

This time Software Security

By investigating
**Buffer
overflows**

and other memory safety vulnerabilities

- History
- Memory layouts
- Buffer overflow fundamentals

Software

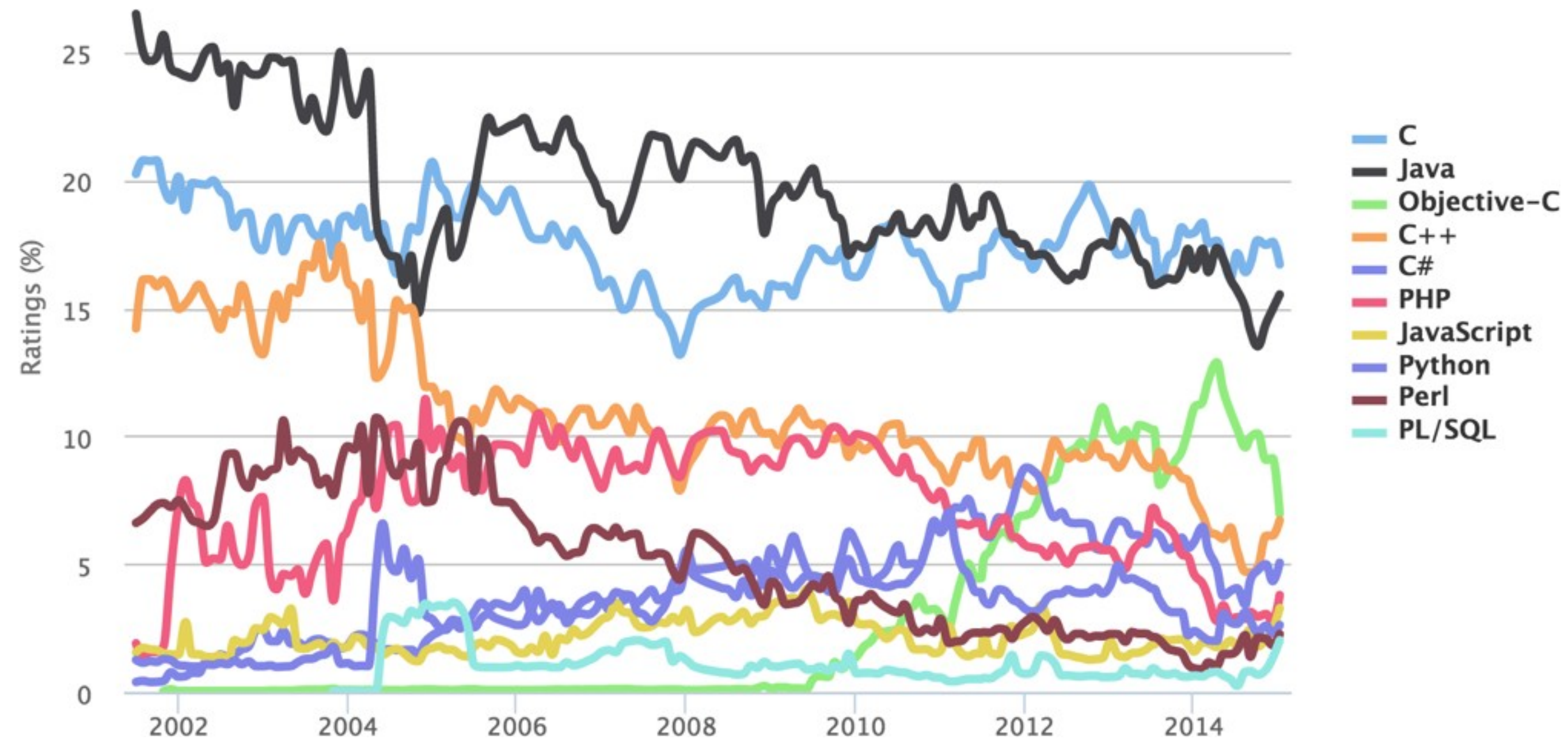
Security

- 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?

We're going to focus on C

C is still very popular



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



- **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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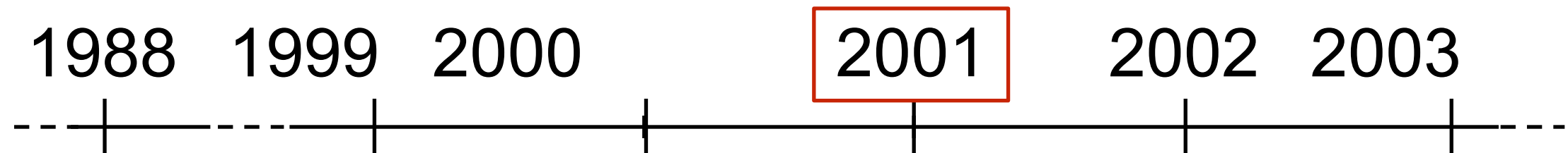


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Robert Morris is now a professor at MIT

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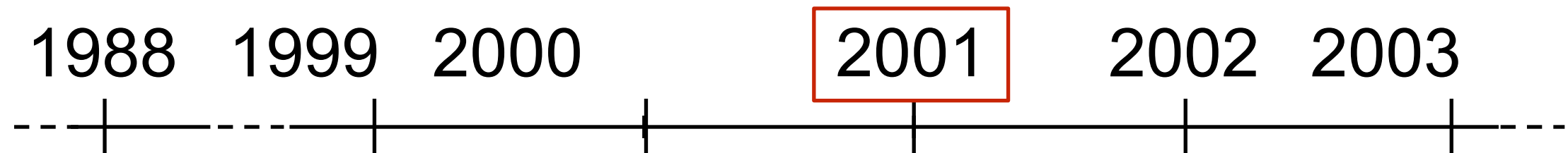
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- **CodeRed**
 - Exploited an overflow in the MS-IIS
 - server 300,000 machines infected in 14 hours

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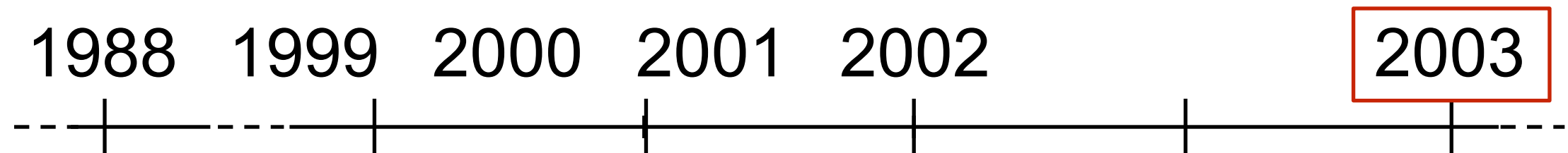


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The harm can be substantial



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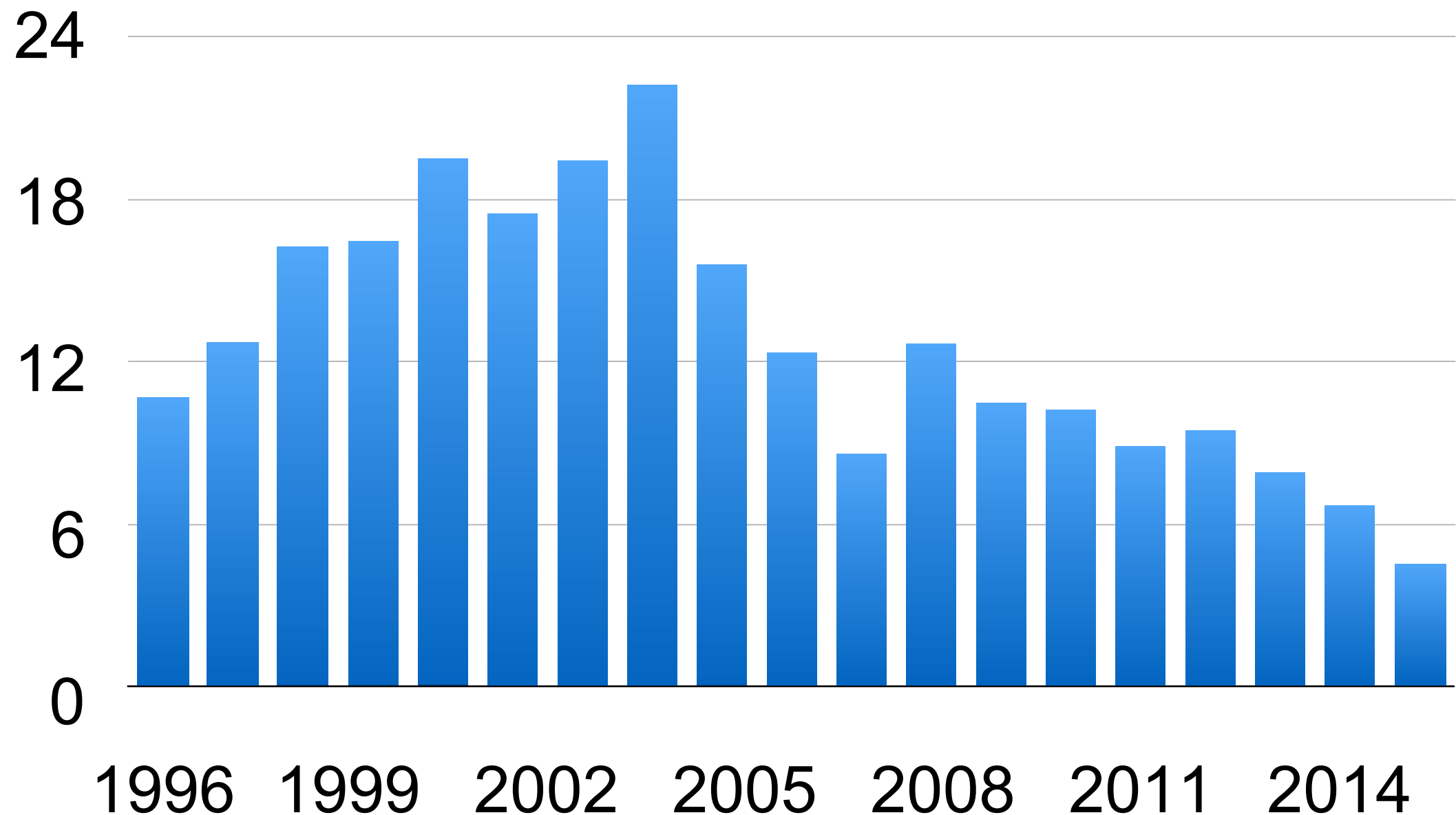
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GHOST: glibc vulnerability introduced in 2000,
only just announced two days ago

Buffer overflows are prevalent

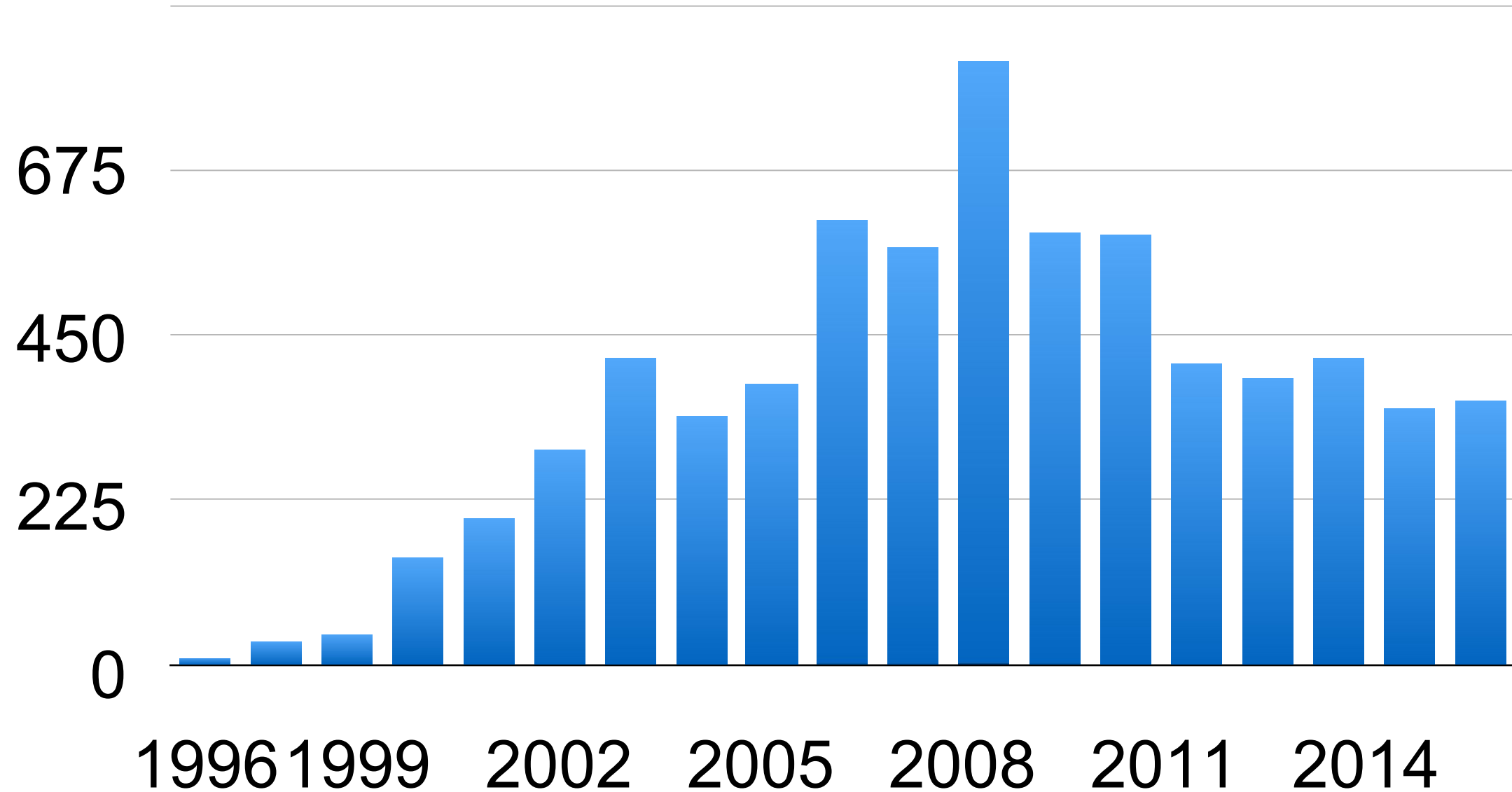
Percent of *all* vulnerabilities



<http://web.nvd.nist.gov/view/vuln/statistics>

Buffer overflows are prevalent

Total number of buffer overflow
vulnerabilities 900



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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
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[7]	75.0	CWE-798	Use of Hard-coded Credentials
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Later

This class
Later

E-voting

Later

Our goals

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

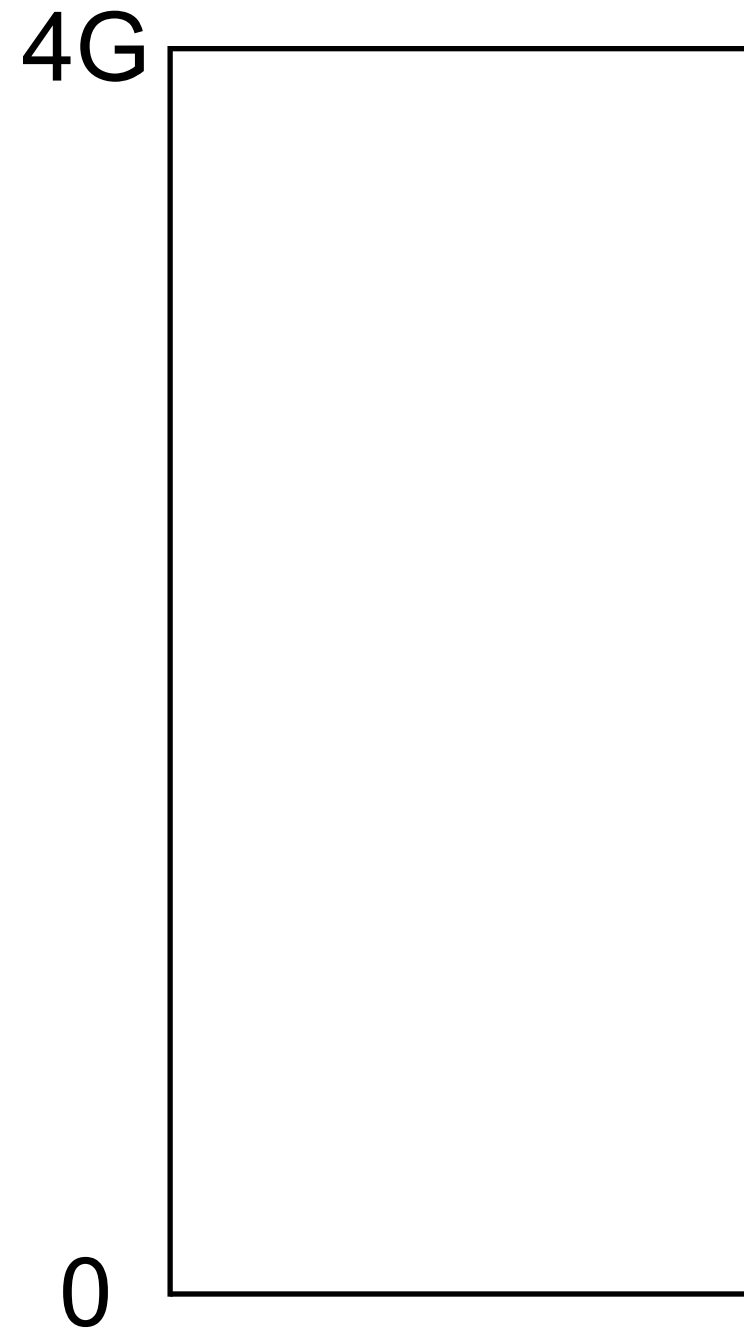
Analyzing security requires a whole-systems view

Memory layout

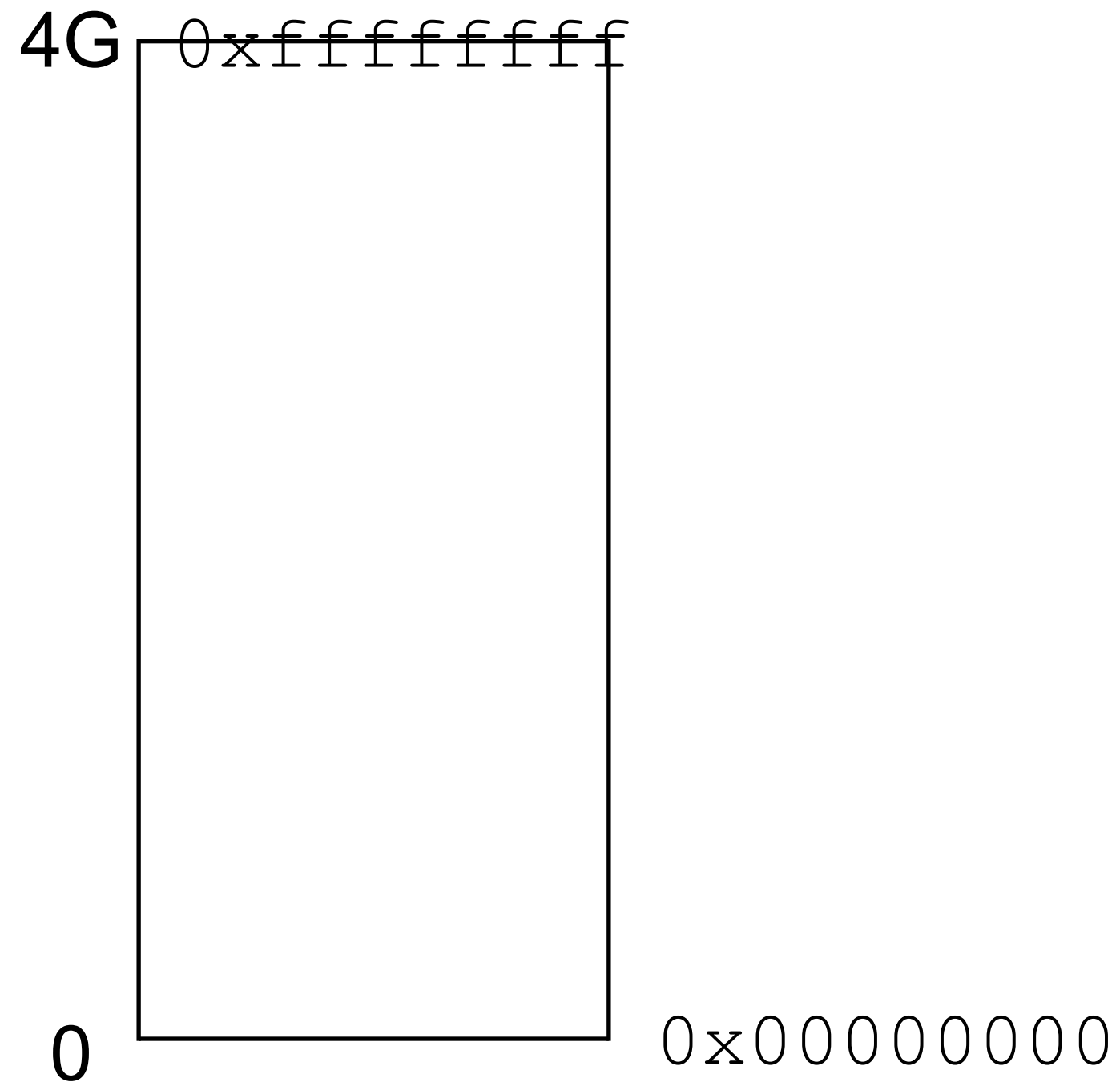
Refresh

- 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

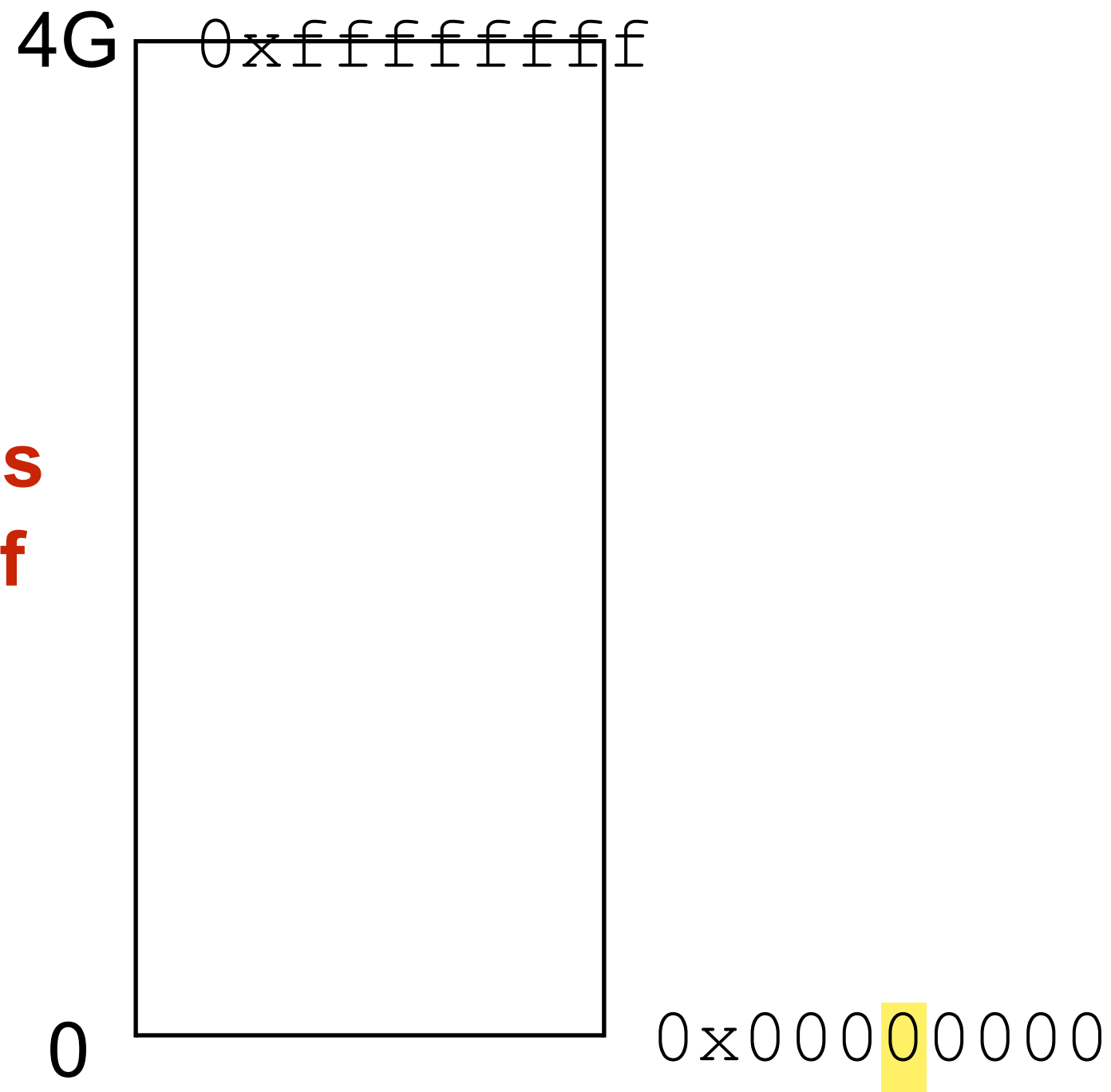


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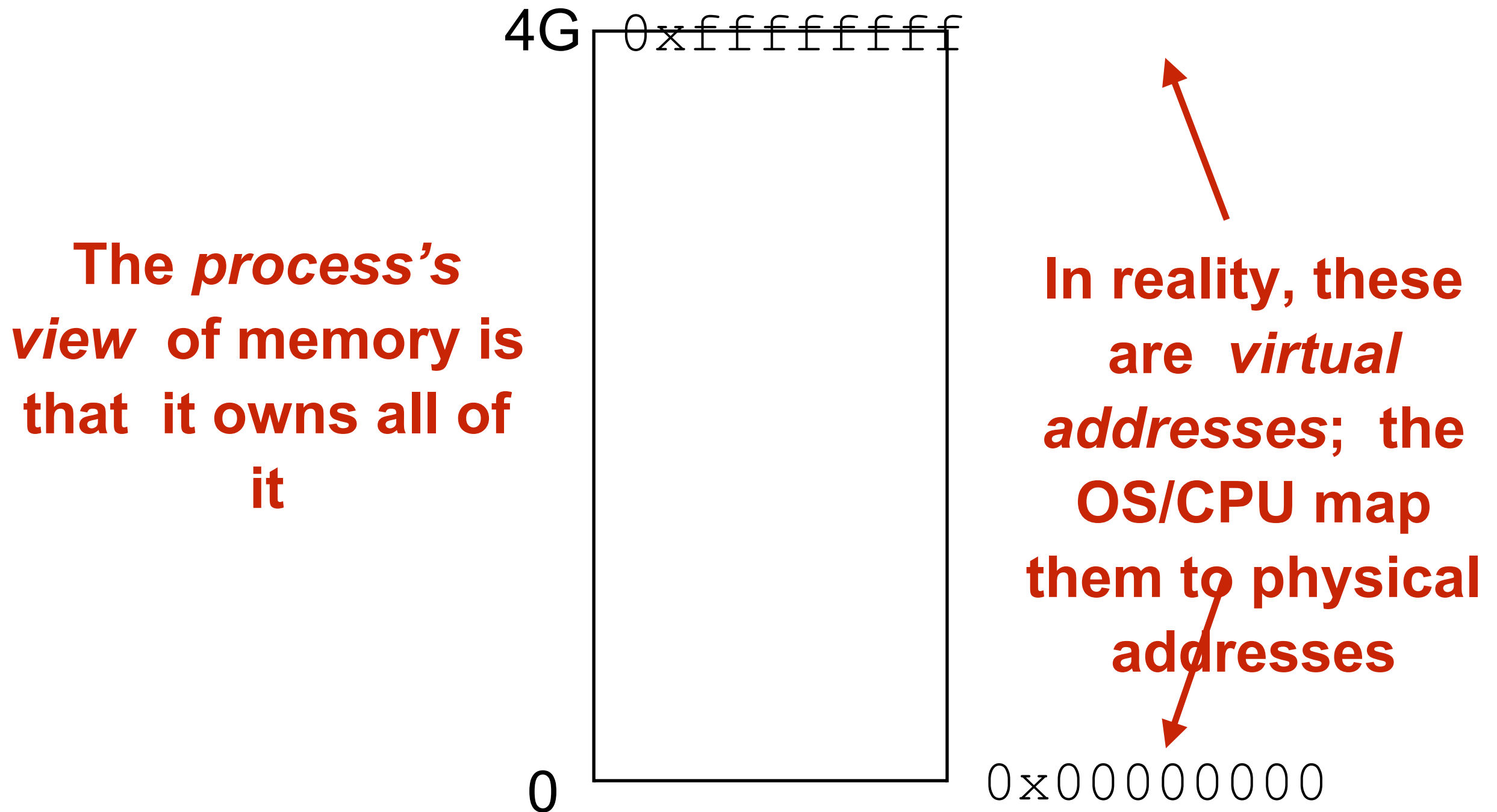


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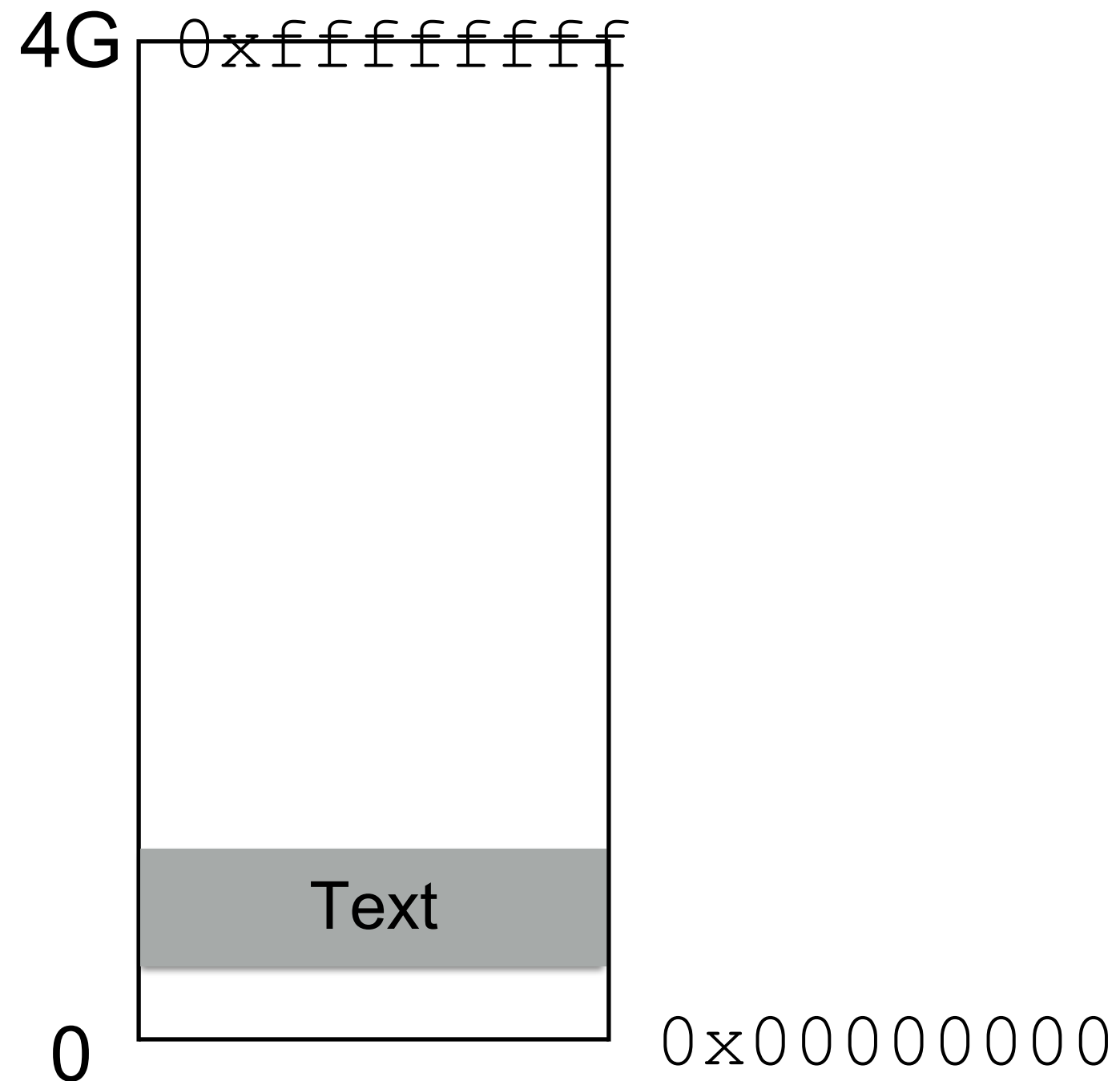
**The *process's*
view of memory is
that it owns all of
it**



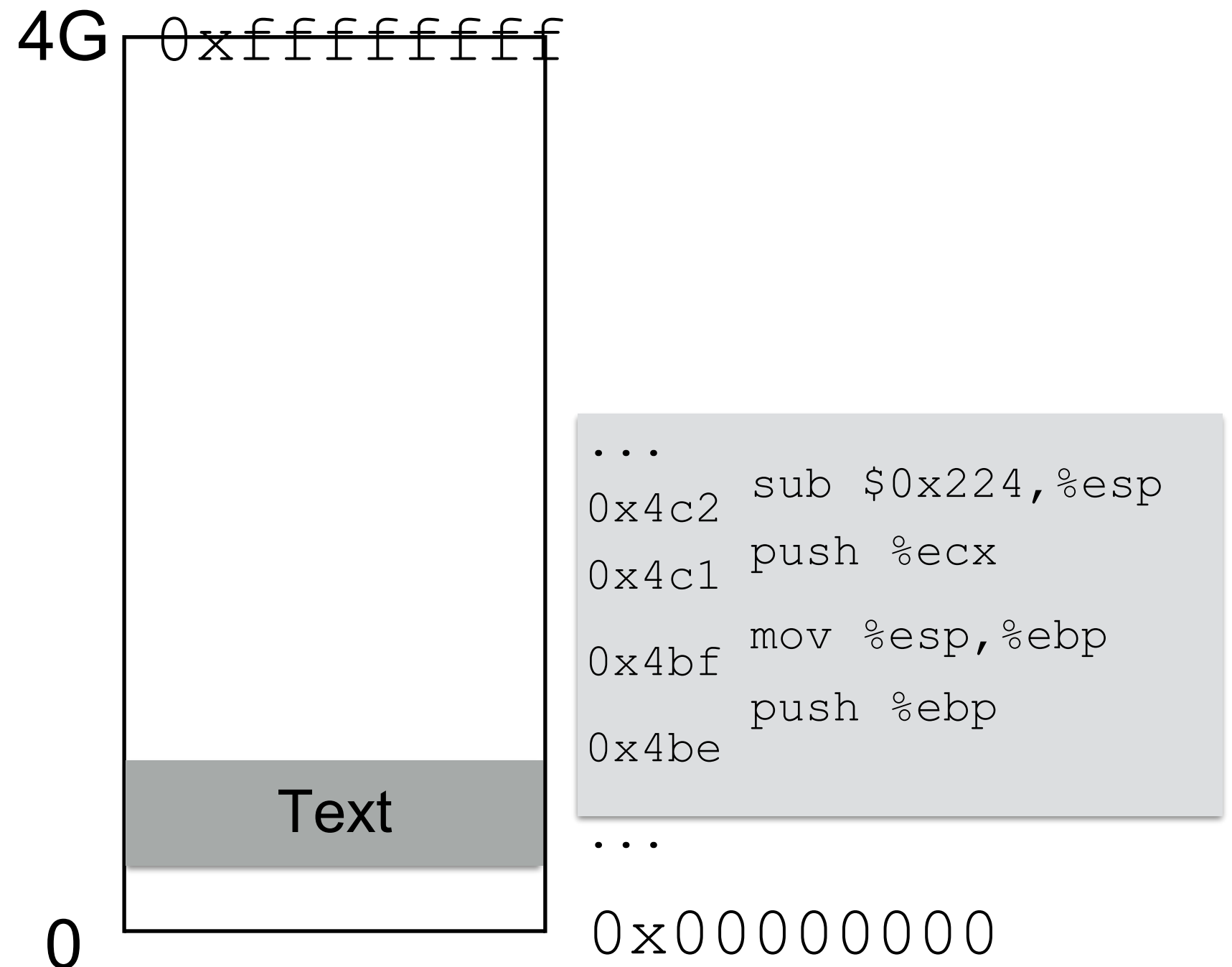
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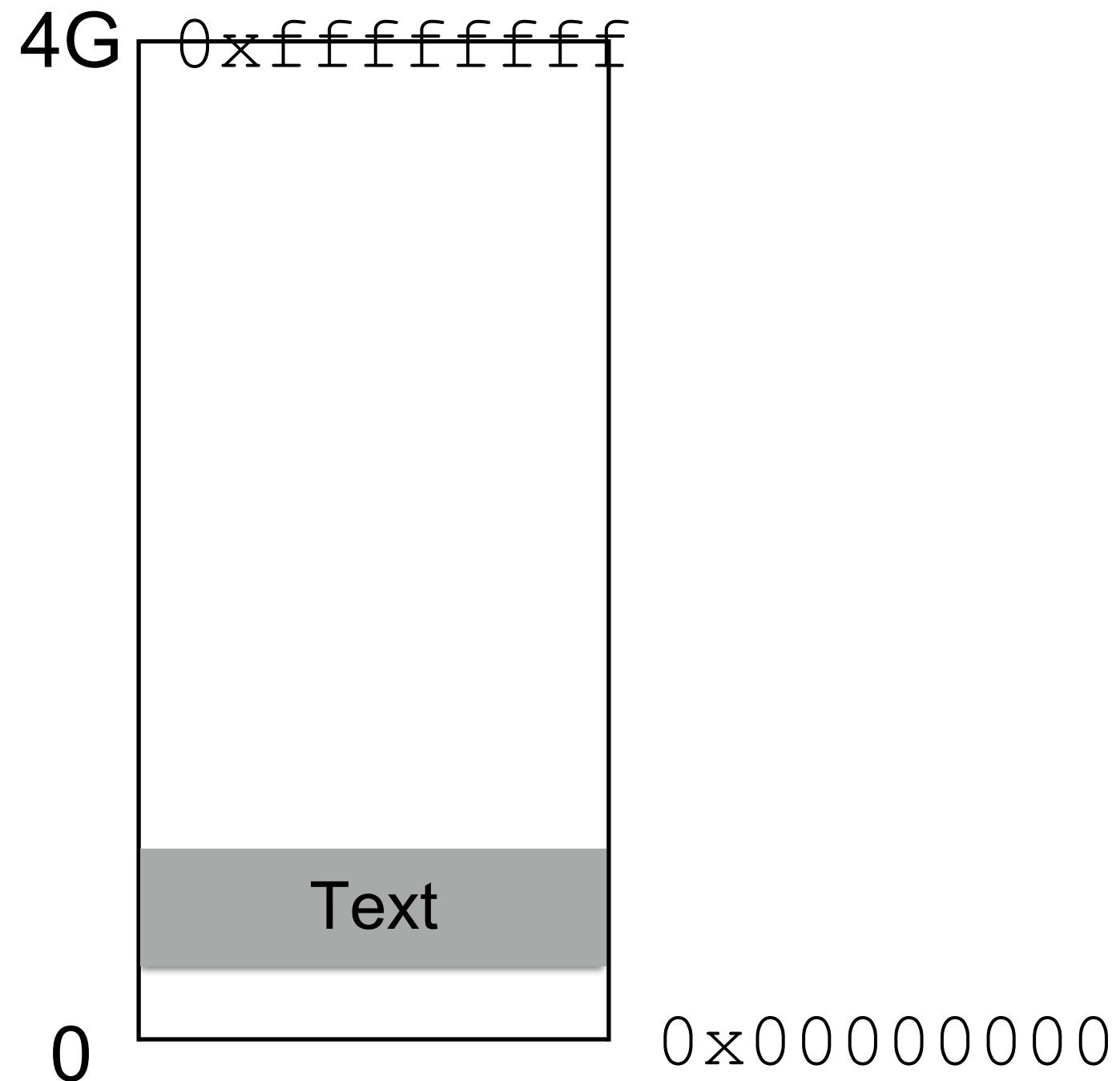
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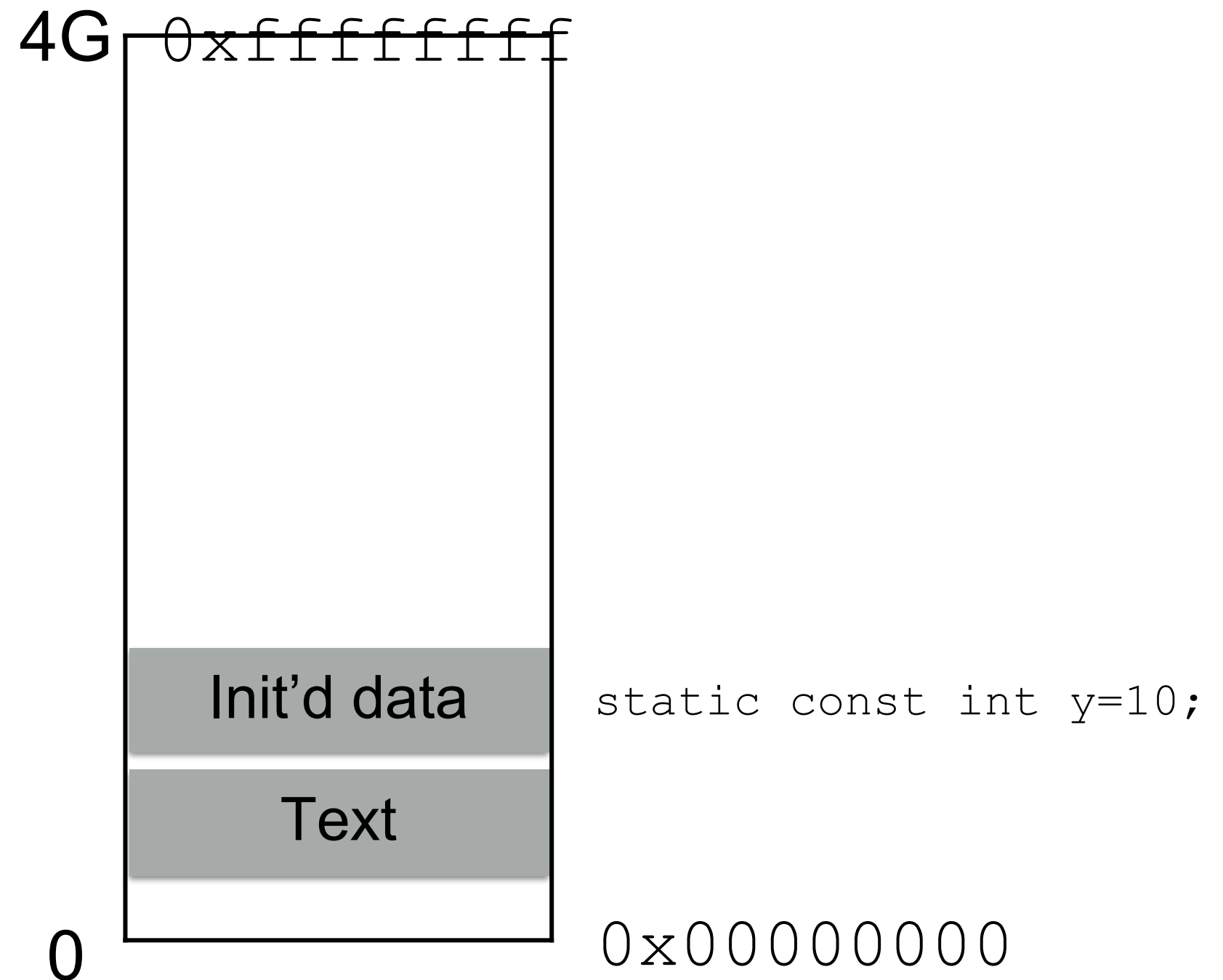
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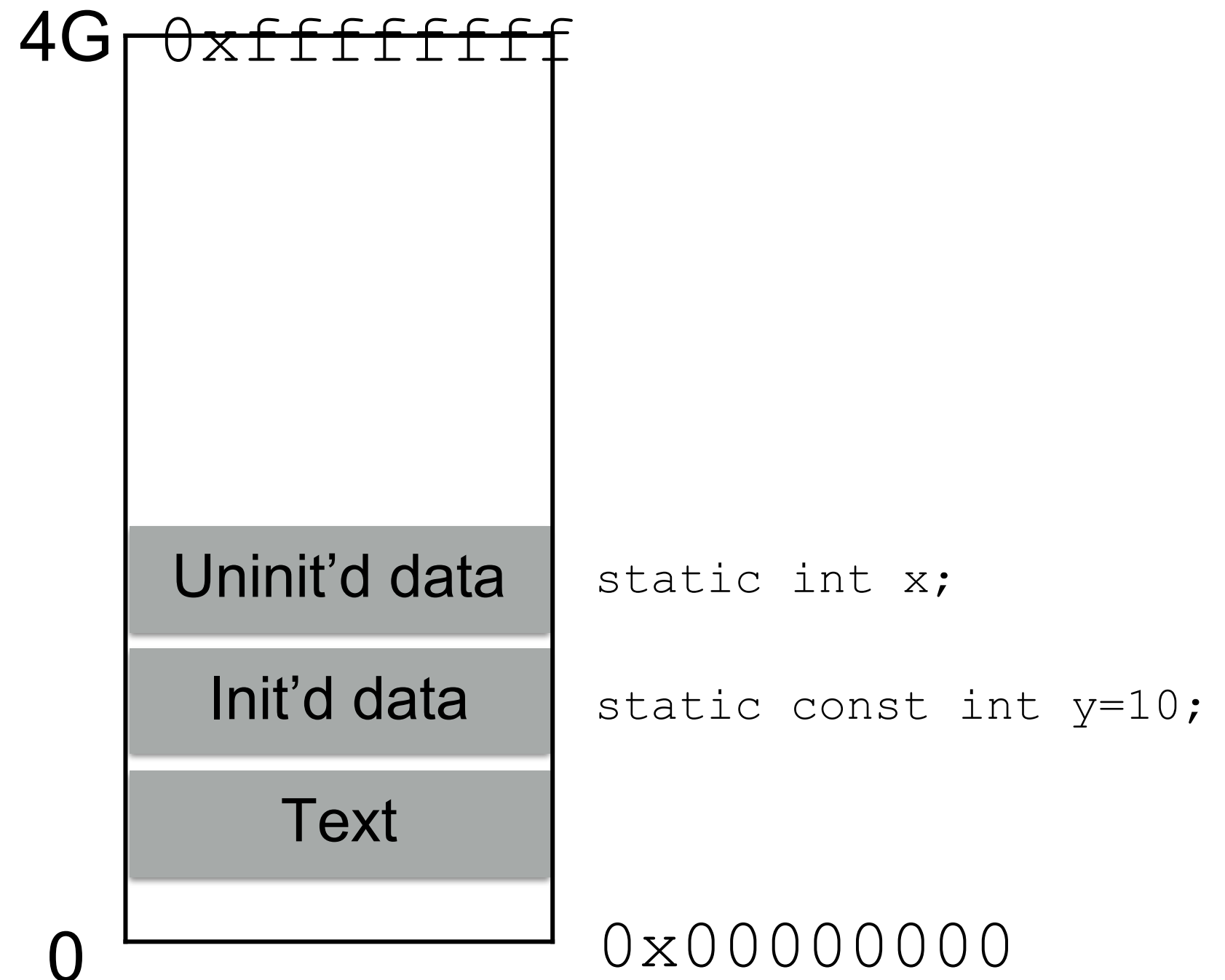
Data's location depends on how it's created



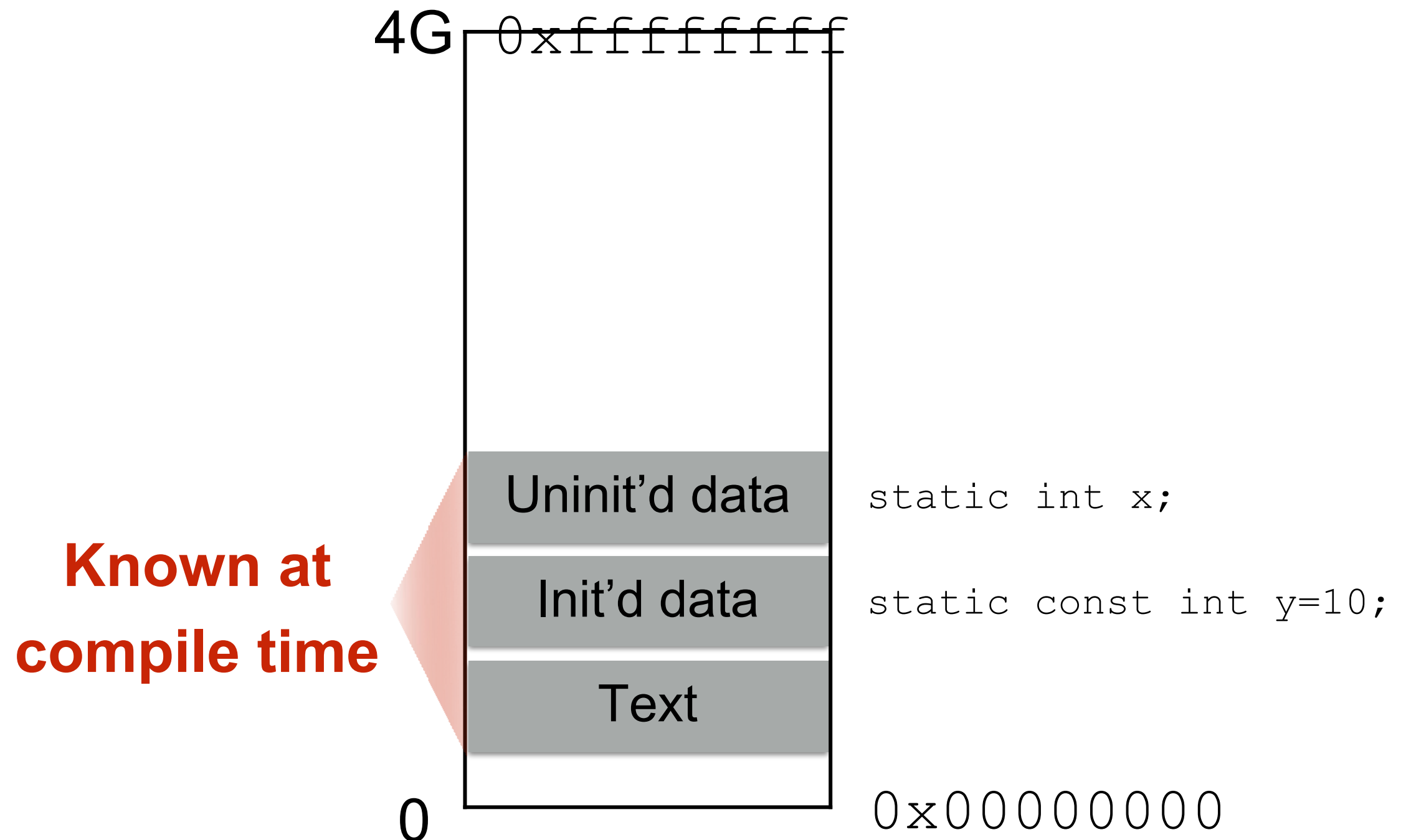
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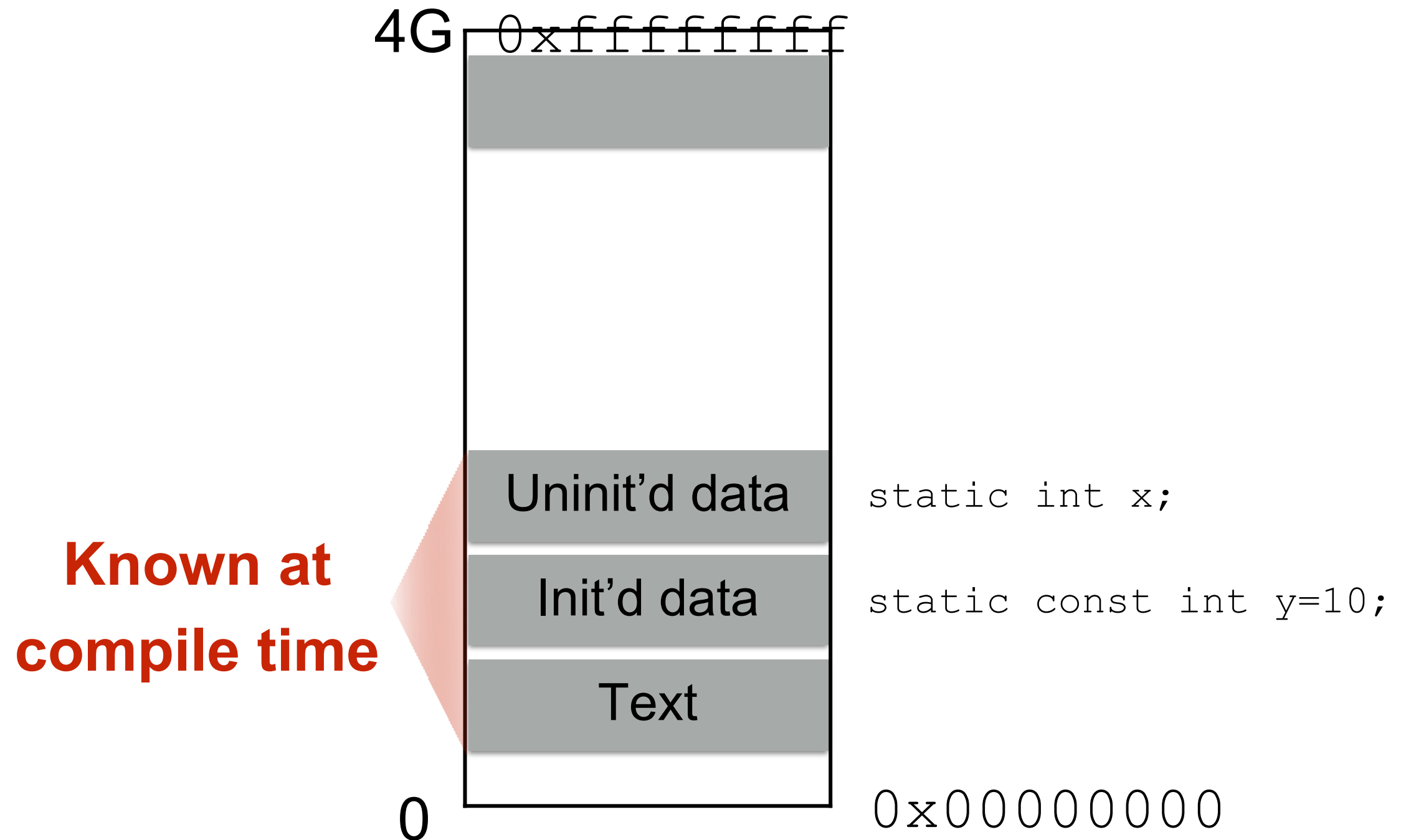
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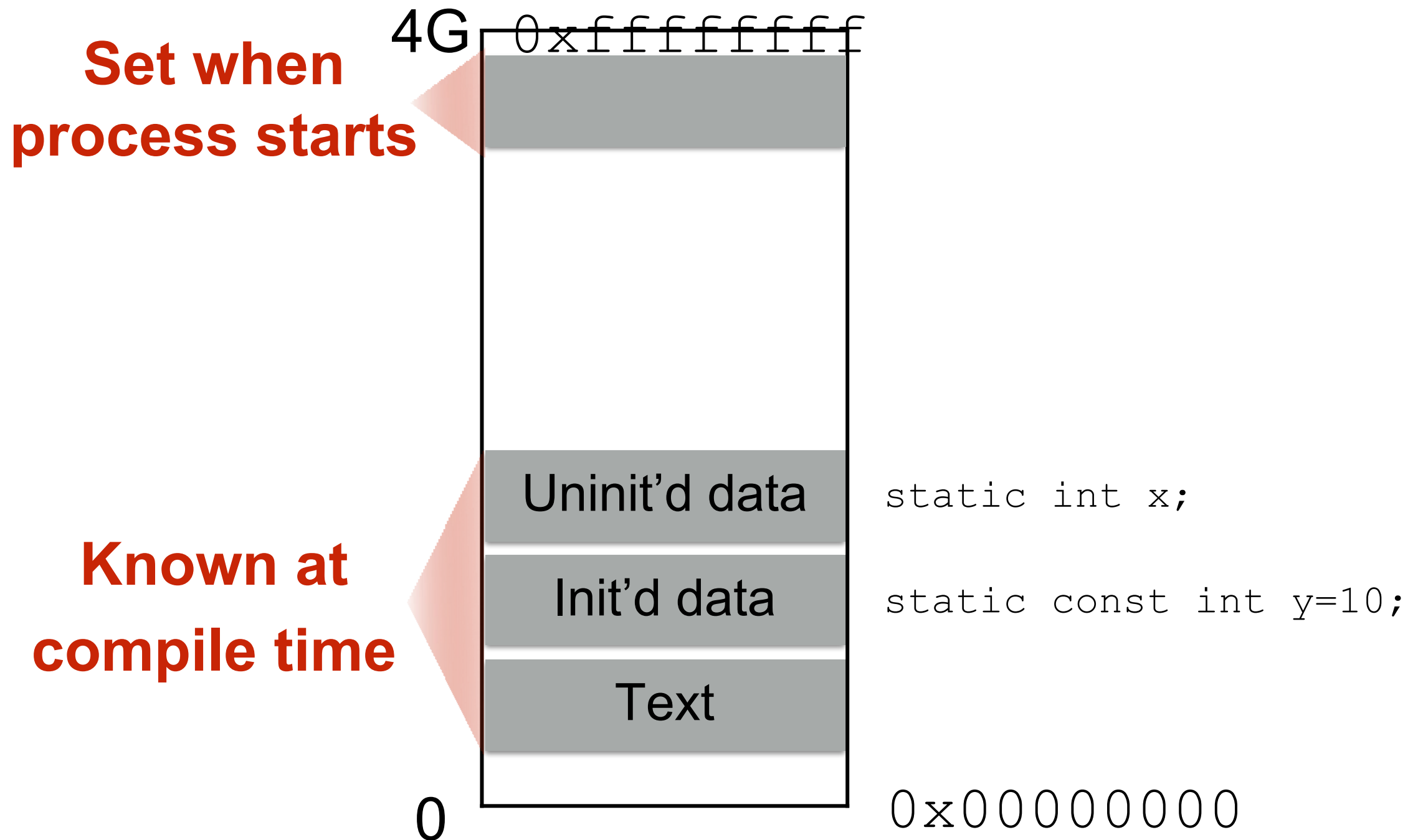
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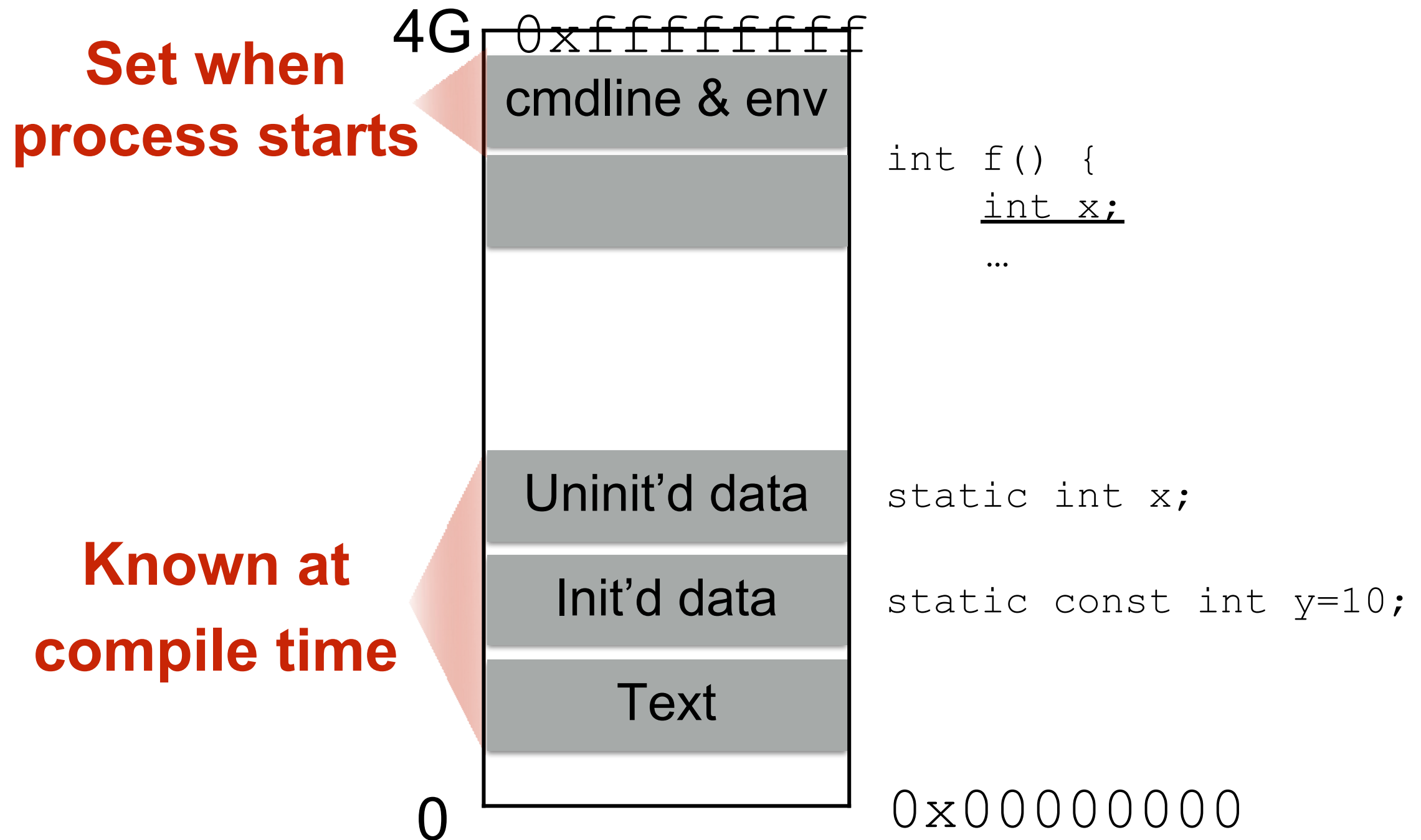
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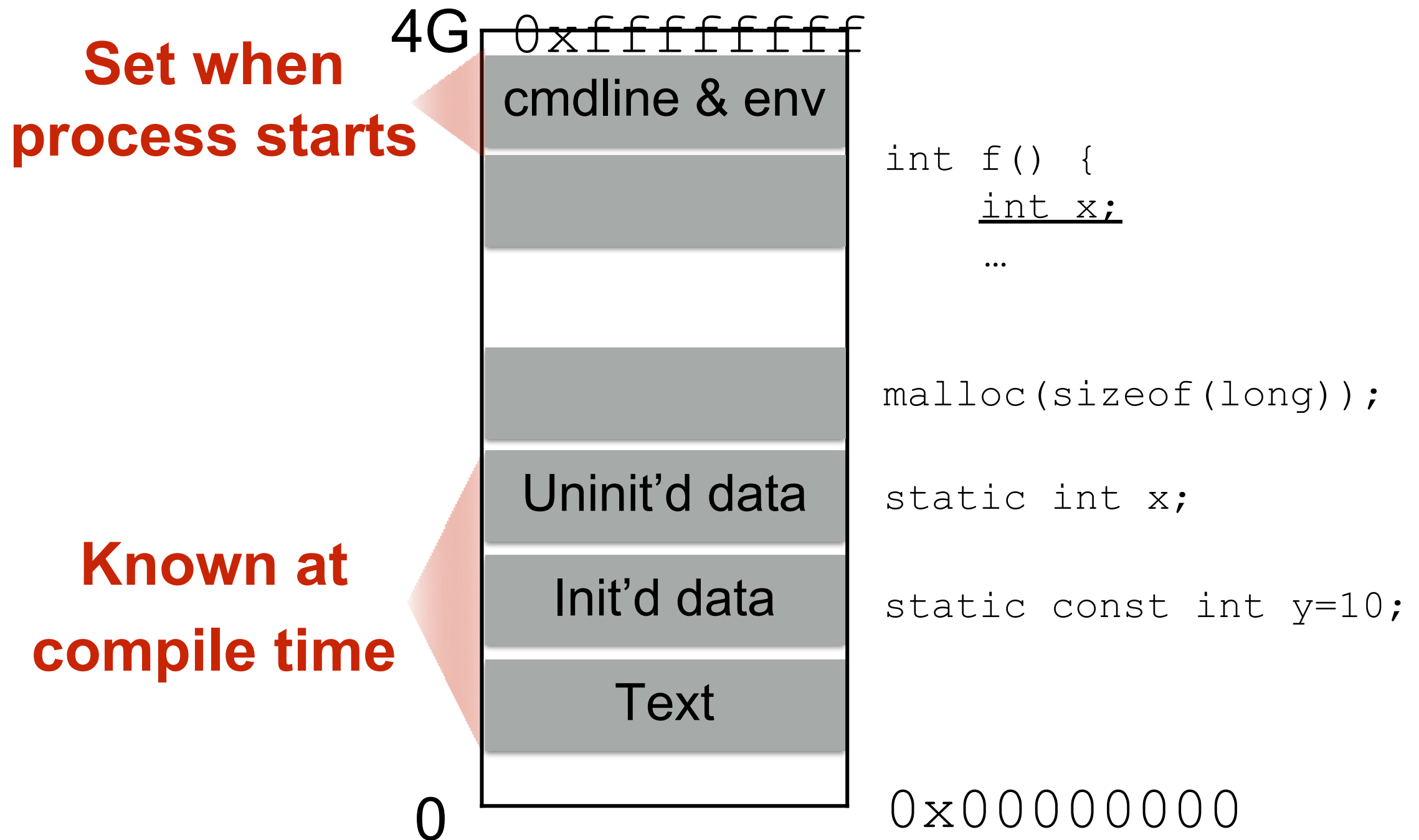
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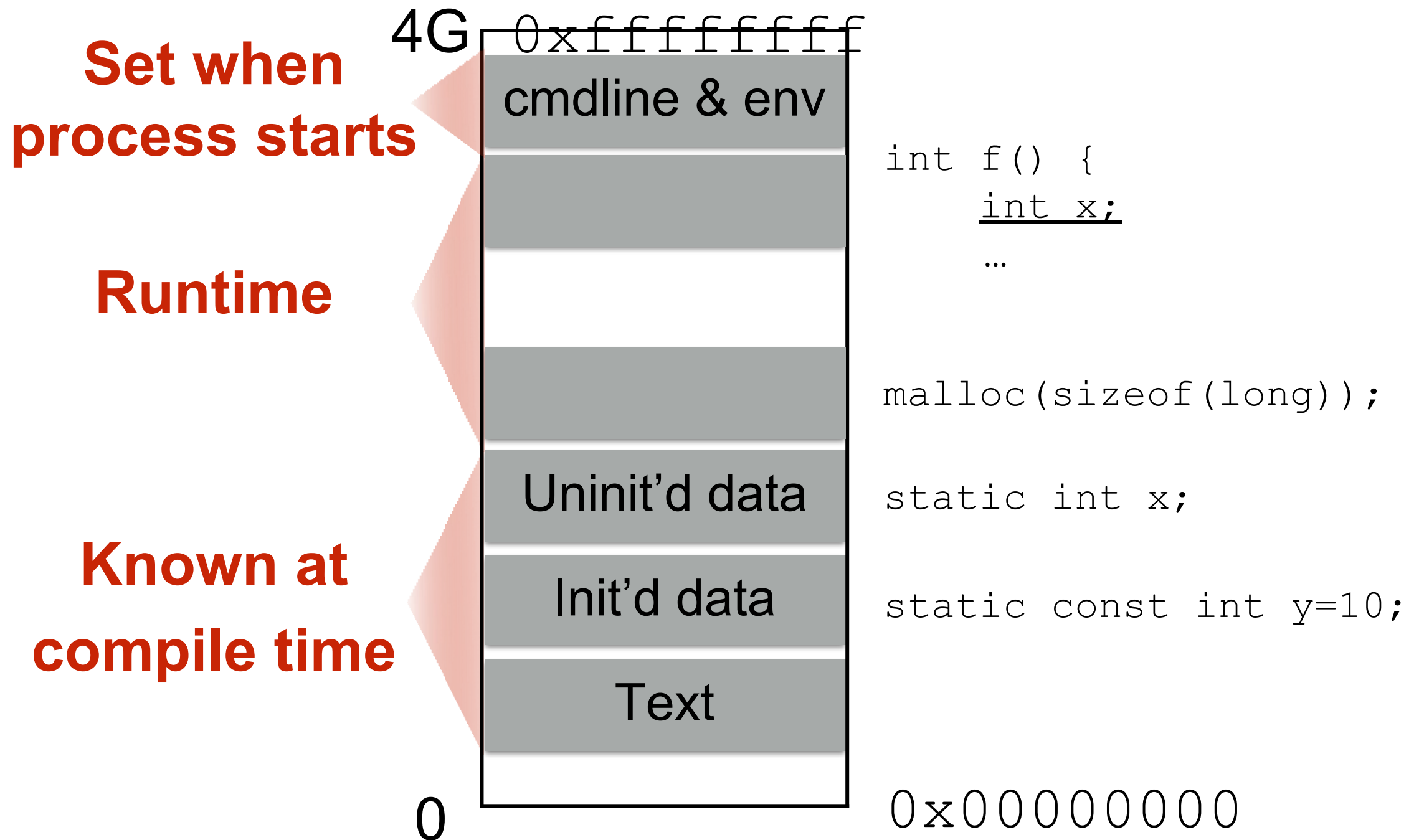
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We are going to focus on runtime attacks

Stack and heap grow in opposite directions

0x00000000

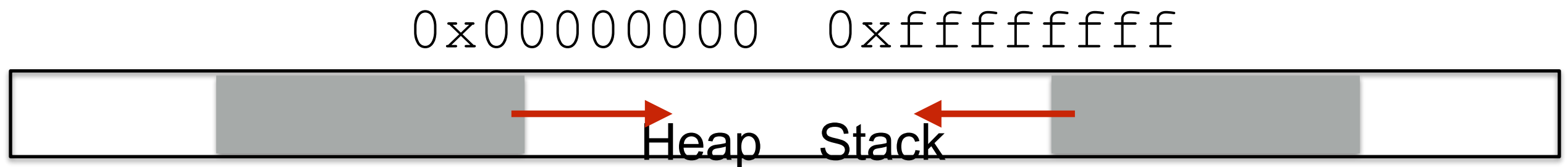
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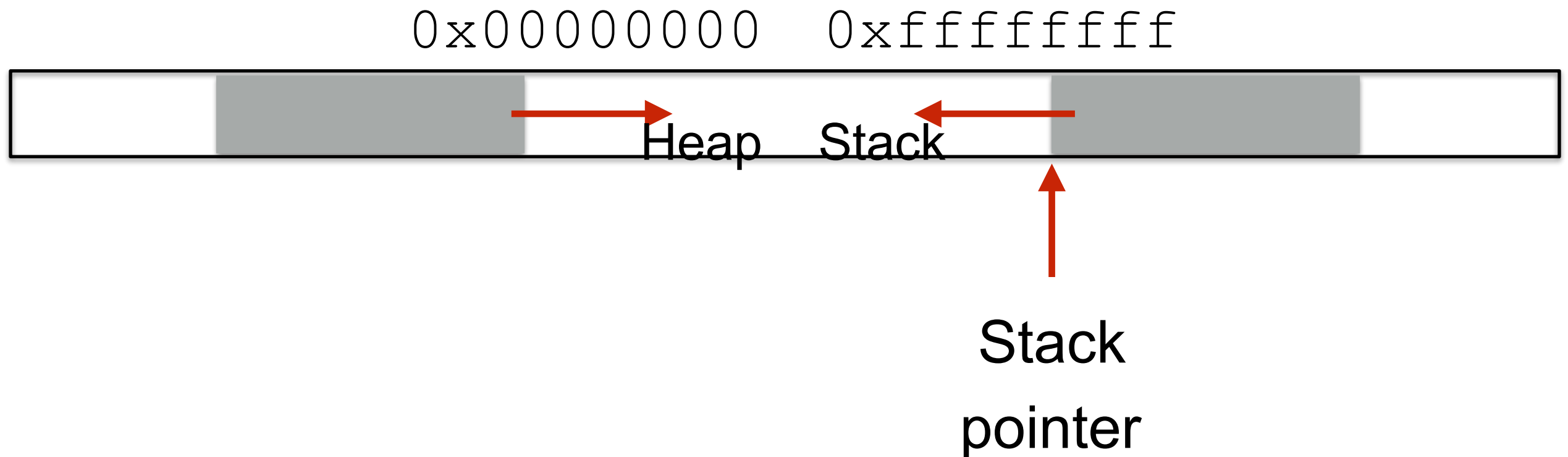
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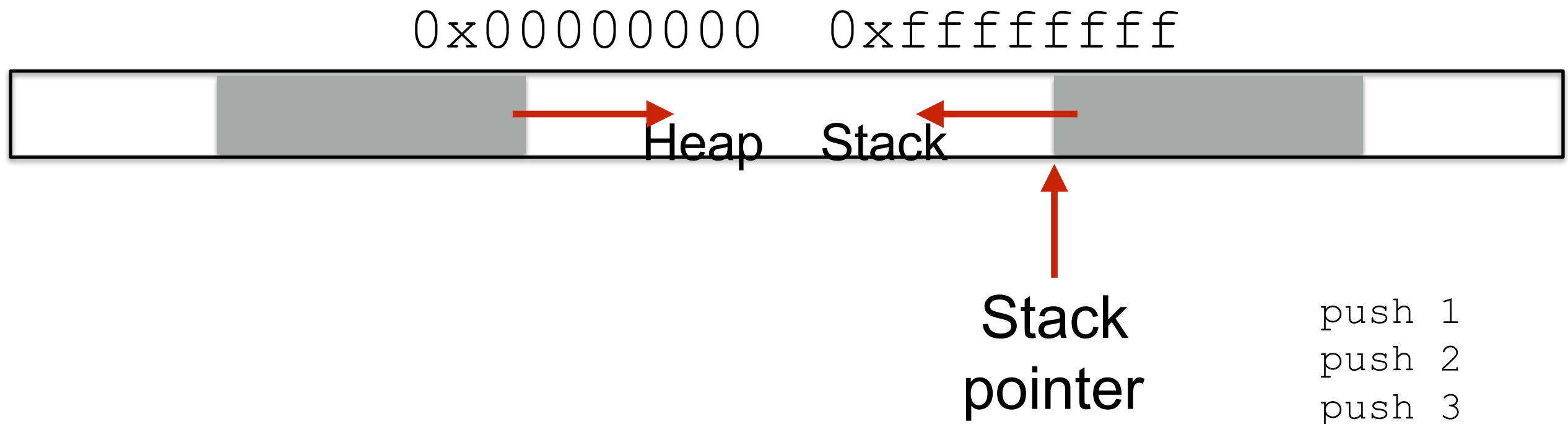
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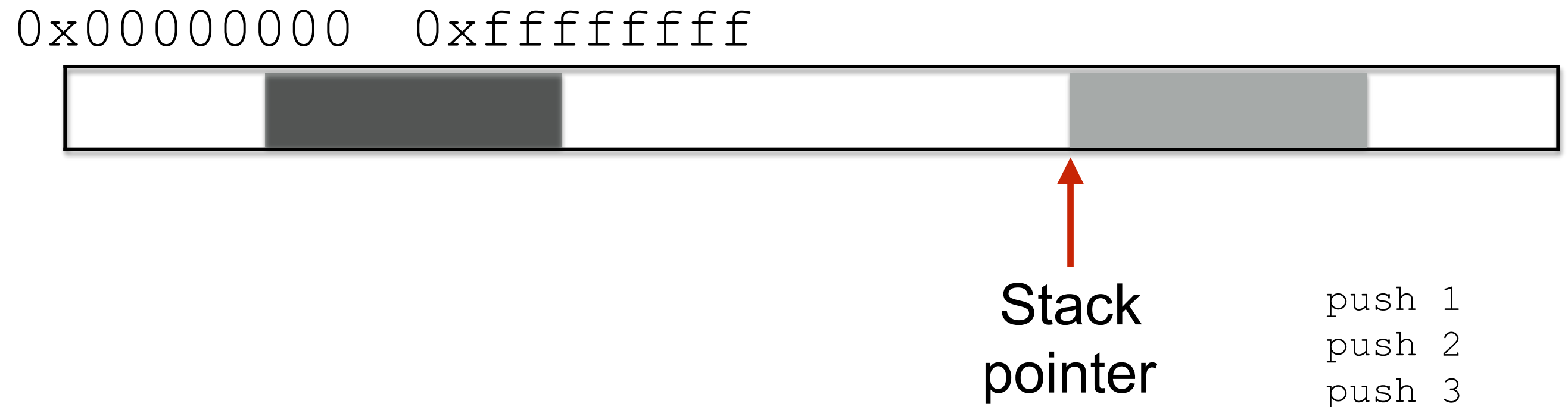
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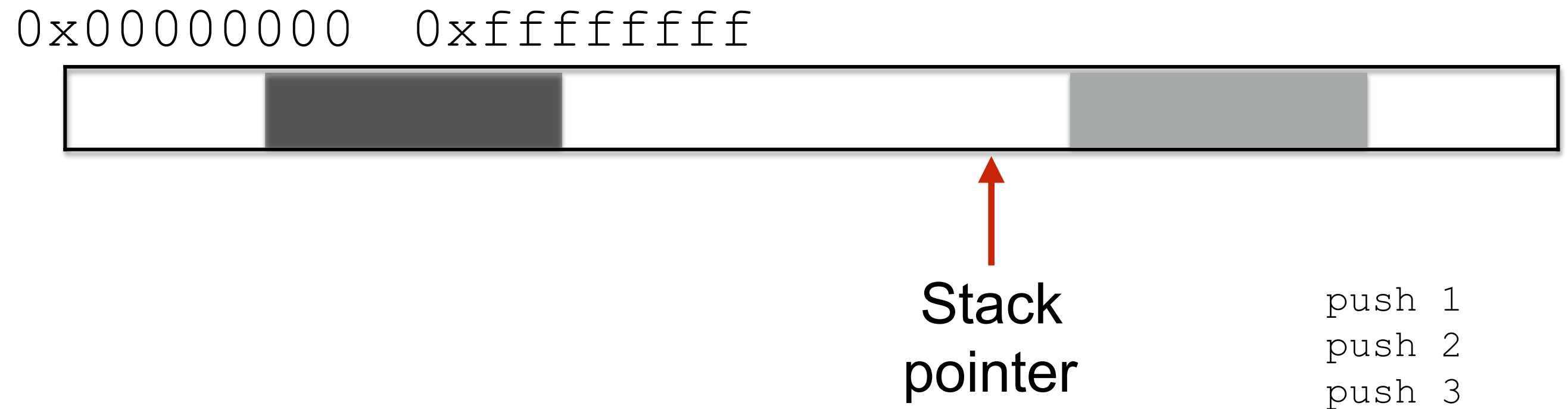
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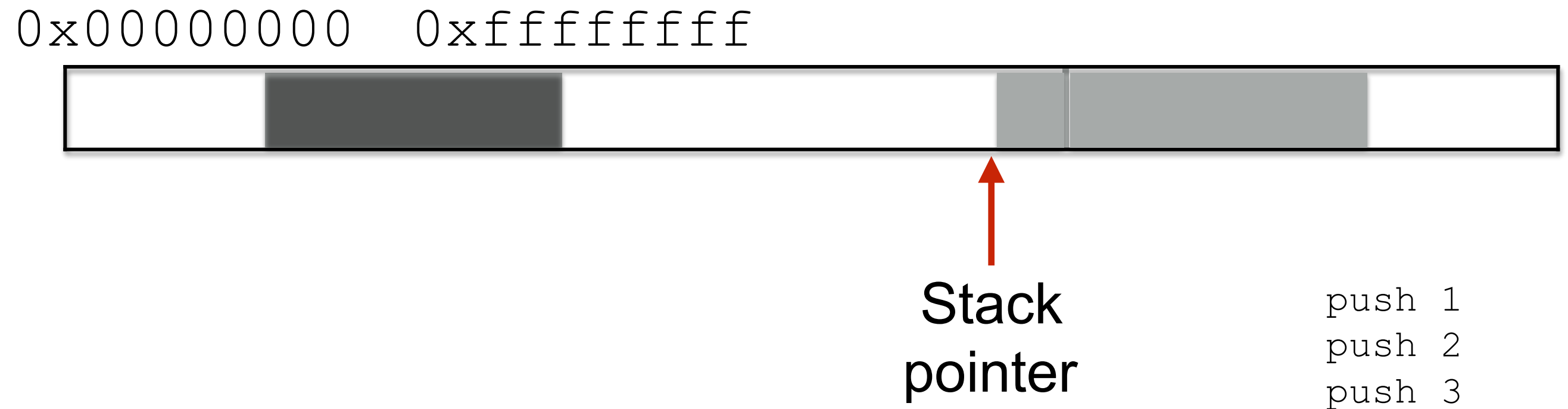
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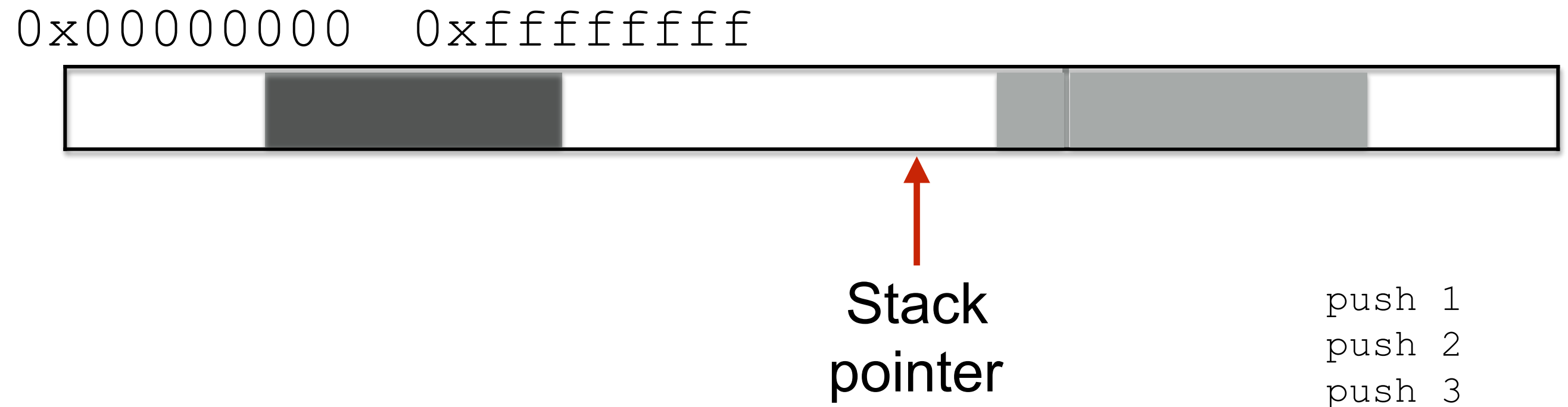
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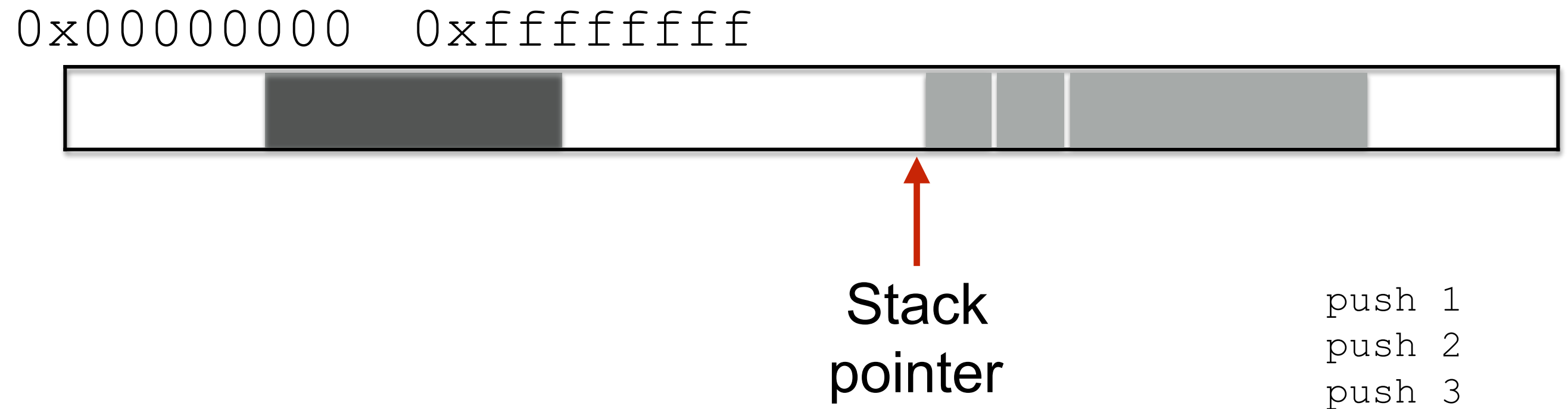
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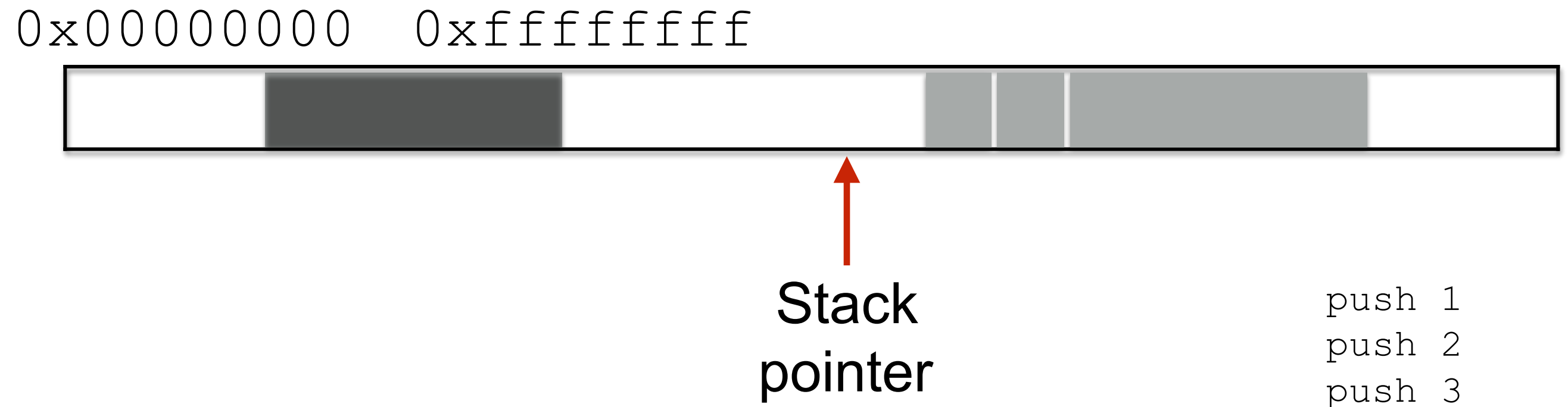
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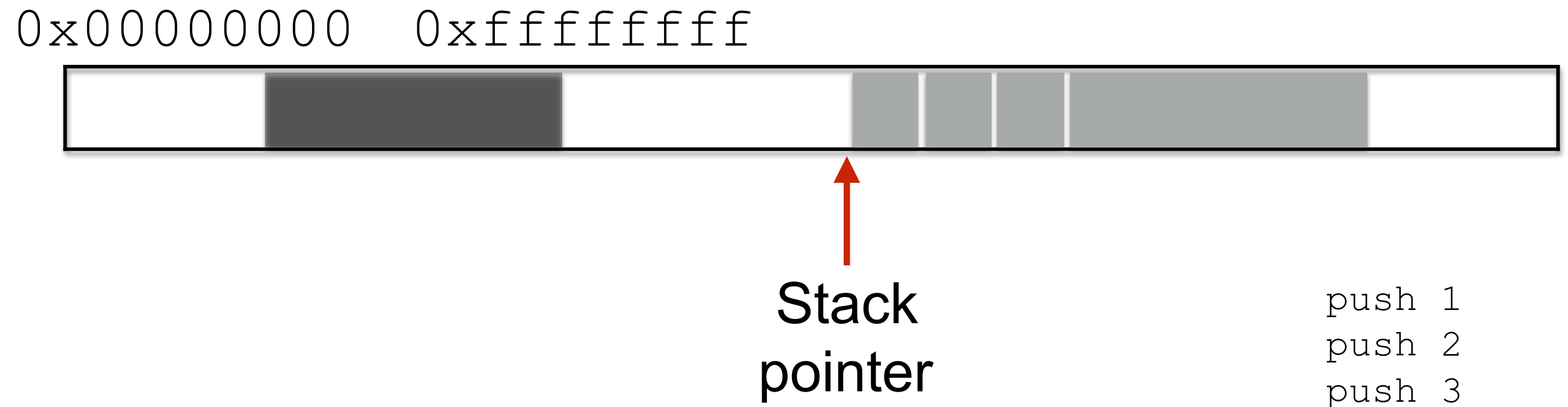
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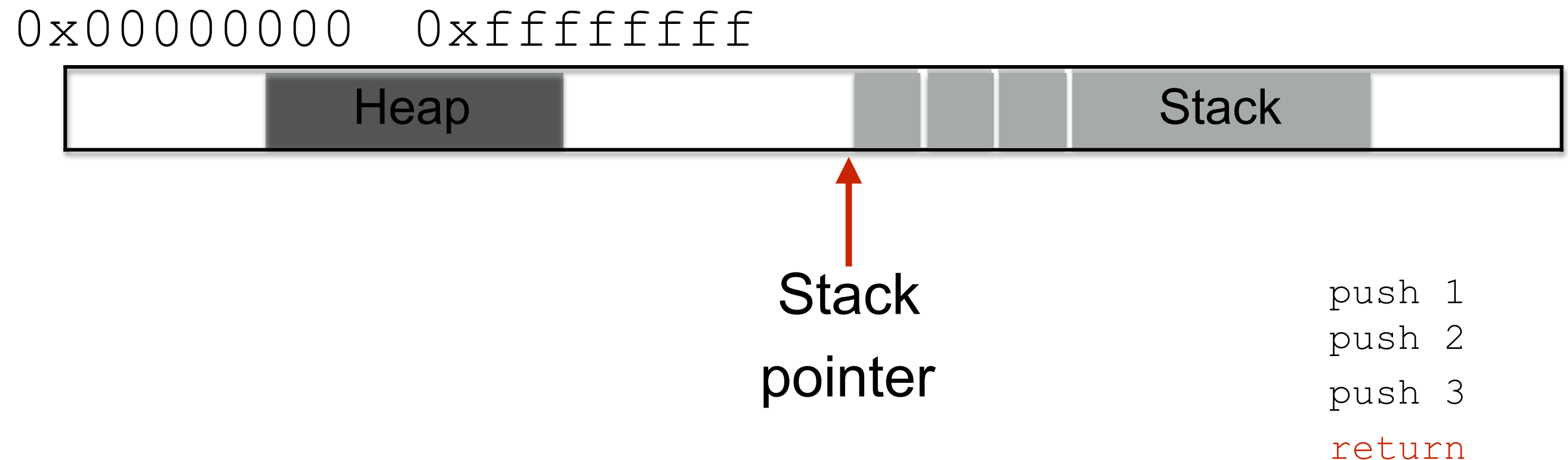
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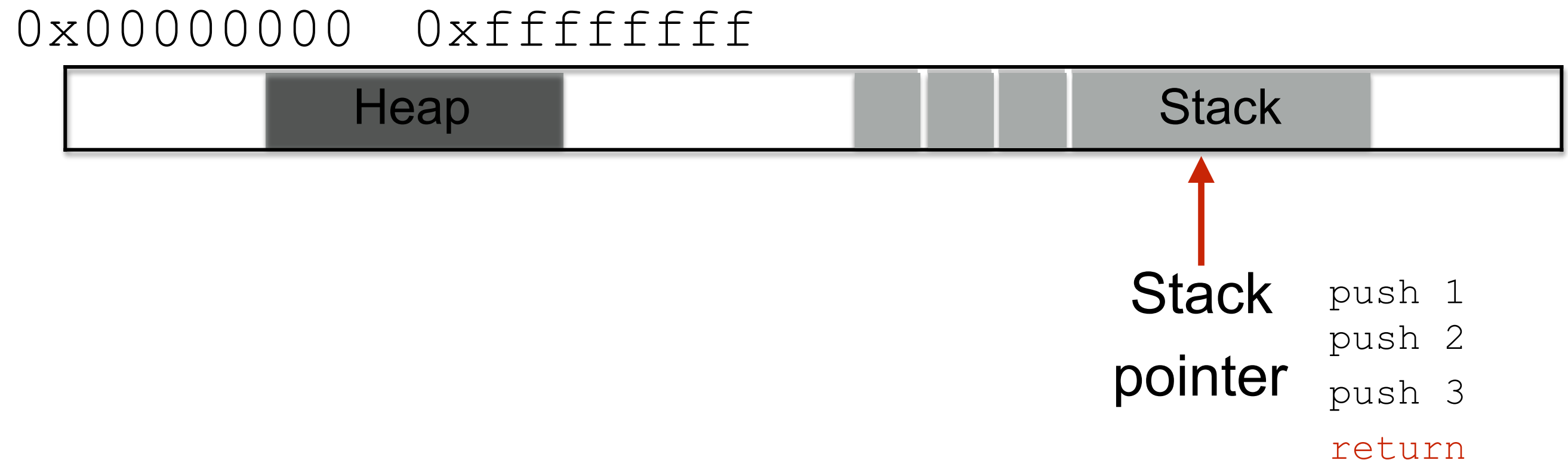
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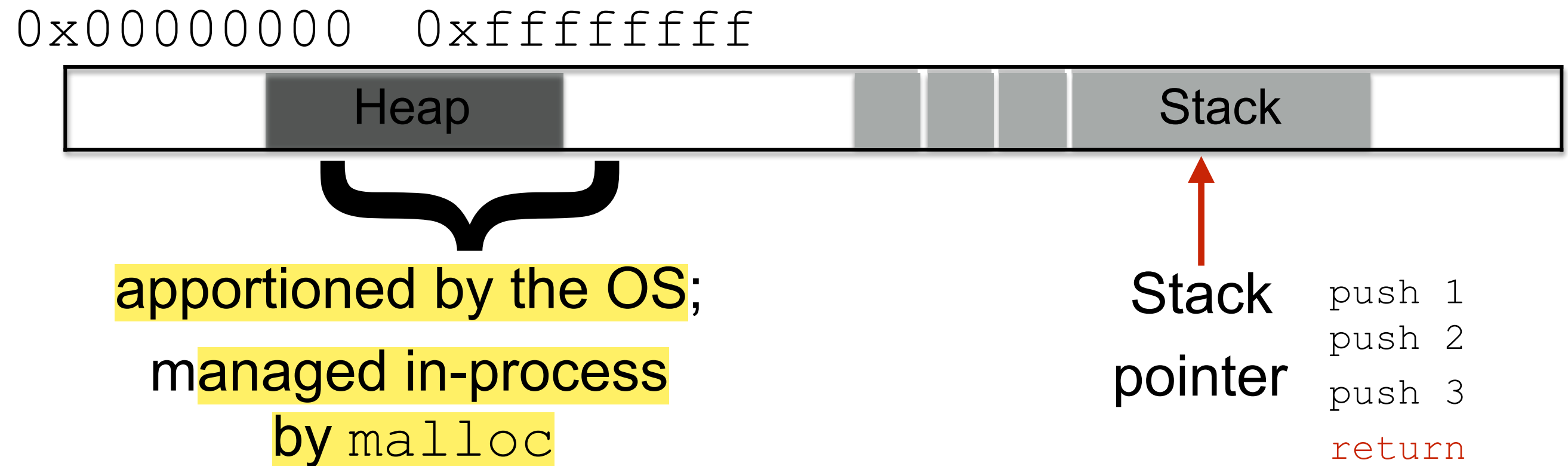
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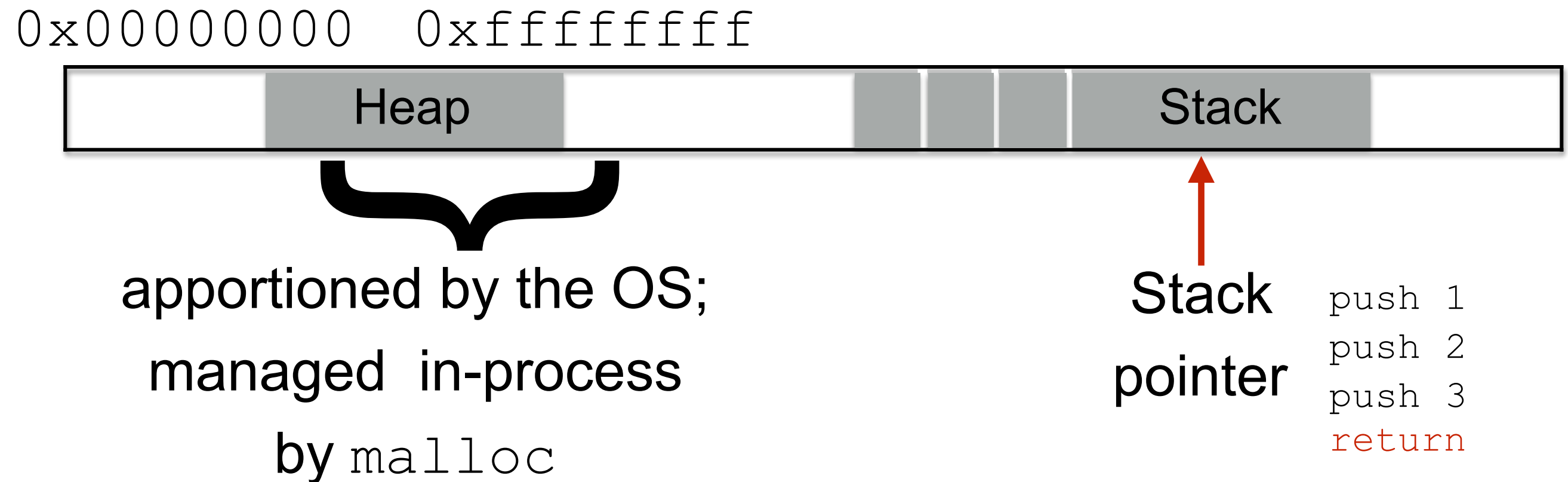
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Focusing on the stack for

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;
}
```

0x00000000

0xffffffff



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**Arguments
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**Local variables
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Accessing variables

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void func(char *arg1, int arg2, int arg3)
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**Undecidable at
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- I don't know where loc2 is,

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

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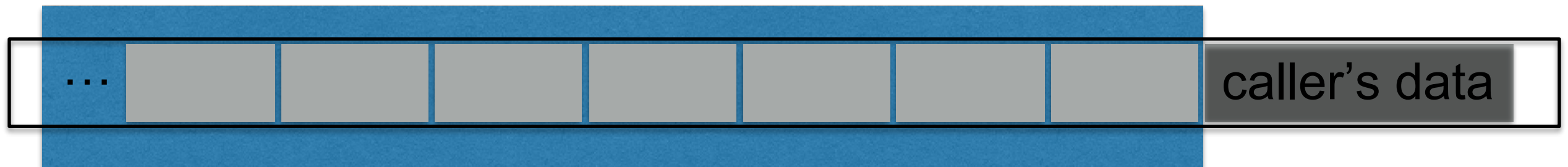
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Stack frame
for *this* call to func

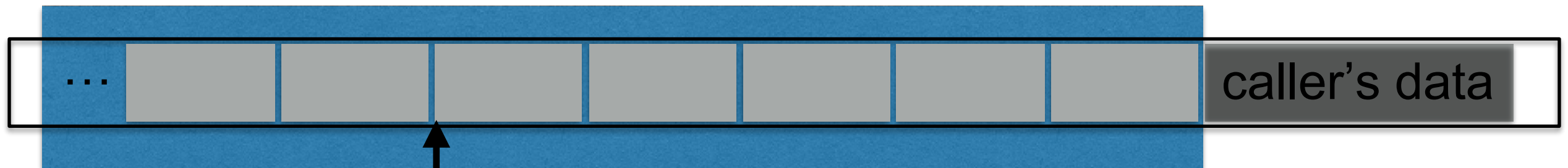
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Accessing variables

```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4]
    int loc2;
    int loc3;
    ...
    loc2++; Q: Where is (this) loc2?
    ...
}
```

0x00000000

0xffffffff



Stack frame

for *this* call to func

%ebp

Frame pointer

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

Accessing variables

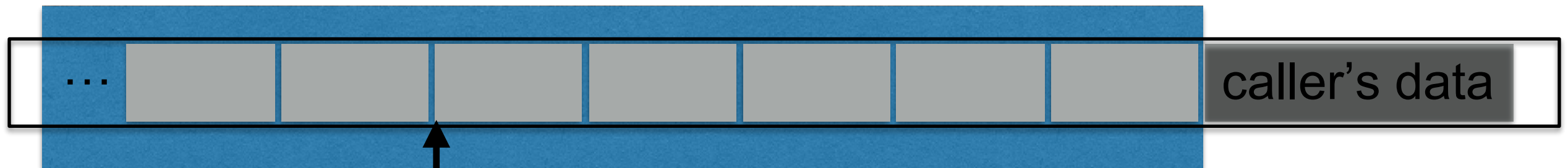
```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4]
    int  loc2;
    int  loc3;
    ...
    loc2++;
    ...
}
```

Q: Where is (this) loc2?

A: -8(%ebp)

0x00000000

0xffffffff



Stack frame

for *this* call to func

Frame pointer

%ebp

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

Notation

`%ebp` A memory address

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

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Notation

`0xbfff03b8` `%ebp` A memory address

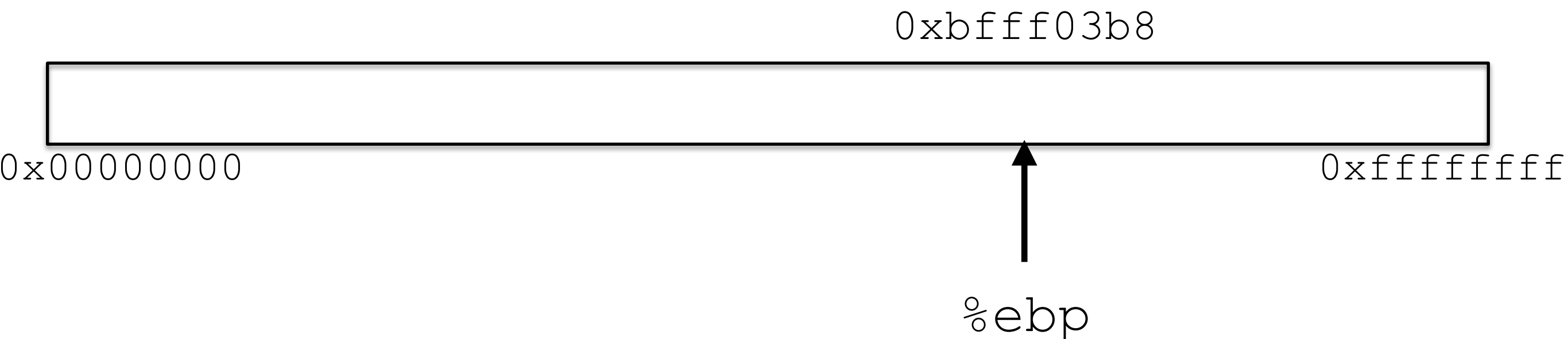
`(%ebp)` The value at memory address `%ebp`
(like dereferencing a pointer)



Notation

0xbfff03b8 %ebp A memory address

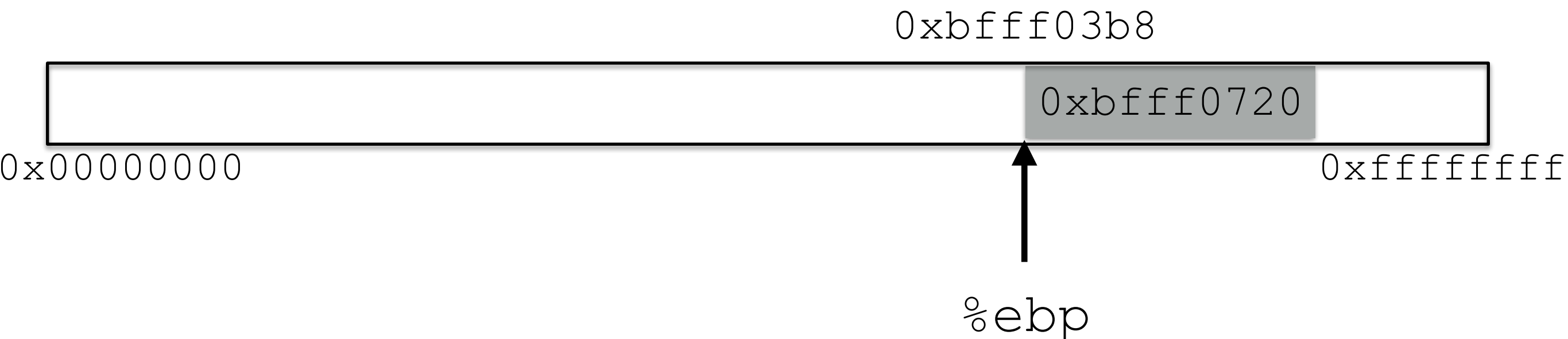
(%ebp) The value at memory address %ebp
(like dereferencing a pointer)



Notation

`0xbfff03b8` `%ebp` A memory address

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

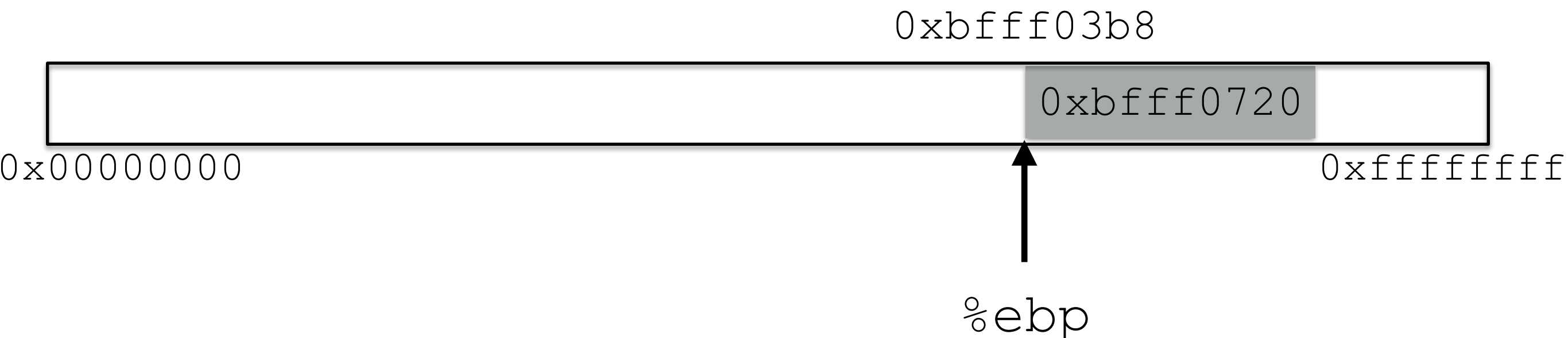


Notation

0xbfff03b8 %ebp A memory address

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

pushl %ebp

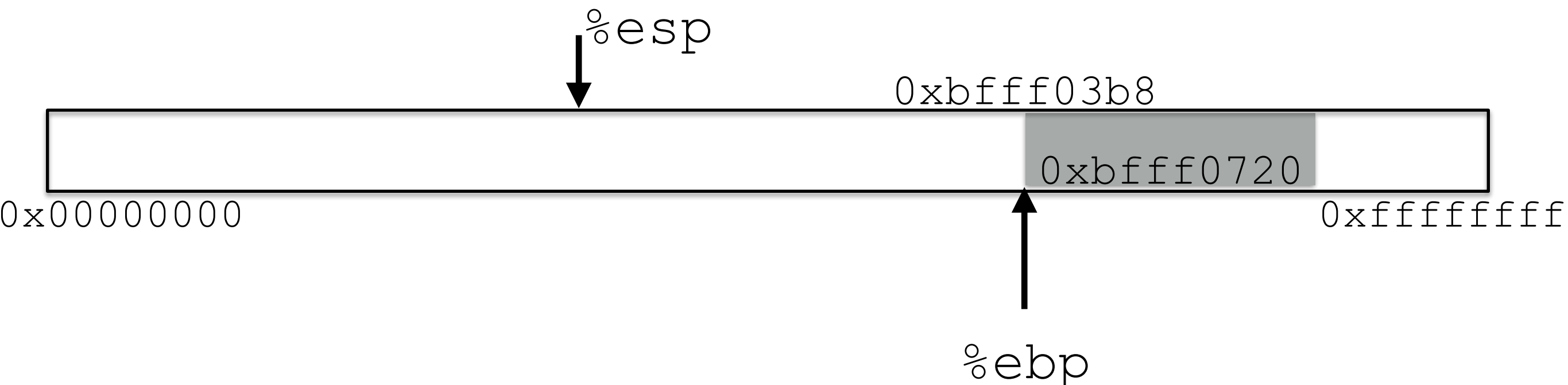


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0xbfff0720 (%ebp) The value at memory address %ebp
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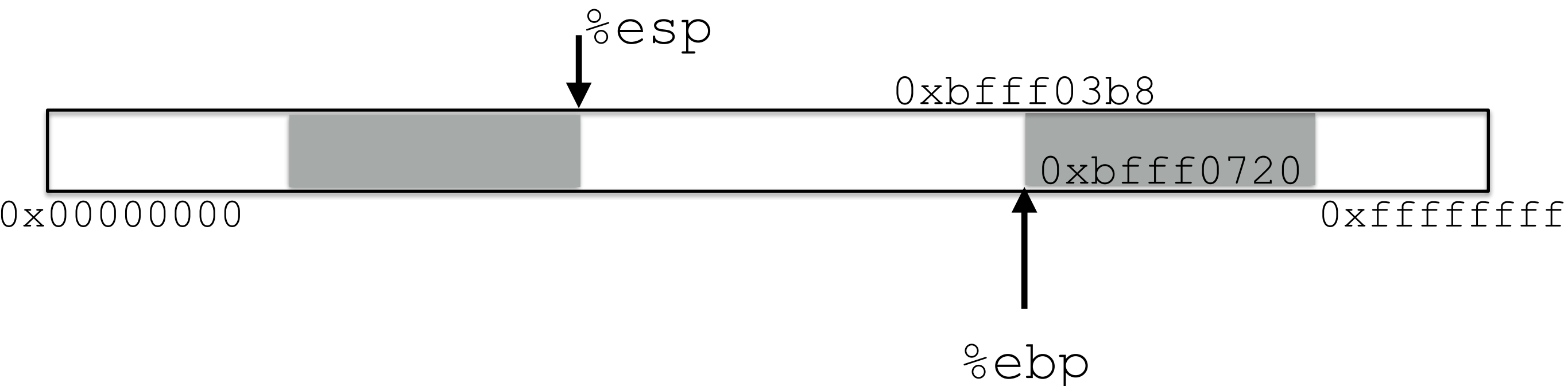


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pushl %ebp

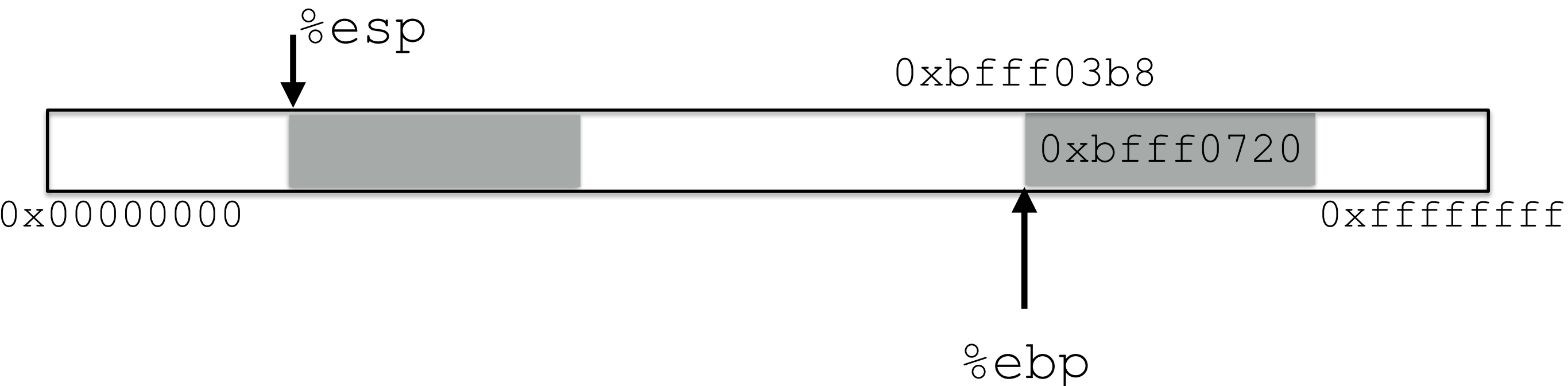


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pushl %ebp

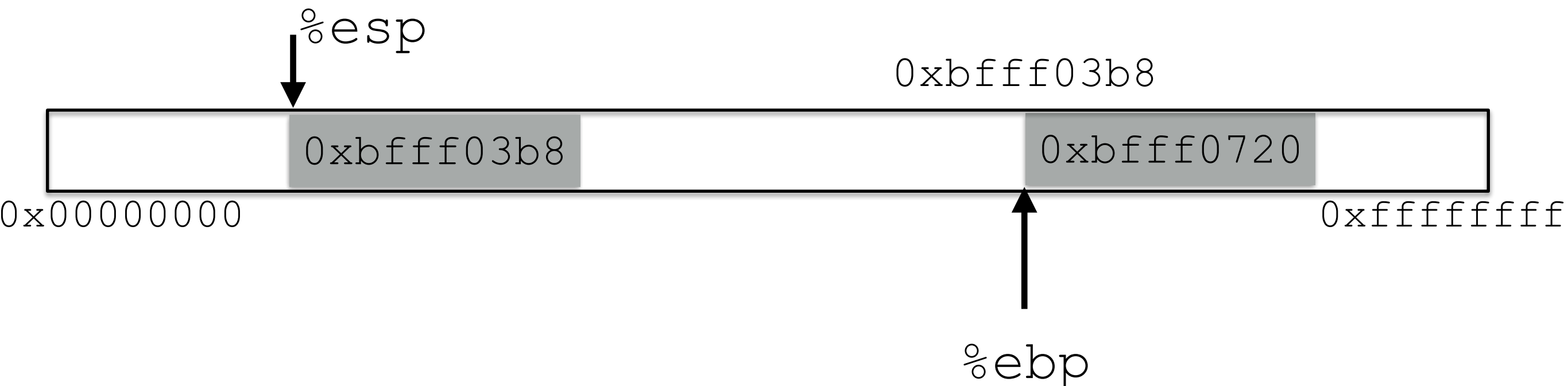


Notation

0xbfff03b8 %ebp A memory address

0xbfff0720 (%ebp) The value at memory address %ebp
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pushl %ebp

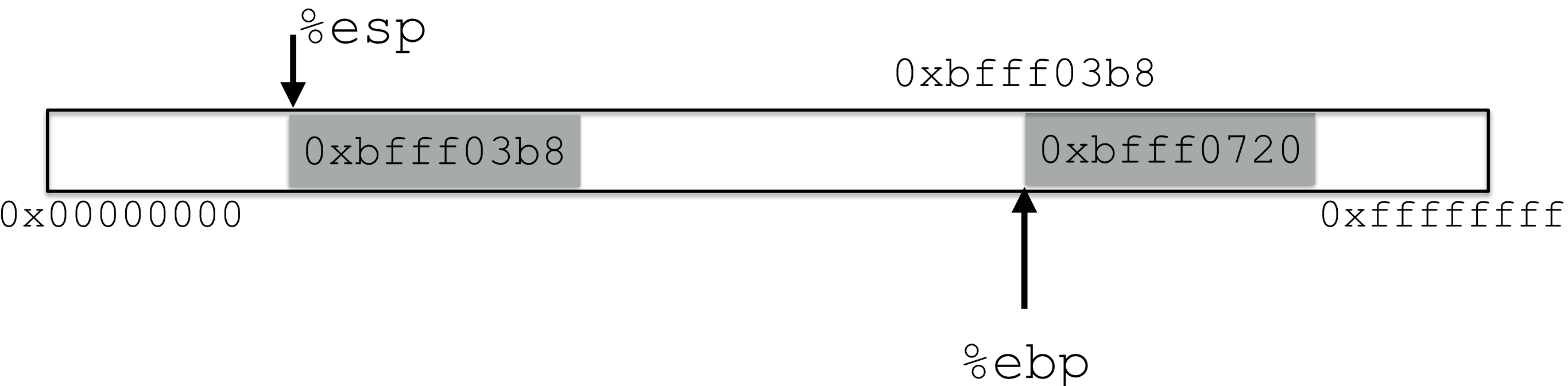


Notation

0xbfff03b8 %ebp A memory address

0xbfff0720 (%ebp) The value at memory address %ebp
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```
pushl %ebp  
movl  %esp %ebp /* %ebp = %esp */
```

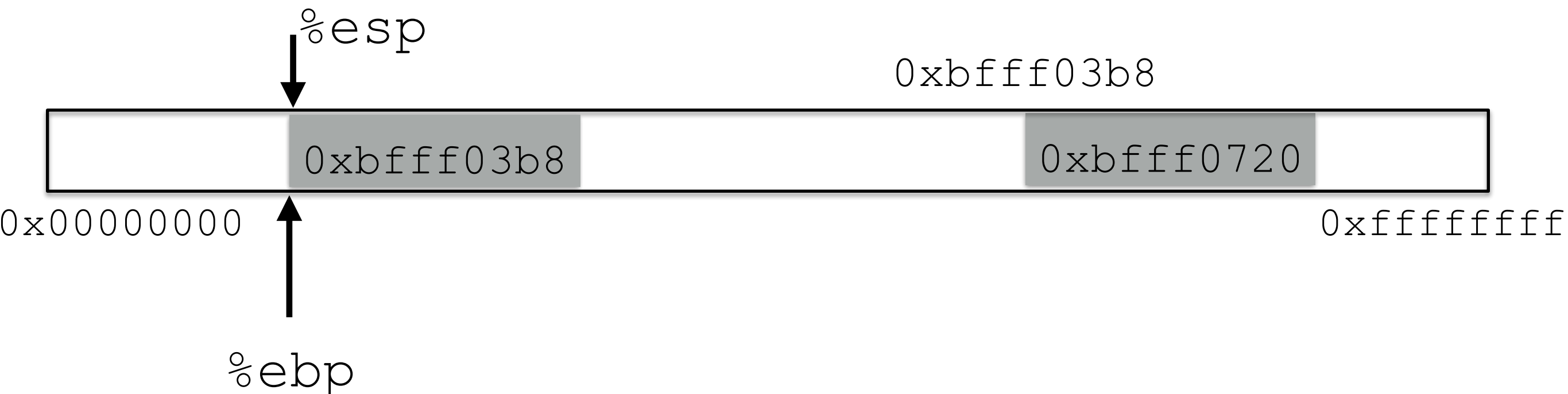


Notation

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0xbfff0720 (%ebp) The value at memory address %ebp
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movl  %esp %ebp /* %ebp = %esp */
```



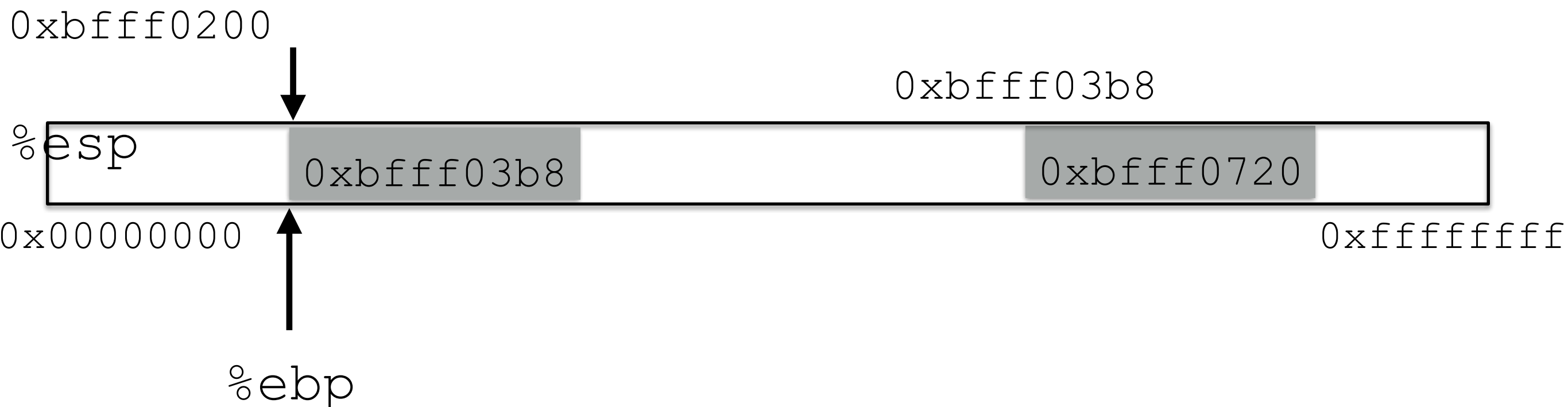
Notation

0xbfff03b8 %ebp A memory address

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

```
pushl %ebp
```

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

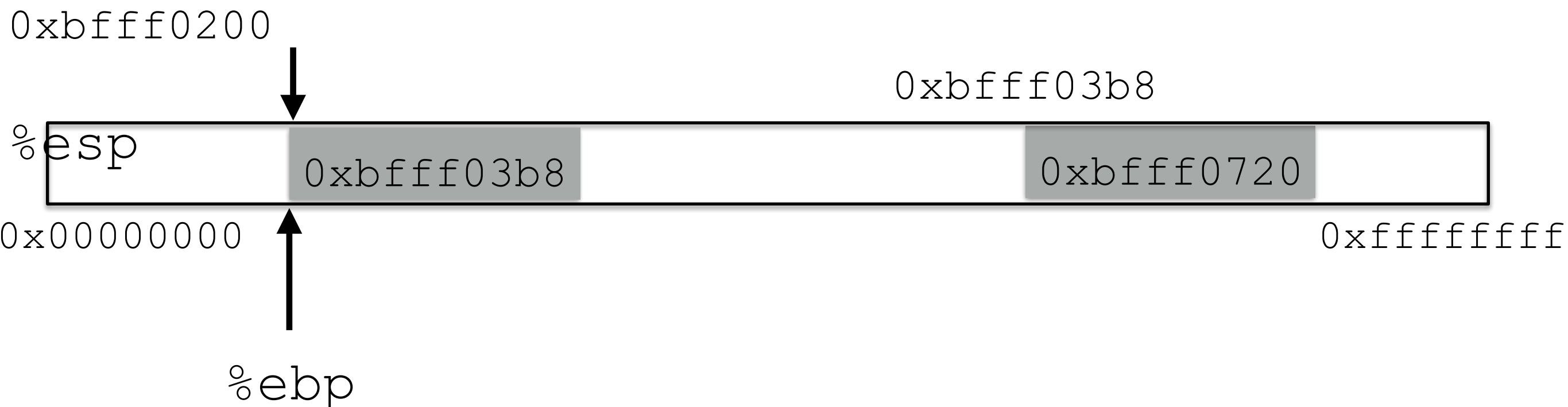


Notation

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

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

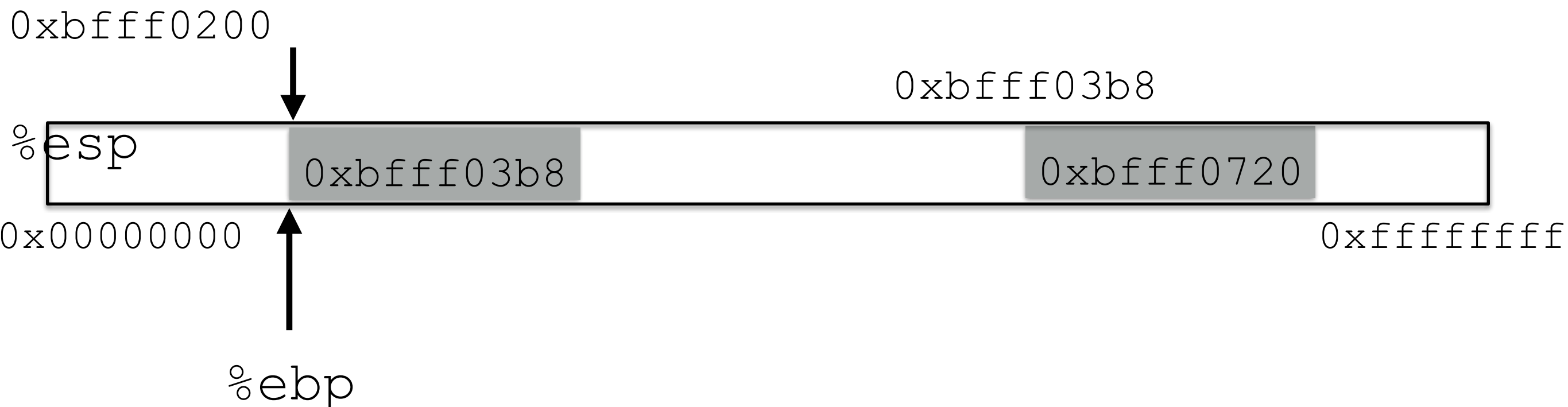


Notation

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

~~0xbfff0720~~ `(%ebp)` The value at memory address `%ebp`
`0xbfff03b8` (like dereferencing a pointer)

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

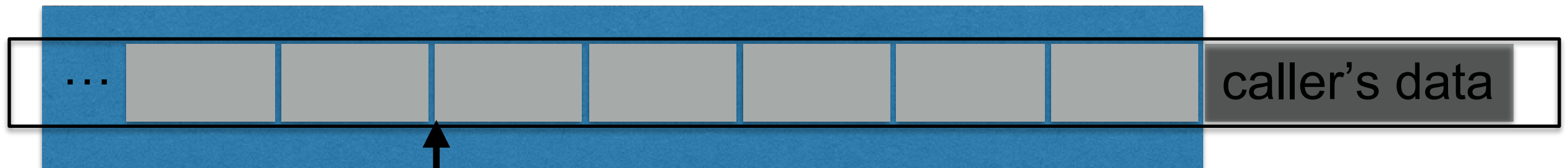


Returning from functions

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

0x00000000

0xffffffff



%ebp

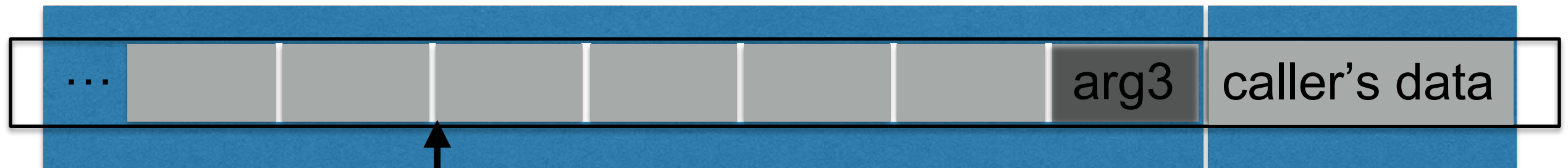
Stack frame
for *this* call to func

Returning from functions

```
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{  
    ...  
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    ...  
}
```

0x00000000

0xffffffff



%ebp

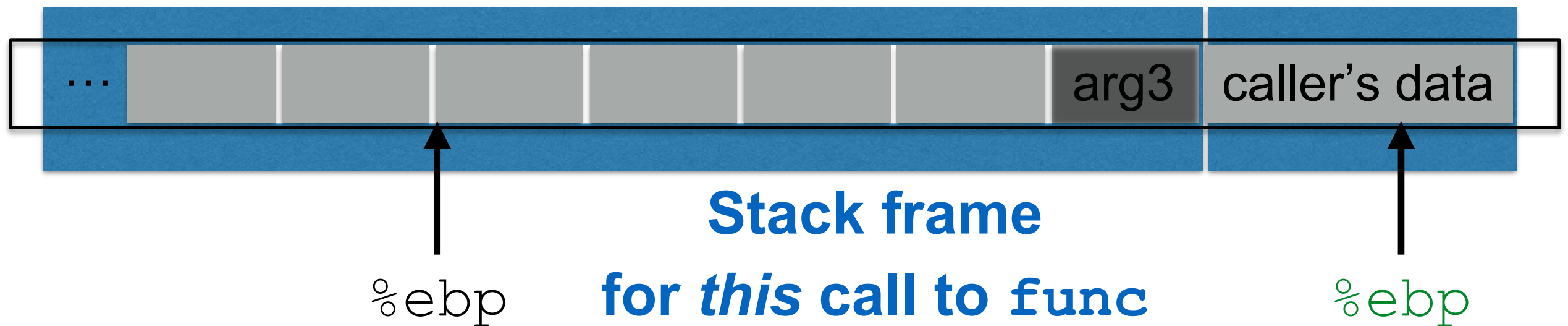
Stack frame
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Returning from functions

```
int main()  
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    ...  
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```

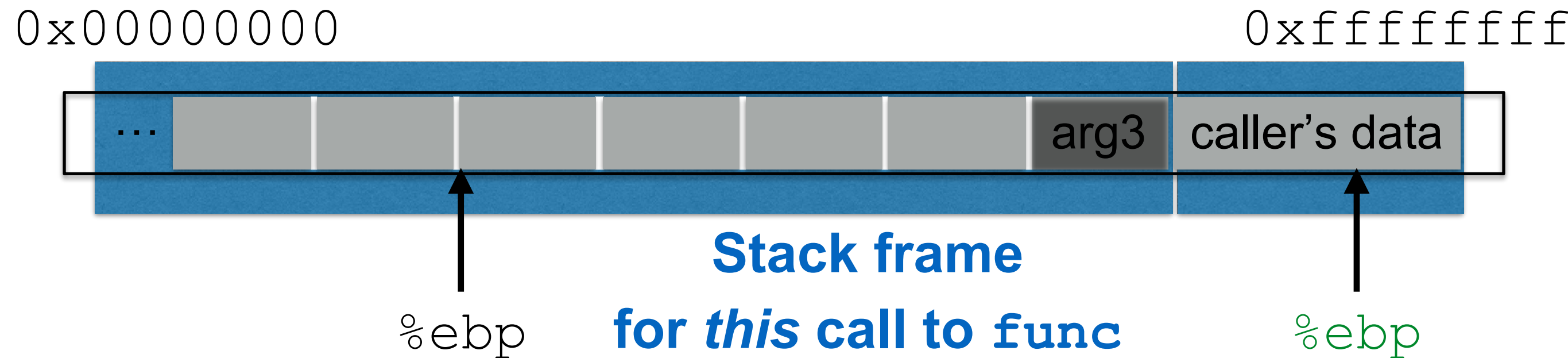
0x00000000

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Returning from functions

```
int main()  
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    ...  
    func("Hey", 10, -3);  
    ... Q: How do we restore %ebp?  
}
```

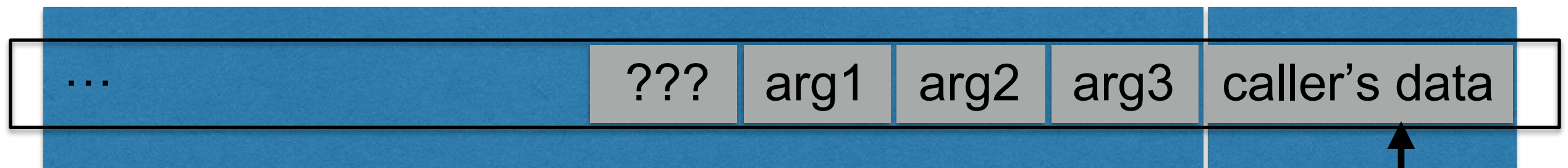


Returning from functions

```
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    ... Q: How do we restore %ebp?  
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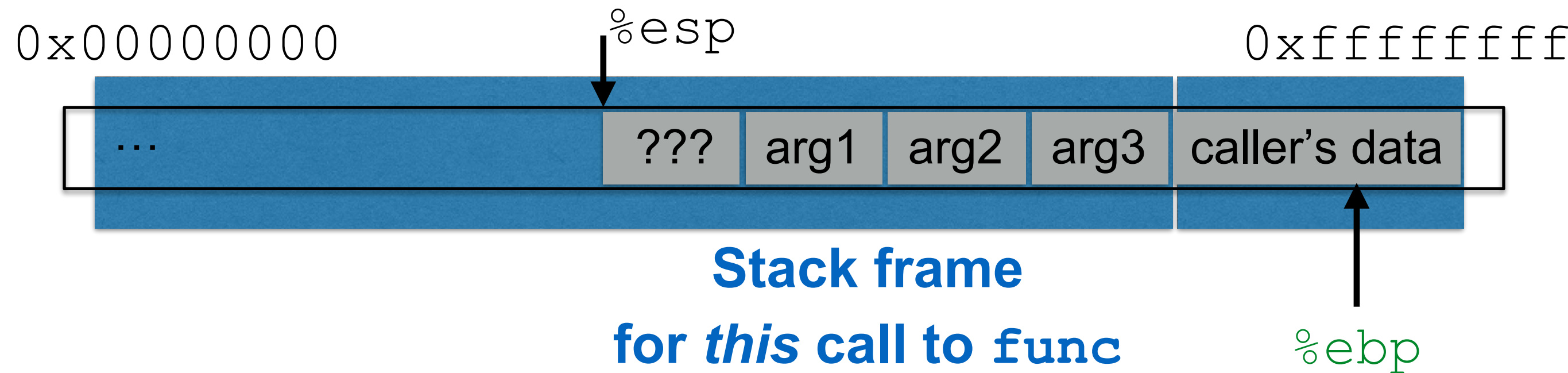


Stack frame
for *this* call to func

%ebp

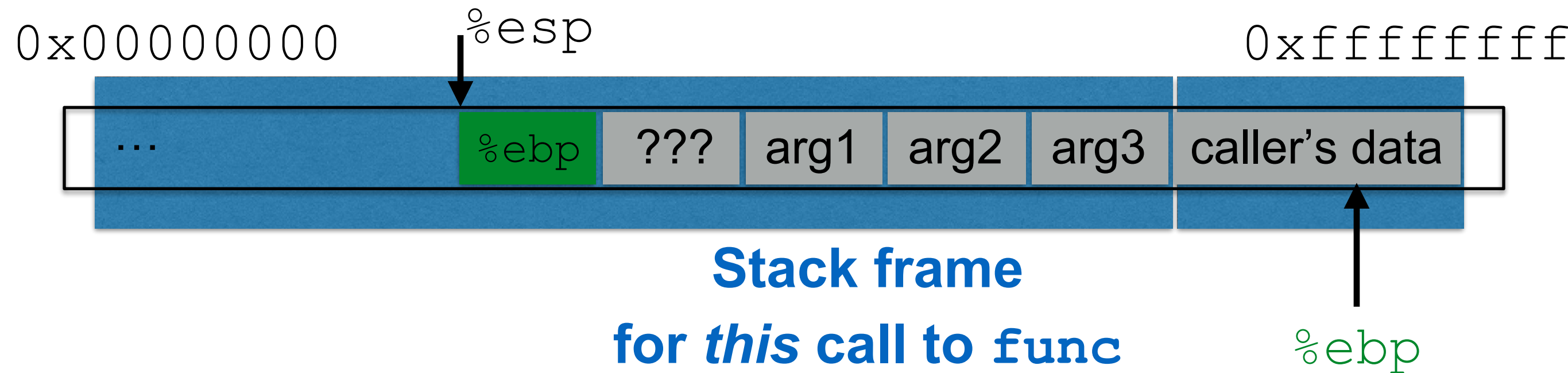
Returning from functions

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int main()  
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Returning from functions

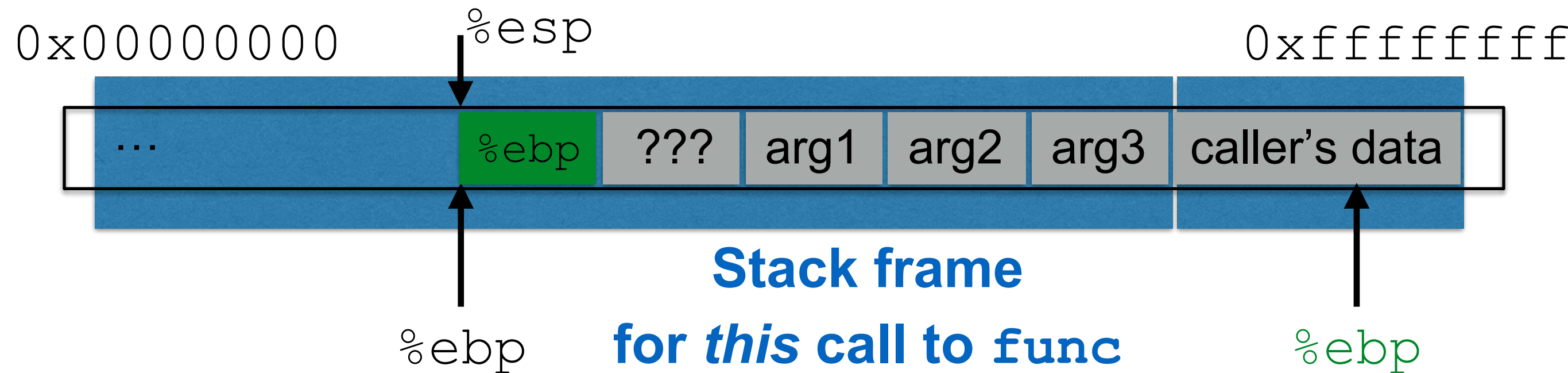
```
int main()  
{  
    ...  
    func("Hey", 10, -3);  
    ... Q: How do we restore %ebp?  
}
```



1. Push `%ebp` before locals

Returning from functions

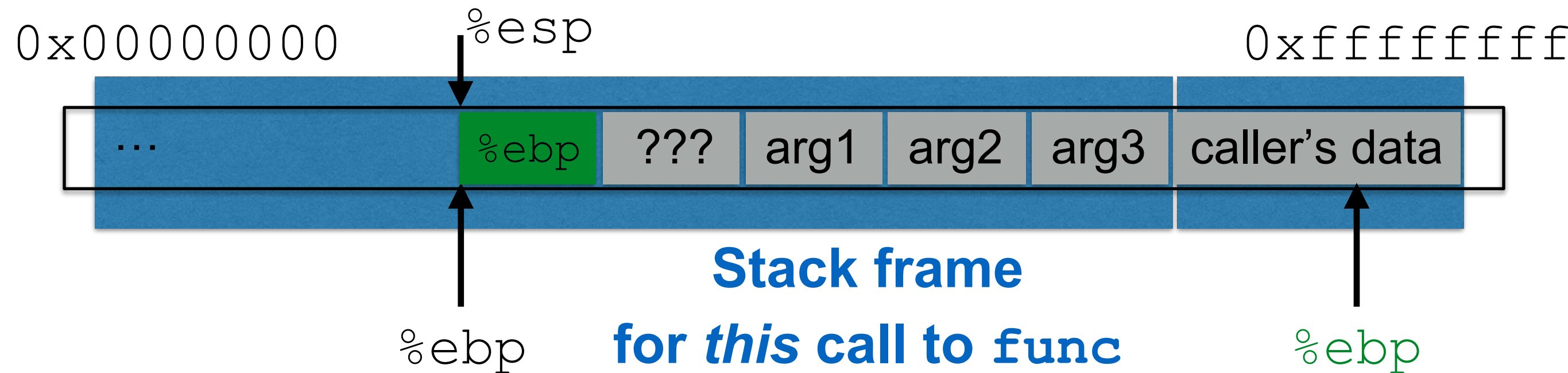
```
int main()  
{  
    ...  
    func("Hey", 10, -3);  
    ... Q: How do we restore %ebp?  
}
```



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

Returning from functions

```
int main()  
{  
    ...  
    func("Hey", 10, -3);  
    ... Q: How do we restore %ebp?  
}
```



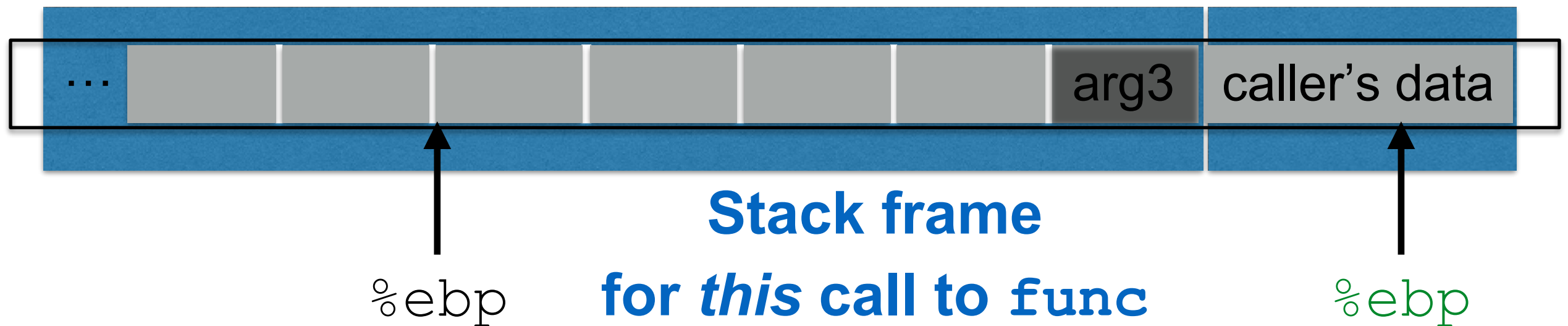
- 1. Push %ebp before locals**
- 2. Set %ebp to current %esp**
- 3. Set %ebp to (%ebp) at return**

Returning from functions

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

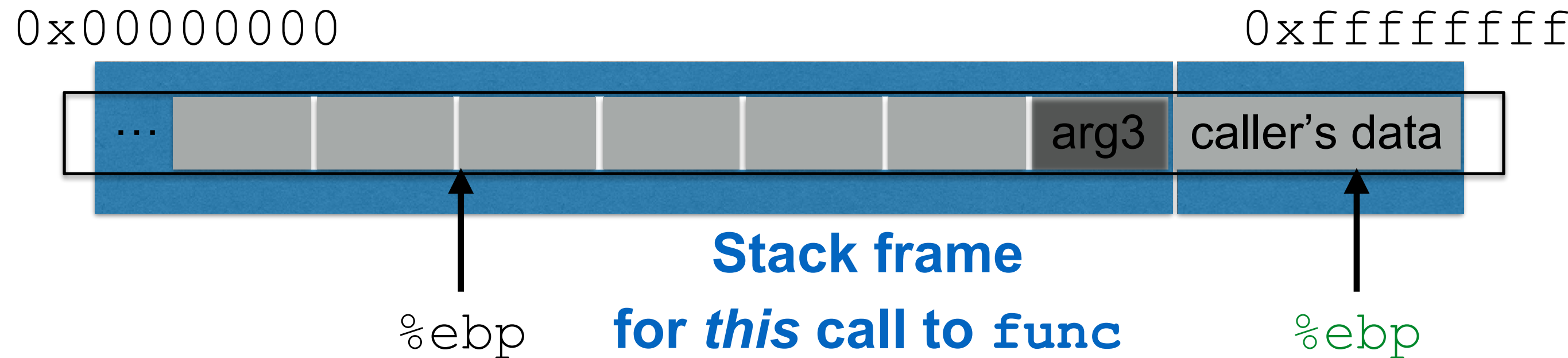
0x00000000

0xffffffff

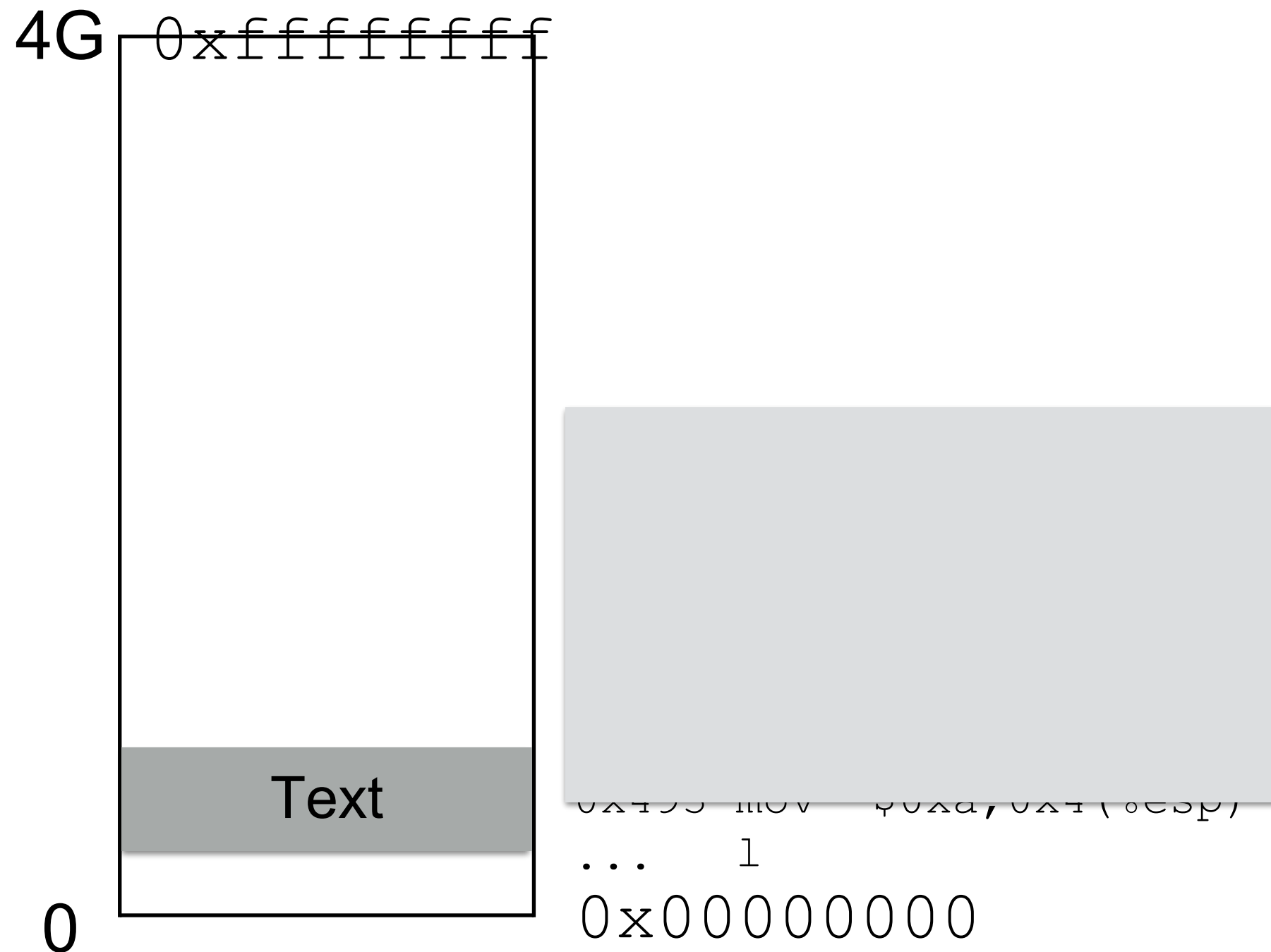


Returning from functions

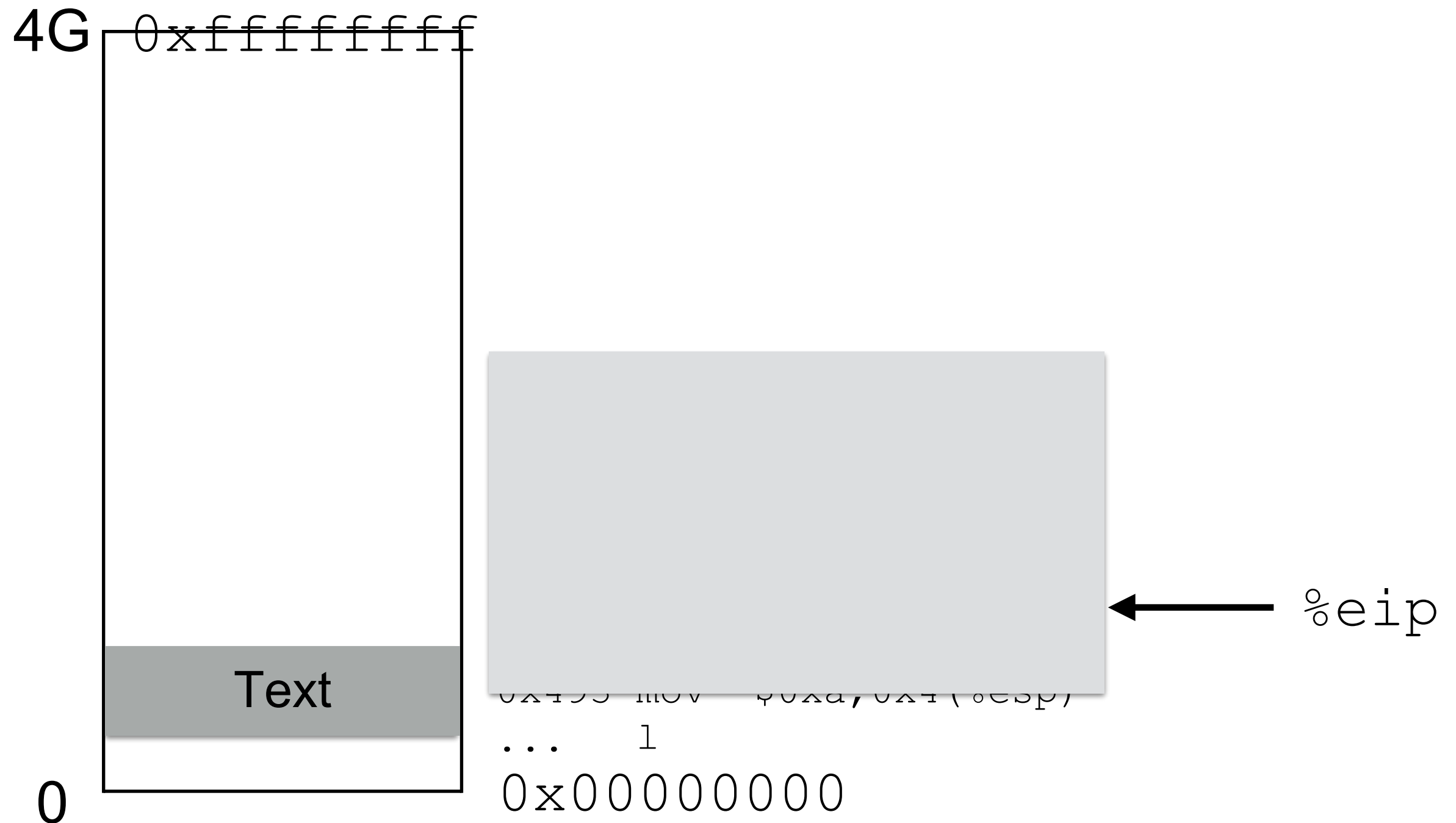
```
int main()  
{  
    ...  
    func("Hey", 10, -3);  
    ... Q: How do we resume here?  
}
```



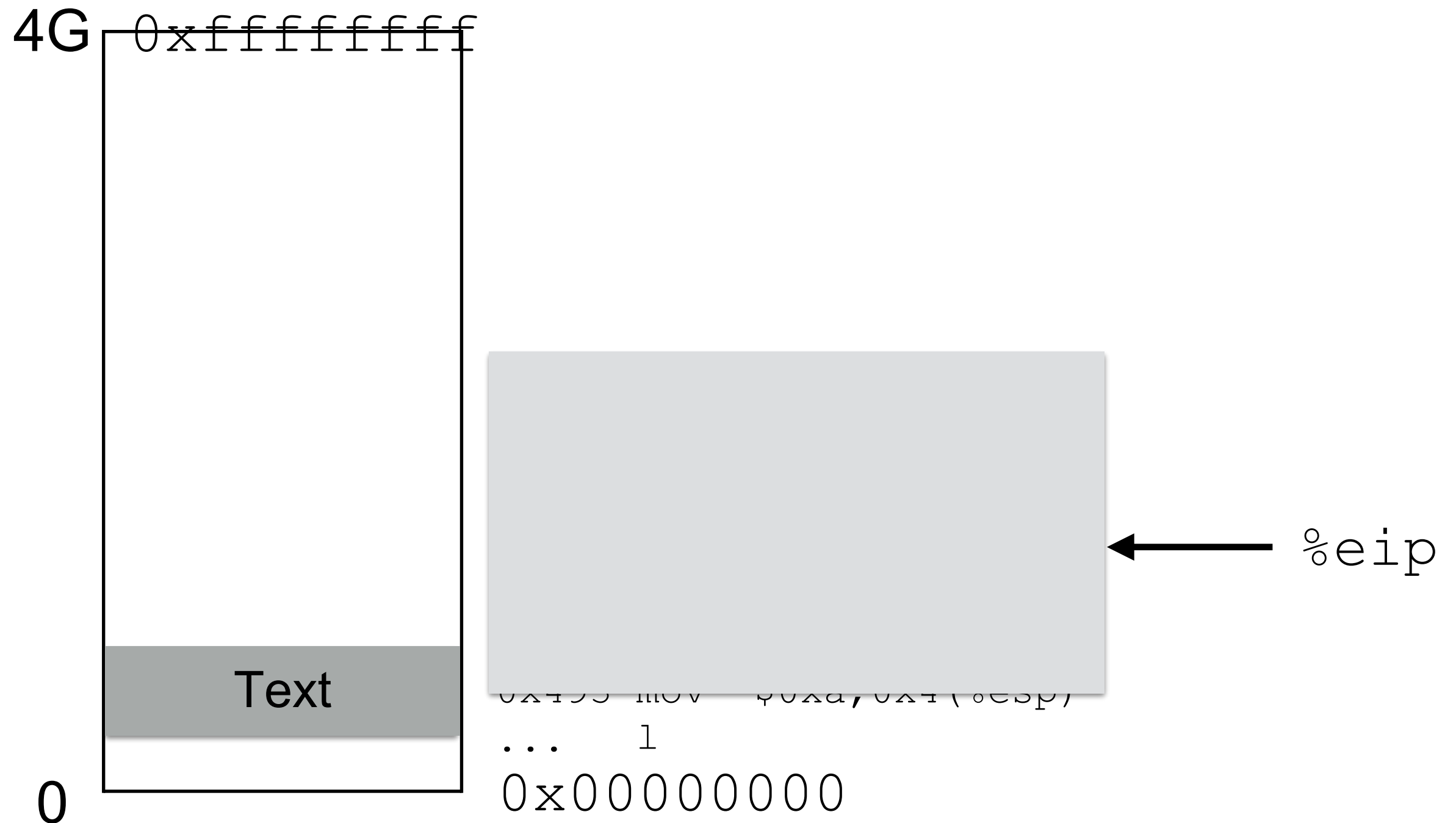
The instructions themselves are in memory



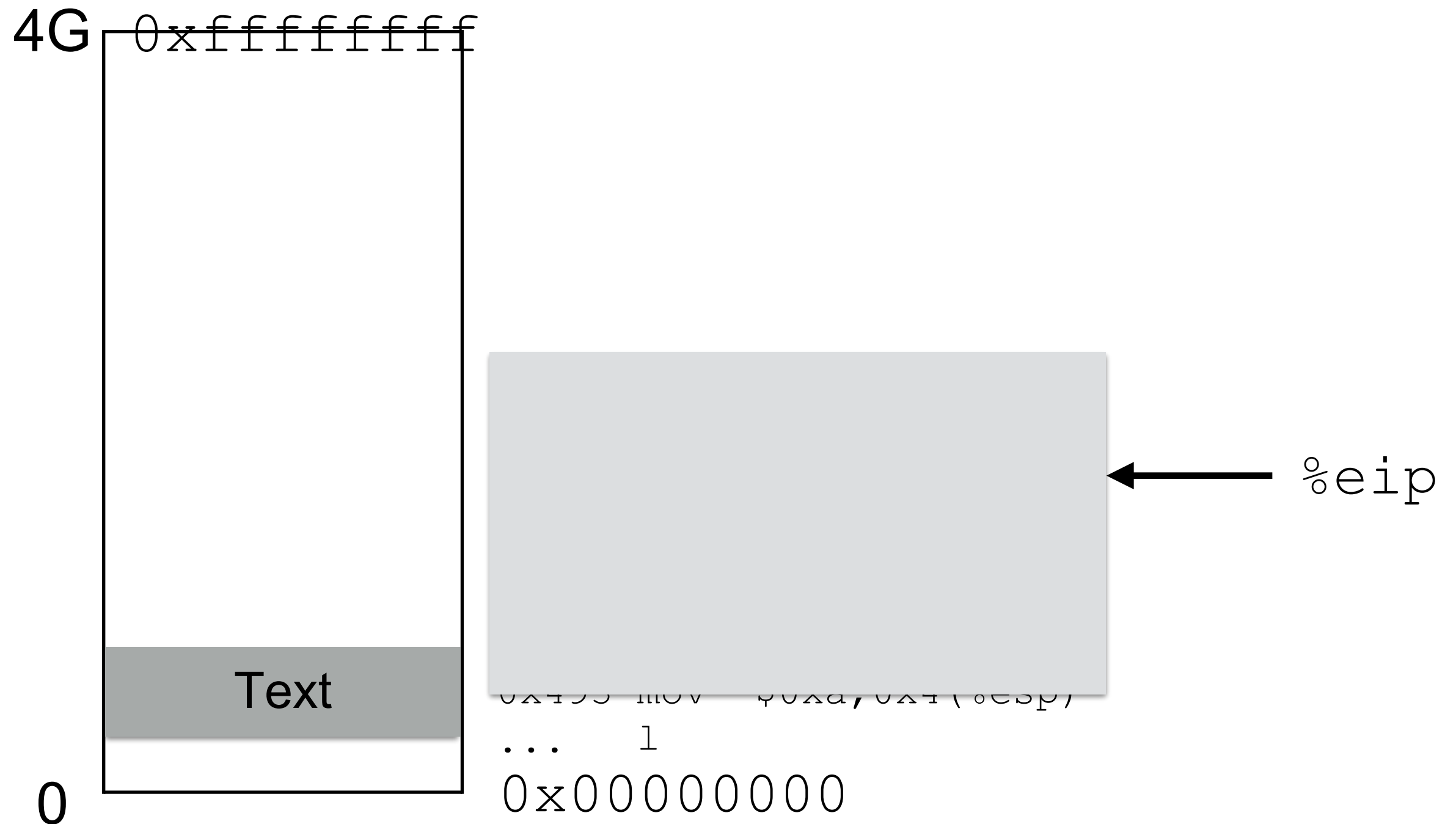
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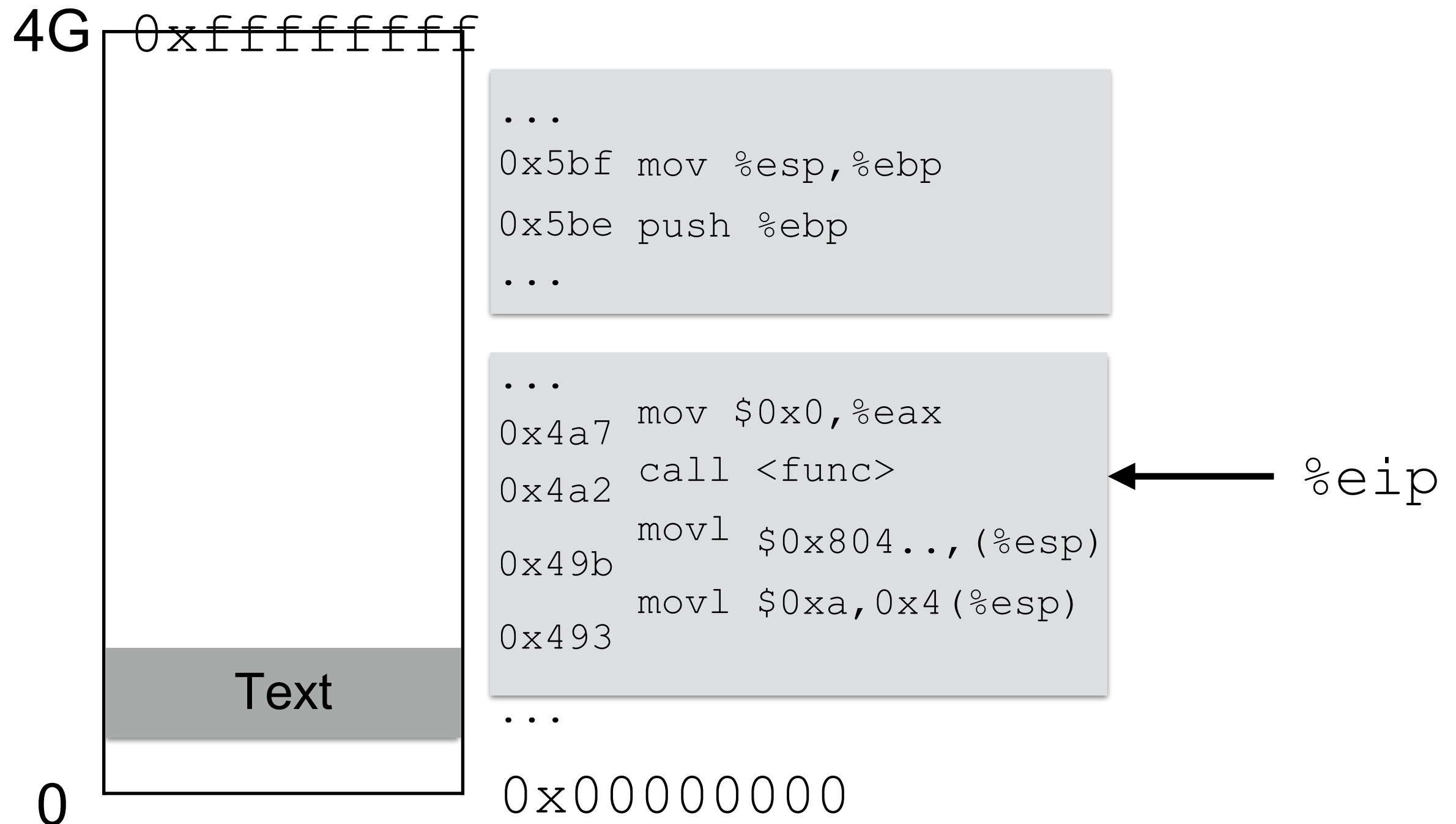
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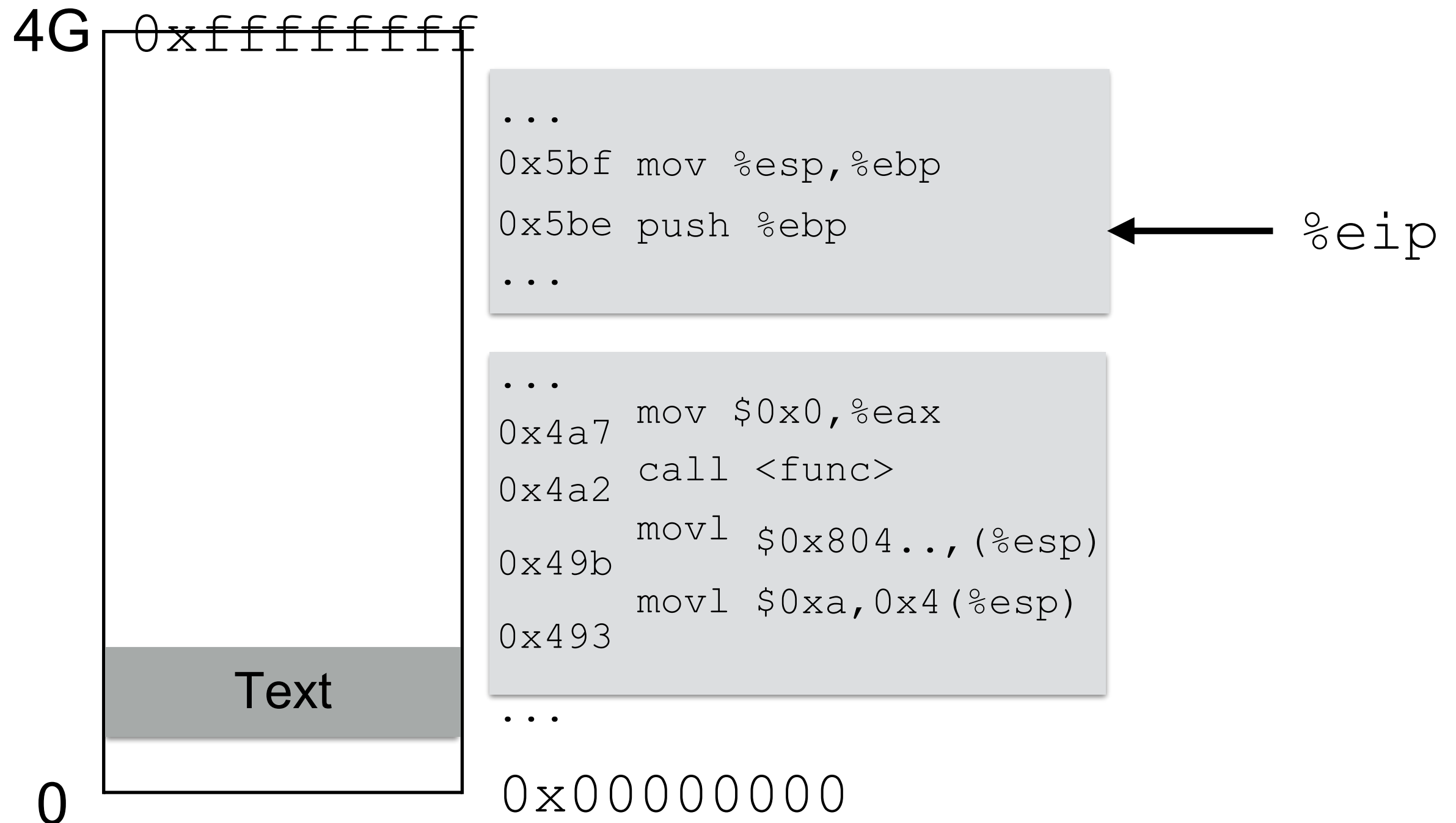
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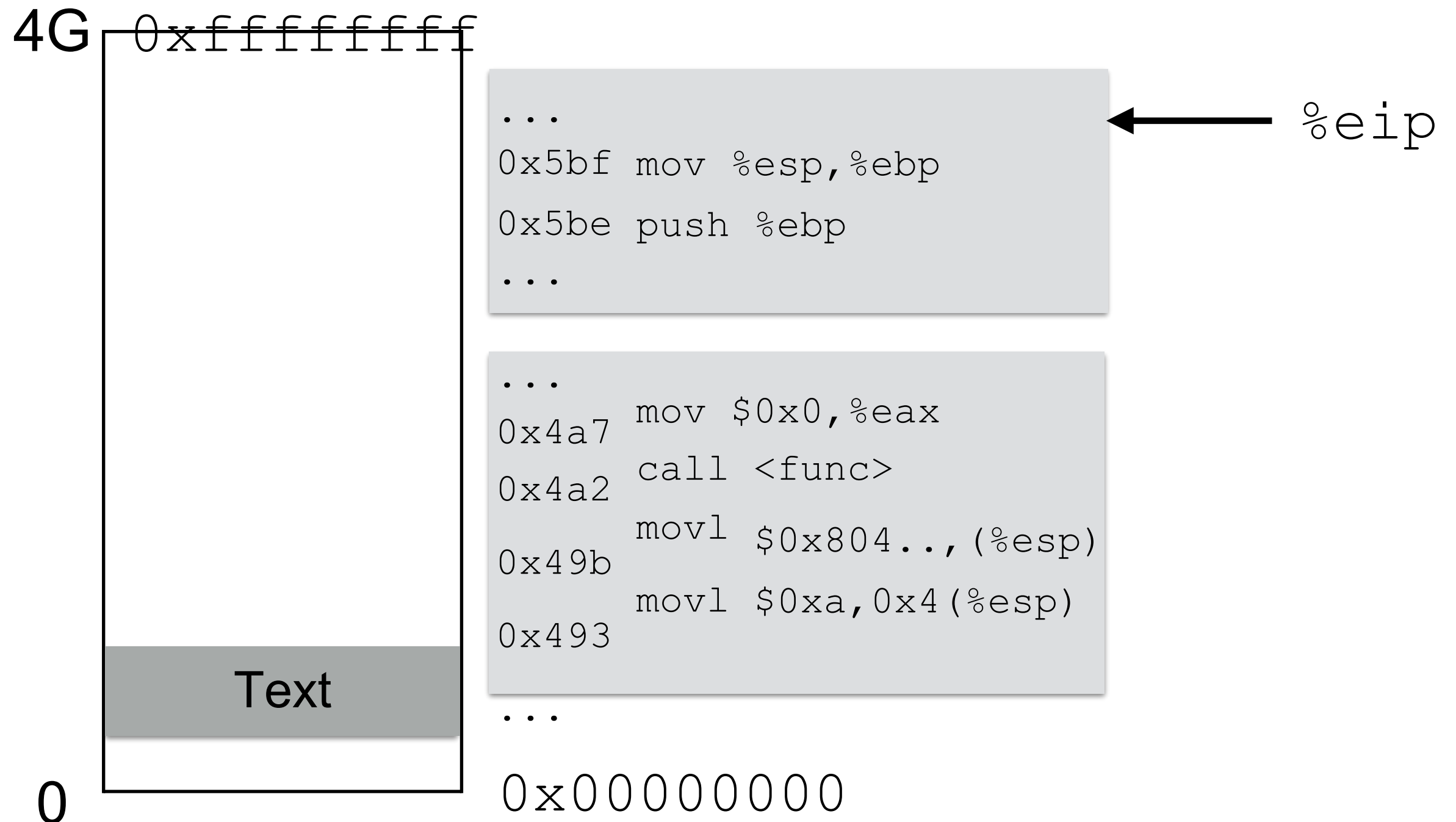
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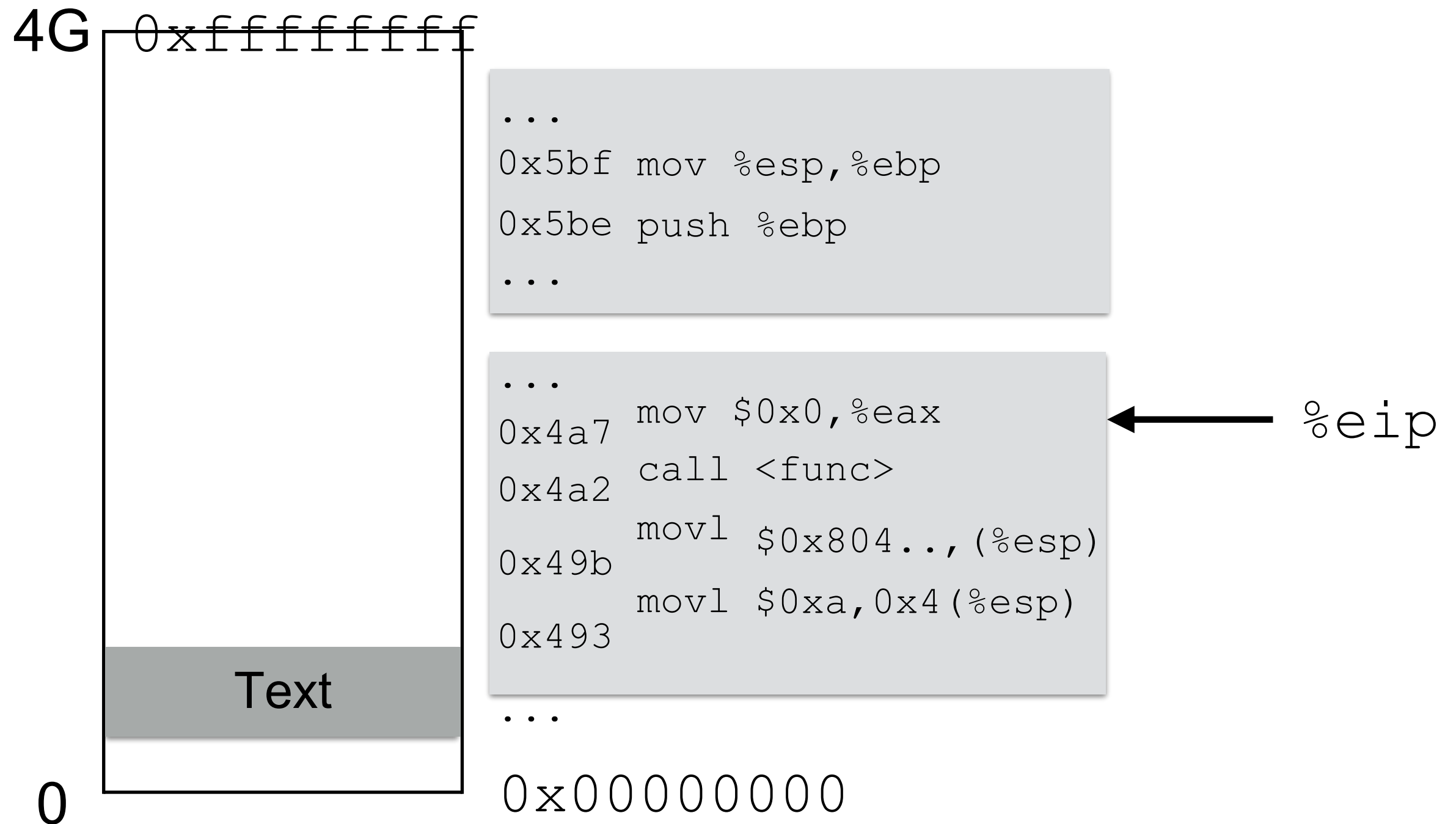
The instructions themselves are in memory



The instructions themselves are in memory

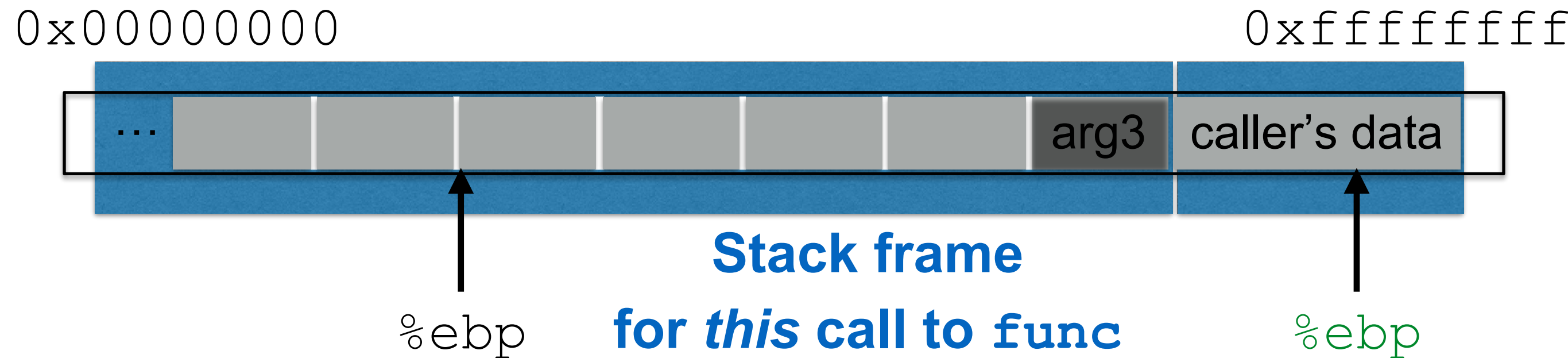


The instructions themselves are in memory



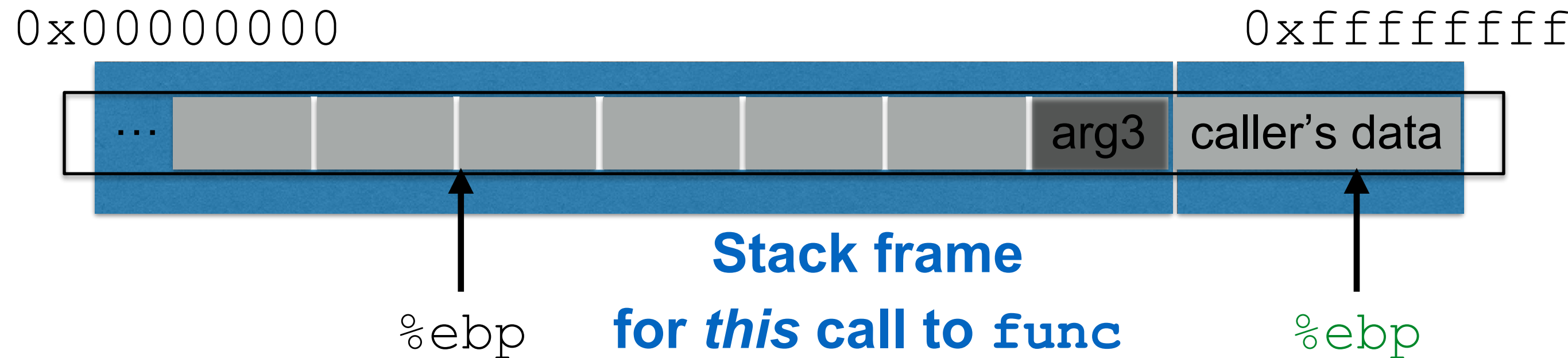
Returning from functions

```
int main()  
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Returning from functions

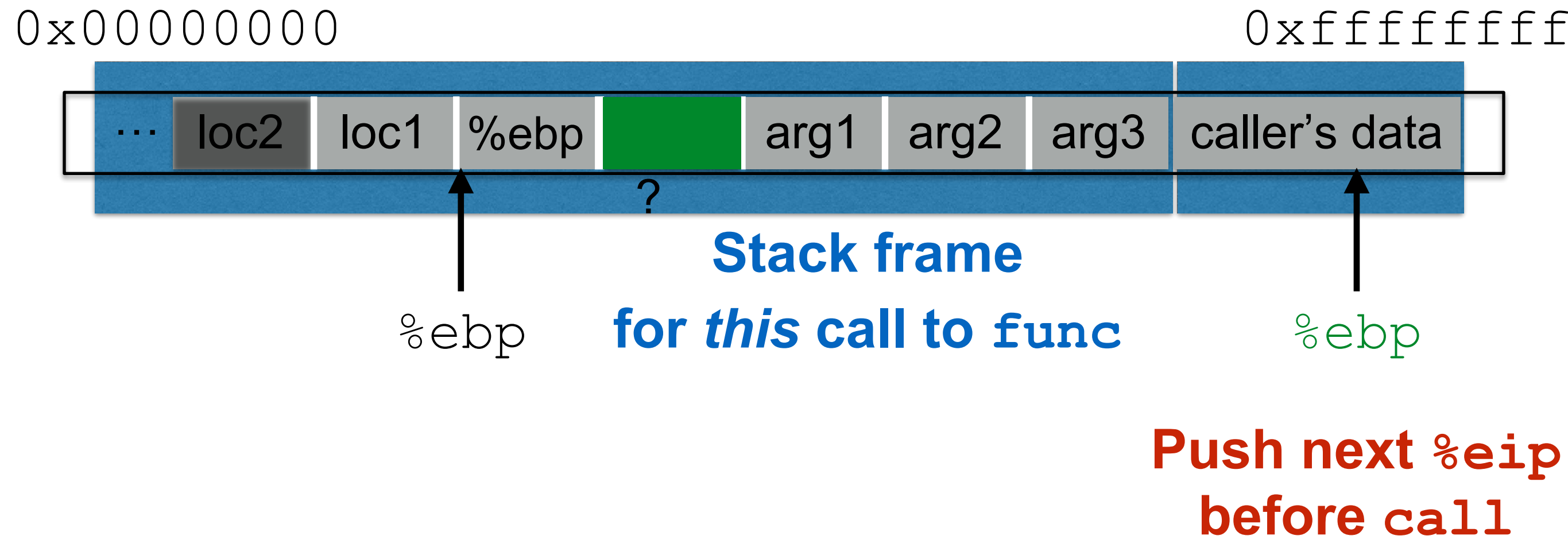
```
int main()  
{  
    ...  
    func("Hey", 10, -3);  
    ... Q: How do we resume here?  
}
```



**Push next %eip
before call**

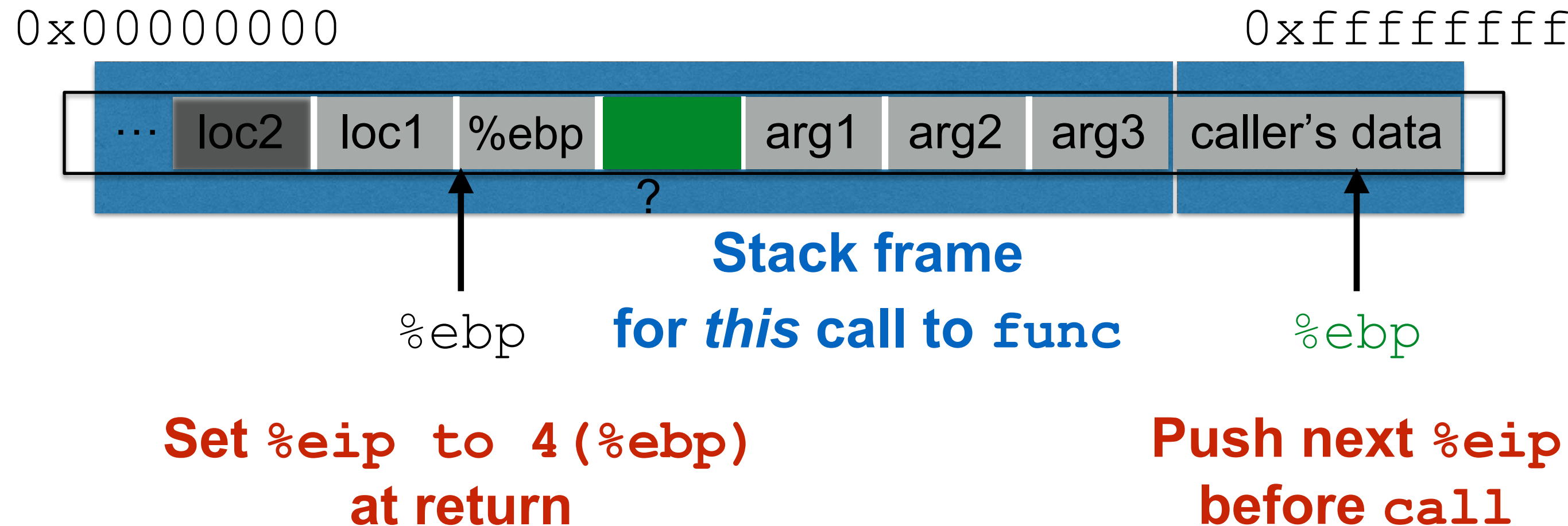
Returning from functions

```
int main()  
{  
    ...  
    func("Hey", 10, -3);  
    ... Q: How do we resume here?  
}
```



Returning from functions

```
int main()  
{  
    ...  
    func("Hey", 10, -3);  
    ... Q: How do we resume here?  
}
```



Stack and functions: Summary

Stack and functions: Summary

Calling function:

1. **Push arguments** onto the stack (in reverse)
2. **Push the return address**, i.e., the address of the instruction you want run after control returns to you: `%eip+something`
3. **Jump to the function's address**

Stack and functions: Summary

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Called function:

4. **Push the old frame pointer** onto the stack: `%ebp`
5. **Set frame pointer** `%ebp` to where the end of the stack is right now: `%esp`
6. **Push local variables** onto the stack; access them as offsets from `%ebp`

Stack and functions: Summary

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5. **Set frame pointer** `%ebp` to where the end of the stack is right now: `%esp`
6. **Push local variables** onto the stack; access them as offsets from `%ebp`

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

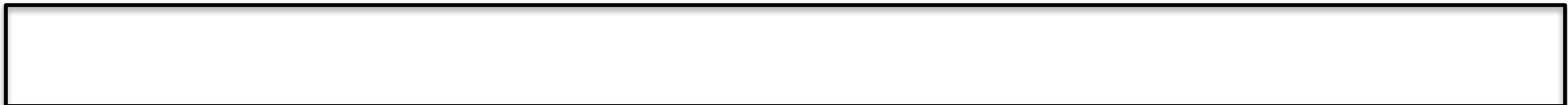
```
void func(char *arg1)
{
    char buffer[4];
    strcpy(buffer, arg1);
    ...
}

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

A buffer overflow example

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

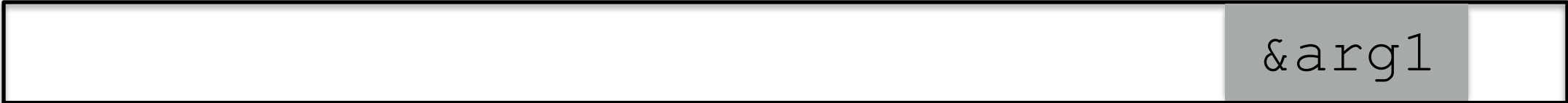
int main()
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    char *mystr = "AuthMe!";
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&arg1

A buffer overflow example

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    char buffer[4];
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```



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buffer

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buffer

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```

M e ! \0



buffer

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{
    char *mystr = "AuthMe!";
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    ...
}
```

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



buffer

A buffer overflow example

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{
    char buffer[4];
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    ...
}

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

Upon return, sets %ebp to
0x0021654d M e ! \0



buffer

SEGFAULT

(0-00016551)

A buffer overflow example

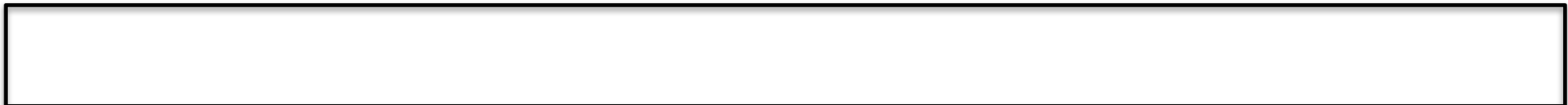
```
void func(char *arg1)
{
    int authenticated = 0;
    char buffer[4];
    strcpy(buffer, arg1);
    if(authenticated) { ...
}

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

A buffer overflow example

```
void func(char *arg1)
{
    int authenticated = 0;
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int main()
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A buffer overflow example

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{
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int main()
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&arg1

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}

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{
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    ...
}
```



A buffer overflow example

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int main()
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A buffer overflow example

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void func(char *arg1)
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    if(authenticated) { ...
}

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



authenticated

A buffer overflow example

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

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



A buffer overflow example

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void func(char *arg1)
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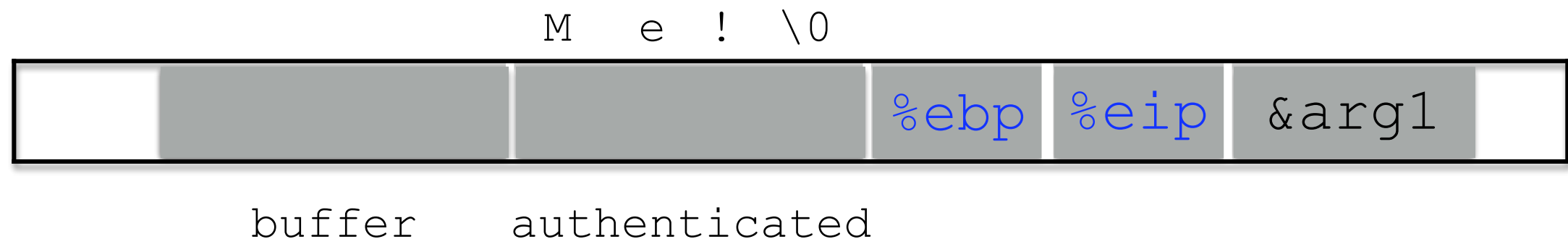
int main()
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    func(mystr);
    ...
}
```



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}

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

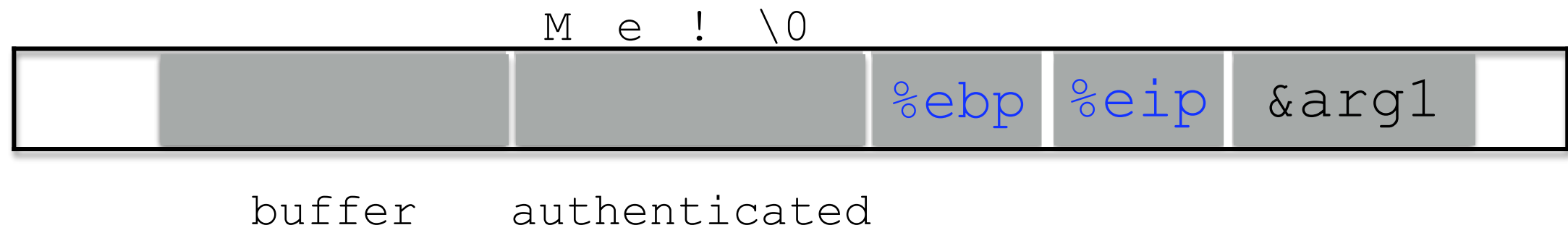


A buffer overflow example

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

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

Code still runs; user now 'authenticated'




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

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

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

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

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

```
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](#)
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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

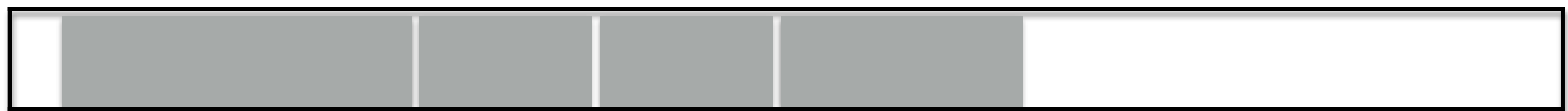
The vulnerability in IE is an invalid pointer reference, Microsoft said in [security advisory 979352](#), which it issued on Thursday. Under certain conditions, the invalid pointer can be accessed after an object is deleted, the advisory states. In specially crafted attacks, like the ones launched against 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 ways
 - Text
 - input
 - Packets
 - Environment variables File input...

What's the worst that could happen?

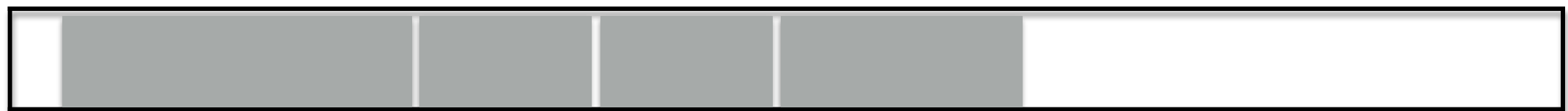
```
void func(char *arg1)
{
    char buffer[4];
    strcpy(buffer, arg1);
    ...
}
```



buffer

What's the worst that could happen?

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

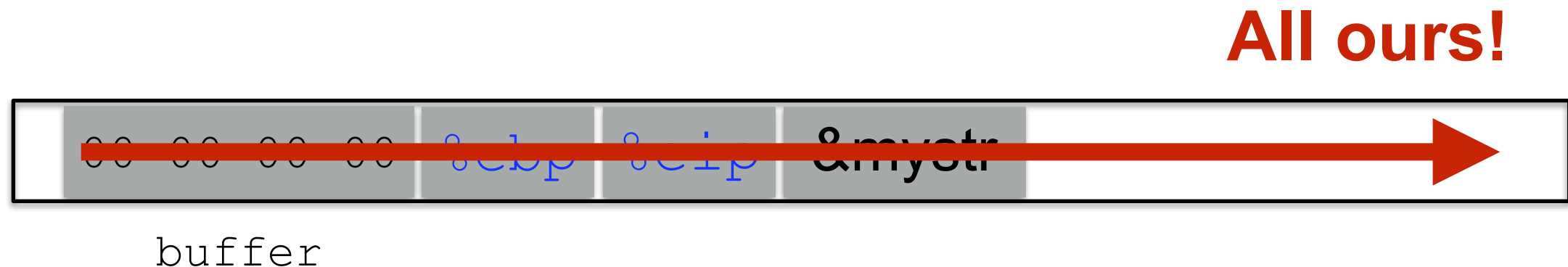


buffer

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

What's the worst that could happen?

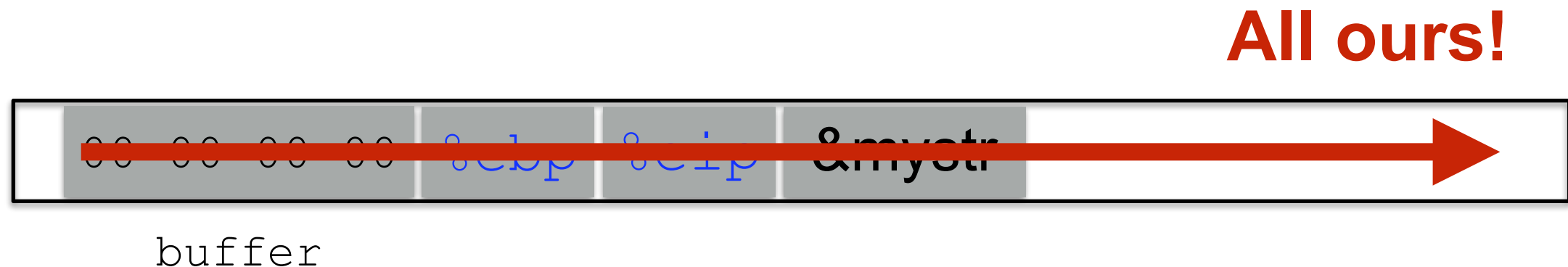
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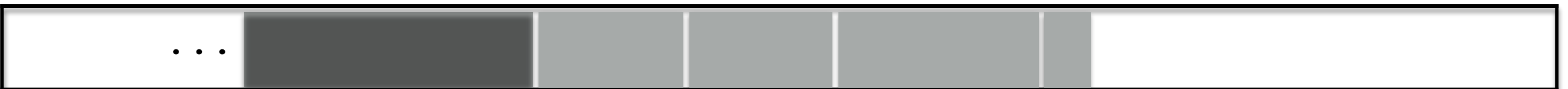
**strcpy will let you write as much as you want (til a
'\0')**

What could you write to memory to wreck havoc?

Code injection

High-level idea

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



buffer

High-level idea

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



buffer

(1) Load my own code into memory

High-level idea

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

%eip



buffer

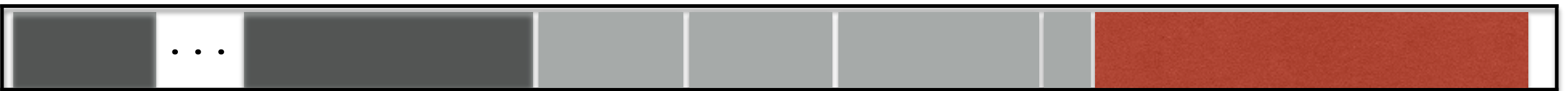
(1) Load my own code into memory

(2) Somehow get %eip to point to it

High-level idea

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    ...
}
```

%eip



buffer

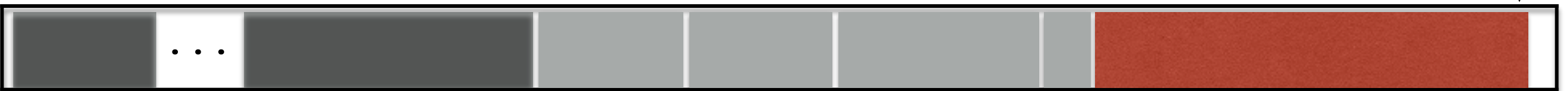
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High-level idea

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

%eip



buffer

(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
 - There are 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);
}
```

Shellcode

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#include <stdio.h>
int main( ) {
    char *name[2];
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}
```

Assembly

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

Shellcode

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

Machine code

Shellcode

```
#include <stdio.h>
int main( ) {
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```

Assembly

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pushl %eax
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```

...

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

...

Machine code

(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)
 - `setuid(0)` to set the effective userid to root
 - It's allowed to because root is the owner
- What is the potential attack?

Effective userid

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- Consider passwd:
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 - `setuid(0)` to set the effective userid to root
 - It's allowed to because root is the owner
- What is the potential attack?

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
- We have to use whatever code is already running

%eip



Text

...

00 00 00 00

%ebp

%eip

&arg1

...

\x0f \x3c \x2f ...

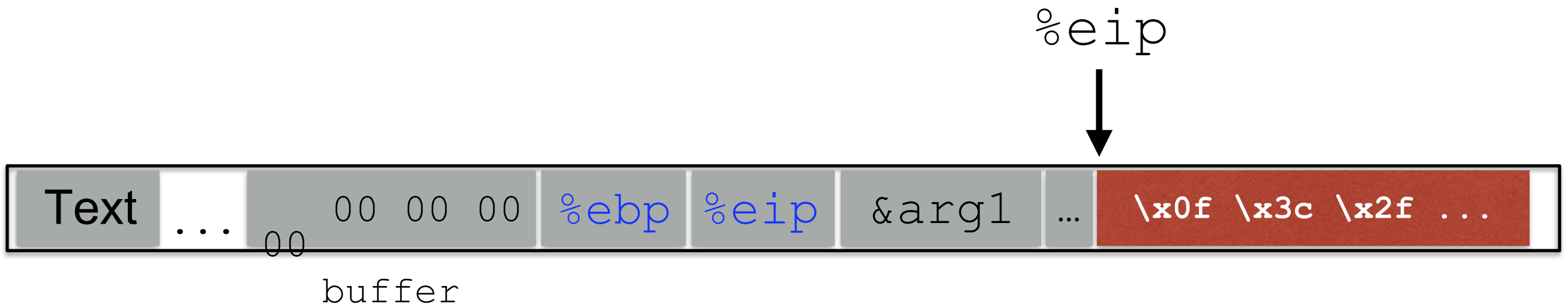
buffer

Thoughts?

Challenge 2

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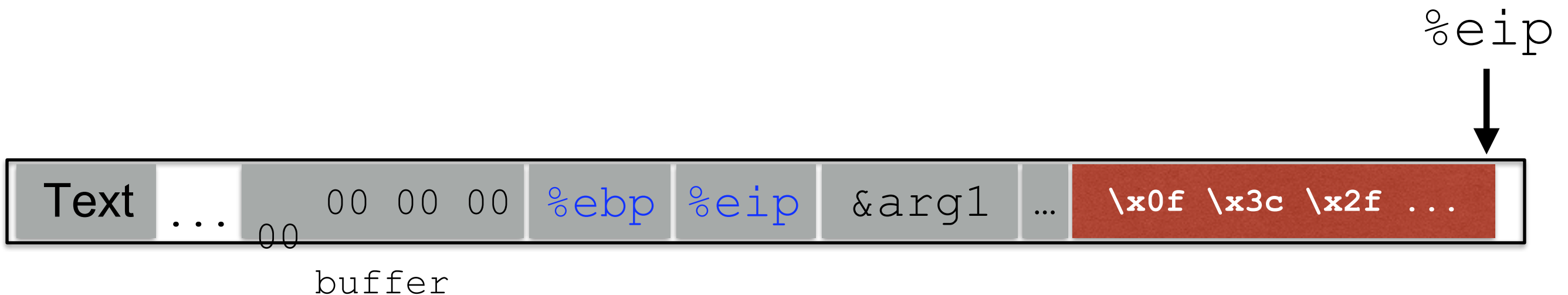


Thoughts?

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?

Stack and functions: Summary

Calling function:

1. Push arguments onto the stack (in reverse)
2. Push the return address, i.e., the address of the instruction you want run after control returns to you: `%eip+something`
3. Jump to the function's address

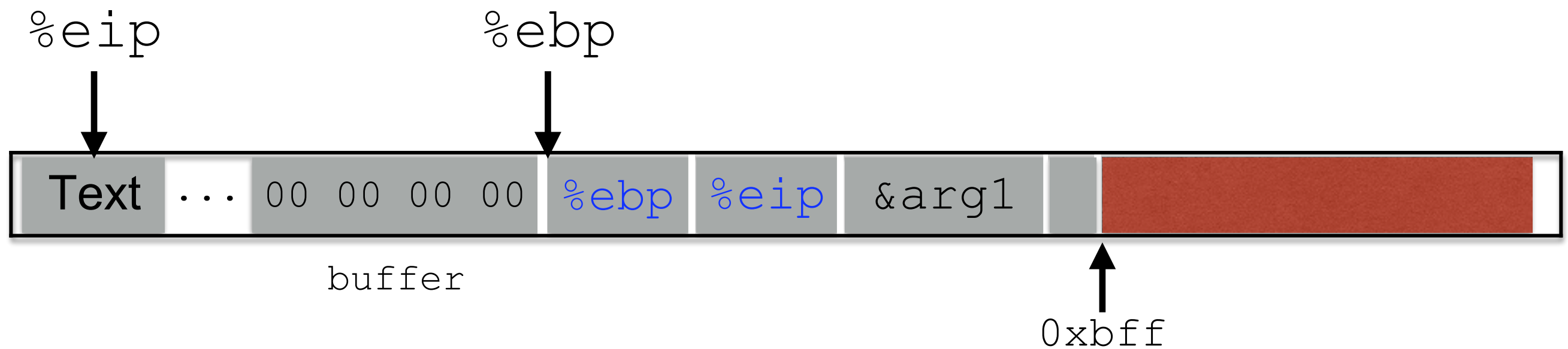
Called function:

4. Push the old frame pointer onto the stack: `%ebp`
5. Set frame pointer `%ebp` to where the end of the stack is right now: `%esp`
6. Push local variables onto the stack; access them as offsets from `%ebp`

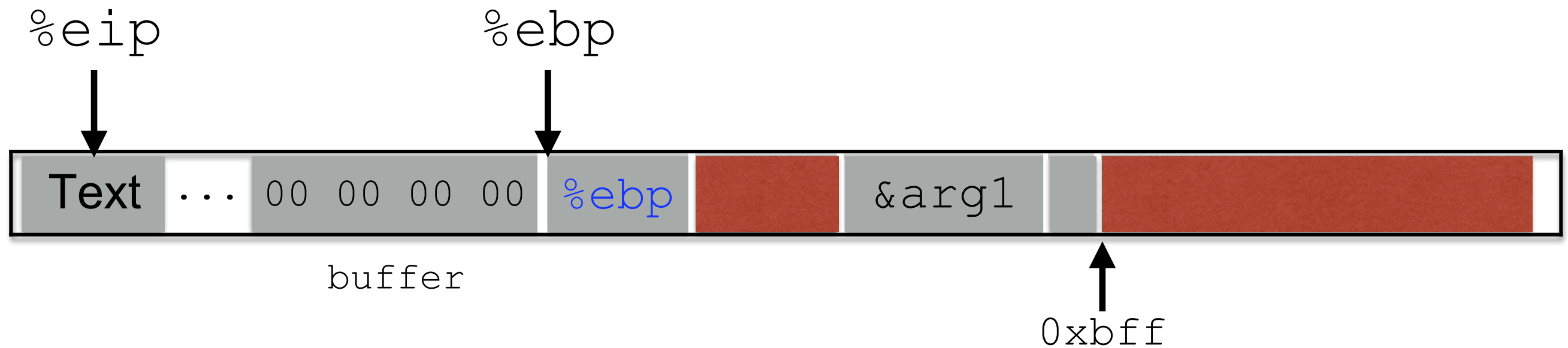
Returning function:

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

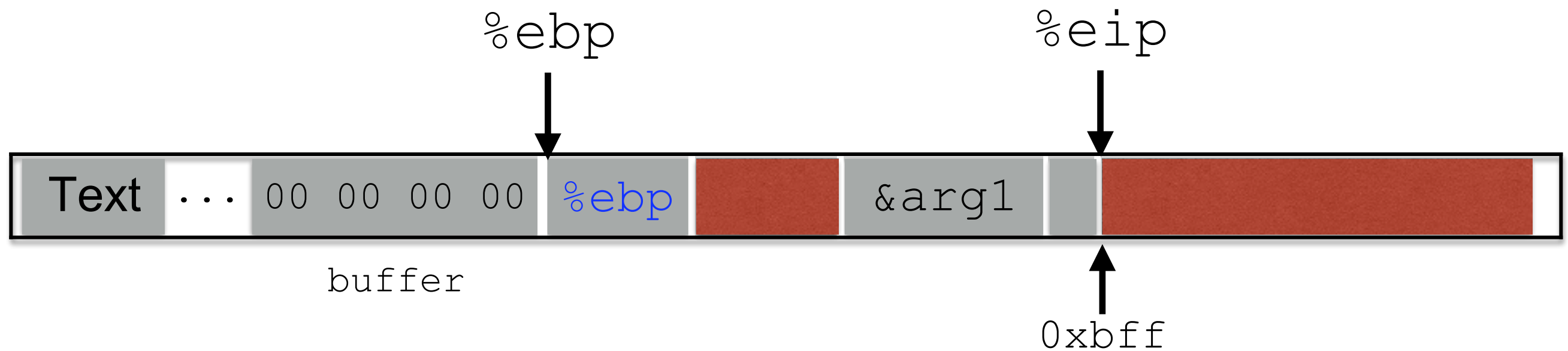
Hijacking the saved %eip



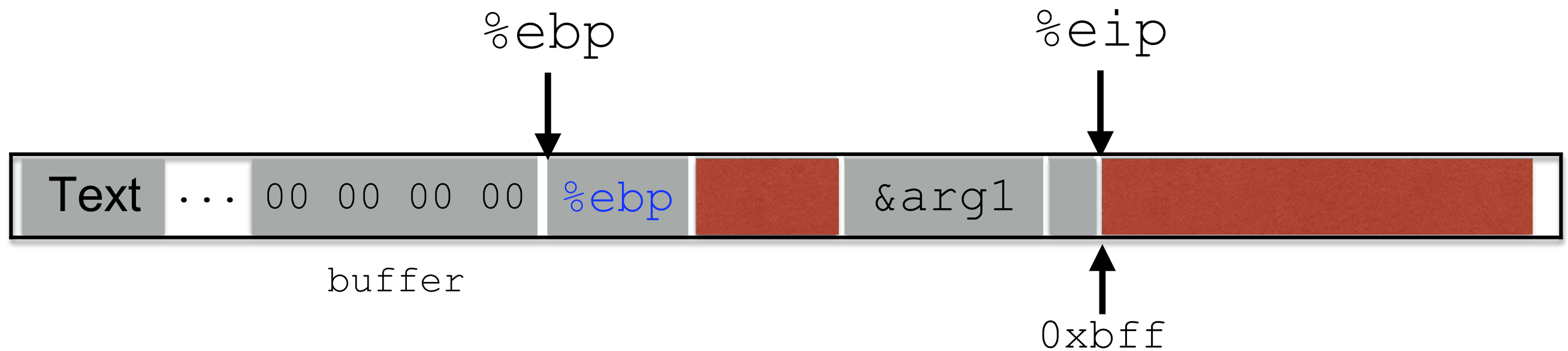
Hijacking the saved `%eip`



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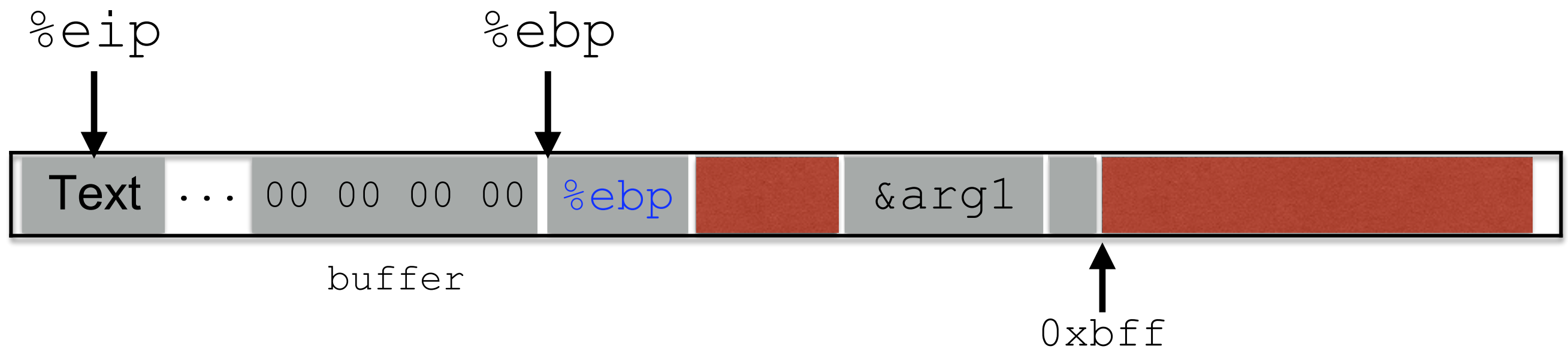
Hijacking the saved `%eip`



But how do we know the address?

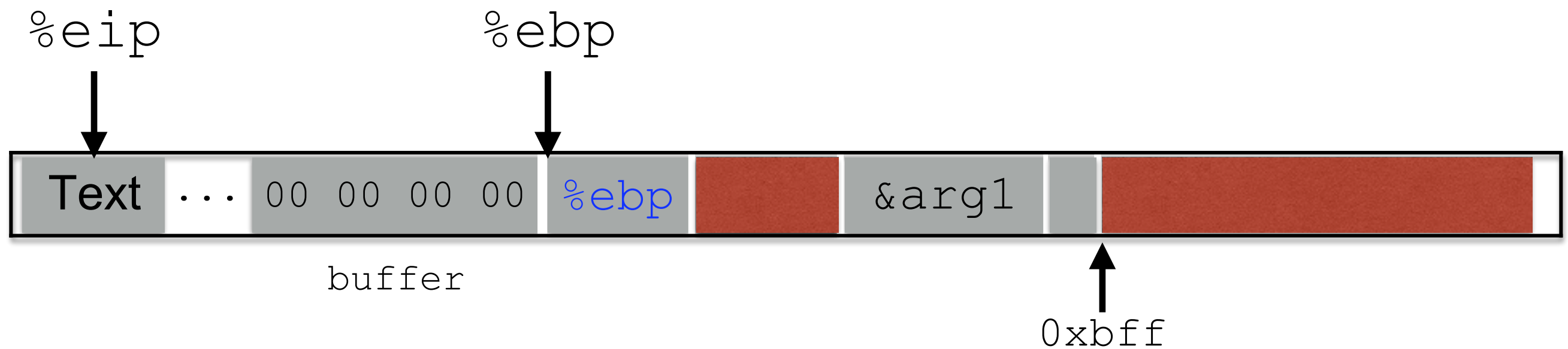
Hijacking the saved `%eip`

What if we are wrong?



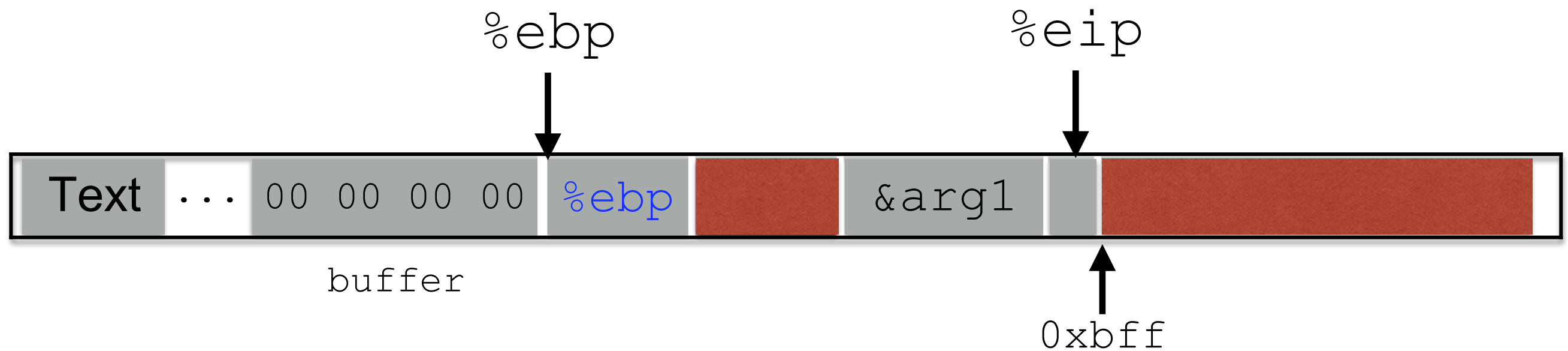
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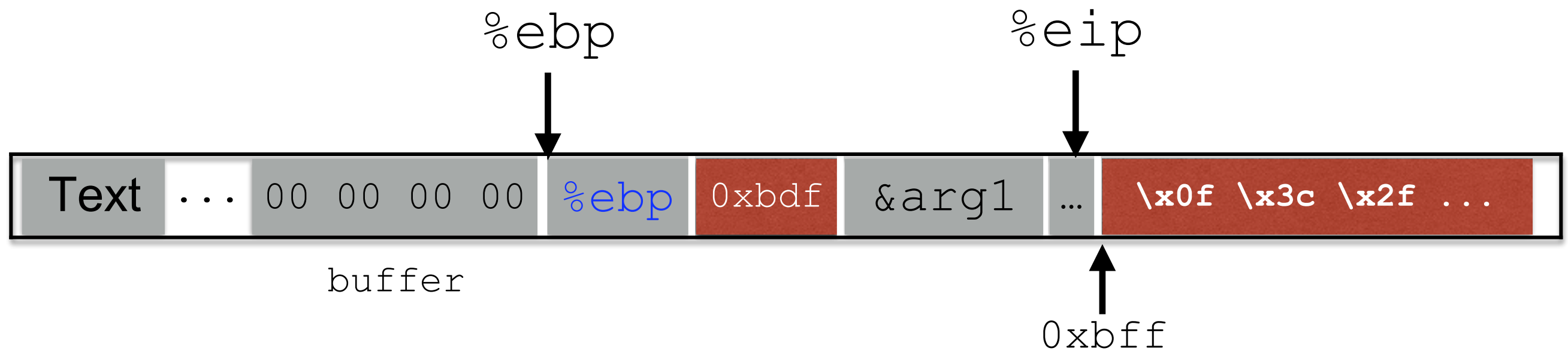
Hijacking the saved `%eip`

What if we are wrong?



Hijacking the saved `%eip`

What if we are wrong?



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

Challenge 3

Finding the return address

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- If we don't have access to the code, we don't know how far the buffer is from the saved `%ebp`

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- Worst case scenario: it's a 32 (or 64) bit memory space, which means 2^{32} (2^{64}) possible answers

Challenge 3

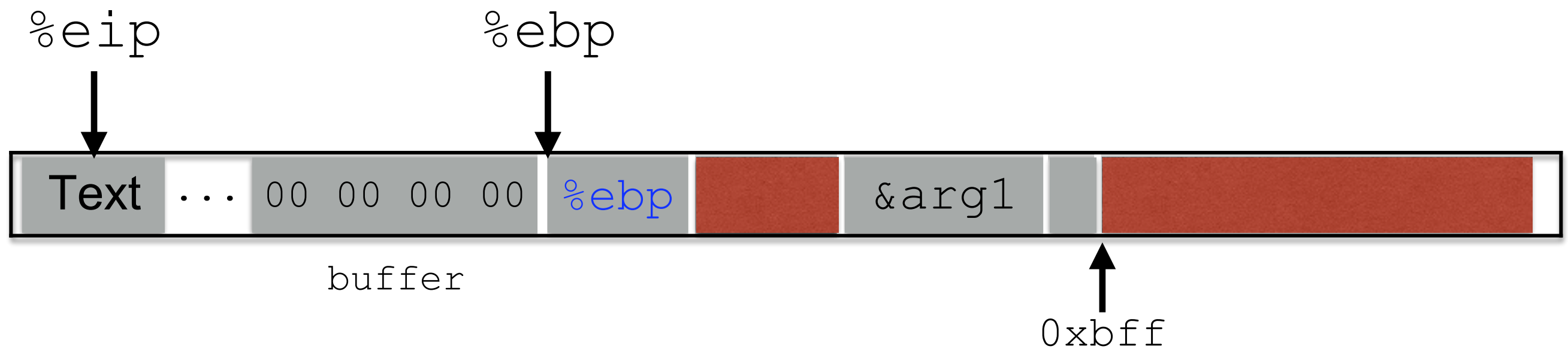
Finding the return address

- 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 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

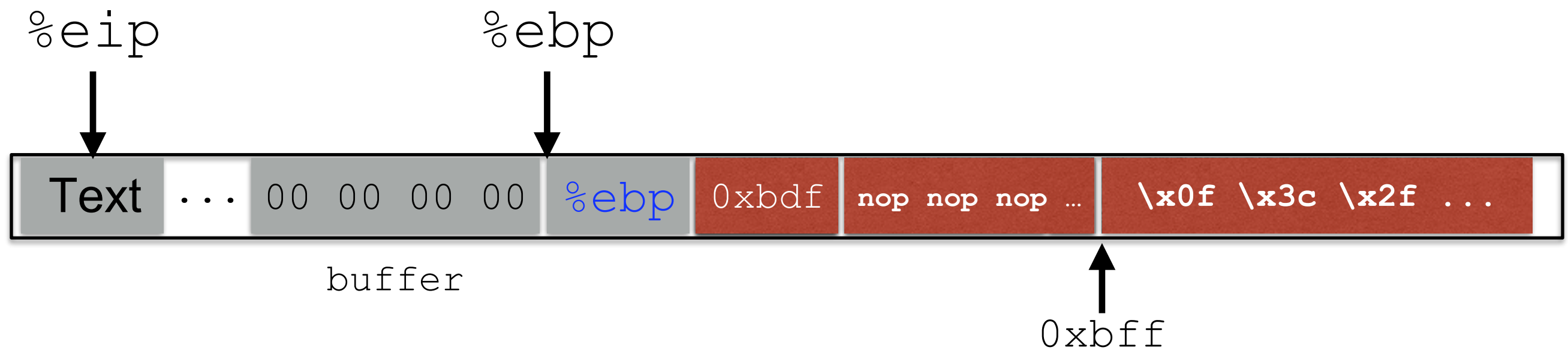
Improving our chances: **nop sleds**

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



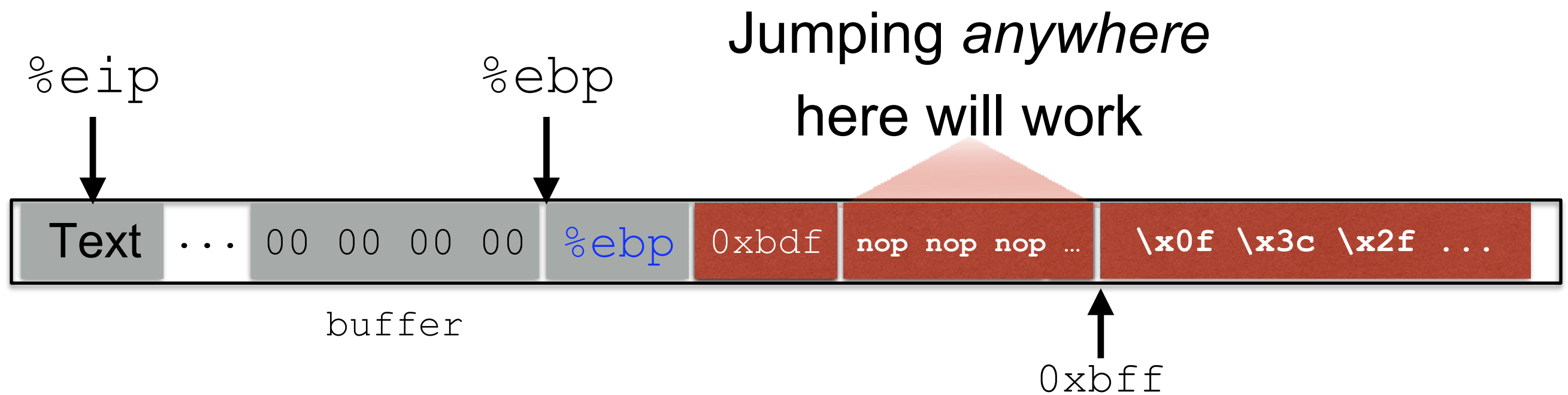
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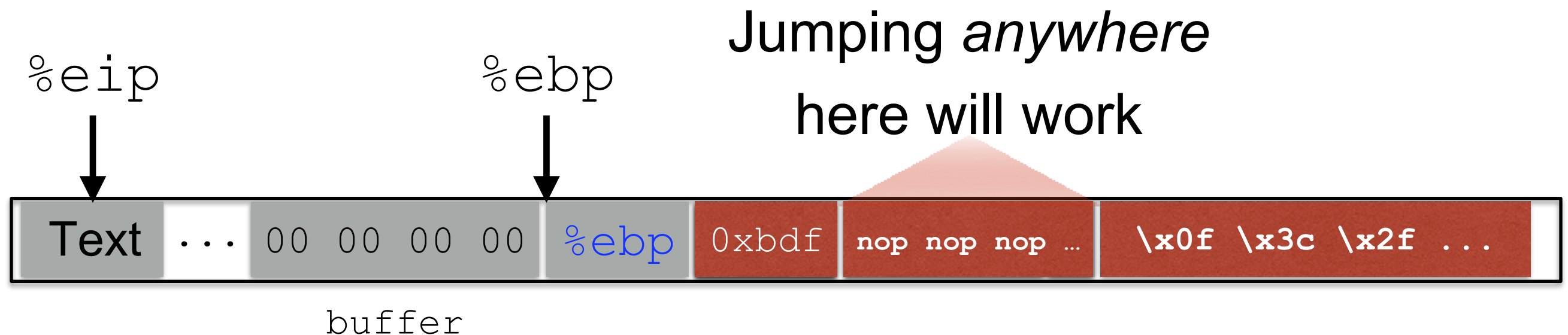
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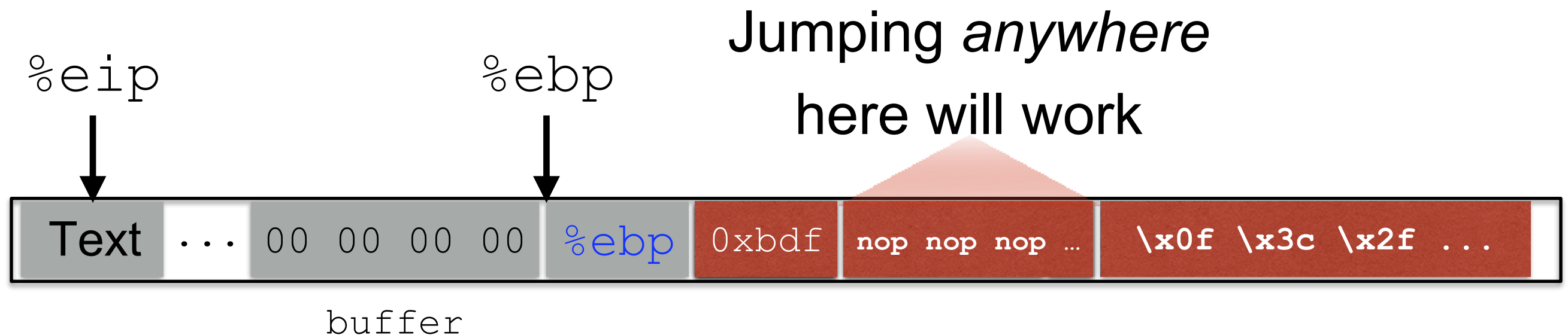
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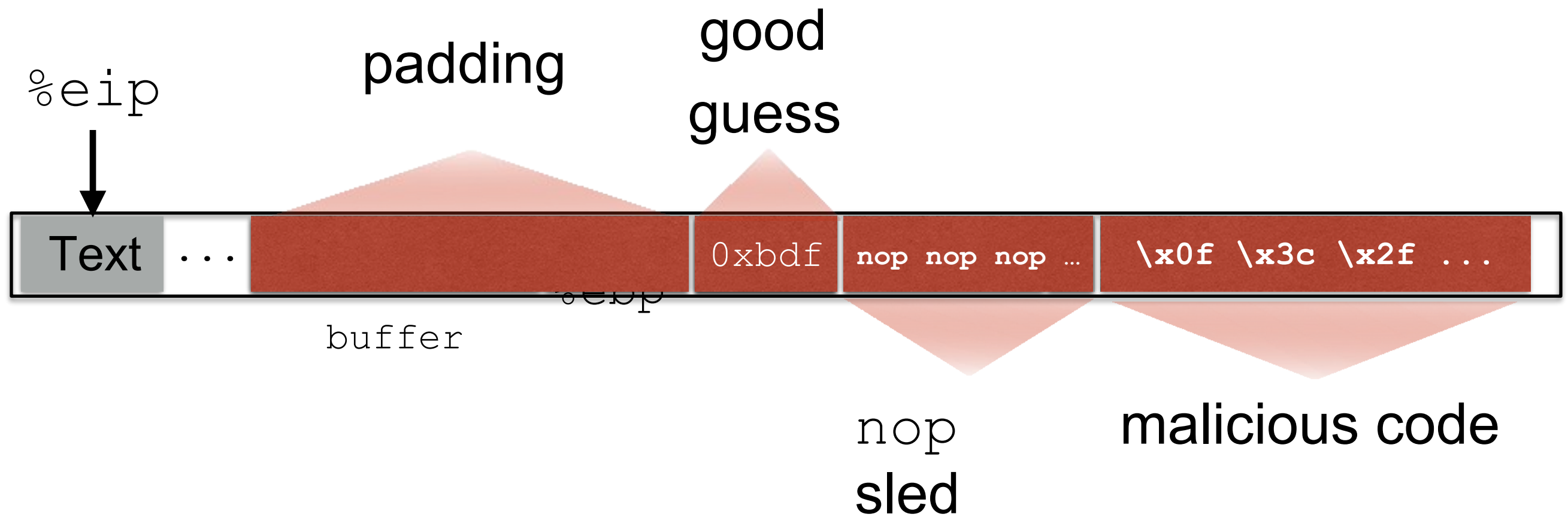
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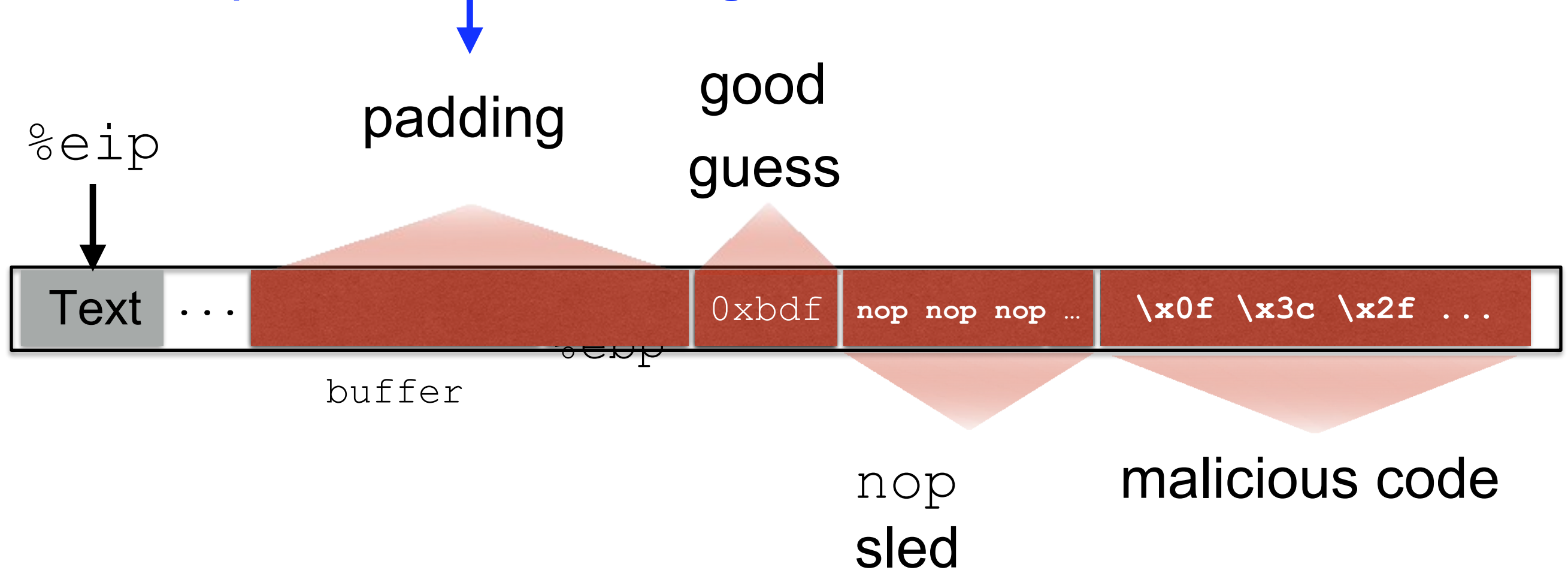
**Now we improve our chances
of guessing by a factor of #nops**

Putting it all together



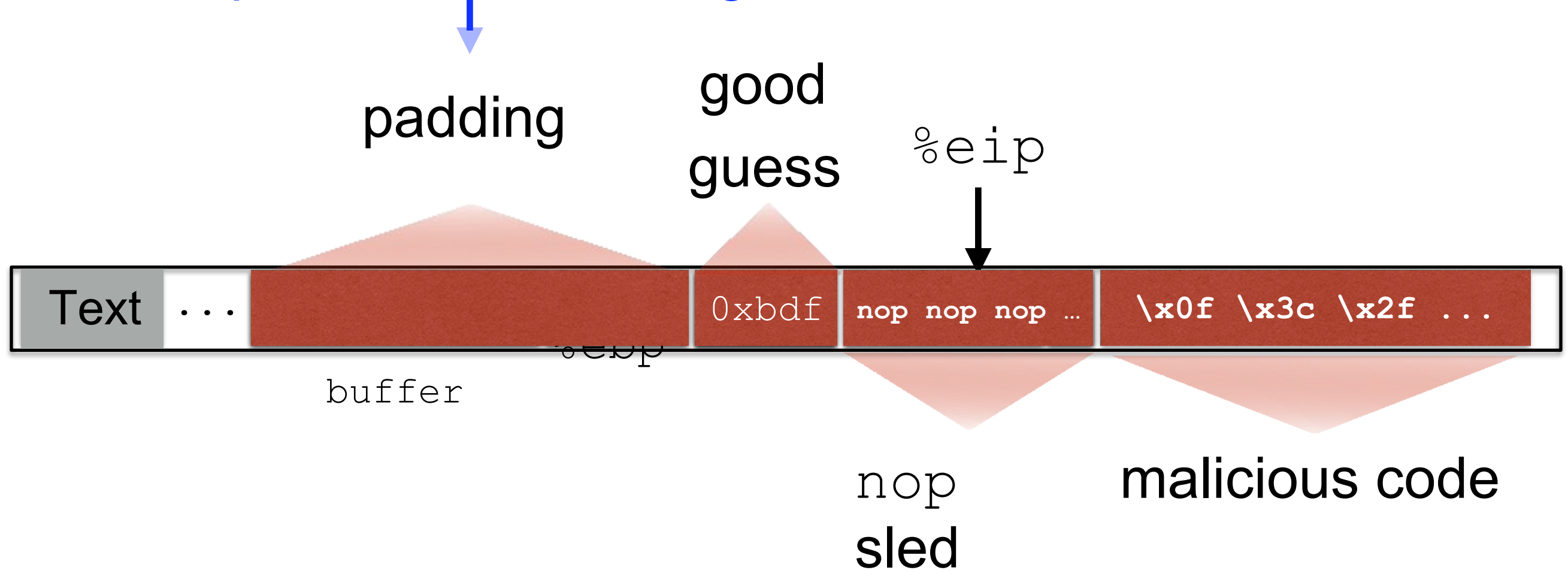
Putting it all together

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



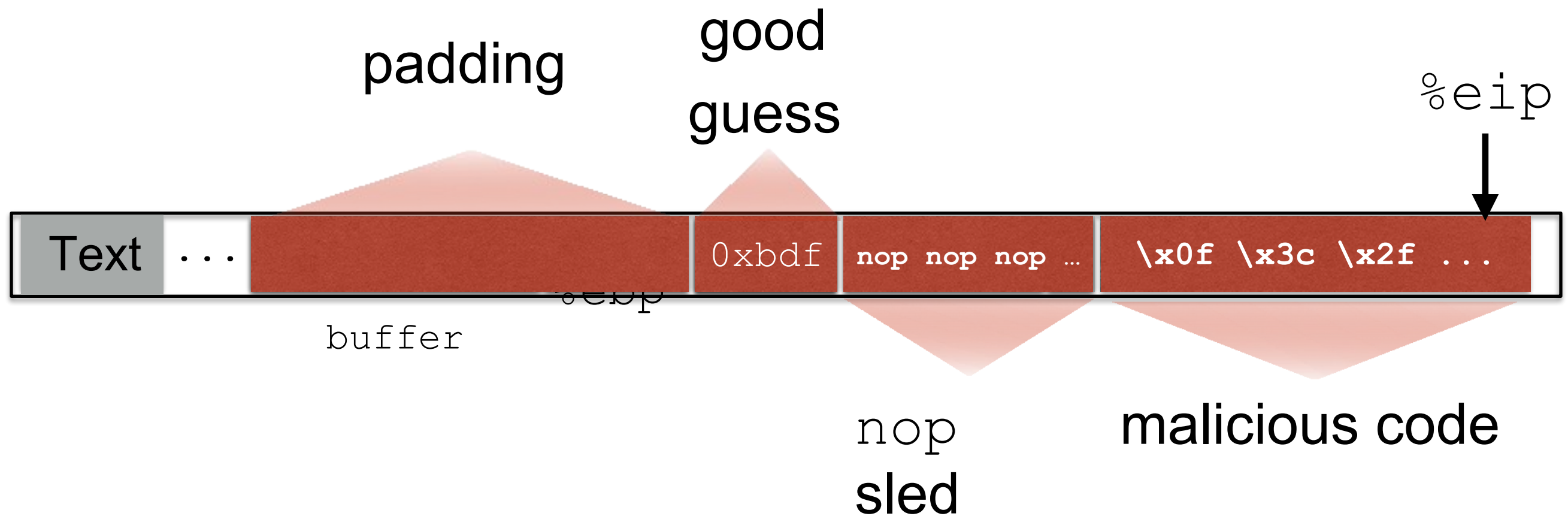
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Putting it all together

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Next time

Continuing with

**Software
Security**



More attacks, and
Defenses

Required reading:

“StackGuard: Simple Stack Smash Protection for GCC”