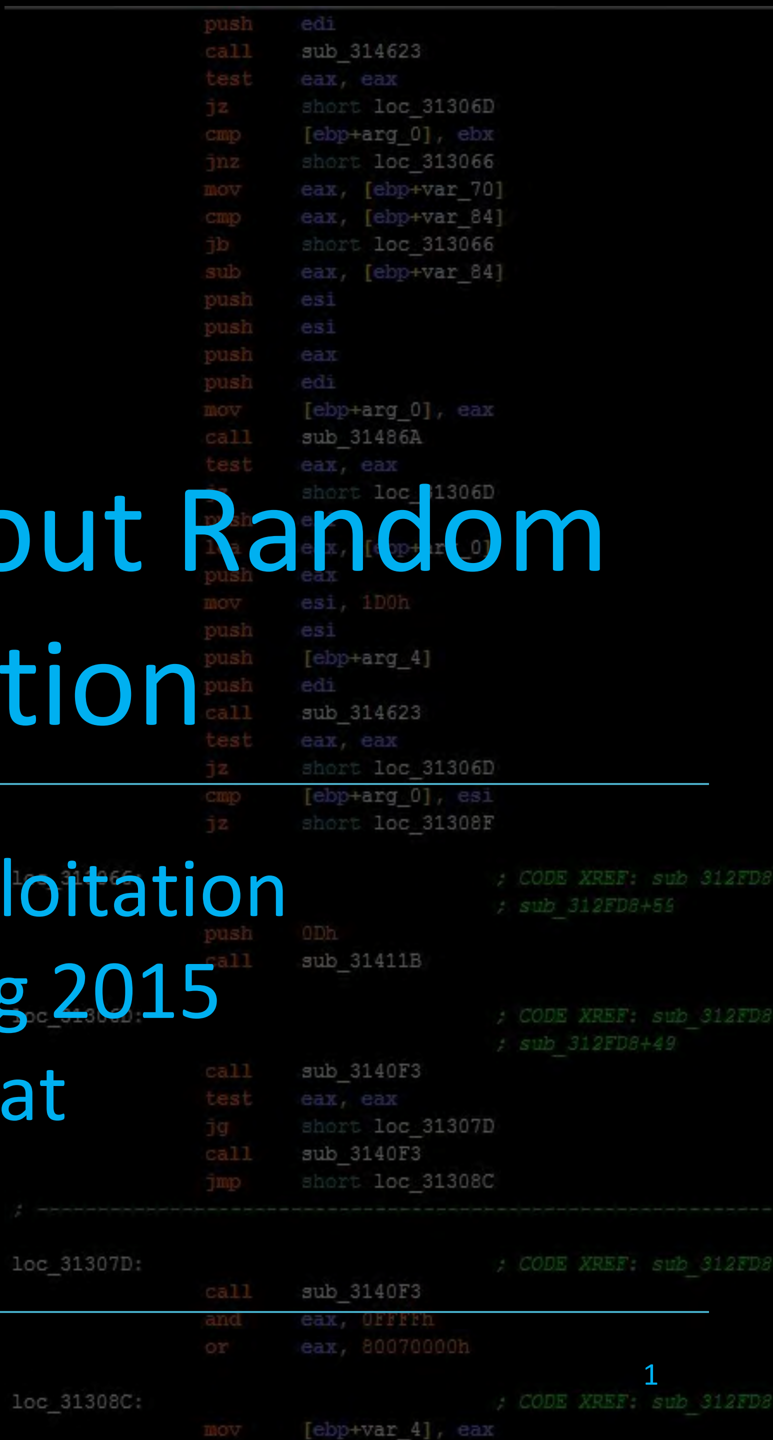
Address Space Layout Random Randomization

Modern Binary Exploitation
CSCI 4968 - Spring 2015
Patrick Biernat



Lecture Overview

1. Introducing ASLR
2. Position Independent Executables
3. Bypassing ASLR, Examples
4. Conclusion

```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

Modern Exploit Mitigations

- Theres a number of modern exploit mitigations that we've generally been turning off for the labs and exercises
  - DEP
  - ASLR
  - Stack Canaries
  - … ?

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                push    edi
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                [illegible]
                call    sub_31486A
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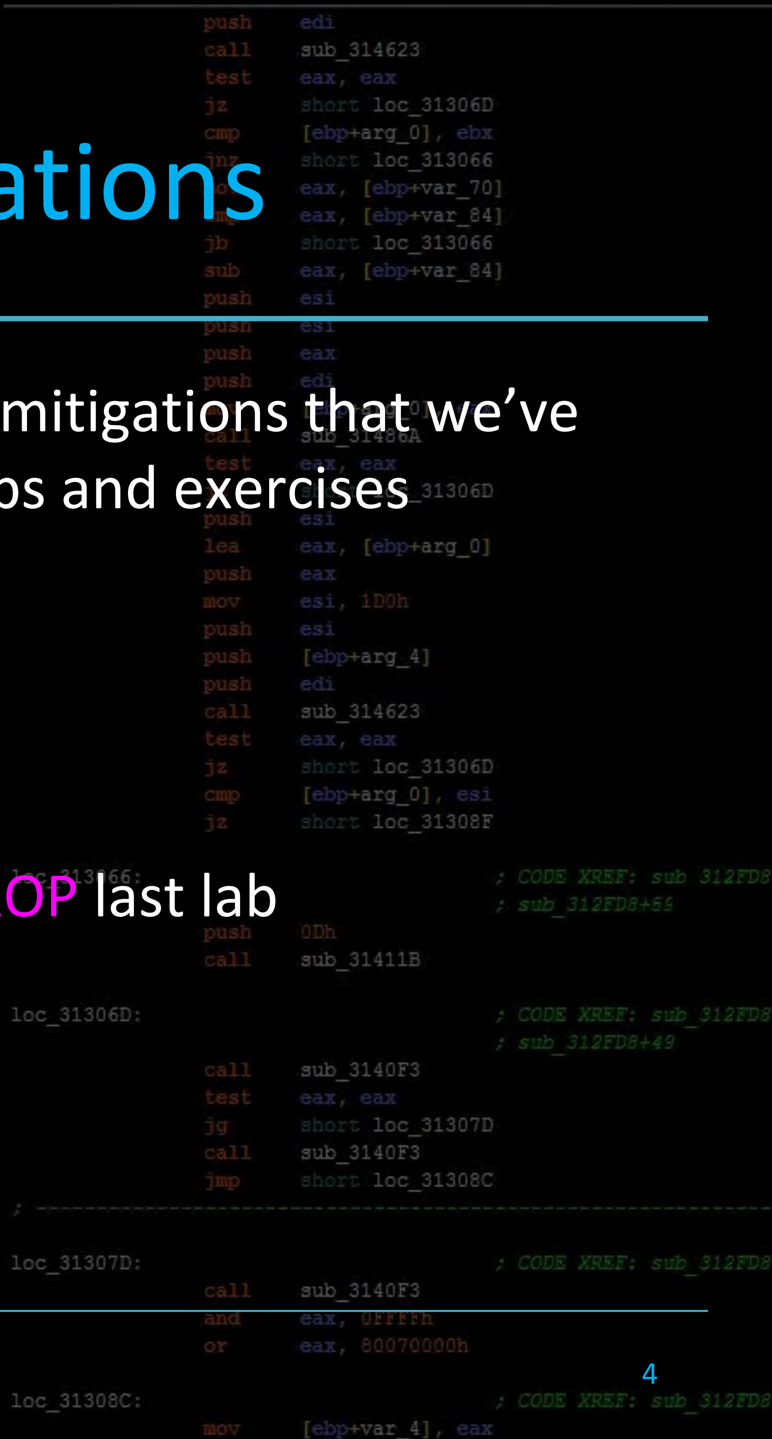
- We turned on DEP and introduced ROP last lab



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            push    edi
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            test    eax, eax
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            jnz     short loc_313066
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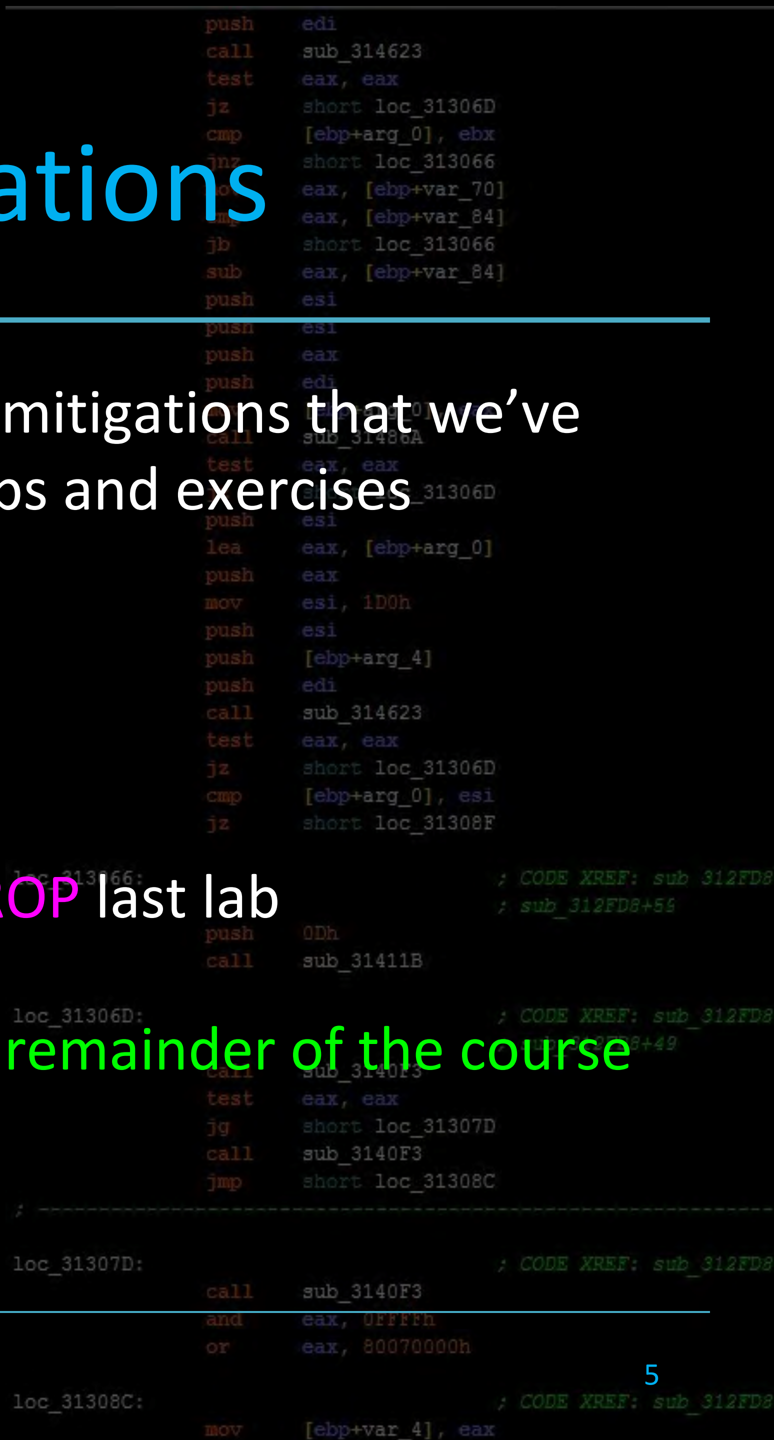
Modern Exploit Mitigations

- Theres a number of modern exploit mitigations that we've generally been turning off for the labs and exercises
  - DEP
  - ASLR
  - Stack Canaries
  - … ?

- We turned on DEP and introduced ROP last lab

- Today we turn ASLR back on for the remainder of the course



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call    sub_31486A
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                  31306D
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push    [ebp+arg_4]
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test    eax, eax
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mov     [ebp+var_4], eax
```

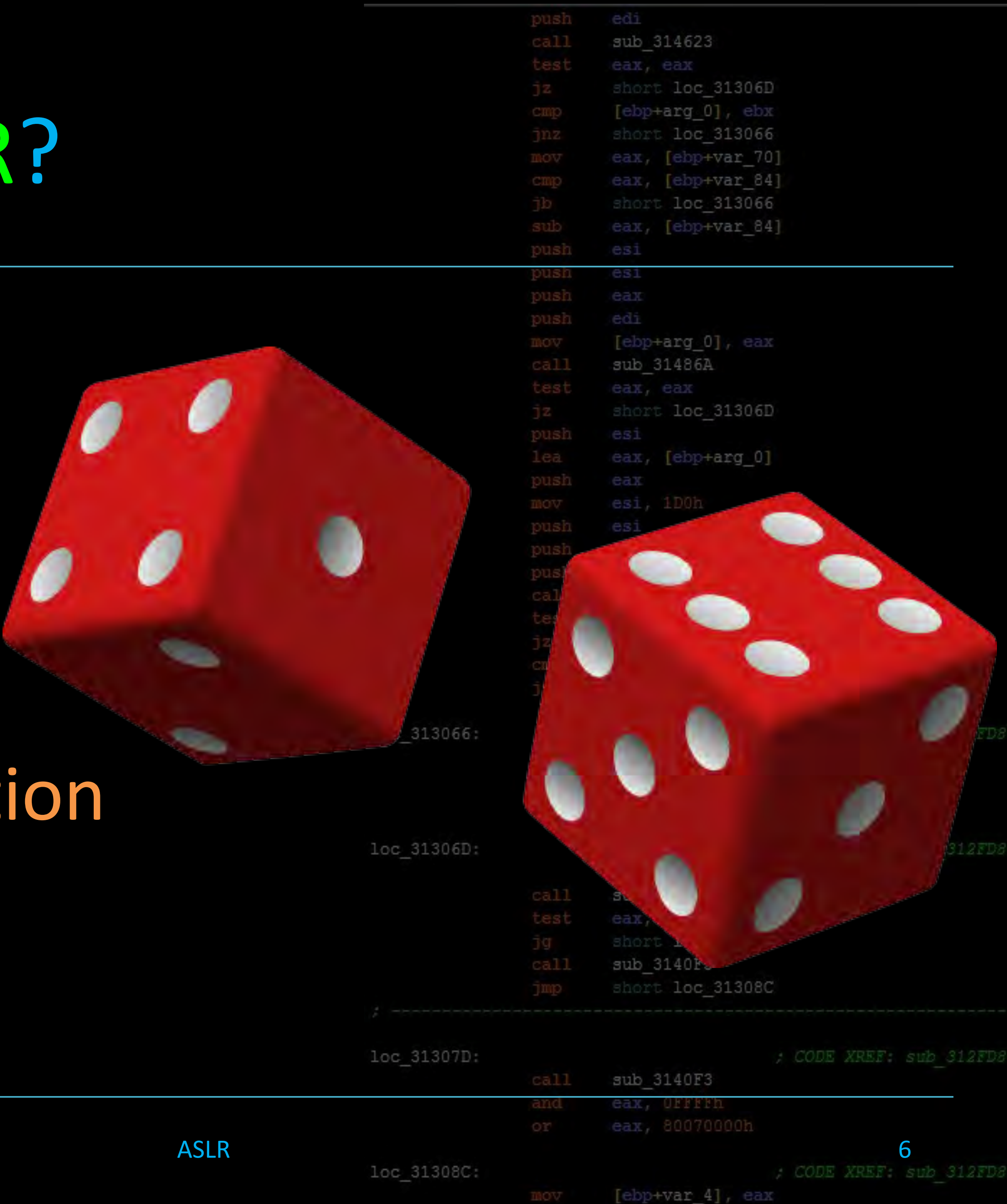
What is ASLR?

A: Address

S: Space

L: Layout

R: Randomization



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                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push
                pus
                cal
                te
                jz
                cm
                j
 313066:                                                 FD8

loc_31306D:                                          312FD8

                call    su
                test    eax,
                jg      short l
                call    sub_3140F
                jmp     short loc_31308C
; ---------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```
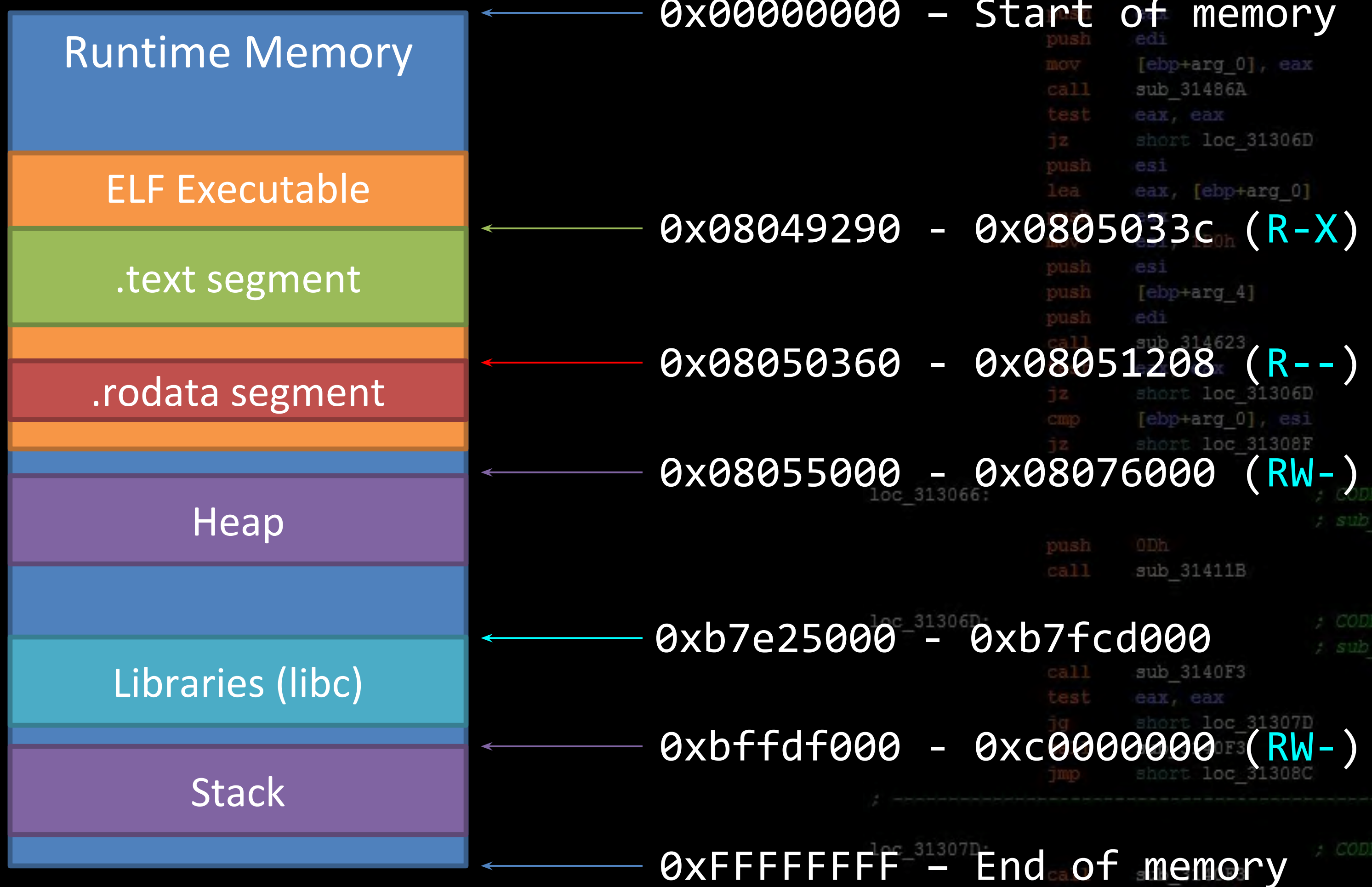

Course Terminology

- Address Space Layout Randomization
  - An exploit mitigation technology used to ensure that address ranges for important memory segments are random for every execution
  - Meant to mitigate exploits leveraging hardcoded stack, heap, code, libc addresses
  - Known as ASLR for short

Runtime Process Without ASLR



Runtime Memory

ELF Executable

.text segment

.rodata segment

Heap

Libraries (libc)

Stack

0x00000000 – Start of memory

0x08049290 - 0x0805033c (R-X)

0x08050360 - 0x08051208 (R--)

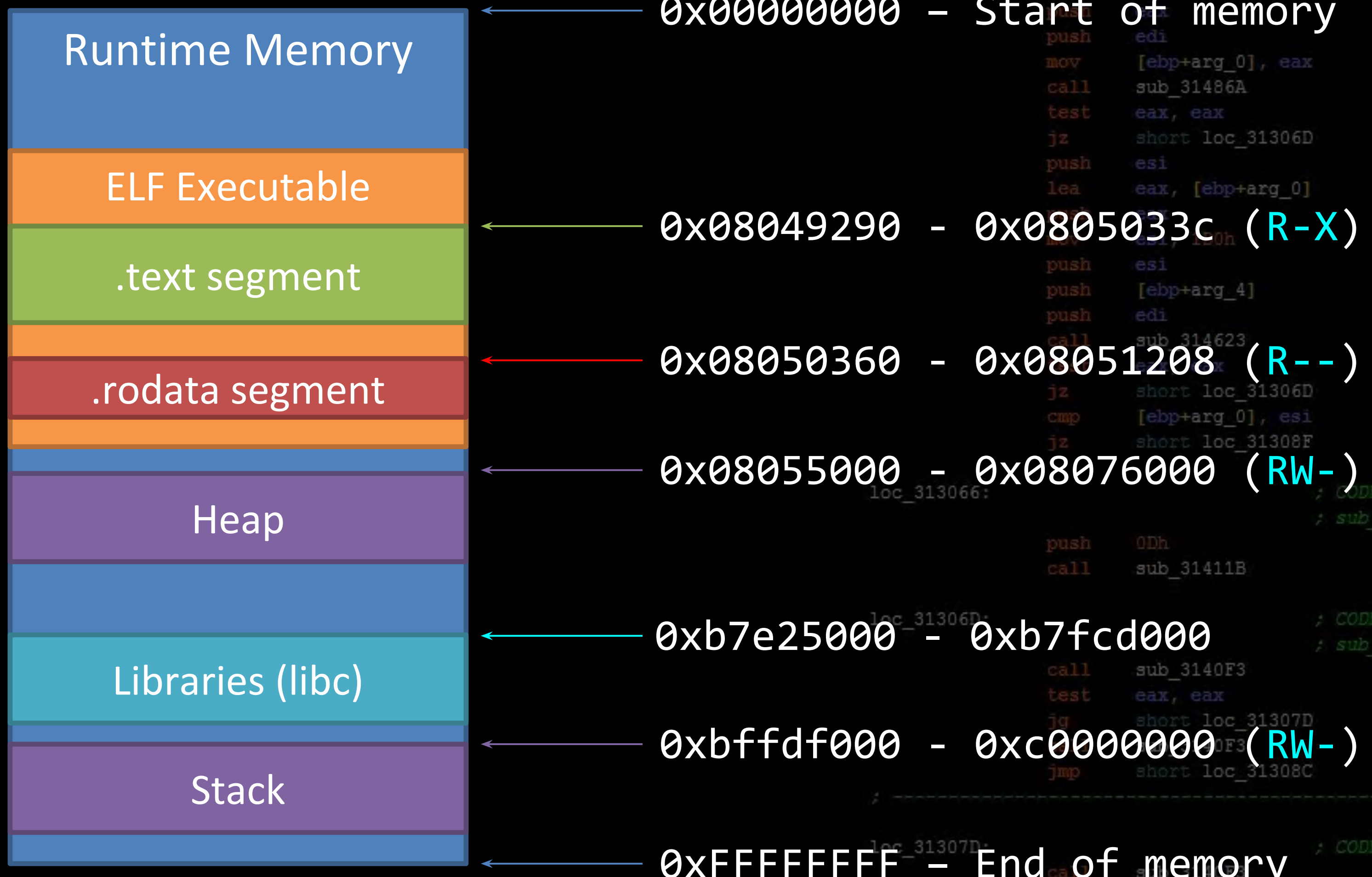
0x08055000 - 0x08076000 (RW-)

0xb7e25000 - 0xb7fcd000

0xbffdf000 - 0xc0000000 (RW-)

0xFFFFFFFF – End of memory

Run #1 Without ASLR



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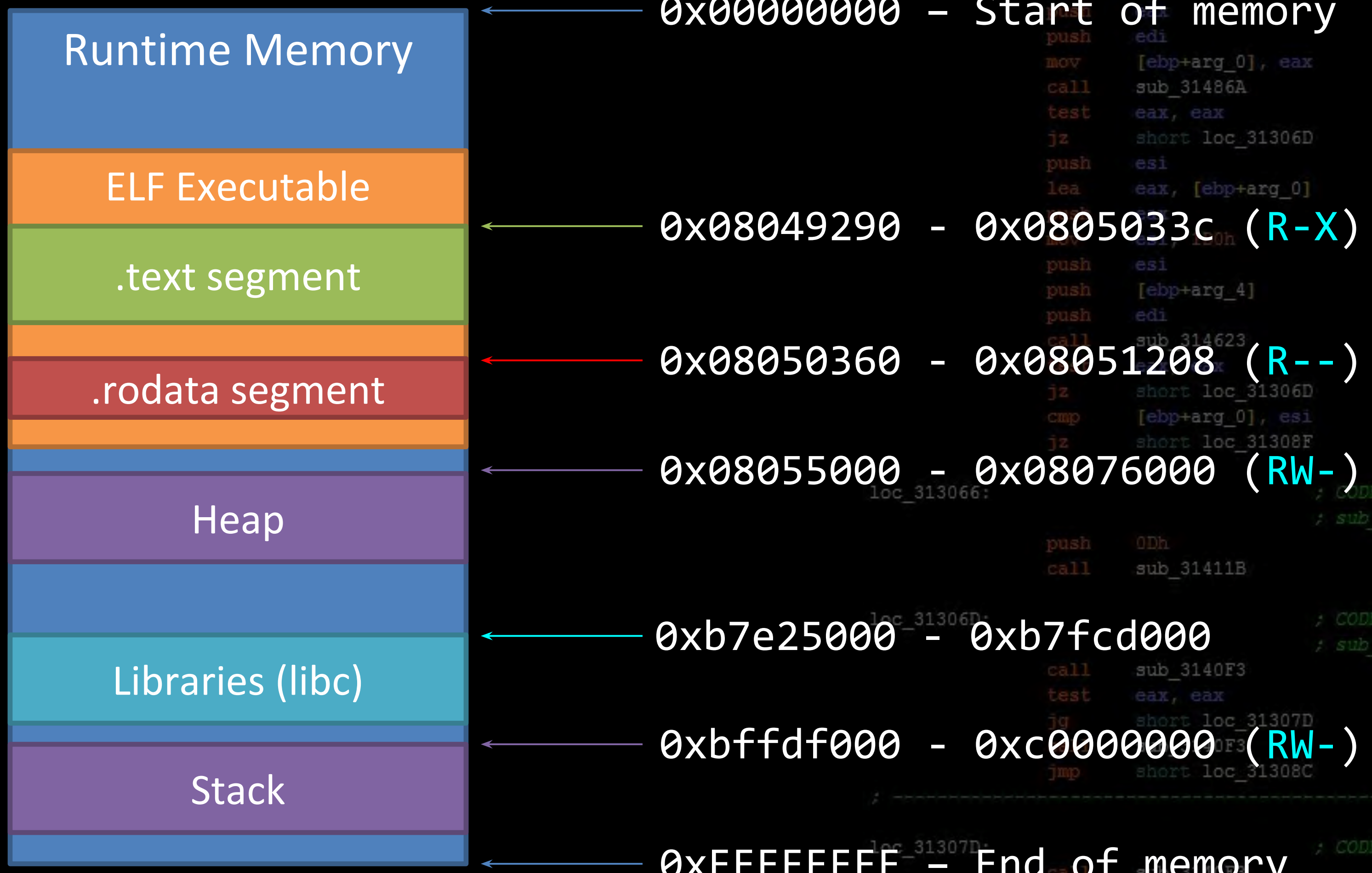
Run #2 Without ASLR



0x00000000 – Start of memory

0x08049290 - 0x0805033c (R-X)

0x08050360 - 0x08051208 (R--)

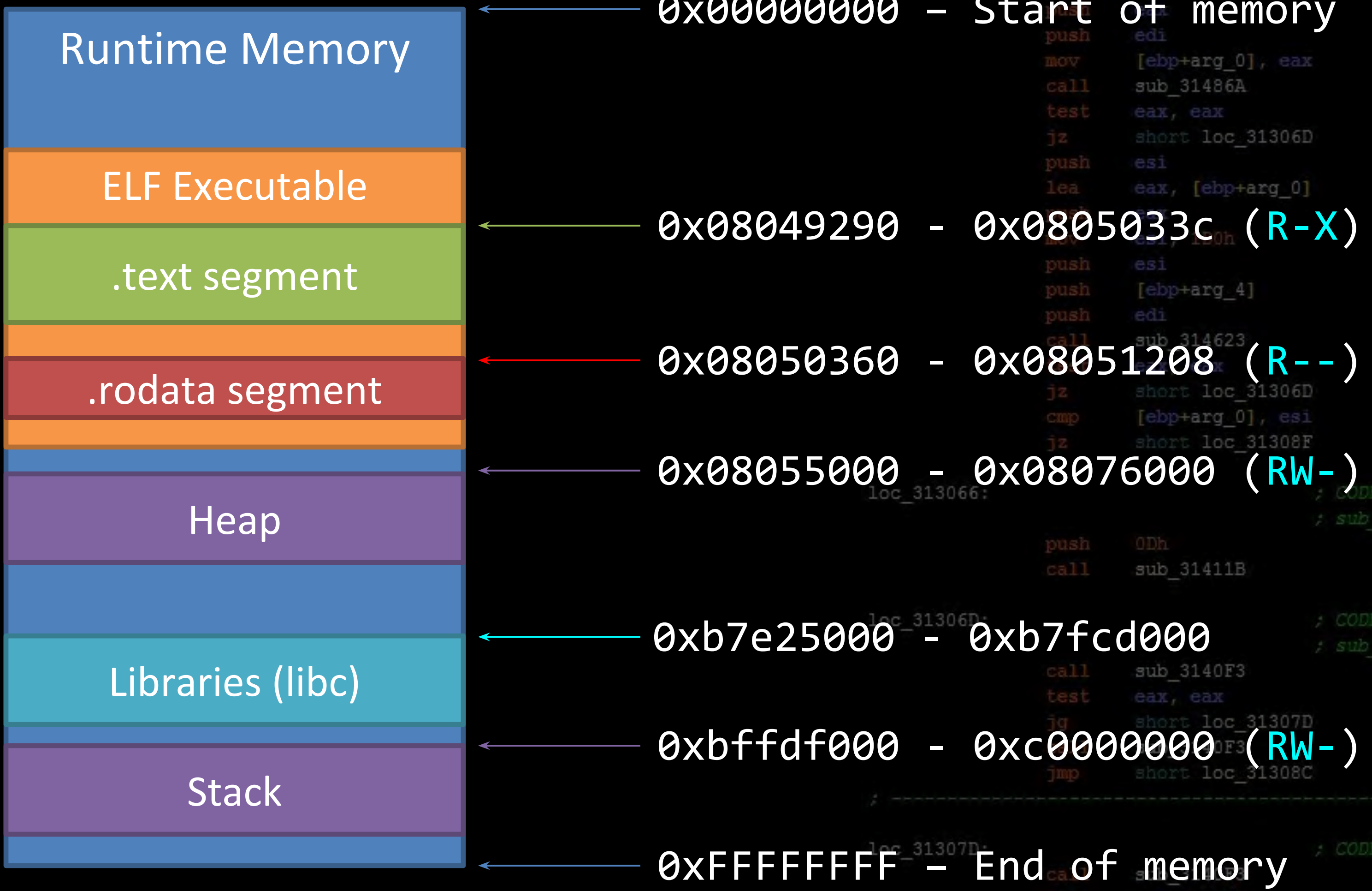
0x08055000 - 0x08076000 (RW-)

0xb7e25000 - 0xb7fcd000

0xbffdf000 - 0xc0000000 (RW-)

0xFFFFFFFF – End of memory

Run #3 Without ASLR



0x00000000 – Start of memory

0x08049290 - 0x0805033c (R-X)

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0xb7e25000 - 0xb7fcd000

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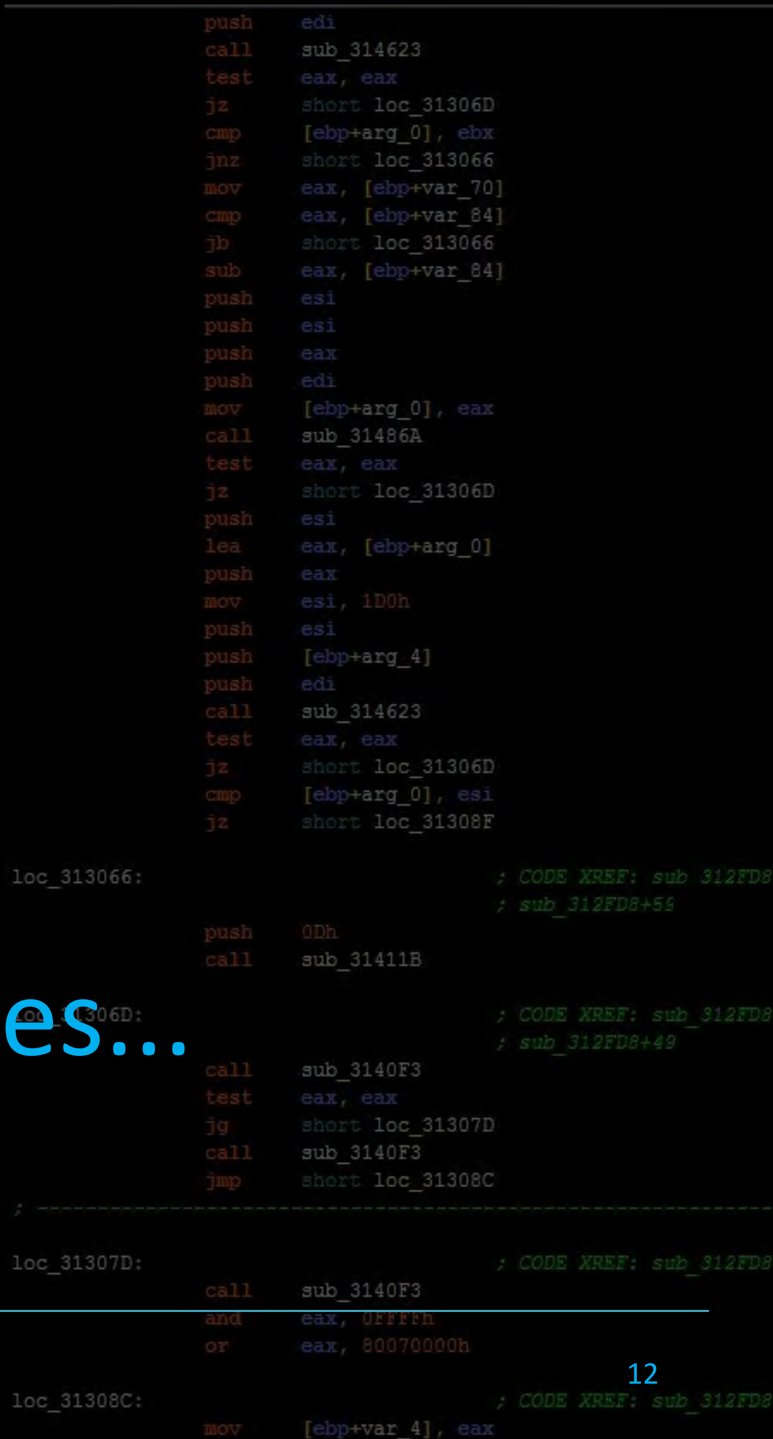
0xFFFFFFFF – End of memory

ya so, nothing changes...



```
                push    edi
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                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
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                push    esi
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                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
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loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
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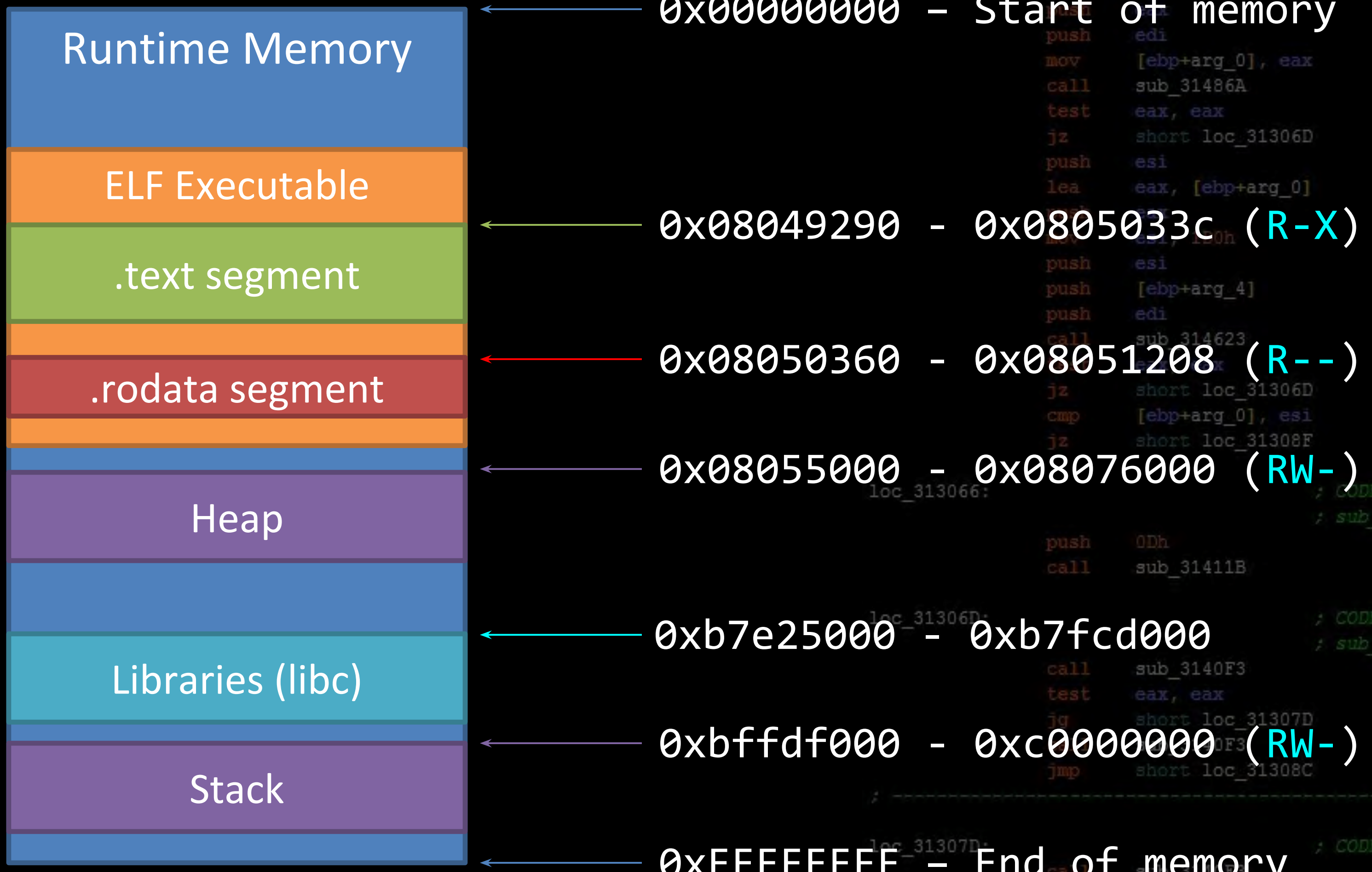
Runtime Process With~~out~~ ASLR



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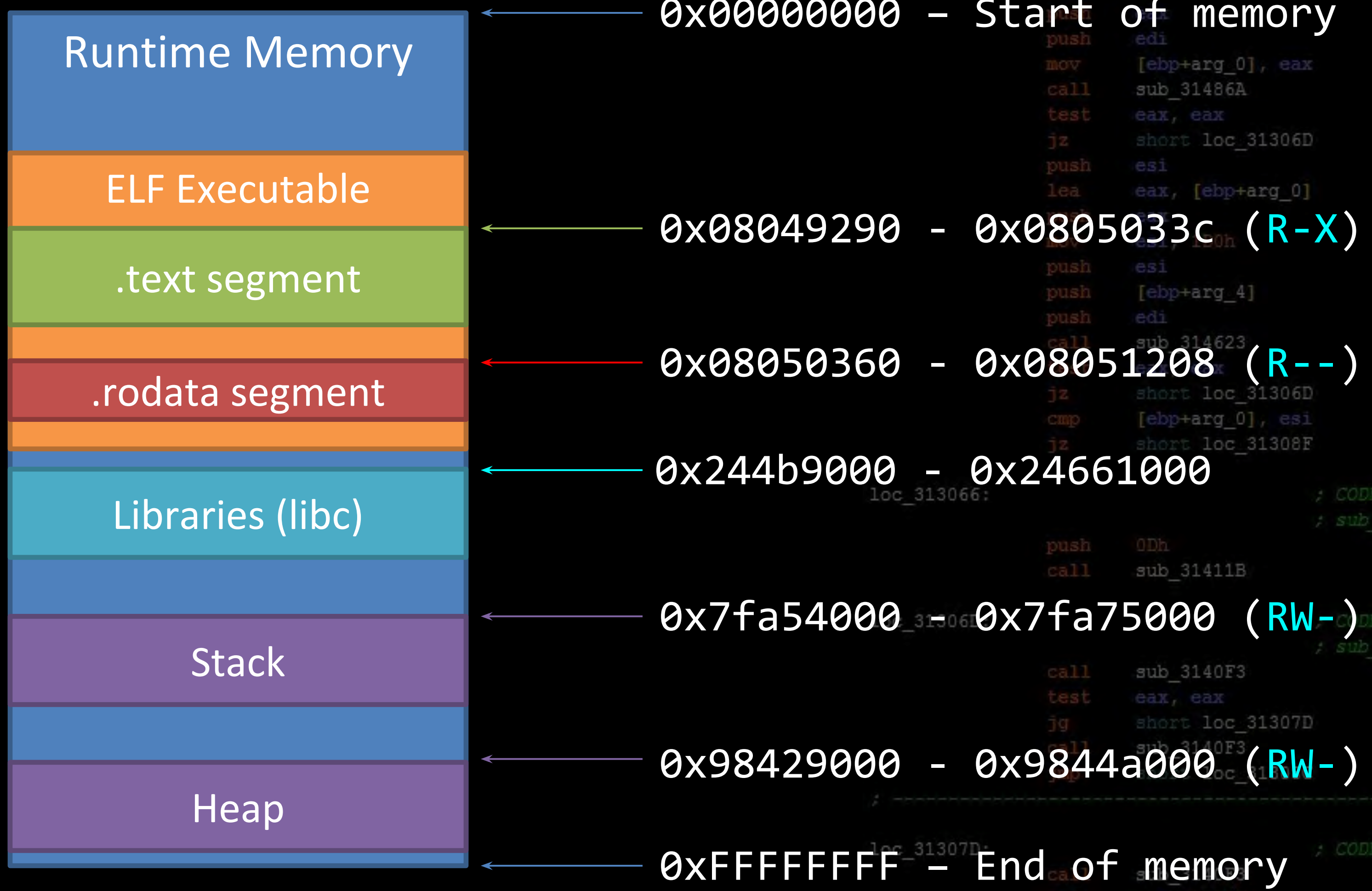
Run #1 With ASLR



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Stack

Heap

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0x08050360 - 0x08051208 (R--)

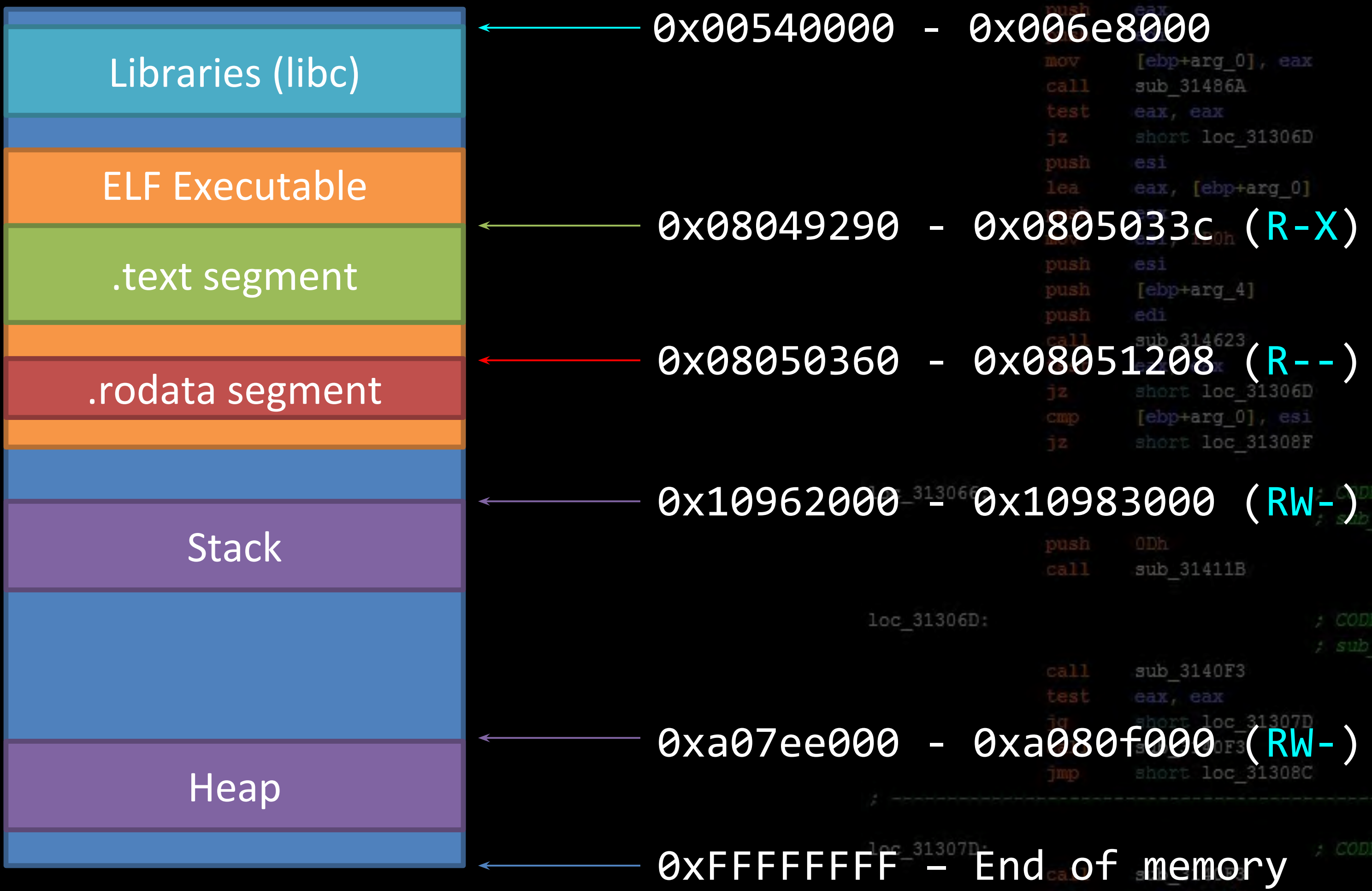
0x244b9000 - 0x24661000

0x7fa54000 - 0x7fa75000 (RW-)

0x98429000 - 0x9844a000 (RW-)

0xFFFFFFFF – End of memory

Run #2 With ASLR



Libraries (libc)

ELF Executable

.text segment

.rodata segment

Stack

Heap

0x00540000 - 0x006e8000

0x08049290 - 0x0805033c (R-X)

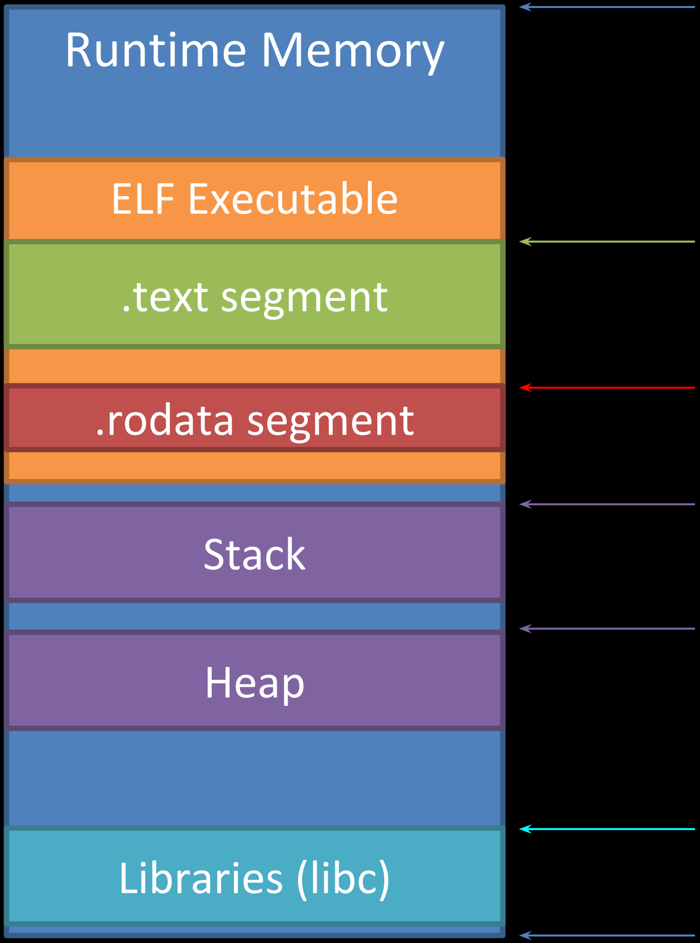
0x08050360 - 0x08051208 (R--)

0x10962000 - 0x10983000 (RW-)

0xa07ee000 - 0xa080f000 (RW-)

0xFFFFFFFF – End of memory

Run #3 With ASLR



0x00000000 – Start of memory

0x08049290 - 0x0805033c (R-X)

0x08050360 - 0x08051208 (R--)

0x094fb000 - 0x0951c000 (RW-)

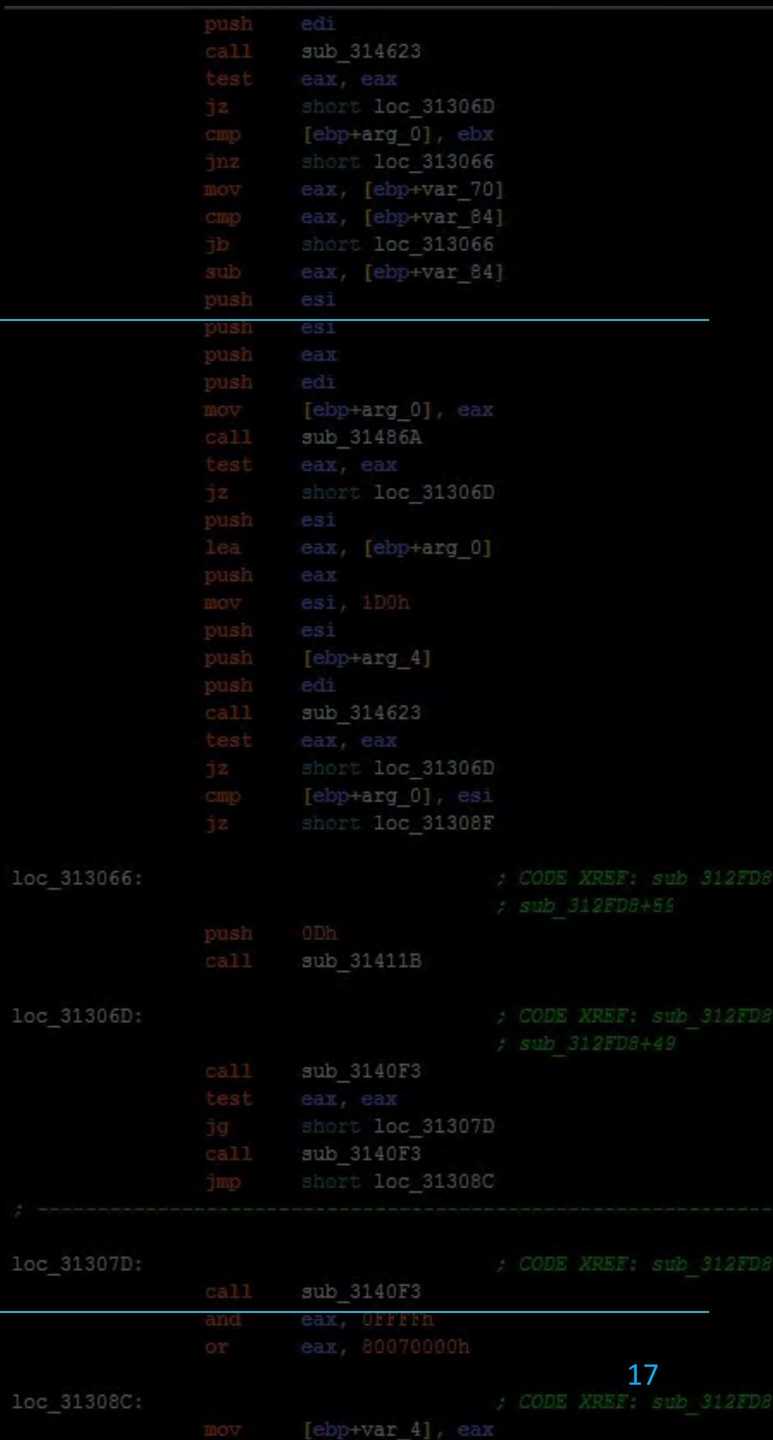
0x43db2000 - 0x43dd3000 (RW-)

0xbf8c3000 - 0xbf8e4000

0xFFFFFFFF – End of memory

ASLR in Action

> Open up a terminal.



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                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
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                jz      short loc_31308F

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                call    sub_3140F3
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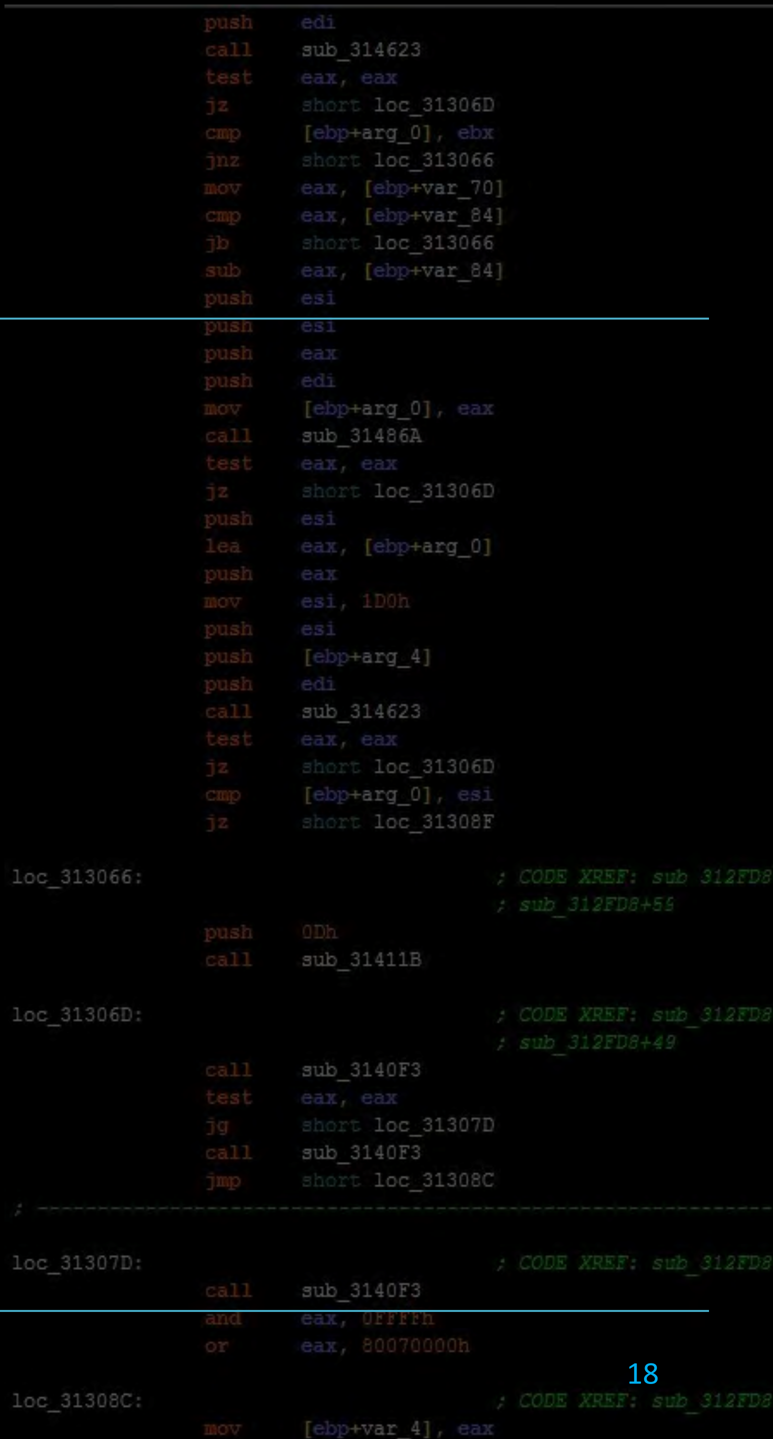
ASLR in Action

- > Open up a terminal.
- > Type “cat /proc/self/maps”



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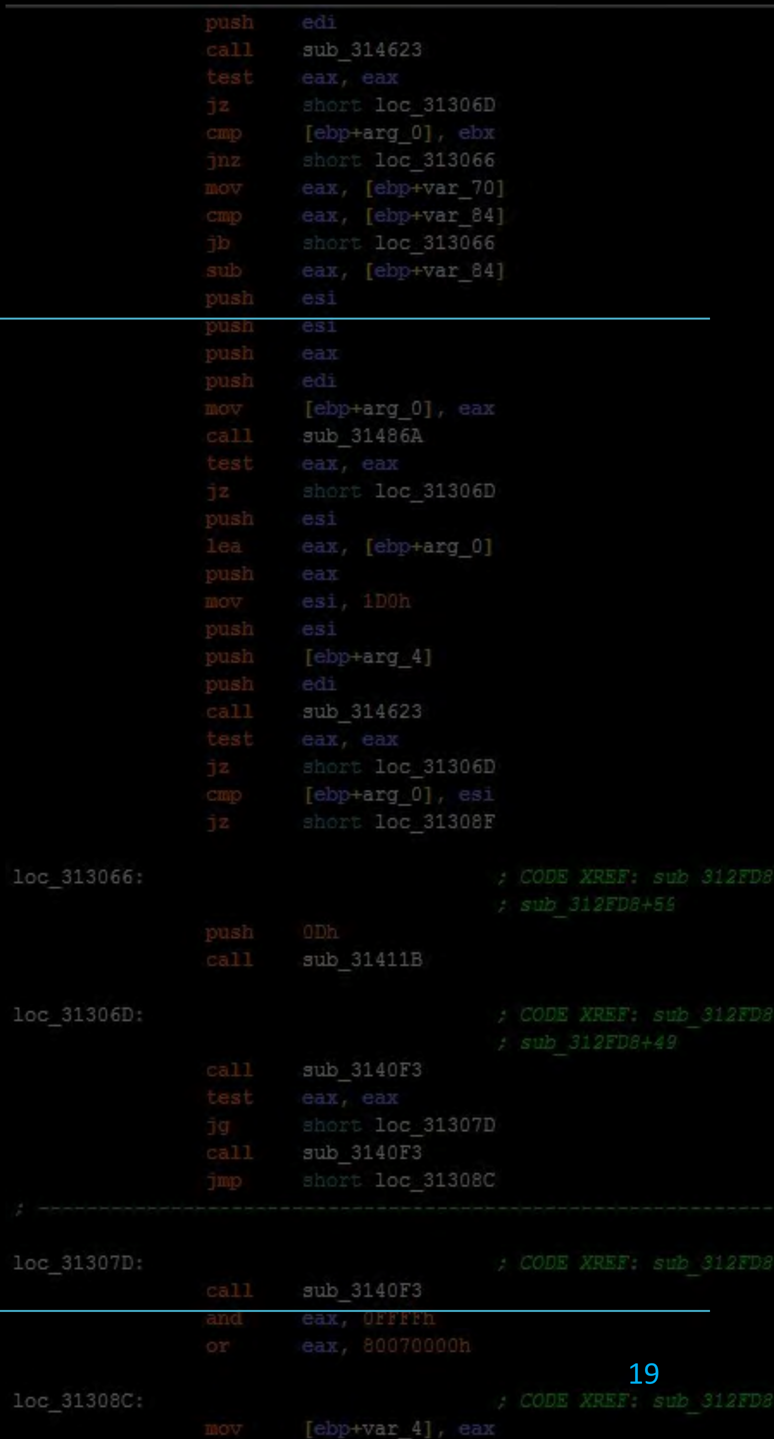
ASLR in Action

- > Open up a terminal.
- > Type “cat /proc/self/maps”
- > Repeat a few times :)



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                jb      short loc_313066
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                push    esi
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                push    edi
                mov     [ebp+arg_0], eax
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```

ASLR in Action

> Open up a terminal.

> Type “cat /proc/self/maps”

> Repeat a few times :)

You’ll see lots of lines like this:

```
bfe49000-bfe6a000 rw-p 00000000 00:00 0          [stack]
  ...
bfa23000-bfa44000 rw-p 00000000 00:00 0          [stack]
  ...
bfdab000-bfdcc000 rw-p 00000000 00:00 0          [stack]
```

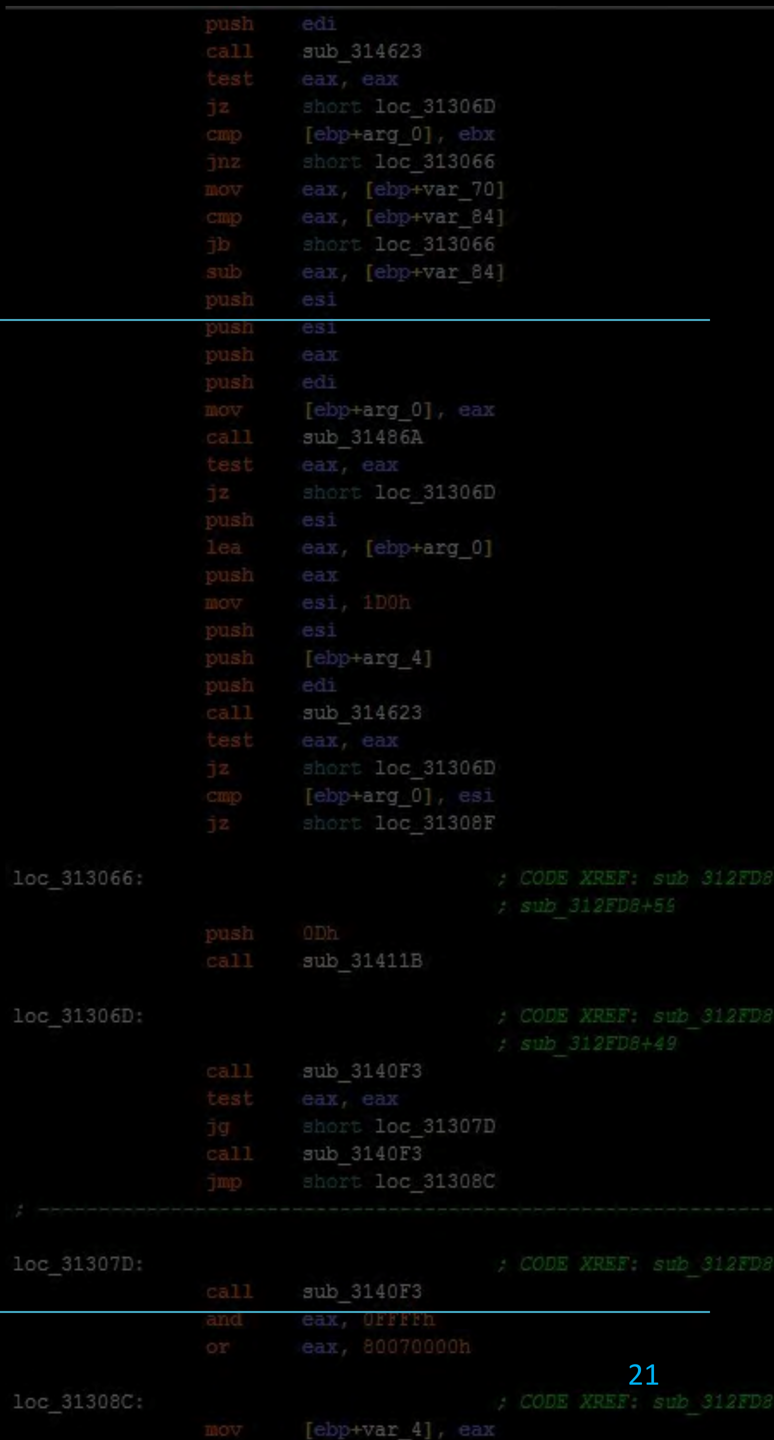
ASLR in Action

> Open up a terminal.

> Type “cat /proc/self/maps”

> Repeat a few times :)

- Stack Address Changes



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                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

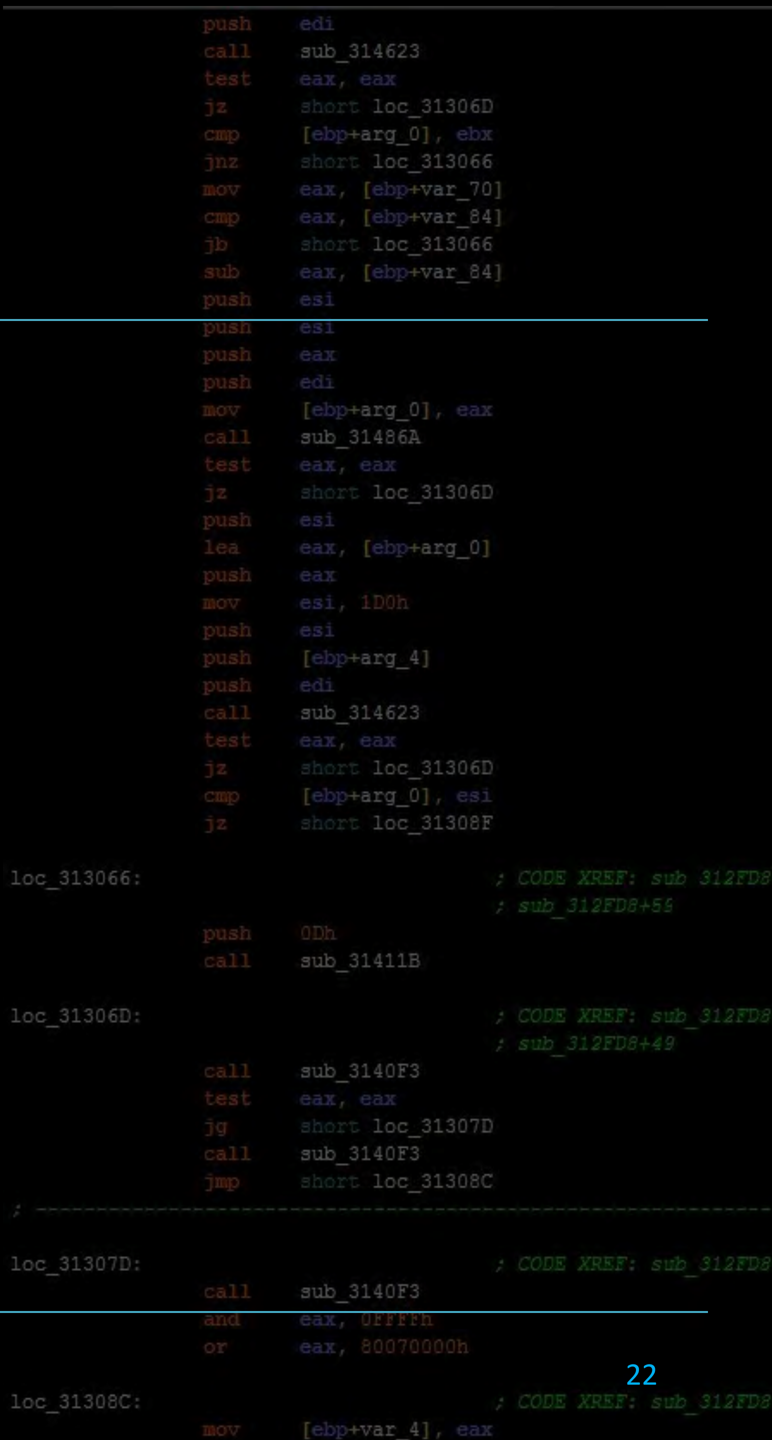
ASLR in Action

> Open up a terminal.

> Type "cat /proc/self/maps"

> Repeat a few times :)

- Stack Address Changes
- Heap Address Changes



```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
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loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

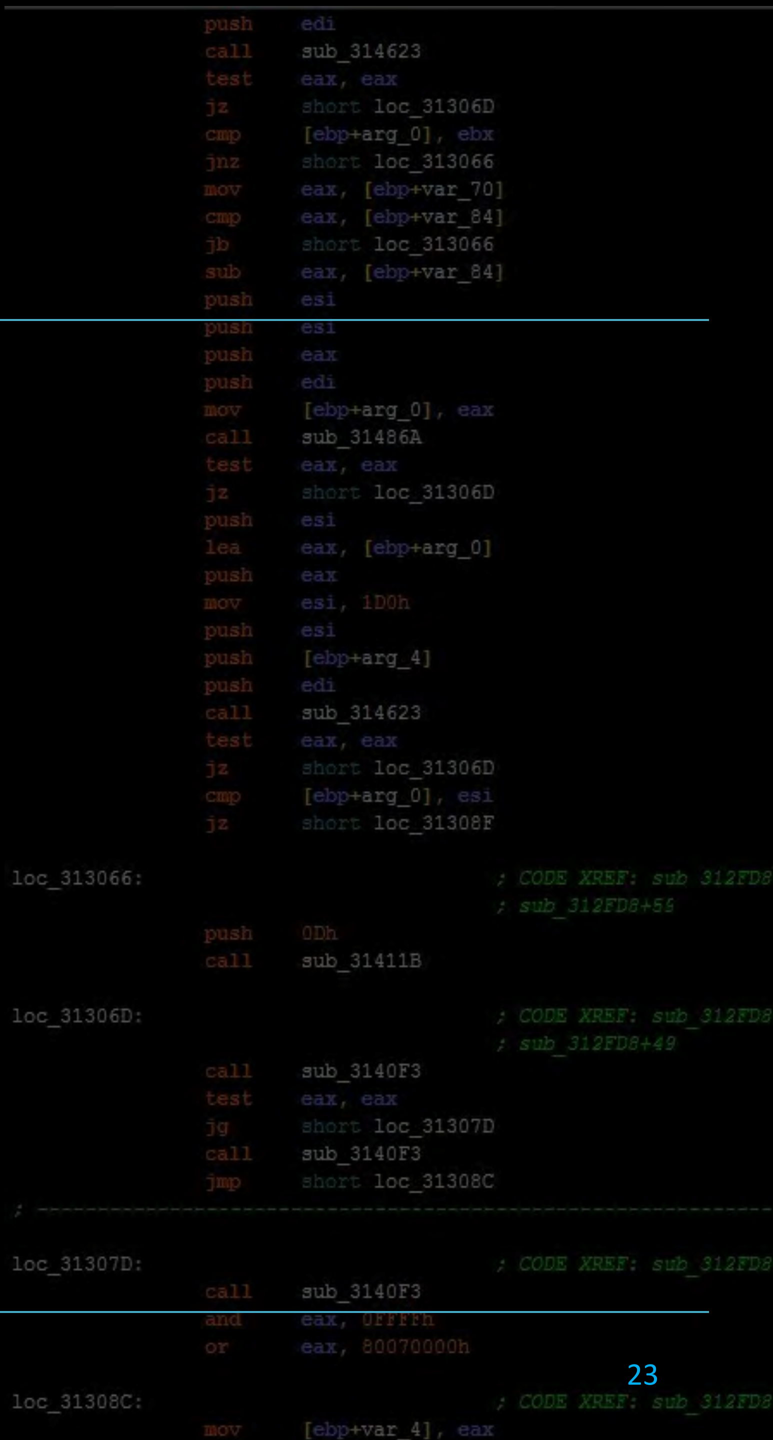
ASLR in Action

> Open up a terminal.

> Type “cat /proc/self/maps”

> Repeat a few times :)

- Stack Address Changes
- Heap Address Changes
- Library Addresses Change



```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
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                push    0Dh
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loc_31306D:                             ; CODE XREF: sub_312FD8
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                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
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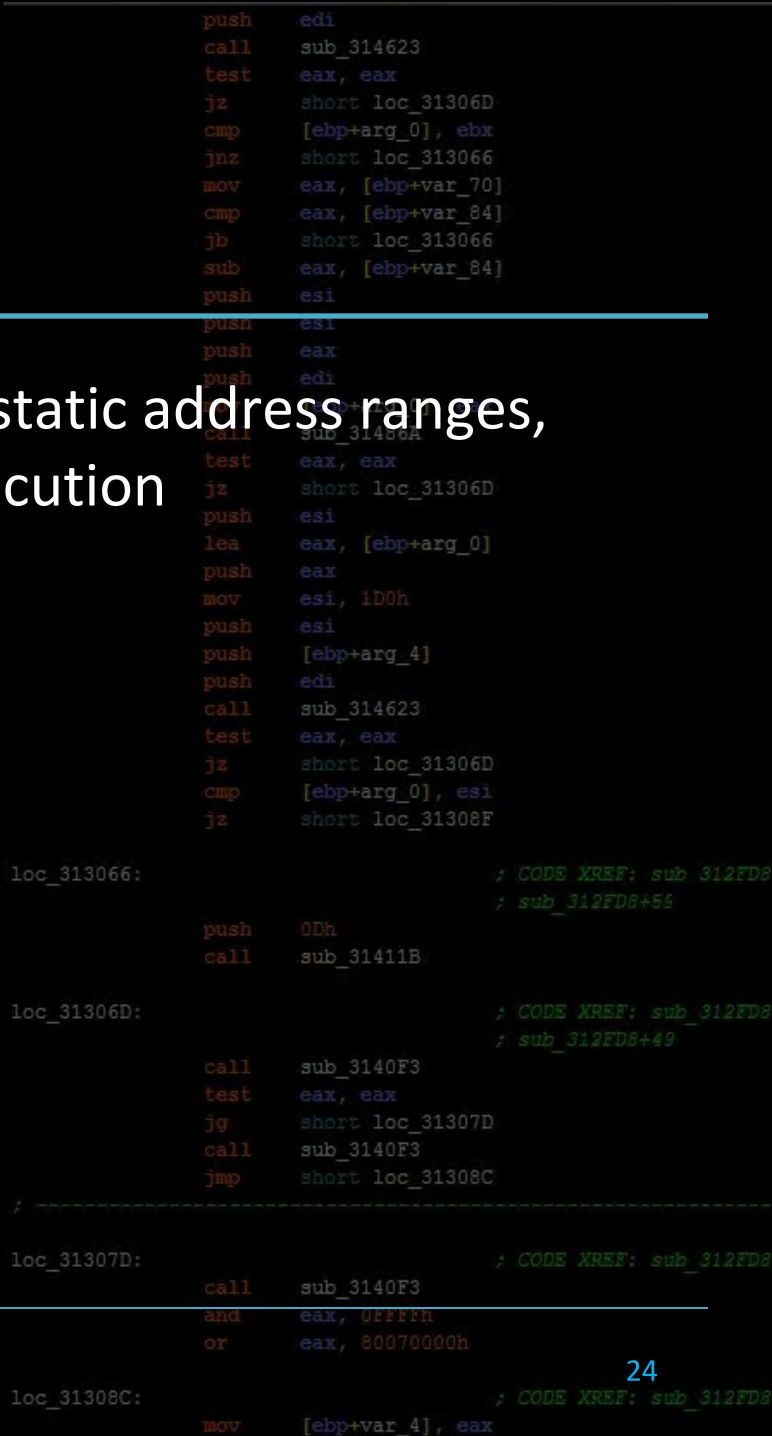
loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

ASLR Basics

- Memory segments are no longer in static address ranges, rather they are unique for every execution



```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
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loc_313066:                             ; CODE XREF: sub_312FD8
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loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
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ASLR Basics

- Memory segments are no longer in static address ranges, rather they are unique for every execution

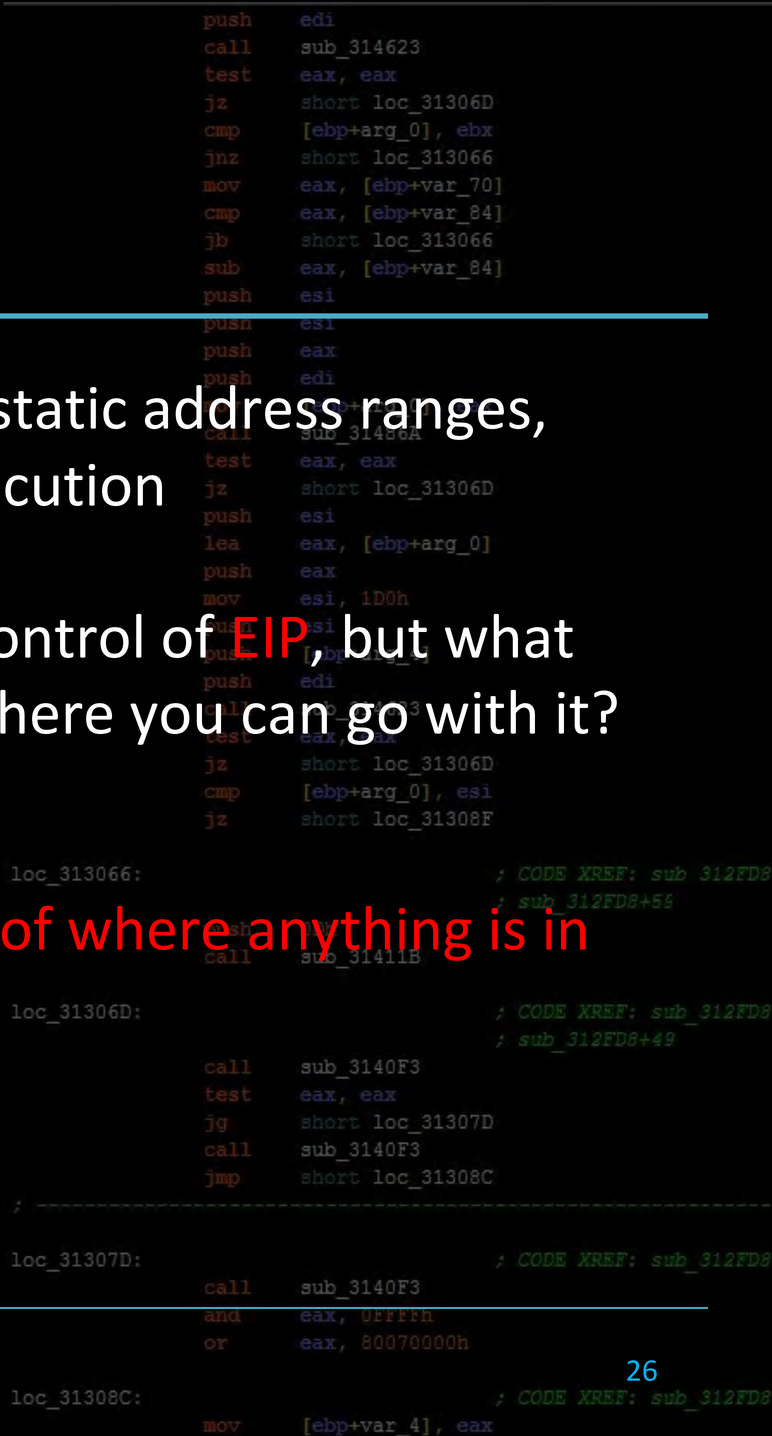
- A simple stack smash may get you control of EIP, but what does it matter if you have no idea where you can go with it?

ASLR Basics

- Memory segments are no longer in static address ranges, rather they are unique for every execution

- A simple stack smash may get you control of EIP, but what does it matter if you have no idea where you can go with it?
  - The essence of ASLR

- You must work with no expectation of where anything is in memory anymore



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                 push    edi
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                 mov     eax, [ebp+var_70]
                 cmp     eax, [ebp+var_84]
                 jb      short loc_313066
                 sub     eax, [ebp+var_84]
                 push    esi
                 push    esi
                 push    eax
                 push    edi
                 [illegible]
                 call    sub_31486A
                 test    eax, eax
                 jz      short loc_31306D
                 push    esi
                 lea     eax, [ebp+arg_0]
                 push    eax
                 mov     esi, 1D0h
                 [illegible]
                 [illegible]
                 push    edi
                 [illegible]
                 [illegible]
                 jz      short loc_31306D
                 cmp     [ebp+arg_0], esi
                 jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                 [illegible]
                 call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                 call    sub_3140F3
                 test    eax, eax
                 jg      short loc_31307D
                 call    sub_3140F3
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; ---------------------------------------------------------------

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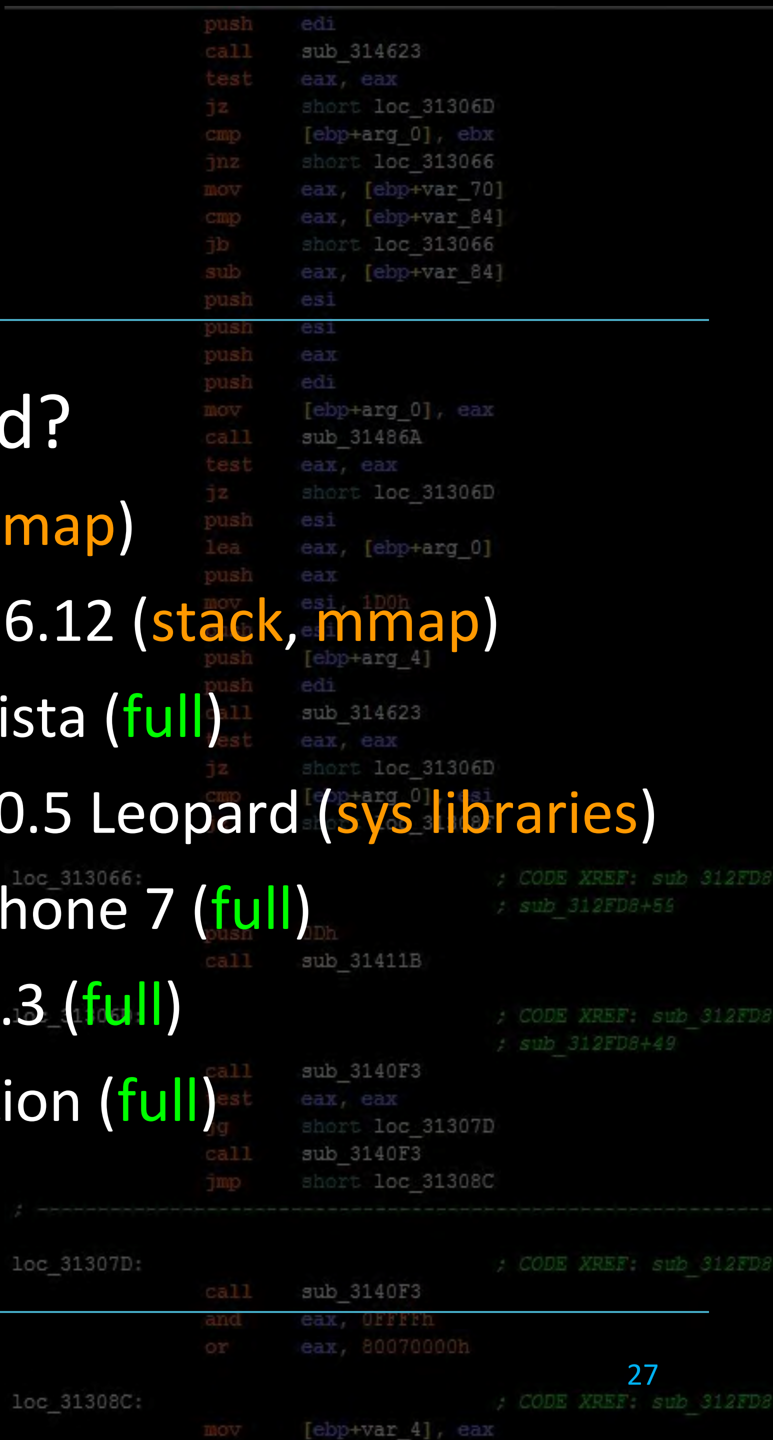
                 mov     [ebp+var_4], eax
```

History of ASLR

- When was ASLR implemented?
  - May 1st, 2004 - OpenBSD 3.5 (mmap)
  - June 17th, 2005 - Linux Kernel 2.6.12 (stack, mmap)
  - January 30th, 2007 - Windows Vista (full)
  - October 26th, 2007 - Mac OSX 10.5 Leopard (sys libraries)
  - October 21st, 2010 - Windows Phone 7 (full)
  - March 11th, 2011 - iPhone iOS 4.3 (full)
  - July 20th, 2011 - Mac OSX 10.7 Lion (full)



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  - October 21st, 2010 - Windows Phone 7 (full)
  - March 11th, 2011 - iPhone iOS 4.3 (full)
  - July 20th, 2011 - Mac OSX 10.7 Lion (full)

perspective: markus is accepted to RPI

Reminder:

Security is rapidly evolving

```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+55
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

Checking for ASLR

```
$ cat /proc/sys/kernel/randomize_va_space
```

Checking for ASLR

```
$ cat /proc/sys/kernel/randomize_va_space
2
```

Checking for ASLR

```
$ cat /proc/sys/kernel/randomize_va_space
2
```

0: No ASLR

1: Conservative Randomization

(Stack, Heap, Shared Libs, PIE, mmap(), VDRO)

2: Full Randomization

(Conservative Randomization + memory managed via brk())

Lecture Overview

1. Introducing ASLR
2. Position Independent Executables
3. Bypassing ASLR, Examples
4. Conclusion

```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                                 ; CODE XREF: sub_312FD8
                                            ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

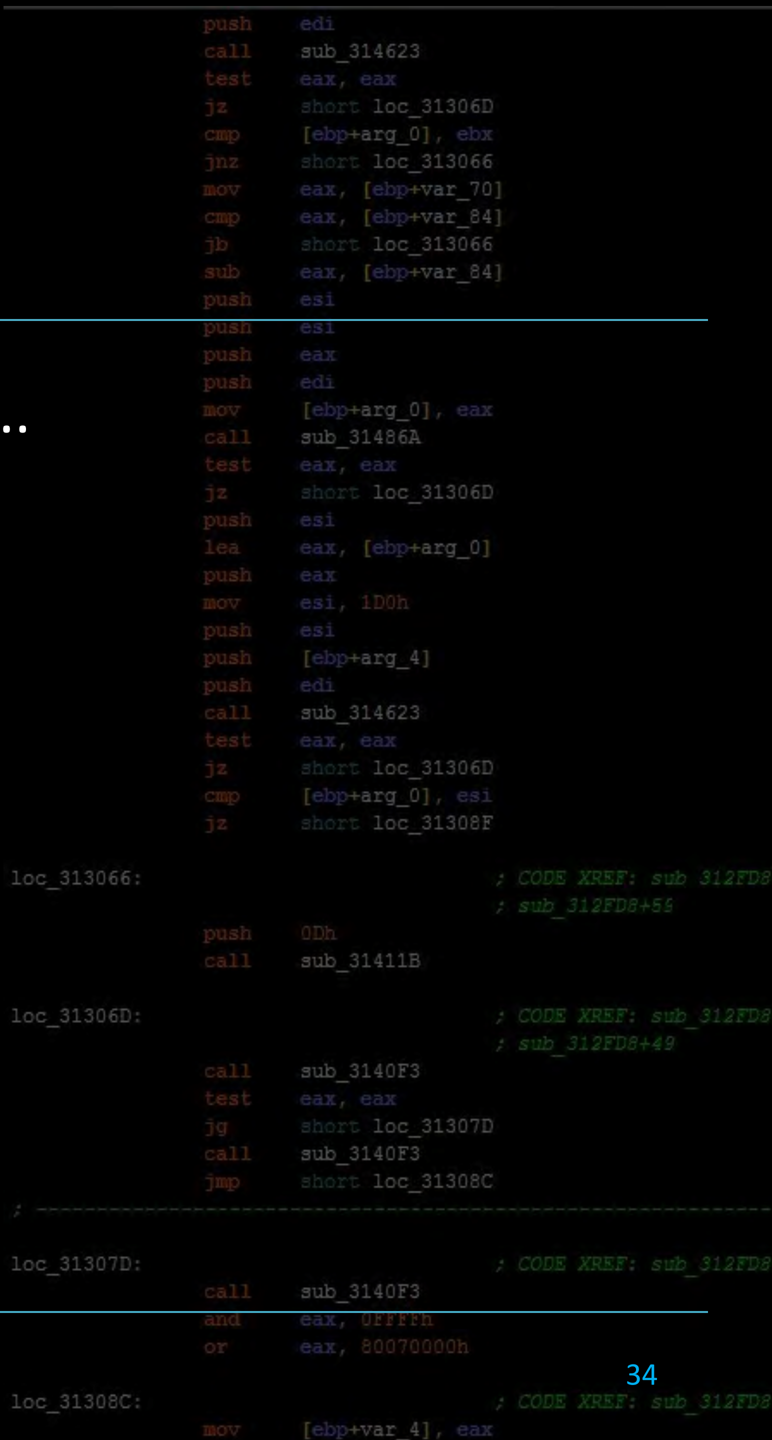
loc_31306D:                                 ; CODE XREF: sub_312FD8
                                            ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------

loc_31307D:                                 ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                                 ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

ELF’s and ASLR

On Linux, not everything is randomized...



```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

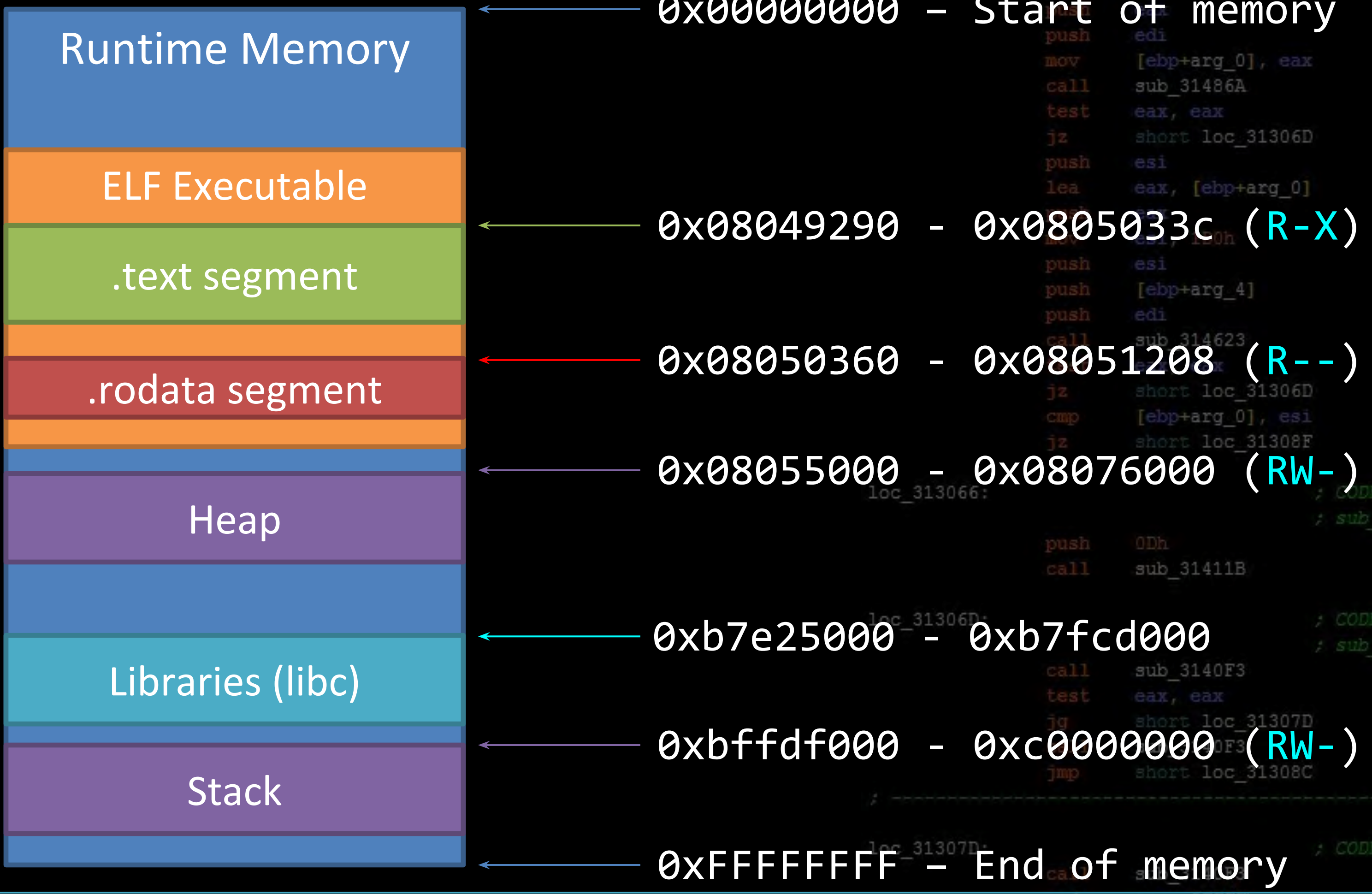
loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

Runtime Process With ASLR



0x00000000 – Start of memory

0x08049290 - 0x0805033c (R-X)

0x08050360 - 0x08051208 (R--)

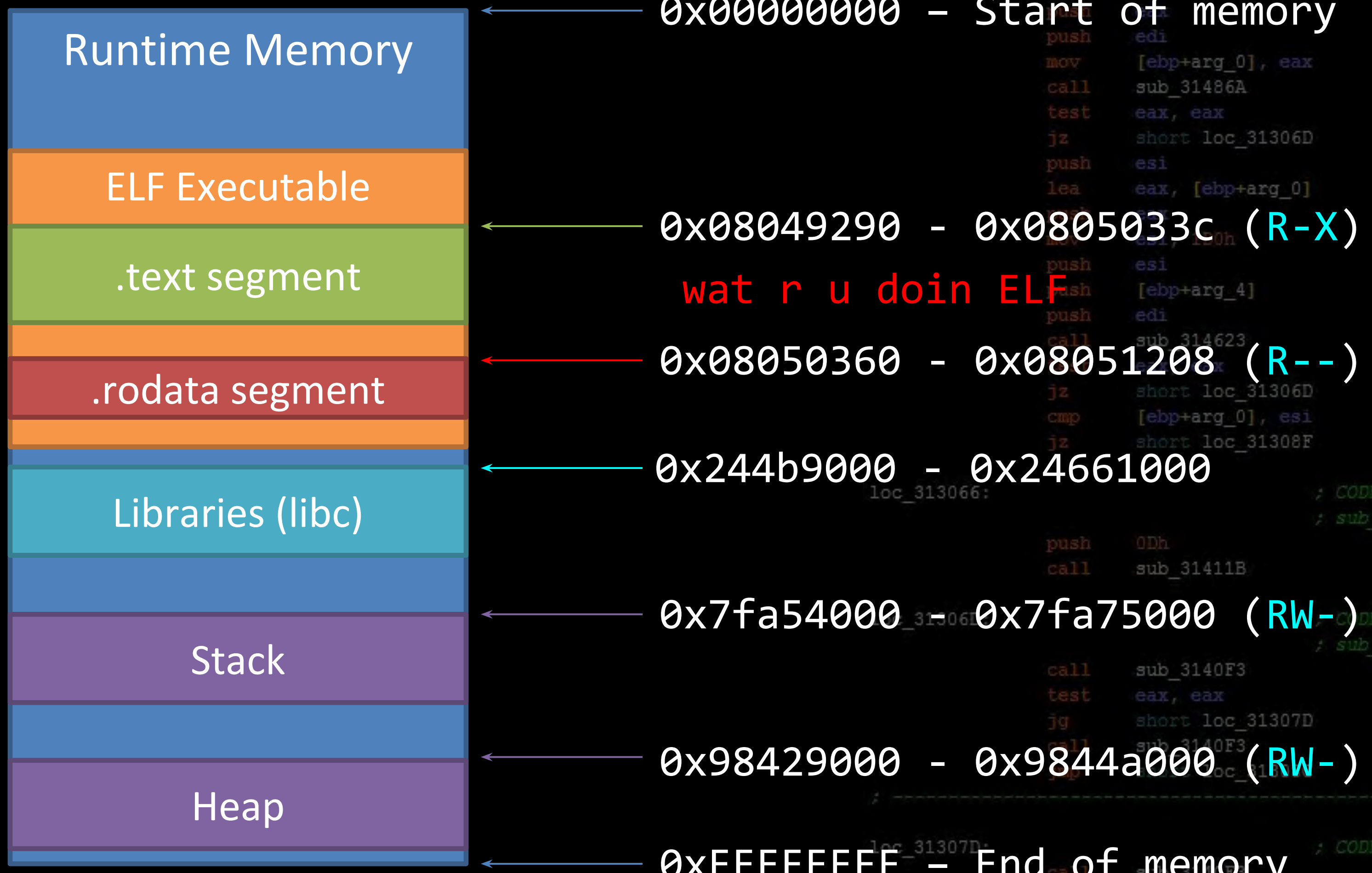
0x08055000 - 0x08076000 (RW-)

0xb7e25000 - 0xb7fcd000

0xbffdf000 - 0xc0000000 (RW-)

0xFFFFFFFF – End of memory

Run #1 With ASLR



Runtime Memory

ELF Executable

.text segment

.rodata segment

Libraries (libc)

Stack

Heap

0x00000000 – Start of memory

0x08049290 - 0x0805033c (R-X)

wat r u doin ELF

0x08050360 - 0x08051208 (R--)

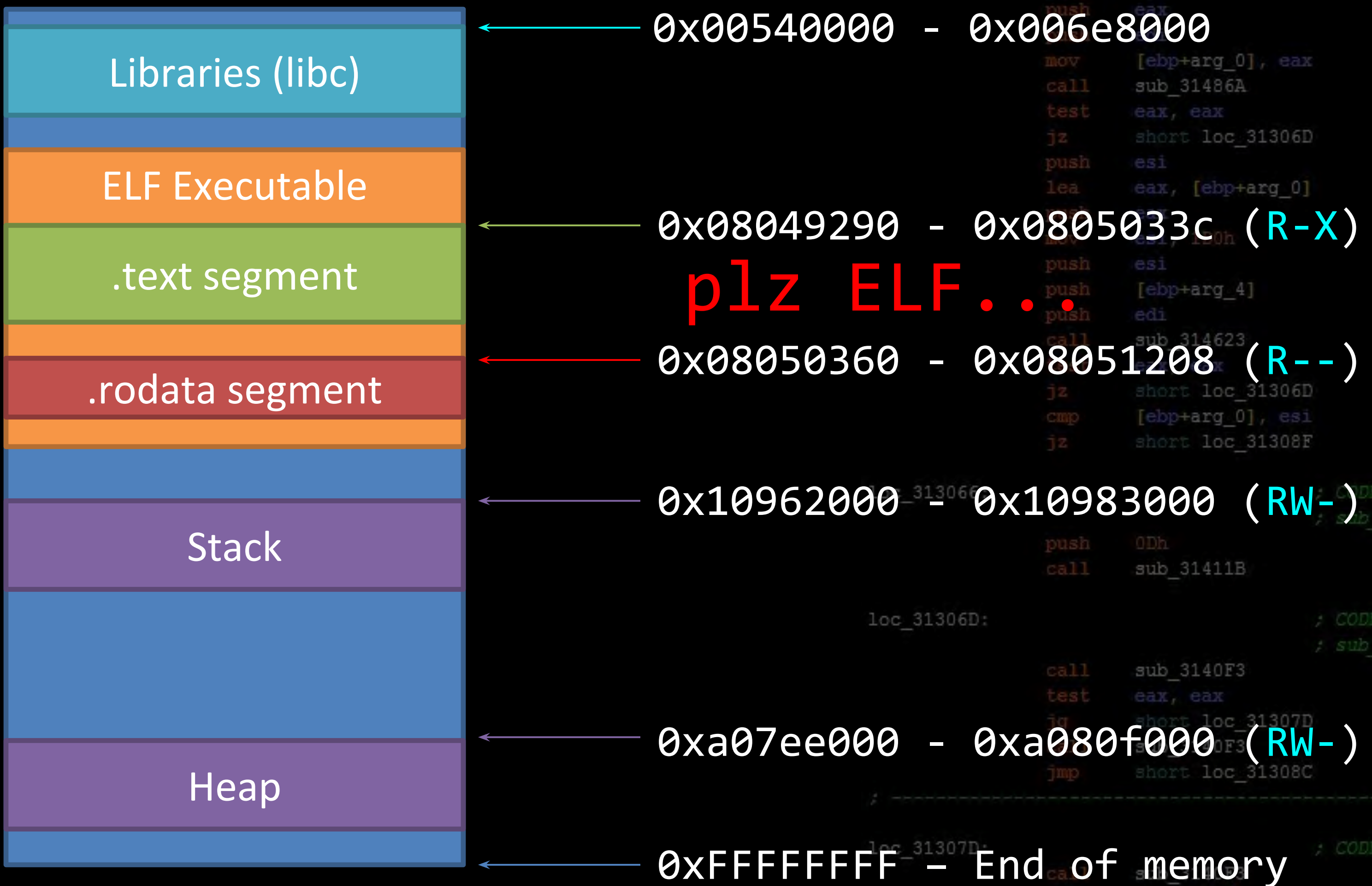
0x244b9000 - 0x24661000

0x7fa54000 - 0x7fa75000 (RW-)

0x98429000 - 0x9844a000 (RW-)

0xFFFFFFFF – End of memory

Run #2 With ASLR



0x00540000 - 0x006e8000

0x08049290 - 0x0805033c (R-X)

plz ELF...

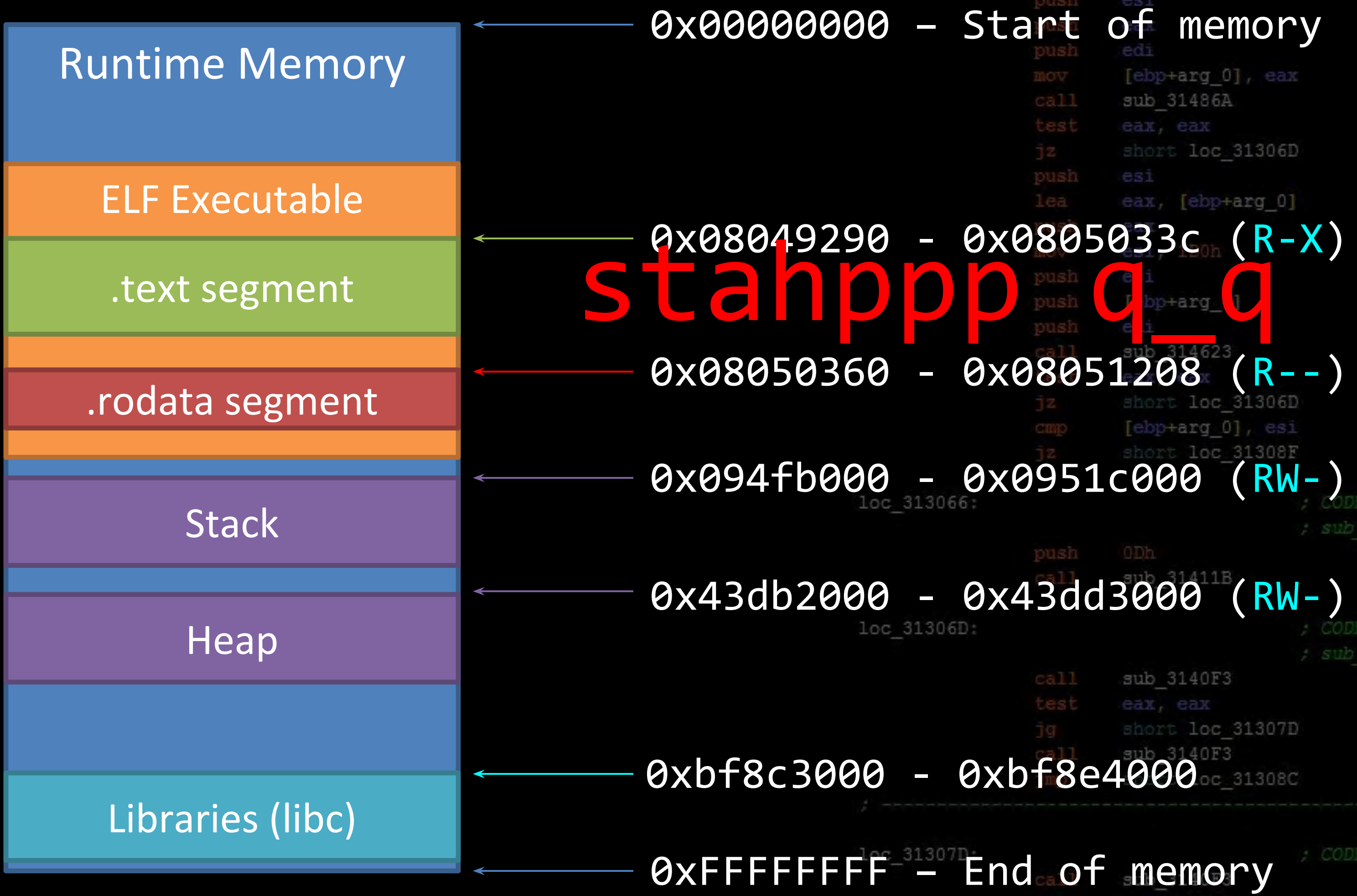
0x08050360 - 0x08051208 (R--)

0x10962000 - 0x10983000 (RW-)

0xa07ee000 - 0xa080f000 (RW-)

0xFFFFFFFF – End of memory

Run #3 With ASLR



Runtime Memory

ELF Executable

.text segment

.rodata segment

Stack

Heap

Libraries (libc)

0x00000000 – Start of memory

0x08049290 - 0x0805033c (R-X)

stahppp q_q

0x08050360 - 0x08051208 (R--)

0x094fb000 - 0x0951c000 (RW-)

0x43db2000 - 0x43dd3000 (RW-)

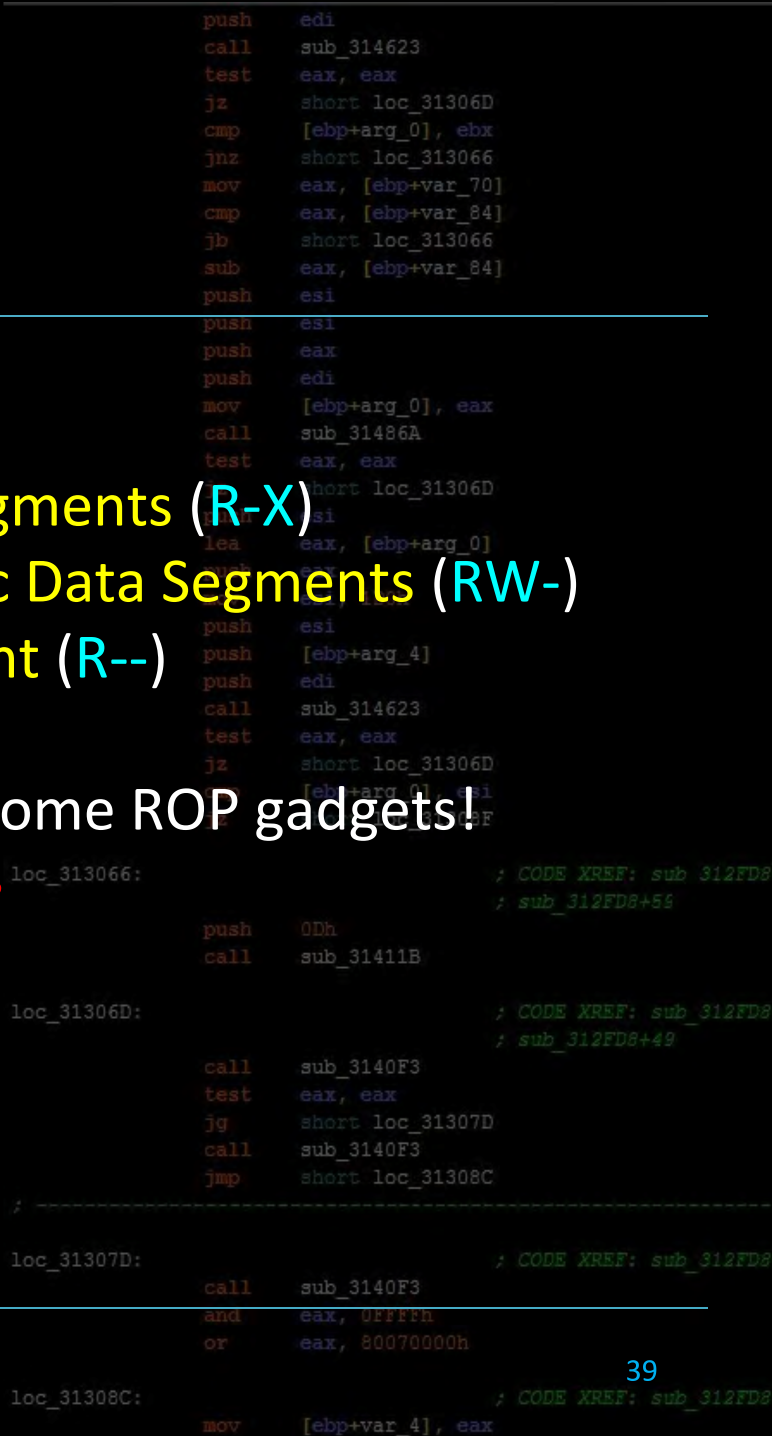
0xbf8c3000 - 0xbf8e4000

0xFFFFFFFF – End of memory

Not Randomized

- Main ELF Binary
  - .text / .plt / .init / .fini - Code Segments (R-X)
  - .got / .got.plt / .data / .bss - Misc Data Segments (RW-)
  - .rodata - Read Only Data Segment (R--)

- At minimum, we can probably find some ROP gadgets!
  - Warning: They won’t be pretty gadgets



```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, [illegible]
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_313[illegible]F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

Course Terminology

- Position Independent Executable
  - Executables compiled such that their base address does not matter, 'position independent code'
  - Shared Libs /must/ be compiled like this on modern Linux
    - eg: libc
  - Known as PIE for short

Applying ASLR to ELF’s

- To make an executable position independent, you must compile it with the flags -pie -fPIE

```
$ gcc -pie -fPIE -o tester tester.c
```

Applying ASLR to ELF's

- To make an executable position independent, you must compile it with the flags -pie -fPIE

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$ gcc -pie -fPIE -o tester tester.c
```
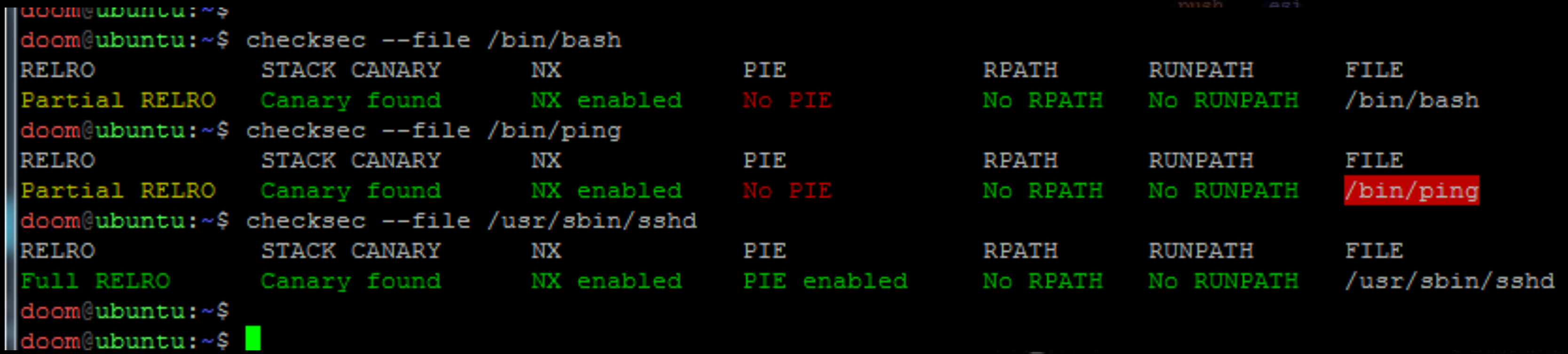

- Without these flag, you are not taking full advantage of ASLR

Checking for PIE

- Most binaries aren’t actually compiled as PIE



```
doom@ubuntu:~$
doom@ubuntu:~$ checksec --file /bin/bash
RELRO           STACK CANARY      NX            PIE             RPATH      RUNPATH      FILE
Partial RELRO   Canary found      NX enabled    No PIE          No RPATH   No RUNPATH   /bin/bash
doom@ubuntu:~$ checksec --file /bin/ping
RELRO           STACK CANARY      NX            PIE             RPATH      RUNPATH      FILE
Partial RELRO   Canary found      NX enabled    No PIE          No RPATH   No RUNPATH   /bin/ping
doom@ubuntu:~$ checksec --file /usr/sbin/sshd
RELRO           STACK CANARY      NX            PIE             RPATH      RUNPATH      FILE
Full RELRO      Canary found      NX enabled    PIE enabled     No RPATH   No RUNPATH   /usr/sbin/sshd
doom@ubuntu:~$
doom@ubuntu:~$ █
```

- Generally only on remote services, as you don’t want your server to get owned

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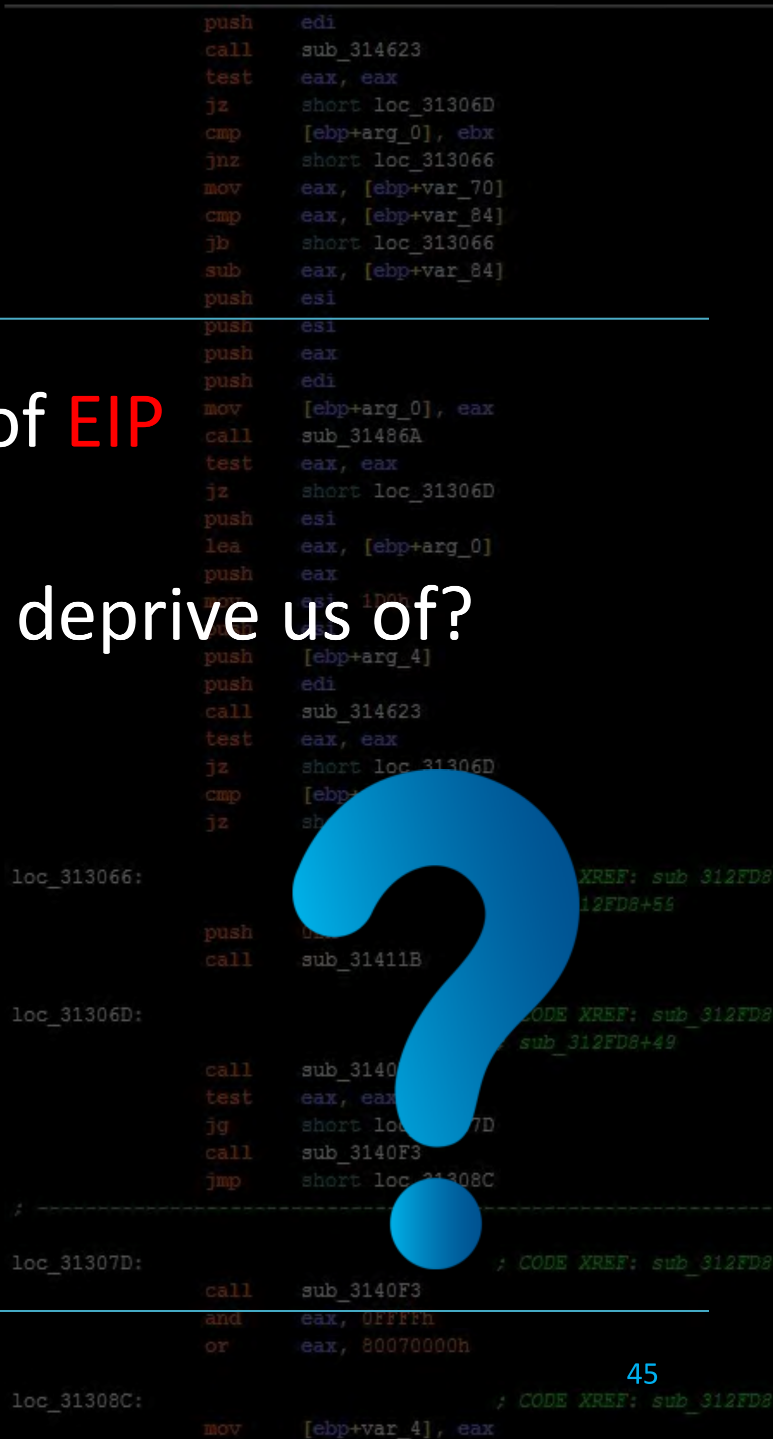
```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

Bypassing ASLR

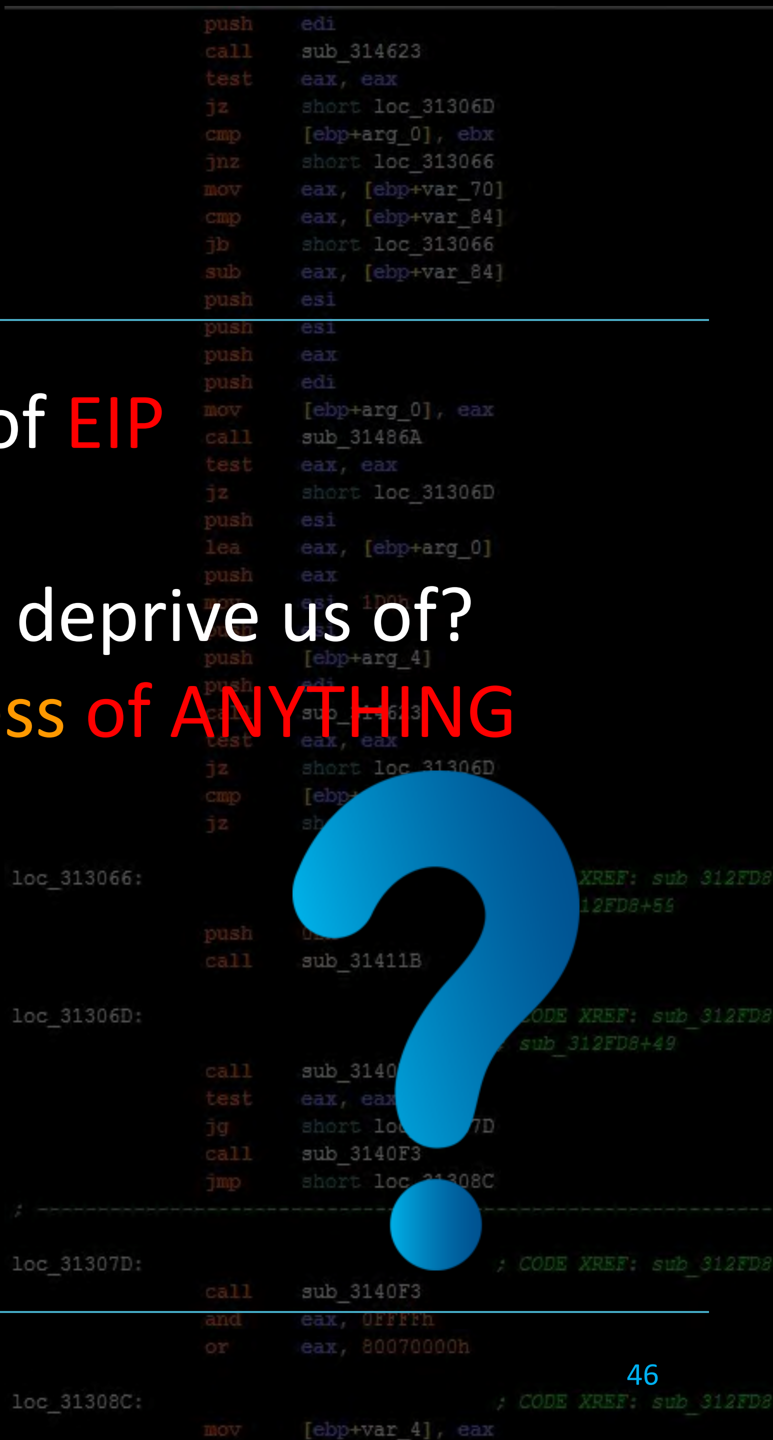
- Assume you can get control of EIP
- What information does ASLR deprive us of?



```
            push    edi
            call    sub_314623
            test    eax, eax
            jz      short loc_31306D
            cmp     [ebp+arg_0], ebx
            jnz     short loc_313066
            mov     eax, [ebp+var_70]
            cmp     eax, [ebp+var_84]
            jb      short loc_313066
            sub     eax, [ebp+var_84]
            push    esi
            push    esi
            push    eax
            push    edi
            mov     [ebp+arg_0], eax
            call    sub_31486A
            test    eax, eax
            jz      short loc_31306D
            push    esi
            lea     eax, [ebp+arg_0]
            push    eax
            mov     esi, 1D0h
            push    [ebp+arg_4]
            push    edi
            call    sub_314623
            test    eax, eax
            jz      short loc_31306D
            cmp     [ebp+
            jz      sh

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
            push    
            call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
            call    sub_3140
            test    eax, eax
            jg      short loc_31307D
            call    sub_3140F3
            jmp     short loc_31308C
; ---------------------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
            call    sub_3140F3
            and     eax, 0FFFFh
            or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
            mov     [ebp+var_4], eax
```

Bypassing ASLR

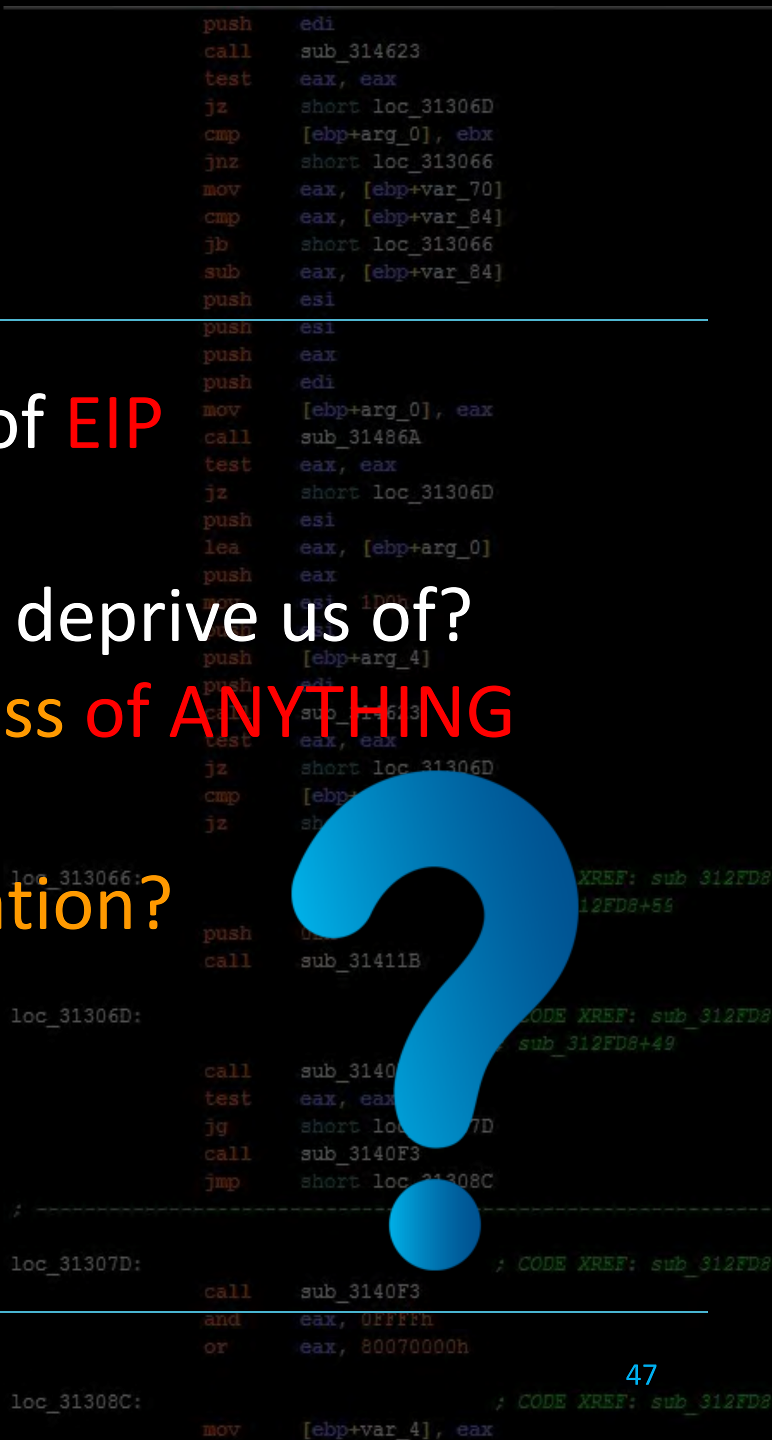
- Assume you can get control of EIP
- What information does ASLR deprive us of?
  - You don't know the address of ANYTHING



```
push    edi
call    sub_314623
test    eax, eax
jz      short loc_31306D
cmp     [ebp+arg_0], ebx
jnz     short loc_313066
mov     eax, [ebp+var_70]
cmp     eax, [ebp+var_84]
jb      short loc_313066
sub     eax, [ebp+var_84]
push    esi
push    esi
push    eax
push    edi
mov     [ebp+arg_0], eax
call    sub_31486A
test    eax, eax
jz      short loc_31306D
push    esi
lea     eax, [ebp+arg_0]
push    eax
push    [ebp+arg_4]
test    eax, eax
jz      short loc_31306D
cmp     [ebp+
jz      sh

loc_313066:                             XREF: sub_312FD8
                                        12FD8+59
push
call    sub_31411B

loc_31306D:                             ODE XREF: sub_312FD8
                                        sub_312FD8+49
call    sub_3140
test    eax, eax
jg      short lo        7D
call    sub_3140F3
jmp     short loc_    308C
; ---------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
call    sub_3140F3
and     eax, 0FFFFh
or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
mov     [ebp+var_4], eax
```

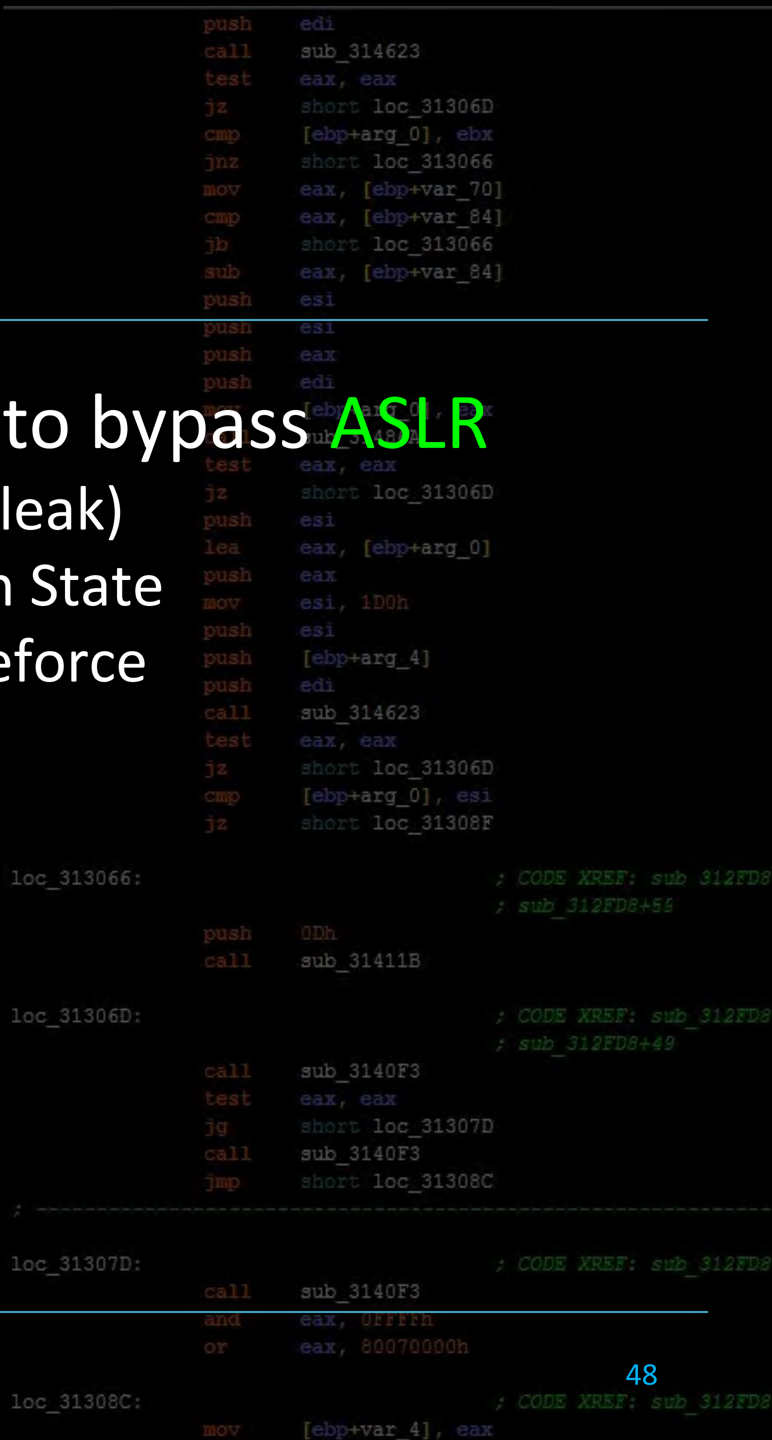
Bypassing ASLR

- Assume you can get control of EIP
- What information does ASLR deprive us of?
  - You don't know the address of ANYTHING
- How can we get that information?
  - Or work around it?



Bypassing ASLR

- There’s a few common ways to bypass ASLR
  - Information disclosure (aka info leak)
  - Partial address overwrite + Crash State
  - Partial address overwrite + Bruteforce



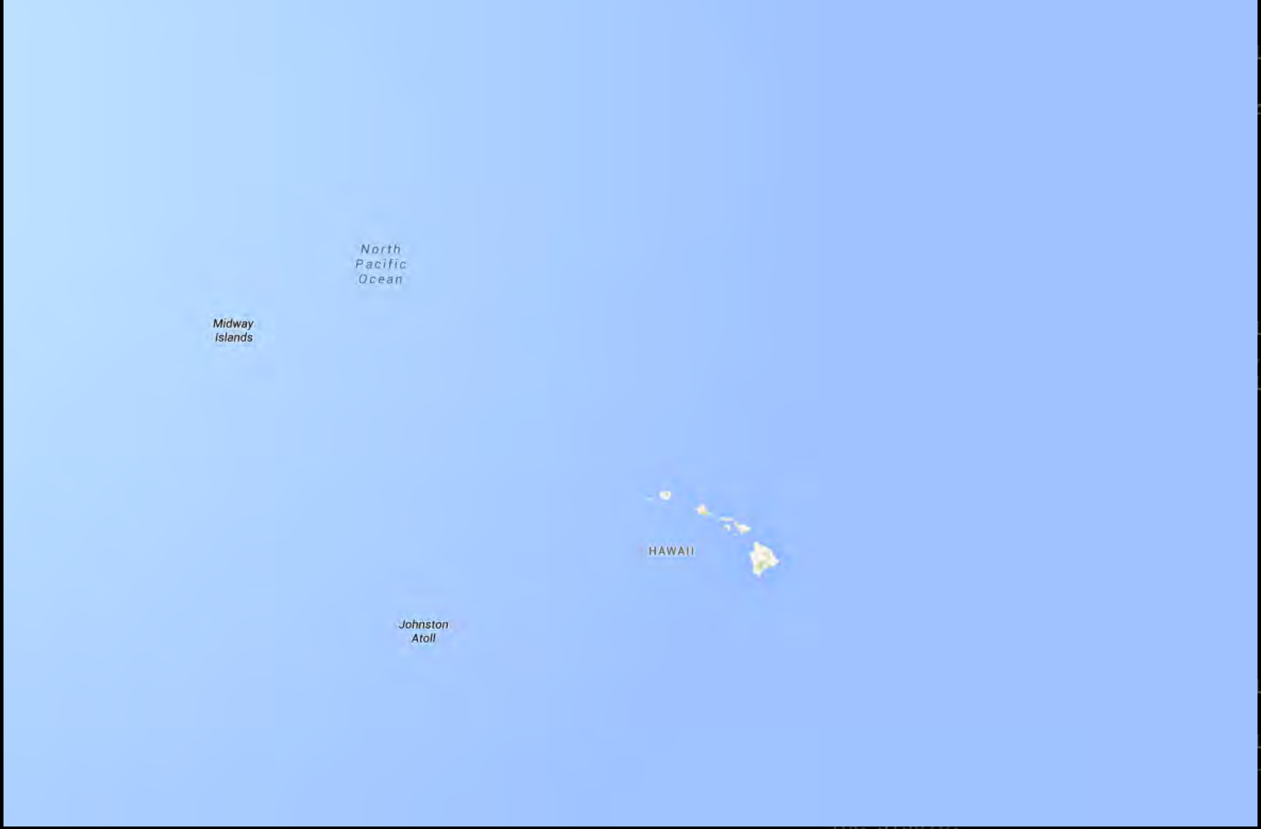
```
          push    edi
          call    sub_314623
          test    eax, eax
          jz      short loc_31306D
          cmp     [ebp+arg_0], ebx
          jnz     short loc_313066
          mov     eax, [ebp+var_70]
          cmp     eax, [ebp+var_84]
          jb      short loc_313066
          sub     eax, [ebp+var_84]
          push    esi
          push    esi
          push    eax
          push    edi
          mov     [ebp+arg_0], eax
          call    sub_31480A
          test    eax, eax
          jz      short loc_31306D
          push    esi
          lea     eax, [ebp+arg_0]
          push    eax
          mov     esi, 1D0h
          push    esi
          push    [ebp+arg_4]
          push    edi
          call    sub_314623
          test    eax, eax
          jz      short loc_31306D
          cmp     [ebp+arg_0], esi
          jz      short loc_31308F

loc_313066:                                  ; CODE XREF: sub_312FD8
                                             ; sub_312FD8+59
          push    0Dh
          call    sub_31411B

loc_31306D:                                  ; CODE XREF: sub_312FD8
                                             ; sub_312FD8+49
          call    sub_3140F3
          test    eax, eax
          jg      short loc_31307D
          call    sub_3140F3
          jmp     short loc_31308C
; ---------------------------------------------------------------

loc_31307D:                                  ; CODE XREF: sub_312FD8
          call    sub_3140F3
          and     eax, 0FFFFh
          or      eax, 80070000h

loc_31308C:                                  ; CODE XREF: sub_312FD8
          mov     [ebp+var_4], eax
```

What are Info Leaks?

- An info leak is when you can extract meaningful information (such as a memory address) from the ASLR protected service or binary
- If you can leak any sort of pointer to code during your exploit, you have likely defeated ASLR
  - Why is a single pointer leak so damning?

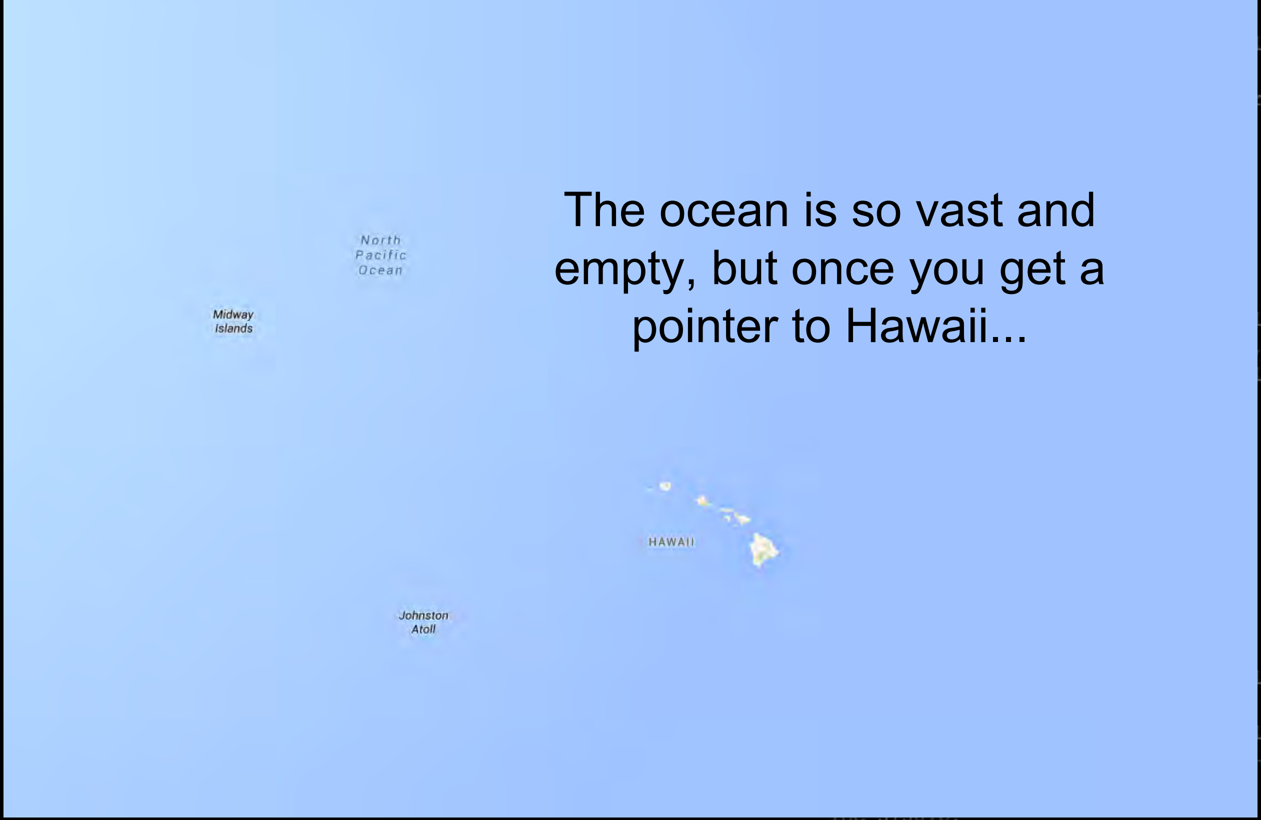
Death by Pointer

Runtime Memory! … or the North Pacific Ocean



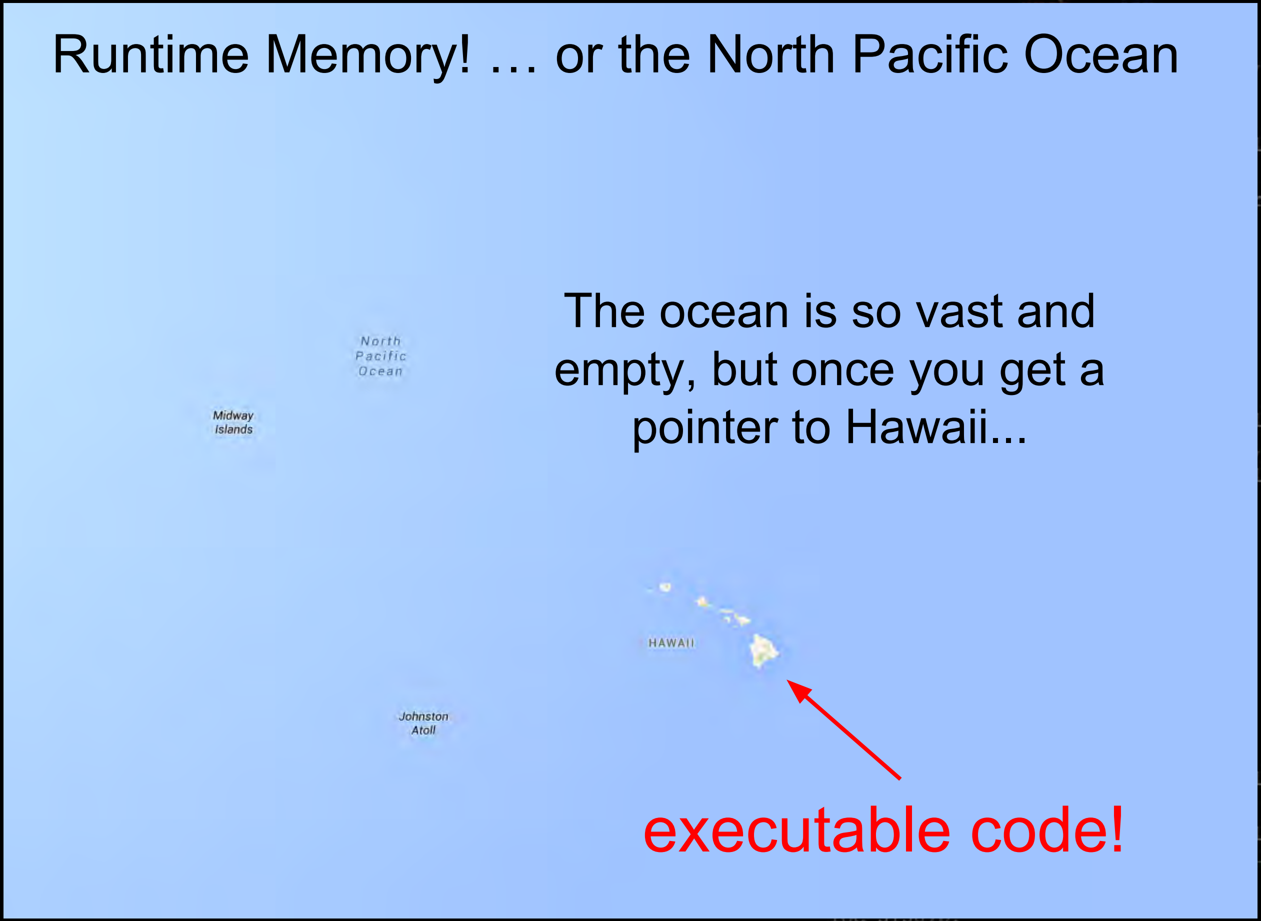
Death by Pointer

Runtime Memory! … or the North Pacific Ocean



The ocean is so vast and empty, but once you get a pointer to Hawaii...

Death by Pointer



Runtime Memory! … or the North Pacific Ocean

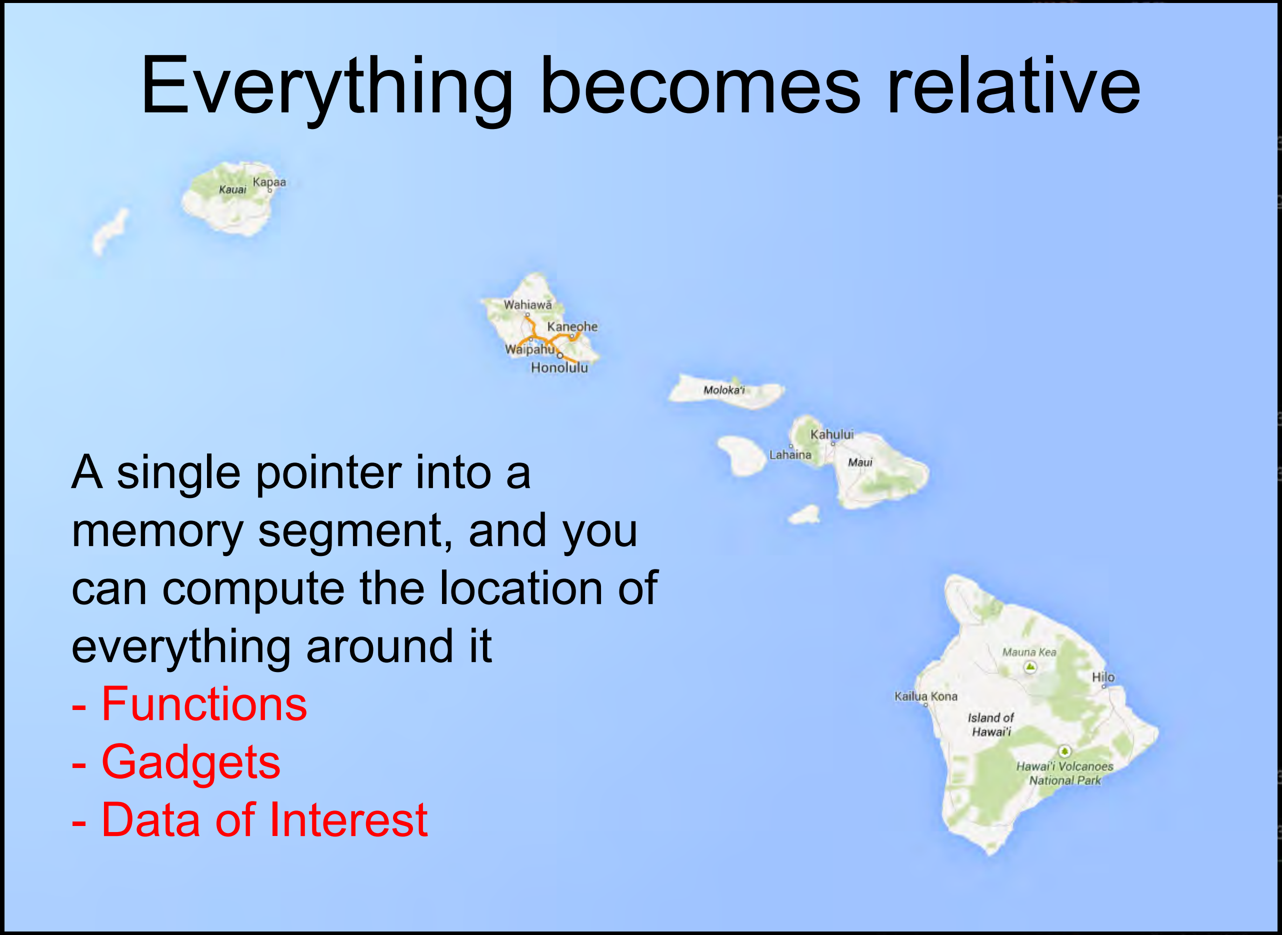
The ocean is so vast and empty, but once you get a pointer to Hawaii...

executable code!

Death by Pointer

Everything becomes relative

Death by Pointer



Everything becomes relative

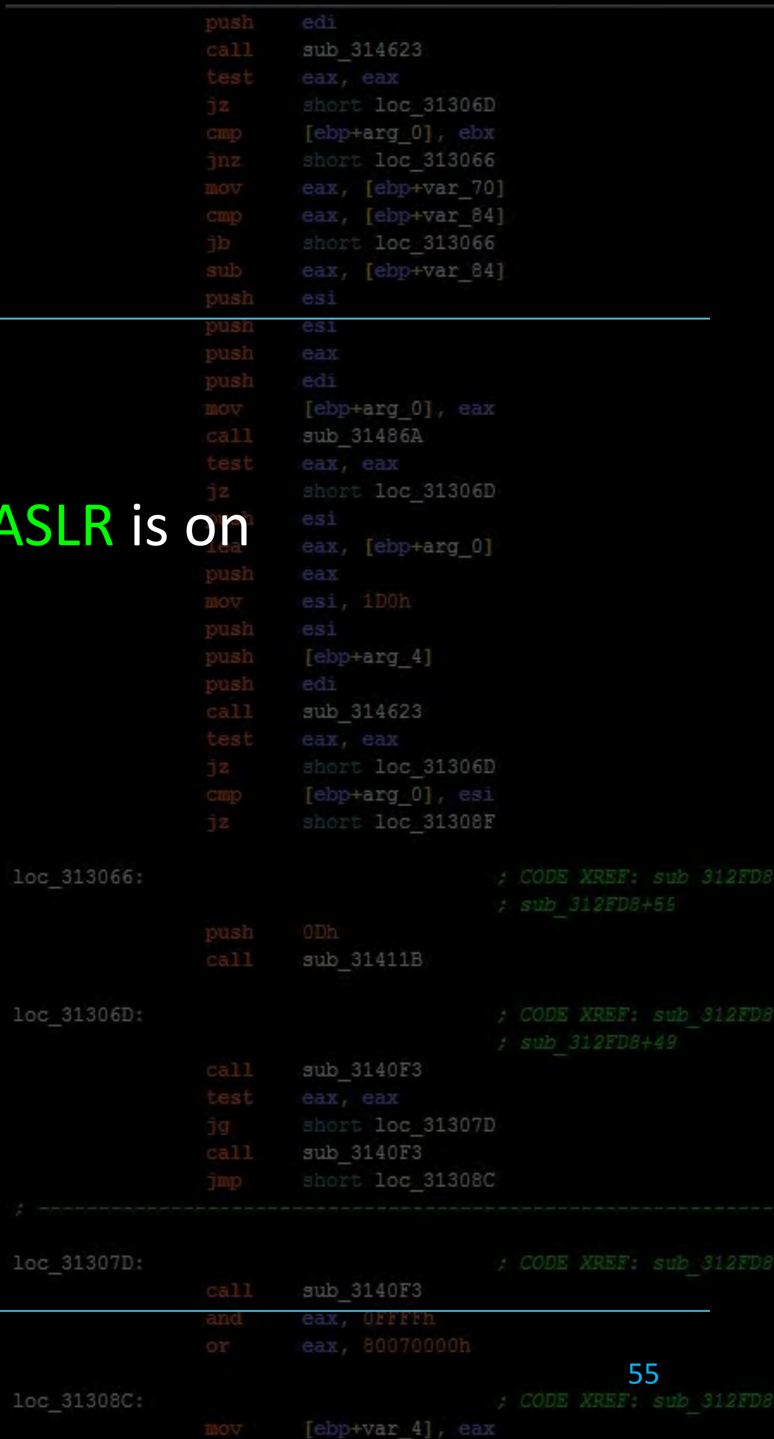
A single pointer into a memory segment, and you can compute the location of everything around it

- Functions
- Gadgets
- Data of Interest

Using Info Leaks

By Example:

- -You have a copy of the libc binary, ASLR is on



```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

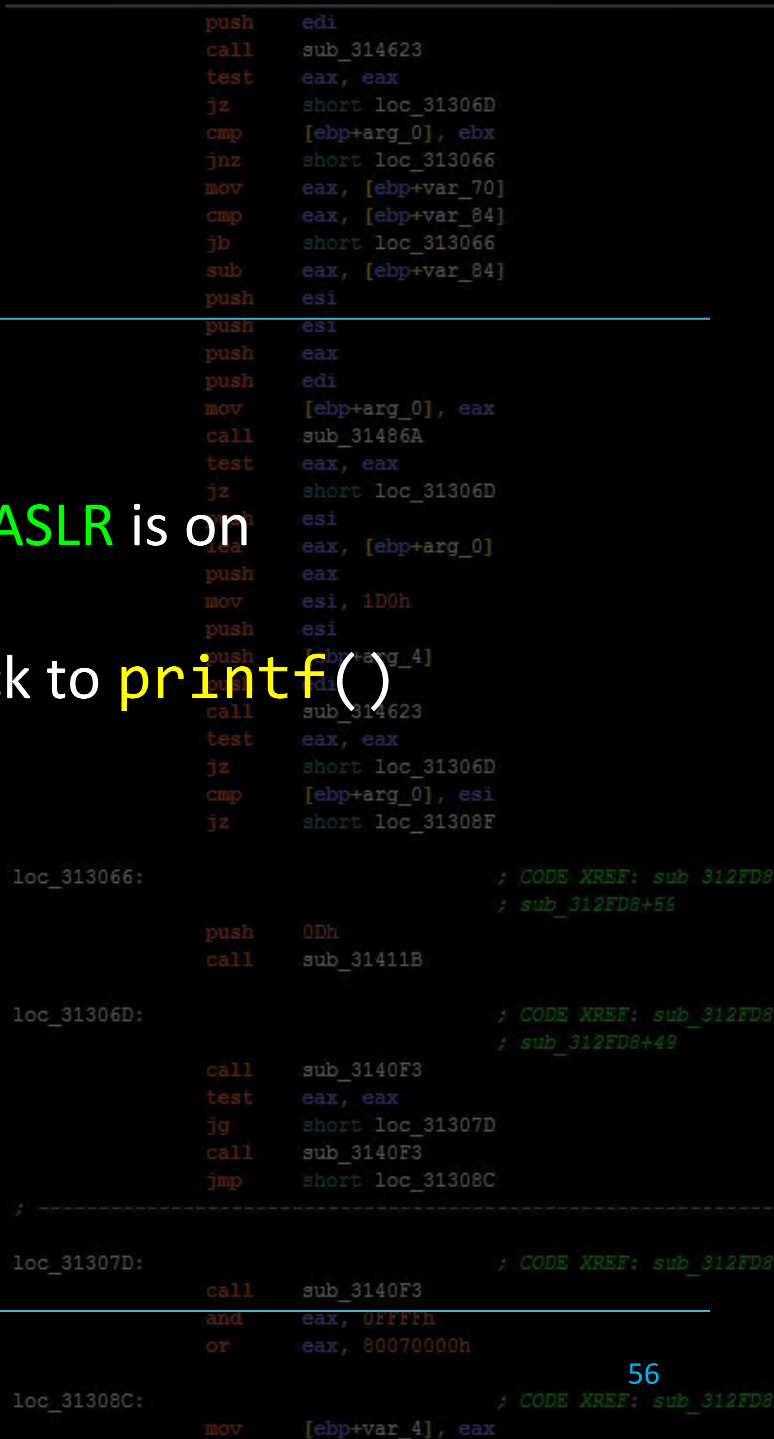
Using Info Leaks

By Example:

-You have a copy of the libc binary, ASLR is on

-You've leaked a pointer off the stack to `printf()`

`printf() is @ 0xb7e72280`



```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

Using Info Leaks

By Example:

-You have a copy of the libc binary, ASLR is on

-You've leaked a pointer off the stack to `printf()`

`printf() is @ 0xb7e72280`

-Look at the libc binary, how far away is system() from printf()?

`system() is -0xD0F0 bytes away from printf()`

Using Info Leaks

By Example:

-You have a copy of the libc binary, ASLR is on

-You've leaked a pointer off the stack to `printf()`

```
printf() is @ 0xb7e72280
```

-Look at the libc binary, how far away is system() from printf()?

```
system() is -0xD0F0 bytes away from printf()
```

```
therefore system() is at @ 0xb7e65190
                    (0xb7e65190-0xD0F0)
```

/levels/lecture/aslr/aslr_leak1

```
ssh lecture@warzone.rpis.ec 22
```

Fully Position Independent Executable:

```
gcc -pie -fPIE -fno-stack-protector ./aslr_leak1.c
```

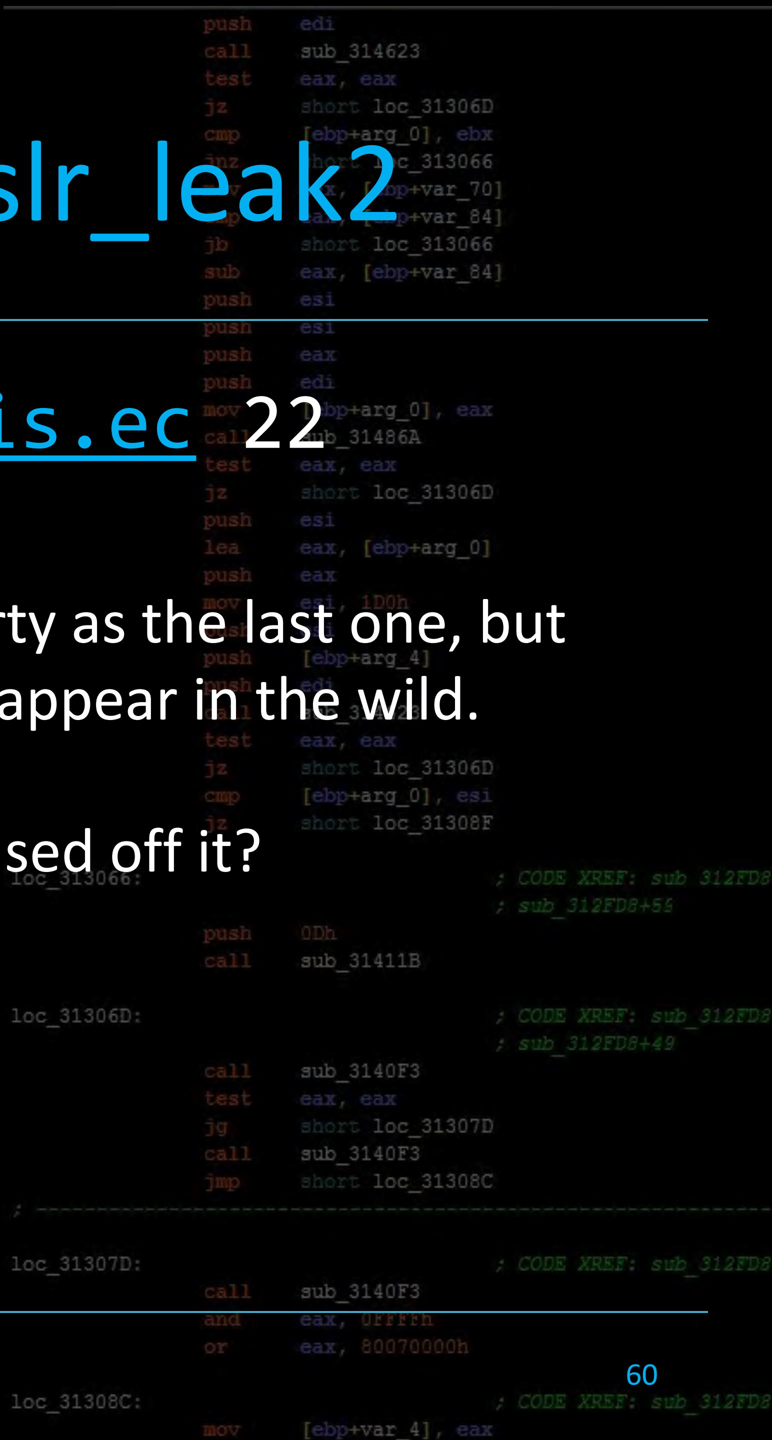
Force it to execute the “i_am_rly_leet” function

/levels/lecture/aslr/aslr_leak2

```
ssh lecture@warzone.rpis.ec 22
```

The exercise is equally as small and dirty as the last one, but this is typically how an infoleak might appear in the wild.

Can you parse it? Build a ROP chain based off it?



Using Info Leaks

- Can be used on hardest scenario of PIE, full ASLR
  - Usually comes with 100% exploit reliability!
  - ‘it just works’
- Info leaks are the most used ASLR bypass in real world exploitation as they give assurances
  - Someone’s life might depend on your exploit landing

Partial Overwrites

- Assume you have no way to leak an address, but you can overwrite one

from multiple runs:

```
0xb756b132
0xb758e132
0xb75e5132
0xb754d132
0xb75cf132
```

Guaranteed 255 byte ROP/ret range around that address

2^4 bits of bruteforce gives you 64kb of range around the addr

2^{12} bits of bruteforce will give you ROP/ret across all of libc

Partial Overwrites

- Assume you have no way to leak an address, but you can overwrite one

  from multiple runs:

```
0xb756b132
0xb758e132
0xb75e5132
0xb754d132
0xb75cf132
```

100% exploit reliability

6.25% exploit reliability

0.024% exploit reliability

Bruteforcing

- Note that these bruteforcing details apply only to Ubuntu 32bit

- Don’t bother to try bruteforcing addresses on a 64bit machine of any kind

- Ubuntu ASLR is rather weak, low entropy

ASLR Tips

- What does your crash state look like?
  - What's in the registers?
  - What's on the stack around you?

- Even if you can't easily leak some data address out of a register or off the stack, there's nothing that's stopping you from using it for stuff
  - As always: get creative

```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

Lecture Overview

1. Introducing ASLR
2. Position Independent Executables
3. Bypassing ASLR, Examples
4. Conclusion

```
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], ebx
                jnz     short loc_313066
                mov     eax, [ebp+var_70]
                cmp     eax, [ebp+var_84]
                jb      short loc_313066
                sub     eax, [ebp+var_84]
                push    esi
                push    esi
                push    eax
                push    edi
                mov     [ebp+arg_0], eax
                call    sub_31486A
                test    eax, eax
                jz      short loc_31306D
                push    esi
                lea     eax, [ebp+arg_0]
                push    eax
                mov     esi, 1D0h
                push    esi
                push    [ebp+arg_4]
                push    edi
                call    sub_314623
                test    eax, eax
                jz      short loc_31306D
                cmp     [ebp+arg_0], esi
                jz      short loc_31308F

loc_313066:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+59
                push    0Dh
                call    sub_31411B

loc_31306D:                             ; CODE XREF: sub_312FD8
                                        ; sub_312FD8+49
                call    sub_3140F3
                test    eax, eax
                jg      short loc_31307D
                call    sub_3140F3
                jmp     short loc_31308C
; ---------------------------------------------------------------

loc_31307D:                             ; CODE XREF: sub_312FD8
                call    sub_3140F3
                and     eax, 0FFFFh
                or      eax, 80070000h

loc_31308C:                             ; CODE XREF: sub_312FD8
                mov     [ebp+var_4], eax
```

In Closing

- Like other mitigation technologies, ASLR is a ‘tack on’ solution that only makes things harder

- The vulnerabilities and exploits become both more complex and precise the deeper down the rabbit hole we go

Modern Exploit Mitigations

- DEP & ASLR are the two main pillars of modern exploit mitigation technologies

- Congrats, being able to bypass these mean that you’re probably capable of writing exploits for real vulnerabilities