E4 FD FF FF 51 FF 15 8C  UÇ...PììS²  Q .î
00010690  0E 01 00 BA 30 00 00 00  81 C2 00 00 DF FF 52 8D  ...¦0...ü-..  Rì
000106A0  85 E4 FD FF FF 50 FF 15  8C 0E 01 00 8D 8D F8 FD  àS²  P .î...ìì°²
```

↓

```
000105D0 55                   push   ebp
000105D1 8B EC                mov    ebp, esp
000105D3 81 EC DC 07 00 00    sub    esp, 7DCh
000105D9 C6 85 E3 FD FF FF+   mov    [ebp+var_21D], 0
000105E0 68 14 01 00 00       push   114h
000105E5 8D 85 98 F8 FF FF    lea    eax, [ebp+var_768]
000105EB 50                   push   eax
000105EC FF 15 04 13 01 00    call   ds:dword_11304
000105F2 C7 85 98 F8 FF FF+   mov    [ebp+var_768], 114h
000105FC 8D 8D 98 F8 FF FF    lea    ecx, [ebp+var_768]
00010602 51                   push   ecx
00010603 FF 15 00 13 01 00    call   ds:dword_11300
00010609 85 C0                test   eax, eax
0001060B 7C 37                jl     short loc_10644
0001060D 83 BD 9C F8 FF FF+   cmp    [ebp+var_764], 5
00010614 75 1B                jnz    short loc_10631
00010616 83 BD A0 F8 FF FF+   cmp    [ebp+var_760], 1
0001061D 75 12                jnz    short loc_10631
0001061F 83 BD A8 F8 FF FF+   cmp    [ebp+var_758], 2
00010626 75 09                jnz    short loc_10631
00010628 C6 85 2B F8 FF FF+   mov    [ebp+var_7D5], 1
0001062F EB 07                jmp    short loc_10638
```

→ push, mov, sub, mov, push, lea, push, call, mov, . . .

→ pmsm plpcmlpc tjczczczmJ

<pmsmplpc>, <msmplpcm>, <smplpcml>, <mplpcmlp>, <plpcmlpc>

Using OpCode *n*-grams

```
000105D0  55 8B EC 81 EC DC 07 00  00 C6 85 E3 FD FF FF 00  Uï8ü8_...¦àp²  .
000105E0  68 14 01 00 00 8D 85 98  F8 FF FF 50 FF 15 04 13  h....ìàÿ°  P ...
000105F0  01 00 C7 85 98 F8 FF FF  14 01 00 00 8D 8D 98 F8  ..¦àÿ°  ....ììÿ°
00010600  FF FF 51 FF 15 00 13 01  00 85 C0 7C 37 83 BD 9C    Q .....à+|7â+£
00010610  F8 FF FF 05 75 1B 83 BD  A0 F8 FF FF 01 75 12 83  °  .u.â+á°  .u.â
00010620  BD A8 F8 FF FF 02 75 09  C6 85 2B F8 FF FF 01 EB  +¿°  .u.¦à+°  .d
00010630  07 C6 85 2B F8 FF FF 00  8A 95 2B F8 FF FF 88 95  .¦à+°  .èò+°  êò
00010640  E3 FD FF FF 0F B6 85 E3  FD FF FF 85 C0 75 0A B8  p²  .¦àp²  à+u.+
00010650  01 00 00 00 E9 81 06 00  00 8D 8D D8 F9 FF FF 89  ....Tü...ìì+·  ë
00010660  8D E8 FD FF FF 66 C7 85  E4 FD FF FF 00 00 66 C7  ìF²  f¦àS²  ..f¦
00010670  85 E6 FD FF FF 00 02 0F  B7 15 E4 12 01 00 8D 04  àµ²  ...+.S...ì.
00010680  55 80 0F 01 00 50 8D 8D  E4 FD FF FF 51 FF 15 8C  UÇ...PììS²  Q .î
00010690  0E 01 00 BA 30 00 00 00  81 C2 00 00 DF FF 52 8D  ...¦0...ü-..  Rì
000106A0  85 E4 FD FF FF 50 FF 15  8C 0E 01 00 8D 8D F8 FD  àS²  P .î...ìì°²
```

↓

```
000105D0 55                   push   ebp
000105D1 8B EC                mov    ebp, esp
000105D3 81 EC DC 07 00 00    sub    esp, 7DCh
000105D9 C6 85 E3 FD FF FF+   mov    [ebp+var_21D], 0
000105E0 68 14 01 00 00       push   114h
000105E5 8D 85 98 F8 FF FF    lea    eax, [ebp+var_768]
000105EB 50                   push   eax
000105EC FF 15 04 13 01 00    call   ds:dword_11304
000105F2 C7 85 98 F8 FF FF+   mov    [ebp+var_768], 114h
000105FC 8D 8D 98 F8 FF FF    lea    ecx, [ebp+var_768]
00010602 51                   push   ecx
00010603 FF 15 00 13 01 00    call   ds:dword_11300
00010609 85 C0                test   eax, eax
0001060B 7C 37                jl     short loc_10644
0001060D 83 BD 9C F8 FF FF+   cmp    [ebp+var_764], 5
00010614 75 1B                jnz    short loc_10631
00010616 83 BD A0 F8 FF FF+   cmp    [ebp+var_760], 1
0001061D 75 12                jnz    short loc_10631
0001061F 83 BD A8 F8 FF FF+   cmp    [ebp+var_758], 2
00010626 75 09                jnz    short loc_10631
00010628 C6 85 2B F8 FF FF+   mov    [ebp+var_7D5], 1
0001062F EB 07                jmp    short loc_10638
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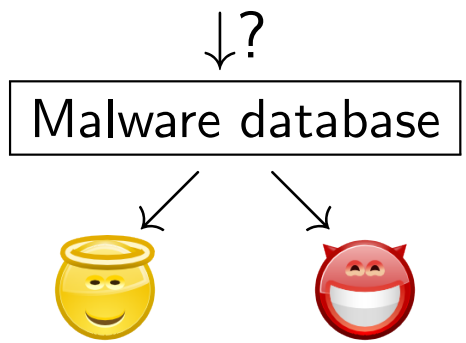

Code similarity

The compiler disregards:

- comments and indentation
- variable names and redundant parentheses

similar C code $\rightarrow$ similar ASM code $\rightarrow$ similar n-grams

Bitdefender

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Definition

Jaccard similarity:

$$sim(A, B) = \frac{|A \cap B|}{|A \cup B|}$$

Bitdefender

Code emulation

How can you automatically infer the effects of a program without actually running it?

- create a minimalistic virtual environment
- **disassemble each instruction**
- emulate it inside the virtual environment

An emulator must keep track of

- registers
- memory
- environment

Agenda

The bootstrap concept

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- How can an operating system start itself?

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- What happens when a computer starts?
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- when switched on, the processor starts executing code at `FFFF:0000`, where BIOS code is located
- BIOS searches for boot sectors

The boot sector

- has 512 bytes
- ends with `0xAA55`
- will load at `0000:7C00`
- has access to BIOS interrupts


```
[org 0x7c00]                    ; BIOS always loads the boot sector to 00:7c00
EntryPoint:
    jmp     .Code               ; avoid executing our data as code

.Message:
    db "Hello world!", 0        ; embed the message inside the generated binary

.Code:                          ; local label, actually EntryPoint.Code

    ; init data and stack (cs:ip already set, otherwise we wouldn't be here)
    xor     ax,     ax          ; ax <- 0
    mov     ds,     ax          ; data segment starts at 0 (same as cs)
    mov     ss,     ax          ; stack segment starts at 0
    mov     sp,     0x7c00      ; Top-Of-Stack at 7c00 (going backwords)

    ; print the message
    mov     ax,     0xb800
    mov     es,     ax          ; es <- b800 = address of video text matrix
    mov     si,     .Message
    cld                         ; make sure string instructions go forward

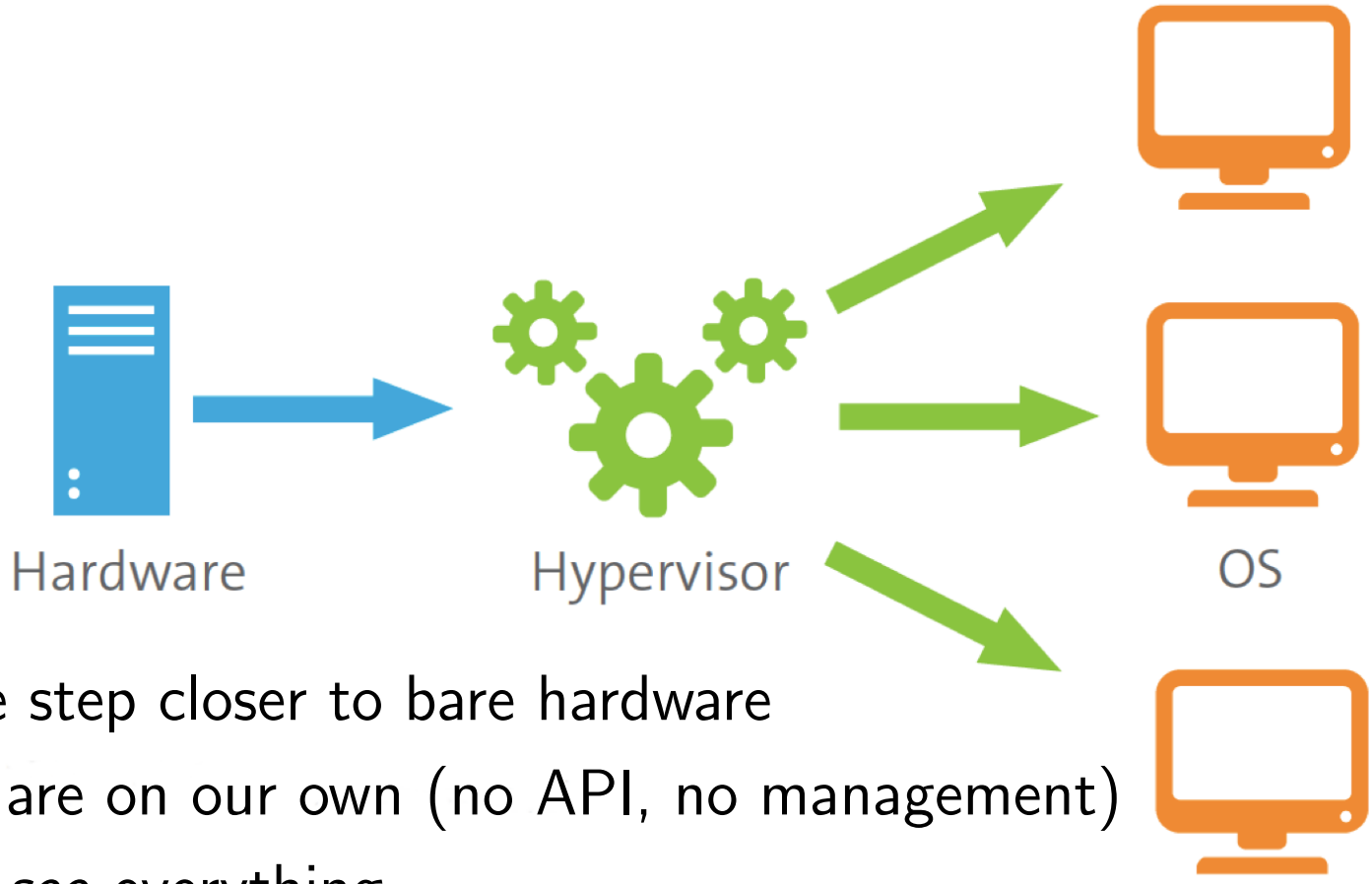
.PrintLoop:
    lodsb                       ; al <- ds:[si], si<-si+1 (al = next char)
    test    al,     al          ; check if this is the null terminator
    jz      .PrintDone          ; if so, exit the loop
    stosb                       ; es:[di]<-al, al<-al+1 (write ASCII code to video mem)
    mov     al,     7
    stosb                       ; write the color code (7=white)
    jmp     .PrintLoop

.PrintDone:

    ; stop boot flow
    hlt
    jmp     .PrintDone          ; just a safety measure

times 512 - 2 - ($ - $$) db 0 ; add zeroes until we get to 510
    dw      0x55aa              ; add the boot signature at sector end
```

Hypervisors



- one step closer to bare hardware
- we are on our own (no API, no management)
- we *see* everything

Hypervisor lifecycle

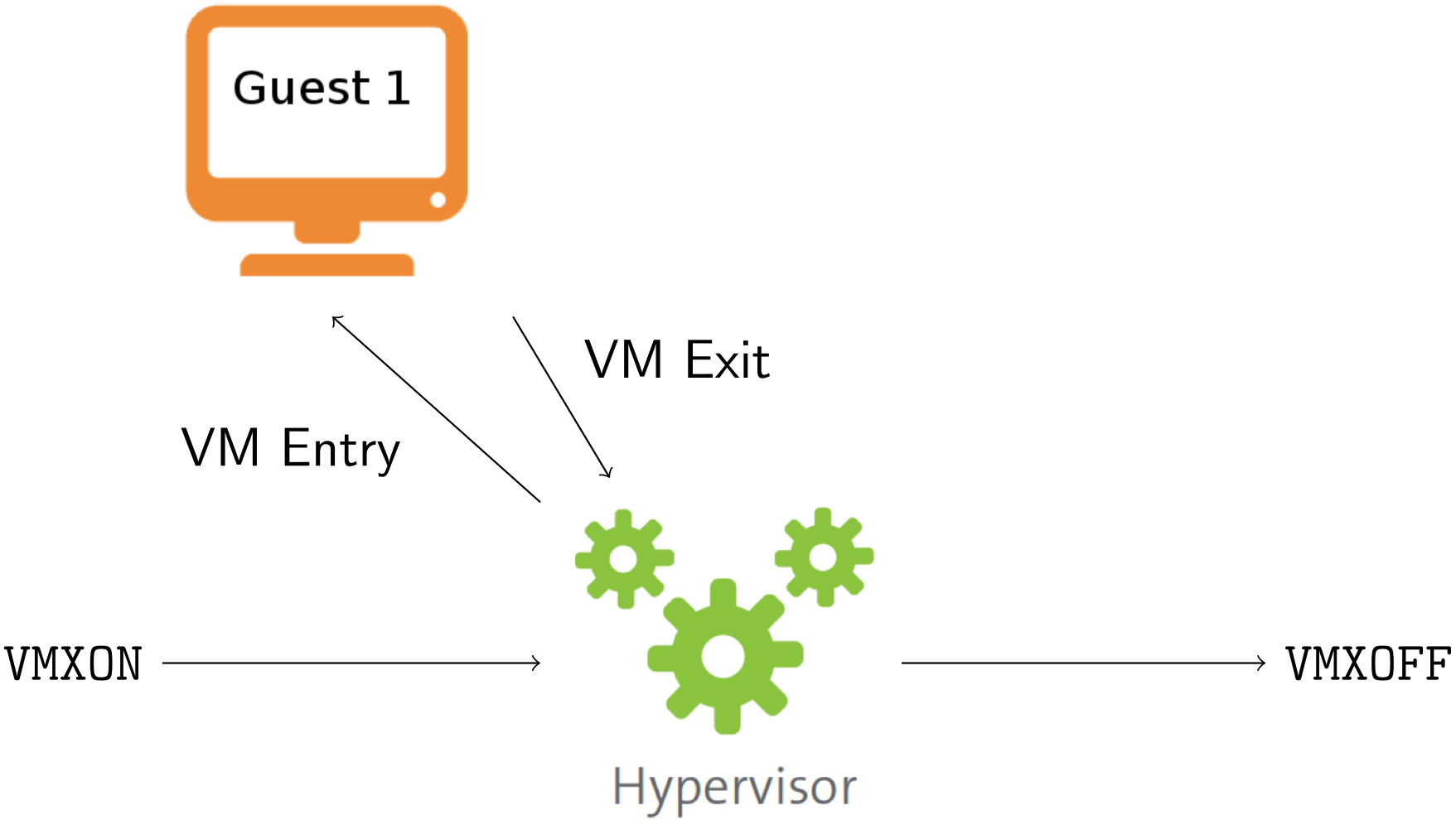
Hypervisor lifecycle

VMXON ⟶

Hypervisor

Hypervisor lifecycle

Hypervisor lifecycle



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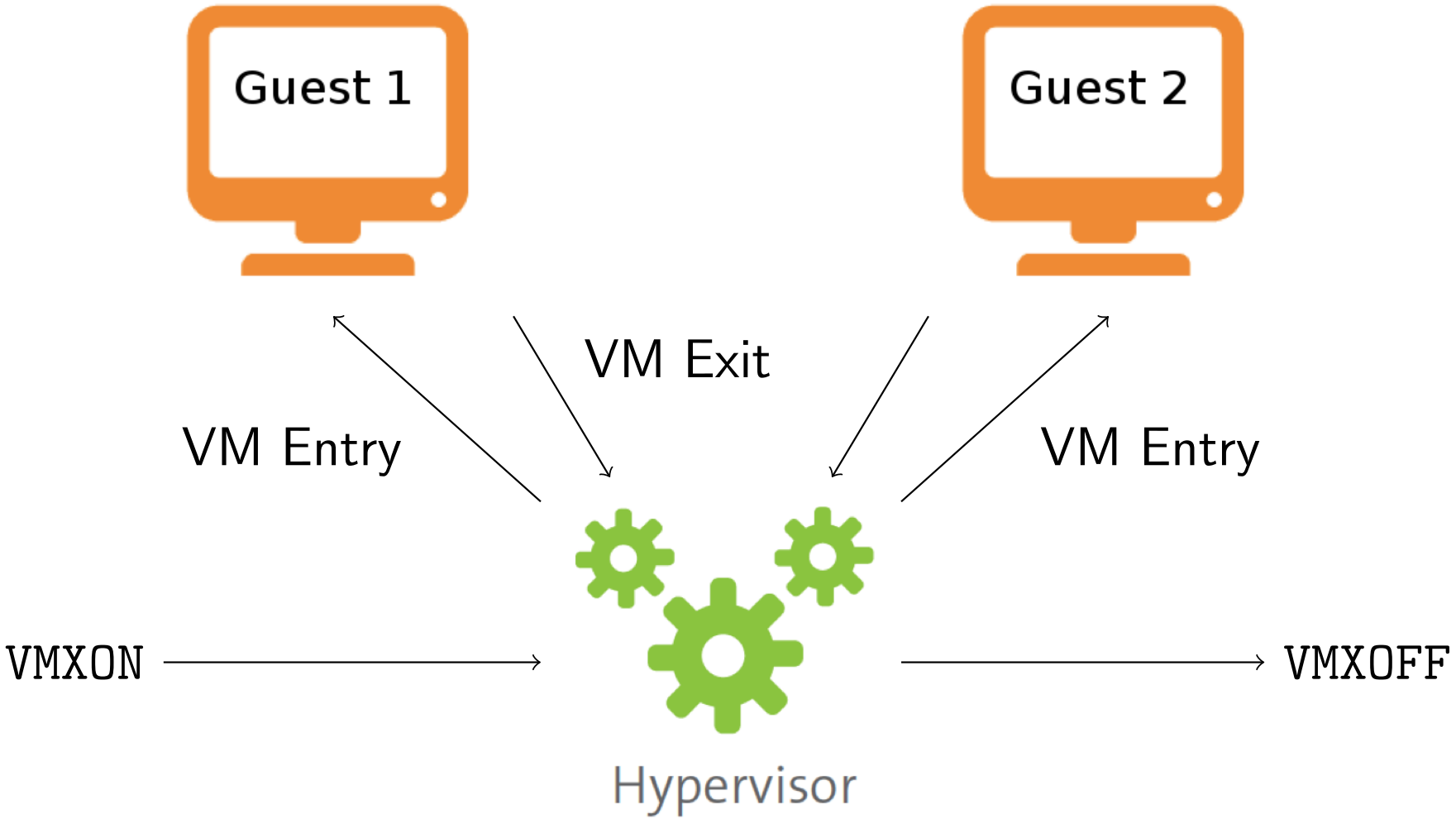

Bitdefender

Hypervisor snippets in Assembly

Find the current memory address:

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call $+5
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Bitdefender

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Bitdefender

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Setting the IDT and GDT:

```
lidt    [ebp + bootIdt]

lea     eax, [ebp + bootGdt.tableStart]
mov     [ebp + bootGdt.base], eax
lgdt    [ebp + bootGdt]
```

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```

Switch from 32 to 64 bit mode:

```
;enable PAE
mov     eax, cr4
or      eax, CR4_PAE
mov     cr4, eax
;set the LME bit in EFER
mov     ecx, IA32_EFER
rdmsr
or      eax, IA32_EFER_LME
wrmsr
;activate paging
mov     eax, [ebp + bootCtx.Cr3]
mov     cr3, eax
mov     eax, cr0
or      eax, 0x80000000 ;PG bit
mov     cr0, eax
```


Thank you!
ASM