This time

We will begin our 1st section:
Software Security

By investigating
Buffer overflows
and other memory safety vulnerabilities

- History
- Memory layouts
- Buffer overflow fundamentals

Software security

- Security is a form of dependability
  - Does the code do “what it should”
  - To this end, we follow the software lifecycle

- Distinguishing factor: an *active, malicious* attacker

- Attack model
  - The developer is trusted
  - But the attacker can provide any inputs
    - Malformed strings
    - Malformed packets
    - etc.

What harm could an attacker possibly cause?

screensaver --prompt=“Don’t unlock plz”

Don't unlock plz

Locked by dml
press ctrl-c to logout

```
screensaver --prompt=“Don’t unlock pretty plz”
```

Don't unlock pretty
plz

Locked by dml
press ctrl-c to logout

```
screensaver --prompt=“Don’t unlock plz␠␠␠\
␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠”
```

Don't unlock plz

Locked by dml

press ctrl-c to logout

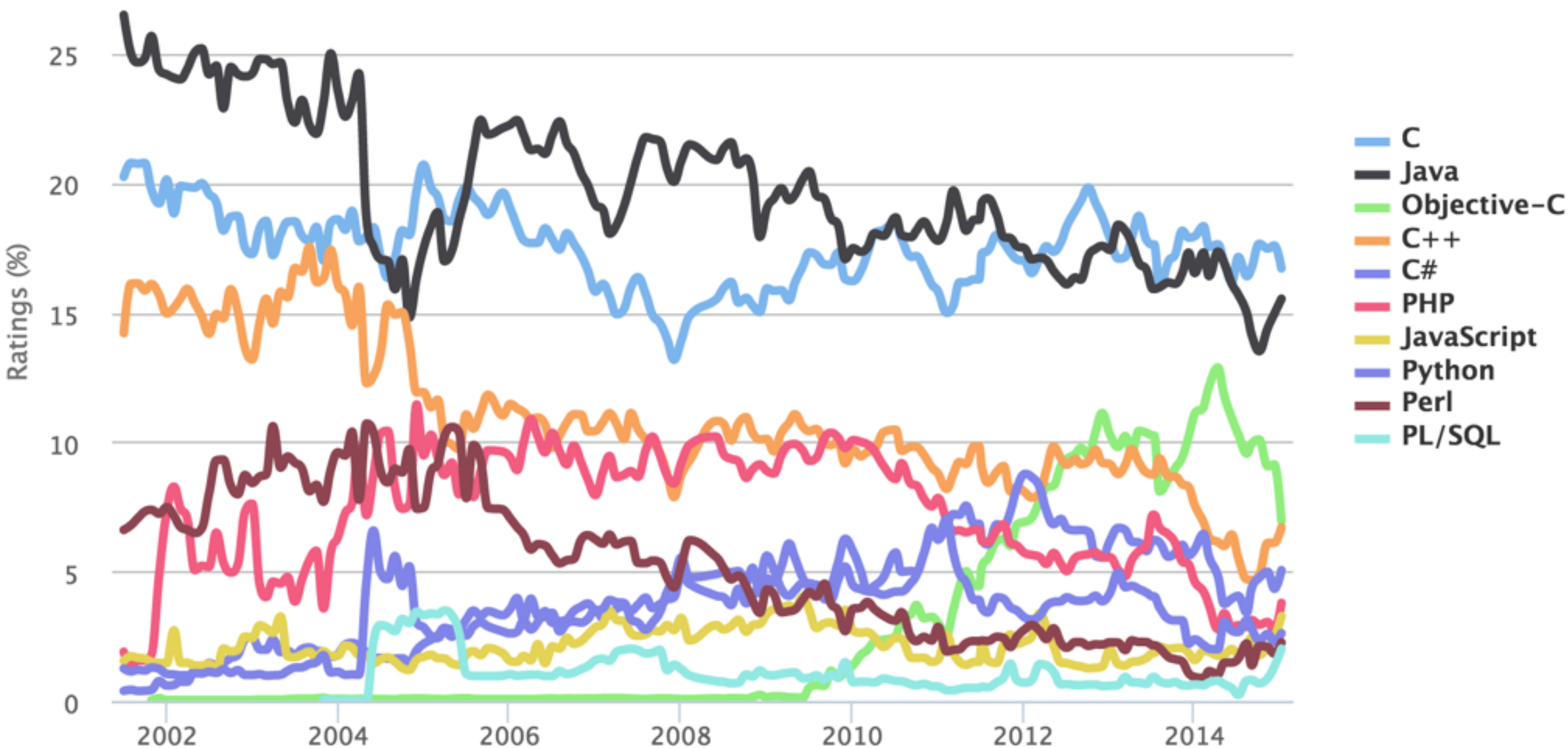
```
screensaver –prompt=“Under maintenance;\
Do not interrupt␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠\
␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠␠”
```

Under maintenance;
Do not interrupt

Locked by dml
press ctrl-c to logout

We're going to focus on C

C is still very popular



http://www.tiobe.com

We're going to focus on C

Many mission critical systems are written in C

- Most kernels & OS utilities
  - `fingerd`
  - X windows server
- Many high-performance servers
  - Microsoft IIS
  - Microsoft SQL server
- Many embedded systems
  - Mars rover
- But the techniques apply more broadly
  - Wiibrew: "Twilight Hack" exploits buffer overflow when saving the name of Link's horse, Epona

We're going to focus on C

The harm can be substantial

1988 1999 2000 2001 2002 2003

- Morris worm
  - Propagated across machines (too aggressively, thanks to a bug)
  - One way it propagated was a **buffer overflow attack** against a vulnerable version of `fingerd` on VAXes
    - Sent a special string to the finger daemon, which caused it to execute code that created a new worm copy
    - Didn't check OS: caused Suns running BSD to crash
  - End result: $10-100M in damages, probation, community service

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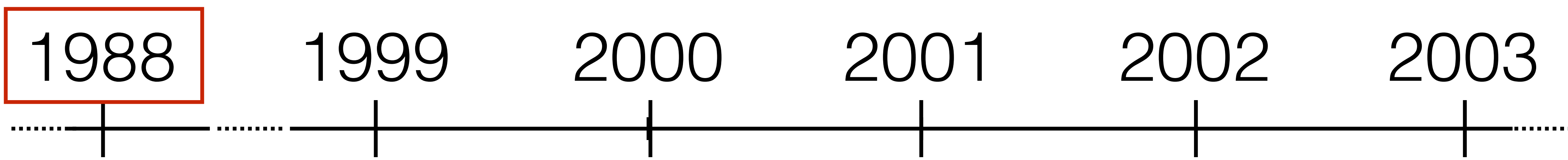

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Robert Morris is now a professor at MIT

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1988 1999 2000 $\boxed{2001}$ 2002 2003

- CodeRed
    - Exploited an overflow in the MS-IIS server
    - 300,000 machines infected in 14 hours

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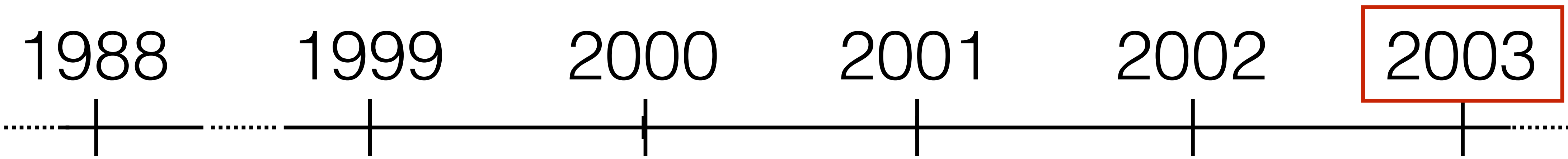

- SQL Slammer
  - Exploited an overflow in the MS-SQL server
  - 75,000 machines infected in 10 *minutes*

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23-Year-Old X11 Server Security Vulnerability Discovered

Posted by **Unknown Lamer** on Wednesday January 08, 2014 @10:11
from the stack-smashing-for-fun-and-profit dept.

An anonymous reader writes

> "The recent report of X11/X.Org security in bad shape rings more truth today. The X.Org Foundation announced today that they've found a X11 security issue that dates back to 1991. The issue is a possible stack buffer overflow that could lead to privilege escalation to root and affects all versions of the X Server back to X11R5. After the vulnerability being in the code-base for 23 years, it was finally uncovered via the automated cppcheck static analysis utility."

There's a `scanf` used when loading BDF fonts that can overflow using a carefully crafted font. Watch out for those obsolete early-90s bitmap fonts.

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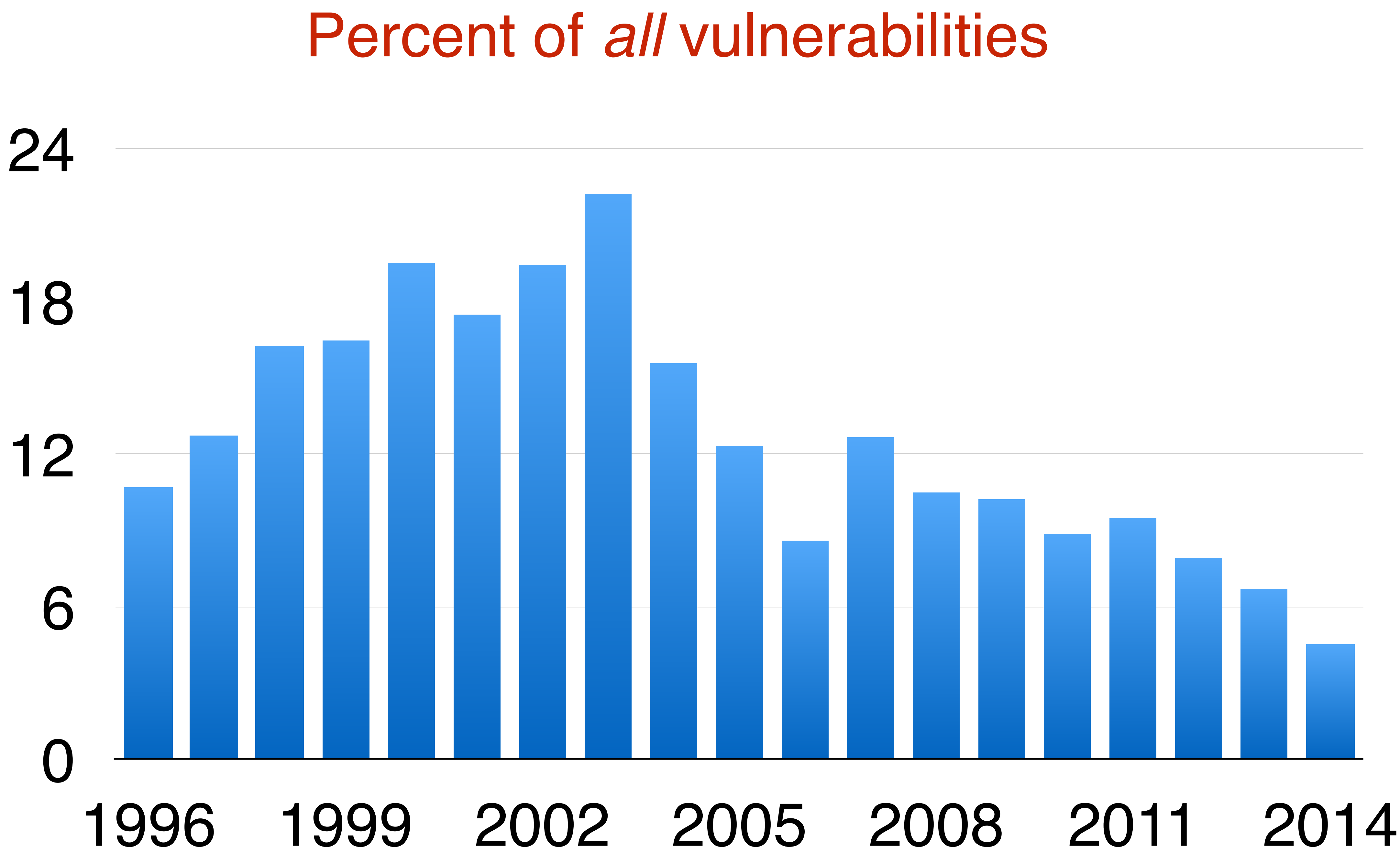
GHOST: glibc vulnerability introduced in 2000, only just announced two days ago

Buffer overflows are prevalent



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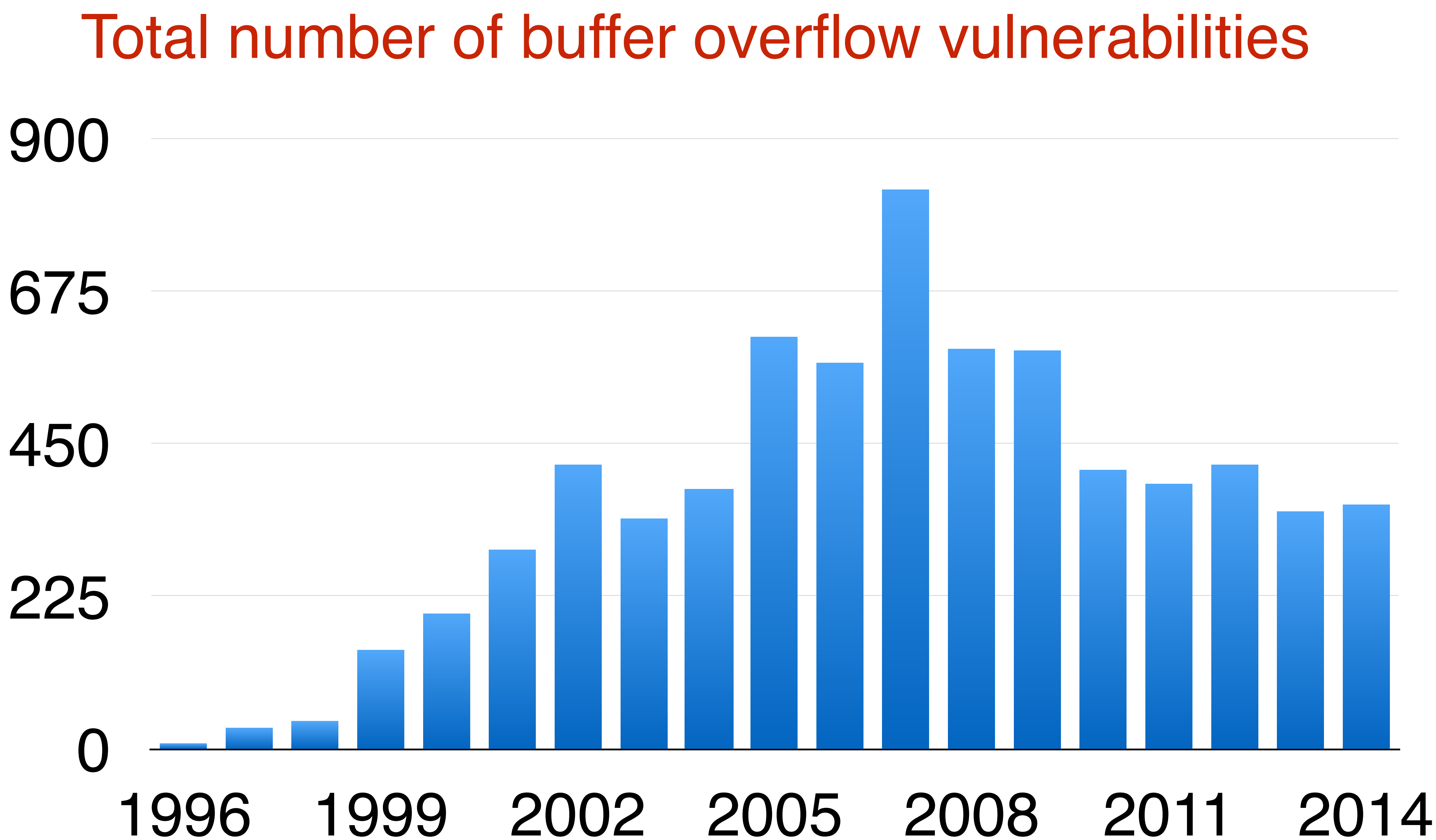

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Brief Listing of the Top 25

This is a brief listing of the Top 25 items, using the general ranking.

NOTE: 16 other weaknesses were considered for inclusion in the Top 25, but their general scores were not high enough. They are listed in a separate "On the Cusp" page.

Rank	Score	ID	Name
[1]	93.8	CWE-89	Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection')
[2]	83.3	CWE-78	Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection')
[3]	79.0	CWE-120	Buffer Copy without Checking Size of Input ('Classic Buffer Overflow')
[4]	77.7	CWE-79	Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting')
[5]	76.9	CWE-306	Missing Authentication for Critical Function
[6]	76.8	CWE-862	Missing Authorization
[7]	75.0	CWE-798	Use of Hard-coded Credentials
[8]	75.0	CWE-311	Missing Encryption of Sensitive Data
[9]	74.0	CWE-434	Unrestricted Upload of File with Dangerous Type
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Our goals

- Understand how these attacks work, and how to defend against them
- These require knowledge about:
  - The compiler
  - The OS
  - The architecture

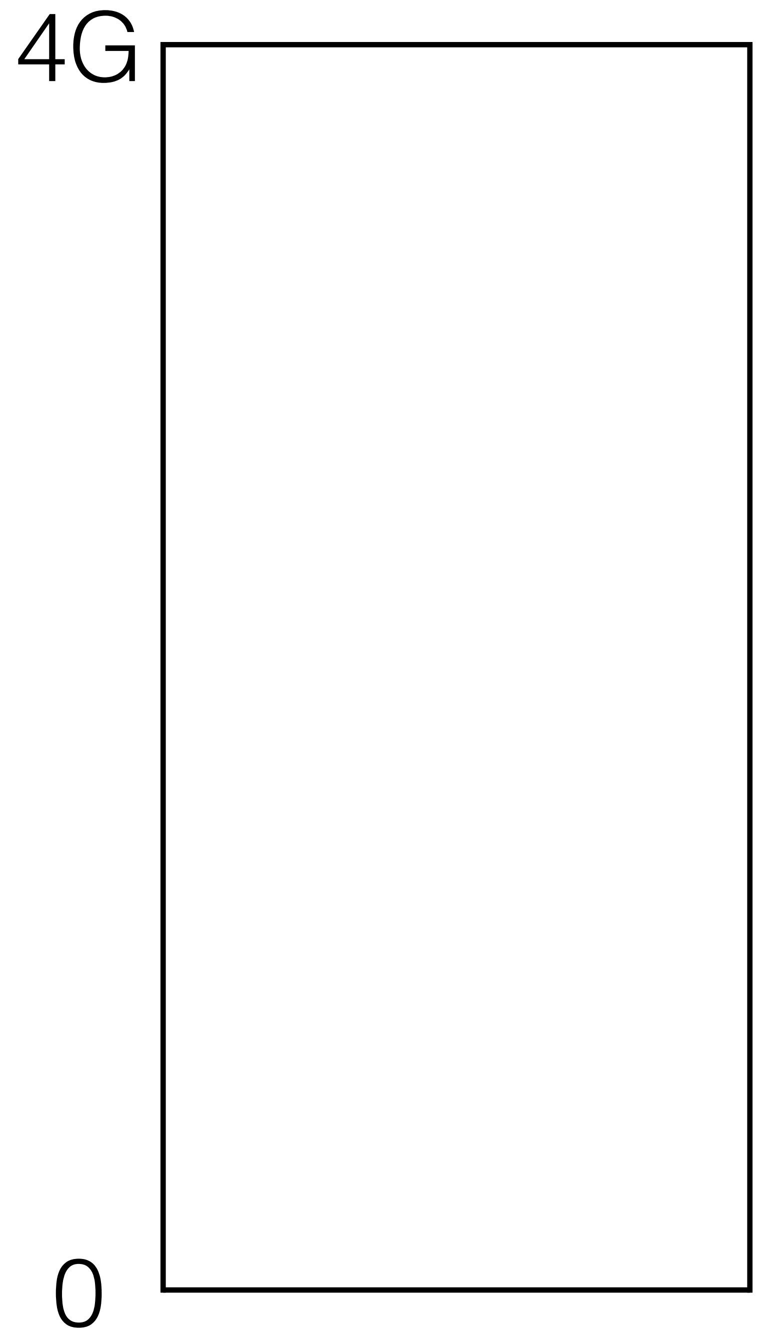
Analyzing security requires a whole-systems view

Memory layout

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

All programs are stored in memory



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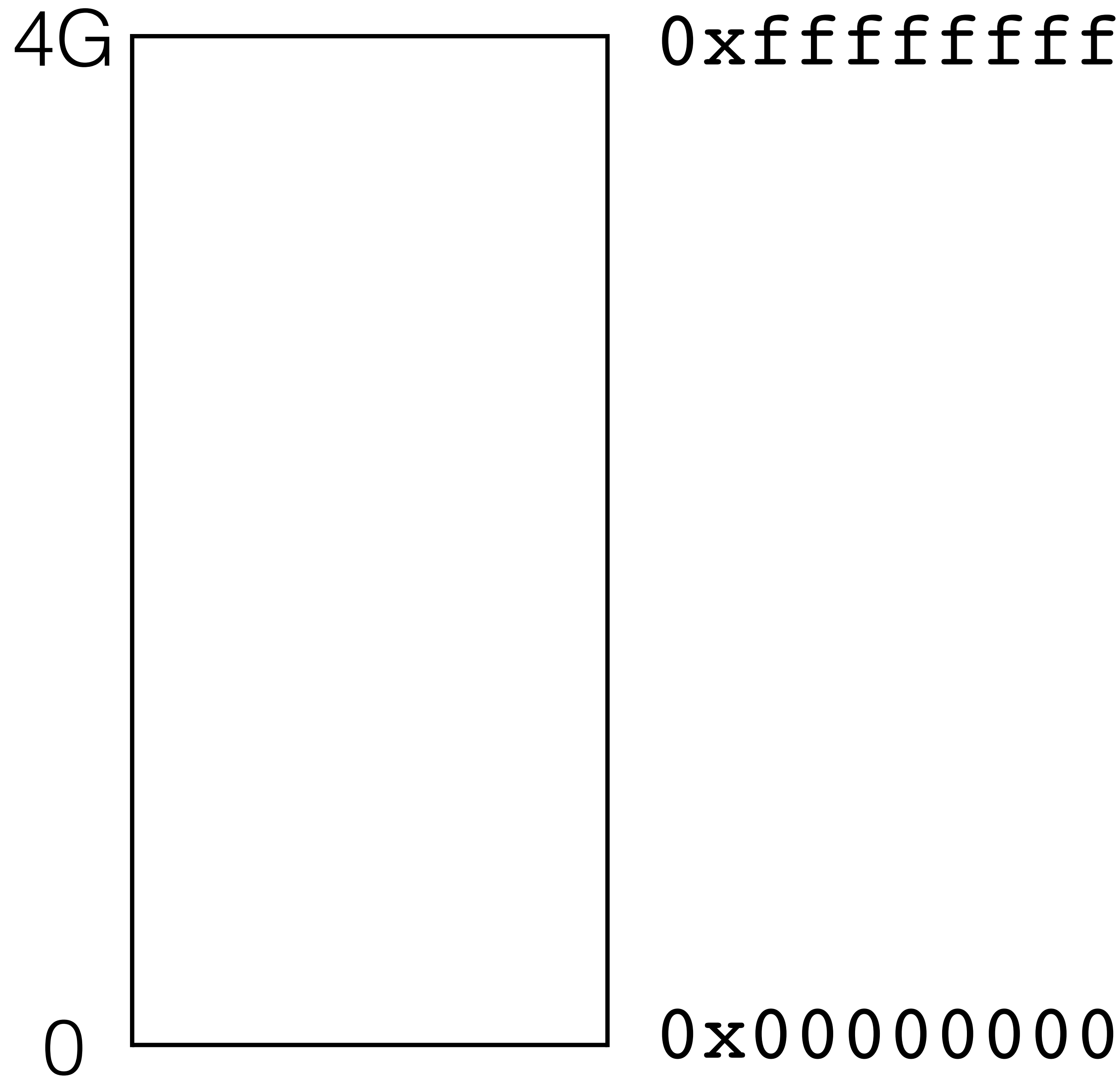

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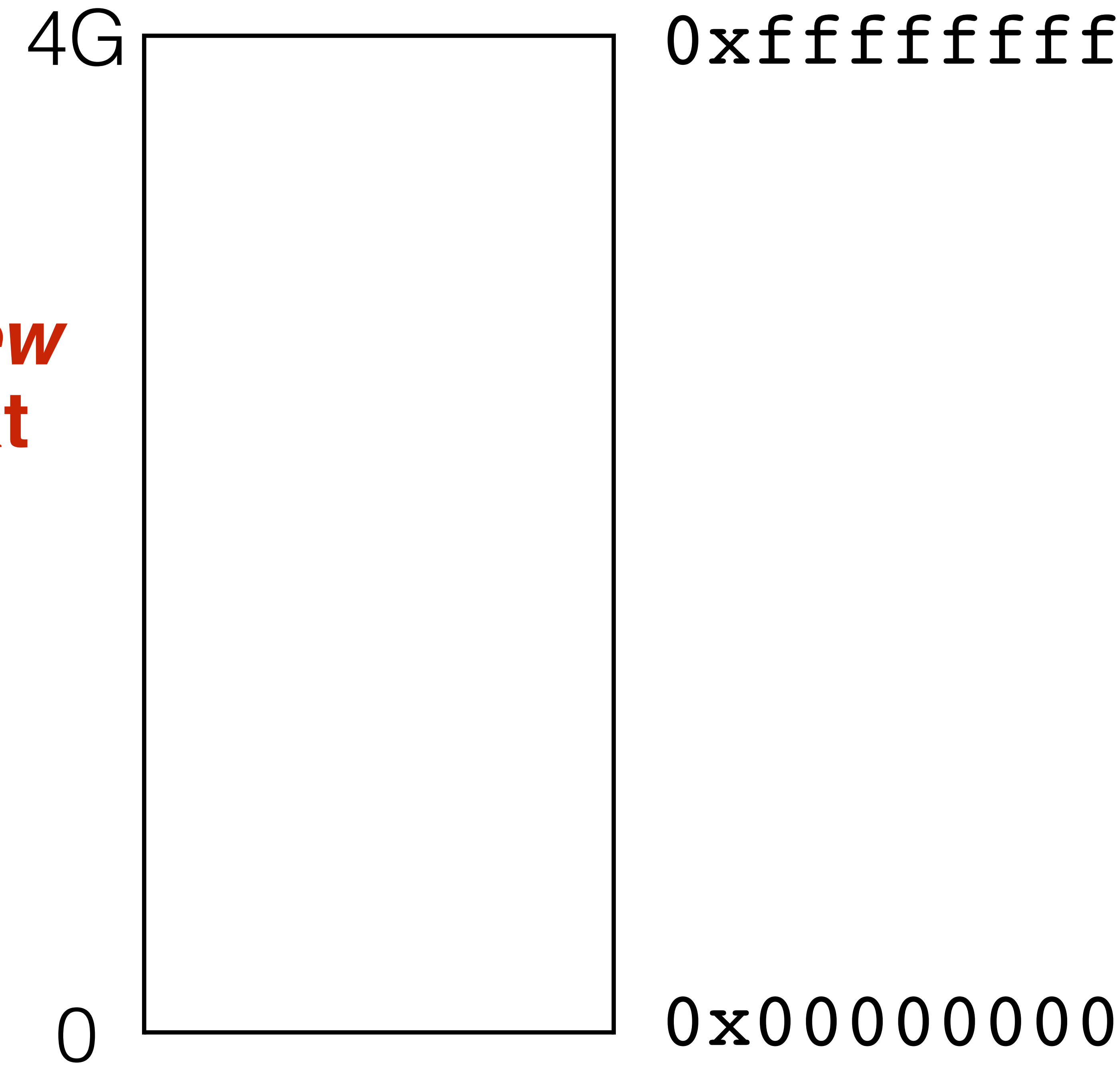
The *process's view* of memory is that it owns all of it



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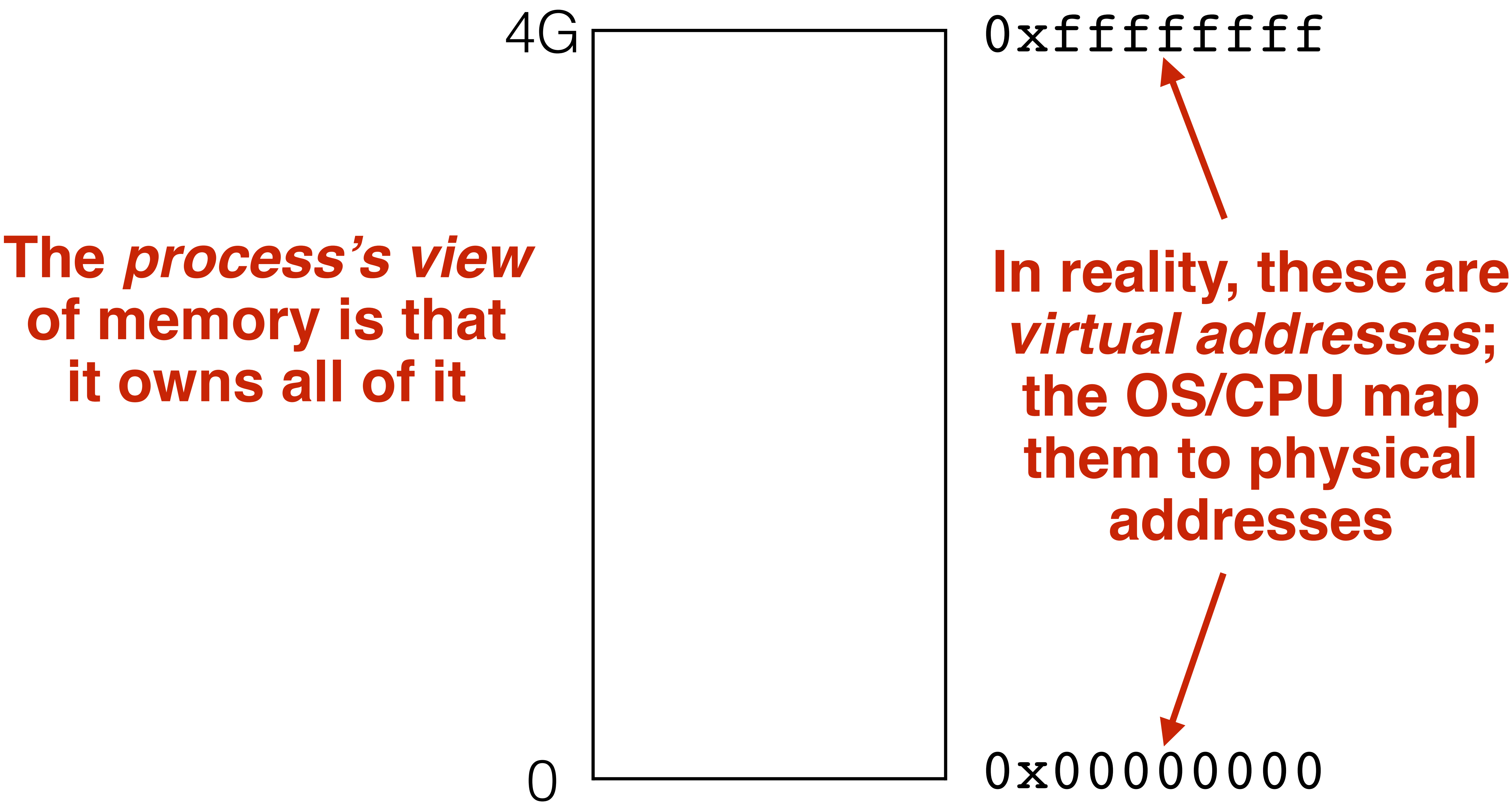

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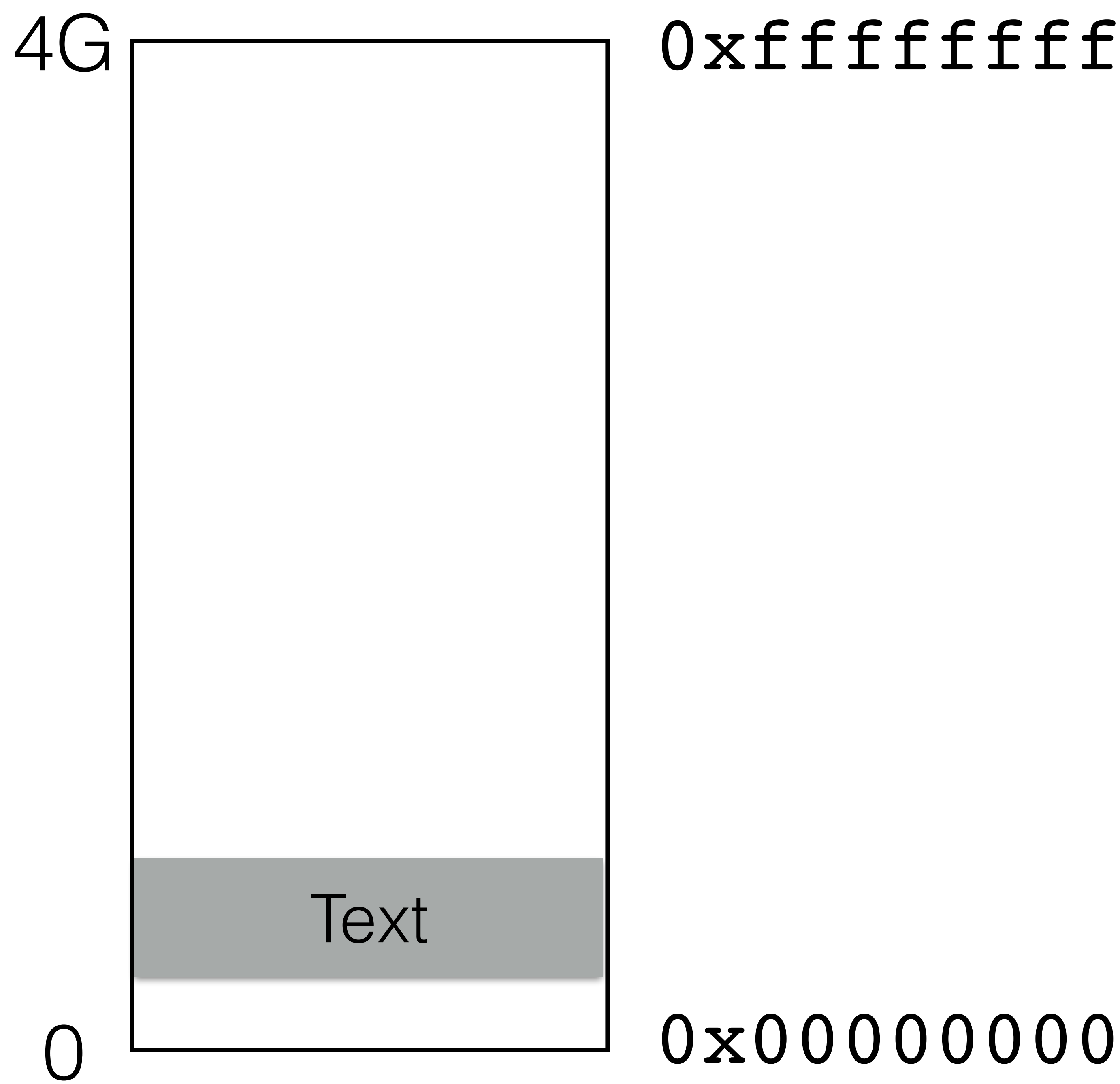

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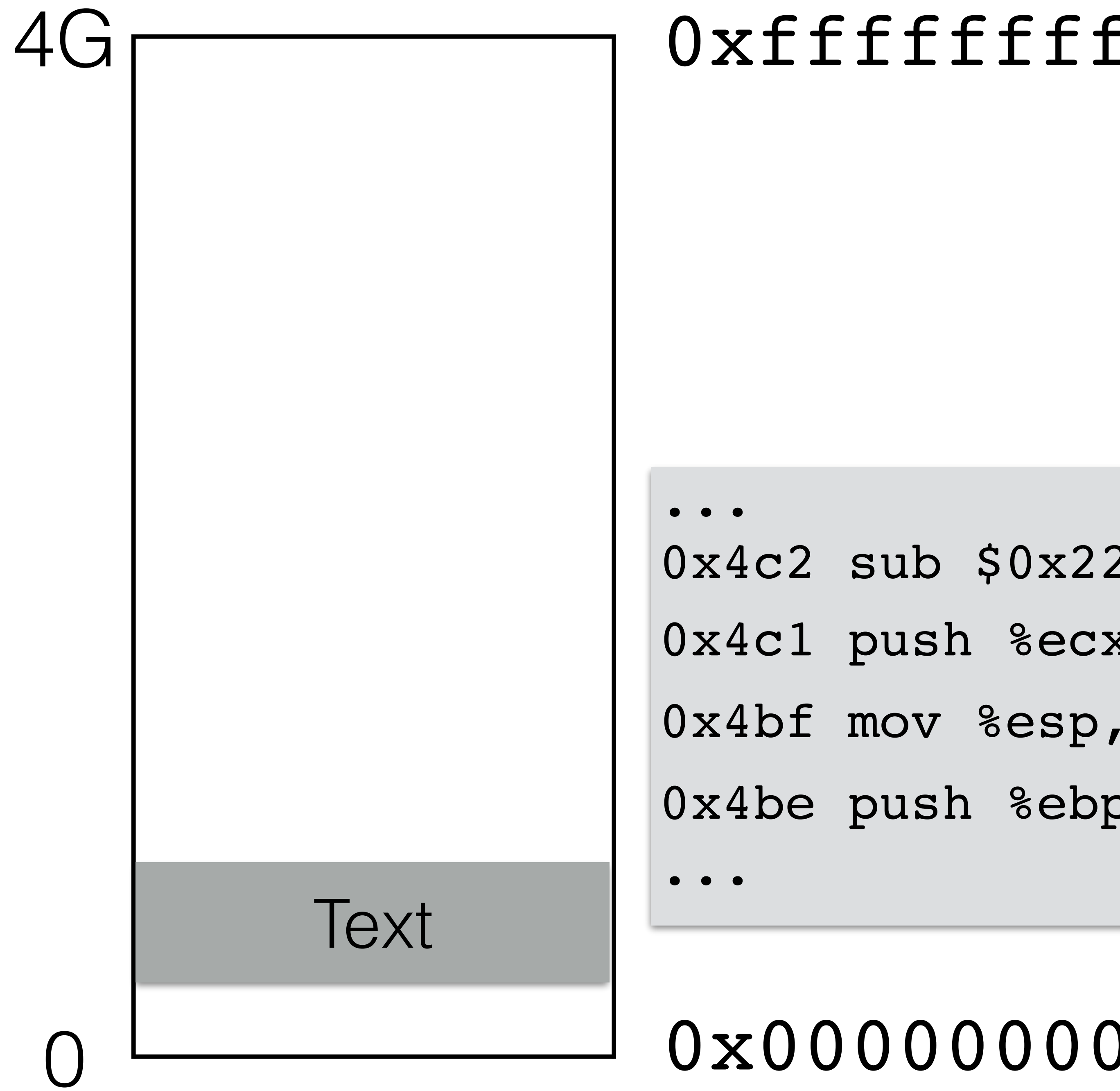
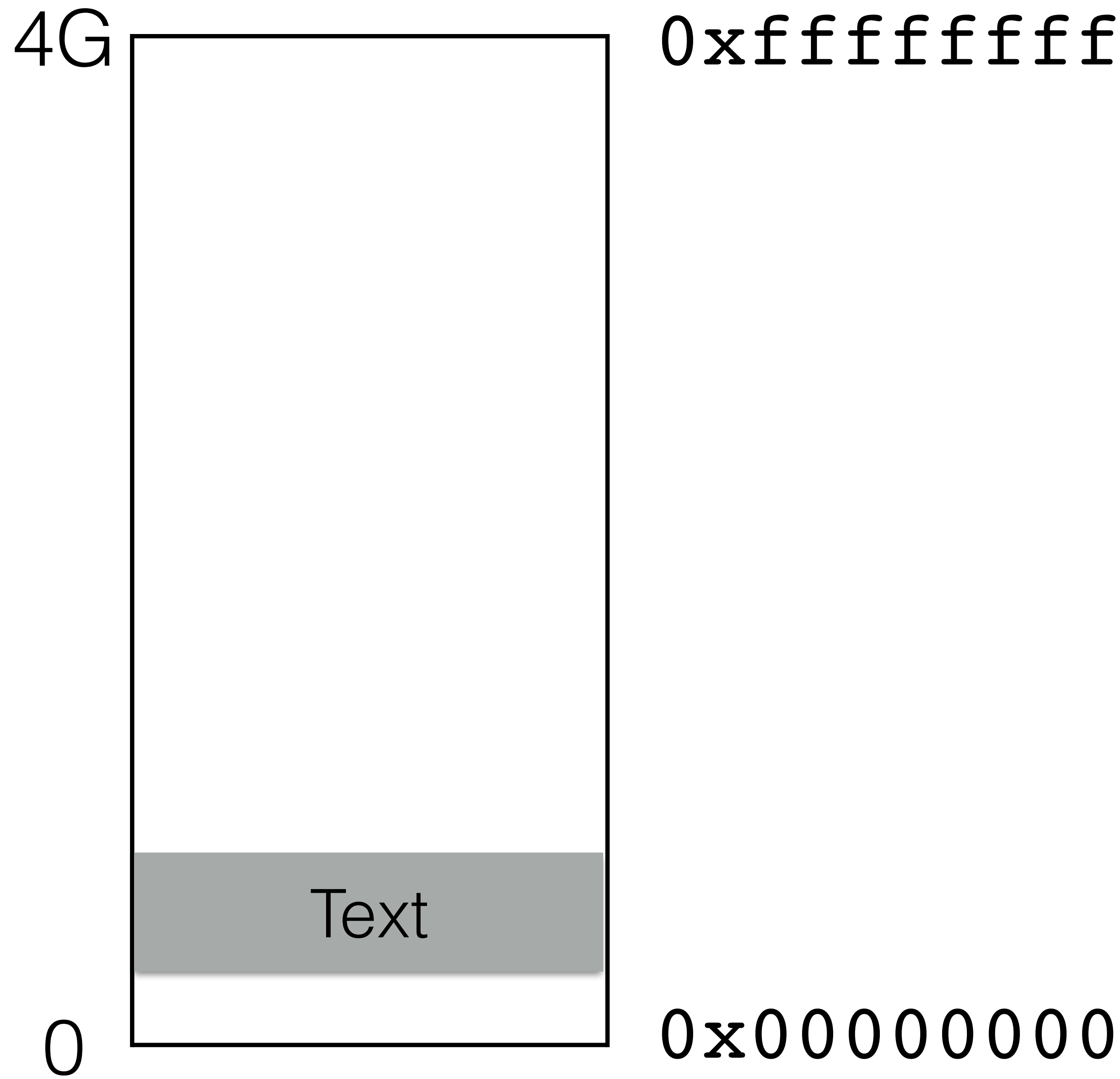



```
...
0x4c2 sub $0x224,%esp
0x4c1 push %ecx
0x4bf mov %esp,%ebp
0x4be push %ebp
...
```

Data's location depends on how it's created



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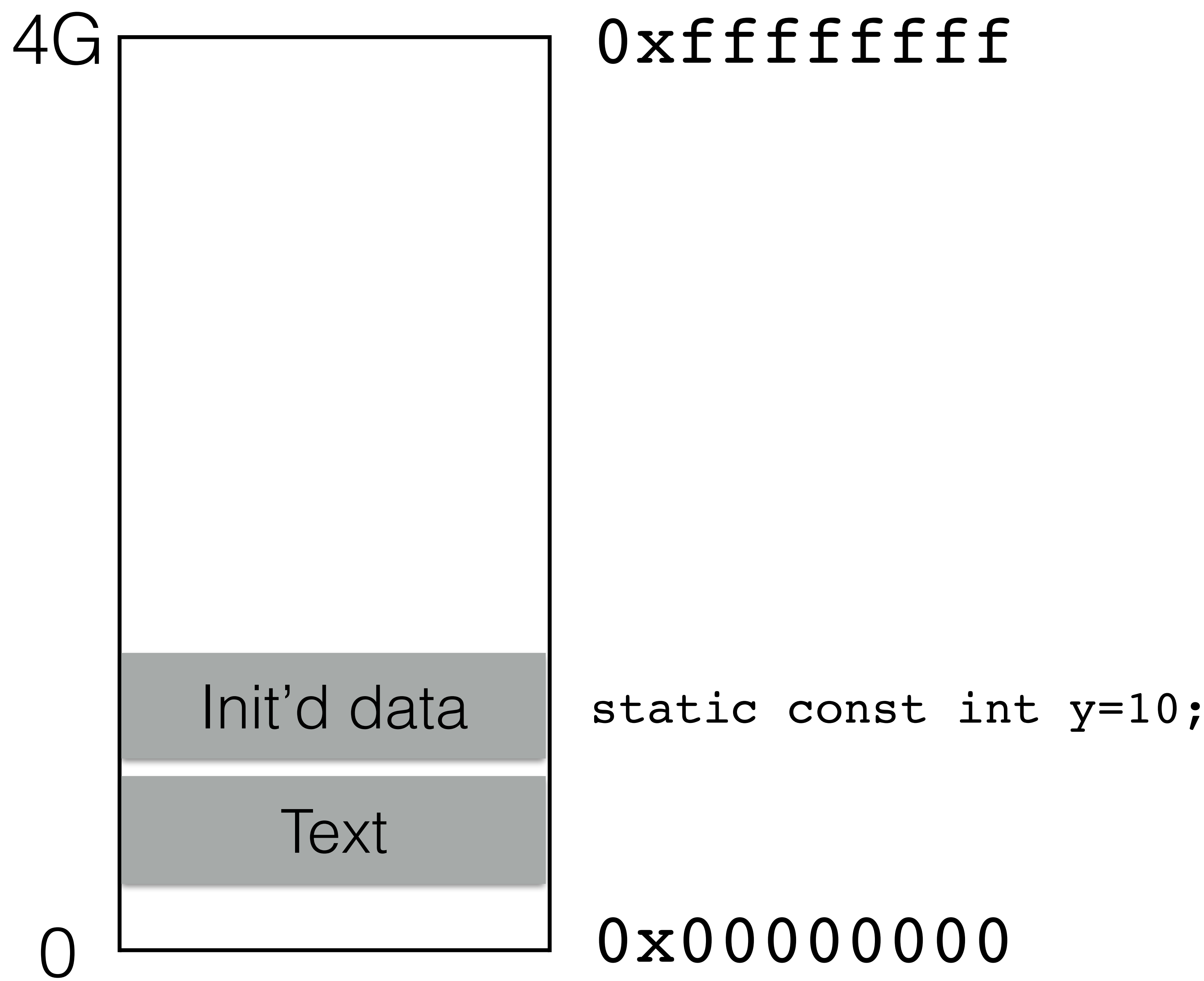

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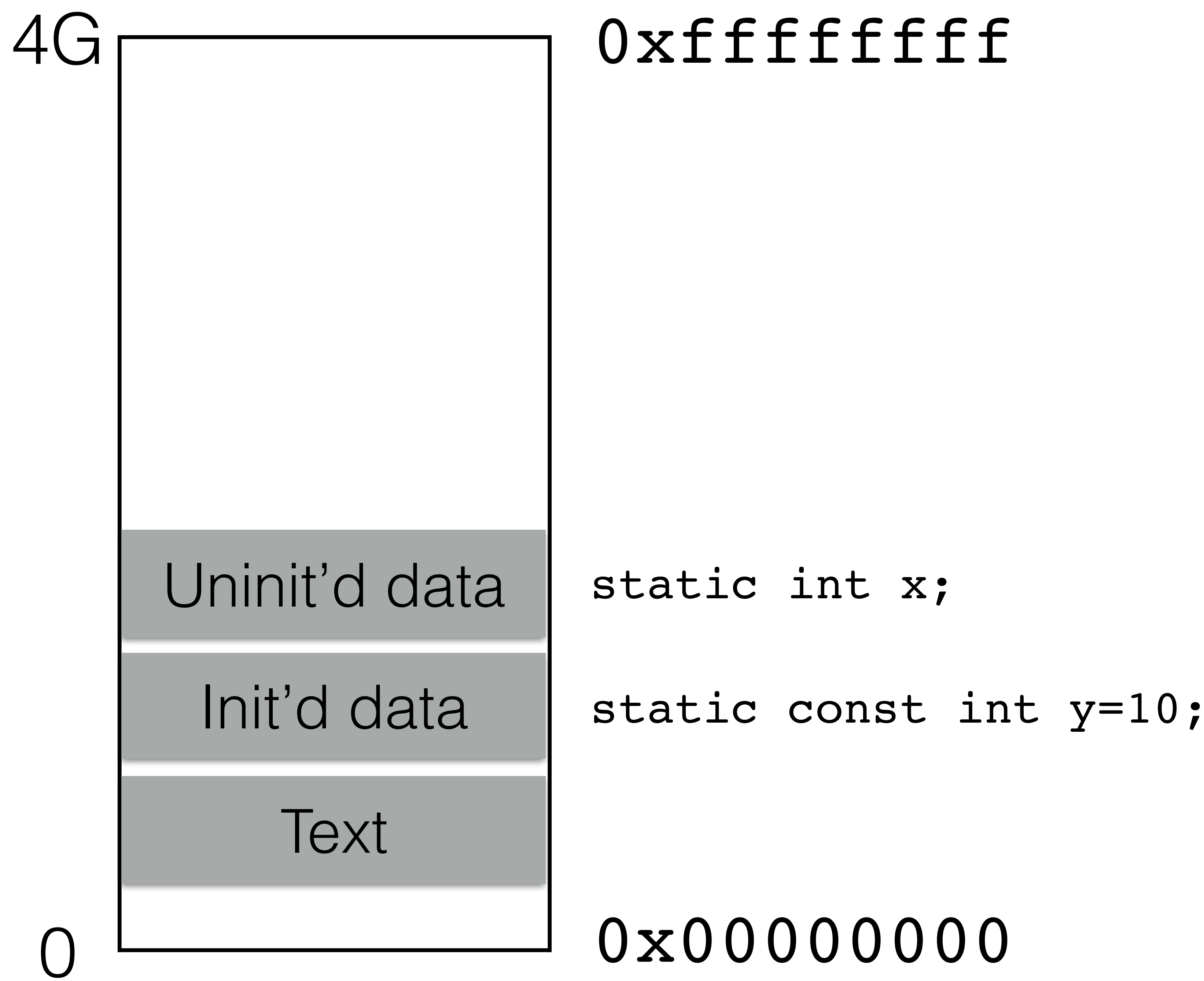

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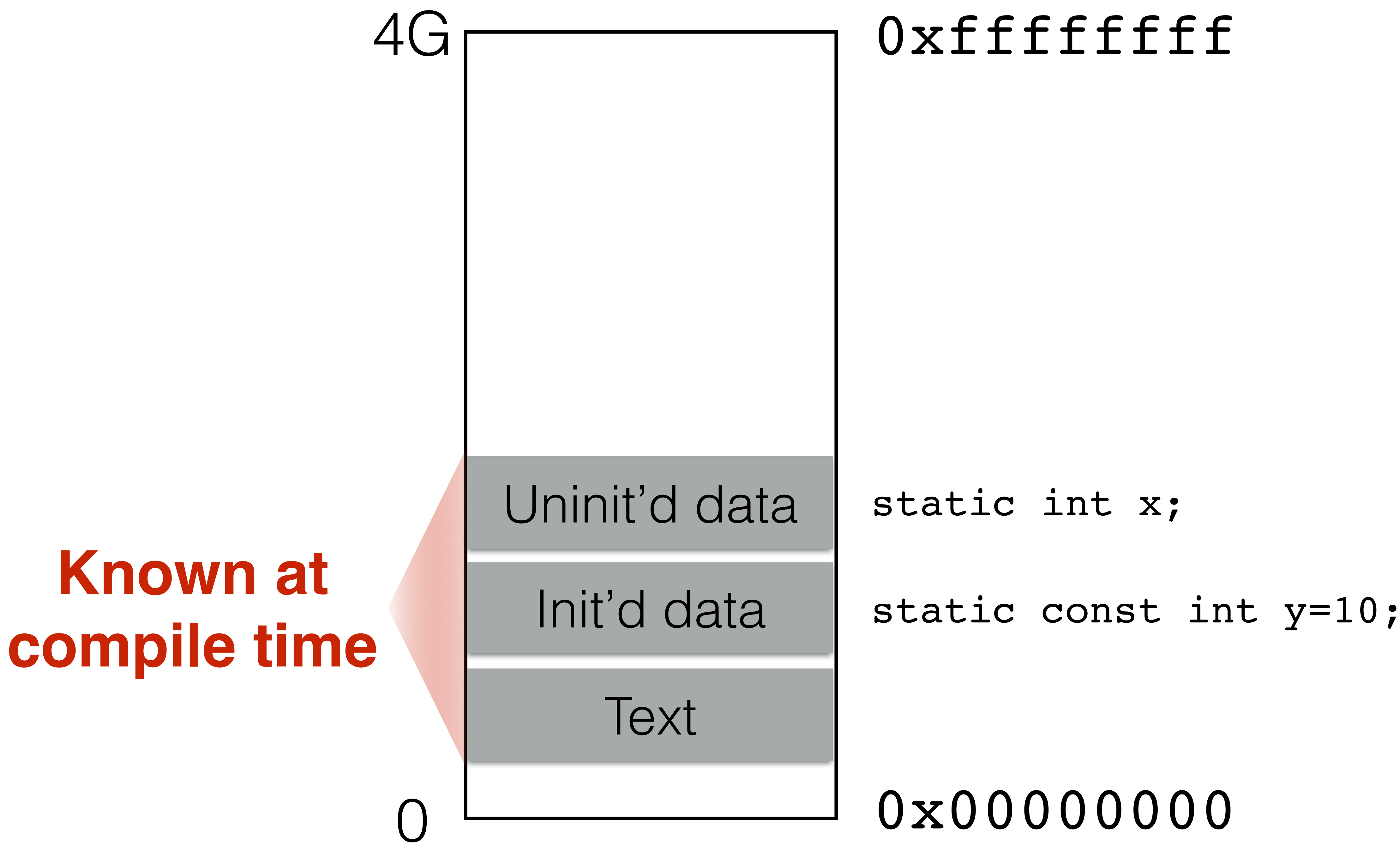

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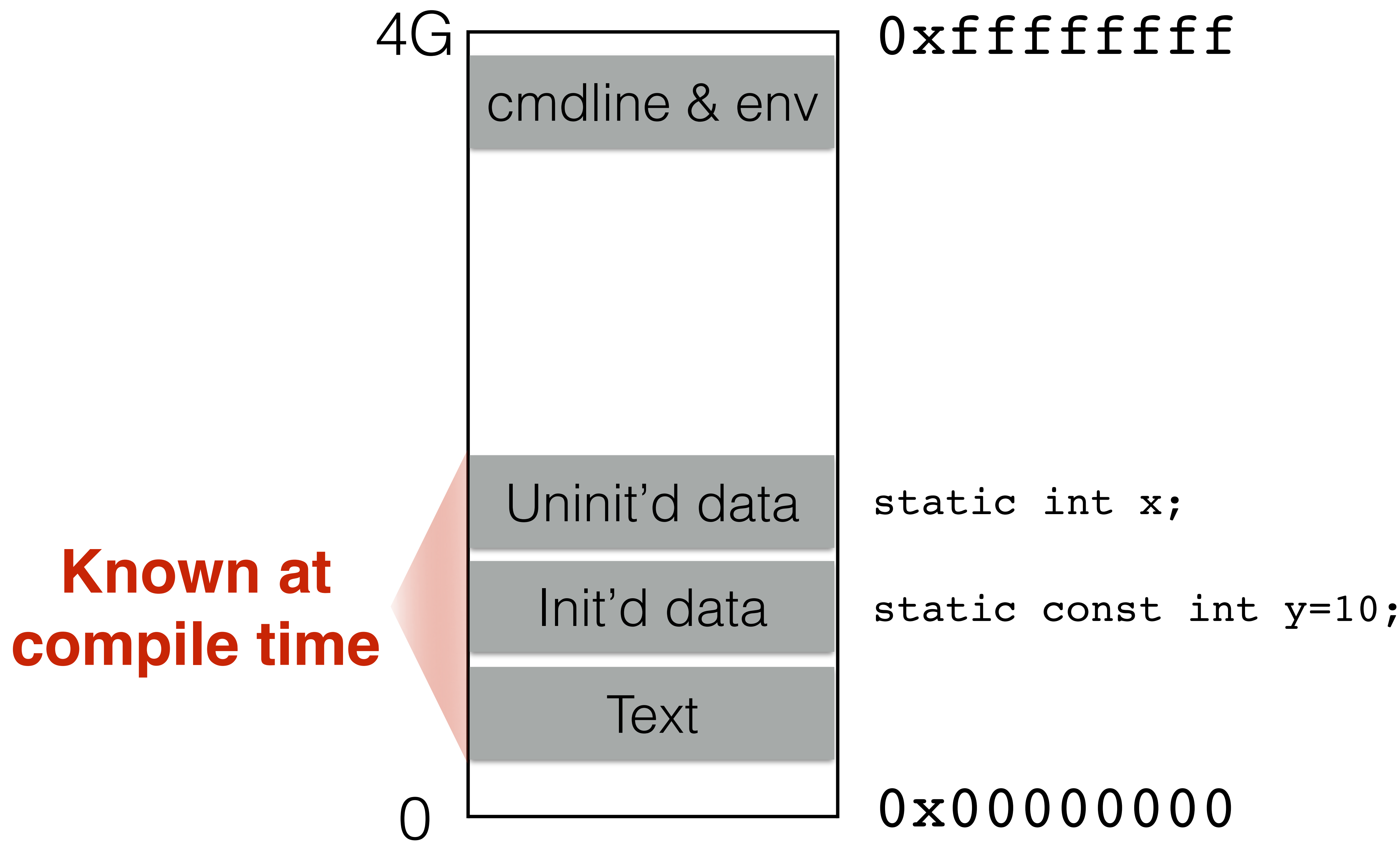

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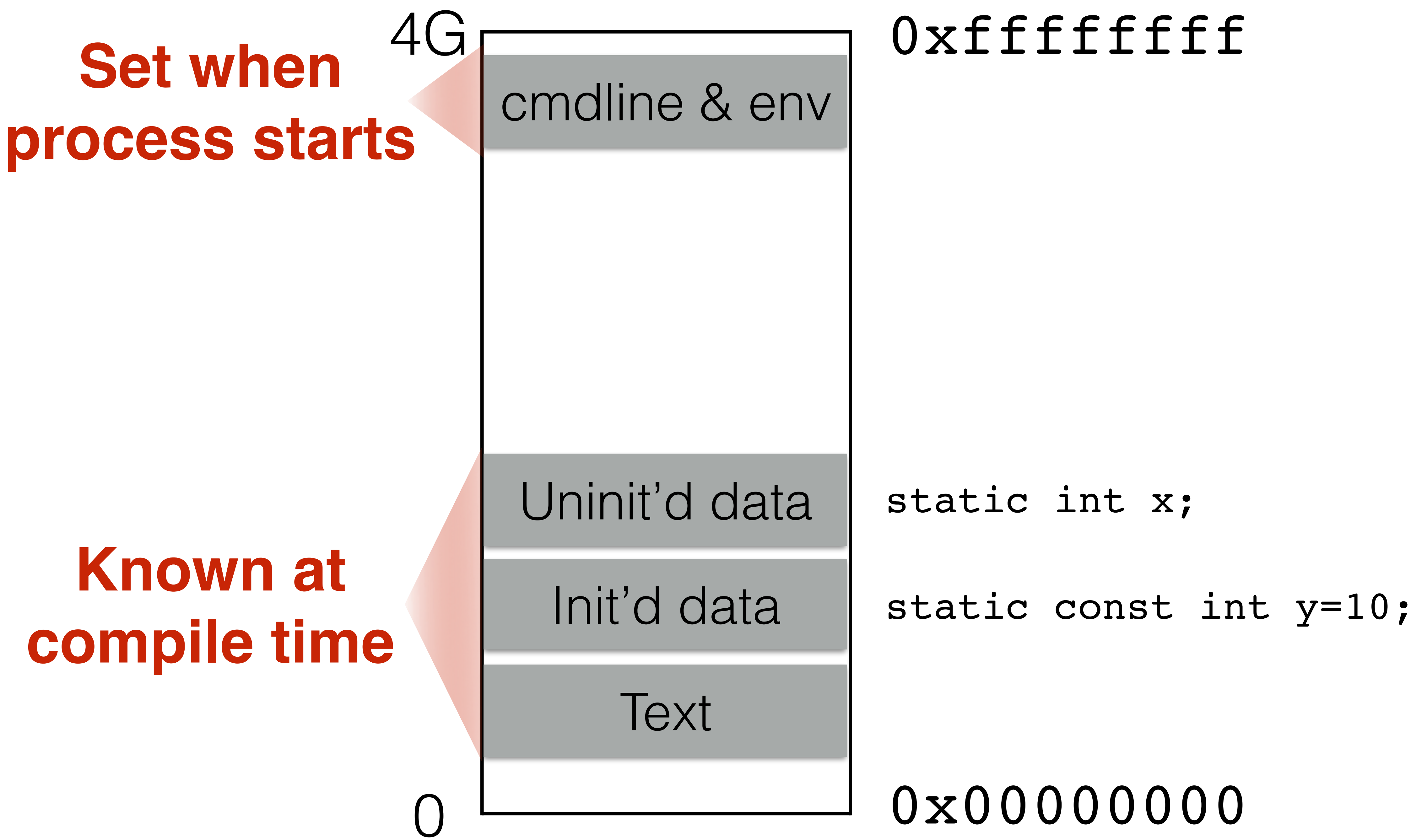

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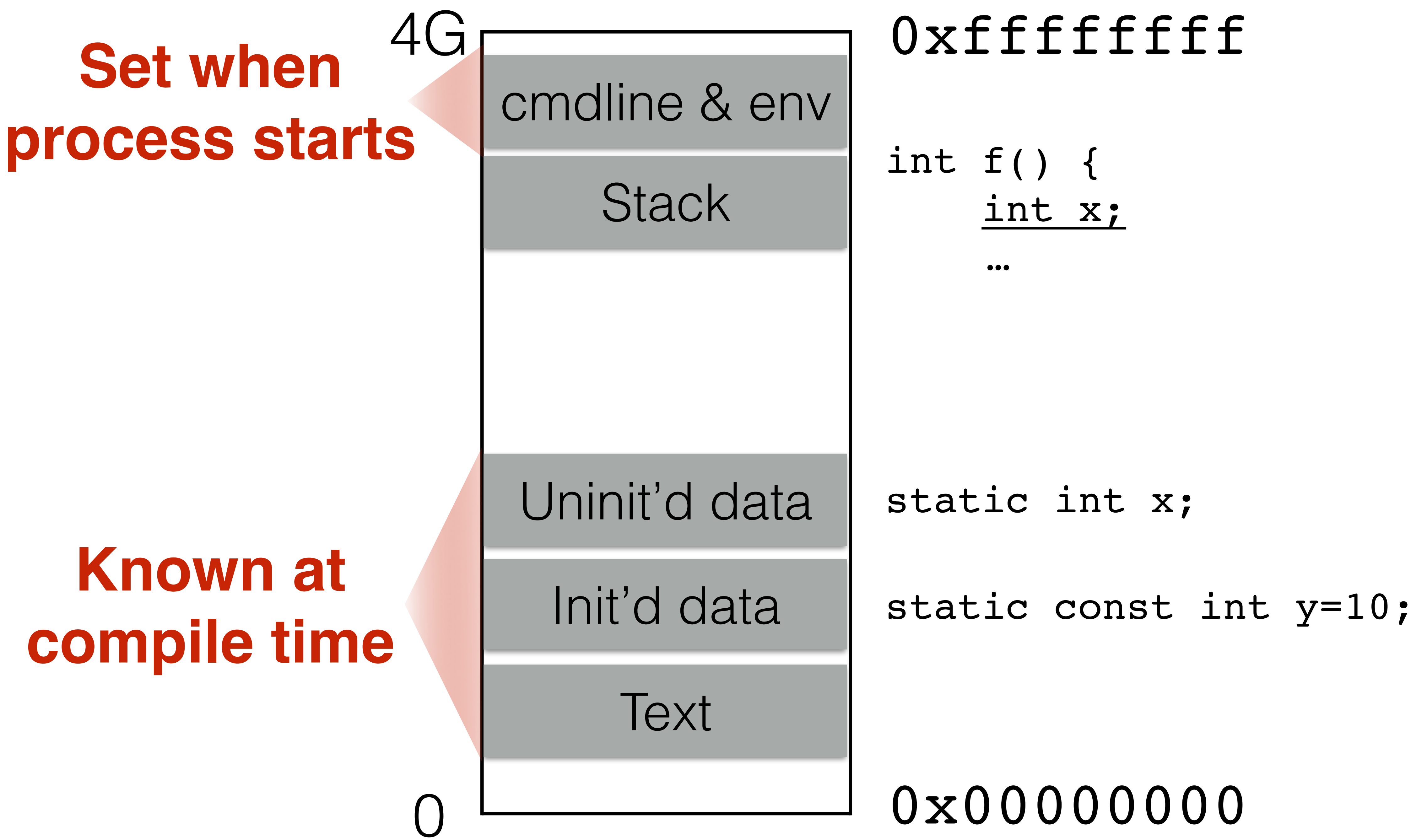

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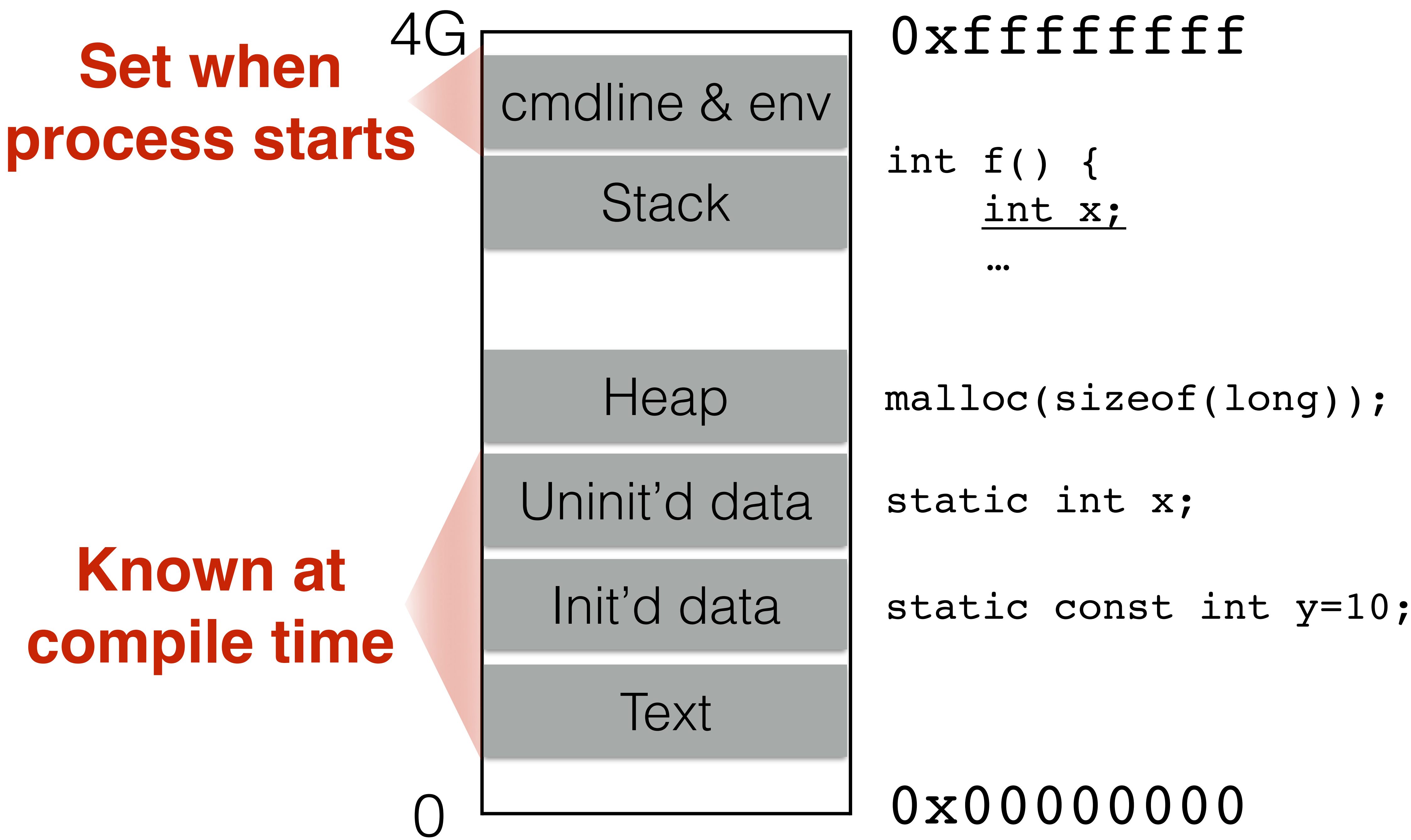

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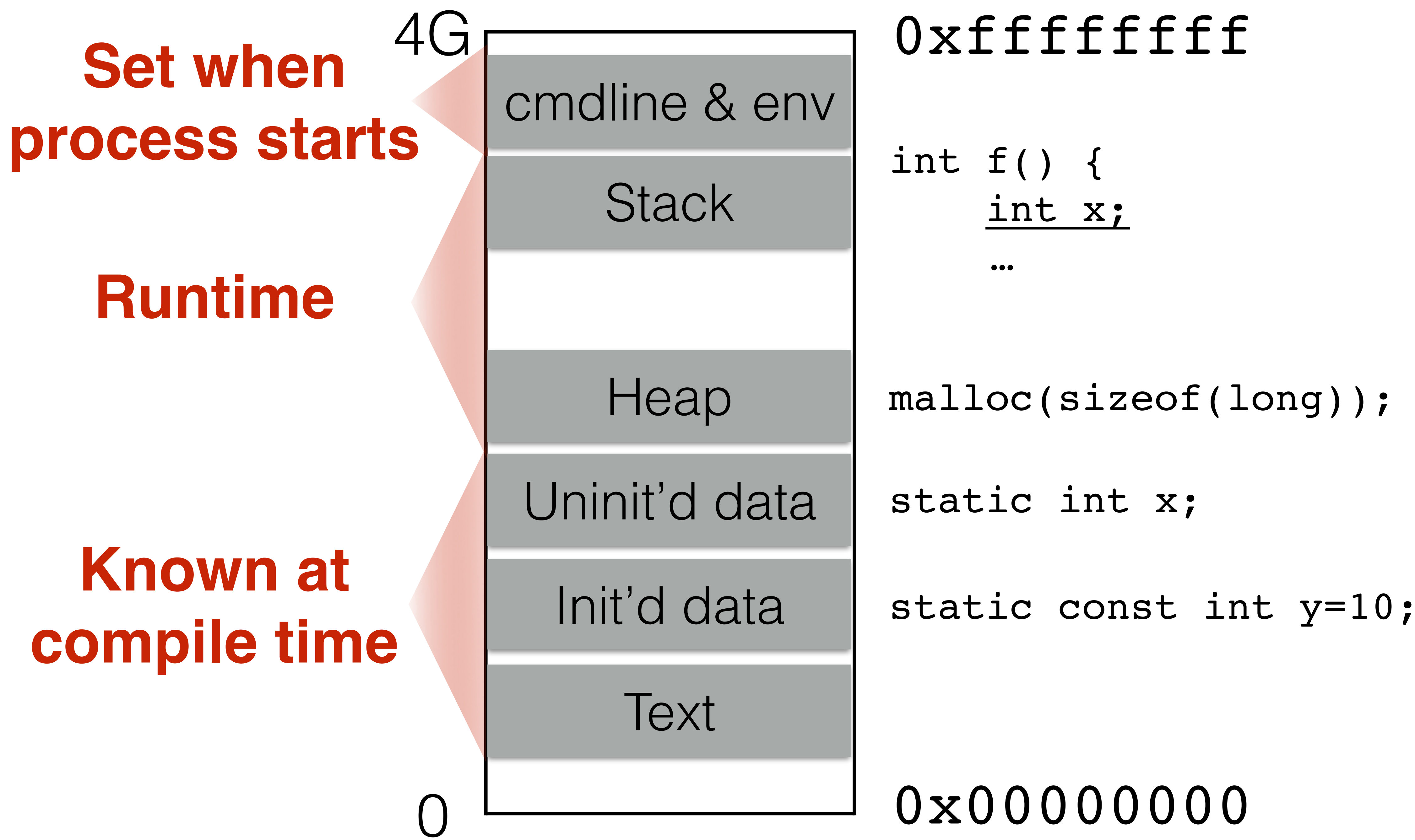

We are going to focus on runtime attacks

Stack and heap grow in opposite directions

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

`0x00000000` `0xffffffff`

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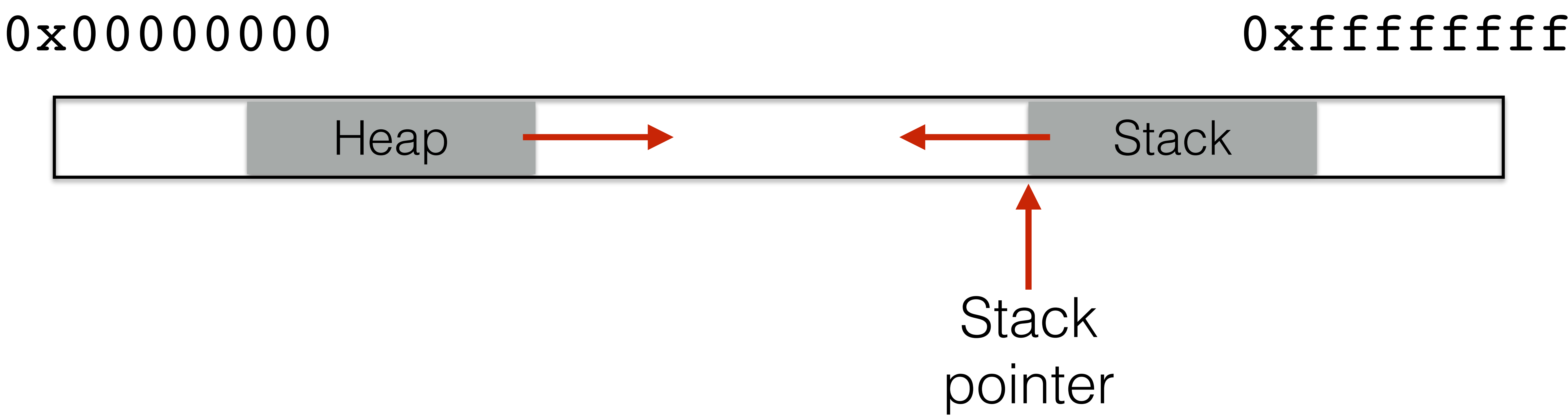

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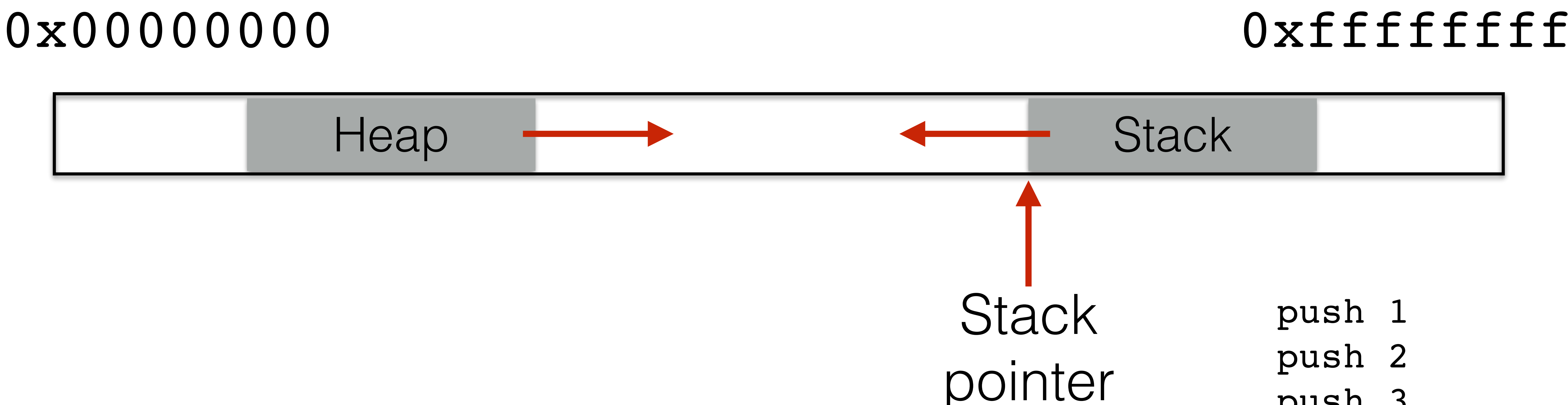


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push 1
push 2
push 3
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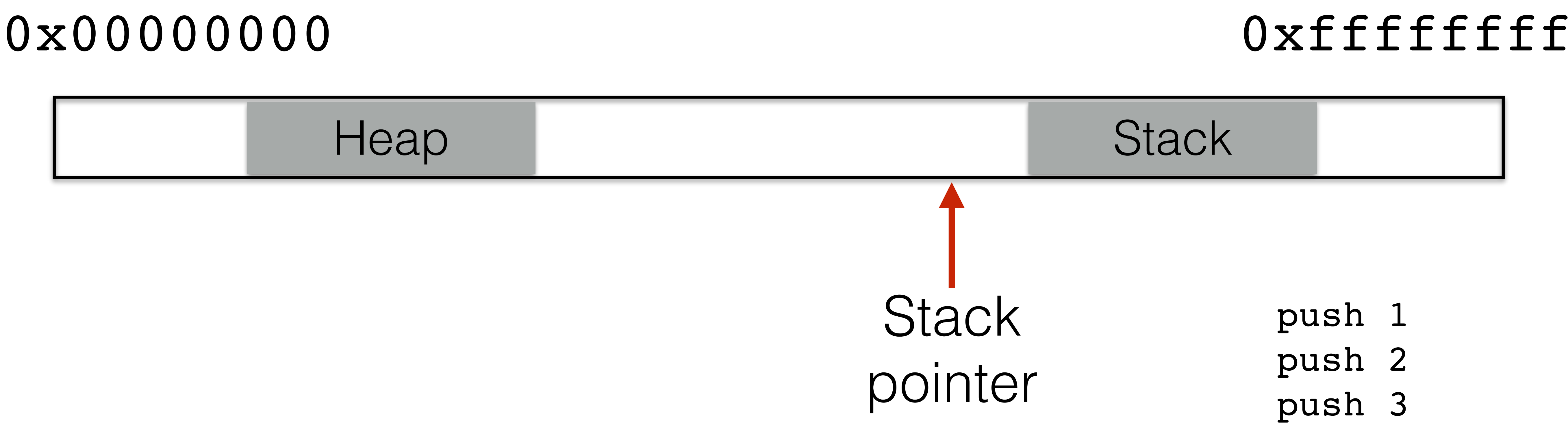

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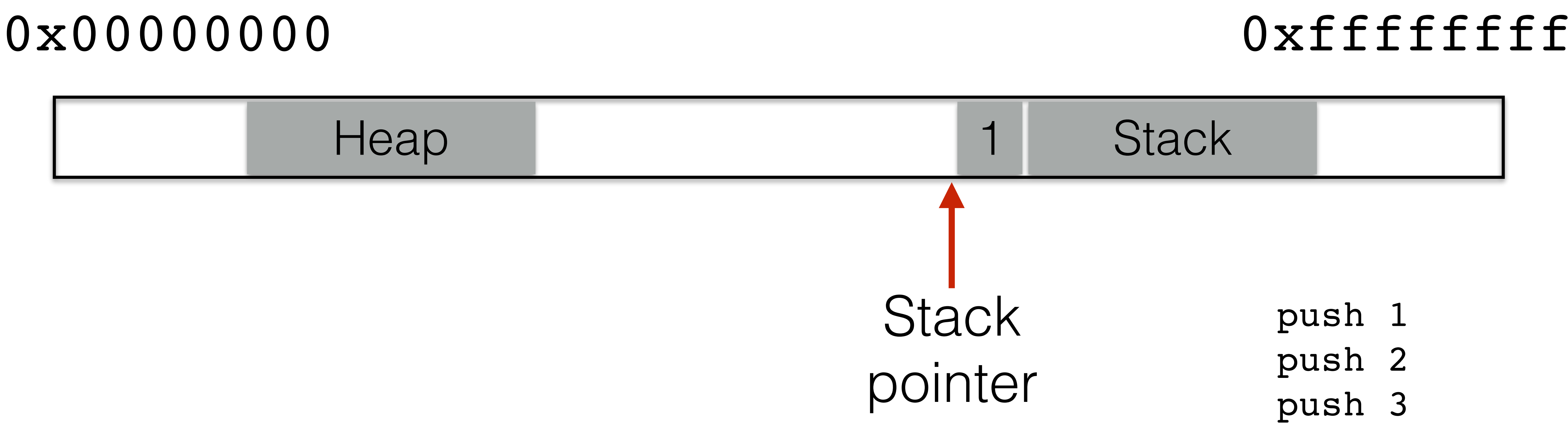

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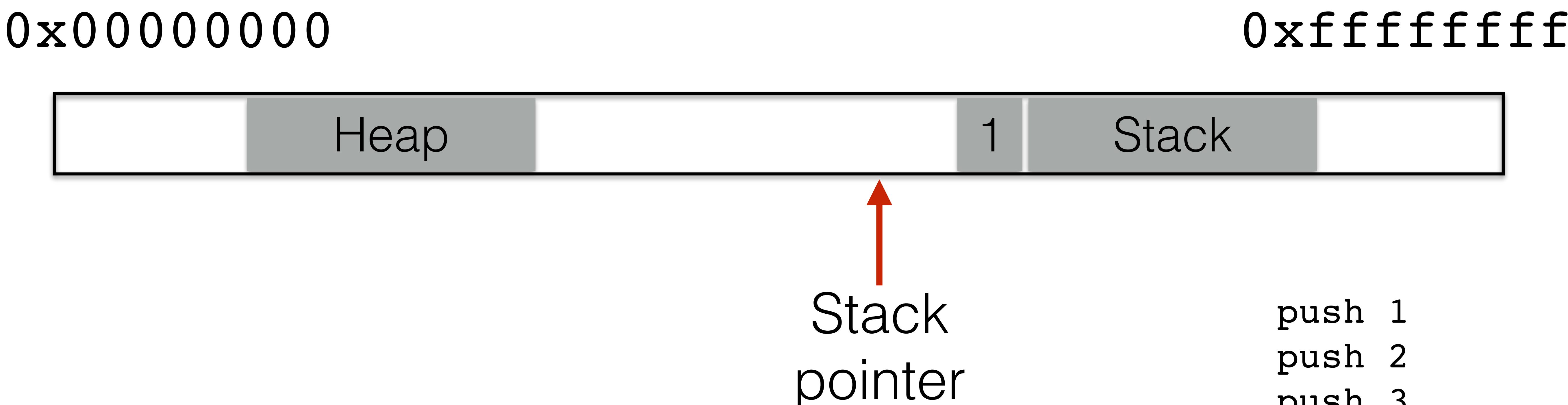


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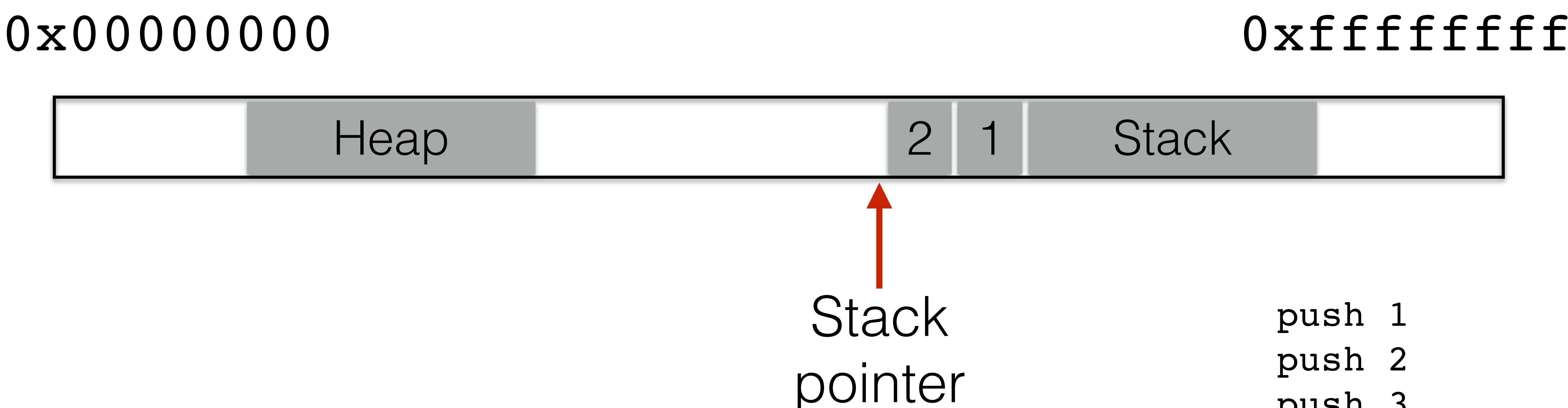


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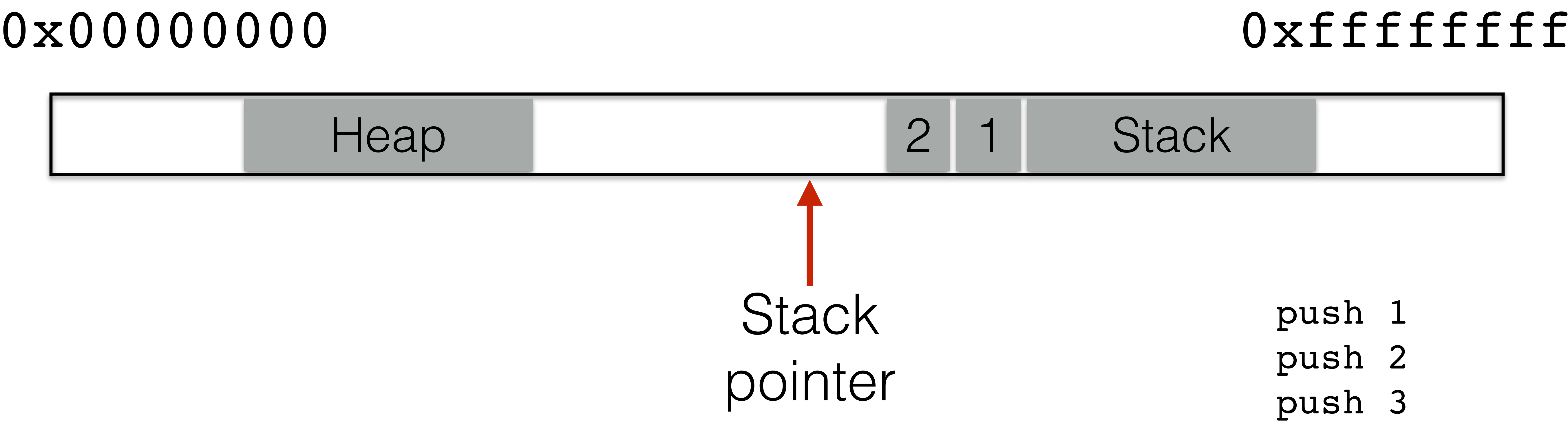

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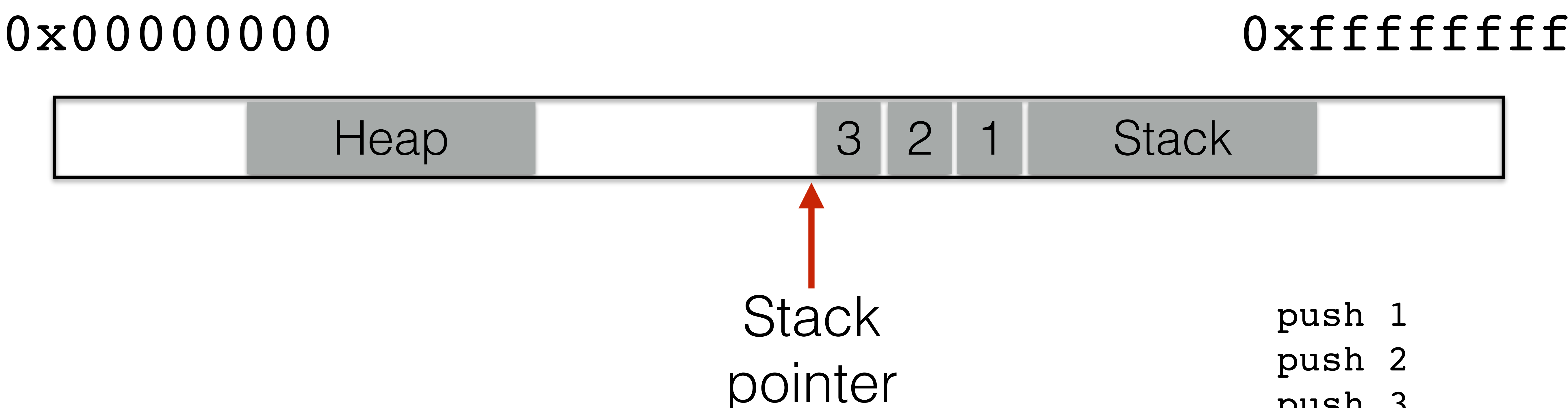


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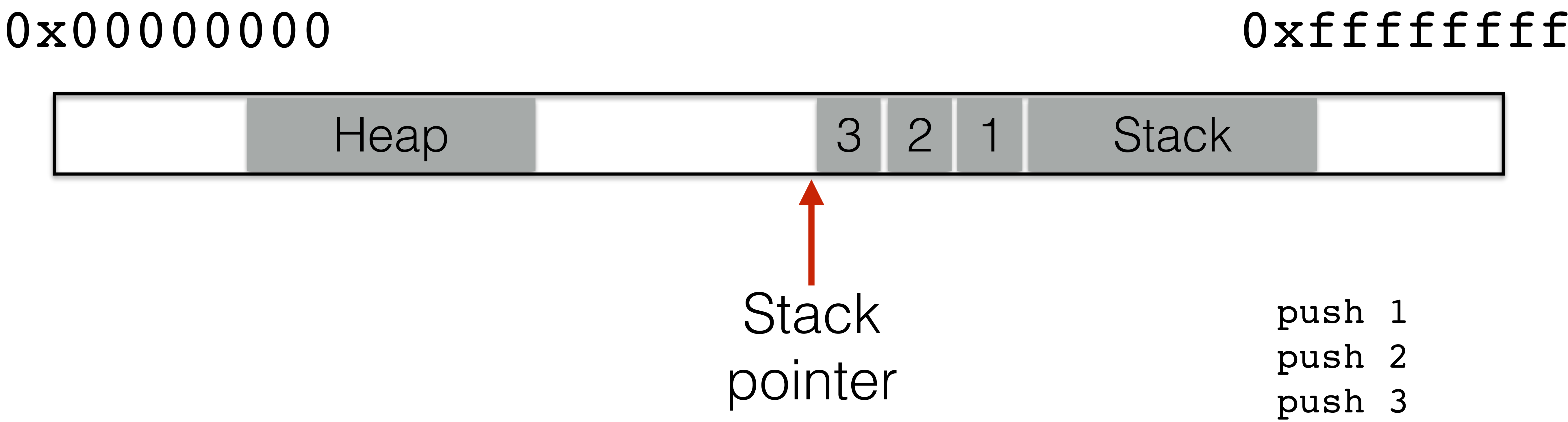


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push 1
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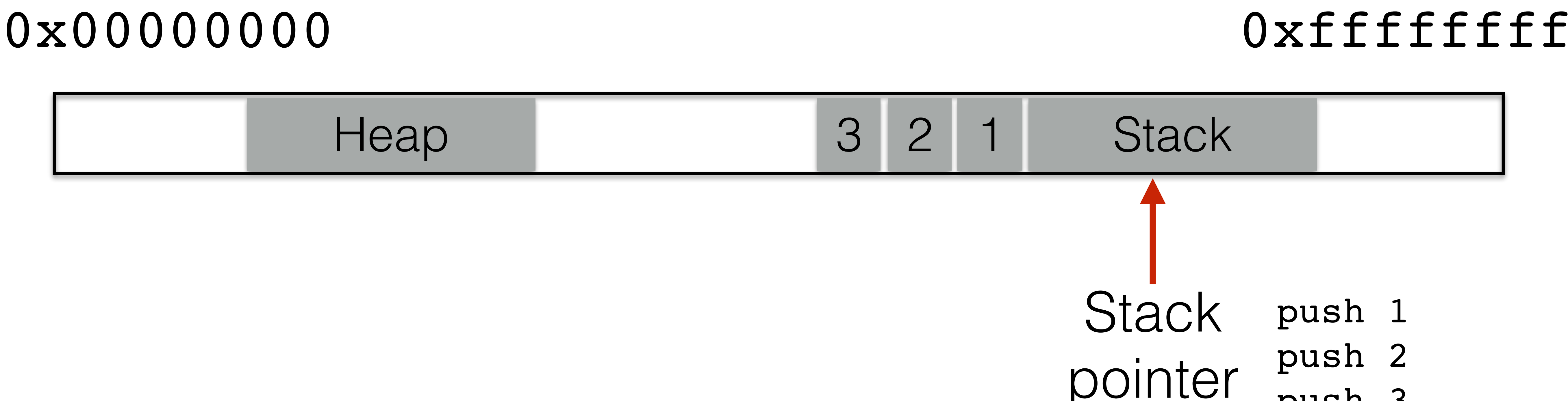


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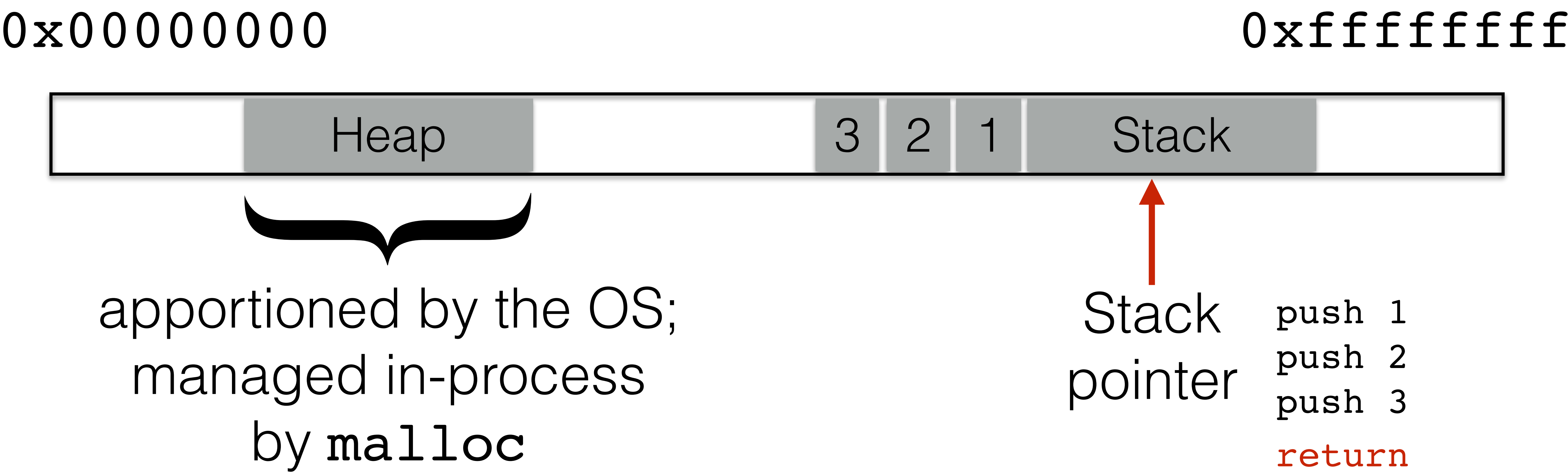

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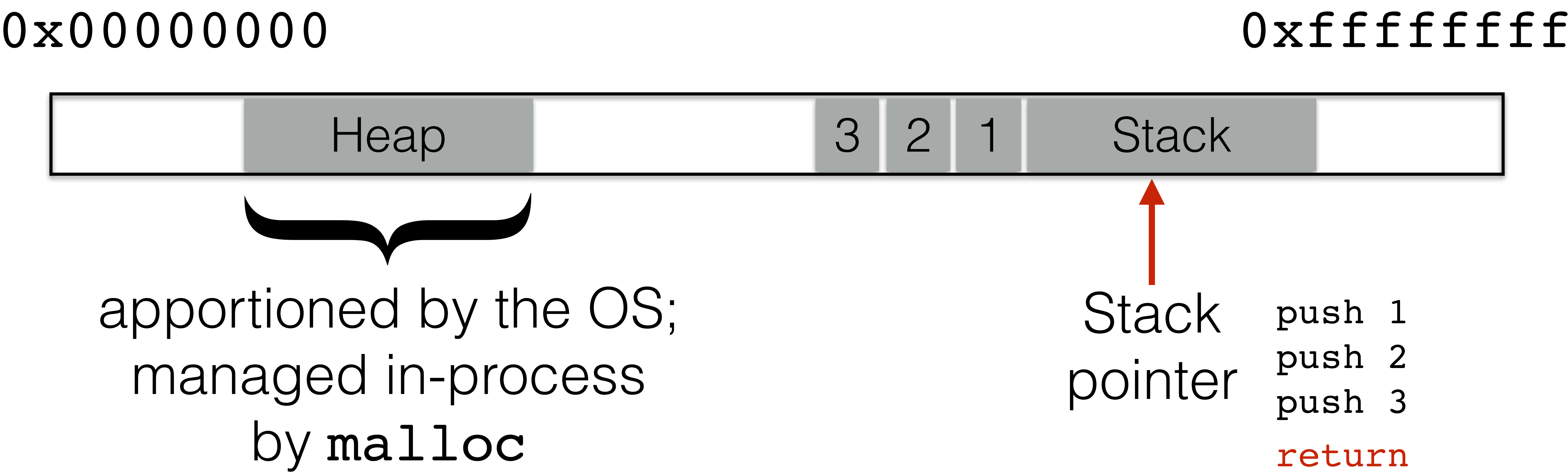


Focusing on the stack for now

Stack layout when calling functions

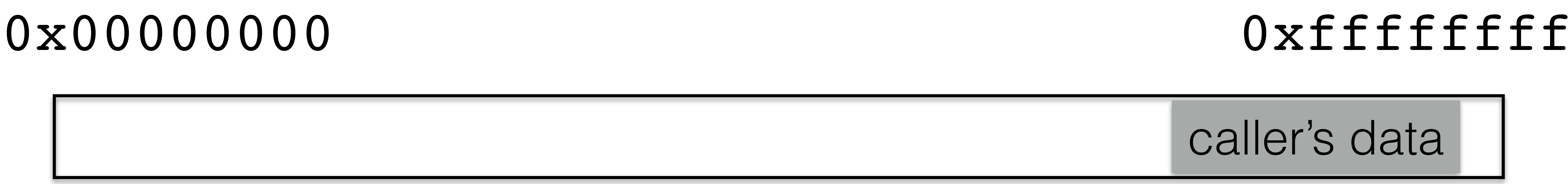
- What do we do when we *call* a function?
  - What data need to be stored?
  - Where do they go?

- How do we *return* from a function?
  - What data need to be *restored*?
  - Where do they come from?

Code examples

Stack layout when calling functions

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



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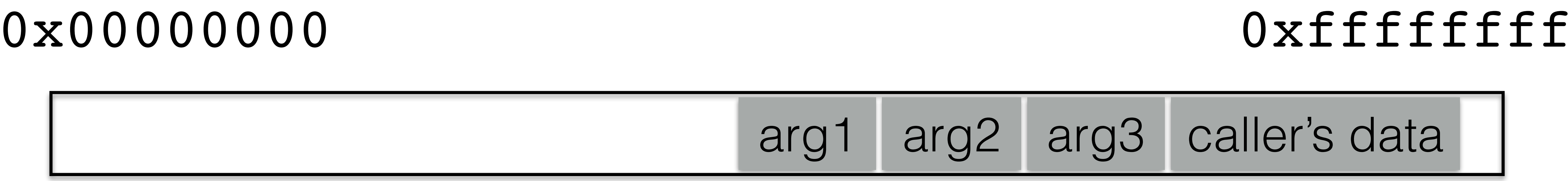

Arguments pushed in reverse order of code

Stack layout when calling functions

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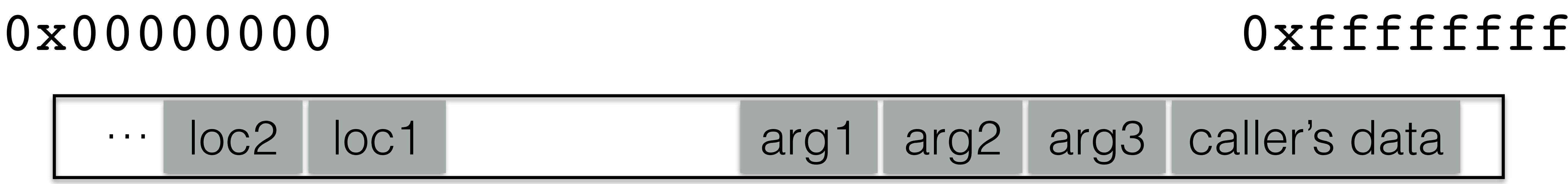
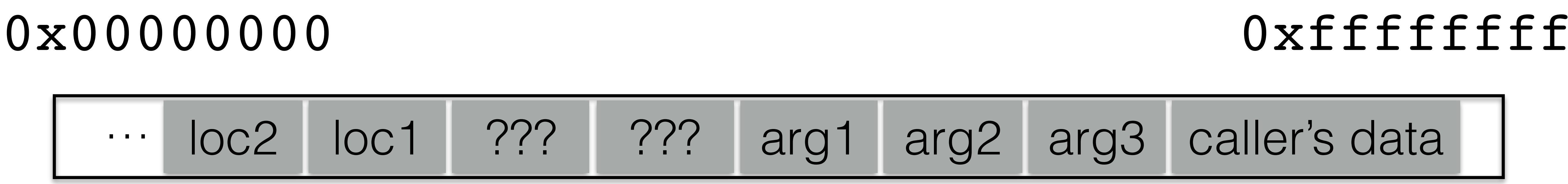


Local variables pushed in the same order as they appear in the code

Arguments pushed in reverse order of code

Stack layout when calling functions

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



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Accessing variables

```
void func(char *arg1, int arg2, int arg3)
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    loc2++;
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```

0x00000000 0xffffffff

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```

Q: Where is (this) `loc2`?

0x00000000 0xffffffff

···	loc2	loc1	???	???	arg1	arg2	arg3	caller's data

Accessing variables

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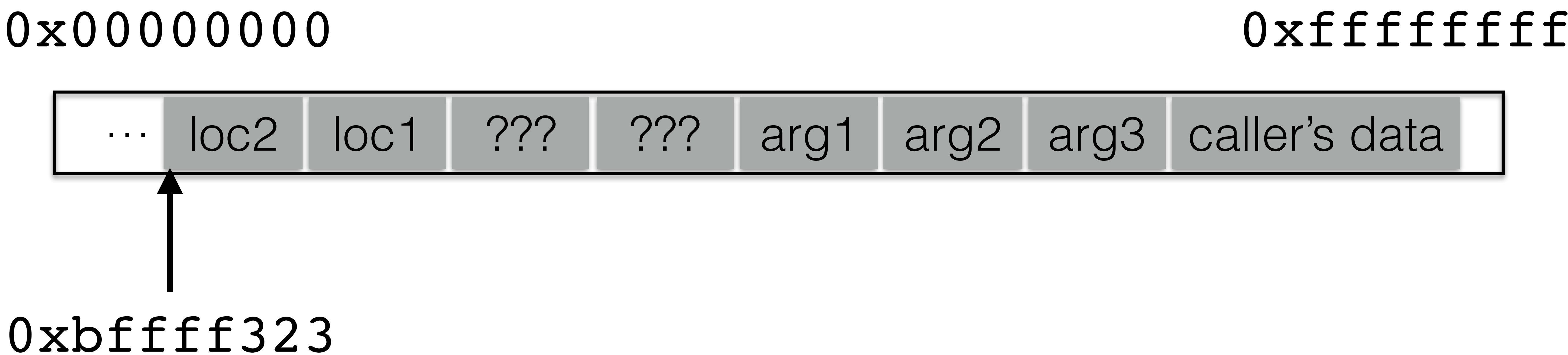

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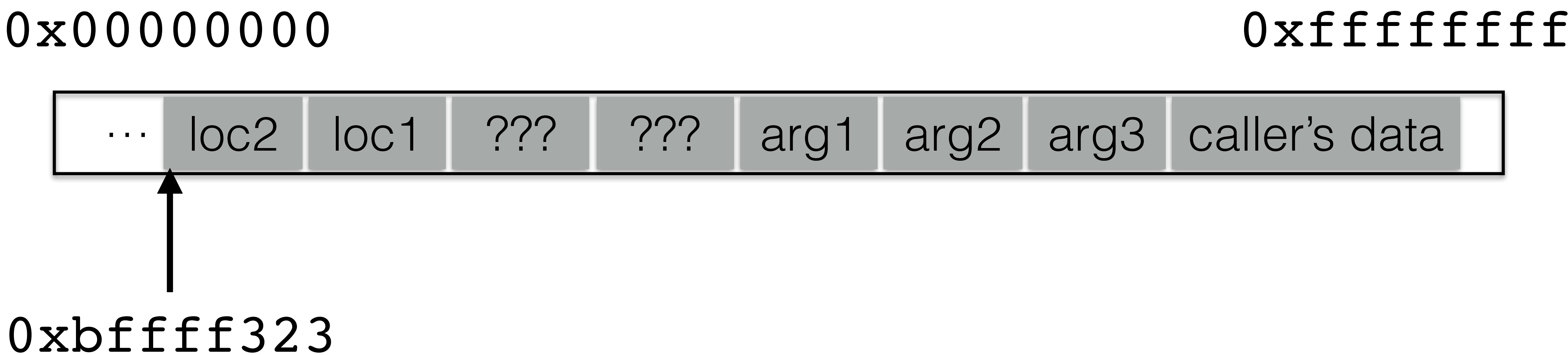

Undecidable at compile time

Accessing variables

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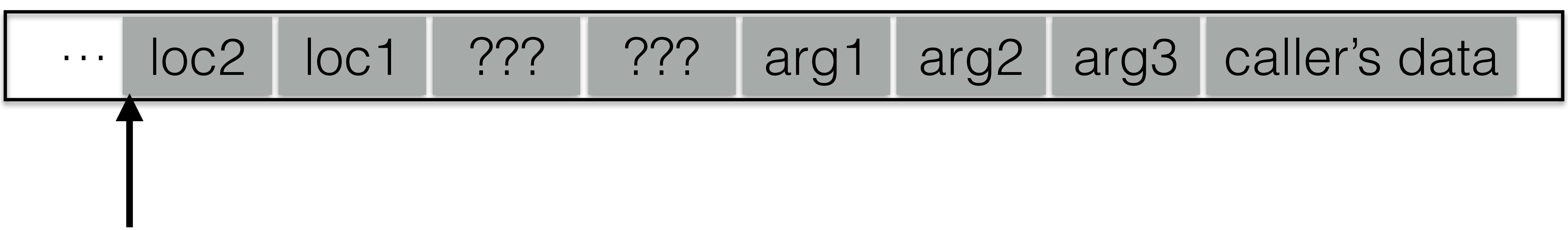

0xbffff323

Undecidable at compile time

- I don't know where loc2 is,

Accessing variables

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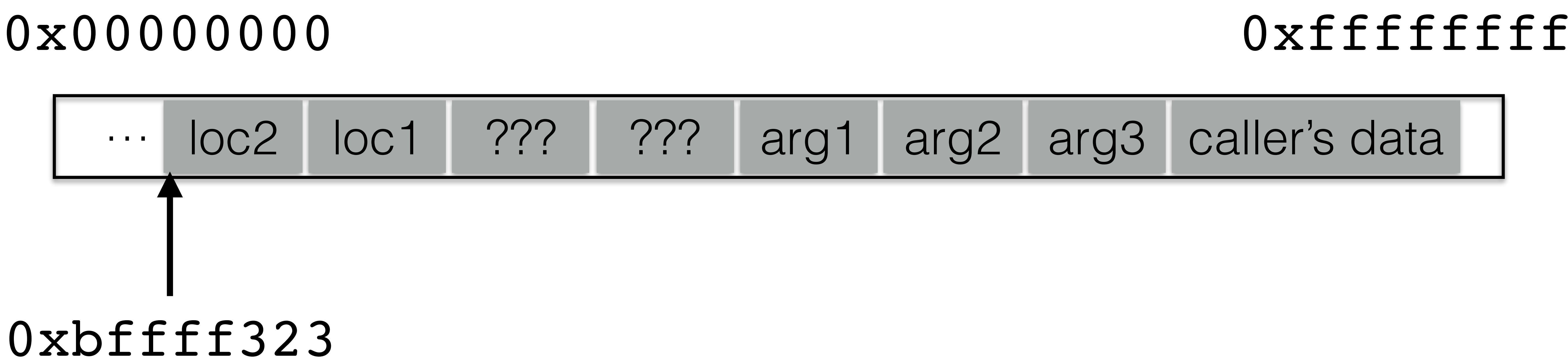

Undecidable at compile time

- I don't know where loc2 is,
- and I don't know how many args

Accessing variables

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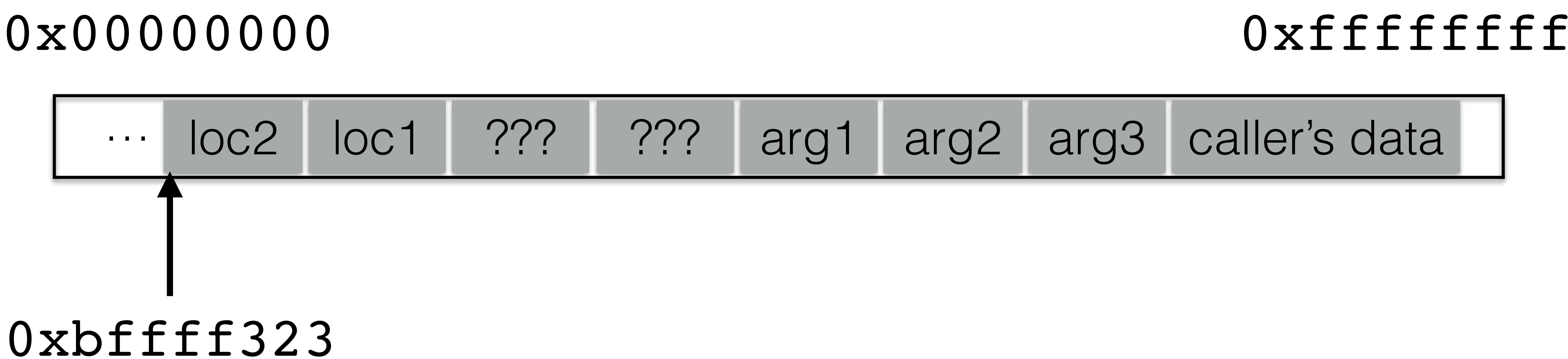

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- I don't know where loc2 is,
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- *but* loc2 is *always* 8B before "???"s

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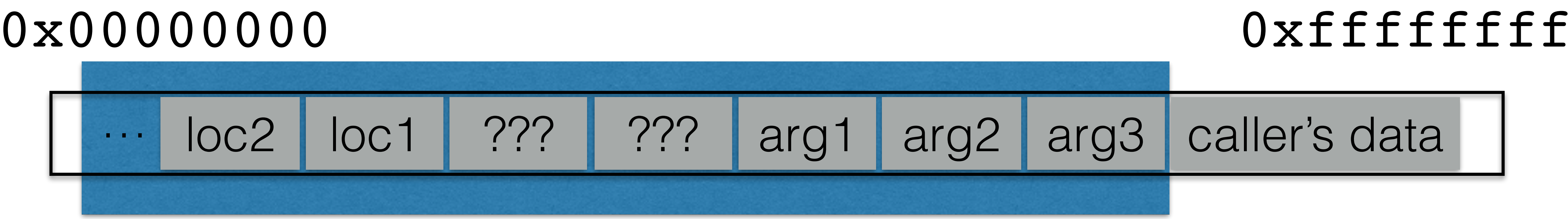

Stack frame
for *this* call to `func`

- I don't know where loc2 is,
- and I don't know how many args
- *but* loc2 is *always* 8B before "???"s

Accessing variables

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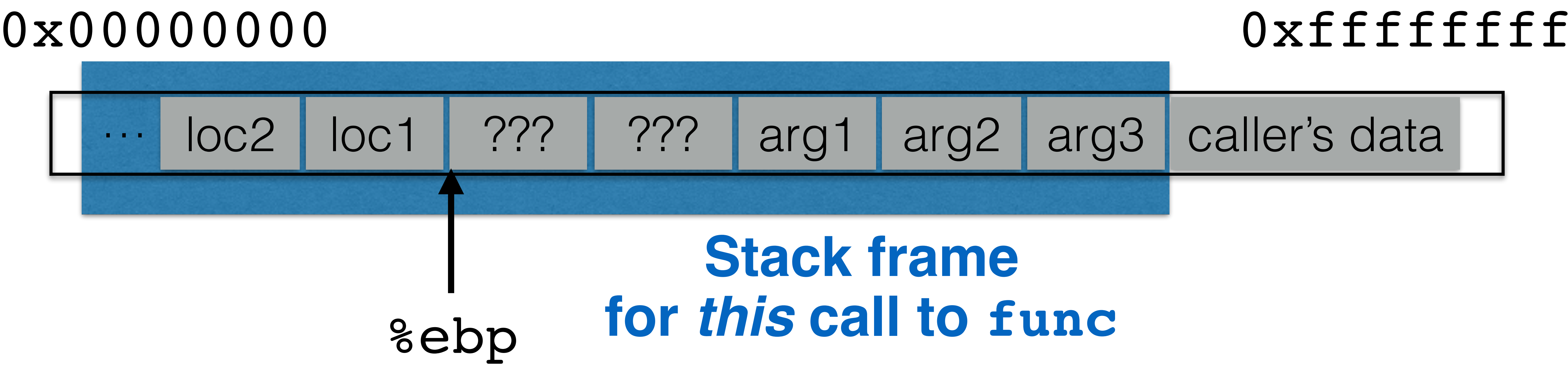

Frame pointer

- I don't know where loc2 is,
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- *but* loc2 is *always* 8B before "???"s

Accessing variables

```
void func(char *arg1, int arg2, int arg3)
{
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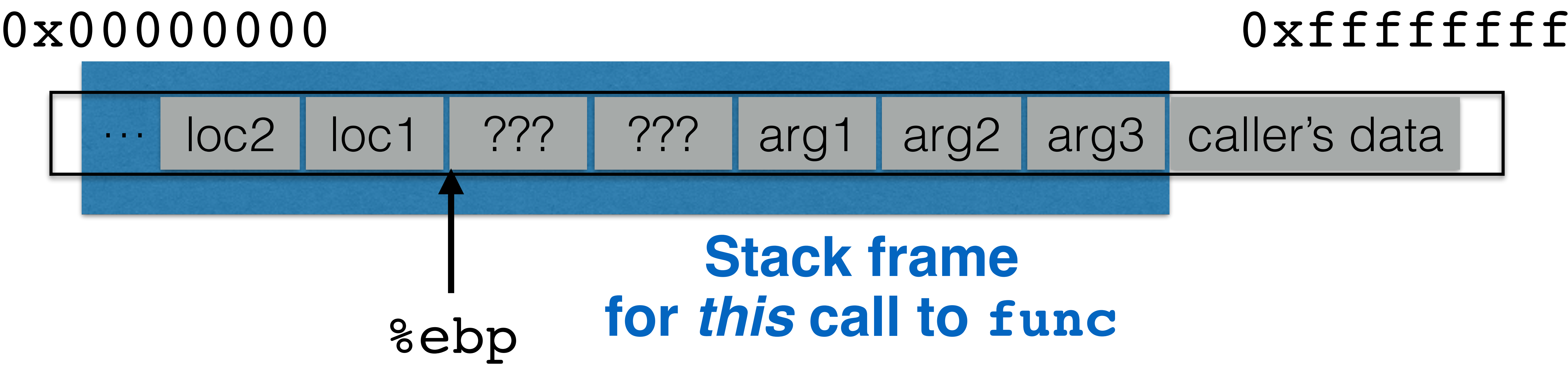
    int  loc3;
    ...
    loc2++;
    ...
}
```

Q: Where is (this) `loc2`?

A: -8(%ebp)



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Notation

`%ebp`	A memory address
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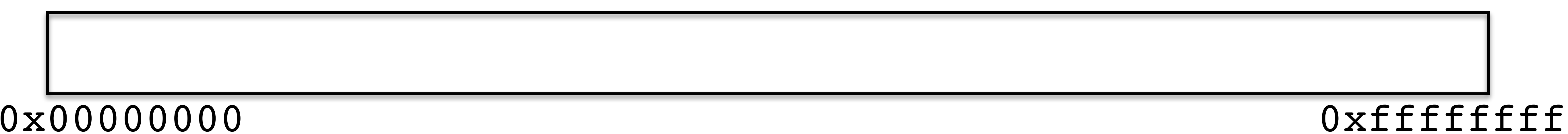

Notation

`0xbfff03b8` **`%ebp`** A memory address

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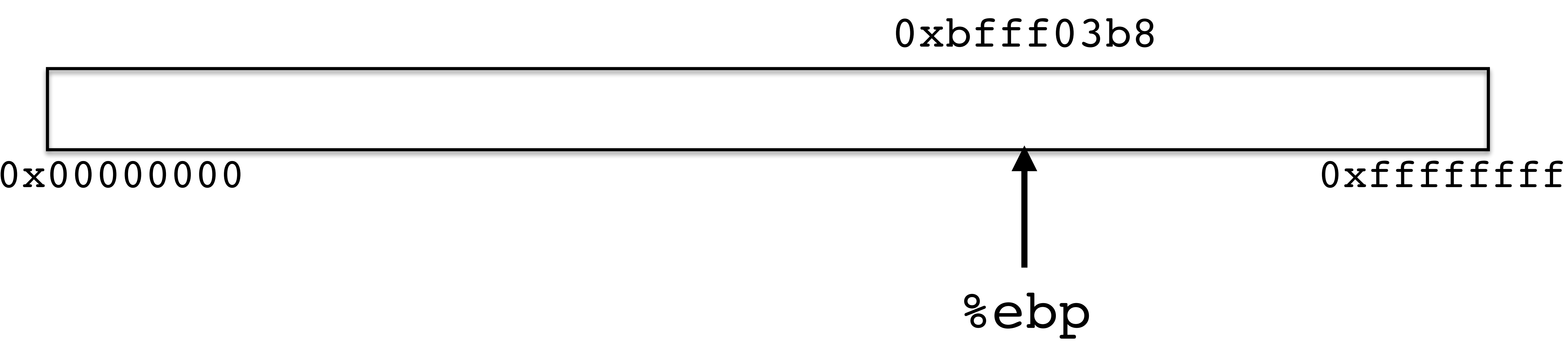

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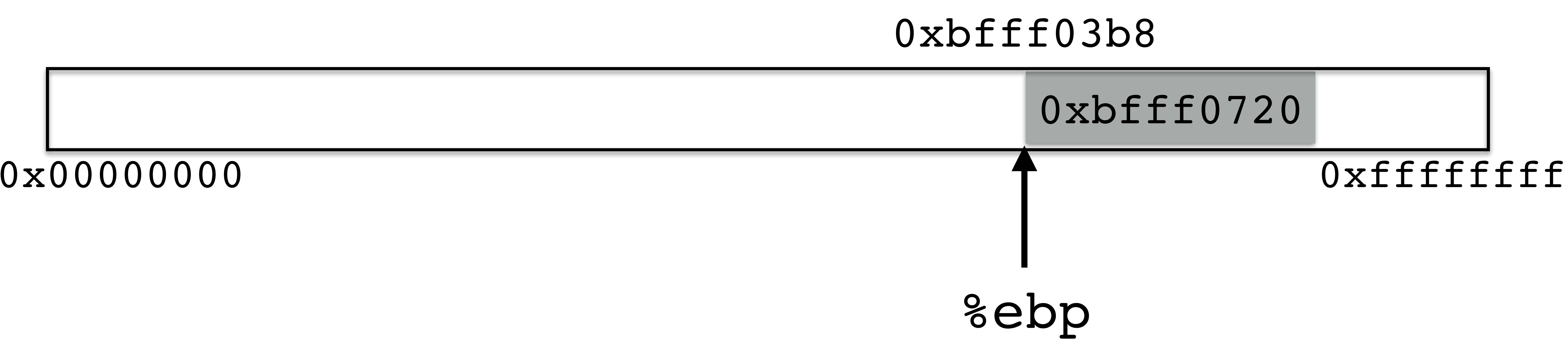
`0xbfff0720`	**`(%ebp)`**	The value at memory address **`%ebp`** (like dereferencing a pointer)



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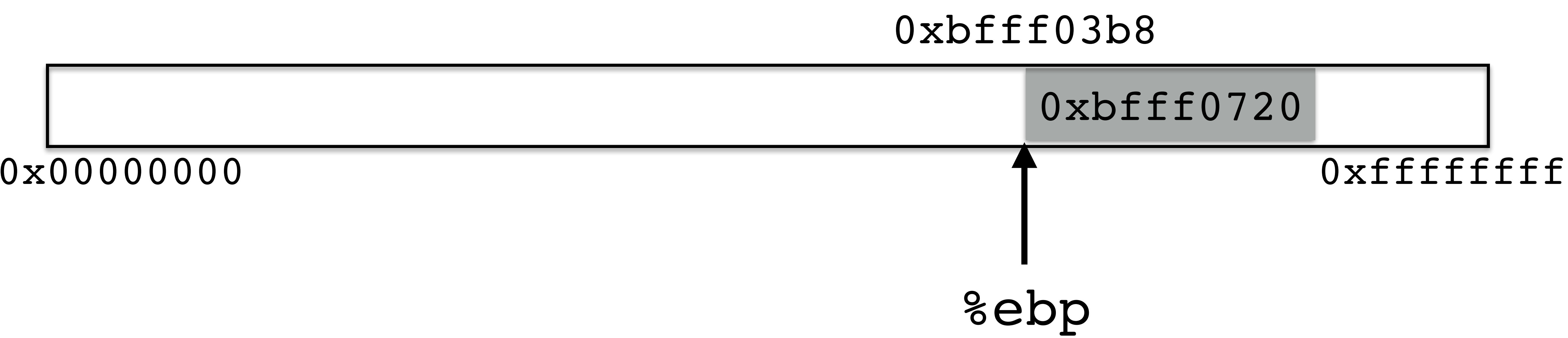

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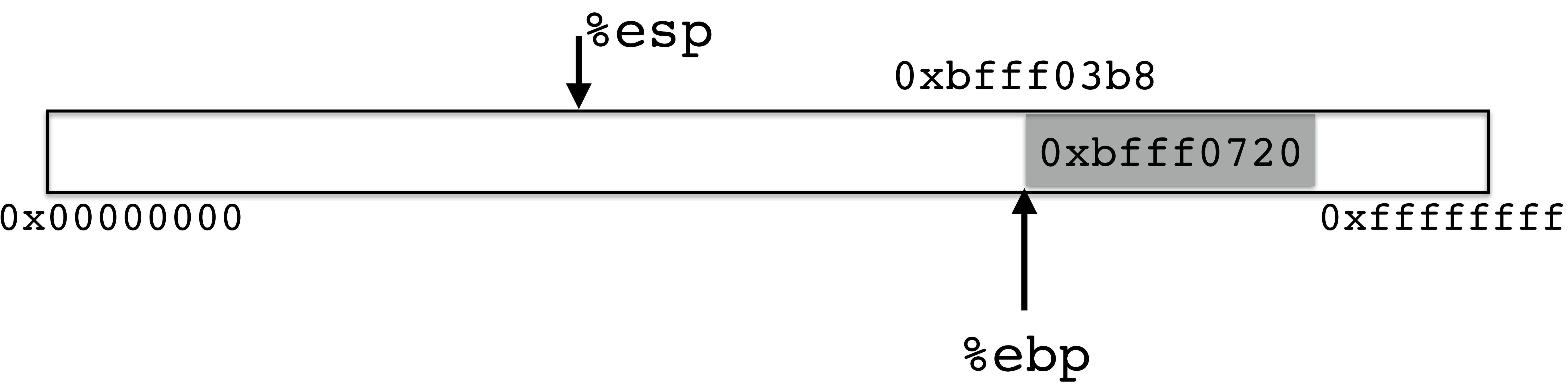

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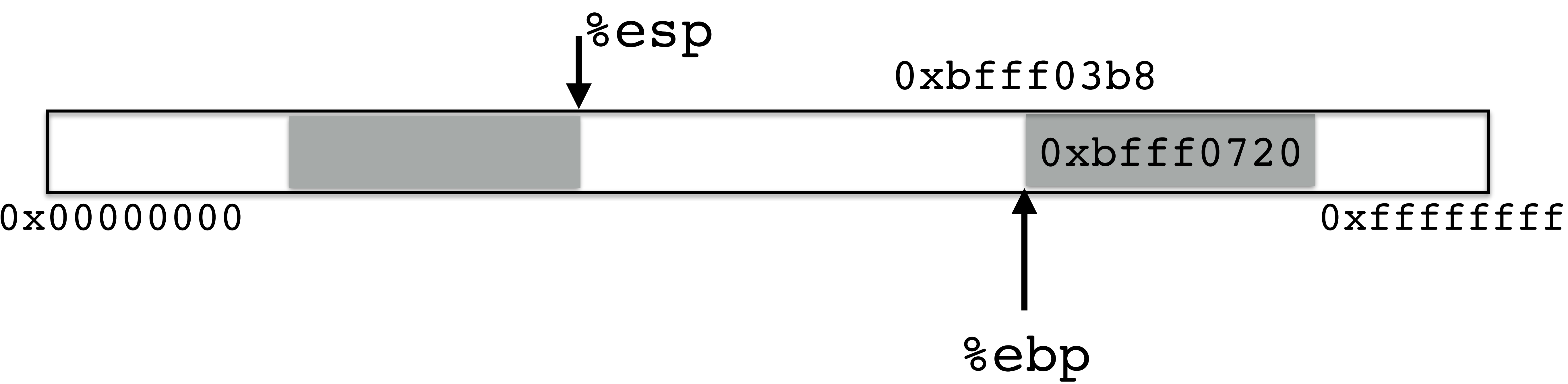

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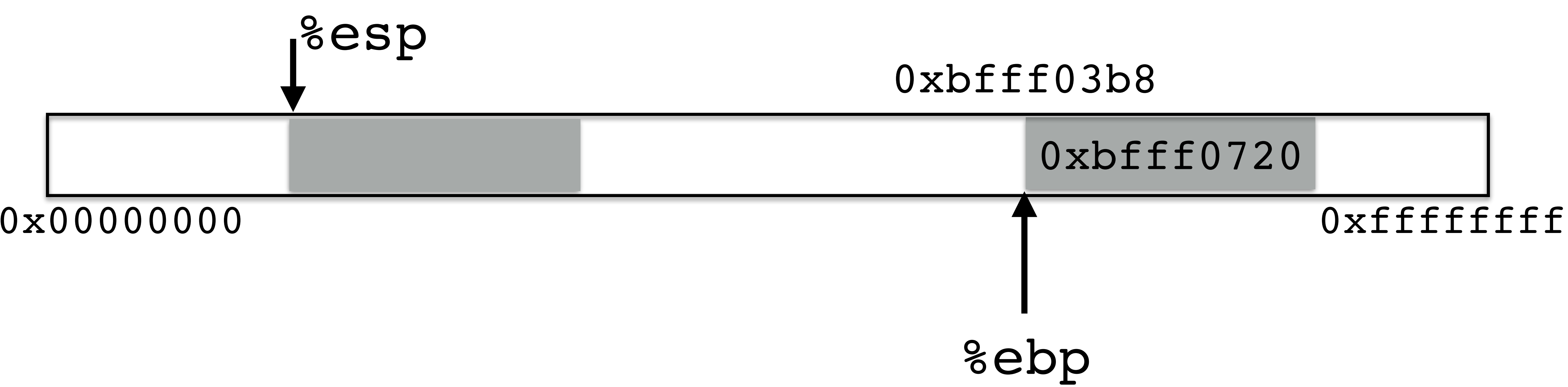

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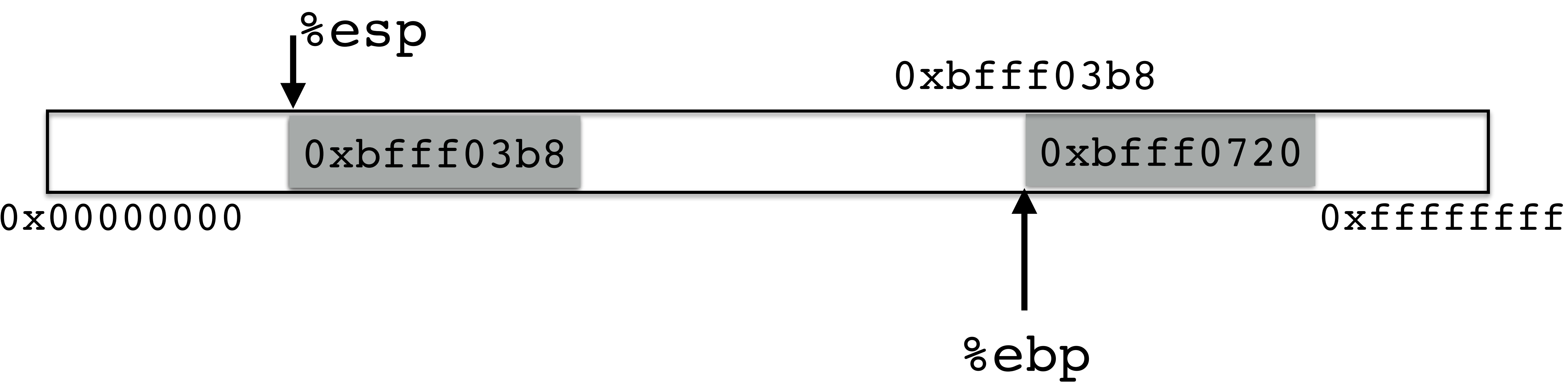

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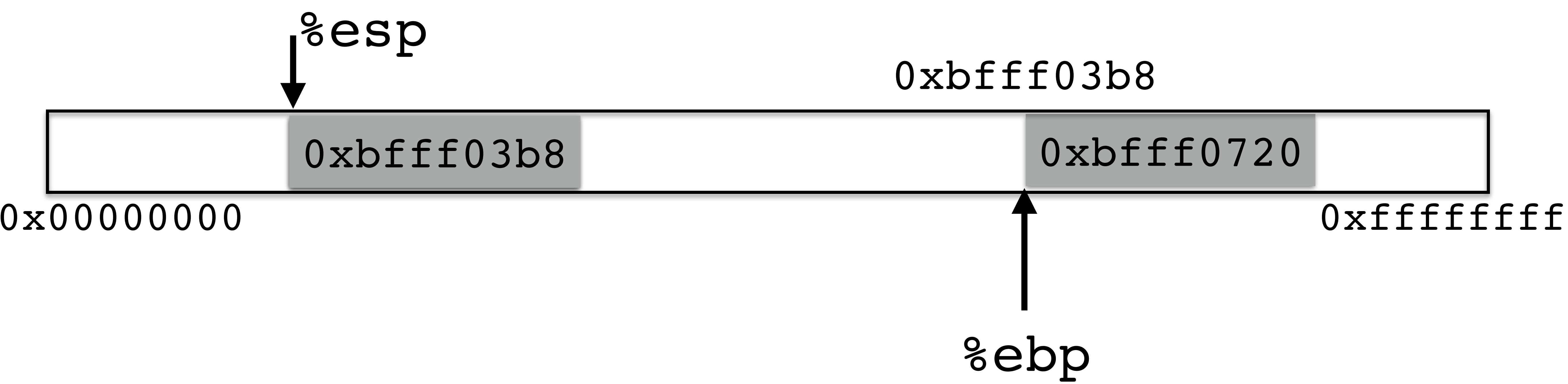

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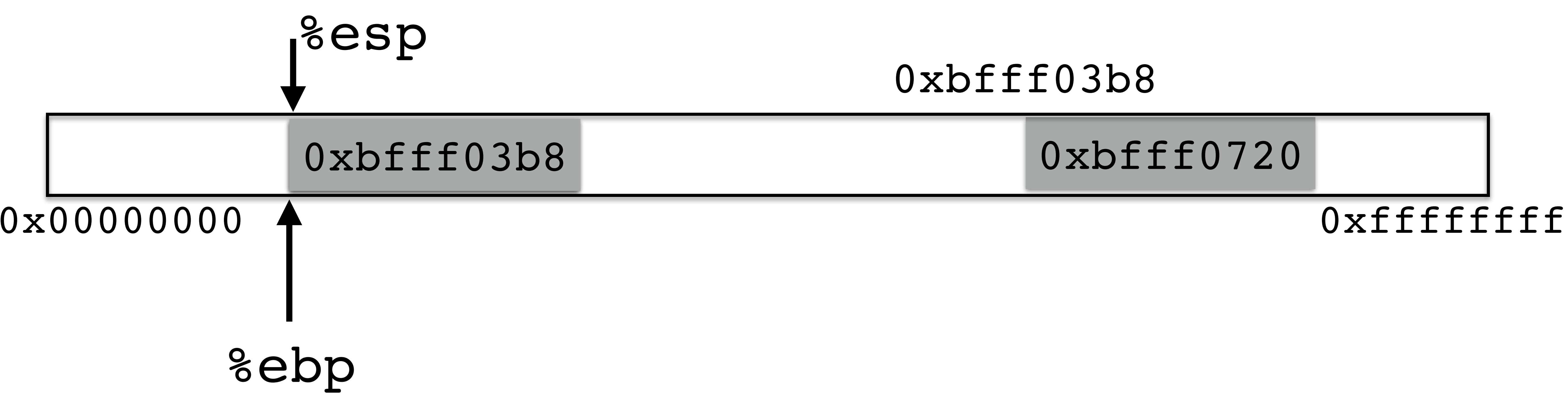

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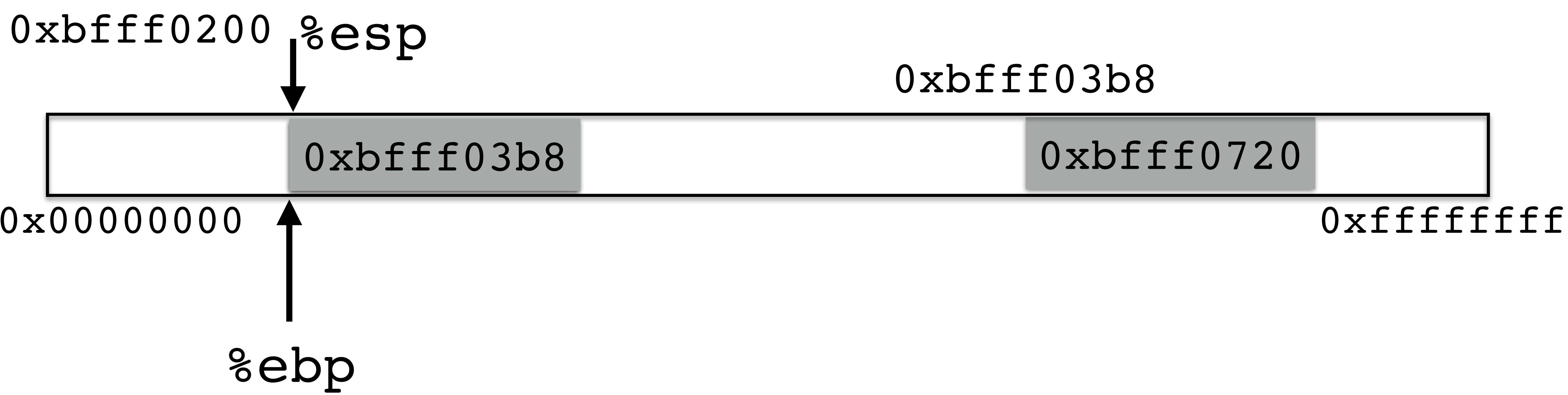

Notation

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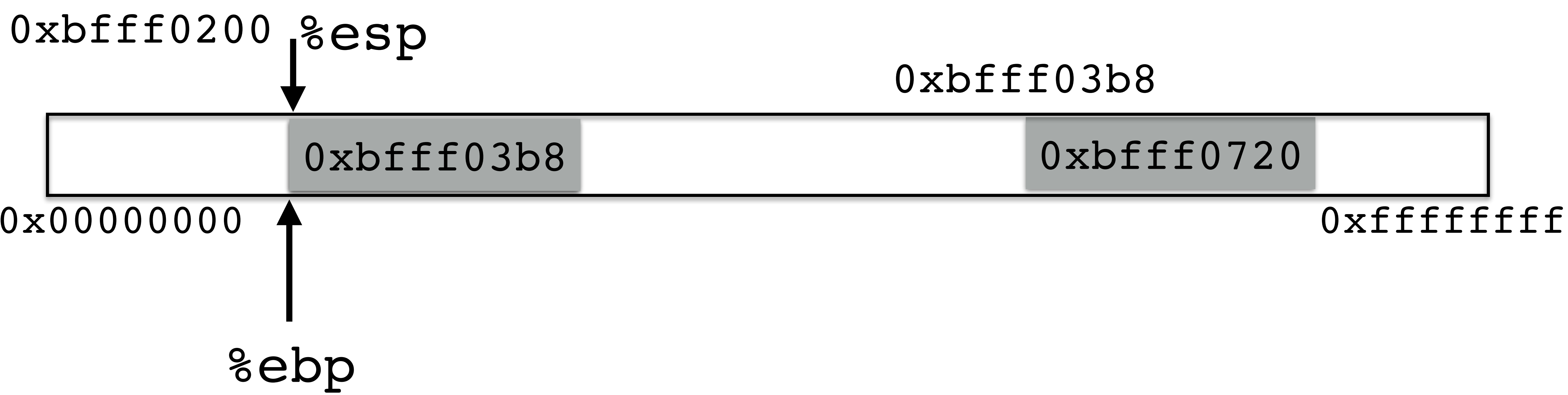

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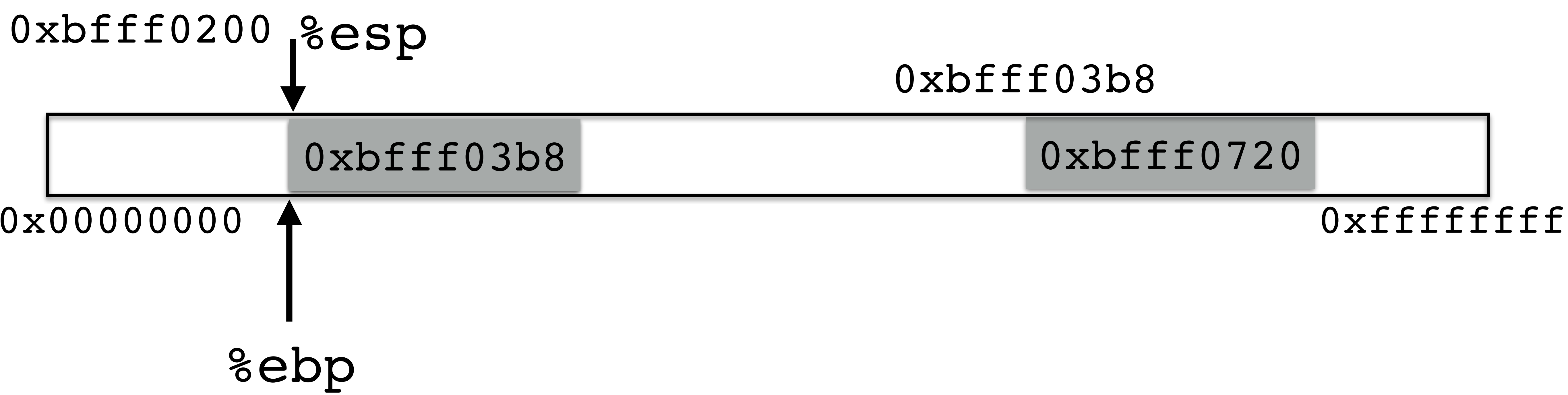

Returning from functions

```
int main()
{
     ...
     func("Hey", 10, -3);
     ...
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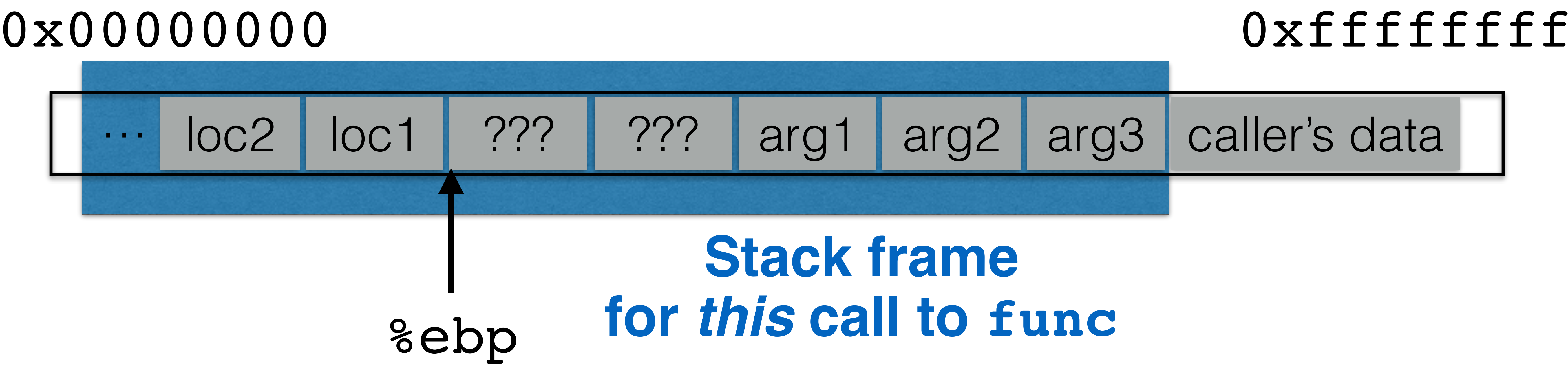

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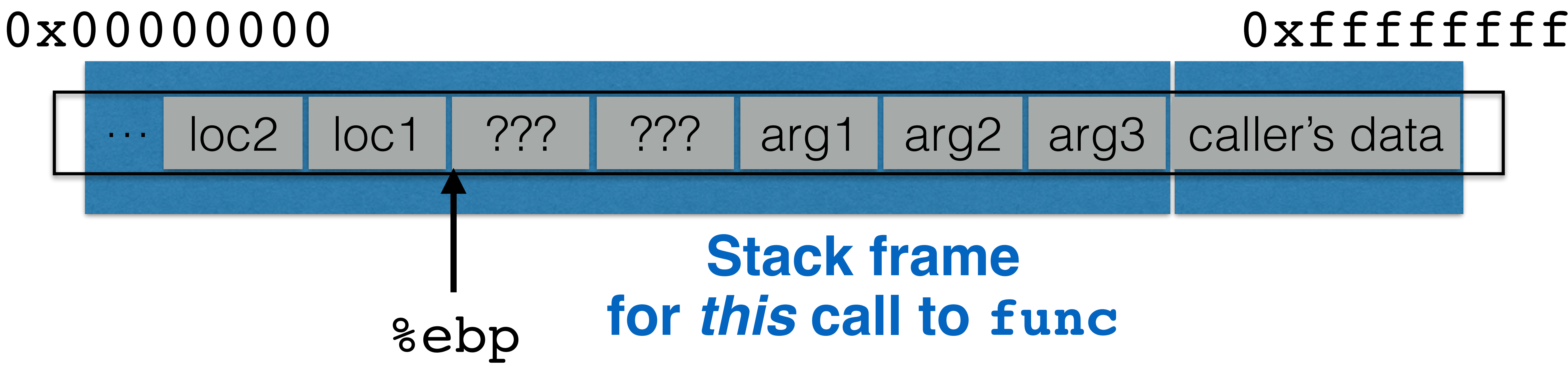

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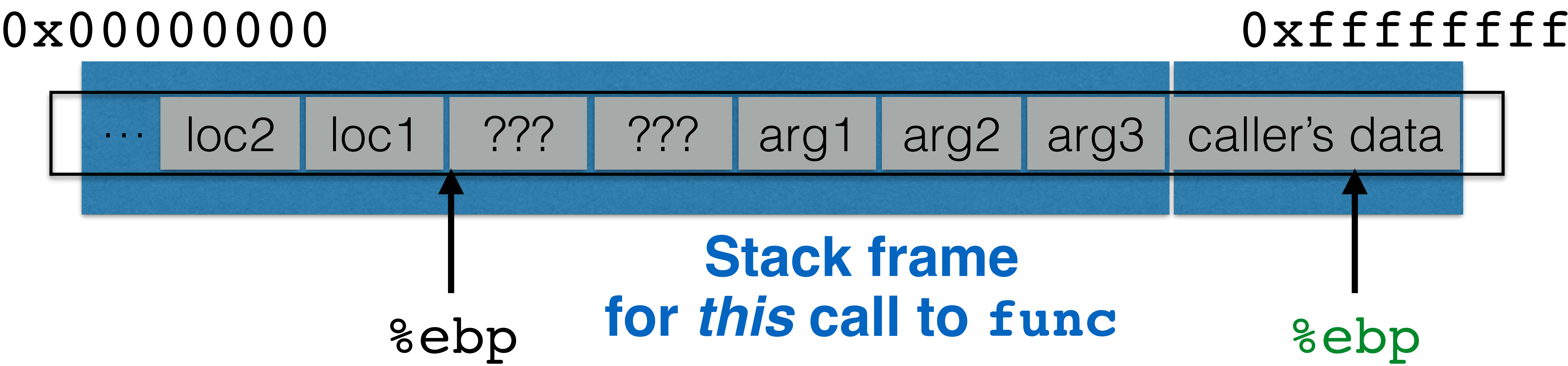

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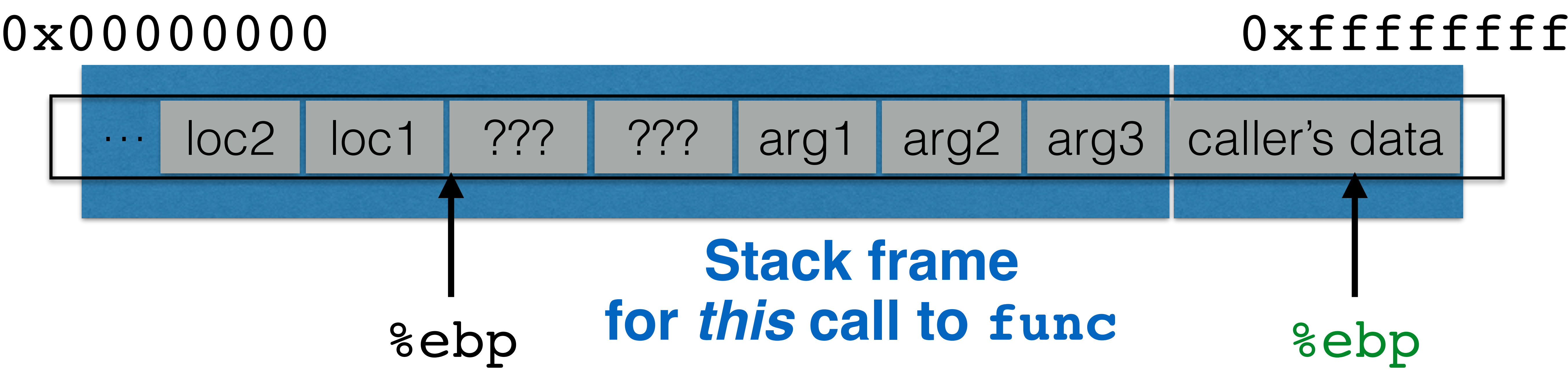
Q: How do we restore %ebp?



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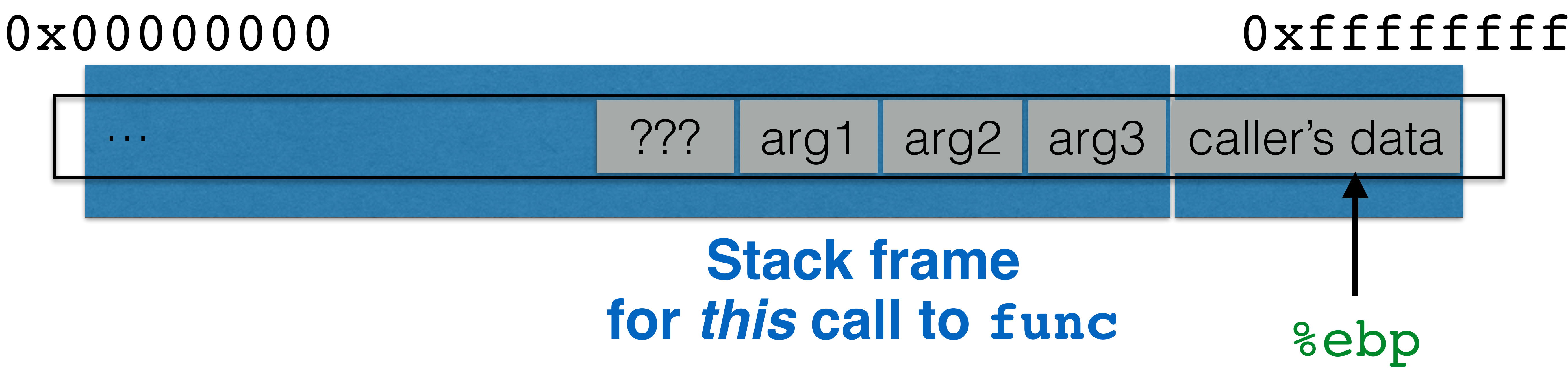

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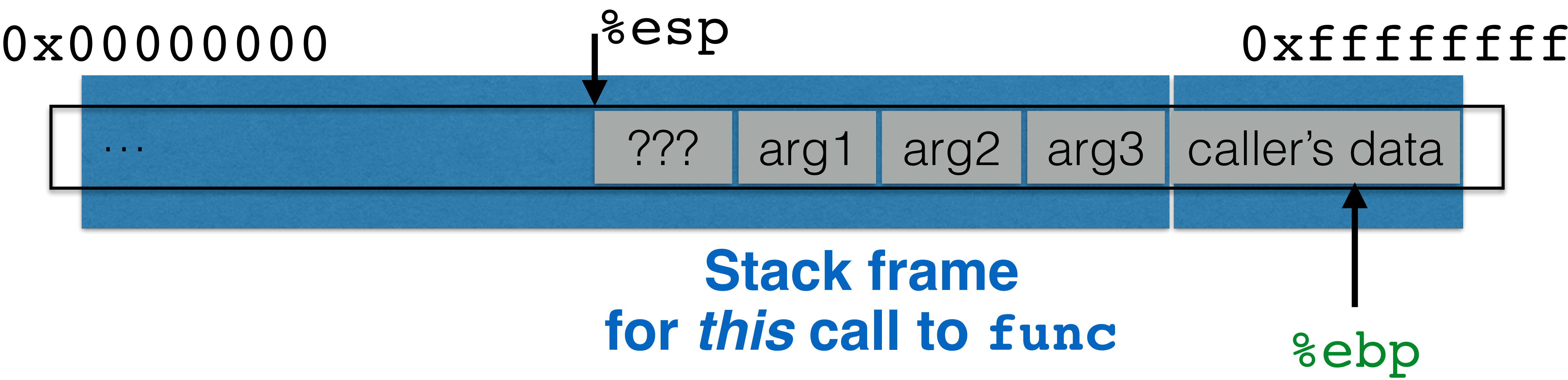

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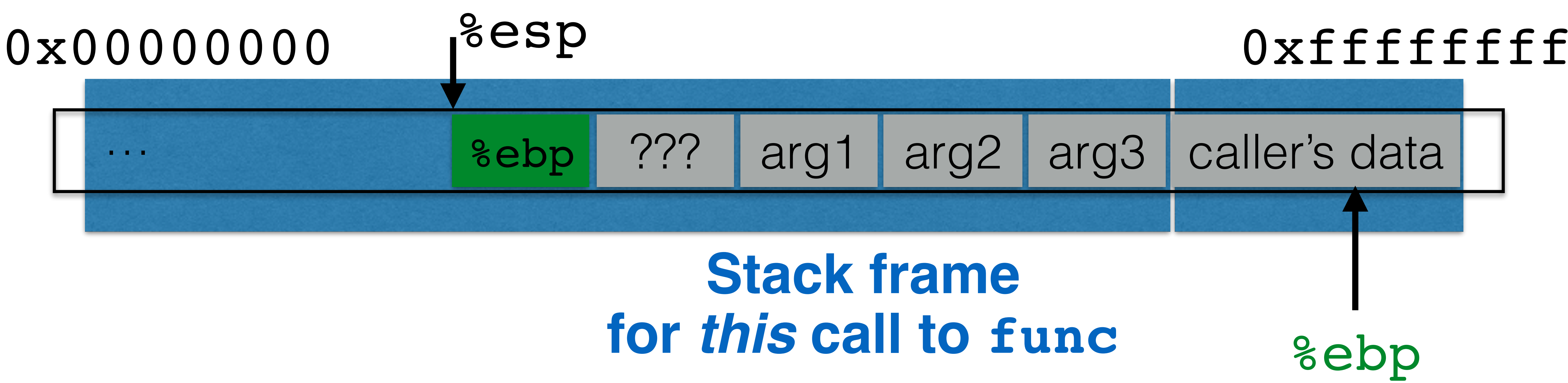

1. Push `%ebp` before `locals`

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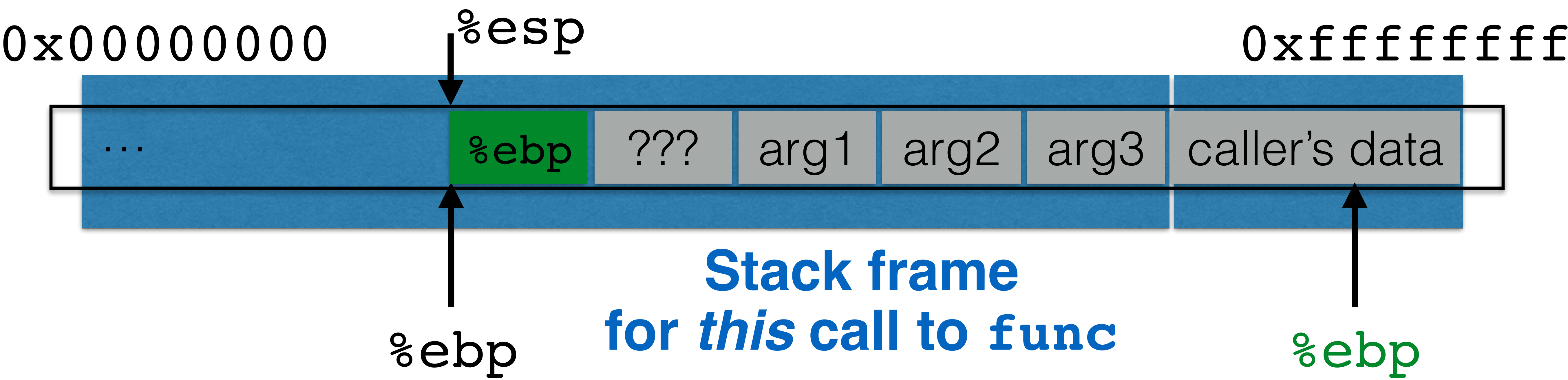

1. **Push `%ebp` before `locals`**
2. **Set `%ebp` to current `%esp`**

Returning from functions

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}
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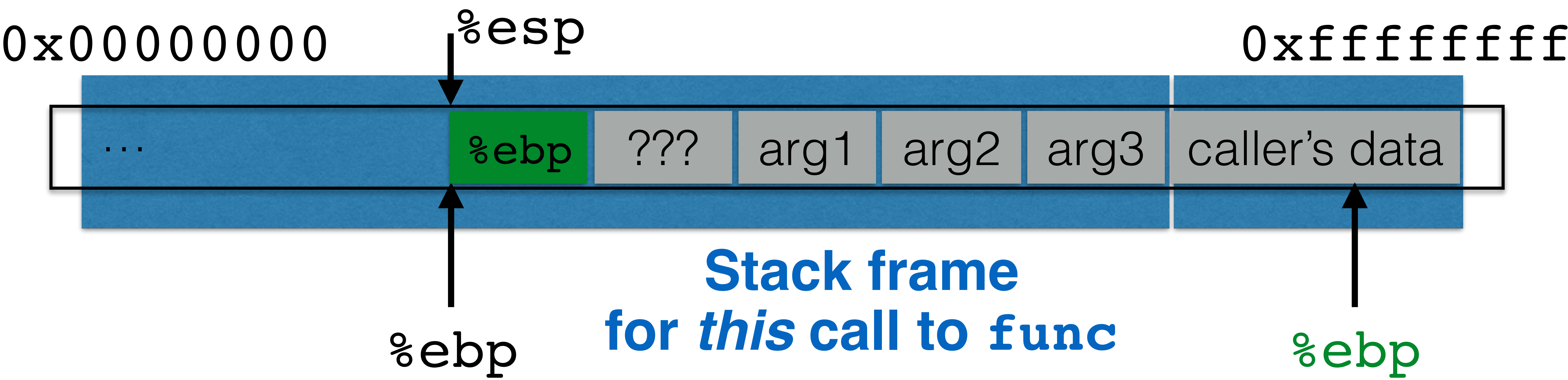

1. **Push `%ebp` before `locals`**
2. **Set `%ebp` to current `%esp`**
3. **Set `%ebp` `to(%ebp)` at return**

Returning from functions

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int main()
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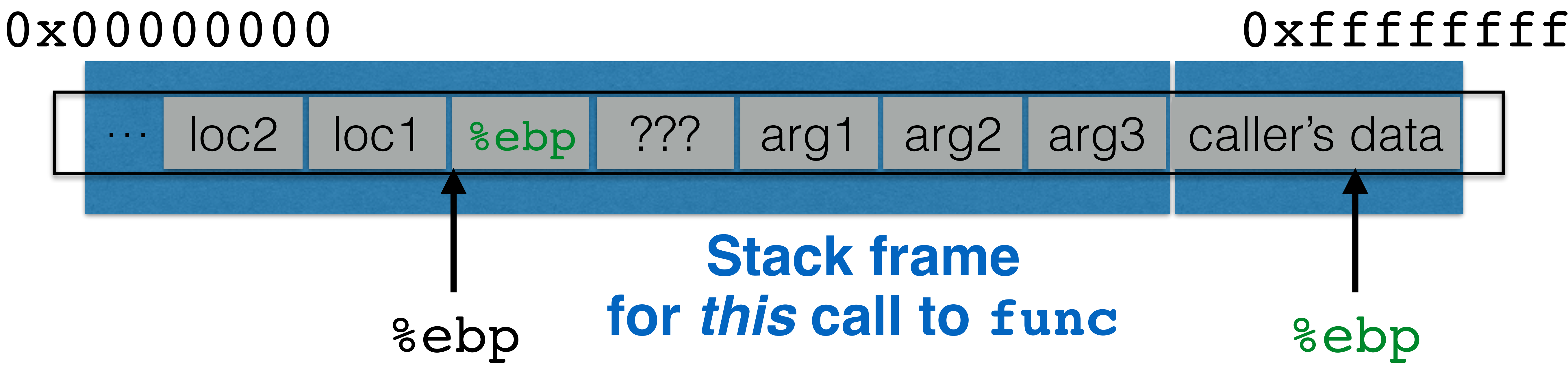
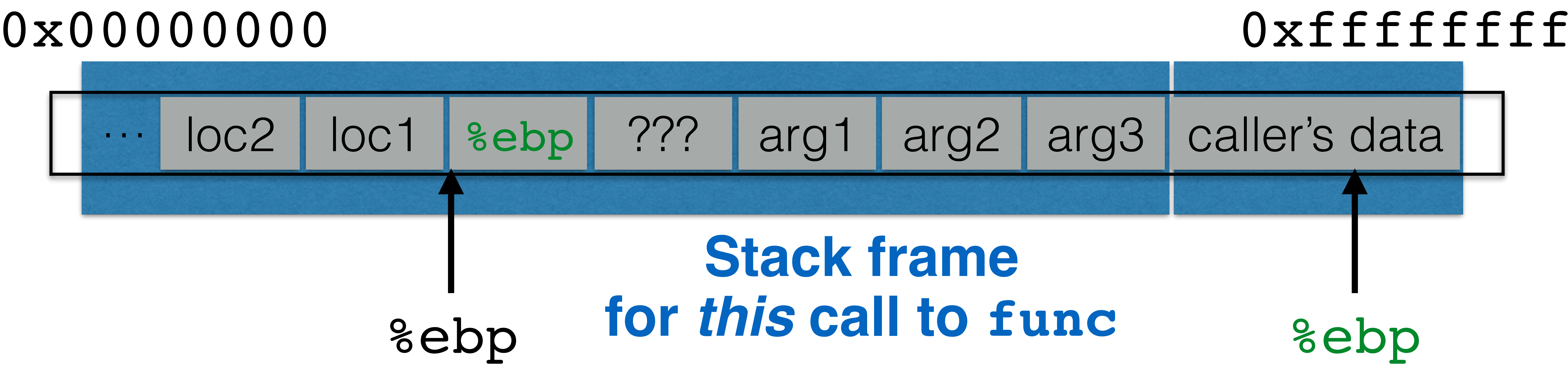
    ...
}
```



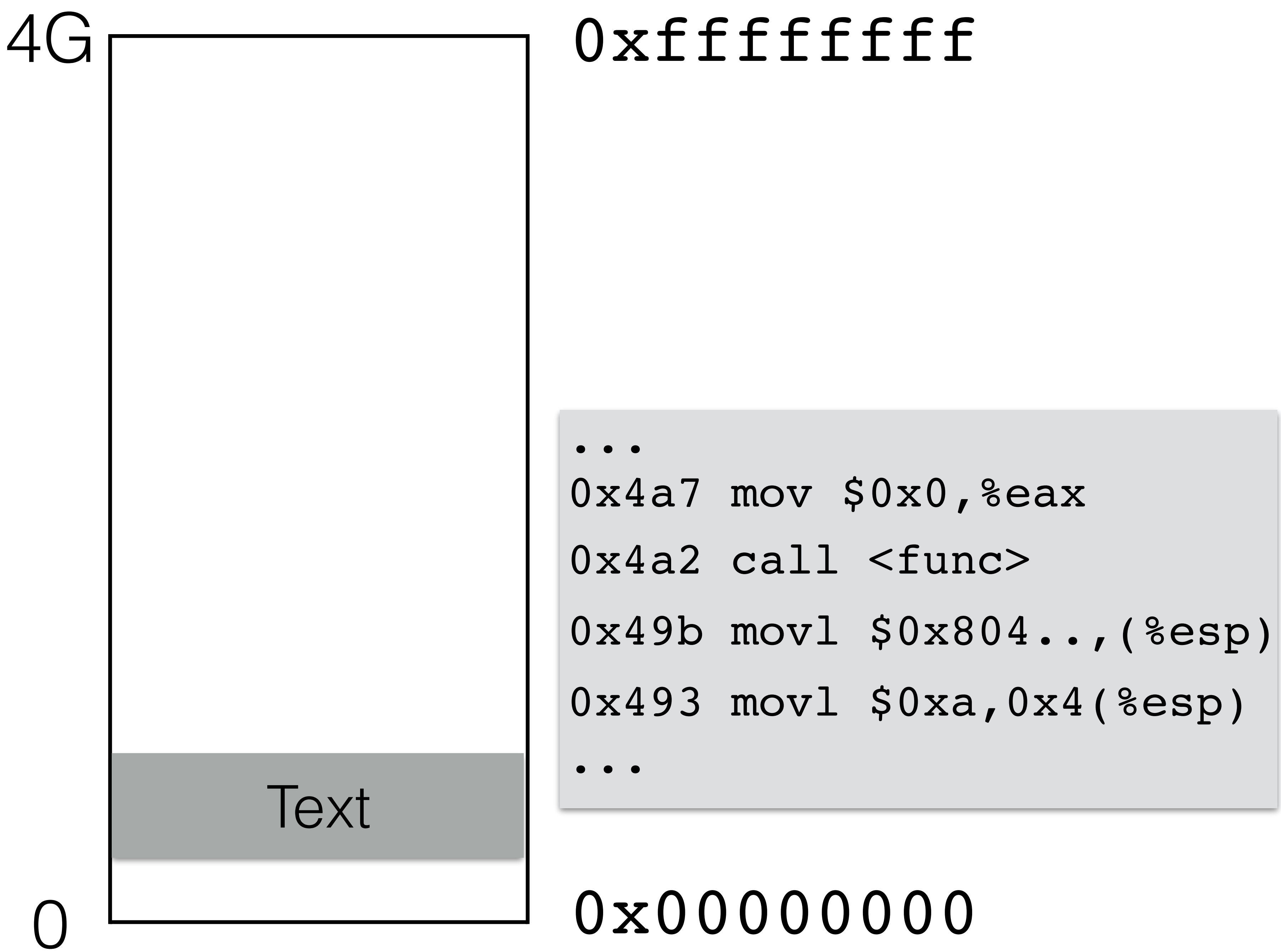
Returning from functions

```
int main()
{
    ...
    func("Hey", 10, -3);
    ...
}
```

Q: How do we resume here?



The instructions themselves are in memory



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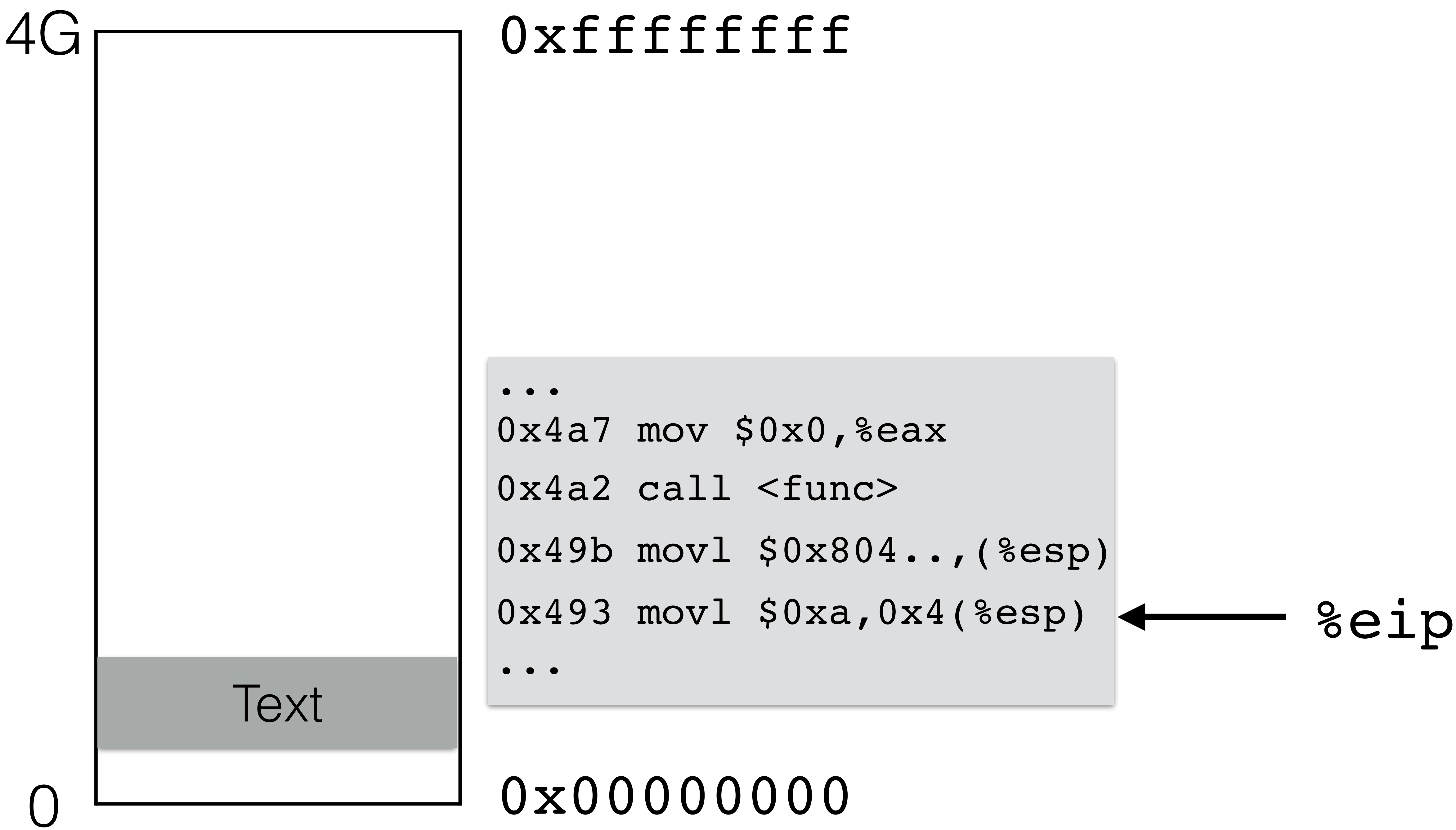

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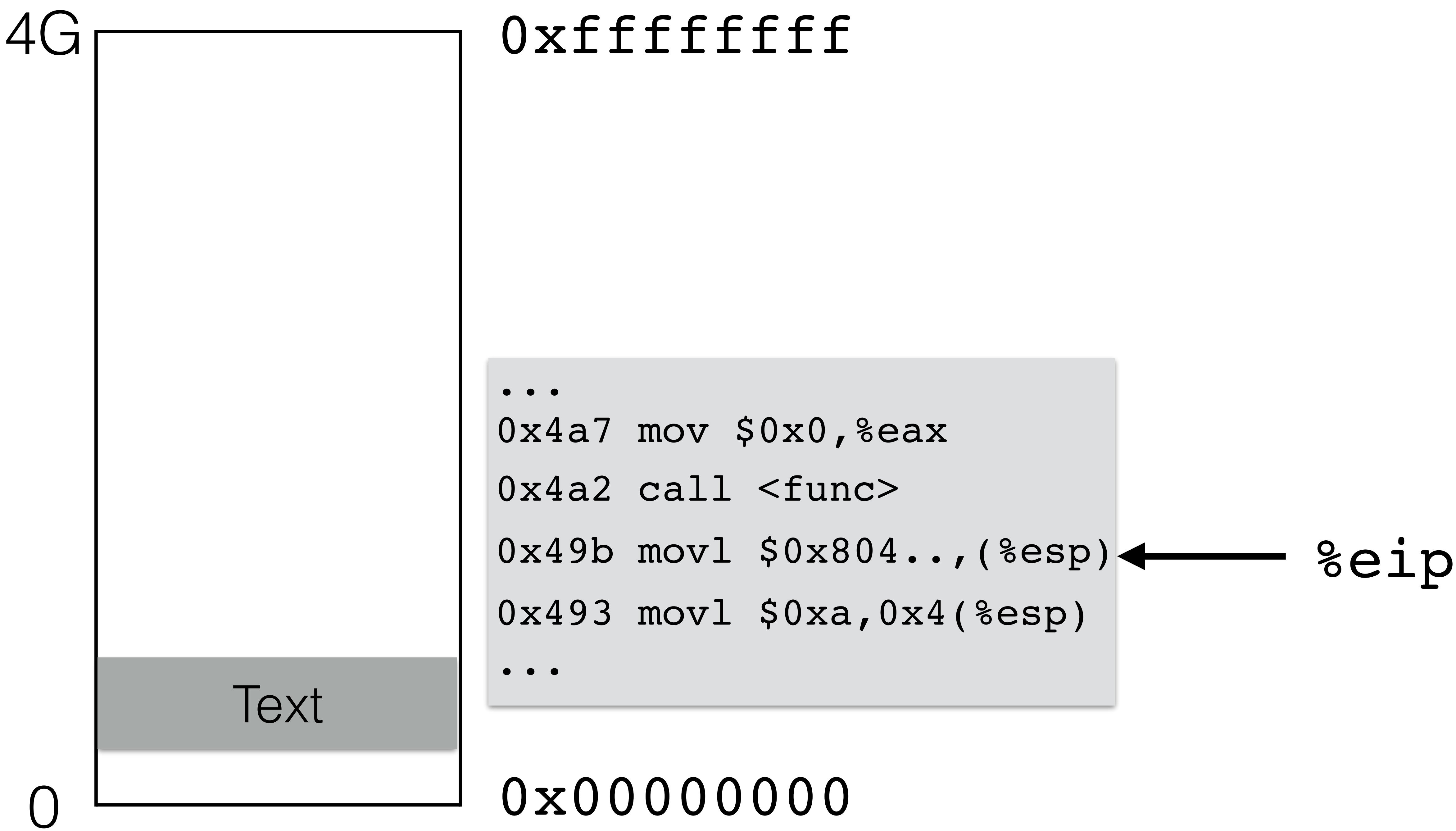

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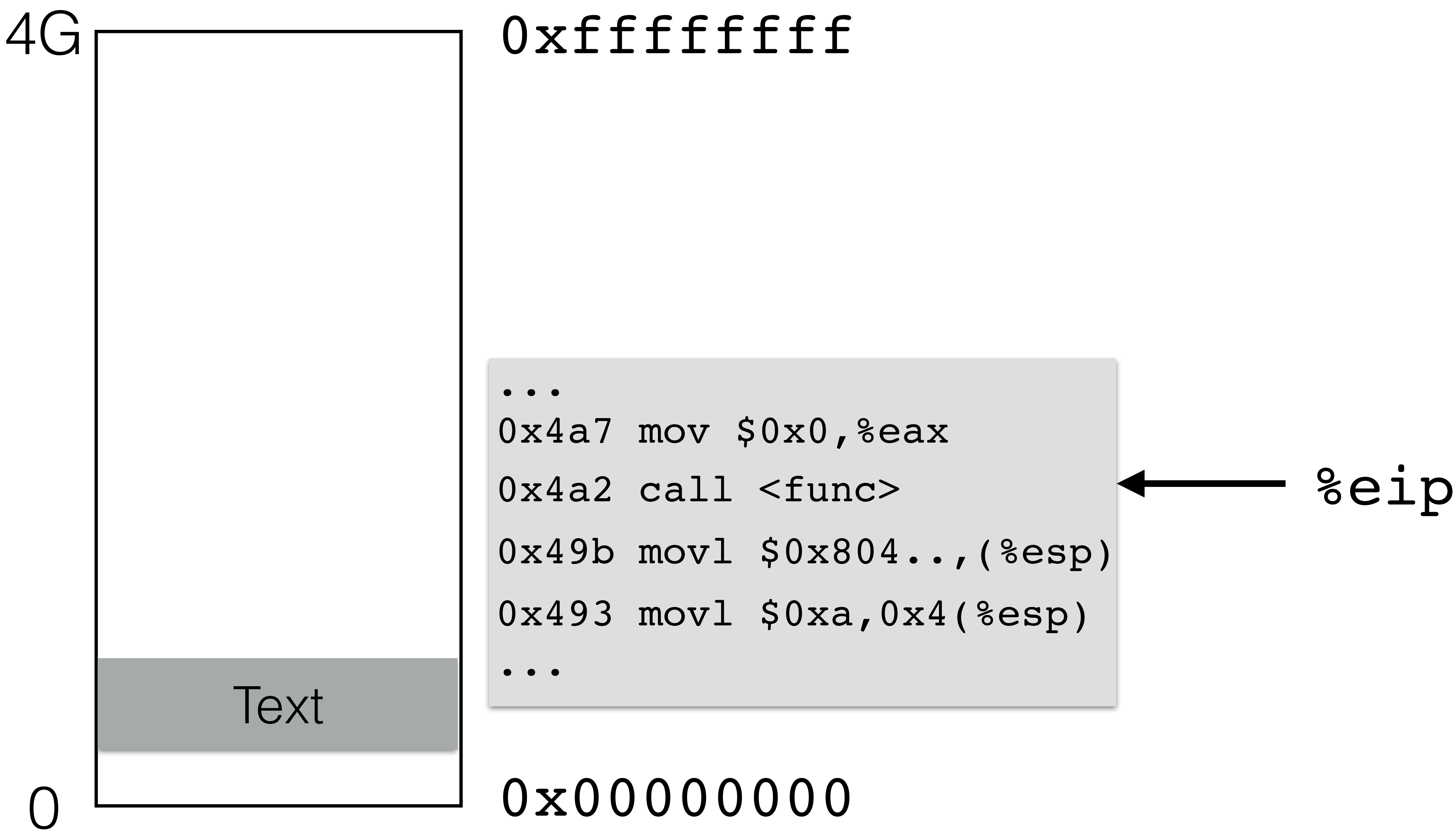

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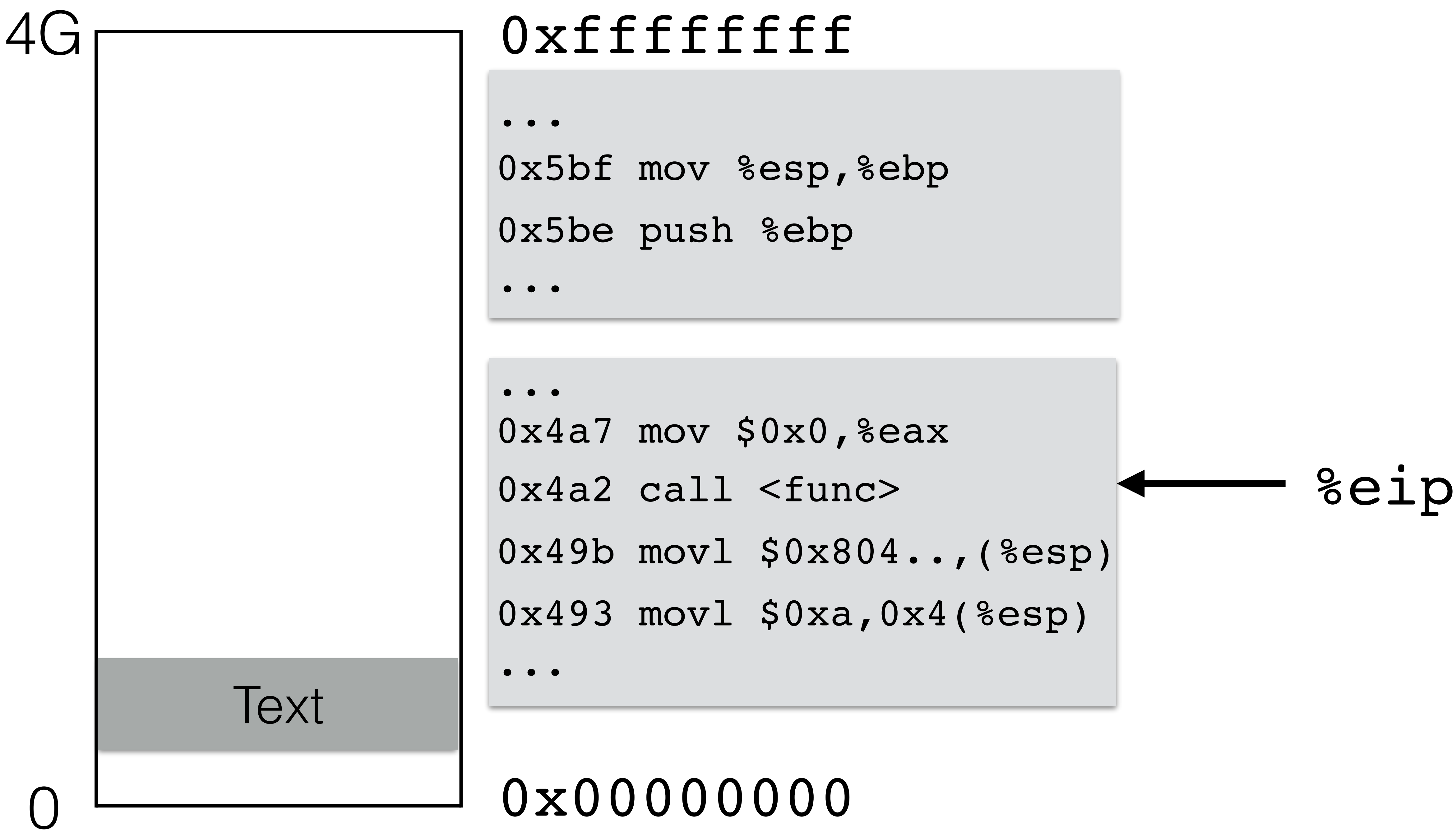

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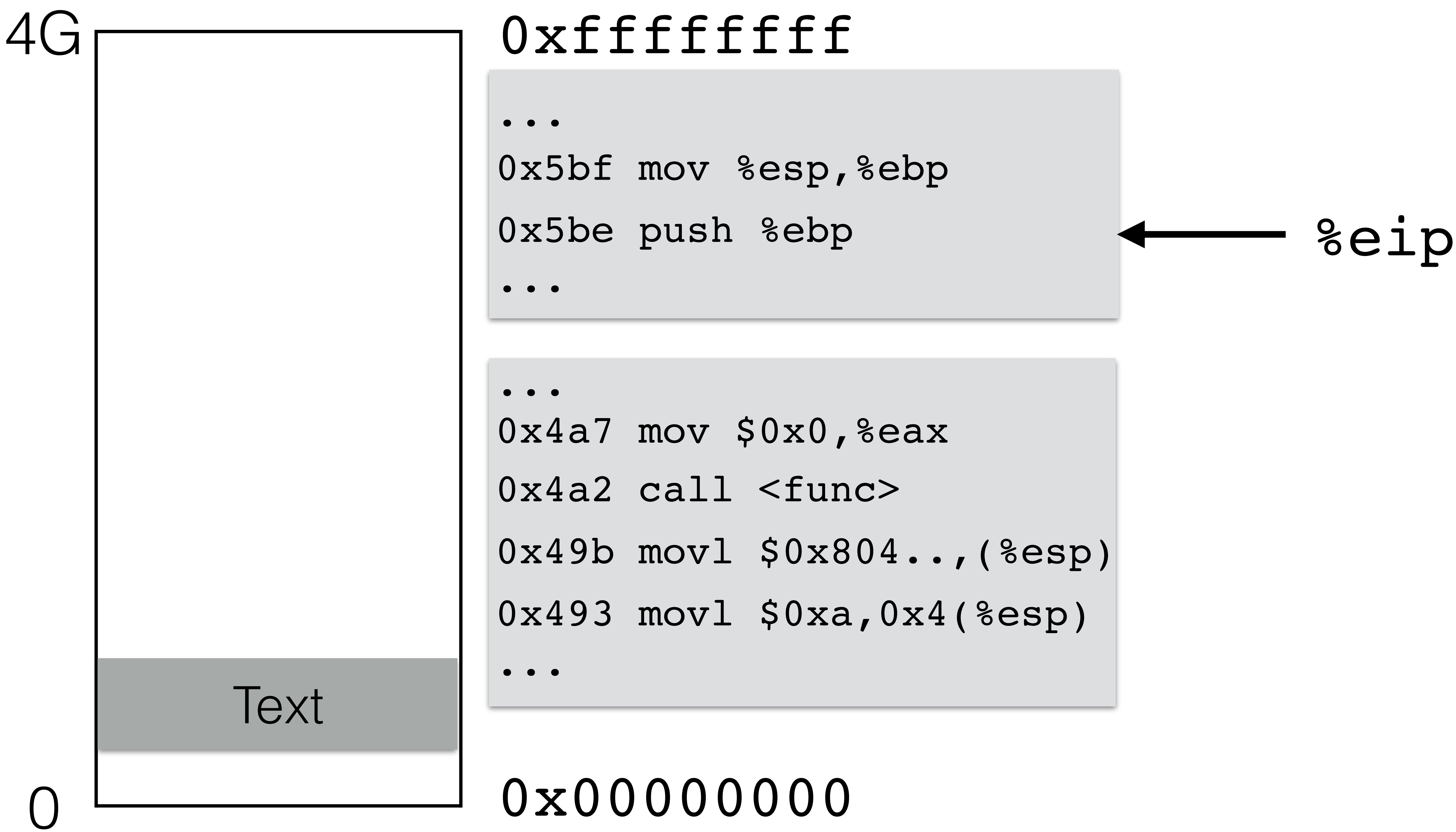

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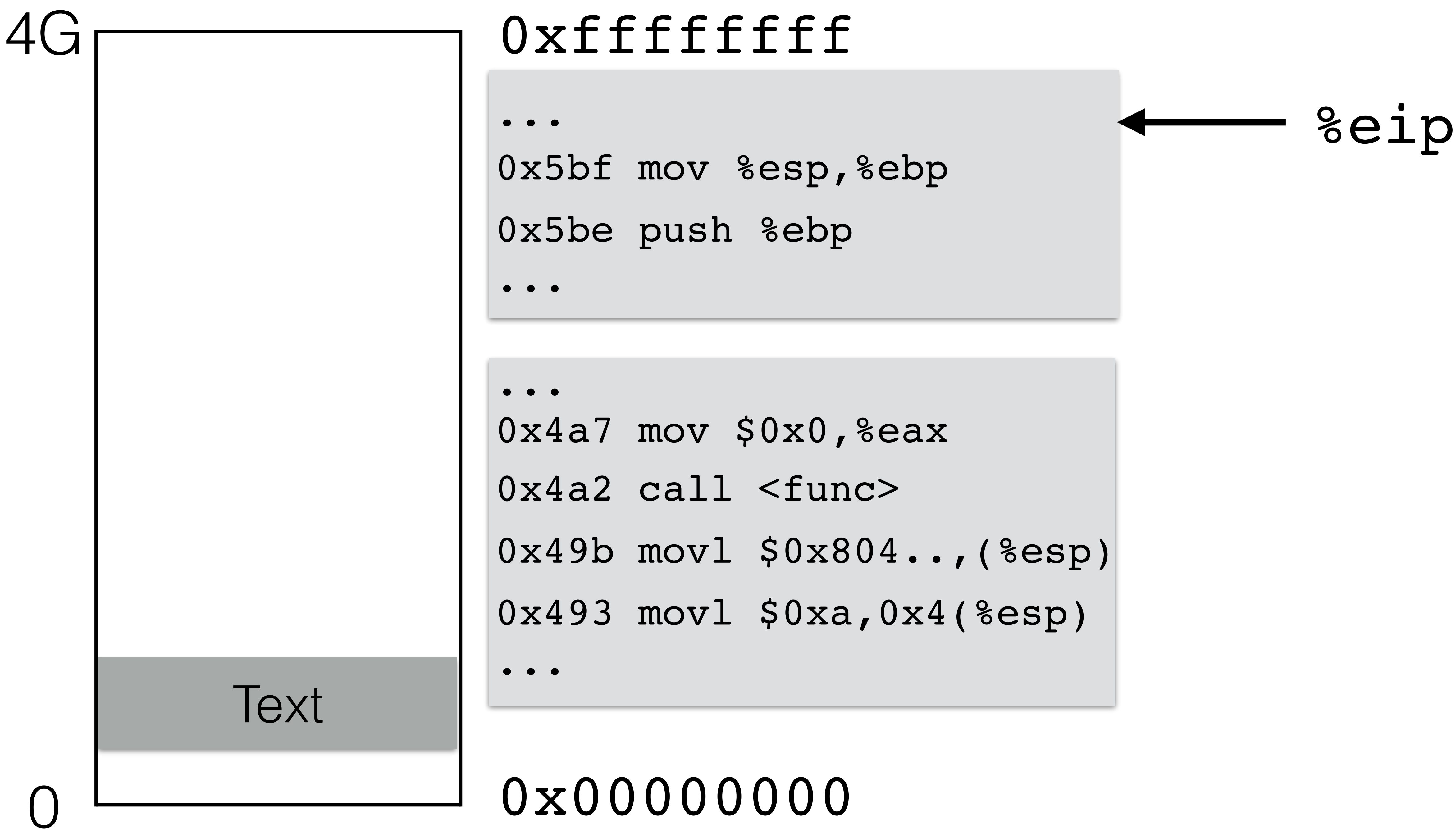

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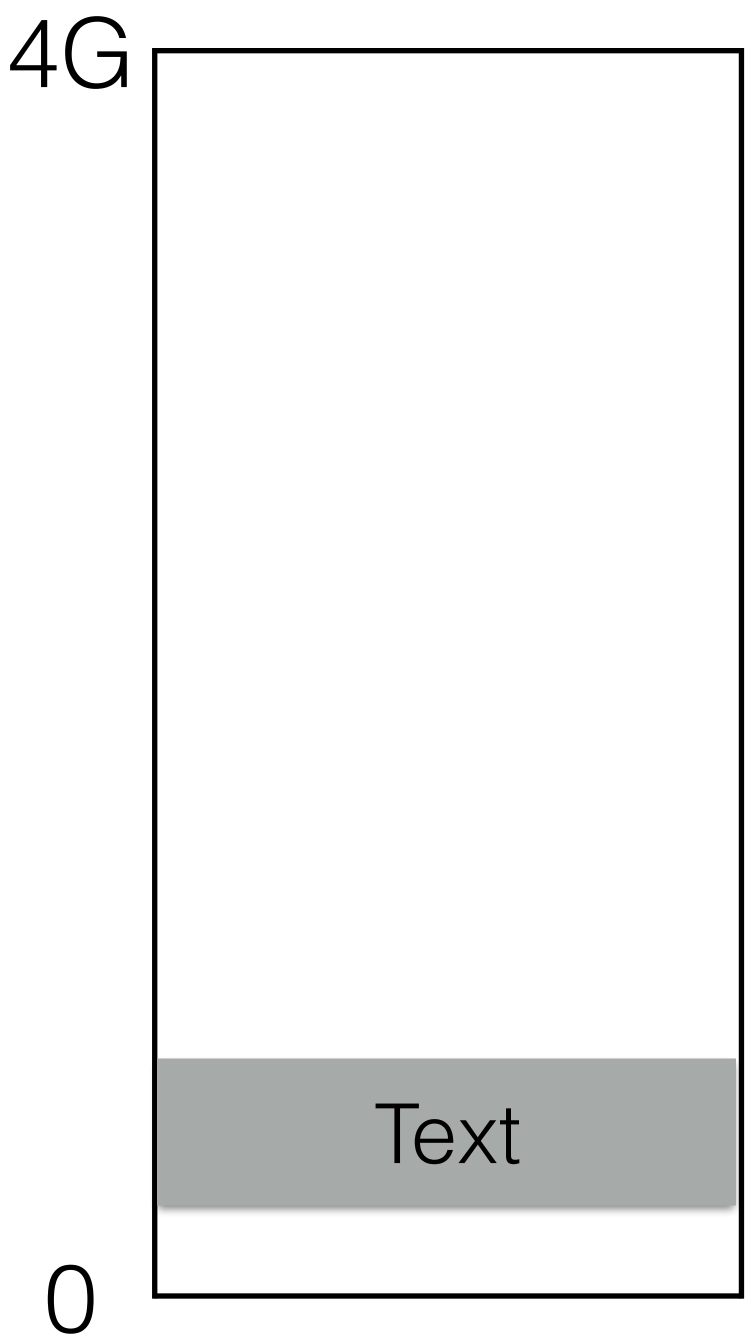



```
0xffffffff

...
0x5bf mov %esp,%ebp
0x5be push %ebp
...

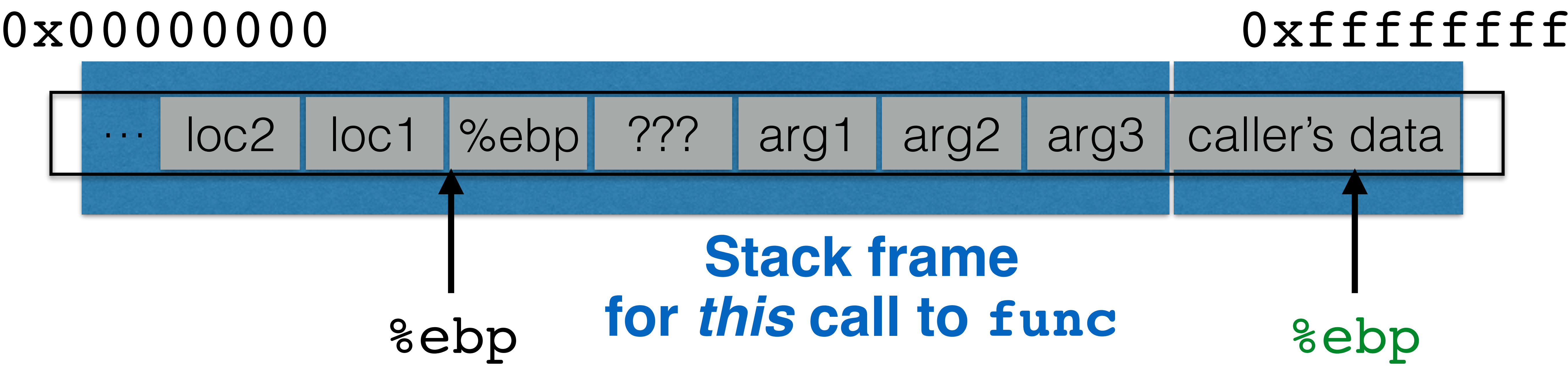
...
0x4a7 mov $0x0,%eax      <- %eip
0x4a2 call <func>
0x49b movl $0x804..,(%esp)
0x493 movl $0xa,0x4(%esp)
...

0x00000000
```

Returning from functions

```
int main()
{
    ...
    func("Hey", 10, -3);
    ...
}
```

Q: How do we resume here?



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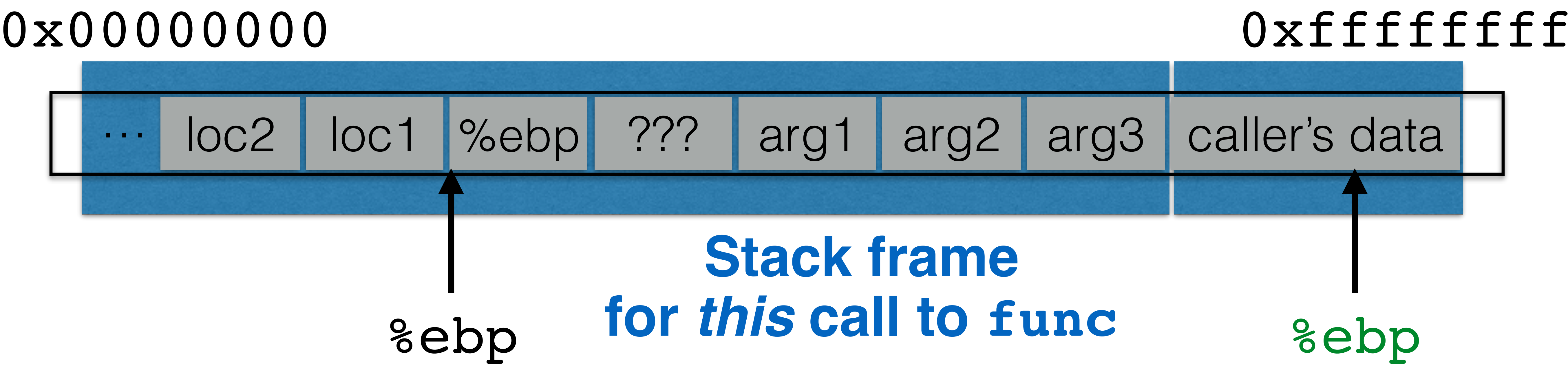
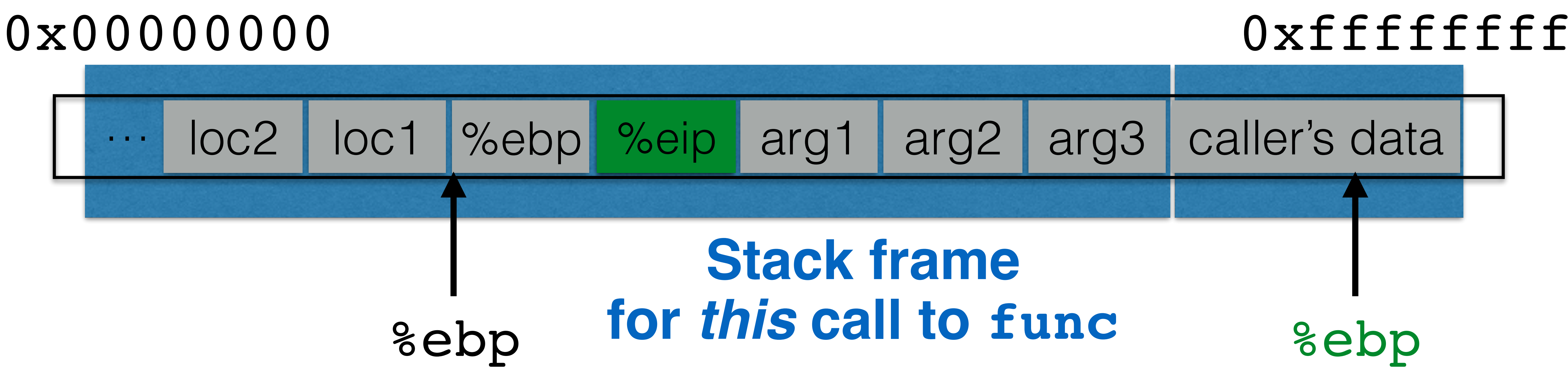


Push next `%eip` before `call`

Returning from functions

```
int main()
{
    ...
    func("Hey", 10, -3);
    ... 
}
```

Q: How do we resume here?

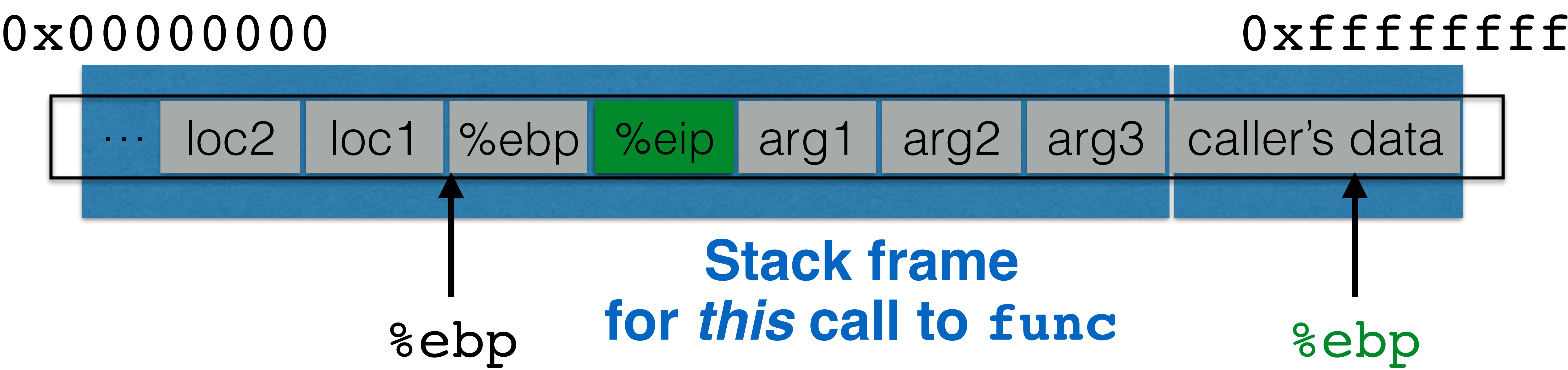


Push next `%eip` before `call`

Returning from functions

```
int main()
{
    ...
    func("Hey", 10, -3);
    ... 
}
```

Q: How do we resume here?



Set `%eip to 4(%ebp)` at return

Push next `%eip` before `call`

Stack and functions: Summary

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Calling function:

1. **Push arguments** onto the stack (in reverse)
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Returning function:

7. **Reset the previous stack frame**: %ebp = (%ebp)
8. **Jump back to return address**: %eip = 4(%ebp)

Buffer overflows

Buffer overflows from 10,000 ft

- Buffer =
  - Contiguous set of a given data type
  - Common in C
    - All strings are buffers of `char`'s
- Overflow =
  - Put more into the buffer than it can hold
- Where does the extra data go?
- Well now that you're experts in memory layouts…

A buffer overflow example

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

int main()
{
    char *mystr = "AuthMe!";
    func(mystr);
    ...
}
```

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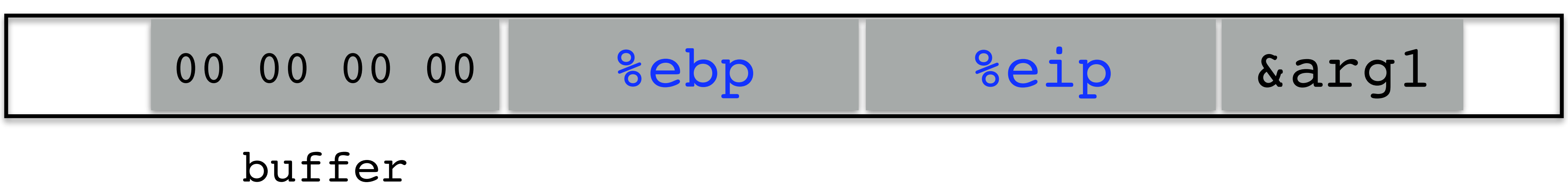

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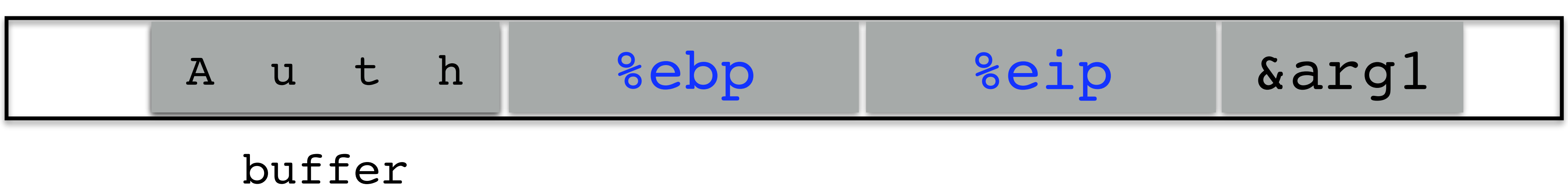

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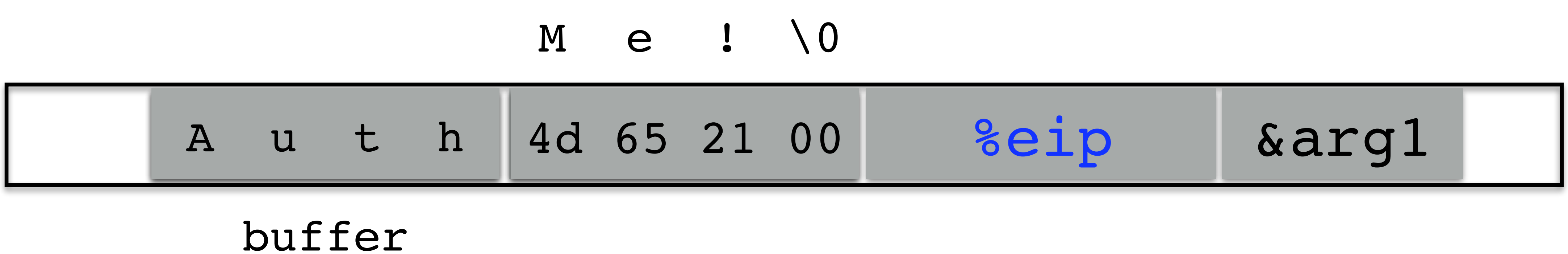

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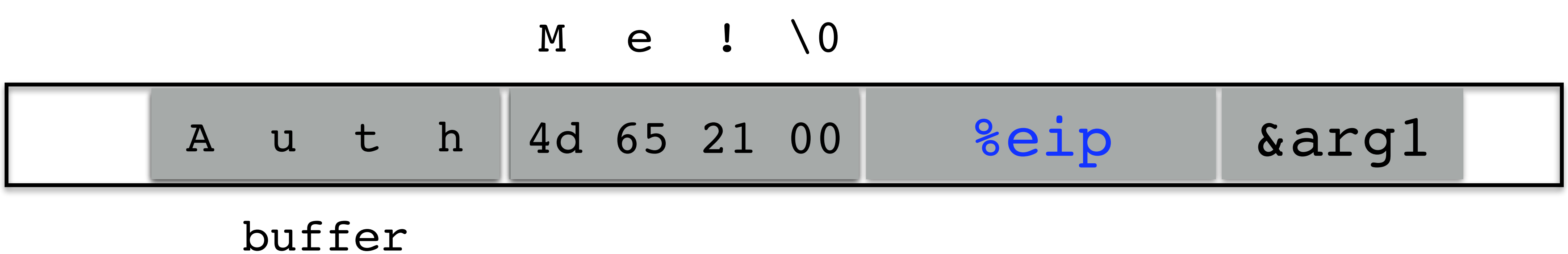
Upon return, sets `%ebp` to `0x0021654d`



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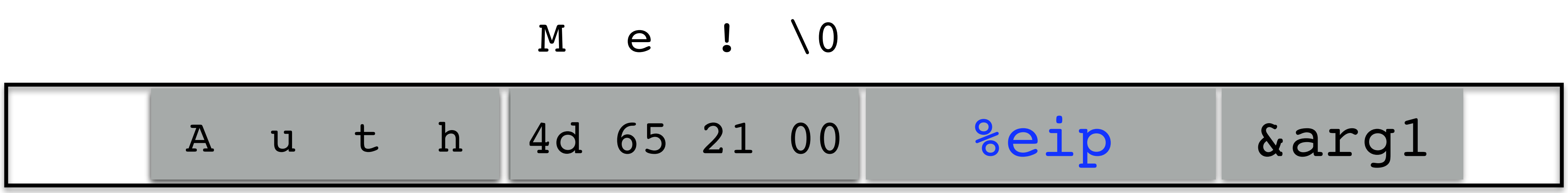

buffer

SEGFAULT (0x00216551)

A 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);
    ...
}
```

A buffer overflow example

```
void func(char *arg1)
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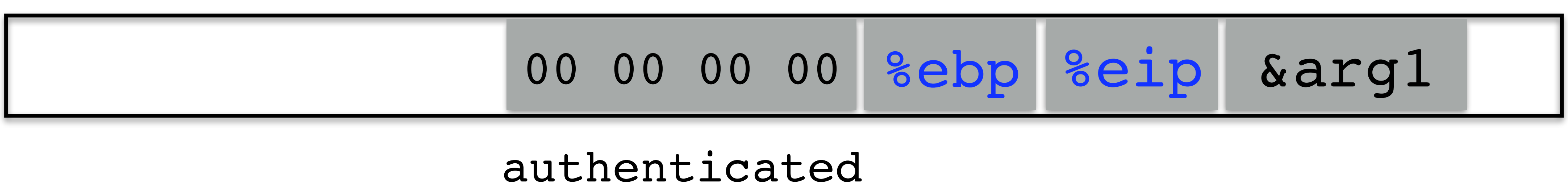

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    func(mystr);
    ...
}
```

	00 00 00 00	00 00 00 00	%ebp	%eip	&arg1	
	buffer	authenticated				

A buffer overflow example

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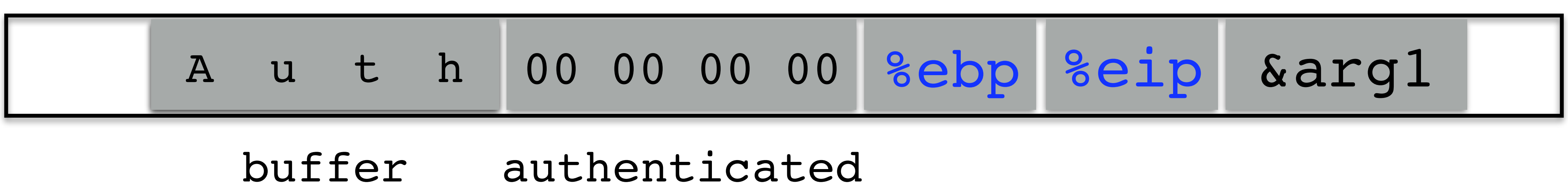

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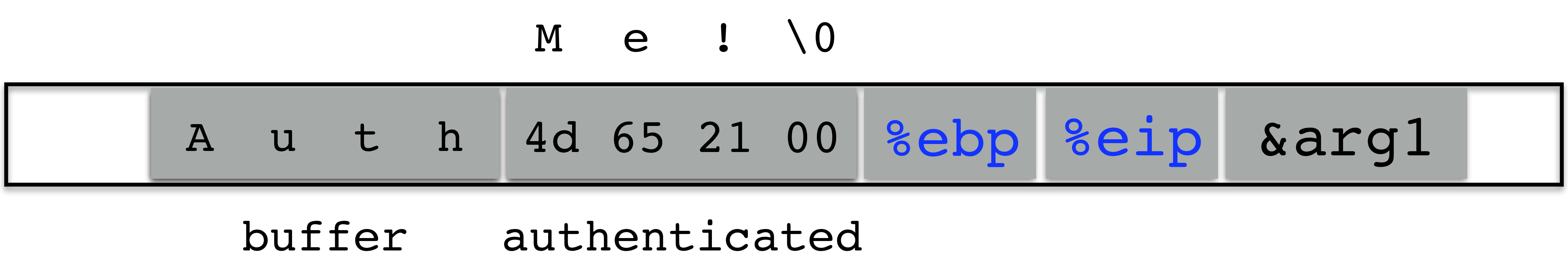

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}

int main()
{
    char *mystr = "AuthMe!";
    func(mystr);
    ...
}
```

Code still runs; user now 'authenticated'

	M e ! \0			
A u t h	4d 65 21 00	%ebp	%eip	&arg1
buffer	authenticated			

```
void vulnerable()
{
    char buf[80];
    gets(buf);
}
```

```c
void vulnerable()
{
    char buf[80];
    gets(buf);
}
```

```c
void still_vulnerable()
{
    char *buf = malloc(80);
    gets(buf);
}
```

```
void safe()
{
    char buf[80];
    fgets(buf, 64, stdin);
}
```

```c
void safe()
{
    char buf[80];
    fgets(buf, 64, stdin);
}
```

```c
void safer()
{
    char buf[80];
    fgets(buf, sizeof(buf), stdin);
}
```

IE's Role in the Google-China War

By Richard Adhikari
TechNewsWorld
01/15/10 12:25 PM PT

A A Text Size
Print Version
E-Mail Article

The hack attack on Google that set off the company's ongoing standoff with China appears to have come through a zero-day flaw in Microsoft's Internet Explorer browser. Microsoft has released a security advisory, and researchers are hard at work studying the exploit. The attack appears to consist of several files, each a different piece of malware.

Computer security companies are scurrying to cope with the fallout from the Internet Explorer (IE) flaw that led to cyberattacks on Google and its corporate and individual customers.

The zero-day attack that exploited IE is part of a lethal cocktail of malware that is keeping researchers very busy.

"We're discovering things on an up-to-the-minute basis, and we've seen about a dozen files dropped on infected PCs so far," Dmitri Alperovitch, vice president of research at McAfee Labs, told TechNewsWorld.

The attacks on Google, which appeared to originate in China, have sparked a feud between the Internet giant and the nation's government over censorship, and it could result in Google pulling away from its business dealings in the country.

Pointing to the Flaw

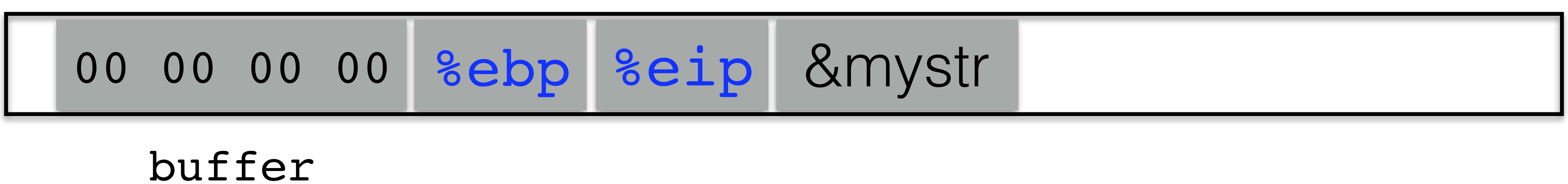
The vulnerability in IE is an invalid pointer reference, Microsoft said in security advisory 979352, which it issued on Thursday. Under certain conditions, the invalid pointer can be accessed after an object is deleted, the advisory states. In specially crafted attacks, like the ones launched against Google and its customers, IE can allow remote execution of code when the flaw is exploited.

User-supplied strings

- In these examples, we were providing our own strings
- But they come from users in myriad aways
  - Text input
  - Packets
  - Environment variables
  - File input…

What's the worst that could happen?

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



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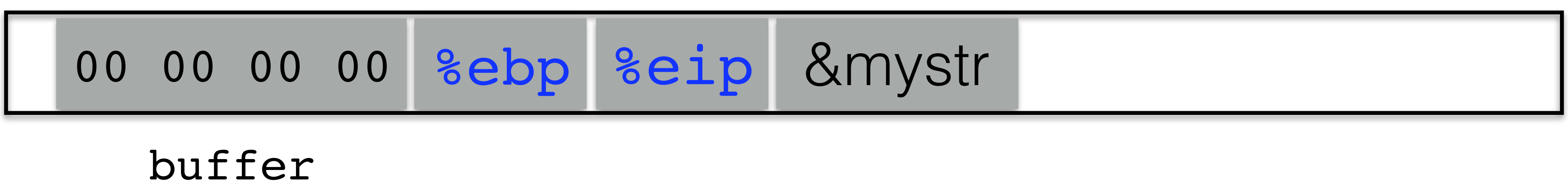
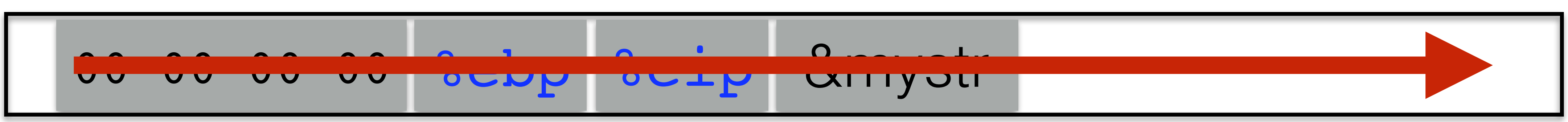


`strcpy` will let you write as much as you want (til a '\0')

What's the worst that could happen?

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

All ours!



buffer

`strcpy` will let you write as much as you want (til a '\0')

What's the worst that could happen?

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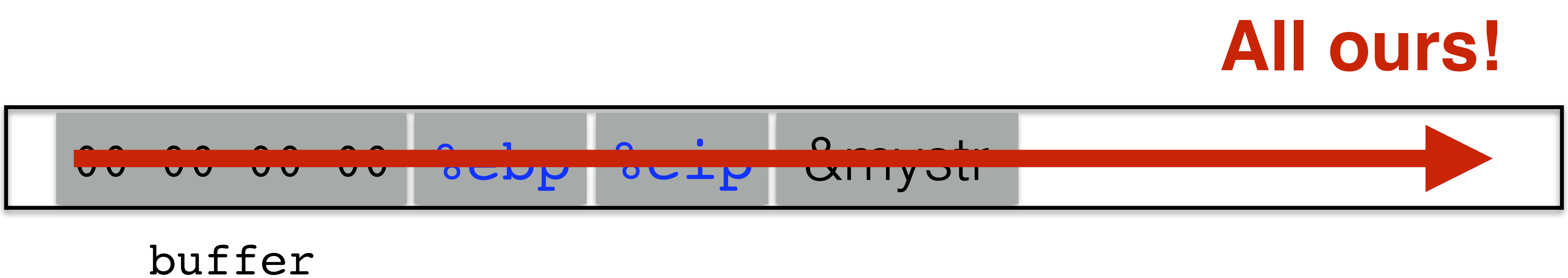

`strcpy` will let you write as much as you want (til a '\0')

What could you write to memory to wreak havoc?

Code injection

High-level idea

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

High-level idea

```
void func(char *arg1)
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```

buffer

(1) Load my own code into memory

High-level idea

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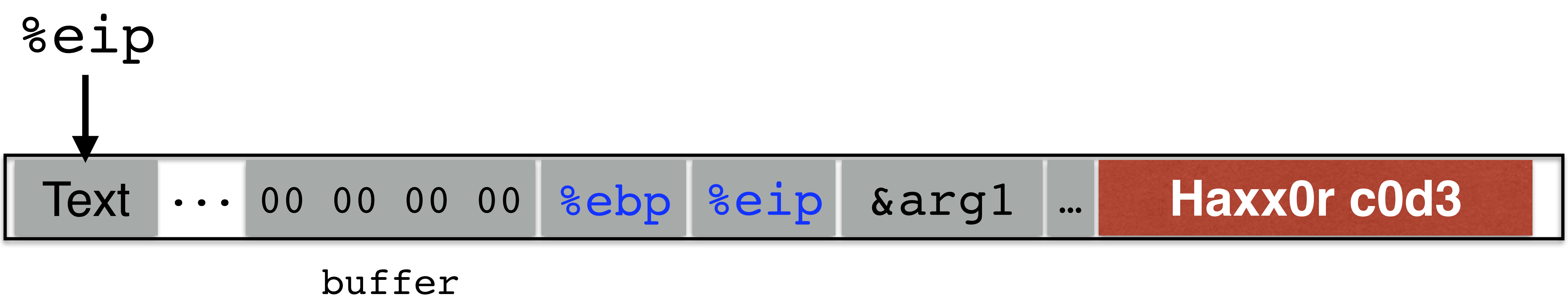

(1) Load my own code into memory

(2) Somehow get `%eip` to point to it

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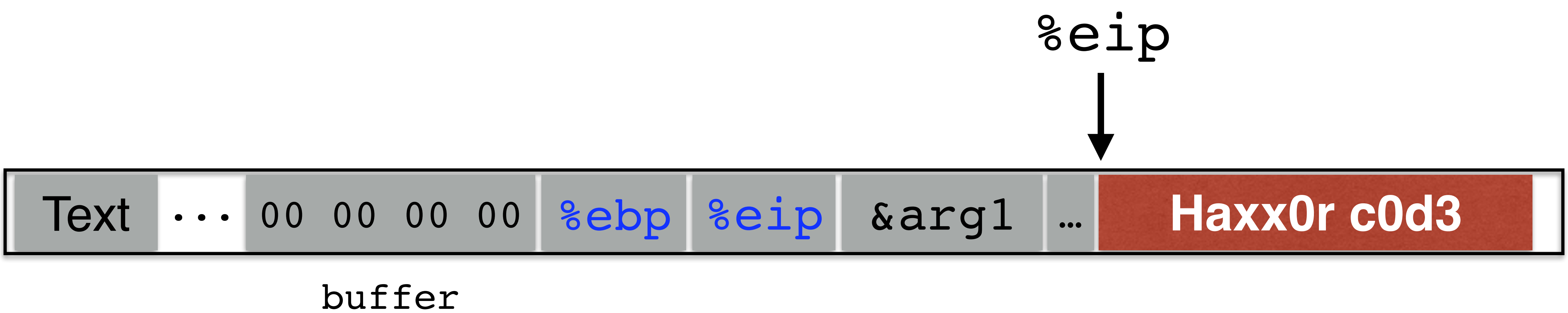

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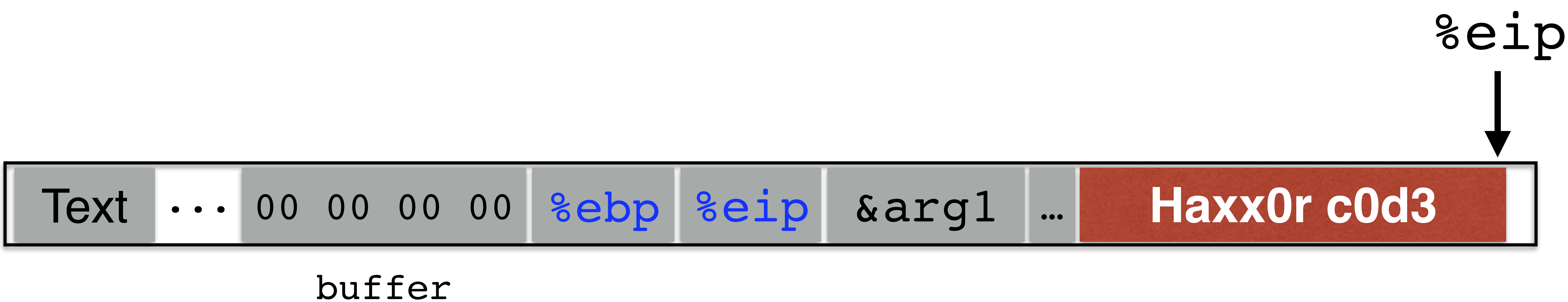

(1) Load my own code into memory

(2) Somehow get `%eip` to point to it

This is nontrivial

- Pulling off this attack requires getting a few things really right (and some things sorta right)

- Think about what is tricky about the attack
    - The key to defending it will be to make the hard parts *really* hard

Challenge 1

Loading code into memory

- It must be the machine code instructions (i.e., already compiled and ready to run)
- We have to be careful in how we construct it:
  - It can't contain any all-zero bytes
    - Otherwise, sprintf / gets / scanf / … will stop copying
    - How could you write assembly to never contain a full zero byte?
  - It can't make use of the loader (we're injecting)
  - It can't use the stack (we're going to smash it)

What kind of code would we want to run?

- Goal: full-purpose shell
  - The code to launch a shell is called “shell code”
  - It is nontrivial to it in a way that works as injected code
    - No zeroes, can’t use the stack, no loader dependence
  - There are many out there
    - And competitions to see who can write the smallest
- Goal: privilege escalation
  - Ideally, they go from guest (or non-user) to root

Shellcode

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

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Assembly

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

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```

Machine code

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

Shellcode

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

(Part of) your input

Privilege escalation

- Permissions later, but for now…
- Recall that each file has:
  - Permissions: read / write / execute
  - For each of: owner / group / everyone else
- Consider a service like passwd
  - Owned by root (and needs to do root-y things)
  - But you want any user to be able to run it

Effective userid

- Userid = the user who ran the process
- Effective userid = what is used to determine what access the process has
- Consider passwd:
  - getuid() will return you (real userid)
  - seteuid(0) to set the effective userid to root
    - It’s allowed to because root is the owner
- What is the potential attack?

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If you can get a root-owned process to run setuid(0)/seteuid(0), then you get root permissions

Challenge 2

Getting our injected code to run

- We can't insert a "jump into my code" instruction
- We have to use whatever code is already running

Thoughts?

Challenge 2

Getting our injected code to run

- We can't insert a "jump into my code" instruction
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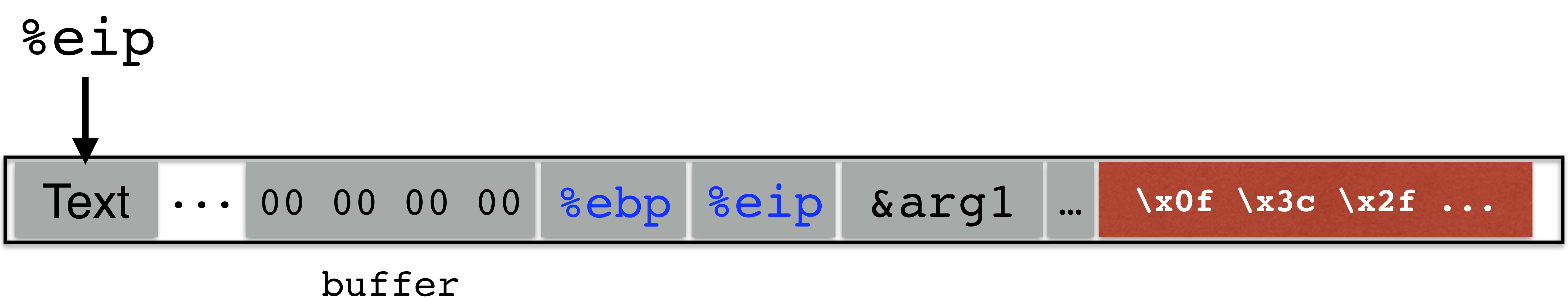

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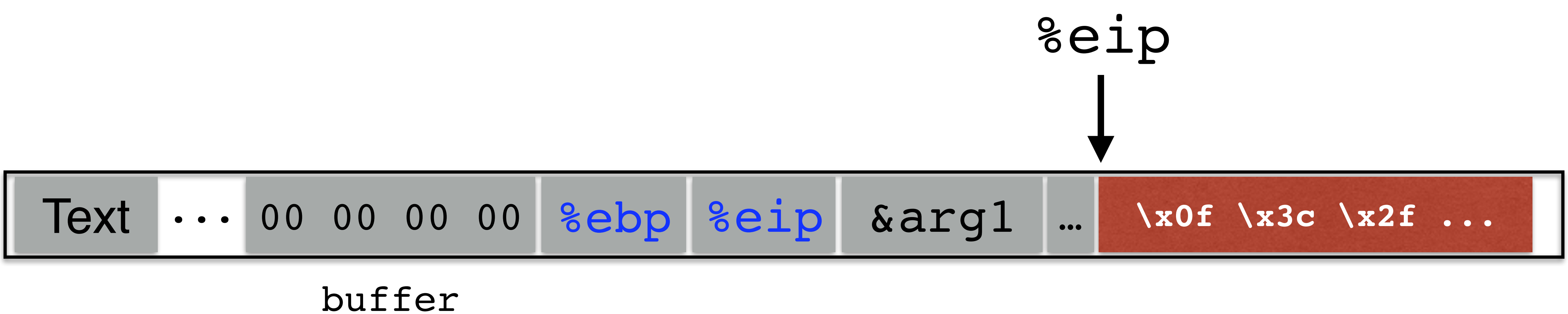

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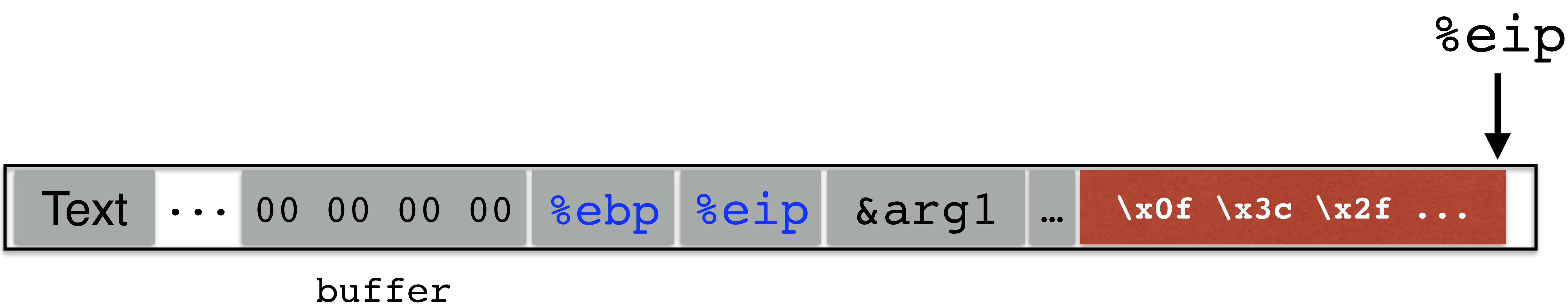

Thoughts?

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2. **Push the return address**, i.e., the address of the instruction you want run after control returns to you: %eip+something
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Returning function:

7. **Reset the previous stack frame**: %ebp = (%ebp)
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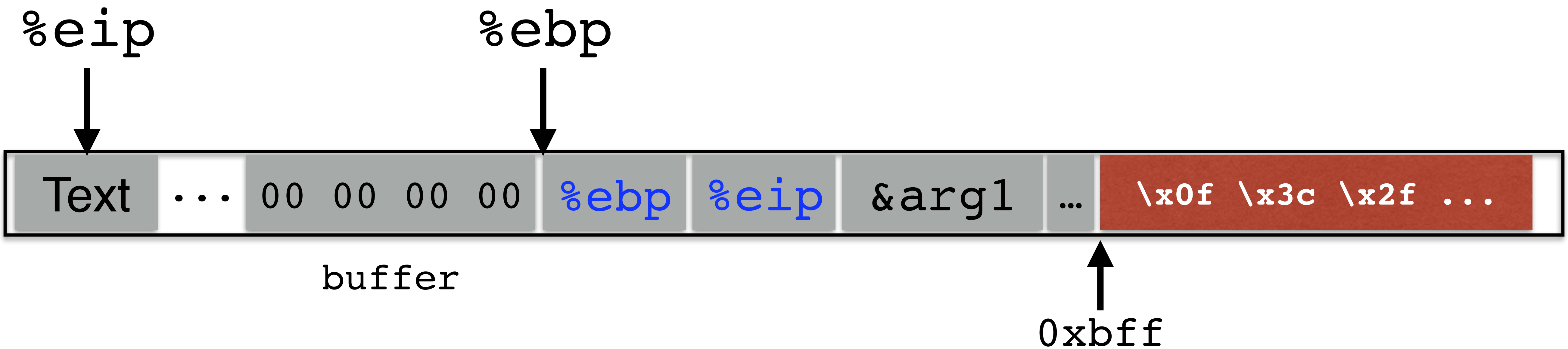
Hijacking the saved `%eip`



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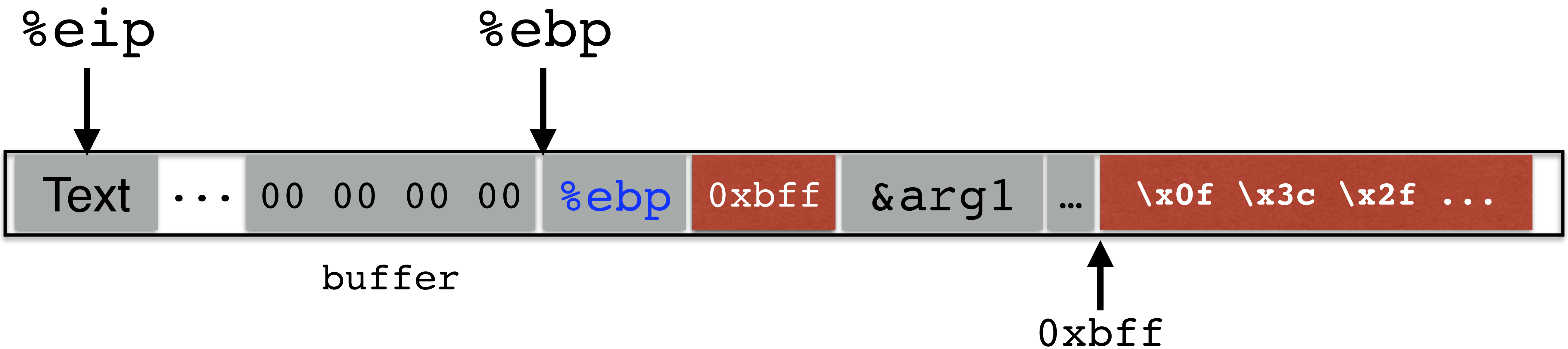

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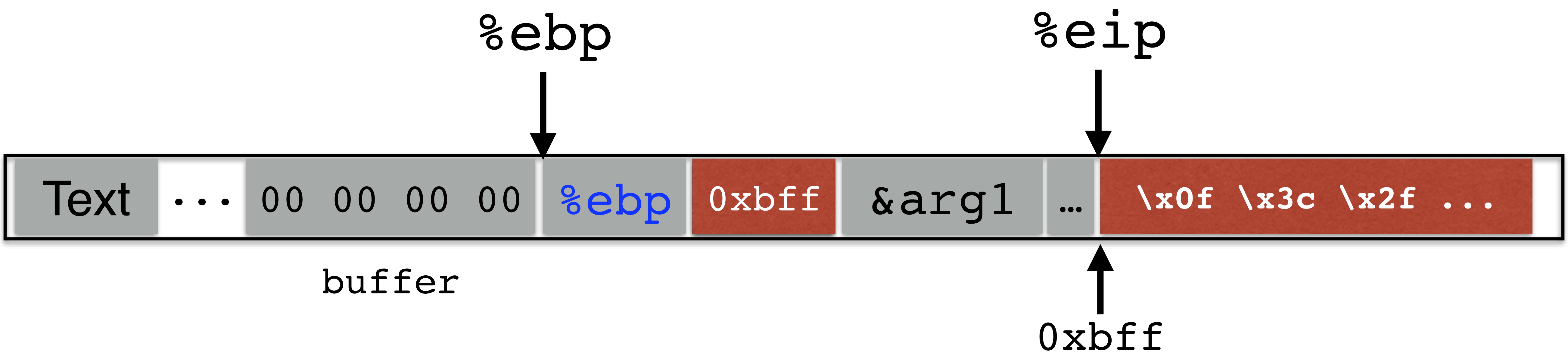
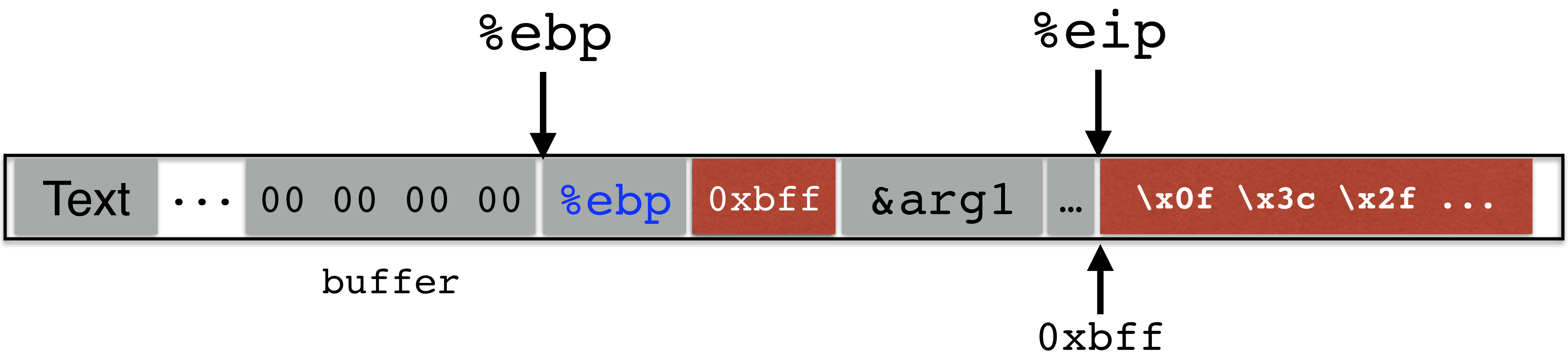


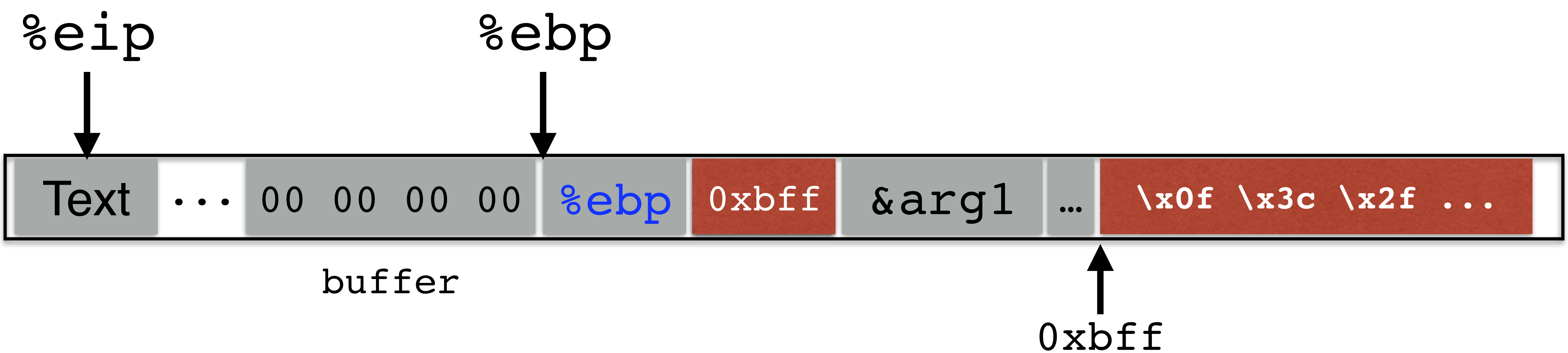
Hijacking the saved `%eip`



But how do we know the address?

Hijacking the saved `%eip`

What if we are wrong?



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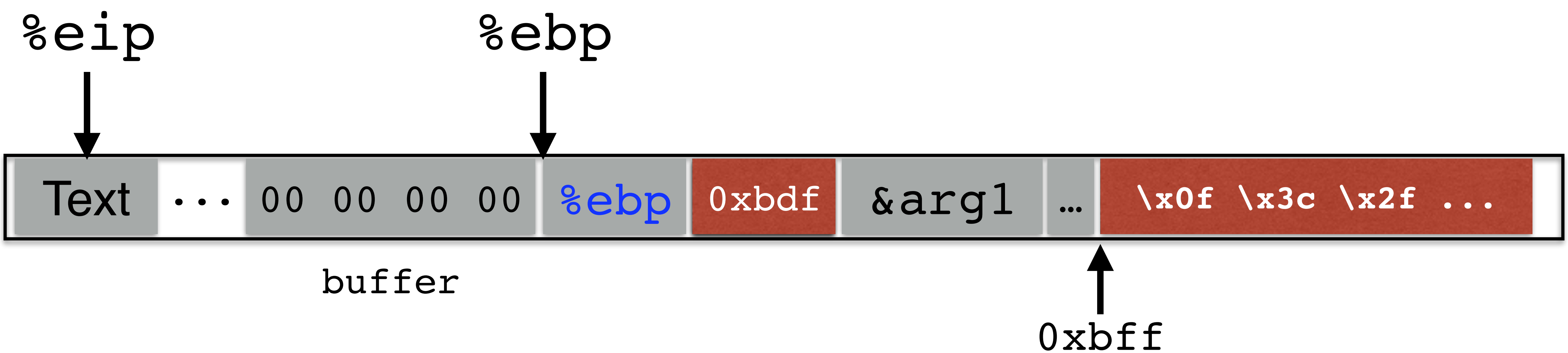

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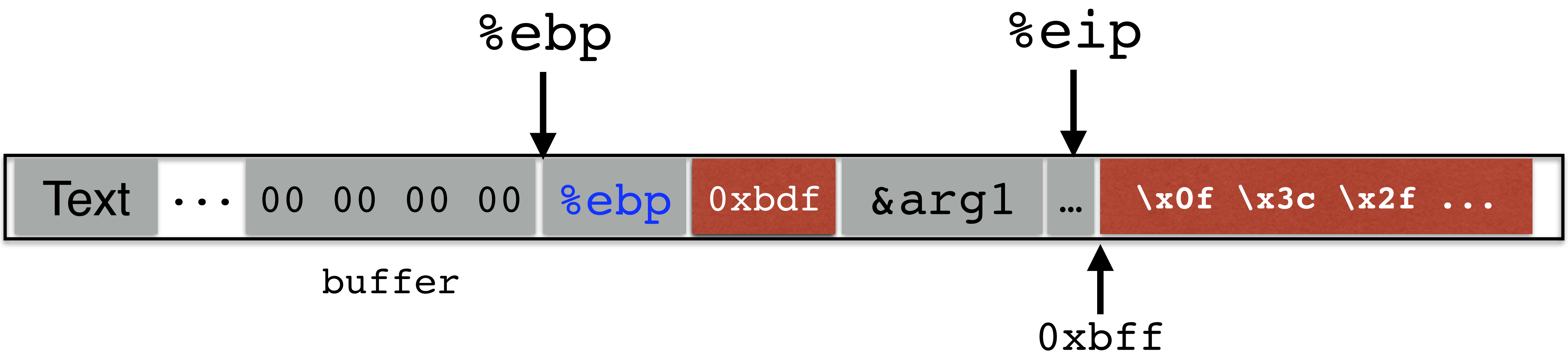

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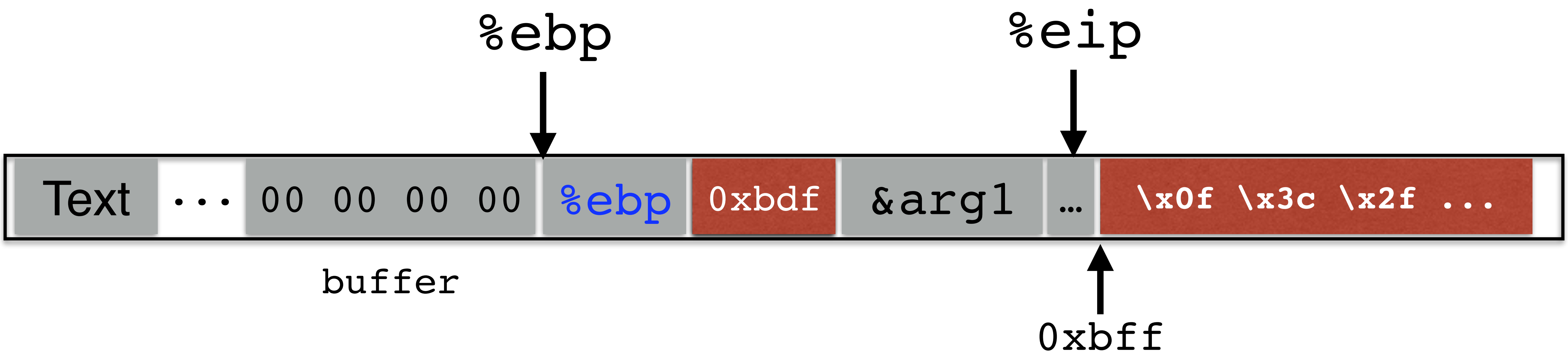

This is most likely data, so the CPU will panic (Invalid Instruction)

Challenge 3

Finding the return address

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Challenge 3

Finding the return address

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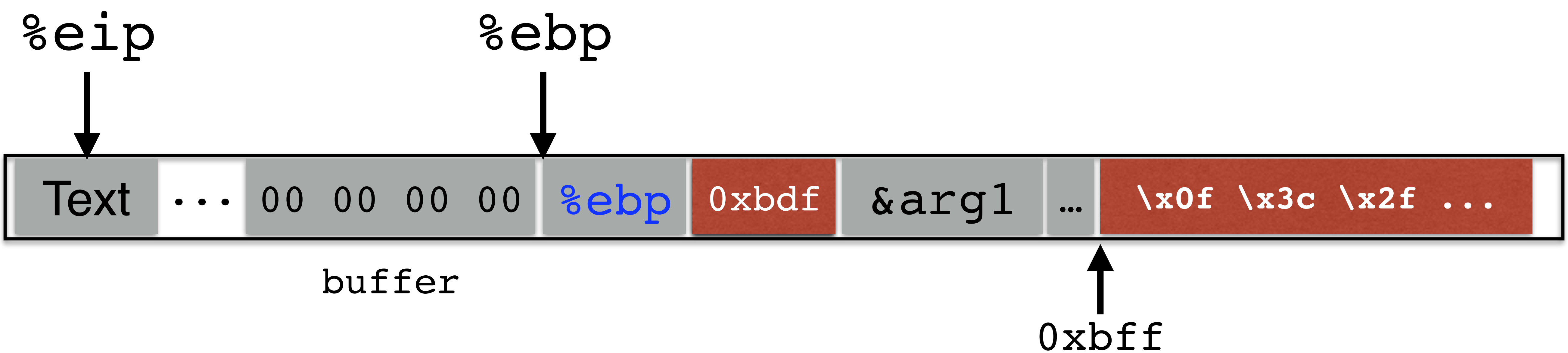
- One approach: just try a lot of different values!
- Worst case scenario: it's a 32 (or 64) bit memory space, which means 2^{32} (2^{64}) possible answers
- But without address randomization:
  - The stack always starts from the same, fixed address
  - The stack will grow, but usually it doesn't grow very deeply (unless the code is heavily recursive)

`gdb` tutorial

Improving our chances: **nop** sleds

nop is a single-byte instruction
(just moves to the next instruction)



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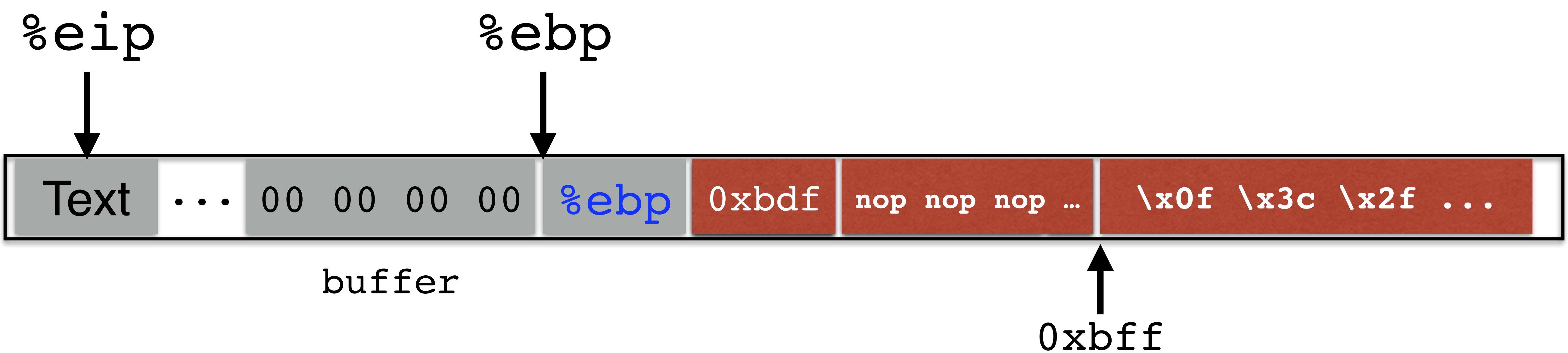

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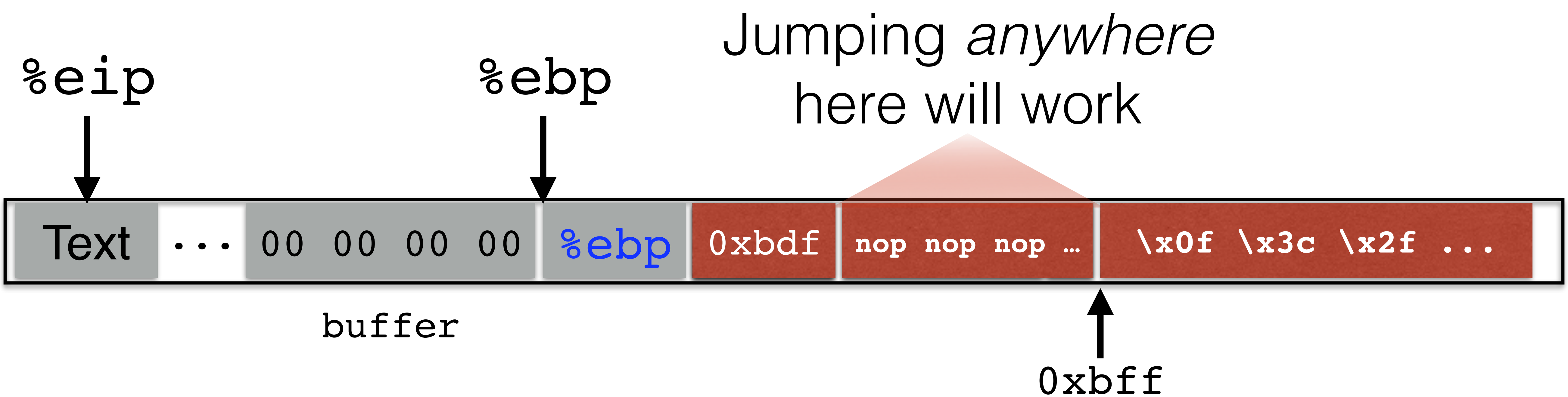

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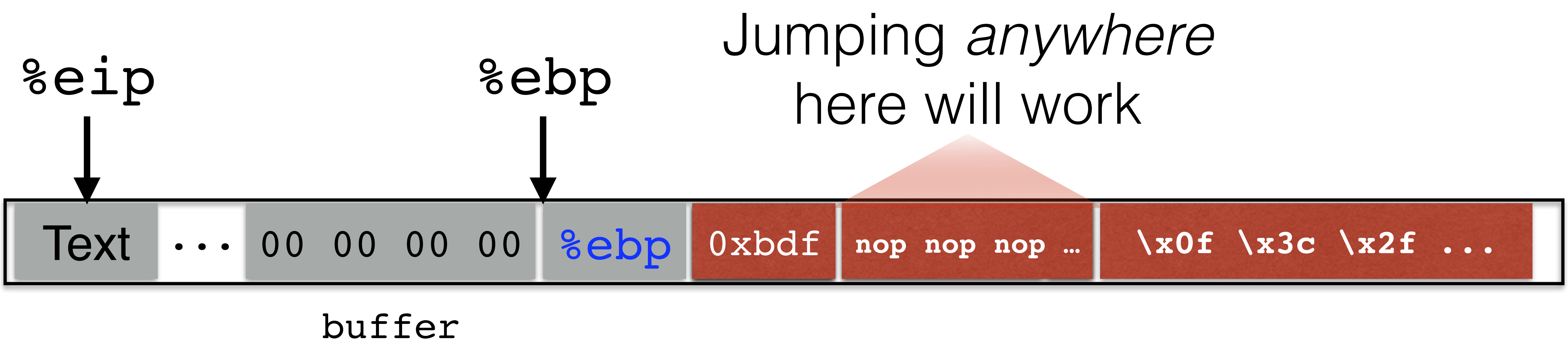

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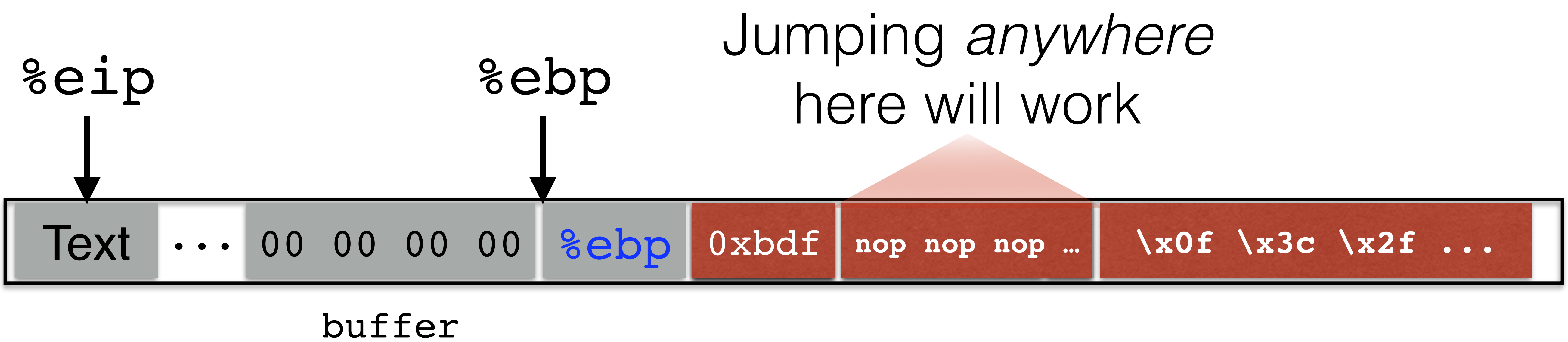
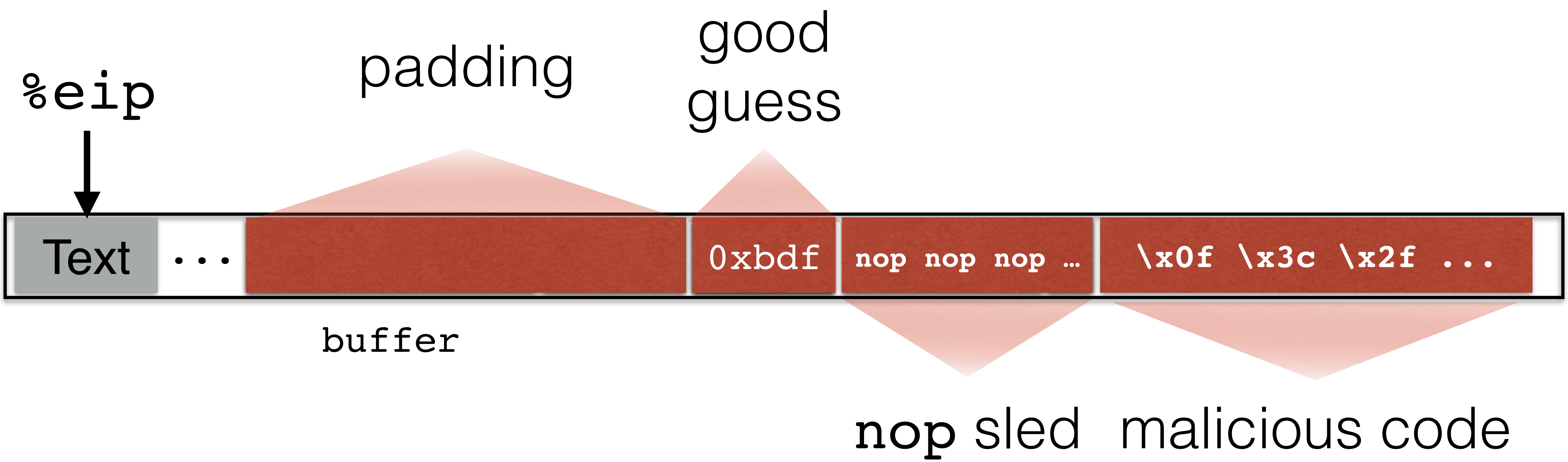


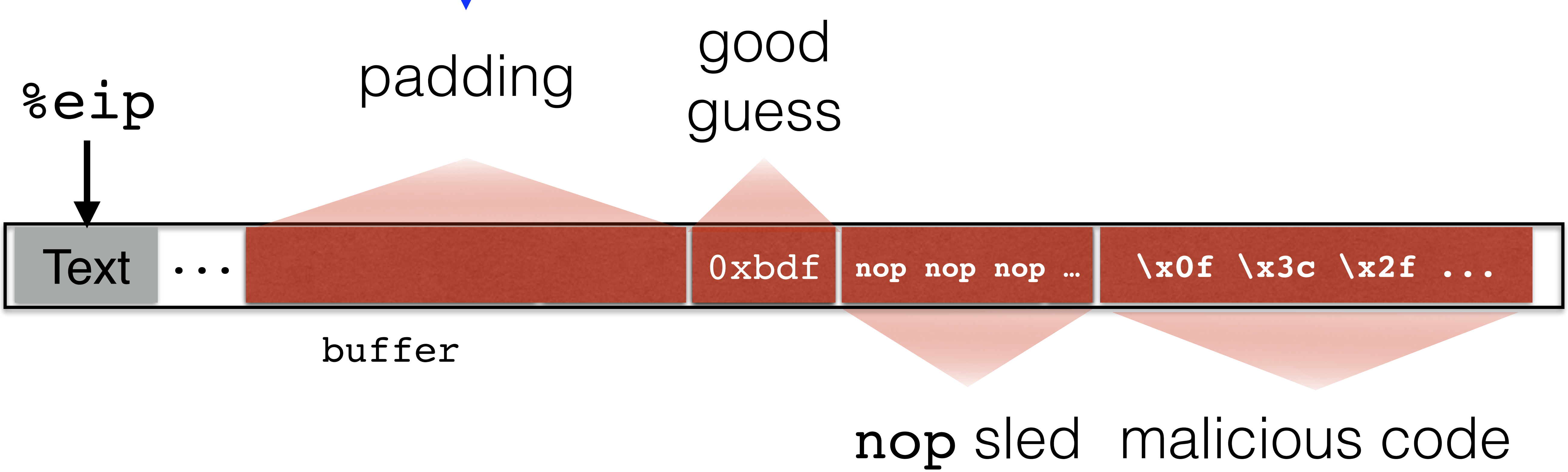
Now we improve our chances of guessing by a factor of #nops

Putting it all together



Putting it all together

But it has to be *something*;
we have to start writing wherever
the input to **gets**/etc. begins.



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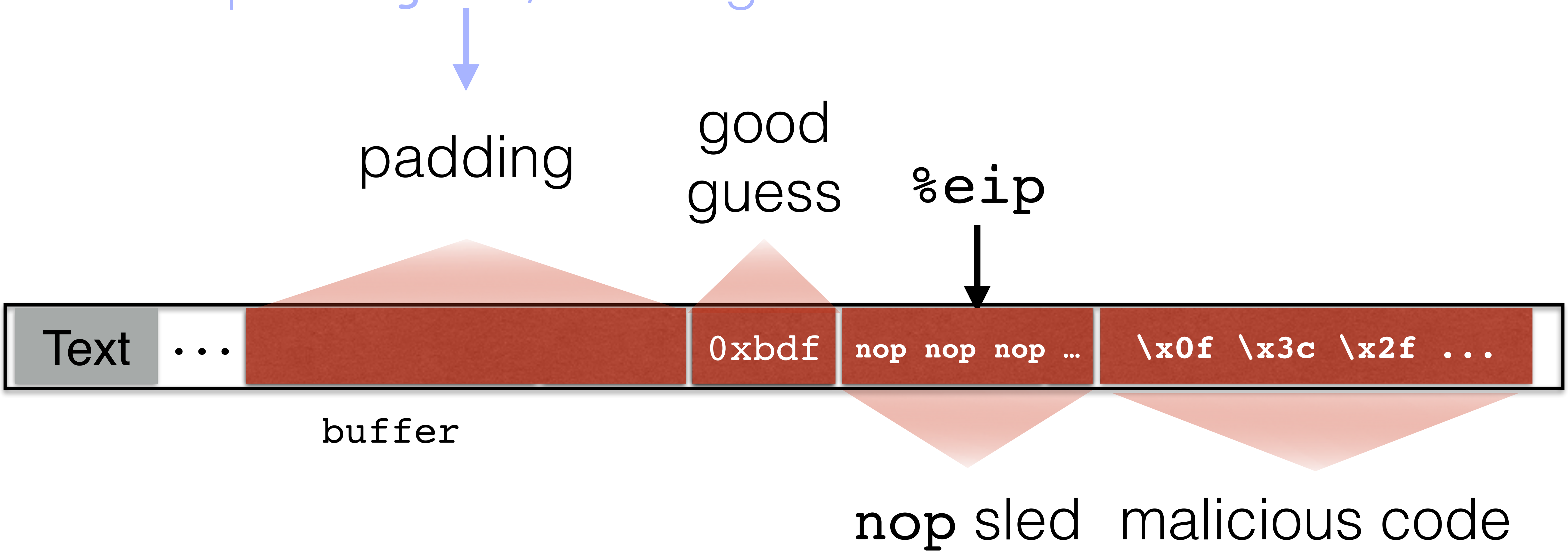

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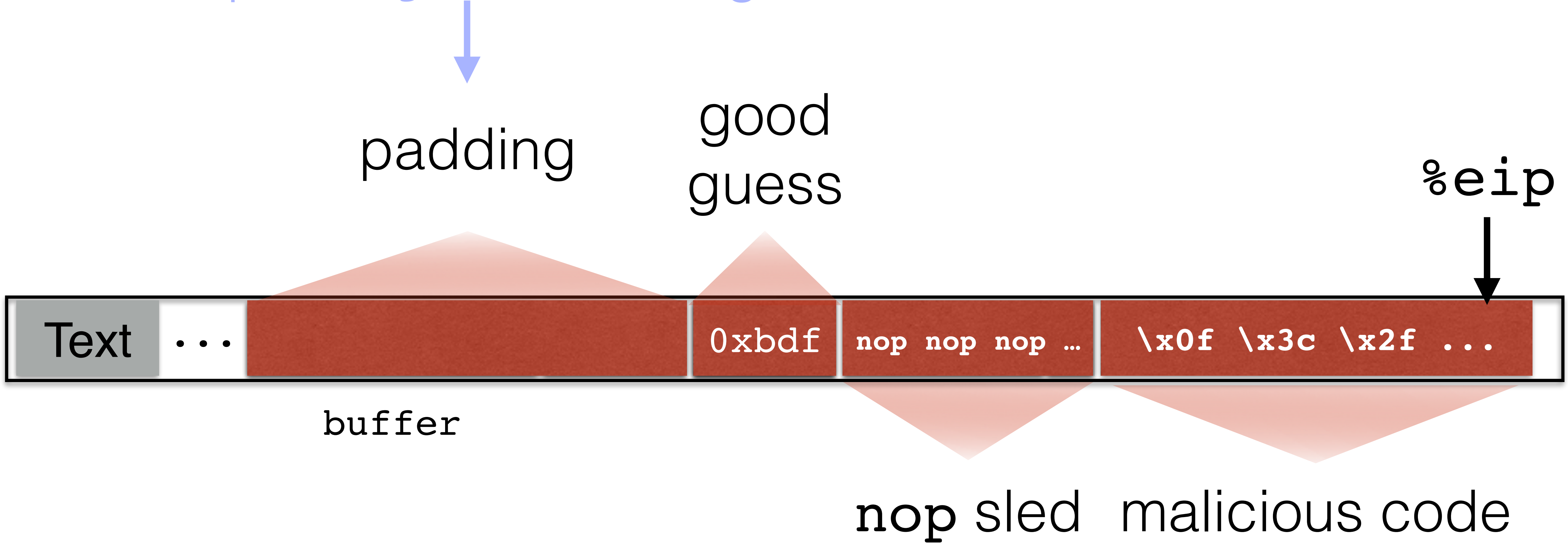

Next time

Continuing with

Software Security

More attacks, and

Defenses

Required reading:

"StackGuard: Simple Stack Smash Protection for GCC"