Binary Exploitation

Intro

ju256

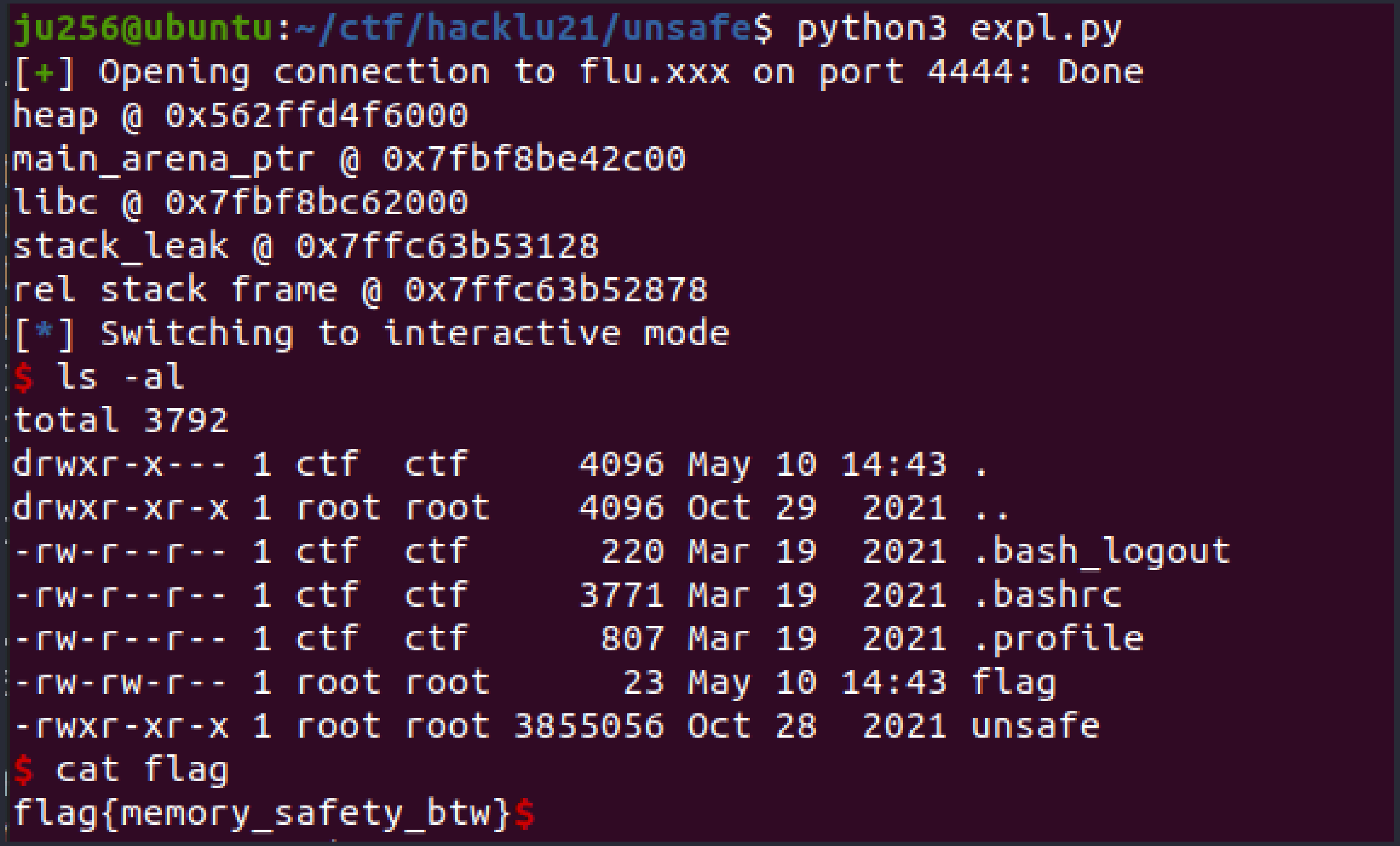
```
  ExecutionContext,
  Injectable,
  UnauthorizedException,
} from '@nestjs/common';
import { UserService } from 'src/user/user.service';

@Injectable()
export class AuthGuard implements CanActivate {
  constructor(private readonly userService: UserService) {}

  async canActivate(context: ExecutionContext): Promise<boolean
    const request = context.switchToHttp().getRequest();
    const token = this.extractTokenFromHeader(request);
    if (!token) {
      throw new UnauthorizedException();
    }
    try {
      const payload = await this.userService.validateJwt(token)
      // 💡 We're assigning the payload to the request object he
      // so that we can access it in our route handlers
      request['user'] = payload;
      catch {
      hrow new UnauthorizedException();

      n true;

      tractTokenFromHeader(request: Request): string | un
      aders: any = request.headers;
      pe, token] = headers.authorization?.split(' ') ??
      e === 'Bearer' ? token : undefined;
```

Overview

- Finding and exploiting bugs in a binary/executable
- Programs written in low-level language
- Reverse engineering often mandatory first step
- Memory corruption vs logic bugs

Binary Exploitation in CTFs

- Often C/C++ binaries written for the competition
- Sometimes real world targets with introduced bugs
  - Chrome: GPNCTF21 TYPE THIS
  - Firefox: 33c3 CTF Feuerfuchs



```
ju256@ubuntu:~/ctf/hacklu21/unsafe$ python3 expl.py
[+] Opening connection to flu.xxx on port 4444: Done
heap @ 0x562ffd4f6000
main_arena_ptr @ 0x7fbf8be42c00
libc @ 0x7fbf8bc62000
stack_leak @ 0x7ffc63b53128
rel stack frame @ 0x7ffc63b52878
[*] Switching to interactive mode
$ ls -al
total 3792
drwxr-x--- 1 ctf  ctf     4096 May 10 14:43 .
drwxr-xr-x 1 root root    4096 Oct 29  2021 ..
-rw-r--r-- 1 ctf  ctf      220 Mar 19  2021 .bash_logout
-rw-r--r-- 1 ctf  ctf     3771 Mar 19  2021 .bashrc
-rw-r--r-- 1 ctf  ctf      807 Mar 19  2021 .profile
-rw-rw-r-- 1 root root      23 May 10 14:43 flag
-rwxr-xr-x 1 root root 3855056 Oct 28  2021 unsafe
$ cat flag
flag{memory_safety_btw}$
```

Objective

(Remote) Code Execution / Shell* on challenge server

Linux userspace

```
system("/bin/sh");
```

Linux kernel

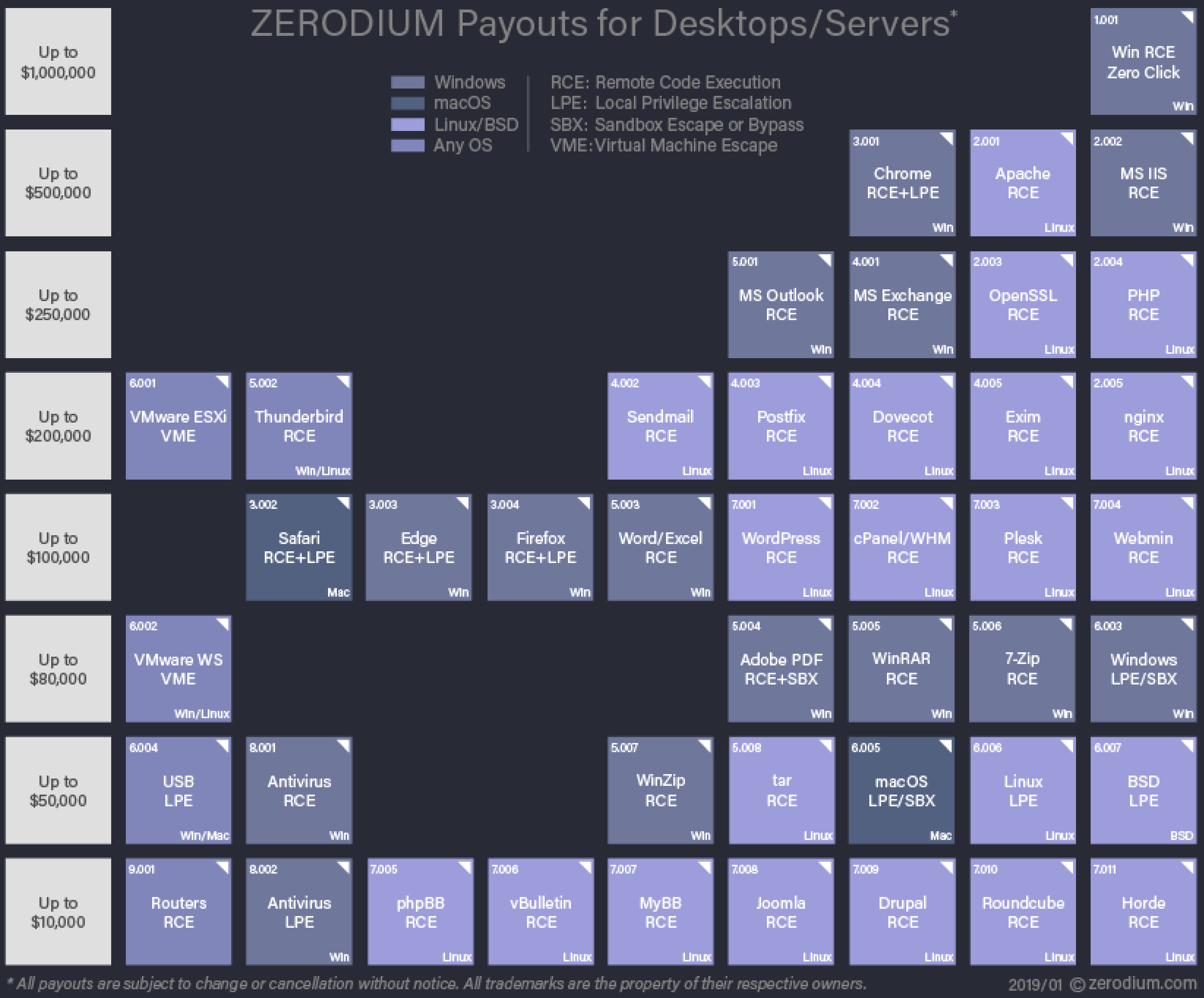
```
setgid(0);
setuid(0);
system("/bin/sh");
```

...

Binary Exploitation in the "Real World"

- Memory-unsafe languages still widely used
  - Browsers
  - Hypervisors
  - Web servers
- Even the "best" codebases contain (a lot of) exploitable bugs

Large (dubious) market for 0-days in popular software



ZERODIUM Payouts for Desktops/Servers*

▨ Windows
▨ macOS
▨ Linux/BSD
▨ Any OS

RCE: Remote Code Execution
LPE: Local Privilege Escalation
SBX: Sandbox Escape or Bypass
VME: Virtual Machine Escape

Up to $1,000,000									1.001 Win RCE Zero Click Win
Up to $500,000							3.001 Chrome RCE+LPE Win	2.001 Apache RCE Linux	2.002 MS IIS RCE Win
Up to $250,000						5.001 MS Outlook RCE Win	4.001 MS Exchange RCE Win	2.003 OpenSSL RCE Linux	2.004 PHP RCE Linux
Up to $200,000	6.001 VMware ESXi VME	5.002 Thunderbird RCE Win/Linux			4.002 Sendmail RCE Linux	4.003 Postfix RCE Linux	4.004 Dovecot RCE Linux	4.005 Exim RCE Linux	2.005 nginx RCE Linux
Up to $100,000		3.002 Safari RCE+LPE Mac	3.003 Edge RCE+LPE Win	3.004 Firefox RCE+LPE Win	5.003 Word/Excel RCE Win	7.001 WordPress RCE Linux	7.002 cPanel/WHM RCE Linux	7.003 Plesk RCE Linux	7.004 Webmin RCE Linux
Up to $80,000	6.002 VMware WS VME Win/Linux					5.004 Adobe PDF RCE+SBX Win	5.005 WinRAR RCE Win	5.006 7-Zip RCE Win	6.003 Windows LPE/SBX Win
Up to $50,000	6.004 USB LPE Win/Mac	8.001 Antivirus RCE Win			5.007 WinZip RCE Win	5.008 tar RCE Linux	6.005 macOS LPE/SBX Mac	6.006 Linux LPE Linux	6.007 BSD LPE BSD
Up to $10,000	9.001 Routers RCE	8.002 Antivirus LPE Win	7.005 phpBB RCE Linux	7.006 vBulletin RCE Linux	7.007 MyBB RCE Linux	7.008 Joomla RCE Linux	7.009 Drupal RCE Linux	7.010 Roundcube RCE Linux	7.011 Horde RCE Linux

** All payouts are subject to change or cancellation without notice. All trademarks are the property of their respective owners.*

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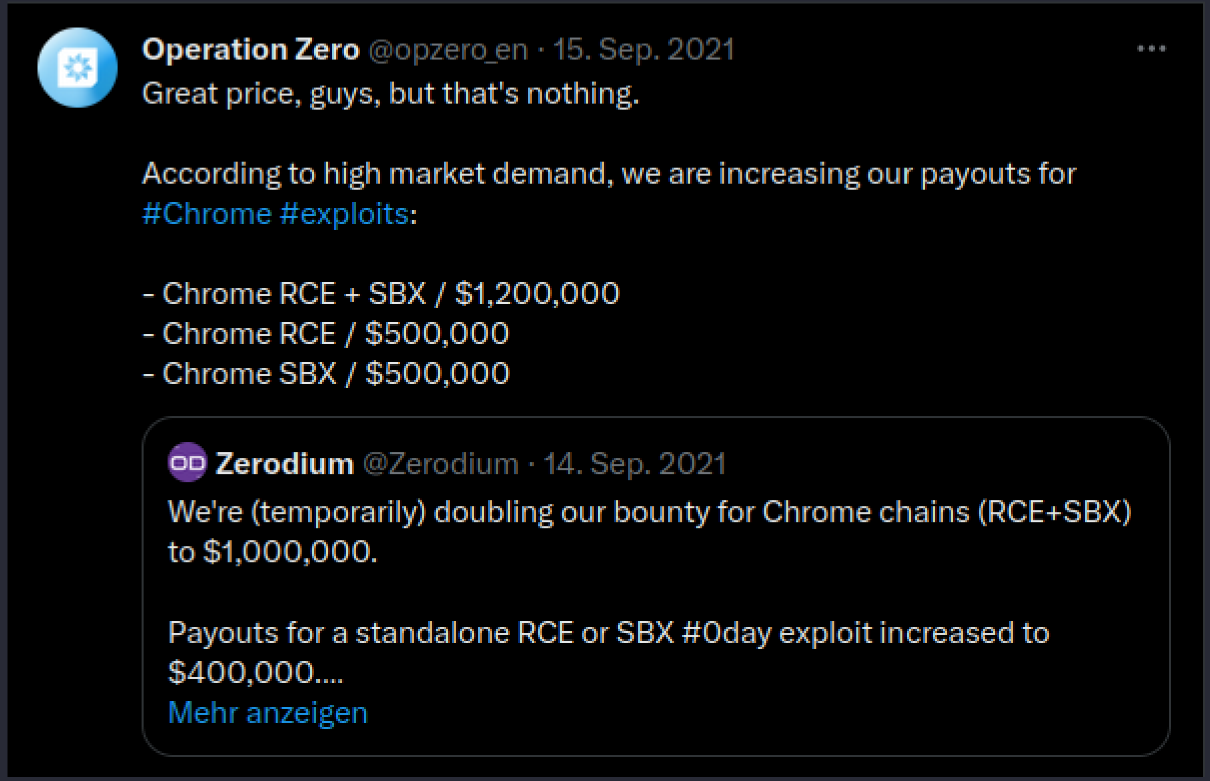
Twitter content as dubios as the market



Operation Zero @opzero_en · 15. Sep. 2021

Great price, guys, but that's nothing.

According to high market demand, we are increasing our payouts for #Chrome #exploits:

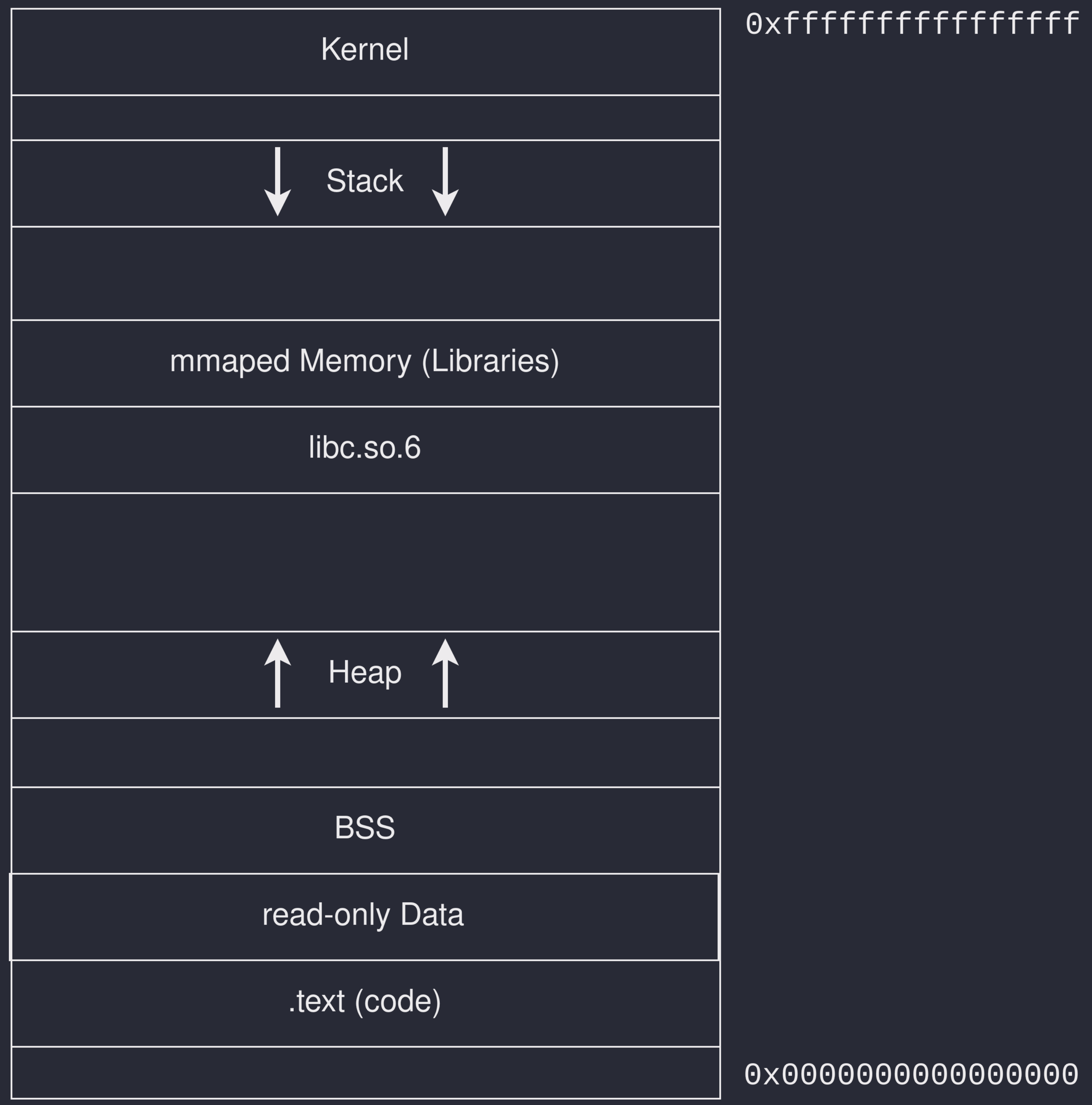
- Chrome RCE + SBX / $1,200,000
- Chrome RCE / $500,000
- Chrome SBX / $500,000

> **Zerodium** @Zerodium · 14. Sep. 2021
>
> We're (temporarily) doubling our bounty for Chrome chains (RCE+SBX) to $1,000,000.
>
> Payouts for a standalone RCE or SBX #0day exploit increased to $400,000....
>
> Mehr anzeigen

Hope is not lost if you don't want to sell to those guys[1]

- ChromeVRP + v8CTF
- kernelCTF
- ...

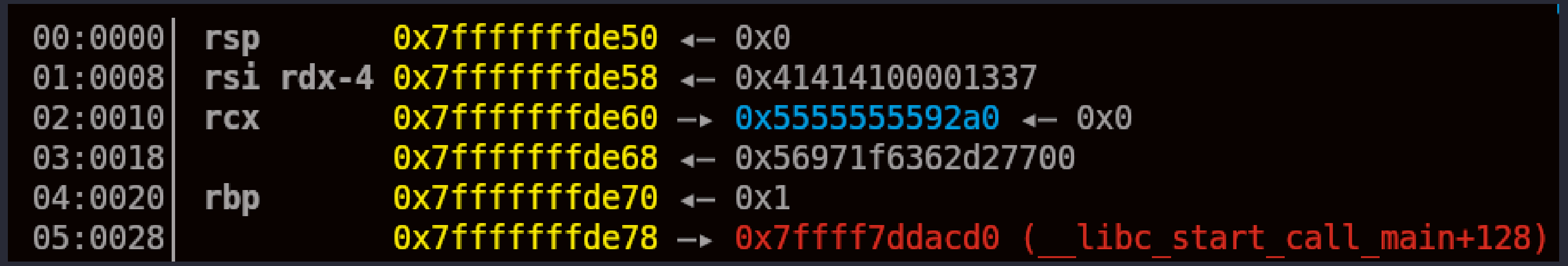
Linux process layout



Stack frames

```c
#include <stdio.h>
#include <stdlib.h>

int main() {
    int a = 0x1337;
    int b = 0x414141;
    char *c = malloc(0x20);
    printf("&a = %p\n&b = %p\n&c = %p\n",
            &a,
            &b,
            &c);

    return 0;
}
```

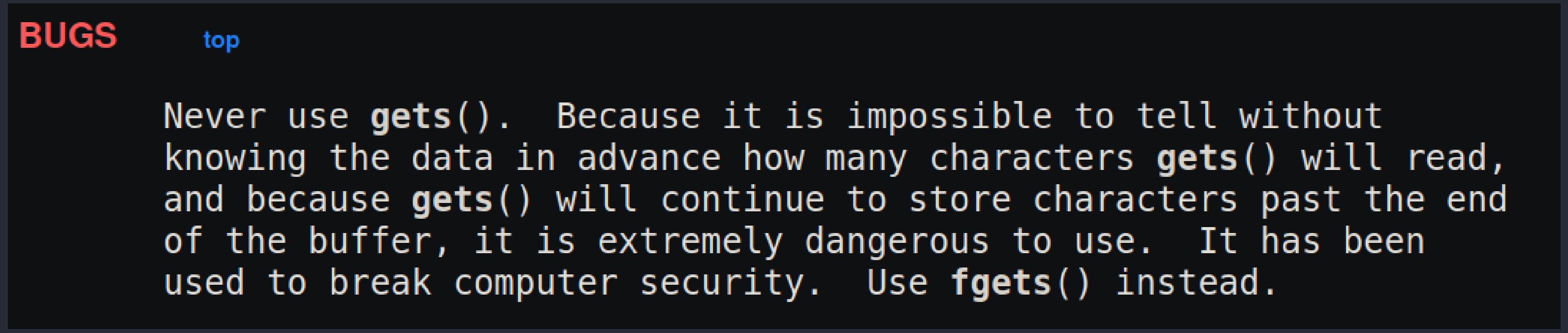
```
&a = 0x7fffffffde58
&b = 0x7fffffffde5c
&c = 0x7fffffffde60
```



```
00:0000│ rsp        0x7fffffffde50 ◂— 0x0
01:0008│ rsi rdx-4  0x7fffffffde58 ◂— 0x41414100001337
02:0010│ rcx        0x7fffffffde60 —▸ 0x5555555592a0 ◂— 0x0
03:0018│            0x7fffffffde68 ◂— 0x56971f6362d27700
04:0020│ rbp        0x7fffffffde70 ◂— 0x1
05:0028│            0x7fffffffde78 —▸ 0x7ffff7ddacd0 (__libc_start_call_main+128)
```

Buffer Overflows

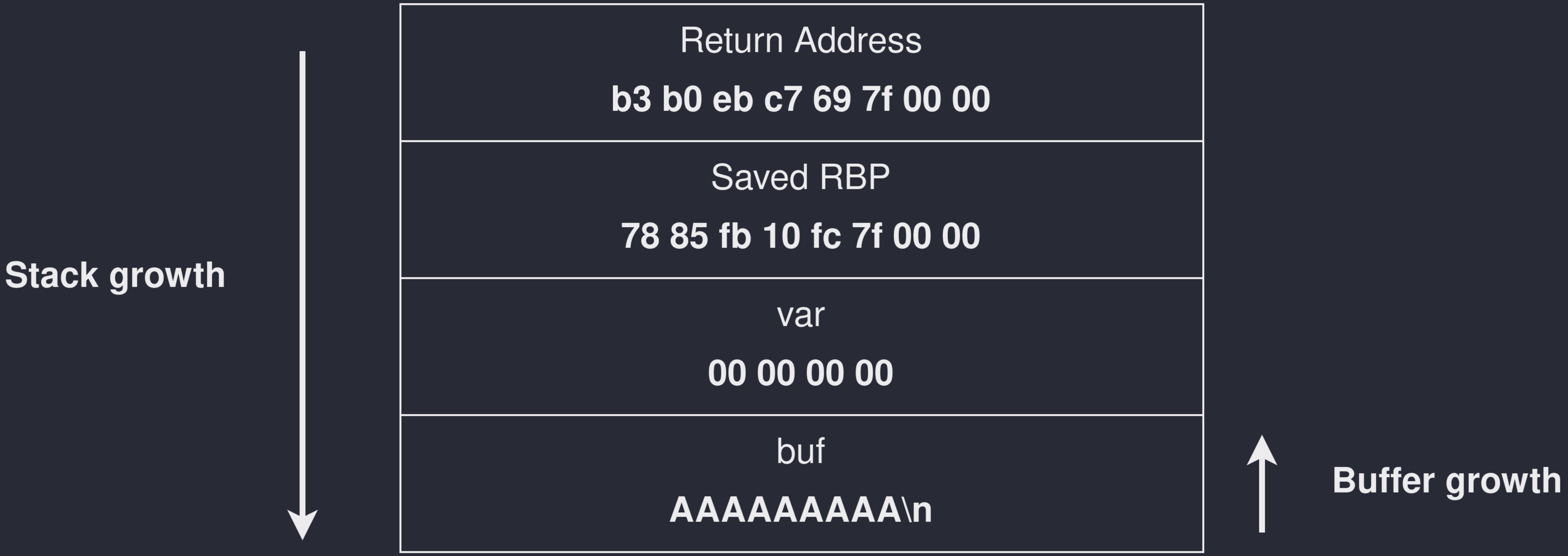
```c
#include <stdio.h>

int main() {
    int var = 0;
    char buf[10];

    gets(buf);

    if (var != 0) {
        puts("Success!");
    }
    return 0;
}
```



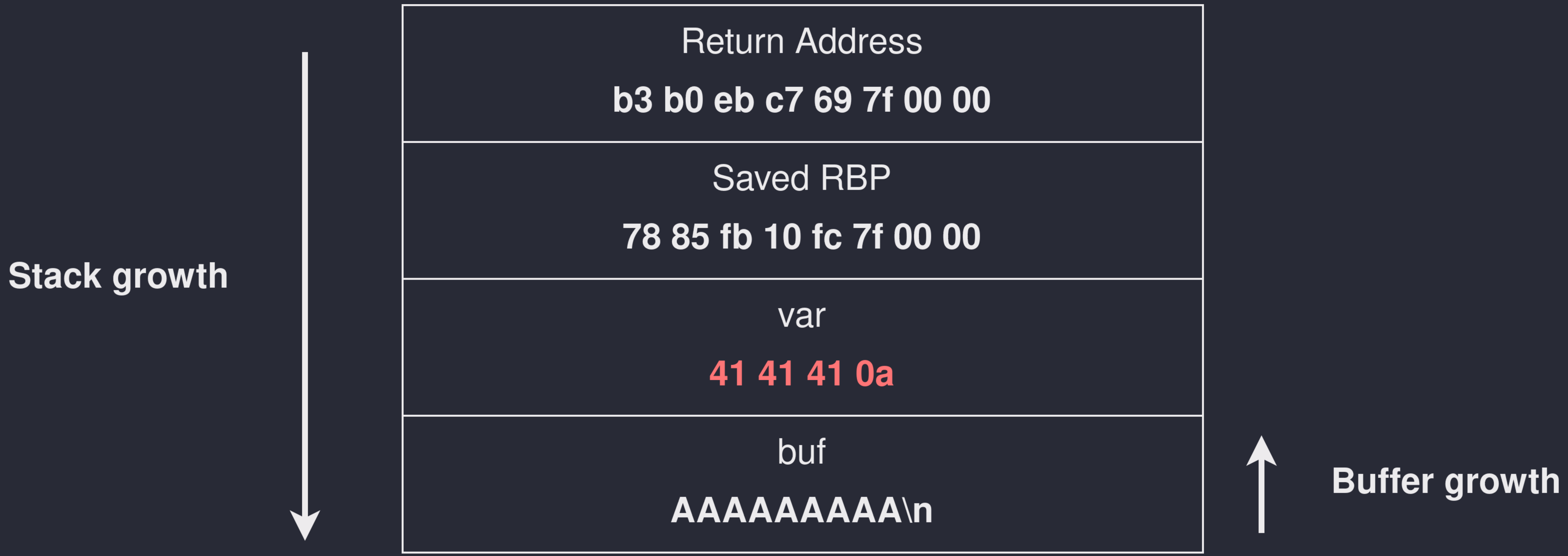
BUGS top

```
Never use gets().  Because it is impossible to tell without
knowing the data in advance how many characters gets() will read,
and because gets() will continue to store characters past the end
of the buffer, it is extremely dangerous to use.  It has been
used to break computer security.  Use fgets() instead.
```

All good if we stay in the buffer



Overflowing the buffer



Return Address

b3 b0 eb c7 69 7f 00 00

Saved RBP

78 85 fb 10 fc 7f 00 00

var

41 41 41 0a

buf

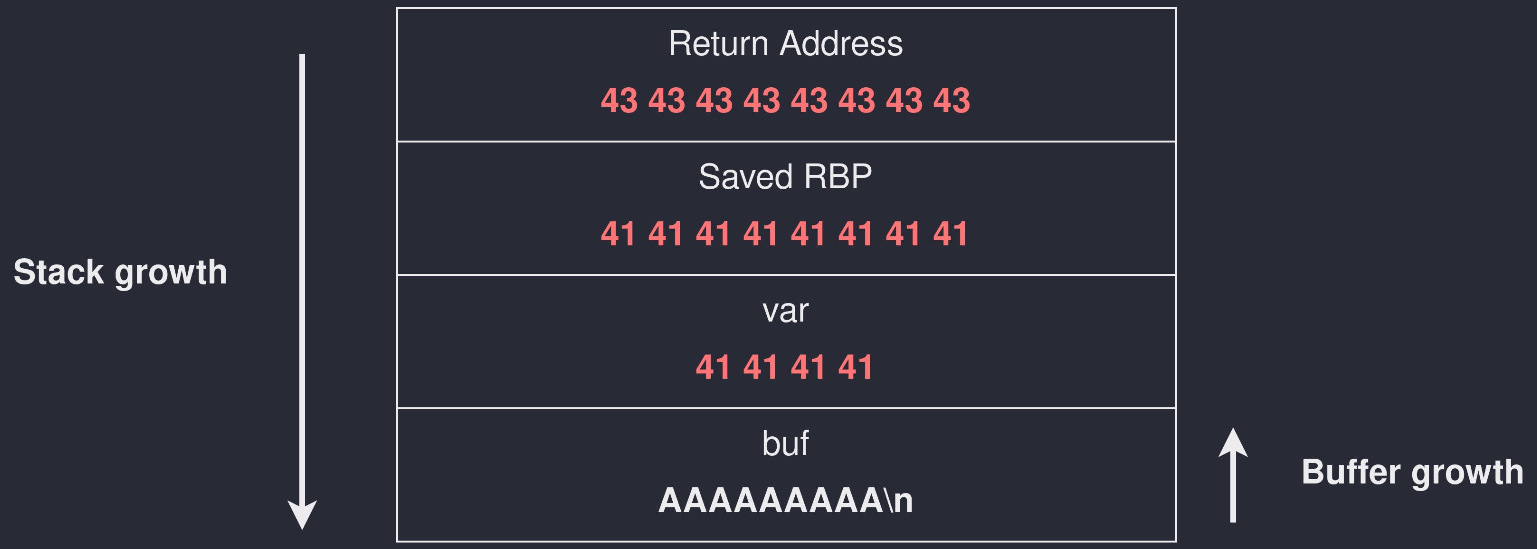
AAAAAAAAA\n

Stack growth

Buffer growth

Overflowing the buffer

- Control over local variables
- Control over frame base pointer (RBP)
- **Control over instruction pointer (RIP)!**



Stack growth

Return Address

43 43 43 43 43 43 43 43

Saved RBP

41 41 41 41 41 41 41 41

var

41 41 41 41

buf

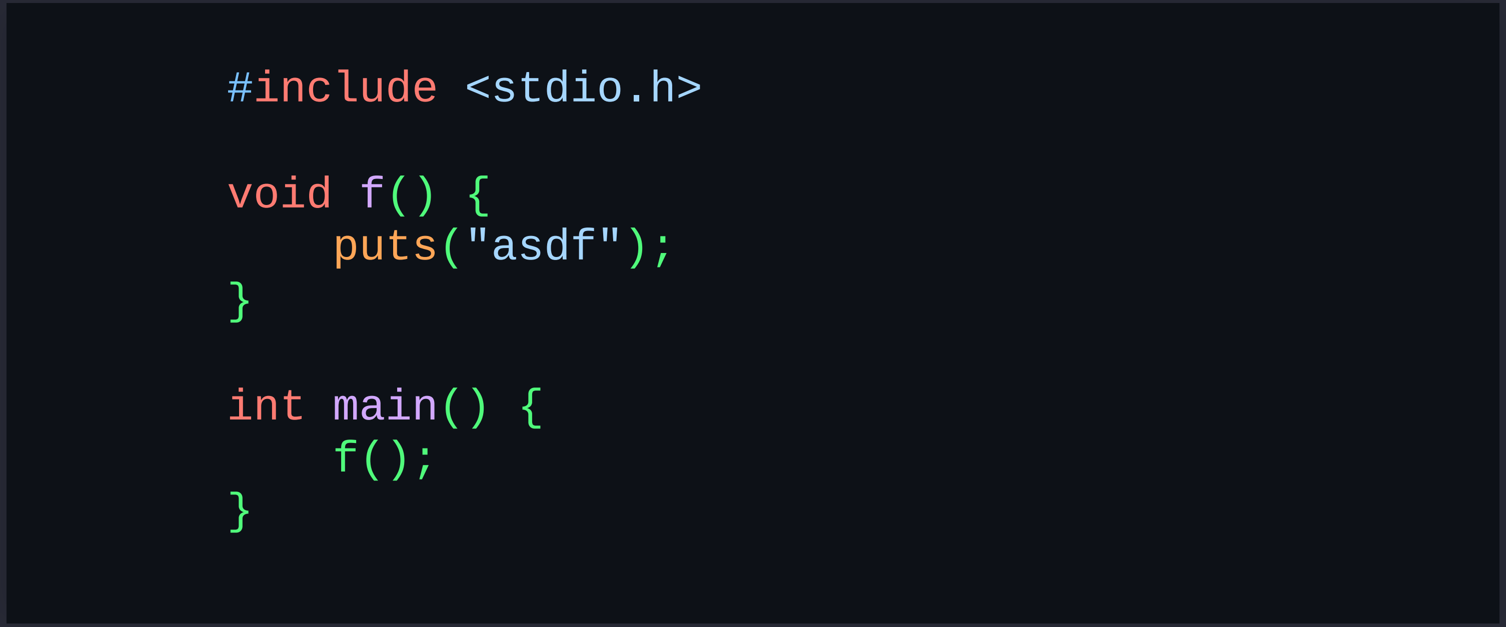
AAAAAAAAA\n

Buffer growth

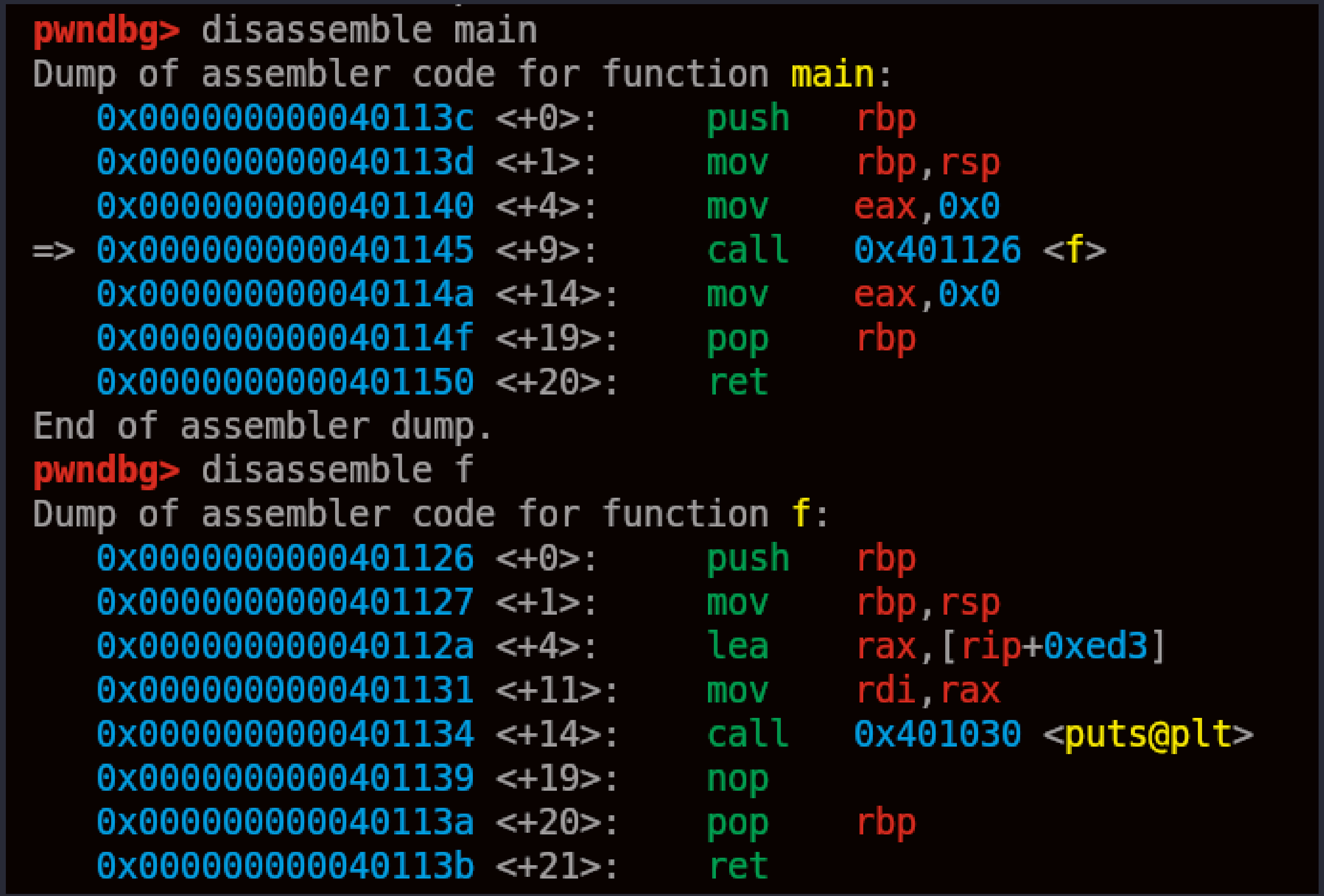
RIP = 0×4343434343434343

Sidenote: function calls in x86

- **call** pushes return address onto the stack
- **ret** pops return address into RIP



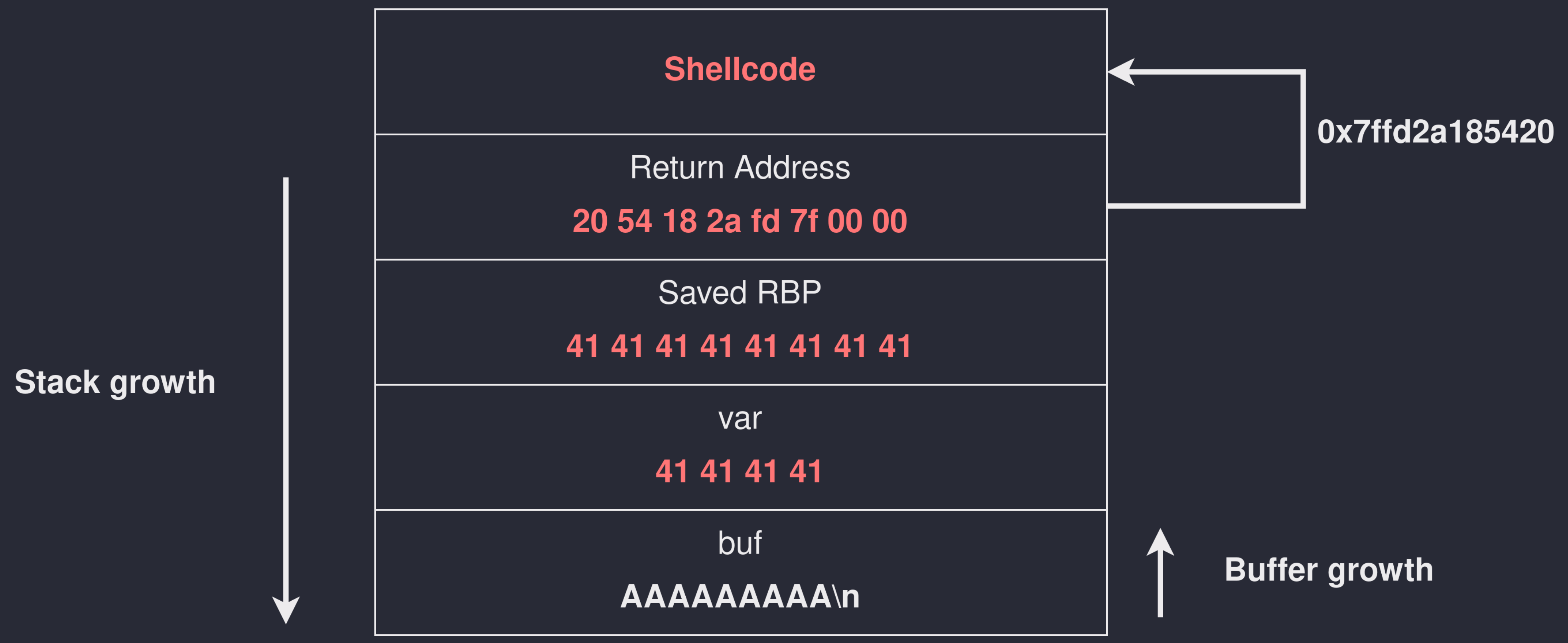
```c
#include <stdio.h>

void f() {
    puts("asdf");
}

int main() {
    f();
}
```



```
pwndbg> disassemble main
Dump of assembler code for function main:
   0x000000000040113c <+0>:     push   rbp
   0x000000000040113d <+1>:     mov    rbp,rsp
   0x0000000000401140 <+4>:     mov    eax,0x0
=> 0x0000000000401145 <+9>:     call   0x401126 <f>
   0x000000000040114a <+14>:    mov    eax,0x0
   0x000000000040114f <+19>:    pop    rbp
   0x0000000000401150 <+20>:    ret
End of assembler dump.
pwndbg> disassemble f
Dump of assembler code for function f:
   0x0000000000401126 <+0>:     push   rbp
   0x0000000000401127 <+1>:     mov    rbp,rsp
   0x000000000040112a <+4>:     lea    rax,[rip+0xed3]
   0x0000000000401131 <+11>:    mov    rdi,rax
   0x0000000000401134 <+14>:    call   0x401030 <puts@plt>
   0x0000000000401139 <+19>:    nop
   0x000000000040113a <+20>:    pop    rbp
   0x000000000040113b <+21>:    ret
```

RIP-control to shell?

Shellcode: Inject our own x86 code into memory and jump to it by overwriting RIP



Shellcode

- Read files
- Open sockets
- Spawn shell
- ...

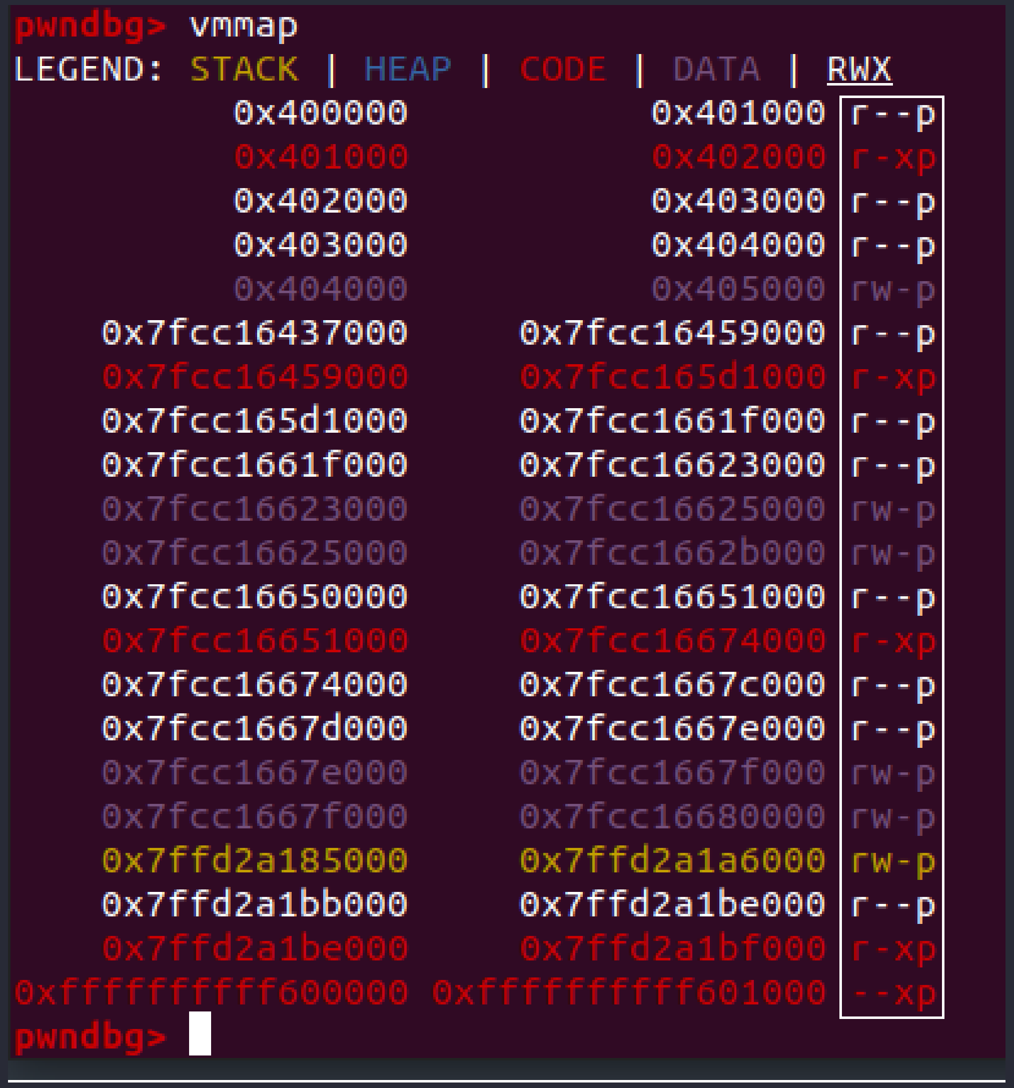
```
mov rax, 0x68732f6e69622f ; /bin/sh\x00
push rax
mov rdi, rsp
xor rsi, rsi
xor rdx, rdx
mov rax, 0x3b ; SYS_execve
; execve("/bin/sh", 0, 0)
syscall
```

What's the catch?

🤮 Mitigations 🤮

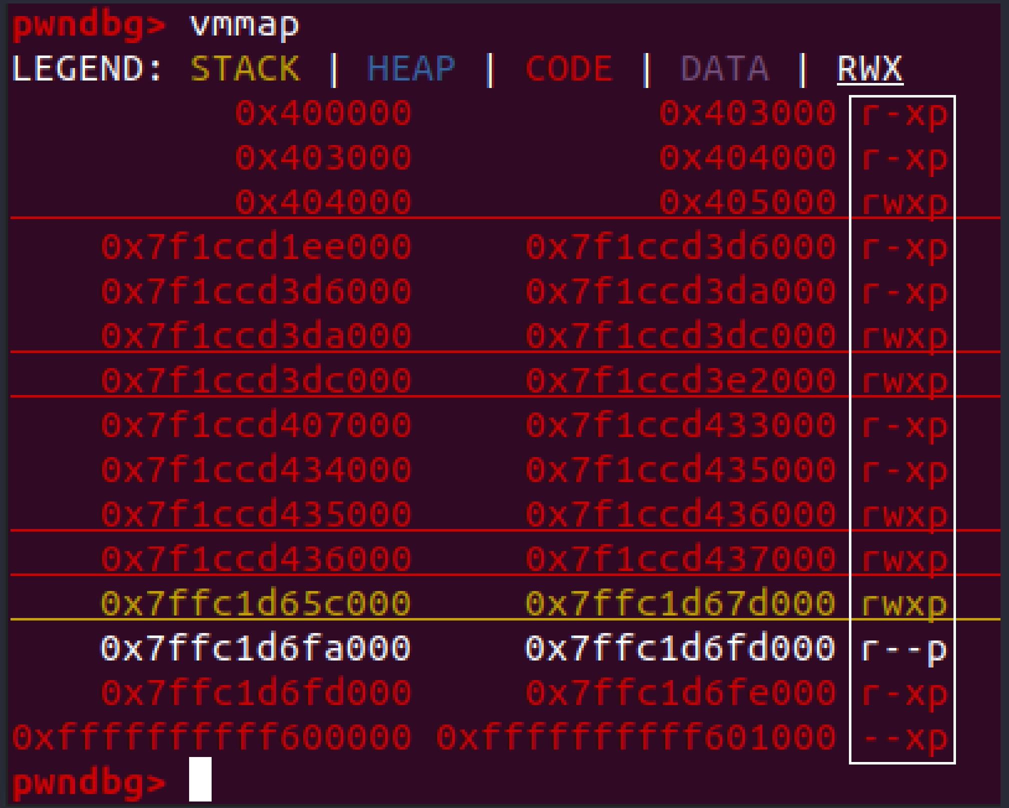
🤮 NX-Bit (No eXecute) / DEP 🤮

- Every page is writable **XOR** executable
- Consequently stack not executable
- Injected shellcode can’t be executed



```
pwndbg> vmmap
LEGEND: STACK | HEAP | CODE | DATA | RWX
          0x400000           0x401000 r--p
          0x401000           0x402000 r-xp
          0x402000           0x403000 r--p
          0x403000           0x404000 r--p
          0x404000           0x405000 rw-p
    0x7fcc16437000     0x7fcc16459000 r--p
    0x7fcc16459000     0x7fcc165d1000 r-xp
    0x7fcc165d1000     0x7fcc1661f000 r--p
    0x7fcc1661f000     0x7fcc16623000 r--p
    0x7fcc16623000     0x7fcc16625000 rw-p
    0x7fcc16625000     0x7fcc1662b000 rw-p
    0x7fcc16650000     0x7fcc16651000 r--p
    0x7fcc16651000     0x7fcc16674000 r-xp
    0x7fcc16674000     0x7fcc1667c000 r--p
    0x7fcc1667d000     0x7fcc1667e000 r--p
    0x7fcc1667e000     0x7fcc1667f000 rw-p
    0x7fcc1667f000     0x7fcc16680000 rw-p
    0x7ffd2a185000     0x7ffd2a1a6000 rw-p
    0x7ffd2a1bb000     0x7ffd2a1be000 r--p
    0x7ffd2a1be000     0x7ffd2a1bf000 r-xp
0xffffffffff600000 0xffffffffff601000 --xp
pwndbg> █
```

- Enabled by default in all modern compilers
- Can be disabled with **-no-pie**



```
pwndbg> vmmap
LEGEND: STACK | HEAP | CODE | DATA | RWX
          0x400000           0x403000 r-xp
          0x403000           0x404000 r-xp
          0x404000           0x405000 rwxp
    0x7f1ccd1ee000     0x7f1ccd3d6000 r-xp
    0x7f1ccd3d6000     0x7f1ccd3da000 r-xp
    0x7f1ccd3da000     0x7f1ccd3dc000 rwxp
    0x7f1ccd3dc000     0x7f1ccd3e2000 rwxp
    0x7f1ccd407000     0x7f1ccd433000 r-xp
    0x7f1ccd434000     0x7f1ccd435000 r-xp
    0x7f1ccd435000     0x7f1ccd436000 rwxp
    0x7f1ccd436000     0x7f1ccd437000 rwxp
    0x7ffc1d65c000     0x7ffc1d67d000 rwxp
    0x7ffc1d6fa000     0x7ffc1d6fd000 r--p
    0x7ffc1d6fd000     0x7ffc1d6fe000 r-xp
0xffffffffff600000 0xffffffffff601000 --xp
pwndbg> 
```

🚀 Bypass: Code Reuse Attacks 🚀

- Instead of injecting own code, use existing code
- Reuse code in binary or libraries
- For stack-based buffer overflows:
  - Overwrite return address with pointer to existing code snippet ("gadget")
  - Gadgets can be chained together if they end in **ret** instruction

Return-oriented programming (ROP)

ROP gadget examples

set register

```
pop <REG>
ret
```

syscall

```
syscall
ret
```

64-bit Write

```
; set rdi and rax with another gadget
mov qword [rdi], rax
ret
```

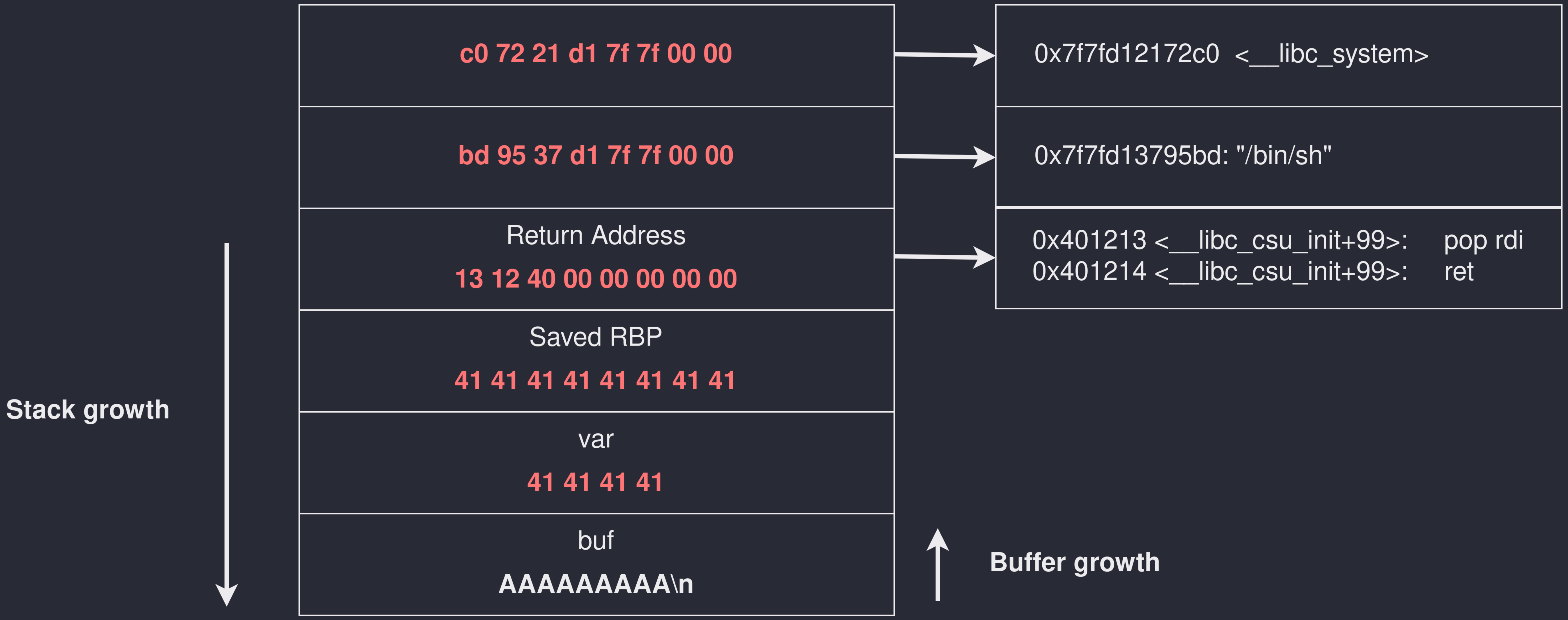
...

ROP chain example

execve("/bin/sh", 0, 0)

```
pop_rdi_gadget
&bin_sh  // Address of "/bin/sh\x00" string in memory
pop_rsi_gadget
0
pop_rdx_gadget
0
pop_rax_gadget
59  // SYS_execve
syscall
```

ROP to shell



c0 72 21 d1 7f 7f 00 00

0x7f7fd12172c0 <__libc_system>

bd 95 37 d1 7f 7f 00 00

0x7f7fd13795bd: "/bin/sh"

Return Address

13 12 40 00 00 00 00 00

```
0x401213 <__libc_csu_init+99>:    pop rdi
0x401214 <__libc_csu_init+99>:    ret
```

Saved RBP

41 41 41 41 41 41 41 41

var

41 41 41 41

buf

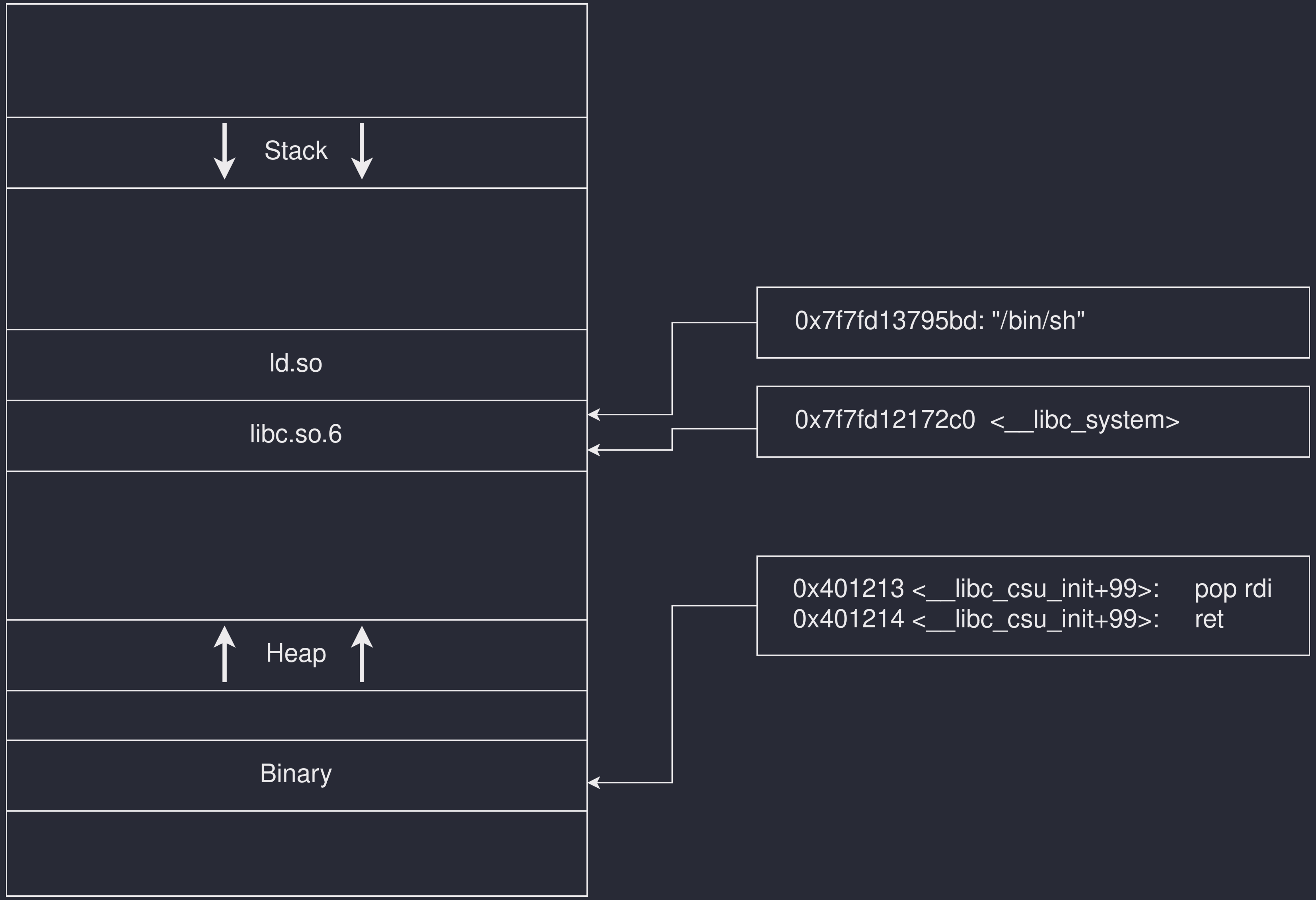
AAAAAAAA\n

Stack growth

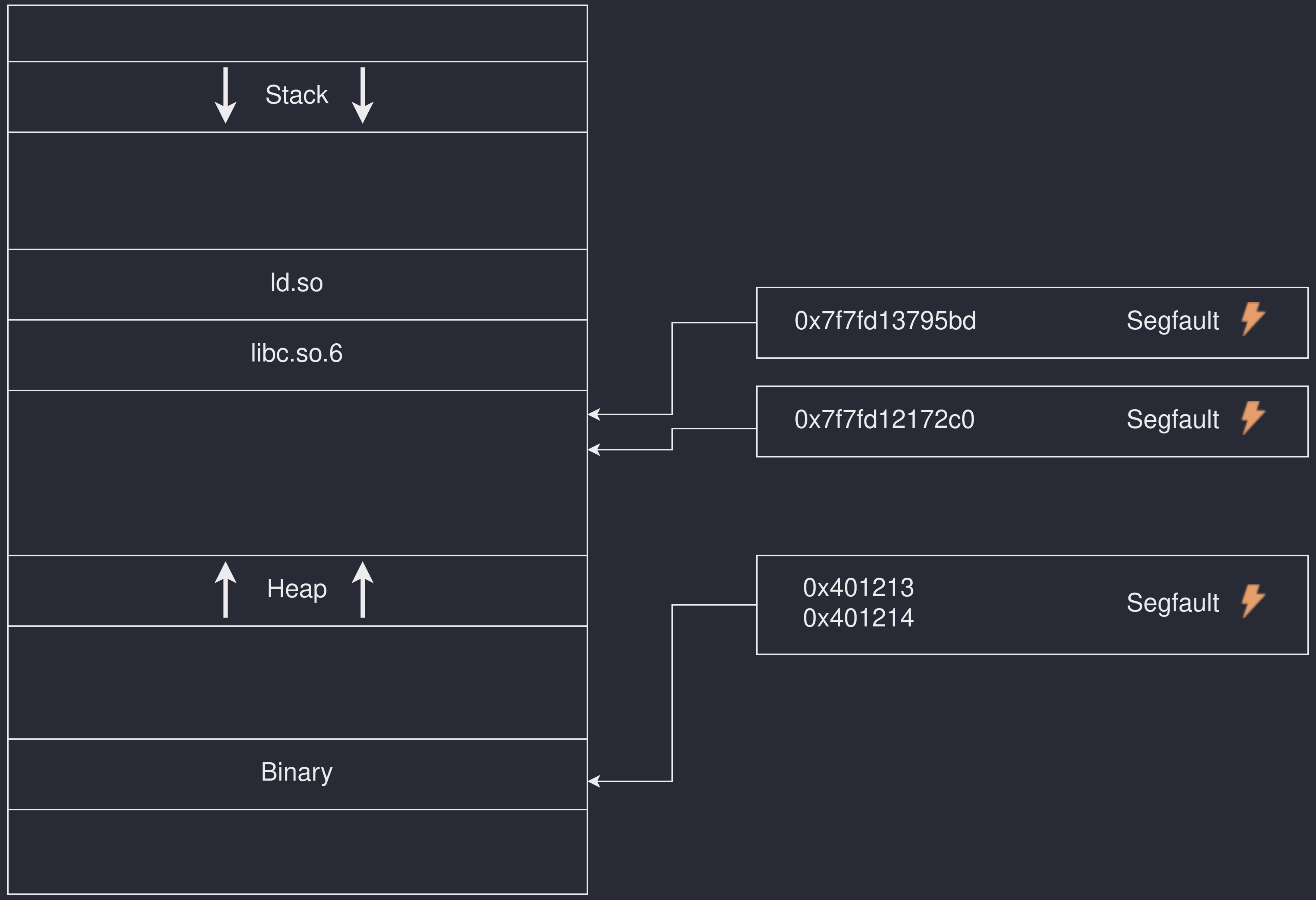
Buffer growth

🤮 Mitigate code reuse attacks 🤮

So far we assumed we know addresses of **gadgets, functions, libraries and stack**


Stack
ld.so
libc.so.6
Heap
Binary
0x7f7fd13795bd: "/bin/sh"
0x7f7fd12172c0 <__libc_system>
0x401213 <__libc_csu_init+99>: pop rdi
0x401214 <__libc_csu_init+99>: ret

Randomized address mappings break our attack



🤮 ASLR and PIE 🤮

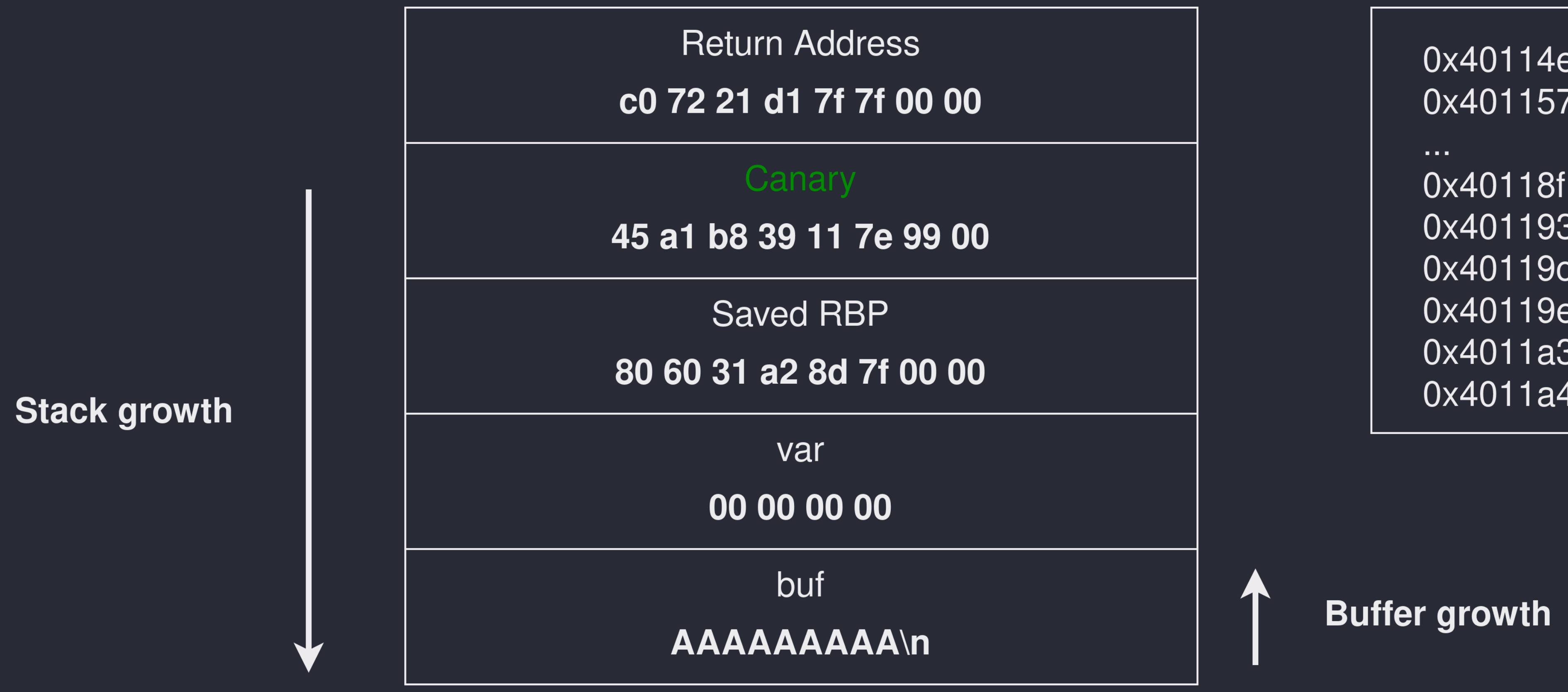
- **A**ddress **S**pace **L**ayout **R**andomization
- Randomized memory layout on every execution
- Linux ASLR is based on 5 randomized (base) addresses
  - Stack, Heap, mmap-Base, vdso
  - Random base address for executable only if **PIE** is enabled

🚀 Bypass ASLR and PIE 🚀

Leak primitive

- Leak of 1 library address derandomizes all libraries
- Leak of 1 address in our binary breaks PIE
- Forked processes share layout with parent

🤮 Canaries 🤮



Return Address
c0 72 21 d1 7f 7f 00 00

Canary
45 a1 b8 39 11 7e 99 00

Saved RBP
80 60 31 a2 8d 7f 00 00

var
00 00 00 00

buf
AAAAAAAAA\n

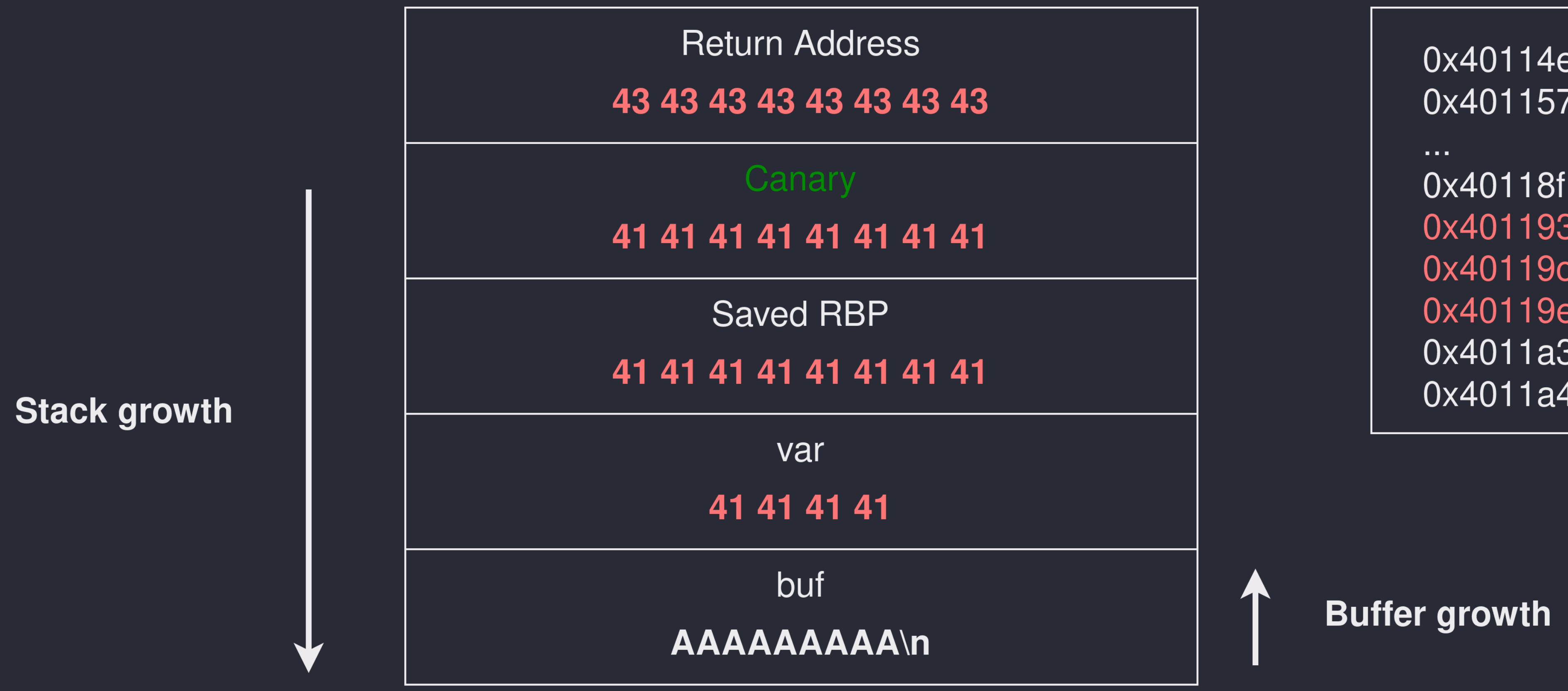
Stack growth

Buffer growth

```
0x40114e <+8>:   mov    rax,QWORD PTR fs:0x28
0x401157 <+17>:  mov    QWORD PTR [rbp-0x8],rax
...
0x40118f  <+73>: mov    rdx,QWORD PTR [rbp-0x8]
0x401193 <+77>:  sub    rdx,QWORD PTR fs:0x28
0x40119c <+86>:  je     0x4011a3 <main+93>
0x40119e <+88>:  call   0x401040 <__stack_chk_fail@plt>
0x4011a3 <+93>:  leave
0x4011a4 <+94>:  ret
```

- Place (7+(1)) random bytes on stack
- Set up in function prologue and verify untouched in epilogue
- Prevent (linear) stack-based buffer overflows

🤮 Canaries 🤮



Return Address
43 43 43 43 43 43 43 43

Canary
41 41 41 41 41 41 41 41

Saved RBP
41 41 41 41 41 41 41 41

var
41 41 41 41

buf
AAAAAAAAA\n

Stack growth

Buffer growth

```
0x40114e <+8>:   mov    rax,QWORD PTR fs:0x28
0x401157 <+17>:  mov    QWORD PTR [rbp-0x8],rax
...
0x40118f  <+73>: mov    rdx,QWORD PTR [rbp-0x8]
0x401193 <+77>:  sub    rdx,QWORD PTR fs:0x28        ⚡
0x40119c <+86>:  je     0x4011a3 <main+93>
0x40119e <+88>:  call   0x401040 <__stack_chk_fail@plt>
0x4011a3 <+93>:  leave
0x4011a4 <+94>:  ret
```

- Leak primitive for canary neccessary
- Overwrite with correct value possible with leak

Tools

- pwndbg extension for gdb
- pwntools for python
- checksec

Start playing at intro.kitctf.de