Exploiting ROP attacks with a unique instruction

Julien Couvy, ***Vrije Universiteit***

Introduction

- ➡ Background information
- ➡ Our project with examples
- ➡ Limitations
- ➡ Results & Conclusion

Return-into-libc and DEP

Data Execution Prevention (aka. W^X)

- Industry response against **code injection** exploits
- Marks all writable locations in a process's address space as **non executable**
- Hardware support in Intel and AMD processors
- Protection available in all modern OS

Return-into-libc

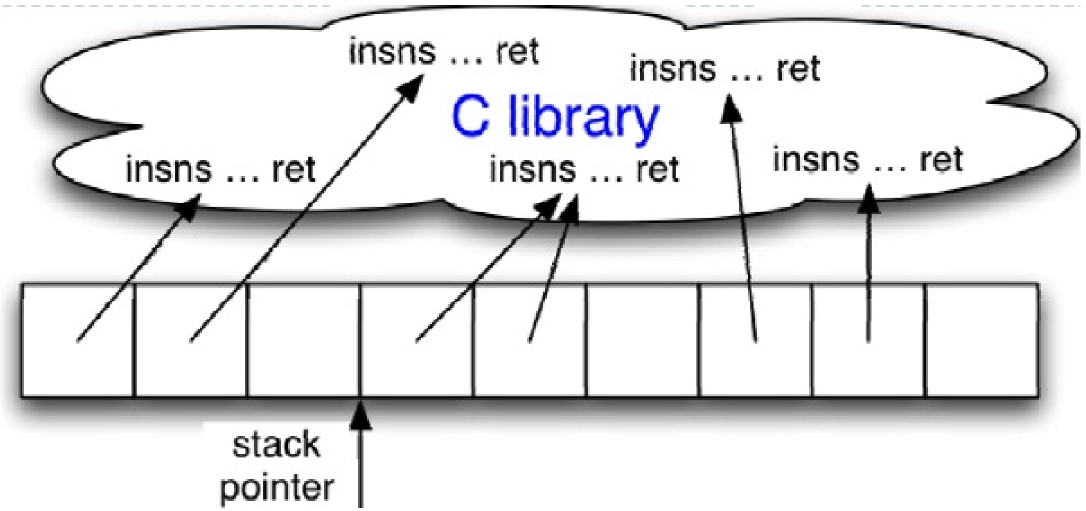
- ➡ Evolution of code injection exploits
- ➡ No injection necessary, **instead** re-use functions present in shared libraries (libc common target)
- ➡ Sensible instructions like `system()` or `printf()`
- ➡ Removed from *glibc*, replaced by safe versions like `execve()`

Return oriented programming

Return oriented programming: Overview

- *The Geometry of Innocent Flesh on the Bone: Return-into-libc without Function Calls (on the x86)*, H.Shacham 2007
- Turing-complete exploit language
- Defeats DEP, code signing, and ASLR (non trivial)
- No function call required

Return oriented programming: Machine level



➡️ The *stack pointer* (%esp) determines which instruction sequence to fetch & execute

➡️ Processor doesn't automatically increment %esp; - but the "ret" at the end of each instruction sequence does

Return oriented programming: Gadgets

- Small instruction sequences ending in `ret`
- Already present in the target binary
- Chain of gadgets = attacker payload

Problem

Cratfting payload is complex and time-consumming...

Can we automate it ?

Our idea: *Mov2Rop*

Mov2Rop: Objectives

➡️ Prove that *return oriented programming* can be made more accessible ==> more dangerous

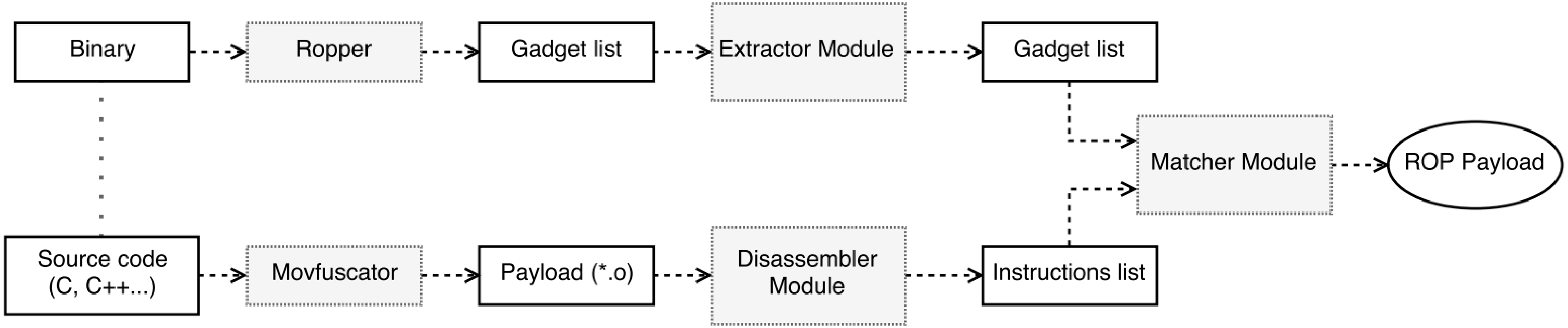
➡️ Automatic gadget extraction and chaining...

➡️ Simplified by targetting `mov` instructions only

Mov2Rop: Tools used

- Language: **Python 3**
- Gadget extraction: **Ropper**
- Disassembly: **Capstone**
- Payload translation: **Movfuscator**

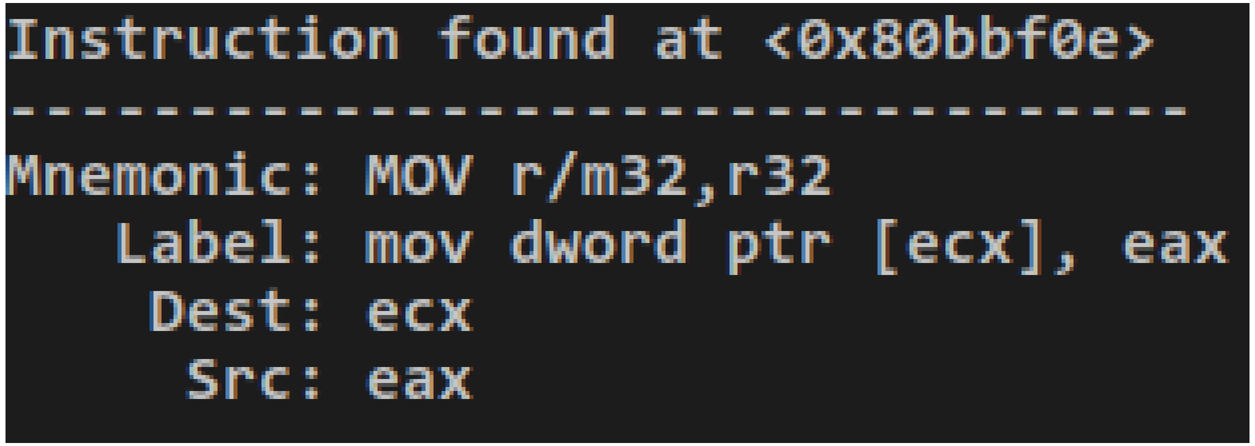
Mov2Rop: Outline



Mov2Rop: Disassembler Module

- ➡ Uses Capstone framework
- ➡ Seaches for `mov` instructions in an object file
- ➡ `mov` instructions are stored in custom **Instruction** data structures

Mov2Rop : Instruction example



```
Instruction found at <0x80bbf0e>
---------------------------------
Mnemonic: MOV r/m32,r32
   Label: mov dword ptr [ecx], eax
    Dest: ecx
     Src: eax
```

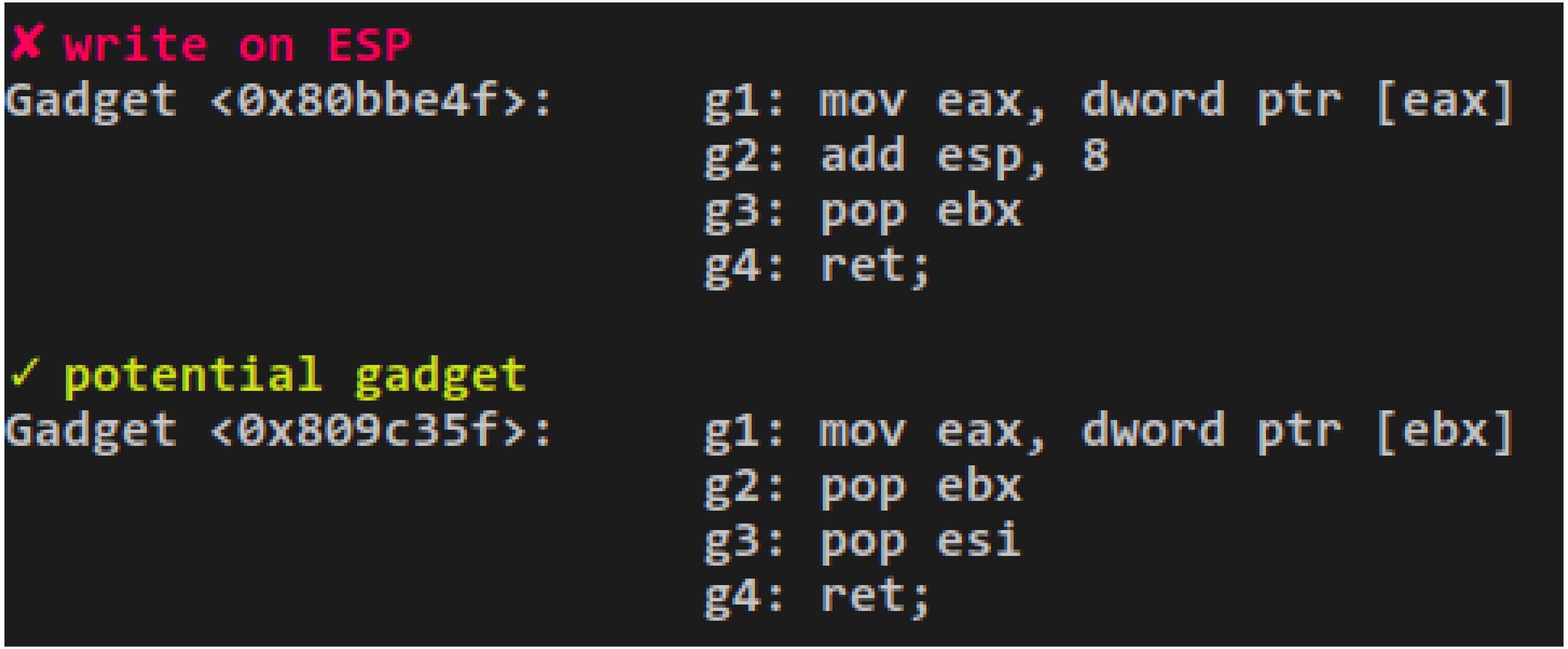
Mov2Rop: Extractor Module

- Ropper's engine in a Python script
- Gadgets are identified with *regular expressions*...

```
ropper -f fibonacci --type rop --search "mov e??, e??"
```

- and stored in custom **Gadget** data structures

Mov2Rop: Gadget example



```
✗ write on ESP
Gadget <0x80bbe4f>:       g1: mov eax, dword ptr [eax]
                          g2: add esp, 8
                          g3: pop ebx
                          g4: ret;

✓ potential gadget
Gadget <0x809c35f>:       g1: mov eax, dword ptr [ebx]
                          g2: pop ebx
                          g3: pop esi
                          g4: ret;
```

Mov2Rop: Matcher Module

➡️ Instruction analysis

- Instructions need to pass a set of rules to be validated

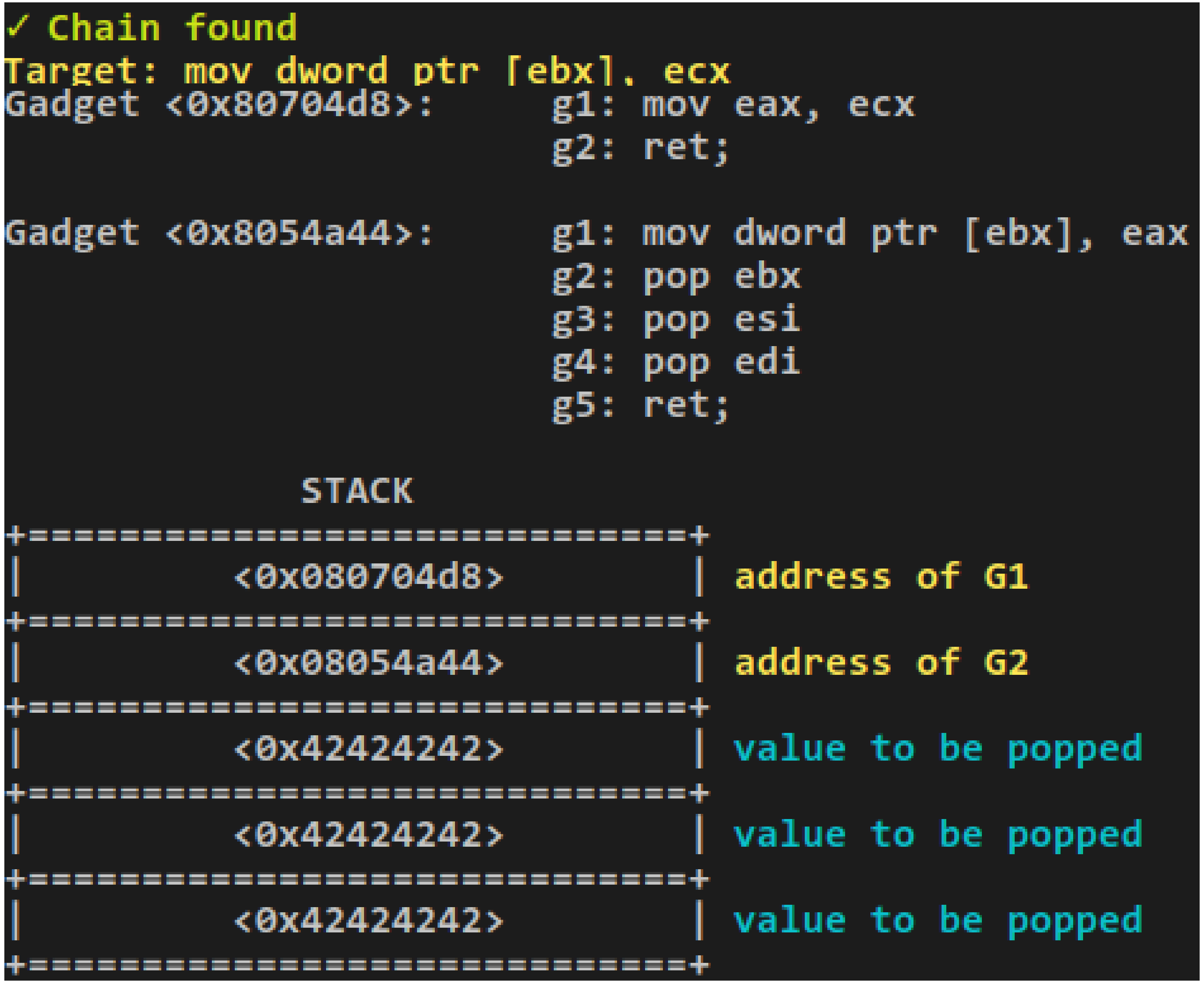
➡️ Gadget chaining

- Tries to map a gadget chain with a payload instruction
- Searches for eventual side-effects

➡️ Stack preparation and visualization

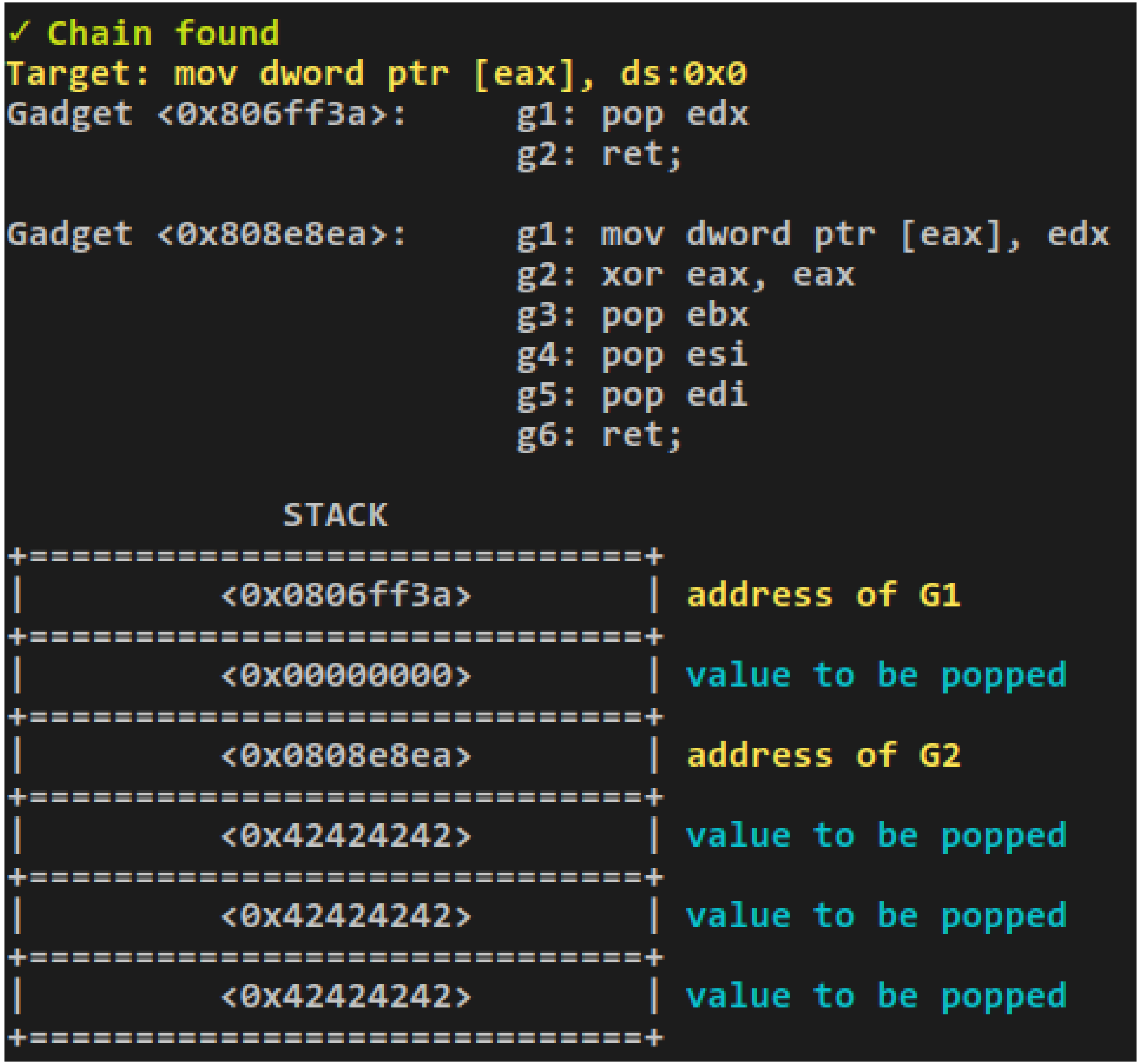
- Stores gadget addresses on the stack
- Searches for `pop` instructions
  I. Safekeeping return addresses chain
  II. Storing immediate values on the stack

Mov2Rop: Chain example



```
✓ Chain found
Target: mov dword ptr [ebx], ecx
Gadget <0x80704d8>:     g1: mov eax, ecx
                        g2: ret;

Gadget <0x8054a44>:     g1: mov dword ptr [ebx], eax
                        g2: pop ebx
                        g3: pop esi
                        g4: pop edi
                        g5: ret;

             STACK
+=============================+
|         <0x080704d8>        | address of G1
+=============================+
|         <0x08054a44>        | address of G2
+=============================+
|         <0x42424242>        | value to be popped
+=============================+
|         <0x42424242>        | value to be popped
+=============================+
|         <0x42424242>        | value to be popped
+=============================+
```

Mov2Rop: Stack preparation example



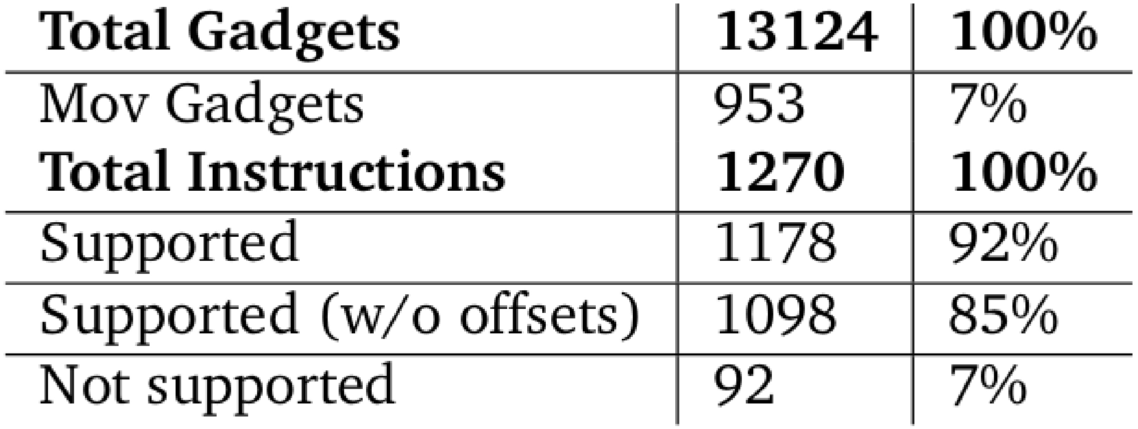
```
✓ Chain found
Target: mov dword ptr [eax], ds:0x0
Gadget <0x806ff3a>:     g1: pop edx
                        g2: ret;

Gadget <0x808e8ea>:     g1: mov dword ptr [eax], edx
                        g2: xor eax, eax
                        g3: pop ebx
                        g4: pop esi
                        g5: pop edi
                        g6: ret;

             STACK
+=============================+
|         <0x0806ff3a>        | address of G1
+=============================+
|         <0x00000000>        | value to be popped
+=============================+
|         <0x0808e8ea>        | address of G2
+=============================+
|         <0x42424242>        | value to be popped
+=============================+
|         <0x42424242>        | value to be popped
+=============================+
|         <0x42424242>        | value to be popped
+=============================+
```

Limitations

- Support only x86 32 bits and instructions using 32 bits registers
- Incomplete side-effect management
- Incomplete `mov` instructions support
- External tools are flawed and limited

Results

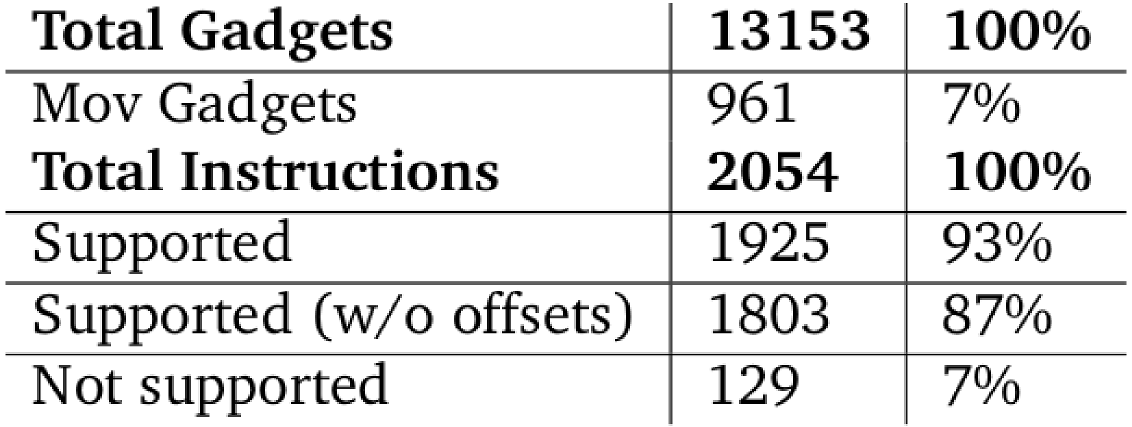
Result 1



Total Gadgets	**13124**	**100%**
Mov Gadgets	953	7%
Total Instructions	**1270**	**100%**
Supported	1178	92%
Supported (w/o offsets)	1098	85%
Not supported	92	7%

Table 2: Statistics on fibonacci.c

Result 2



Total Gadgets	**13153**	**100%**
Mov Gadgets	961	7%
Total Instructions	**2054**	**100%**
Supported	1925	93%
Supported (w/o offsets)	1803	87%
Not supported	129	7%

Table 3: Statistics on hanoi_towers.c

Further work

Two possibilites:

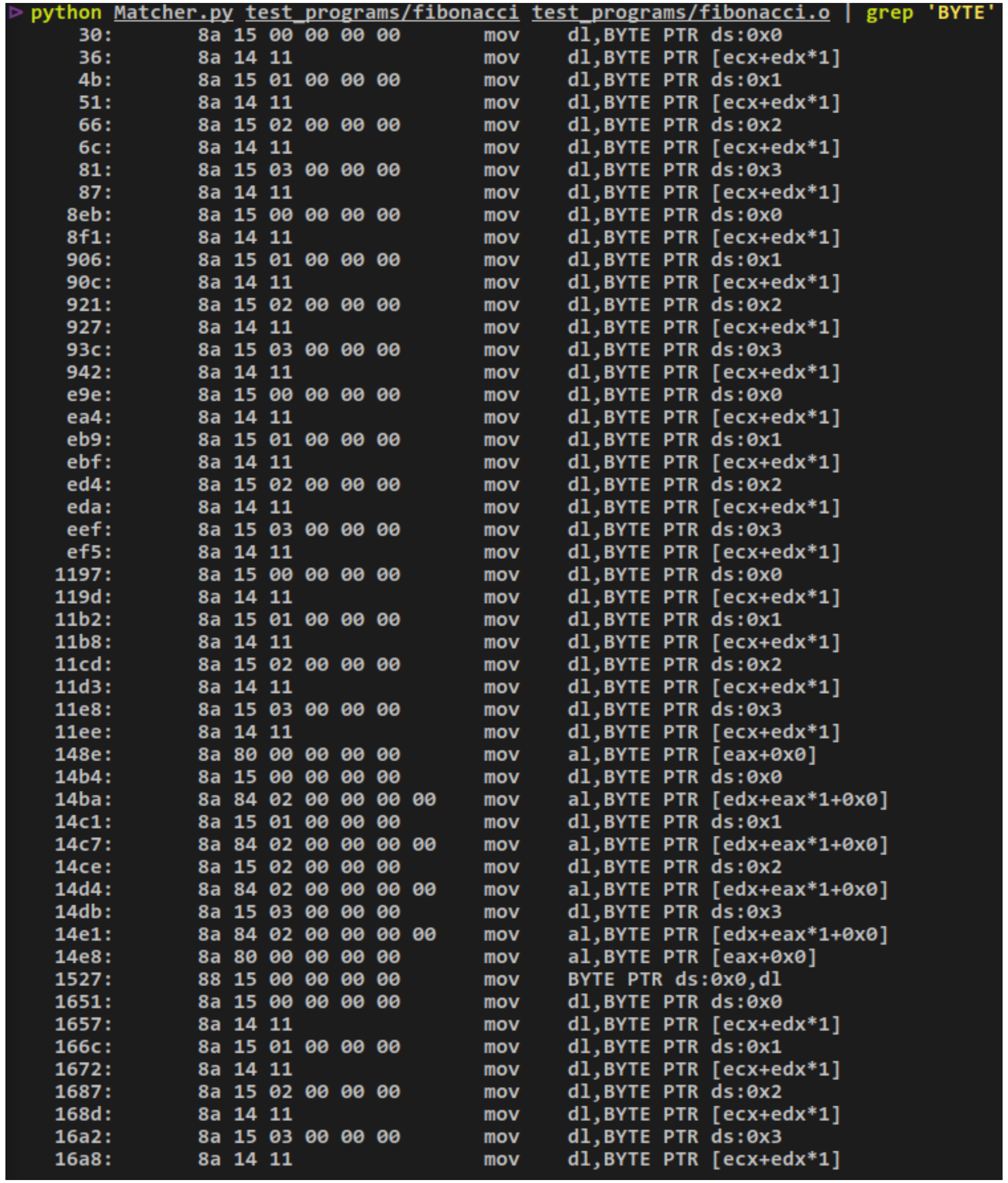
➡️ **Improving current protoype**

- Cover all `mov` instructions
- In depth side-effect verification
- x86_64 support
- ...

➡️ **Integration as backend in LLVM**

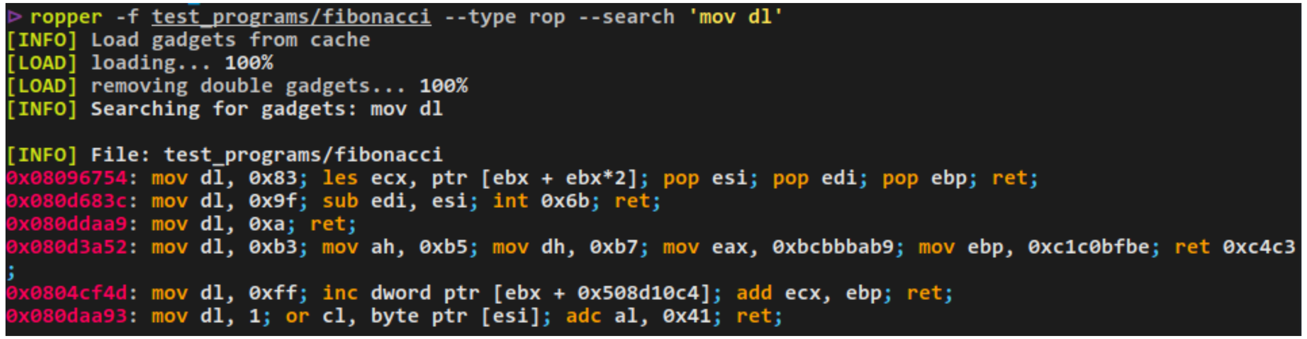
- *Pro:* LLVM = growing project with strong community, LLVM IR allows to use any input language easily
- *Con:* Dropping the idea of `mov` only instructions (original motivation)

Object dump

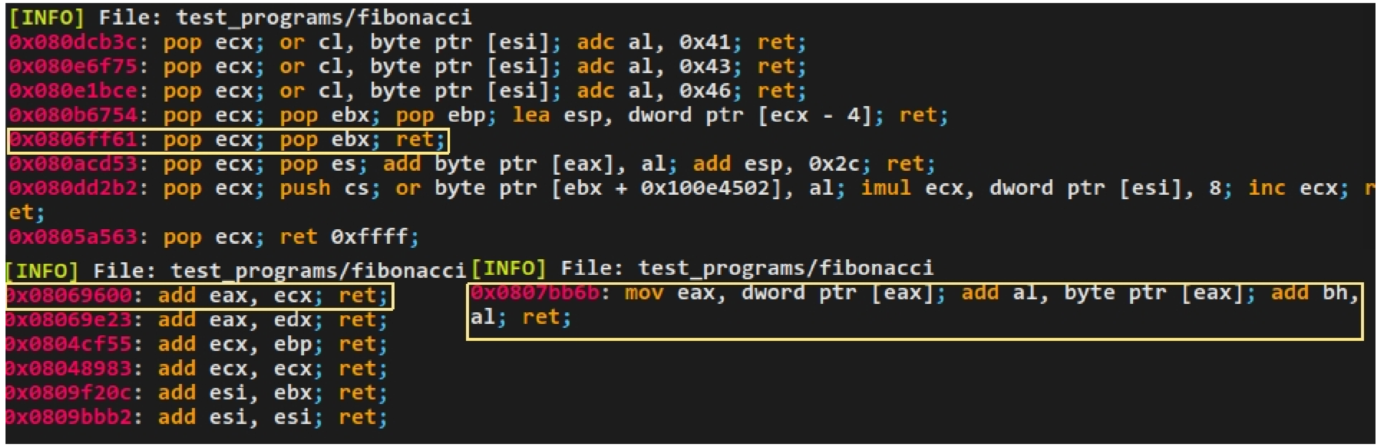
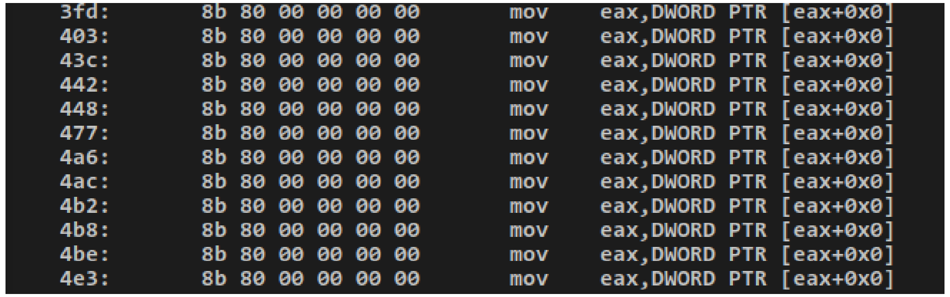


```
▷ python Matcher.py test_programs/fibonacci test_programs/fibonacci.o | grep 'BYTE'
      30:        8a 15 00 00 00 00        mov    dl,BYTE PTR ds:0x0
      36:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
      4b:        8a 15 01 00 00 00        mov    dl,BYTE PTR ds:0x1
      51:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
      66:        8a 15 02 00 00 00        mov    dl,BYTE PTR ds:0x2
      6c:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
      81:        8a 15 03 00 00 00        mov    dl,BYTE PTR ds:0x3
      87:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
     8eb:        8a 15 00 00 00 00        mov    dl,BYTE PTR ds:0x0
     8f1:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
     906:        8a 15 01 00 00 00        mov    dl,BYTE PTR ds:0x1
     90c:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
     921:        8a 15 02 00 00 00        mov    dl,BYTE PTR ds:0x2
     927:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
     93c:        8a 15 03 00 00 00        mov    dl,BYTE PTR ds:0x3
     942:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
     e9e:        8a 15 00 00 00 00        mov    dl,BYTE PTR ds:0x0
     ea4:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
     eb9:        8a 15 01 00 00 00        mov    dl,BYTE PTR ds:0x1
     ebf:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
     ed4:        8a 15 02 00 00 00        mov    dl,BYTE PTR ds:0x2
     eda:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
     eef:        8a 15 03 00 00 00        mov    dl,BYTE PTR ds:0x3
     ef5:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
    1197:        8a 15 00 00 00 00        mov    dl,BYTE PTR ds:0x0
    119d:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
    11b2:        8a 15 01 00 00 00        mov    dl,BYTE PTR ds:0x1
    11b8:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
    11cd:        8a 15 02 00 00 00        mov    dl,BYTE PTR ds:0x2
    11d3:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
    11e8:        8a 15 03 00 00 00        mov    dl,BYTE PTR ds:0x3
    11ee:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
    148e:        8a 80 00 00 00 00        mov    al,BYTE PTR [eax+0x0]
    14b4:        8a 15 00 00 00 00        mov    dl,BYTE PTR ds:0x0
    14ba:        8a 84 02 00 00 00 00     mov    al,BYTE PTR [edx+eax*1+0x0]
    14c1:        8a 15 01 00 00 00        mov    dl,BYTE PTR ds:0x1
    14c7:        8a 84 02 00 00 00 00     mov    al,BYTE PTR [edx+eax*1+0x0]
    14ce:        8a 15 02 00 00 00        mov    dl,BYTE PTR ds:0x2
    14d4:        8a 84 02 00 00 00 00     mov    al,BYTE PTR [edx+eax*1+0x0]
    14db:        8a 15 03 00 00 00        mov    dl,BYTE PTR ds:0x3
    14e1:        8a 84 02 00 00 00 00     mov    al,BYTE PTR [edx+eax*1+0x0]
    14e8:        8a 80 00 00 00 00        mov    al,BYTE PTR [eax+0x0]
    1527:        88 15 00 00 00 00        mov    BYTE PTR ds:0x0,dl
    1651:        8a 15 00 00 00 00        mov    dl,BYTE PTR ds:0x0
    1657:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
    166c:        8a 15 01 00 00 00        mov    dl,BYTE PTR ds:0x1
    1672:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
    1687:        8a 15 02 00 00 00        mov    dl,BYTE PTR ds:0x2
    168d:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
    16a2:        8a 15 03 00 00 00        mov    dl,BYTE PTR ds:0x3
    16a8:        8a 14 11                 mov    dl,BYTE PTR [ecx+edx*1]
```

Gadgets found



```
▷ ropper -f test_programs/fibonacci --type rop --search 'mov dl'
[INFO] Load gadgets from cache
[LOAD] loading... 100%
[LOAD] removing double gadgets... 100%
[INFO] Searching for gadgets: mov dl

[INFO] File: test_programs/fibonacci
0x08096754: mov dl, 0x83; les ecx, ptr [ebx + ebx*2]; pop esi; pop edi; pop ebp; ret;
0x080d683c: mov dl, 0x9f; sub edi, esi; int 0x6b; ret;
0x080ddaa9: mov dl, 0xa; ret;
0x080d3a52: mov dl, 0xb3; mov ah, 0xb5; mov dh, 0xb7; mov eax, 0xbcbbbab9; mov ebp, 0xc1c0bfbe; ret 0xc4c3
;
0x0804cf4d: mov dl, 0xff; inc dword ptr [ebx + 0x508d10c4]; add ecx, ebp; ret;
0x080daa93: mov dl, 1; or cl, byte ptr [esi]; adc al, 0x41; ret;
```

Finding gadgets	Payload instructions
	

```
[INFO] File: test_programs/fibonacci
0x080dcb3c: pop ecx; or cl, byte ptr [esi]; adc al, 0x41; ret;
0x080e6f75: pop ecx; or cl, byte ptr [esi]; adc al, 0x43; ret;
0x080e1bce: pop ecx; or cl, byte ptr [esi]; adc al, 0x46; ret;
0x080b6754: pop ecx; pop ebx; pop ebp; lea esp, dword ptr [ecx - 4]; ret;
0x0806ff61: pop ecx; pop ebx; ret;
0x080acd53: pop ecx; pop es; add byte ptr [eax], al; add esp, 0x2c; ret;
0x080dd2b2: pop ecx; push cs; or byte ptr [ebx + 0x100e4502], al; imul ecx, dword ptr [esi], 8; inc ecx; r
et;
0x0805a563: pop ecx; ret 0xffff;

[INFO] File: test_programs/fibonacci [INFO] File: test_programs/fibonacci
0x08069600: add eax, ecx; ret;        0x0807bb6b: mov eax, dword ptr [eax]; add al, byte ptr [eax]; add bh,
0x08069e23: add eax, edx; ret;        al; ret;
0x0804cf55: add ecx, ebp; ret;
0x08048983: add ecx, ecx; ret;
0x0809f20c: add esi, ebx; ret;
0x0809bbb2: add esi, esi; ret;
```

```
 3fd:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 403:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 43c:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 442:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 448:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 477:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 4a6:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 4ac:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 4b2:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 4b8:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 4be:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
 4e3:        8b 80 00 00 00 00       mov    eax,DWORD PTR [eax+0x0]
```

```
             STACK
+==============================+
|         <0x0806ff61>         | address of G1 <pop ecx; pop ebx; ret;>
+==============================+
|         <0x00000000>         | value required in %ecx
+==============================+
|         <0x42424242>         | dummy value for <pop ebx;>
+==============================+
|         <0x08069600>         | address of G2 <add eax, ecx; ret;>
+==============================+
|         <0x0807bb6b>         | address of G3 <mov eax, dword ptr [eax]...>
+==============================+
              ...
```

Thank you for your attention.

Any questions ?