Class 12

CSC 472 Software Security
ROP (3) & Dynamic Linking & Return-to-libc Attack

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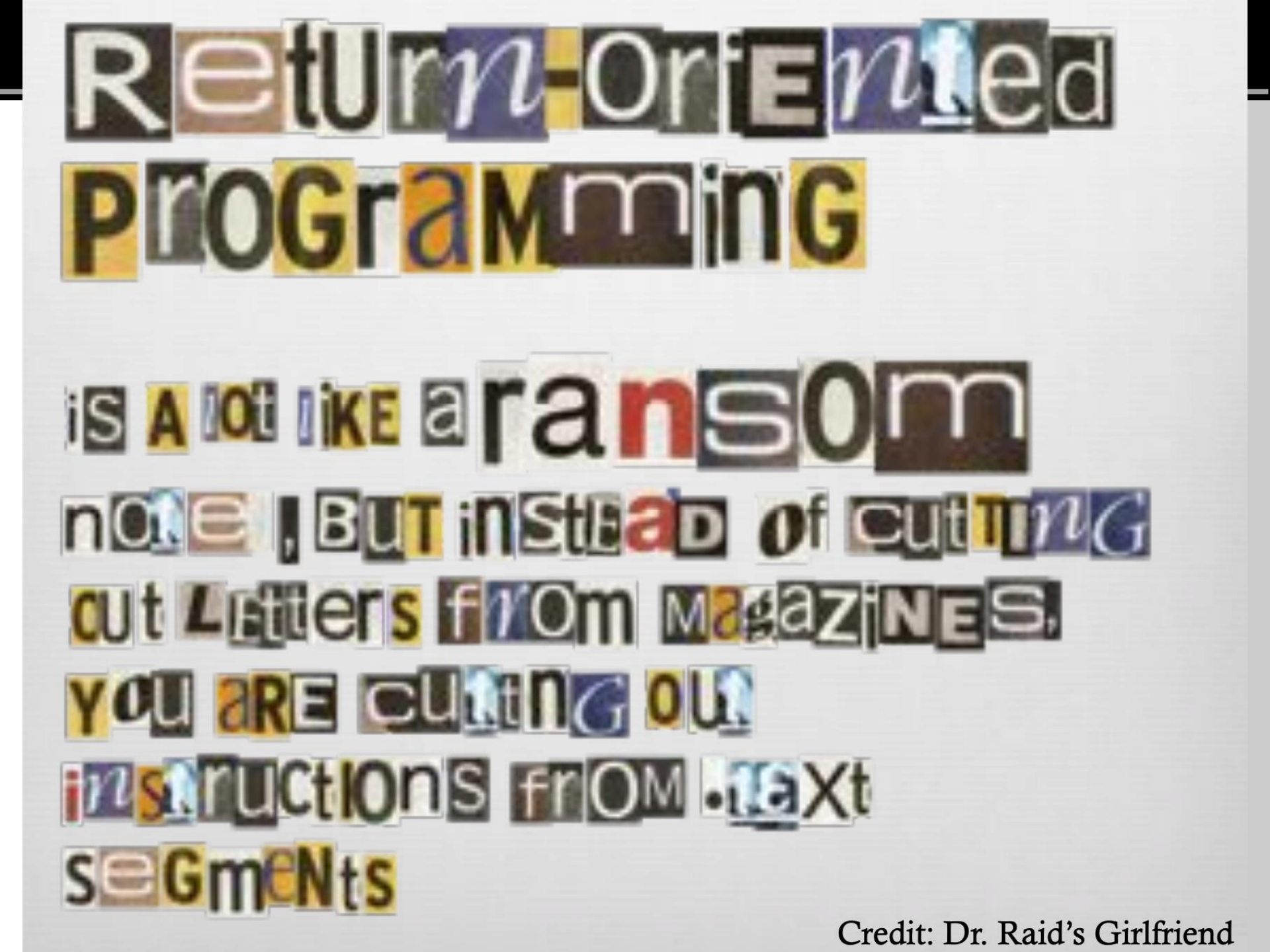
Review

Return-oriented programming (ROP)

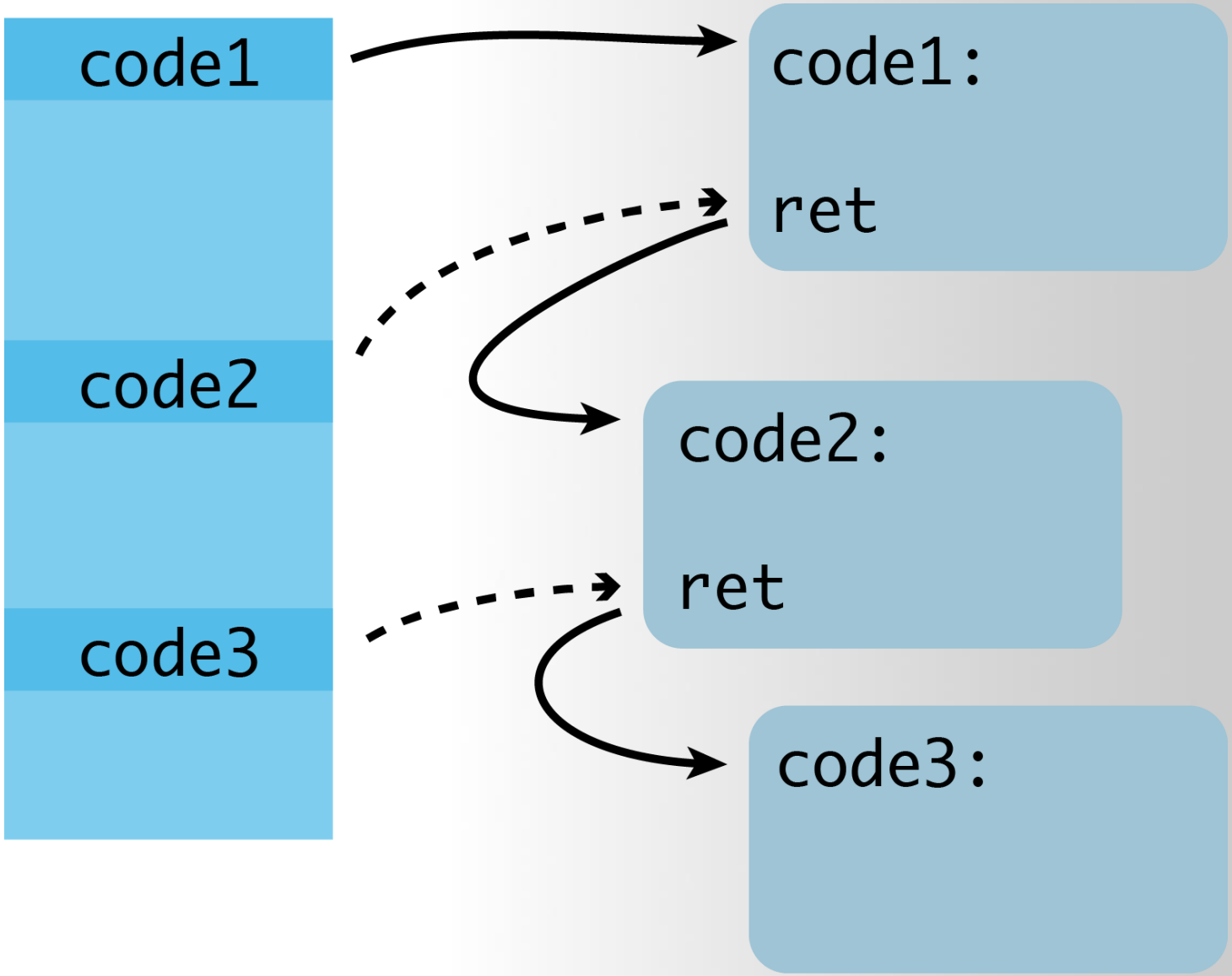
Return-Oriented Programming

is a lot like a ransom note! But instead of cutting cut letters from magazines, you are cutting out instructions from .text segments



Credit: Dr. Raid's Girlfriend

ROP: The Main Idea



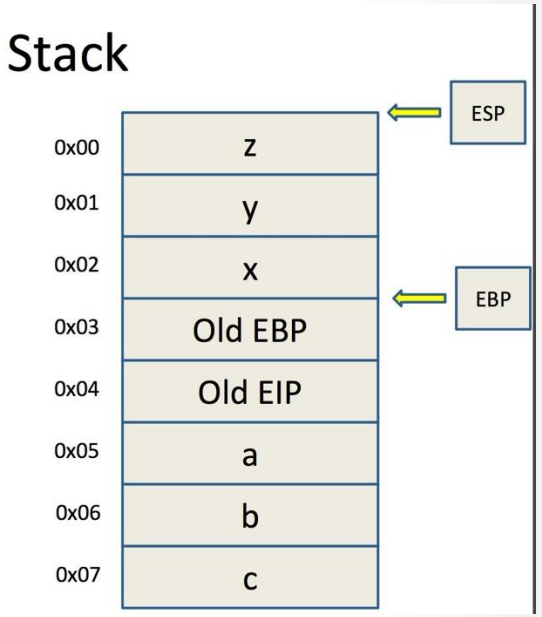
```c
#include <stdio.h>
#include <string.h>

char string[100];

void exec_string() {
  system(string);
}

void add_bin(int magic) {
  if (magic == 0xdeadbeef) {
    strcat(string, "/bin");
  }
}

void add_bash(int magic1, int magic2) {
  if (magic1 == 0xcafebabe && magic2 == 0x0badf00d) {
    strcat(string, "/bash");
  }
}

void vulnerable_function(char *string) {
  char buffer[100];
  gets(buffer);
}

int main(int argc, char** argv) {
  string[0] = 0;
  vulnerable_function(argv[1]);
  return 0;
}
```

Execution Path

- → add_bin()
  - → magic == 0xdeadbeef
- → add_bash()
  - → magic1 == 0xcafebabe
  - → magic2 == 0x0badf00d
- → exec_string()
- → Spawn shell

Return Chaining

```
int foo(int a, int b, int c)
{
    int x;
    int y;
    int z;

    x=y=z=0;
    z=x+y+a+b+c;
    return z;


}
int main(int argc, char **argv) {

        foo(1,2,3);
}
```



First Function Address
Next Function Address
Arguments1 for First Function
Arguments2 for First Function
…

Return Chaining

The previous ROP chain does not work, because argument **0xdeadbeef** is still on the stack, we need to find a way to ”**clean**” it

Execution Path

- → add_bin()
  - → magic == 0xdeadbeef
- → add_bash()
  - → magic1 == 0xcafebabe
  - → magic2 == 0x0badf00d
- → exec_string()
- → Spawn shell

Add_bin() Add_bash() Exec_string()

→ magic == 0xdeadbeef

Solution: use a **pop, ret** gadget to push the argument **0xdeadbeef** into **a register** to remove it from the stack

Dummy Character “A”s
Address for Add_bin()
Address for pop_ret
0xdeadbeef
Address for Add_bash()

Multiple Dummy Character ‘A’ s
Address of add_bin()
Address of pop, ret gadget
0xdeadbeef
Address of add_bash()
Address of pop, pop, ret gadget
0xcafebabe
0x0badf00d
Address of exec_string()

ELF (Executable Linkable Format)

ELF executable for Linux

Executable and Linkable Format (ELF)

Linux	Windows	
ELF file	.exe (PE)	
.so (Shared object file)	.dll (Dynamic Linking Library)	
.a	.lib (static linking library)	
.o (intermediate file between complication and linking, object file)	.obj	

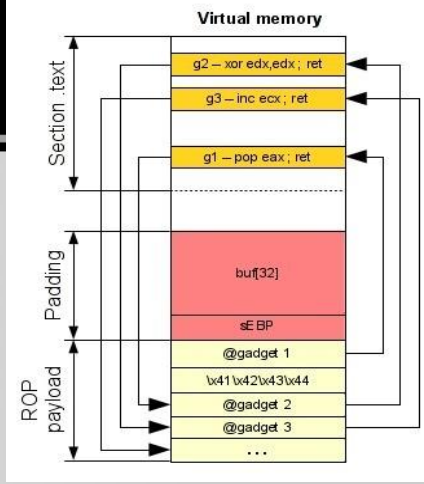
ELF executable for Linux

```
[quake0day@quake0day-wcu Downloads]$ file a
a: ELF 32-bit LSB shared object, Intel 80386, version 1 (SYSV), dynamically li
ed, interpreter /lib/ld-linux.so.2, for GNU/Linux 2.6.32, BuildID[sha1]=da2dba
f2eda3d2b639f8dac80396a994d2df0e, not stripped
```

- ELF32-bit LSB
- Dynamically linked

Section (or Segment) in ELF

```c
int global_init_var = 84;
int golbal_uninit_var;

void func1(int i)
{
    printf("%d\n", i);
}

int main(void)
{
    static int static_var = 85;
    static int static_var2;

    int a = 1;
    int b;
    func1(static_var + static_var2 + a + b);
    return 0;
}
```



ELF file / Object file

- File Header
- .text section
- .data section
- .bss (Block started by symbol) section

```
➜  ~ objdump -h rop

rop:     file format elf32-i386

Sections:
Idx Name          Size      VMA       LMA       File off  Algn
  0 .interp       00000013  00000154  00000154  00000154  2**0
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  1 .note.ABI-tag 00000020  00000168  00000168  00000168  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  2 .note.gnu.build-id 00000024  00000188  00000188  00000188  2**
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  3 .gnu.hash     00000020  000001ac  000001ac  000001ac  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  4 .dynsym       00000090  000001cc  000001cc  000001cc  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  5 .dynstr       000000a2  0000025c  0000025c  0000025c  2**0
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  6 .gnu.version  00000012  000002fe  000002fe  000002fe  2**1
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  7 .gnu.version_r 00000030  00000310  00000310  00000310  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  8 .rel.dyn      00000040  00000340  00000340  00000340  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  9 .rel.plt      00000018  00000380  00000380  00000380  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 10 .init         00000023  00000398  00000398  00000398  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
 11 .plt          00000040  000003c0  000003c0  000003c0  2**4
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
 12 .plt.got      00000010  00000400  00000400  00000400  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
 13 .text         000002e2  00000410  00000410  00000410  2**4
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
 14 .fini         00000014  000006f4  000006f4  000006f4  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
 15 .rodata       00000008  00000708  00000708  00000708  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 16 .eh_frame_hdr 0000005c  00000710  00000710  00000710  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 17 .eh_frame     0000018c  0000076c  0000076c  0000076c  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 18 .init_array   00000004  00001ed4  00001ed4  00000ed4  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 19 .fini_array   00000004  00001ed8  00001ed8  00000ed8  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 20 .dynamic      000000f8  00001edc  00001edc  00000edc  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 21 .got          0000002c  00001fd4  00001fd4  00000fd4  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 22 .data         00000008  00002000  00002000  00001000  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 23 .bss          00000084  00002020  00002020  00001008  2**5
                  ALLOC
 24 .comment      00000024  00000000  00000000  00001008  2**0
                  CONTENTS, READONLY
➜  ~ size rop
   text    data     bss     dec     hex filename
   1948     308     132    2388     954 rop
```

```
➜  ~ objdump -h rop2

rop2:     file format elf32-i386

Sections:
Idx Name          Size      VMA       LMA       File off  Algn
  0 .note.ABI-tag 00000020  080480f4  080480f4  000000f4  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  1 .note.gnu.build-id 00000024  08048114  08048114  00000114  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  2 .rel.plt      00000078  08048138  08048138  00000138  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  3 .init         00000023  080481b0  080481b0  000001b0  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  4 .plt          00000078  080481d8  080481d8  000001d8  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  5 .text         00066f81  08048250  08048250  00000250  2**4
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  6 __libc_freeres_fn 00000ba7  080af1e0  080af1e0  000671e0  2**4
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  7 __libc_thread_freeres_fn 00000127  080afd90  080afd90  00067d90  2**4
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  8 .fini         00000014  080afeb8  080afeb8  00067eb8  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
  9 .rodata       00018898  080afee0  080afee0  00067ee0  2**5
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 10 .eh_frame     000129b0  080c8778  080c8778  00080778  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 11 .gcc_except_table 000000ac  080db128  080db128  00093128  2**0
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 12 .tdata        00000010  080dc6e0  080dc6e0  000936e0  2**2
                  CONTENTS, ALLOC, LOAD, DATA, THREAD_LOCAL
 13 .tbss         00000020  080dc6f0  080dc6f0  000936f0  2**2
                  ALLOC, THREAD_LOCAL
 14 .init_array   00000008  080dc6f0  080dc6f0  000936f0  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 15 .fini_array   00000008  080dc6f8  080dc6f8  000936f8  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 16 .data.rel.ro  000018d4  080dc700  080dc700  00093700  2**5
                  CONTENTS, ALLOC, LOAD, DATA
 17 .got          00000028  080ddfd4  080ddfd4  00094fd4  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 18 .got.plt      00000048  080de000  080de000  00095000  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 19 .data         00000f20  080de060  080de060  00095060  2**5
                  CONTENTS, ALLOC, LOAD, DATA
 20 __libc_subfreeres 00000024  080def80  080def80  00095f80  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 21 __libc_IO_vtables 00000354  080defc0  080defc0  00095fc0  2**5
                  CONTENTS, ALLOC, LOAD, DATA
 22 __libc_atexit 00000004  080df314  080df314  00096314  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 23 __libc_thread_subfreeres 00000004  080df318  080df318  00096318  2**2
                  CONTENTS, ALLOC, LOAD, DATA
 24 .bss          00000cdc  080df320  080df320  0009631c  2**5
                  ALLOC
 25 __libc_freeres_ptrs 00000014  080dfffc  080dfffc  0009631c  2**2
                  ALLOC
 26 .comment      00000024  00000000  00000000  0009631c  2**0
                  CONTENTS, READONLY
➜  ~ size rop2
   text    data     bss     dec     hex filename
```

rop2.c

```
→  ~ gcc -m32 -fno-stack-protector -static -znoexecstack -o rop2 ./rop2.c
```

```c
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <stdint.h>
#include <unistd.h>

void vuln() {
    char buffer[128];
    char * second_buffer;
    uint32_t length = 0;
    puts("Reading from STDIN");
    read(0, buffer, 1024);

    if (strcmp(buffer, "Cool Input") == 0) {
        puts("What a cool string.");
    }
    length = strlen(buffer);
    if (length == 42) {
        puts("LUE");
    }
    second_buffer = malloc(length);
    strncpy(second_buffer, buffer, length);
}

int main() {
    setvbuf(stdin, NULL, _IONBF, 0);
    setvbuf(stdout, NULL, _IONBF, 0);

    puts("This is a big vulnerable example!");
    printf("I can print many things: %x, %s, %d\n", 0xdeadbeef, "Test String",
            42);
    write(1, "Writing to STDOUT\n", 18);
    vuln();
}
```

Since the binary is not big enough to give us a decent number of ROP gadgets, we will cheat a bit and compile the binary as a **statically linked ELF**.
This should include library code in the final executable and bulk up the size of the binary.

Linux System Call

- f we take a look at the syscall reference, we can see that some parameters are expected in the eax, ebx, ecx, and edx registers.
  - eax - holds the number of the syscall to be called
  - ebx - a pointer to the string containing the file name to be executed
  - ecx - a pointer to the array of string pointers representing argv
  - edx - a pointer to the array of string pointers representing envp
- For our purposes, the value that each of the registers should contain are:

eax = 0xb
ebx = "/bin/sh"
ecx = memory address -> 0
edx = memory address -> 0

ROPgadget

```
[quake0day@quake0day-wcu ~]$ ROPgadget --binary main
Gadgets information
============================================================
0x080cc211 : aaa ; add byte ptr [eax], al ; cmp al, 0xb5 ; clc ; jmp dword ptr [
ecx]
0x080cc239 : aaa ; add byte ptr [eax], al ; mov ch, 0xf8 ; jmp dword ptr [ecx]
0x080cc225 : aaa ; add byte ptr [eax], al ; pop eax ; mov ch, 0xf8 ; call dword
ptr [edi]
0x08096d2c : aaa ; add esp, 0x70 ; pop ebx ; pop esi ; pop edi ; ret
0x0809c8a7 : aaa ; div bh ; add esp, 0x10 ; pop ebx ; pop esi ; pop edi ; ret
0x080ace79 : aaa ; push 1 ; push 1 ; call eax
0x0804e4ab : aaa ; push dword ptr [ebx] ; mov eax, dword ptr [esp + 0x20] ; call
 eax
0x0807a21a : aad 0x2d ; ret 0
0x080aac19 : aad 0x89 ; ret 0xe283
```

```
➜  ~ ROPgadget  --binary rop2 --ropchain
```

Dynamic Linking

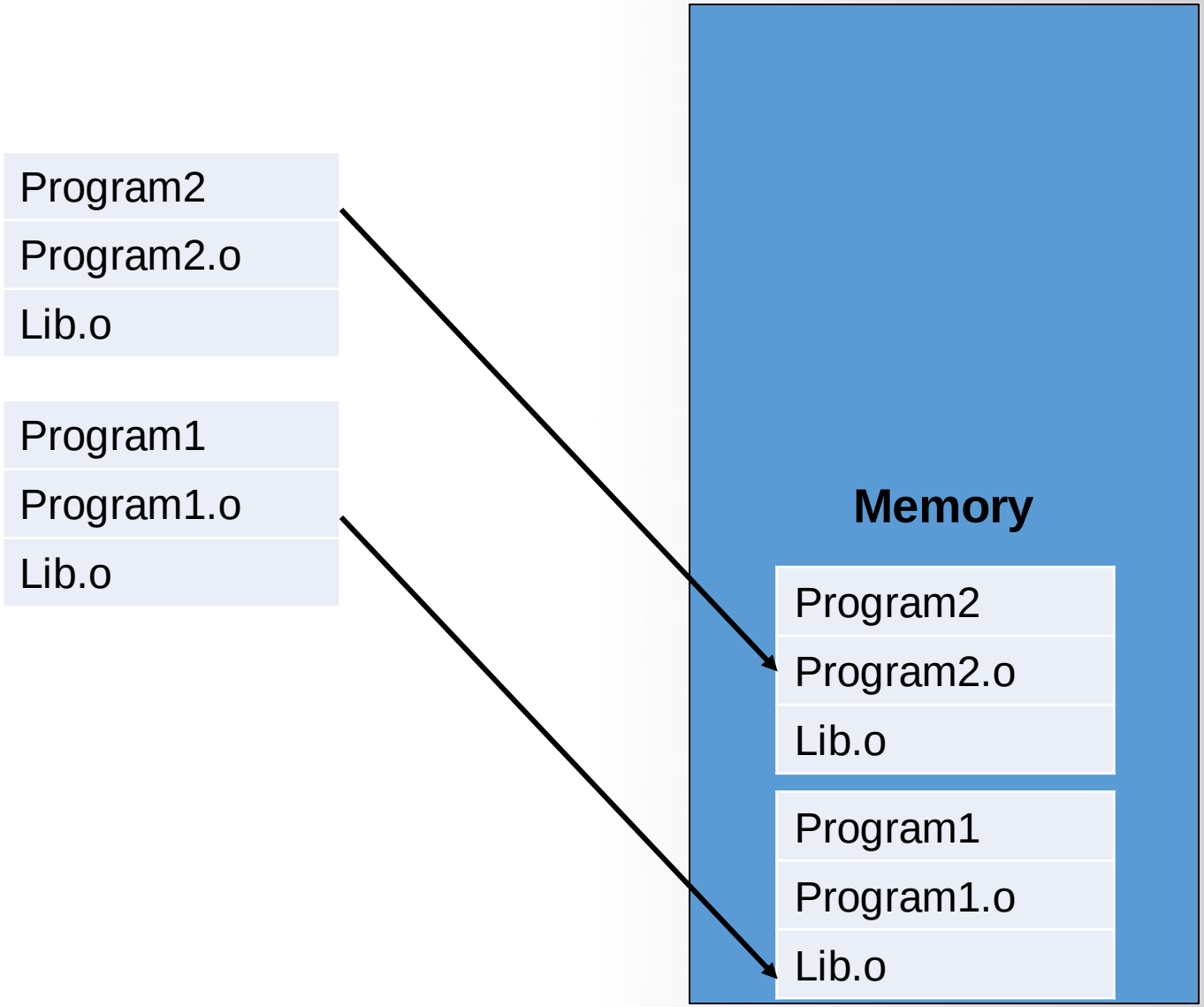
rop2.c

```
→  ~ gcc -m32 -fno-stack-protector -static -znoexecstack -o rop2 ./rop2.c
```

```c
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <stdint.h>
#include <unistd.h>

void vuln() {
    char buffer[128];
    char * second_buffer;
    uint32_t length = 0;
    puts("Reading from STDIN");
    read(0, buffer, 1024);

    if (strcmp(buffer, "Cool Input") == 0) {
        puts("What a cool string.");
    }
    length = strlen(buffer);
    if (length == 42) {
        puts("LUE");
    }
    second_buffer = malloc(length);
    strncpy(second_buffer, buffer, length);
}

int main() {
    setvbuf(stdin, NULL, _IONBF, 0);
    setvbuf(stdout, NULL, _IONBF, 0);

    puts("This is a big vulnerable example!");
    printf("I can print many things: %x, %s, %d\n", 0xdeadbeef, "Test String",
            42);
    write(1, "Writing to STDOUT\n", 18);
    vuln();
}
```

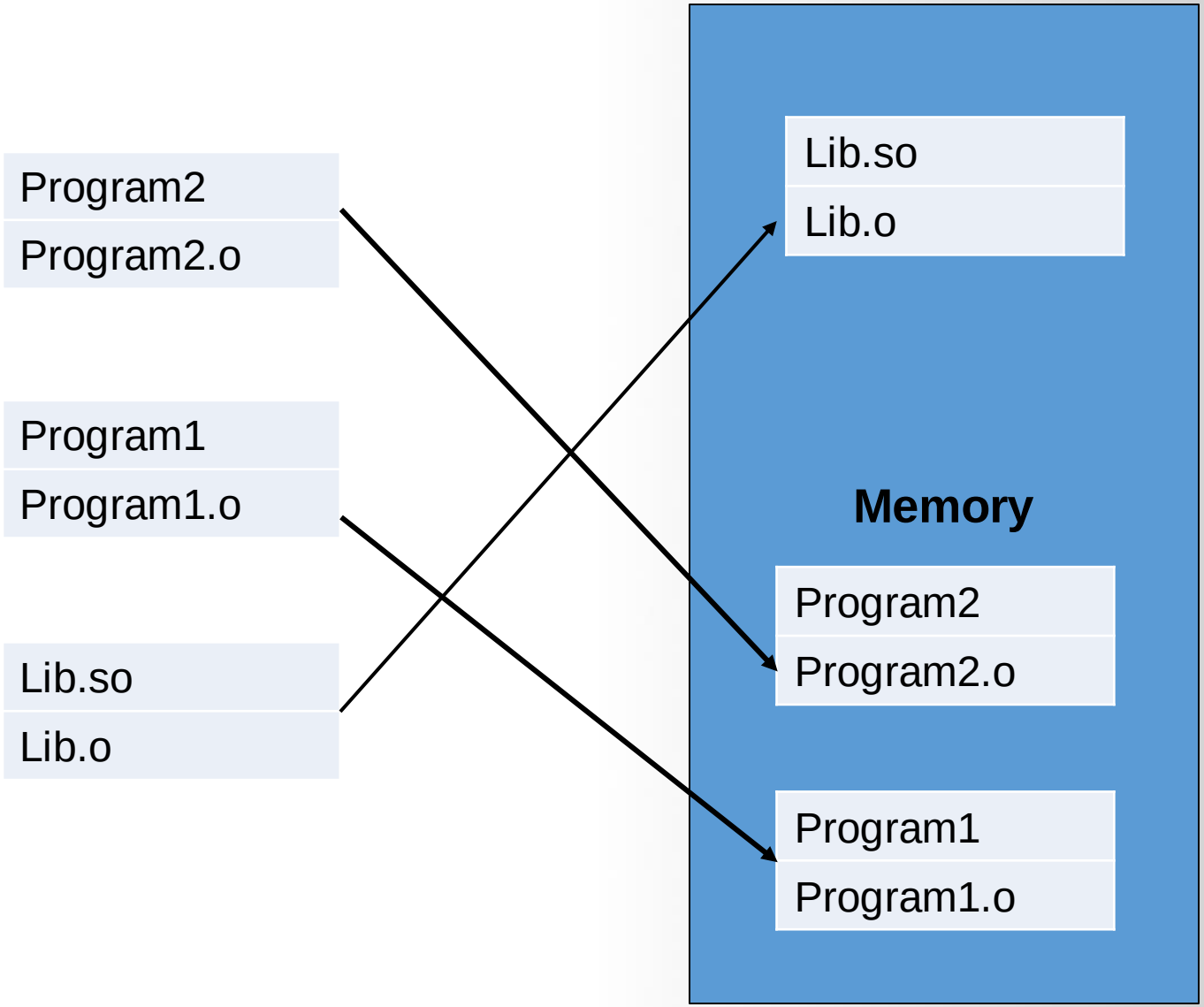
Since the binary is not big enough to give us a decent number of ROP gadgets, we will cheat a bit and compile the binary as a **statically linked ELF**.
This should include library code in the final executable and bulk up the size of the binary.

Drawbacks of Static Linking



Waste space
Hard to maintain

Dynamic Linking



Dynamic Linking in Linux and Windows

Linux	Windows	
ELF file	.exe (PE)	
.so (Shared object file)	**.dll (Dynamic Linking Library)**	
.a	.lib (static linking library)	
.o (intermediate file between complication and linking, object file)	.obj	

Shared library

```
[quake0day@quake0day-wcu Downloads]$ ldd ./a
        linux-gate.so.1 (0xb77c5000)
        libc.so.6 => /usr/lib/libc.so.6 (0xb75dd000)
        /lib/ld-linux.so.2 (0xb77c7000)
```

- ELF is loaded by **ld-linux.so.2** → in charge of memory mapping, load shared library etc..
- You can call functions in **libc.so.6**

Return Orientated Programming (ROP)

What happens if the **binary we have to attack is not large enough to provide us the gadgets we need**?

ret2libc Attack

Introduction

“Getting around non-executable stack (and fix)”, Solar Designer (BUGTRAQ, August 1997)

https://seclists.org/bugtraq/1997/Aug/63

The ret2libc and return oriented programming (ROP) technique relies on overwriting the stack to create a new stack frame that calls the system function.

ret2libc Attack

- We were able to pick from a wealth of ROP gadgets to construct the ROP chain in the previous section because the binary was huge.
- Now, what happens if the **binary we have to attack is not large enough to provide us the gadgets we need**?
- One possible solution, since ASLR is disabled, would be to search for our gadgets in the shared libraries loaded by the program such as **libc**.
- However, if we had these addresses into libc, **we could simplify our exploit to reuse useful functions**. One such useful function could be the system() function.

libc

- C standard library
- Provides functionality for string handling, mathematical computations, input/output processing, memory management, and several other operating system services
  - <stdio.h>
  - <stdlib.h>
  - <string.h>

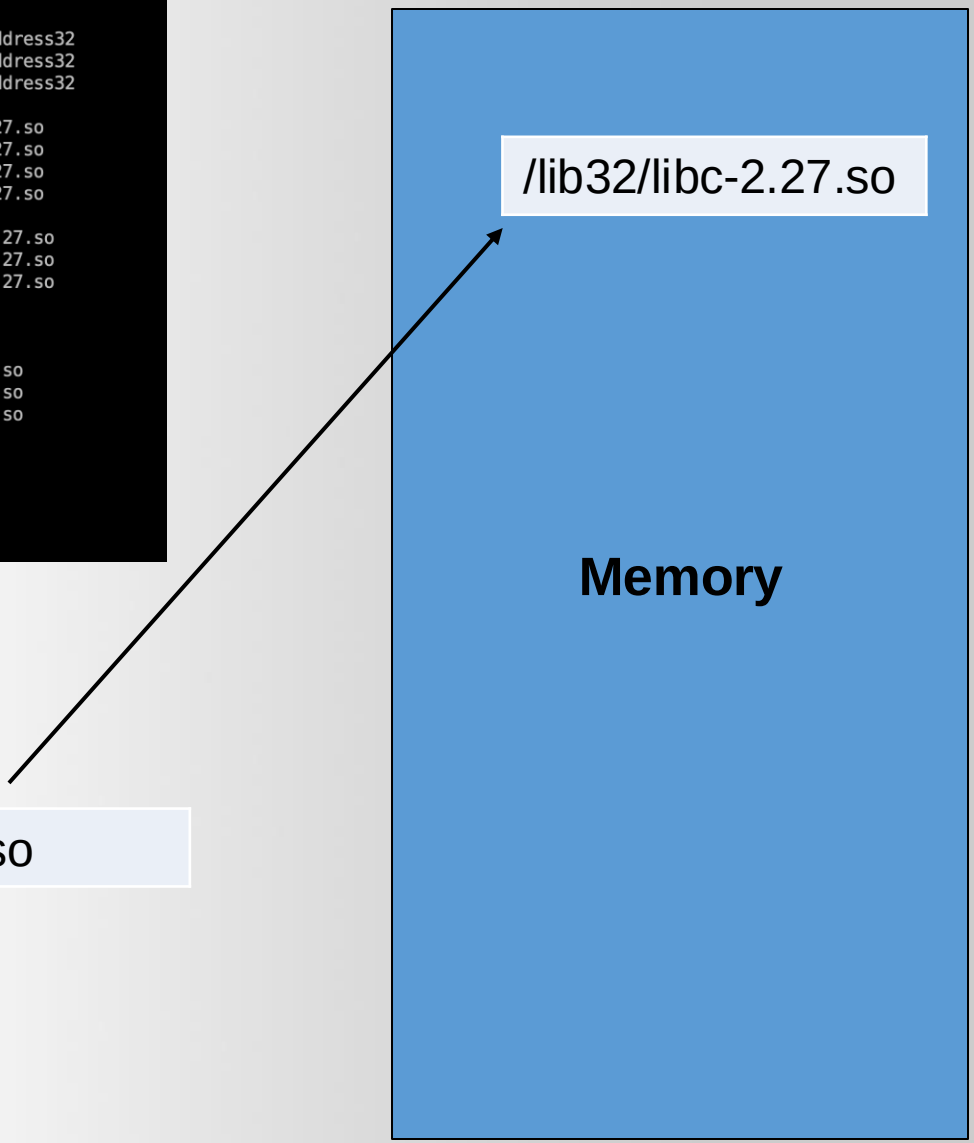
However, if we had these addresses into libc, **we could simplify our exploit to reuse useful functions**. One such useful function could be the system() function.
→ find System() function's address

reveal_address.c

```c
#define _GNU_SOURCE
#include <stdlib.h>
#include <stdio.h>
#include <dlfcn.h>
#include <unistd.h>


int main() {
    puts("This program helps visualise where libc is loaded.\n");
    int pid = getpid();
    char command[500];
    puts("Memory Layout: ");
    sprintf(command, "cat /proc/%d/maps", pid);
    system(command);
    puts("\nFunction Addresses: ");
    printf("System@libc 0x%lx\n", dlsym(RTLD_NEXT, "system"));
    printf("PID: %d\n", pid);
    puts("Press enter to continue.");
    read(0, command, 1);
}
```

reveal_adddress 32 bit version

```
➜  ~ ./reveal_address32
This program helps visualise where libc is loaded.

Memory Layout:
56555000-56556000 r-xp 00000000 08:00 42372                              /root/reveal_address32
56556000-56557000 r--p 00000000 08:00 42372                              /root/reveal_address32
56557000-56558000 rw-p 00001000 08:00 42372                              /root/reveal_address32
56558000-5657a000 rw-p 00000000 00:00 0                                  [heap]
f7de8000-f7fba000 r-xp 00000000 08:00 640006                             /lib32/libc-2.27.so
f7fba000-f7fbb000 ---p 001d2000 08:00 640006                             /lib32/libc-2.27.so
f7fbb000-f7fbd000 r--p 001d2000 08:00 640006                             /lib32/libc-2.27.so
f7fbd000-f7fbe000 rw-p 001d4000 08:00 640006                             /lib32/libc-2.27.so
f7fbe000-f7fc1000 rw-p 00000000 00:00 0
f7fc1000-f7fc4000 r-xp 00000000 08:00 640009                             /lib32/libdl-2.27.so
f7fc4000-f7fc5000 r--p 00002000 08:00 640009                             /lib32/libdl-2.27.so
f7fc5000-f7fc6000 rw-p 00003000 08:00 640009                             /lib32/libdl-2.27.so
f7fcf000-f7fd1000 rw-p 00000000 00:00 0
f7fd1000-f7fd4000 r--p 00000000 00:00 0                                  [vvar]
f7fd4000-f7fd6000 r-xp 00000000 00:00 0                                  [vdso]
f7fd6000-f7ffc000 r-xp 00000000 08:00 640002                             /lib32/ld-2.27.so
f7ffc000-f7ffd000 r--p 00025000 08:00 640002                             /lib32/ld-2.27.so
f7ffd000-f7ffe000 rw-p 00026000 08:00 640002                             /lib32/ld-2.27.so
fffdd000-ffffe000 rw-p 00000000 00:00 0                                  [stack]

Function Addresses:
System@libc 0xf7e24d10
PID: 27150
Press enter to continue.
```



/lib32/libc-2.27.so

reveal_adddress 64 bit version

```
➜  ~ ./reveal_address64
This program helps visualise where libc is loaded.

Memory Layout:
555555554000-555555555000 r-xp 00000000 08:00 42371                      /root/reveal_address64
555555754000-555555755000 r--p 00000000 08:00 42371                      /root/reveal_address64
555555755000-555555756000 rw-p 00001000 08:00 42371                      /root/reveal_address64
555555756000-555555777000 rw-p 00000000 00:00 0                          [heap]
7ffff77e0000-7ffff79c7000 r-xp 00000000 08:00 571                        /lib/x86_64-linux-gnu/libc-2.27.so
7ffff79c7000-7ffff7bc7000 ---p 001e7000 08:00 571                        /lib/x86_64-linux-gnu/libc-2.27.so
7ffff7bc7000-7ffff7bcb000 r--p 001e7000 08:00 571                        /lib/x86_64-linux-gnu/libc-2.27.so
7ffff7bcb000-7ffff7bcd000 rw-p 001eb000 08:00 571                        /lib/x86_64-linux-gnu/libc-2.27.so
7ffff7bcd000-7ffff7bd1000 rw-p 00000000 00:00 0
7ffff7bd1000-7ffff7bd4000 r-xp 00000000 08:00 588                        /lib/x86_64-linux-gnu/libdl-2.27.so
7ffff7bd4000-7ffff7dd3000 ---p 00003000 08:00 588                        /lib/x86_64-linux-gnu/libdl-2.27.so
7ffff7dd3000-7ffff7dd4000 r--p 00002000 08:00 588                        /lib/x86_64-linux-gnu/libdl-2.27.so
7ffff7dd4000-7ffff7dd5000 rw-p 00003000 08:00 588                        /lib/x86_64-linux-gnu/libdl-2.27.so
7ffff7dd5000-7ffff7dfc000 r-xp 00000000 08:00 547                        /lib/x86_64-linux-gnu/ld-2.27.so
7ffff7fe9000-7ffff7fee000 rw-p 00000000 00:00 0
7ffff7ff7000-7ffff7ffa000 r--p 00000000 00:00 0                          [vvar]
7ffff7ffa000-7ffff7ffc000 r-xp 00000000 00:00 0                          [vdso]
7ffff7ffc000-7ffff7ffd000 r--p 00027000 08:00 547                        /lib/x86_64-linux-gnu/ld-2.27.so
7ffff7ffd000-7ffff7ffe000 rw-p 00028000 08:00 547                        /lib/x86_64-linux-gnu/ld-2.27.so
7ffff7ffe000-7ffff7fff000 rw-p 00000000 00:00 0
7ffffffde000-7ffffffff000 rw-p 00000000 00:00 0                          [stack]
ffffffffff600000-ffffffffff601000 r-xp 00000000 00:00 0                  [vsyscall]

Function Addresses:
System@libc 0x7ffff782f440
PID: 27160
Press enter to continue.
```

/lib/x86_64-linux-gnu/libc-2.27.so

/lib/x86_64-linux-gnu/libc-2.27.so

Memory

Ret2lib Shellcode Structure

Function Address
Return Address (Old EIP)
Arguments

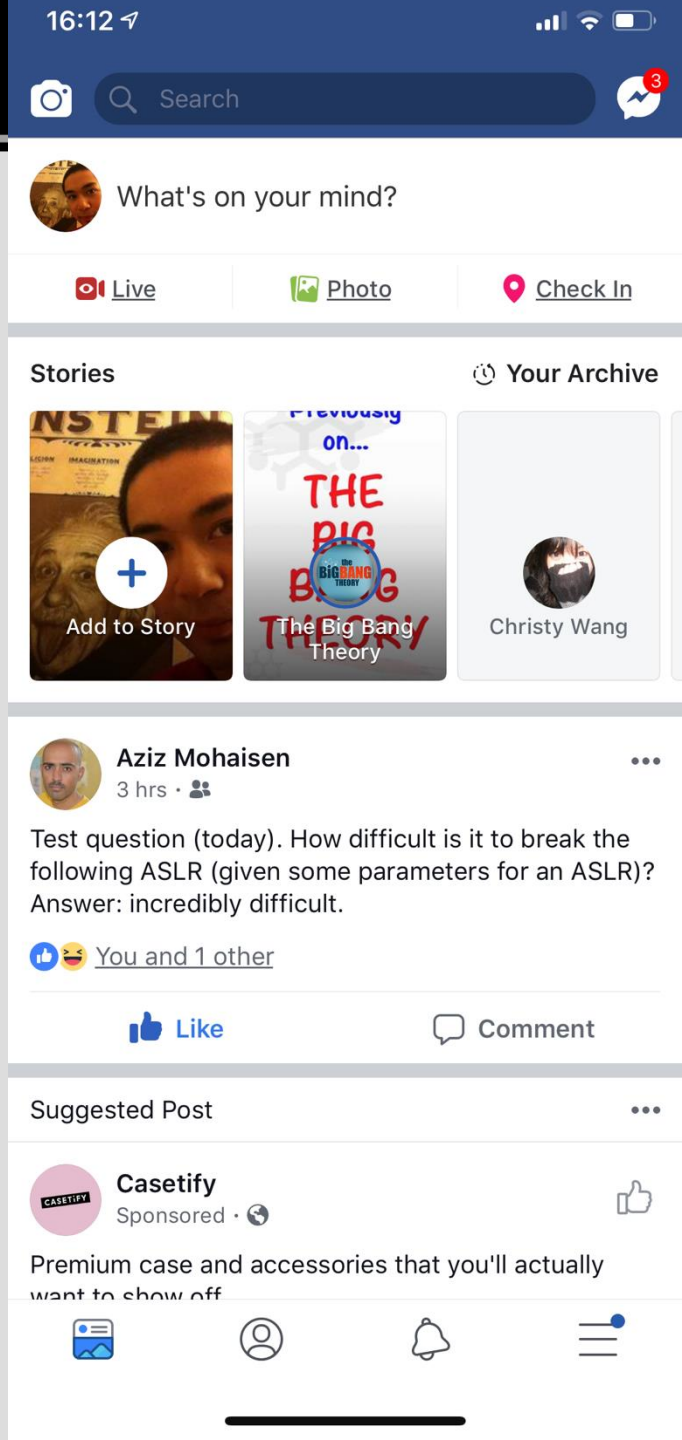
Dummy Characters
Address for System() in libc
Address for Exit() function in libc (if you want to exit the program gracefully)
Address for Command String (“e.g. /bin/sh”)

ret2lib.c

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

void vuln() {
    char buffer[64];
    read(0, buffer, 96);
}

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

Dummy Characters
Address for System() in libc
Address for Exit() function in libc (if you want to exit the program gracefully)
Address for Command String (“e.g. /bin/sh”)

ASLR in Depth (not really...)



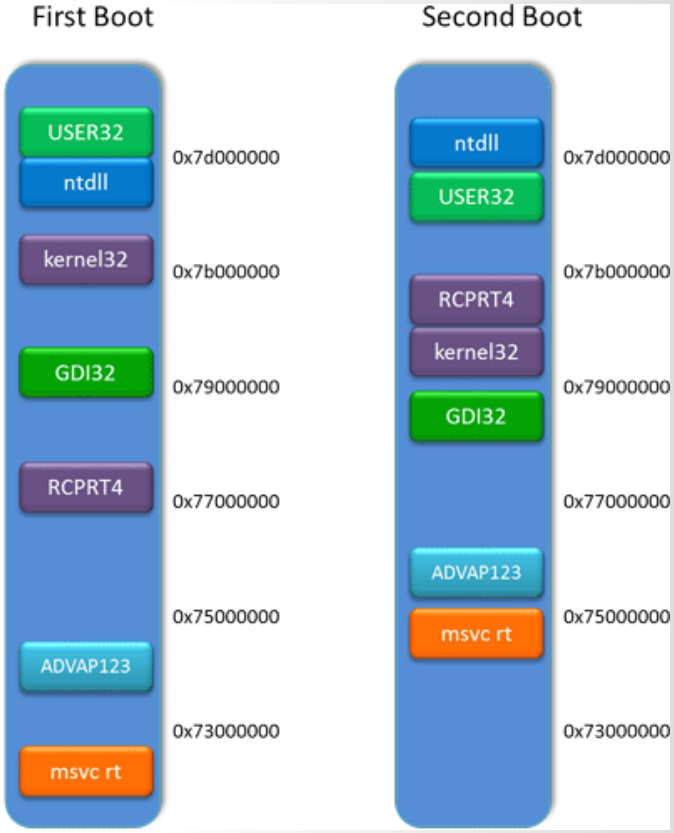
Shutdown ASLR

```
[quake0day-wcu quake0day]# echo 0 > /proc/sys/kernel/randomize_va_space
```

Shutdown ASLR (Address space layout randomization)

Address Space Layout Randomization (ASLR)

- Address Space Layout Randomization (ASLR) is a technology used to help prevent shellcode from being successful.
- It does this by randomly offsetting the location of modules and certain in-memory structures.



Glossary of Terms

- **ASLR (Address Space Layout Randomization):** Security measure in modern OSes to randomize stack and libc addresses on each program execution.
- **Binary:** A binary is the output file from compiling a C or C++ file. Anything in the binary has a *constant address.*
- **Canary:** A canary is some (usually random) value that is used to verify that nothing has been overrwritten. Programs may place canaries in memory, and check that they still have the exact same value after running potentially dangerous code, verifying the integrity of that memory.
- **NX (Non-Executable):** Security measure in modern OSes to separate processor instructions (code) and data (everything that's not code.) This prevents memory from being both executable and writable.
- **ROP (Return Oriented Programming):** Reusing tiny bits of code throughout the binary to construct commands we want to execute.
- **Stack:** The stack is part of the memory for a binary. Local variables and pointers are often stored here. The stack can be randomized.
- **libc:** A binary is *dynamically linked* and has a libc file. This means that the whole set of standard library functions are located somewhere in the memory used by the program.

Q & A