This time

We will continue

Buffer overflows

and other memory safety vulnerabilities

By looking at

Overflow Defenses

- Everything you've always wanted to know about `gdb` but were too afraid to ask
- Overflow defenses
- Other memory safety vulnerabilities

gdb: your new best friend

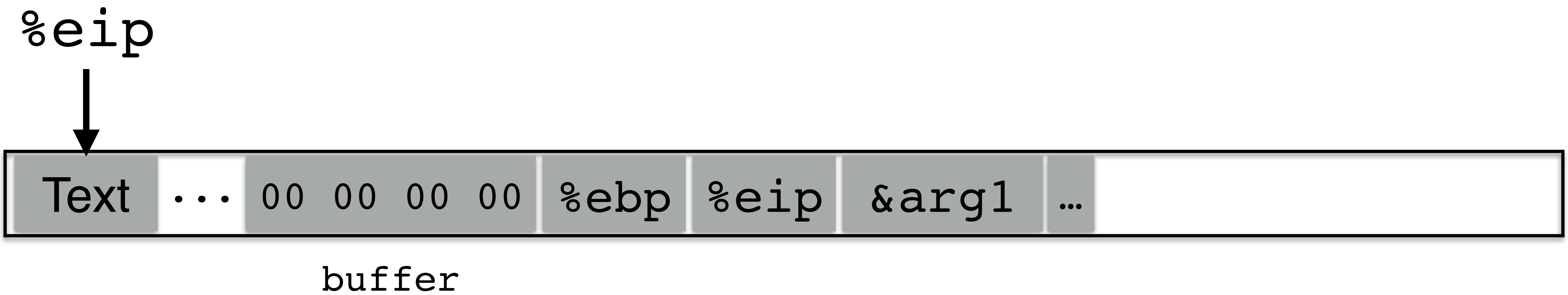
`i f`	Show **i**nfo about the current **f**rame (prev. frame, locals/args, %ebp/%eip)
`i r`	Show **info** about **reg**isters (%ebp, %eip, %esp, etc.)
`x/<n> <addr>`	E**x**amine <n> bytes of memory starting at address <addr>
`b <function>` `s`	Set a **b**reakpoint at <function> **s**tep through execution (into calls)

Recall our challenges

How can we make these even more difficult?

- Putting code into the memory (no zeroes)
- Getting %eip to point to our code (dist buff to stored eip)
- Finding the return address (guess the raw addr)

Detecting overflows with canaries



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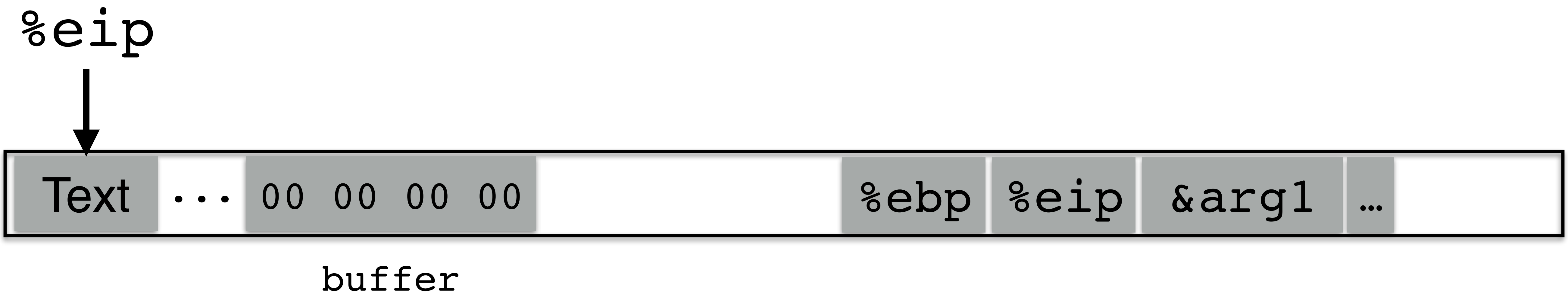

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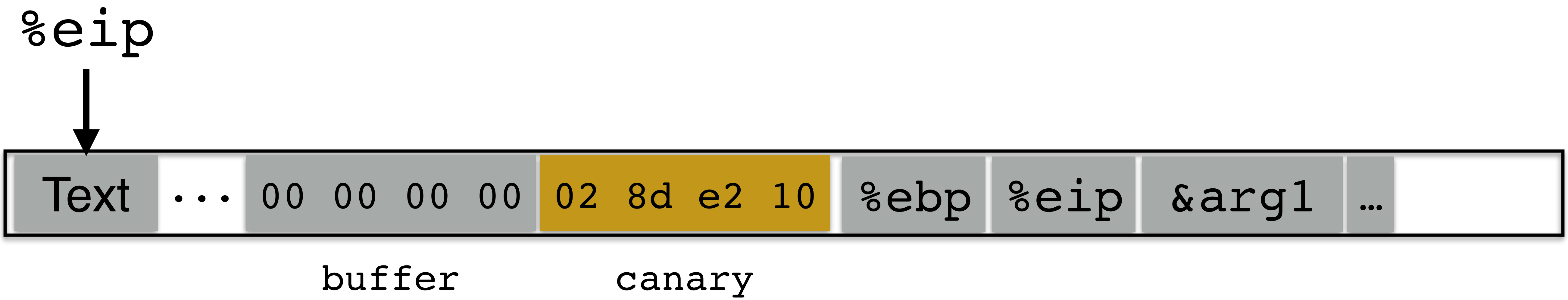

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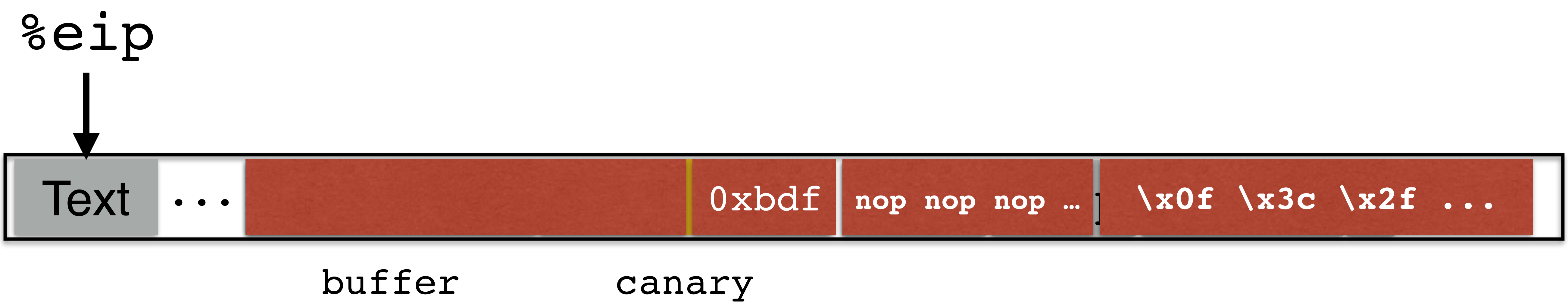

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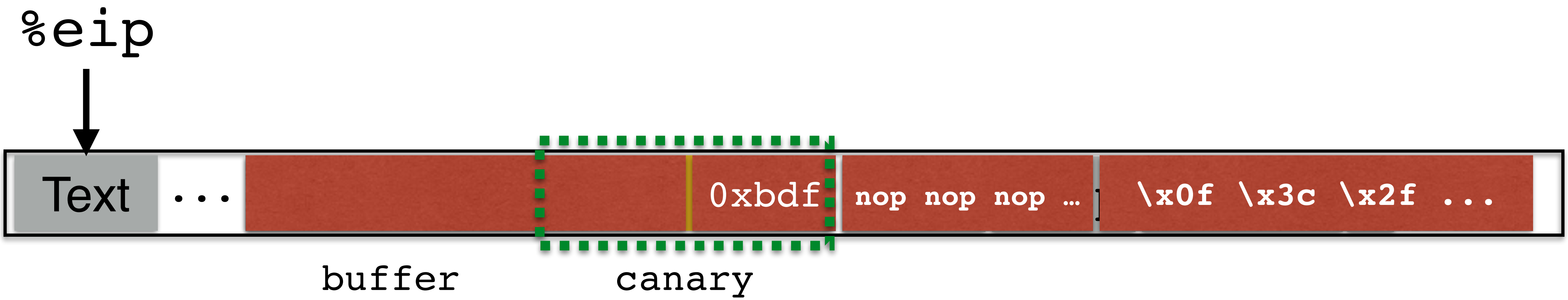

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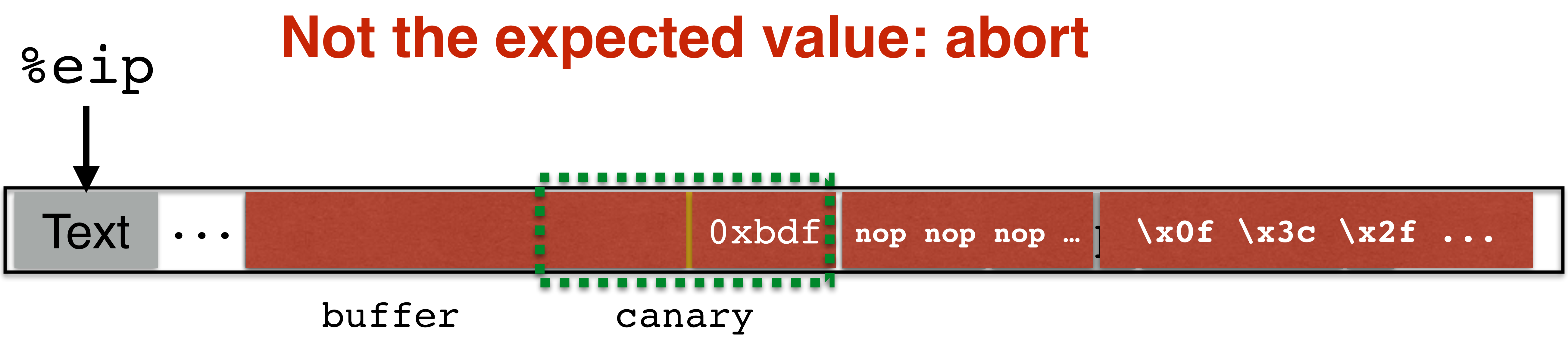

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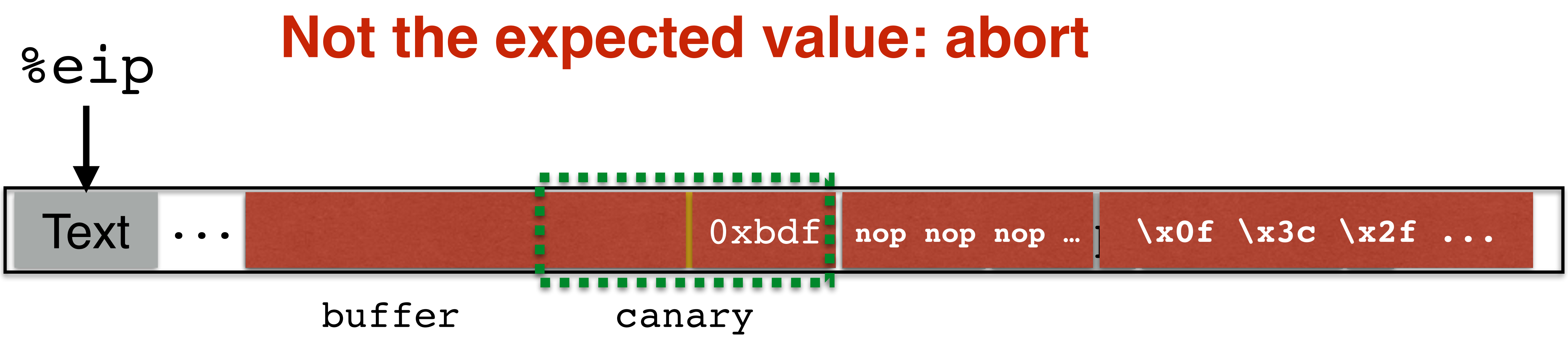

What value should the canary have?

Canary values

From StackGuard [Wagle & Cowan]

1. Terminator canaries (CR, LF, NULL, -1)
   - Leverages the fact that scanf etc. don't allow these
2. Random canaries
   - Write a new random value @ each process start
   - Save the real value somewhere in memory
   - Must write-protect the stored value
3. Random XOR canaries
   - Same as random canaries
   - But store canary XOR some control info, instead

Recall our challenges

How can we make these even more difficult?

- Putting code into the memory (no zeroes)
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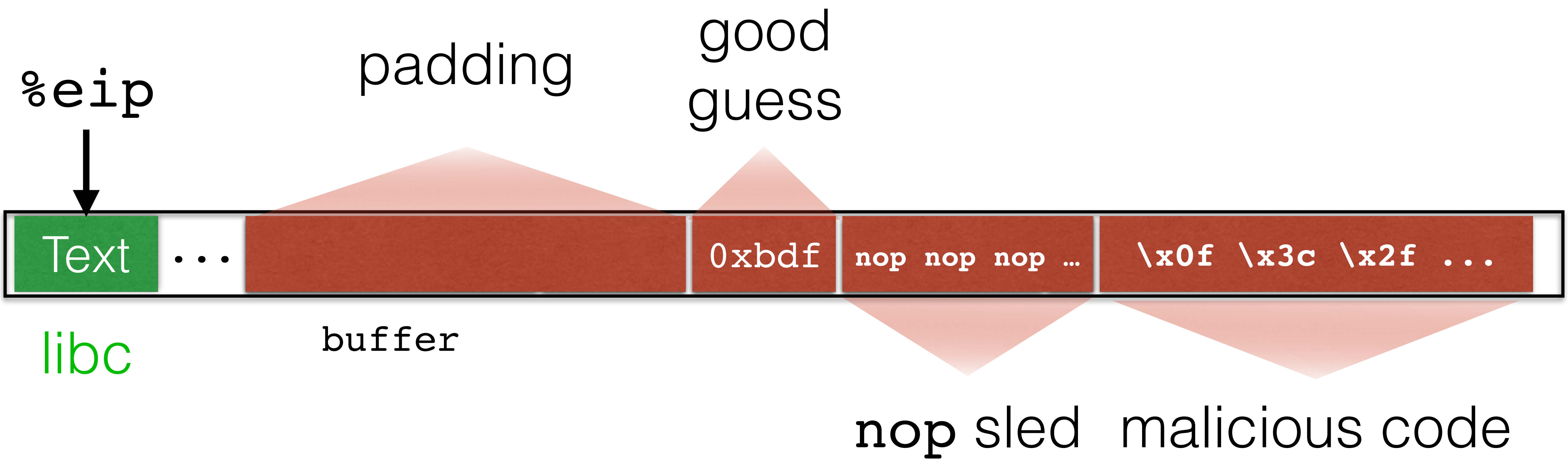
- Finding the return address (guess the raw addr)

More next time…

Return-to-libc



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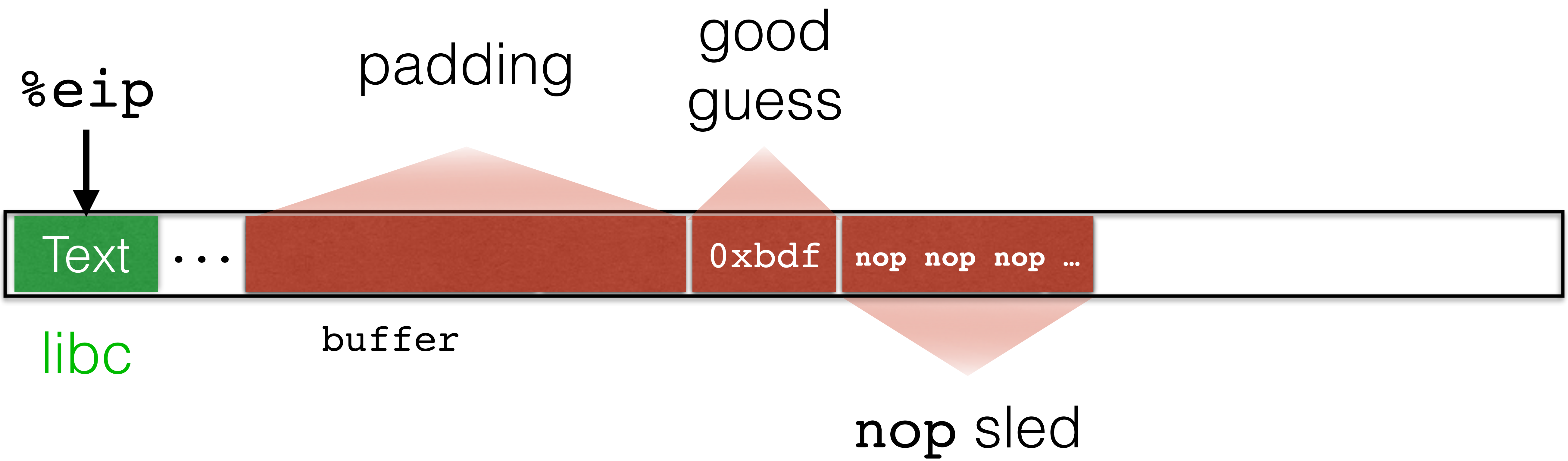

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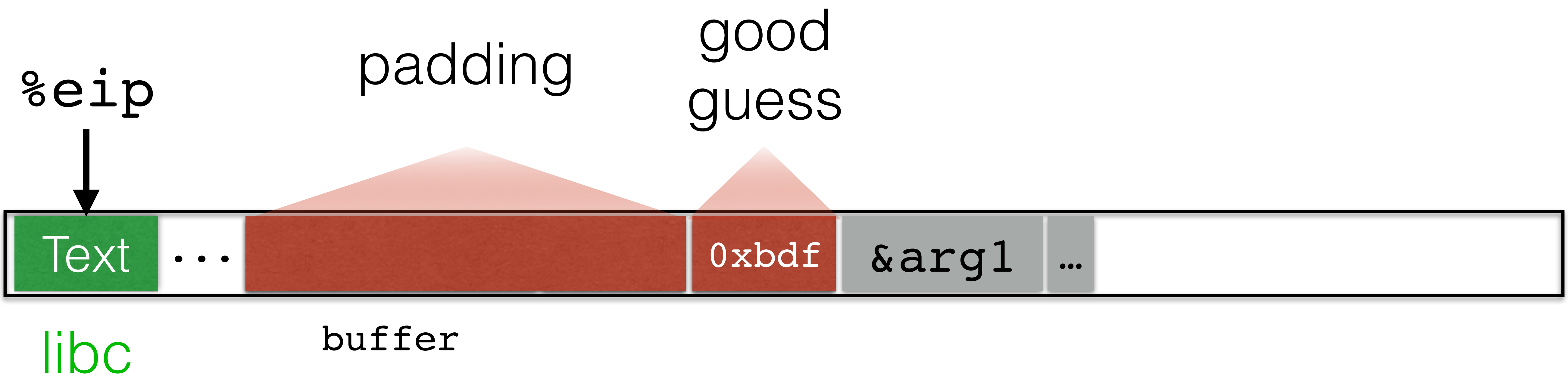

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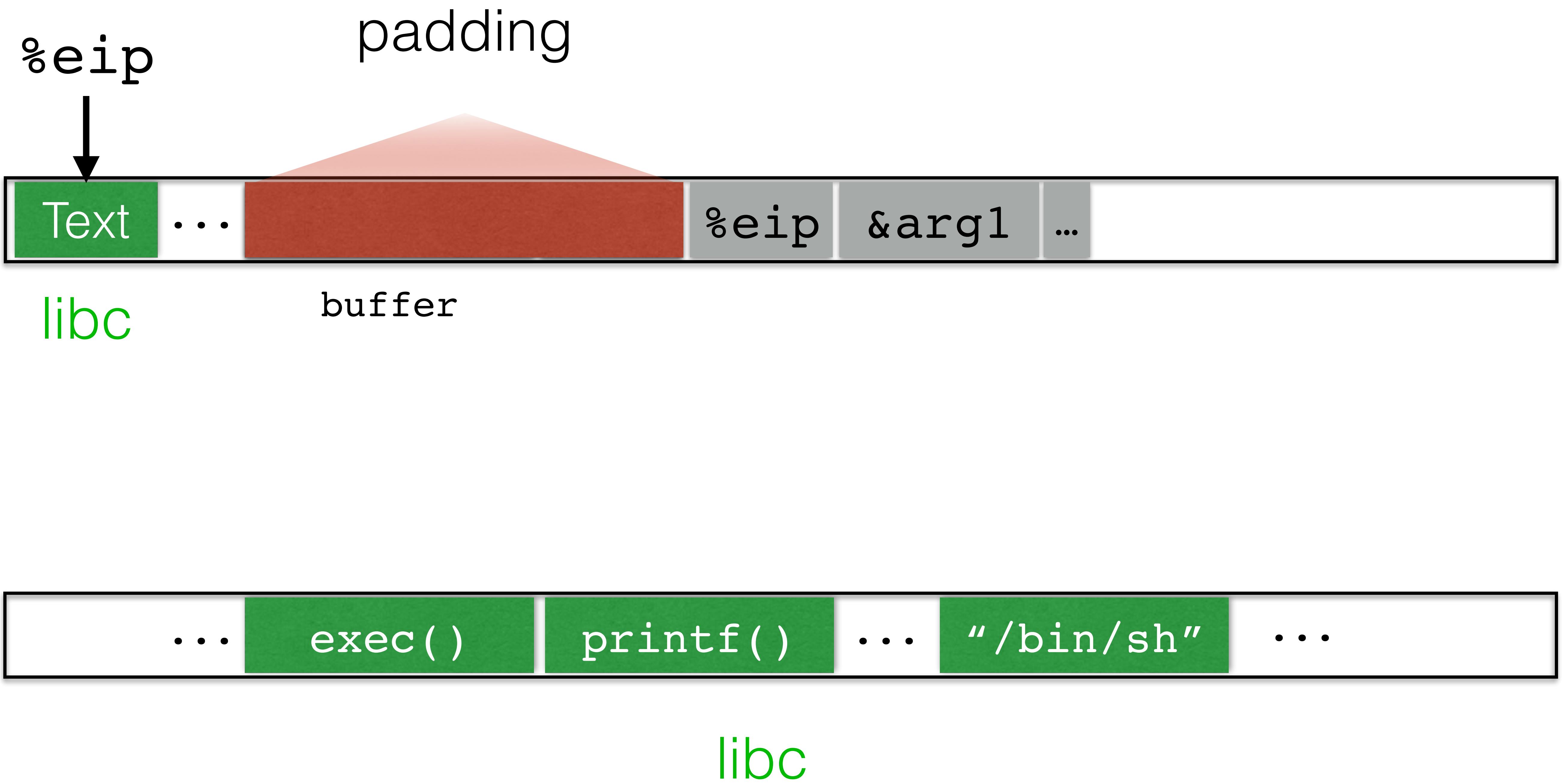

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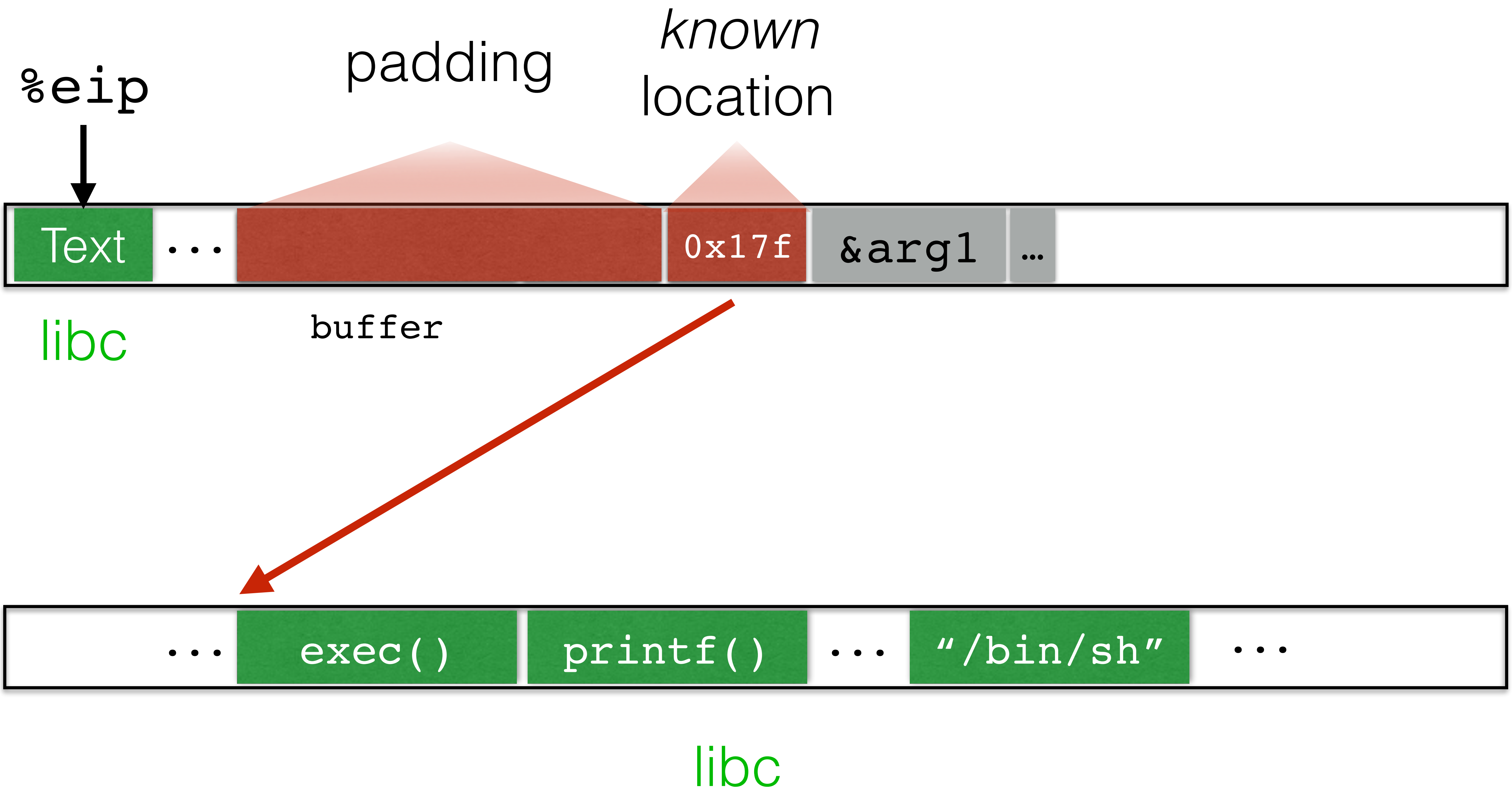

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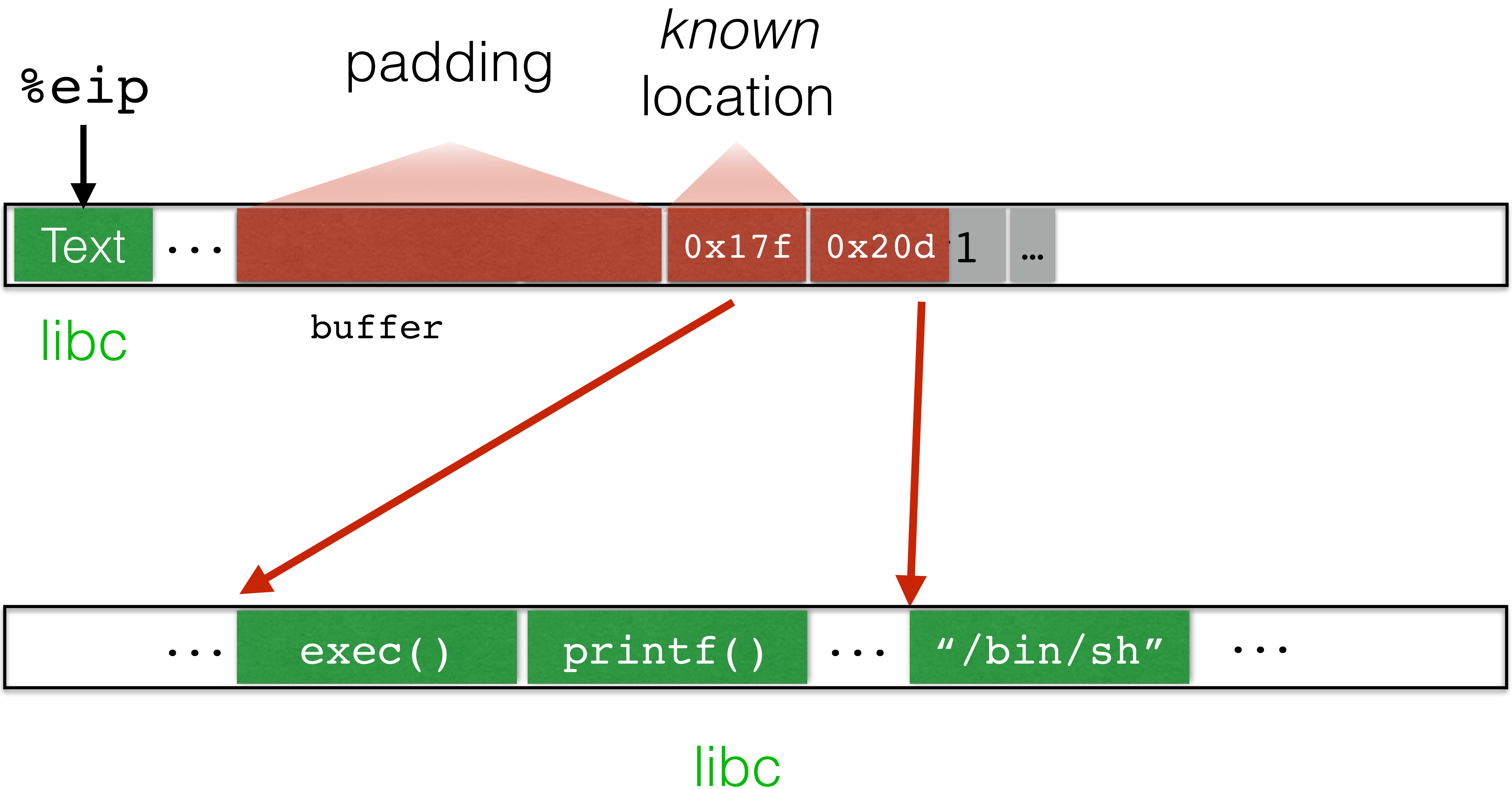

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- Putting code into the memory (no zeroes)
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  - Non-executable stack doesn't work so well
- Finding the return address (guess the raw addr)

Address Space Layout Randomization (ASLR)

- Basic idea: change the layout of the stack
- Slow to adopt
  - Linux in 2005
  - Vista in 2007 (off by default for compatibility with older software
  - OS X in 2007 (for system libraries), 2011 for all apps
  - iOS 4.3 (2011)
  - Android 4.0
  - FreeBSD: no

How would you overcome this as an attacker?

Overflow defenses summary

- Putting code into the memory (no zeroes)
  - Option: Make this detectable with **canaries**

- Getting %eip to point to our code (dist buff to stored eip)
  - **Non-executable stack** doesn’t work so well

- Finding the return address (guess the raw addr)
  - Address Space Layout Randomization (**ASLR**)
    - Many systems slow to adopt; also, how could you get around this?

- Good coding practices

Last time

We continued

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Overflow Defenses

- Finish overflow attacks & other vulnerabilities
- Overflow defenses
- Everything you've always wanted to know about `gdb` but were too afraid to ask

This time

Continuing with
Software Security

Writing & testing for
Secure Code

Required reading:

"StackGuard: Simple Stack Smash Protection for GCC"

Optional reading:

"Basic Integer Overflows"

"Exploiting Format String Vulnerabilities"

http://nob.cs.ucdavis.edu/bishop/secprog/robust.html

Cat and mouse

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  - **Attack response:** Construct needed functionality using **return oriented programming (ROP)**

Return oriented programming (ROP)

Return-oriented Programming

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- Challenges
    - **Find the gadgets** you need
    - **String them together**

Approach

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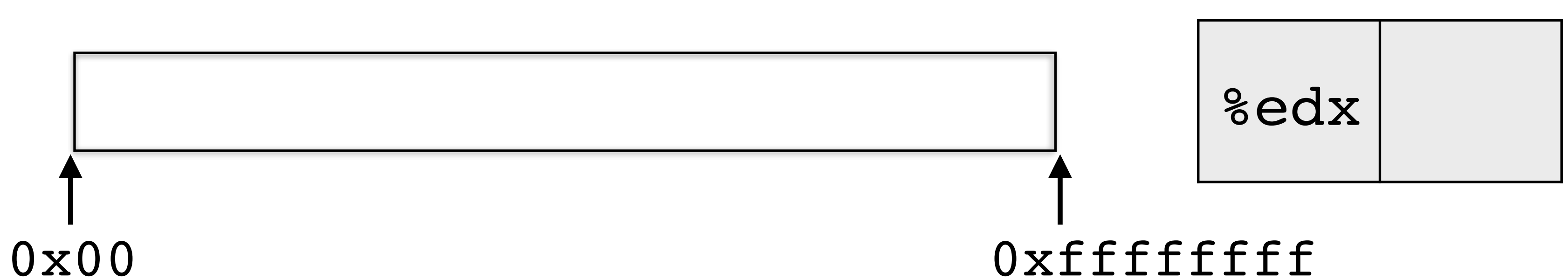
- Gadgets are instruction groups that end with **`ret`**
- Stack serves as the code
  - **`%esp`** = program counter
  - Gadgets invoked via **`ret`** instruction
  - Gadgets get their arguments via **`pop`**, etc.
    - Also on the stack

Simple example

equivalent to

```
mov %edx, 5
```



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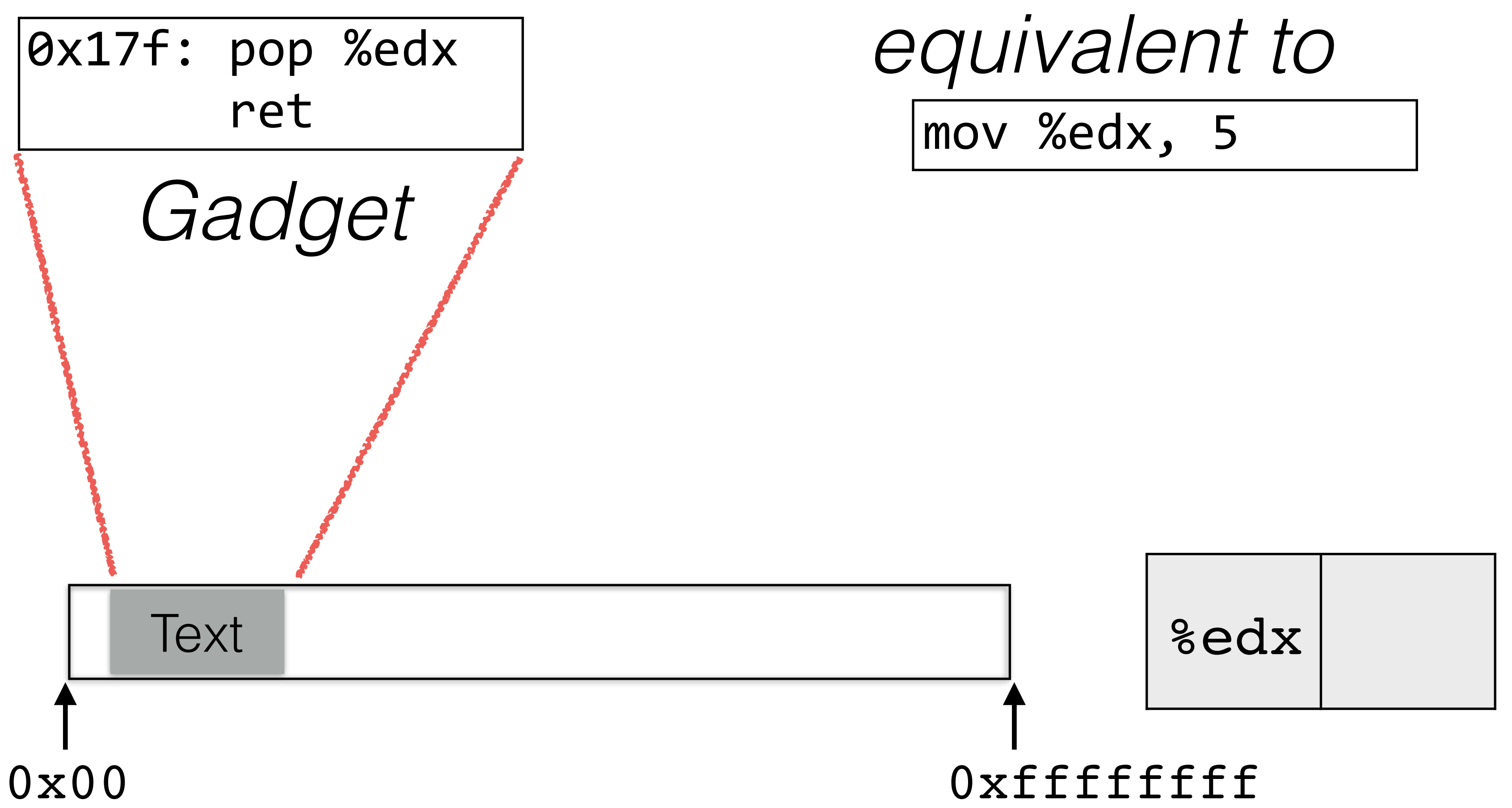

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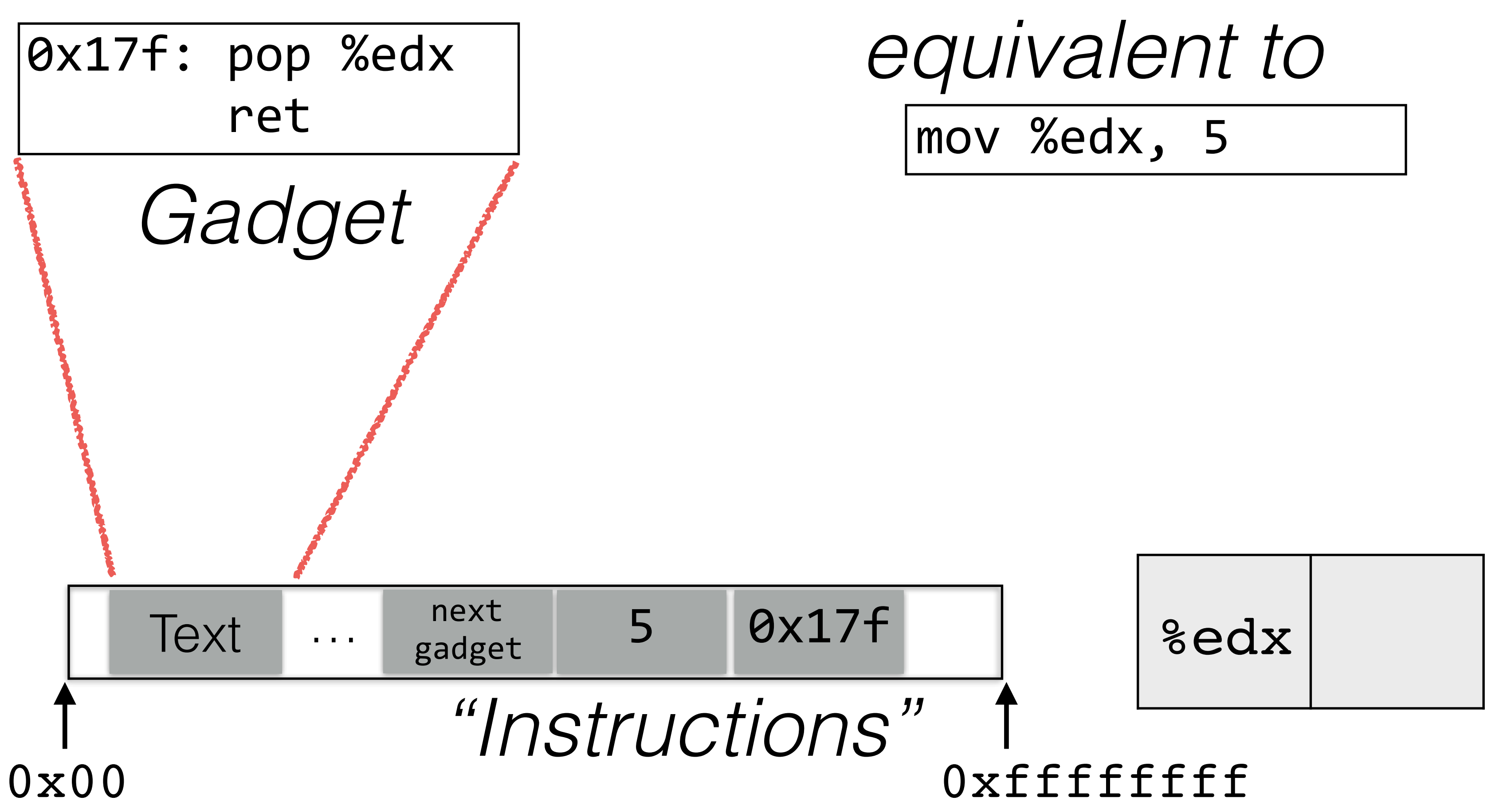

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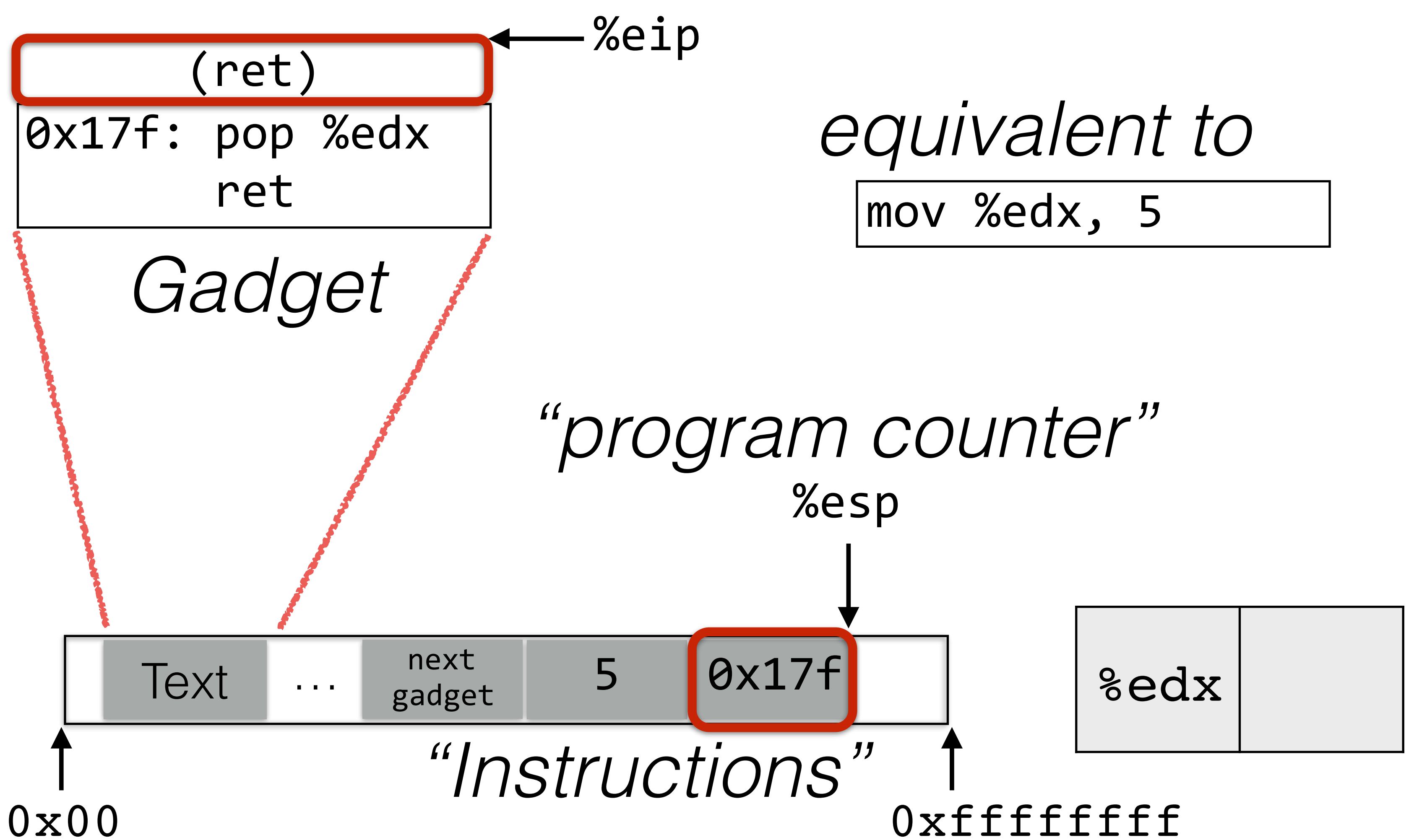

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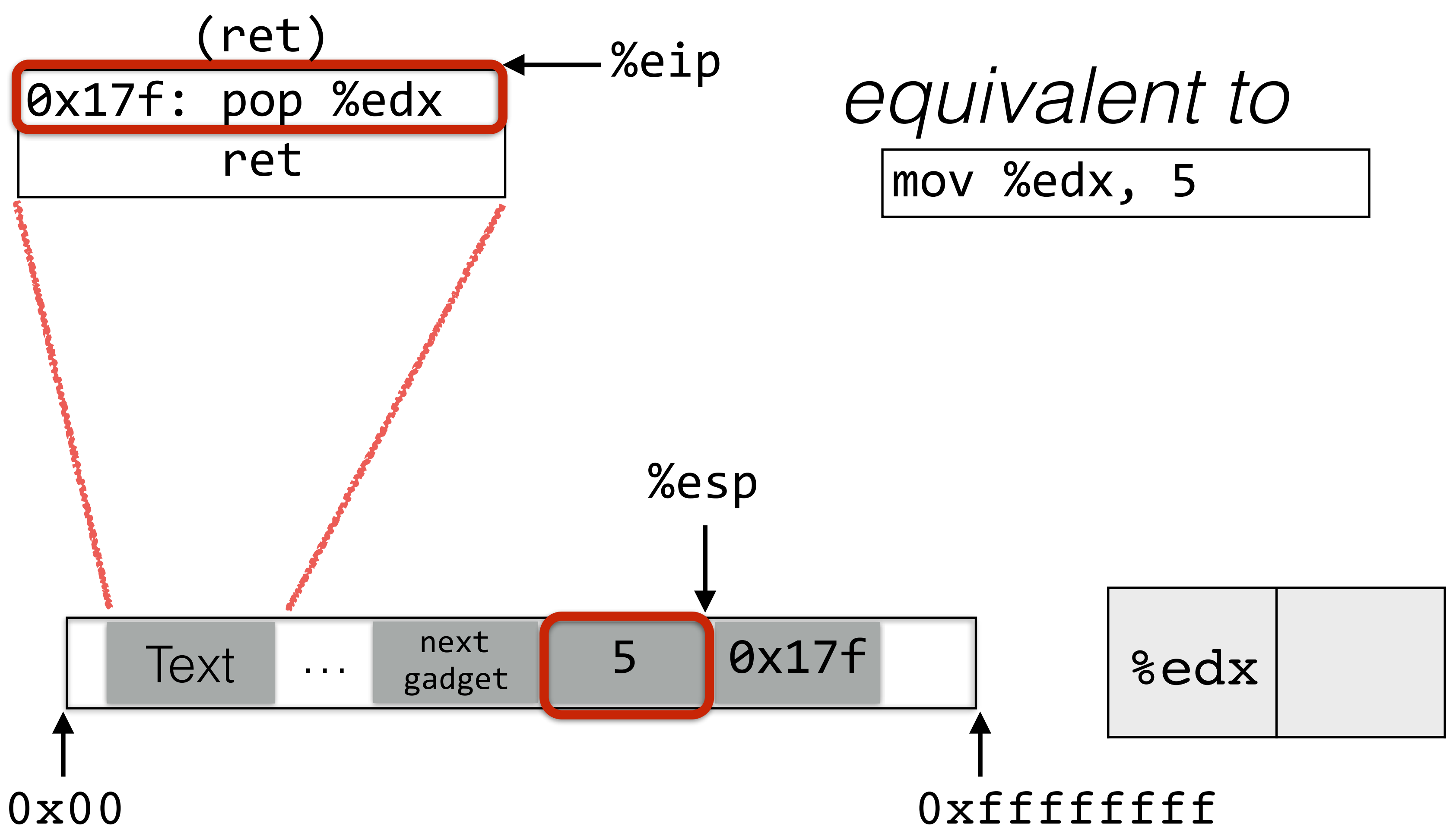

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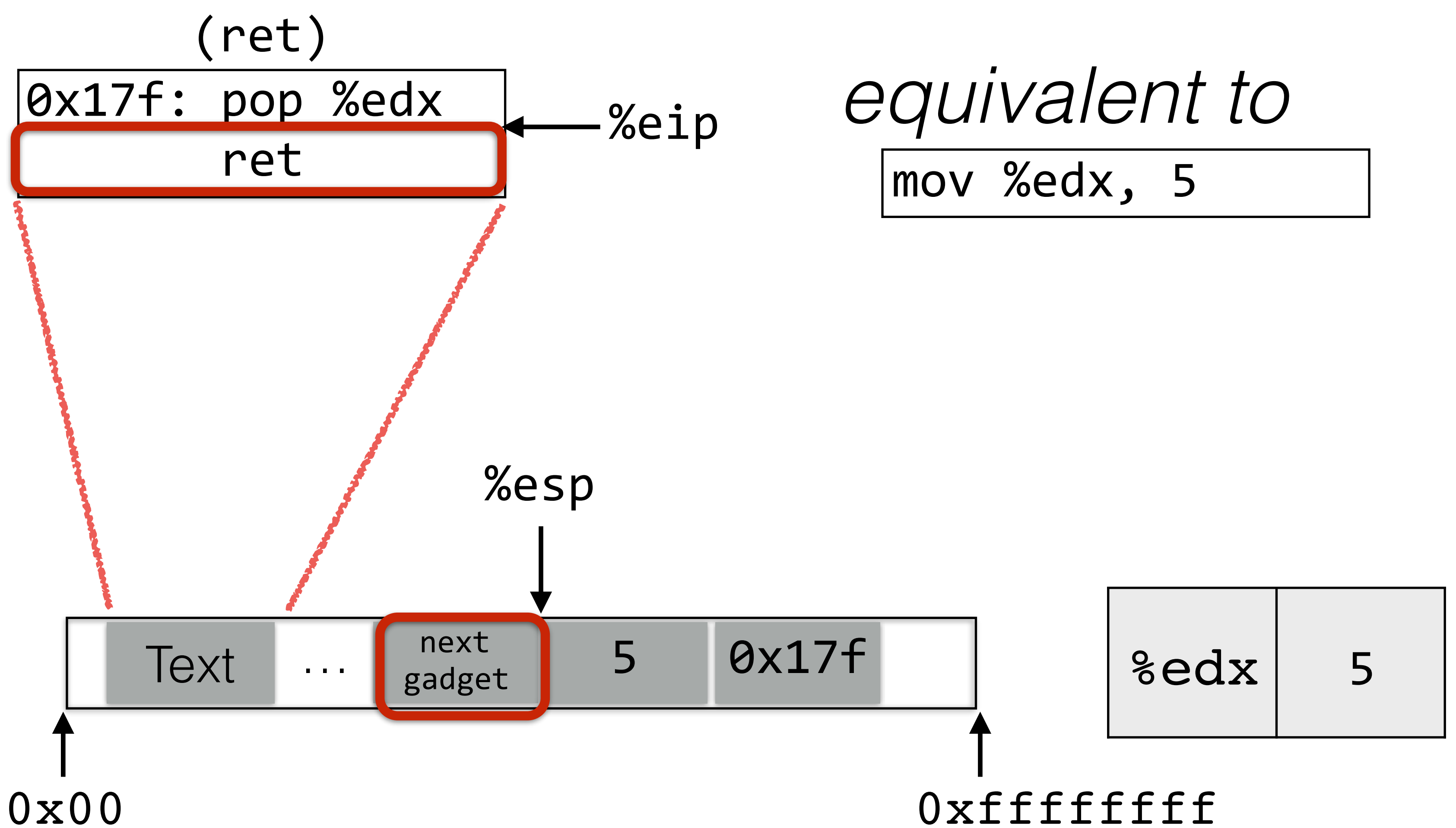

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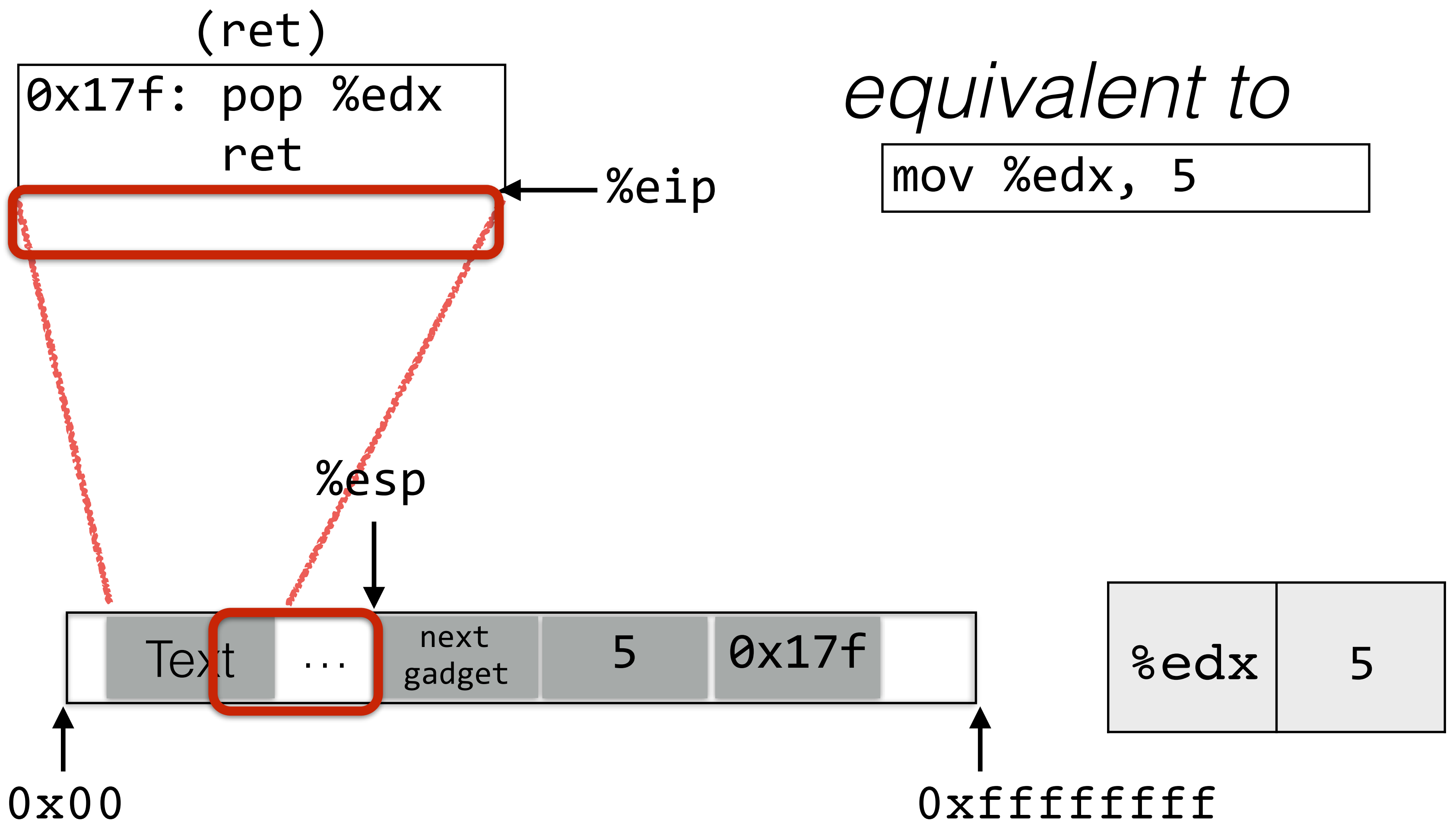
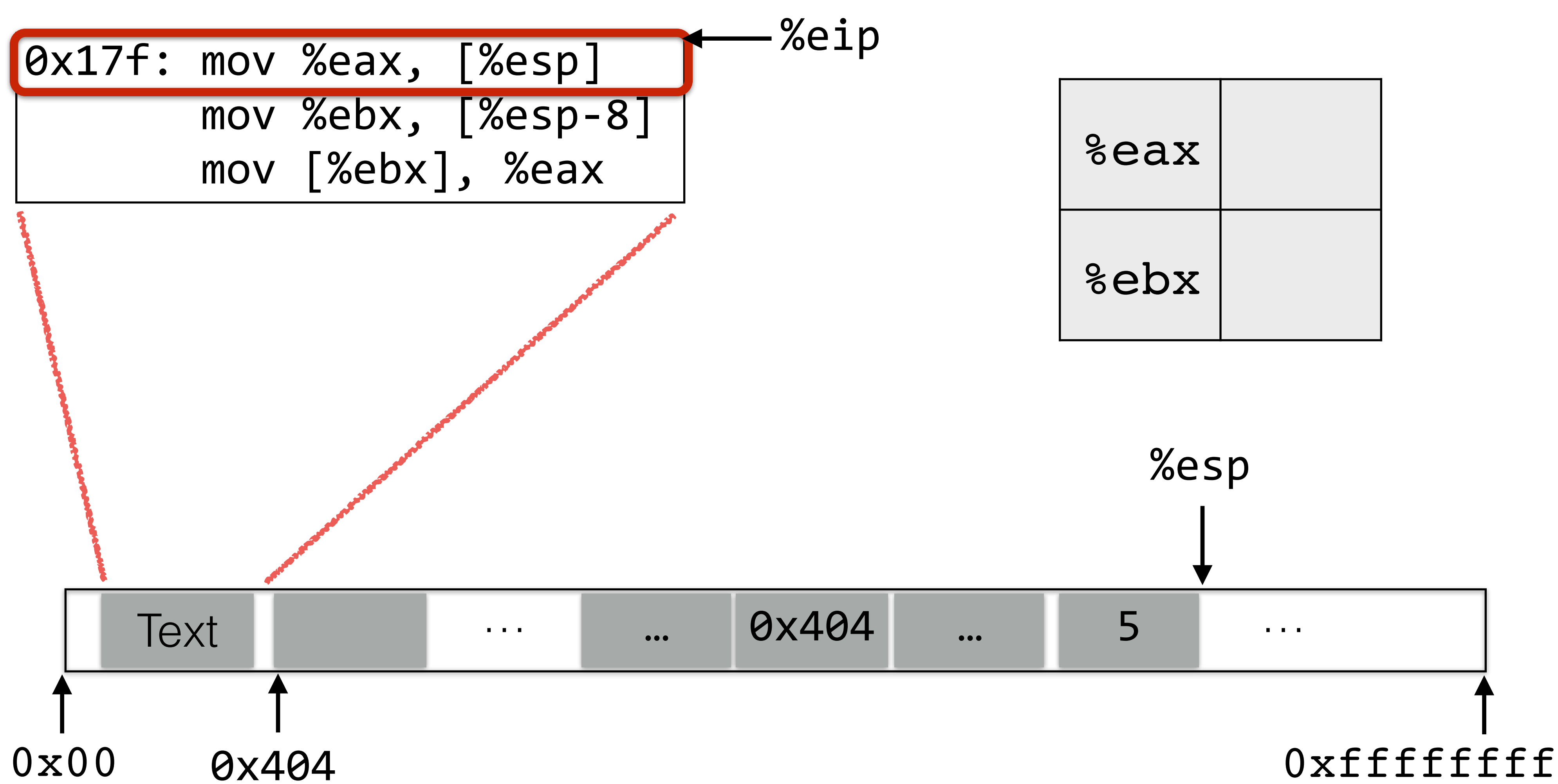


Code sequence



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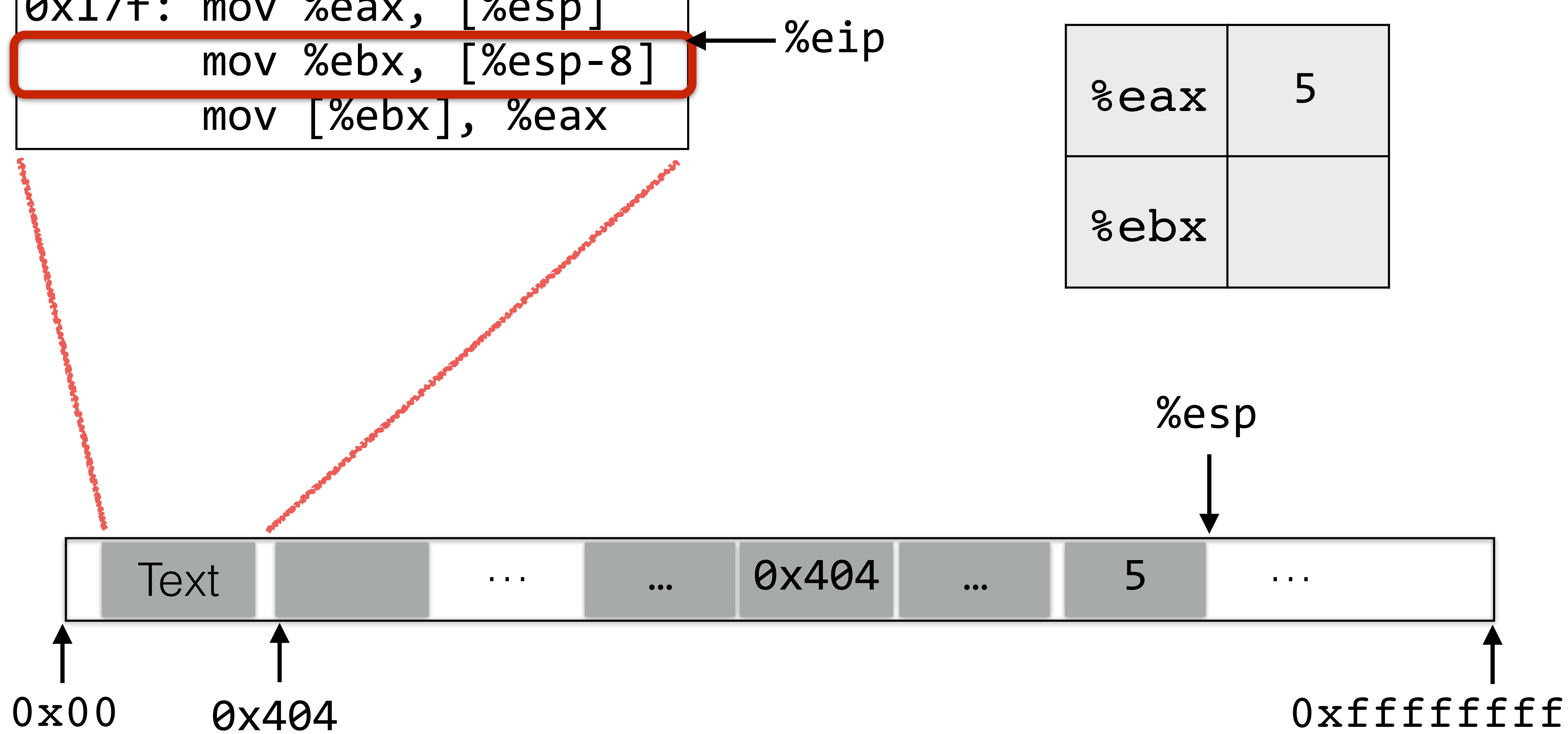

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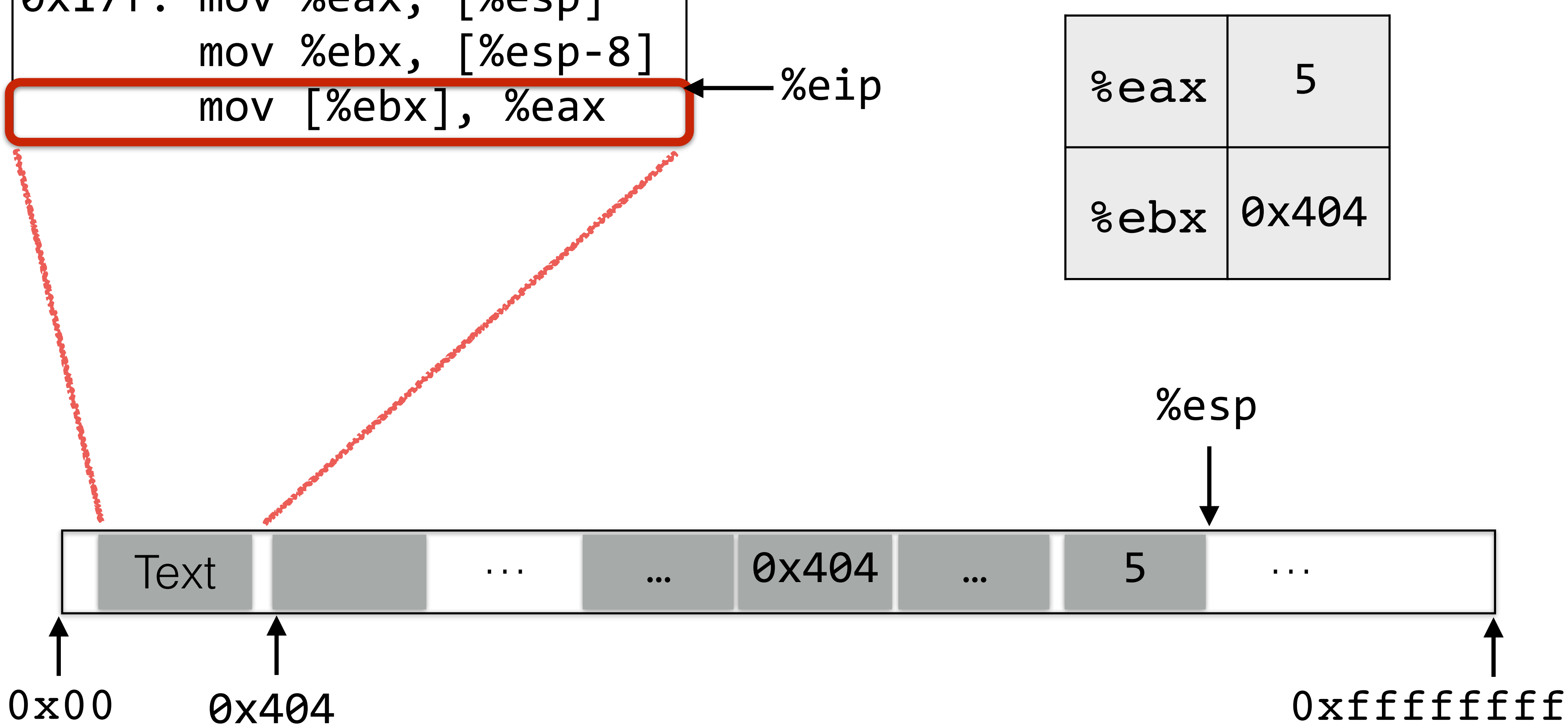

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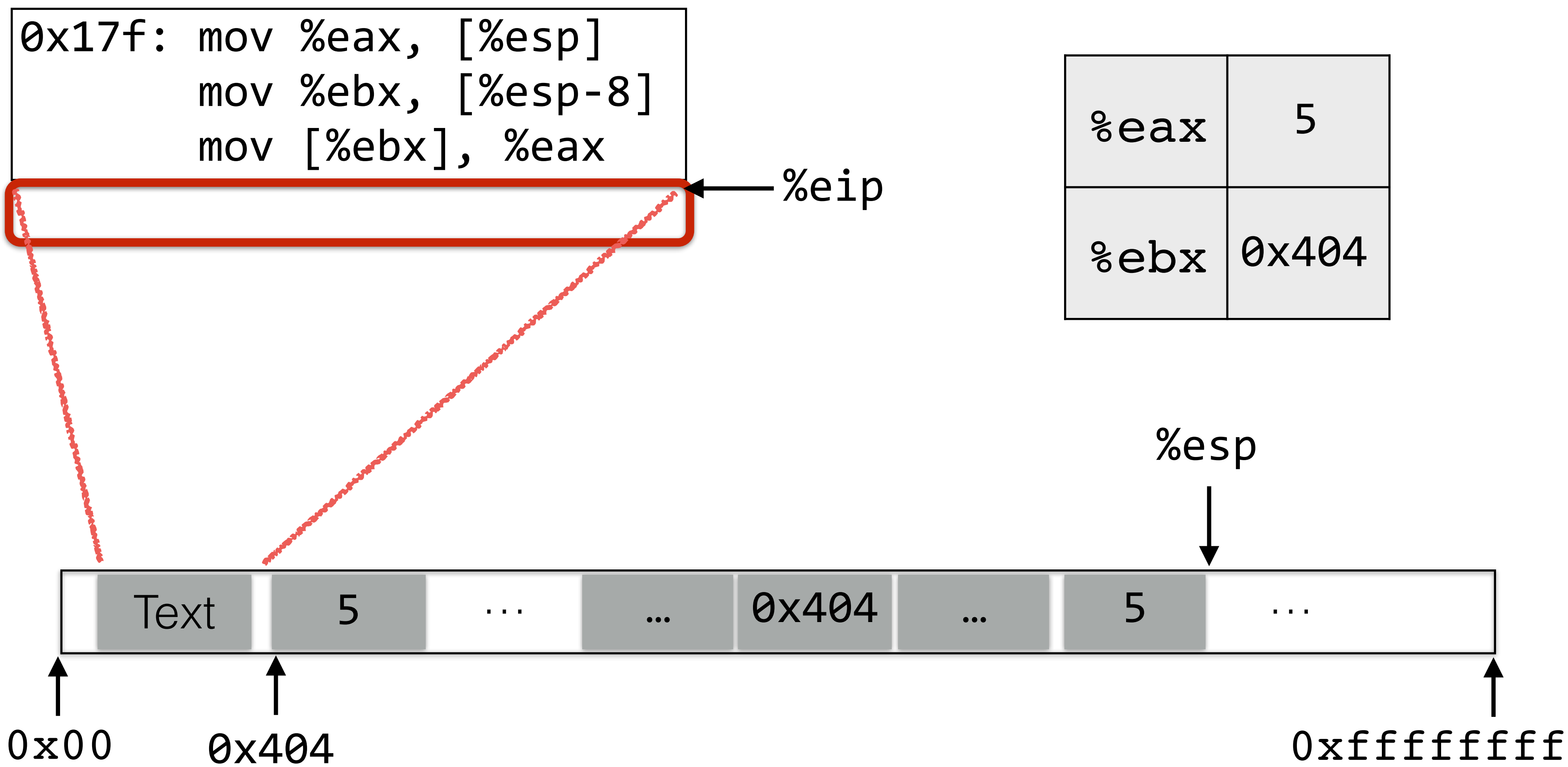

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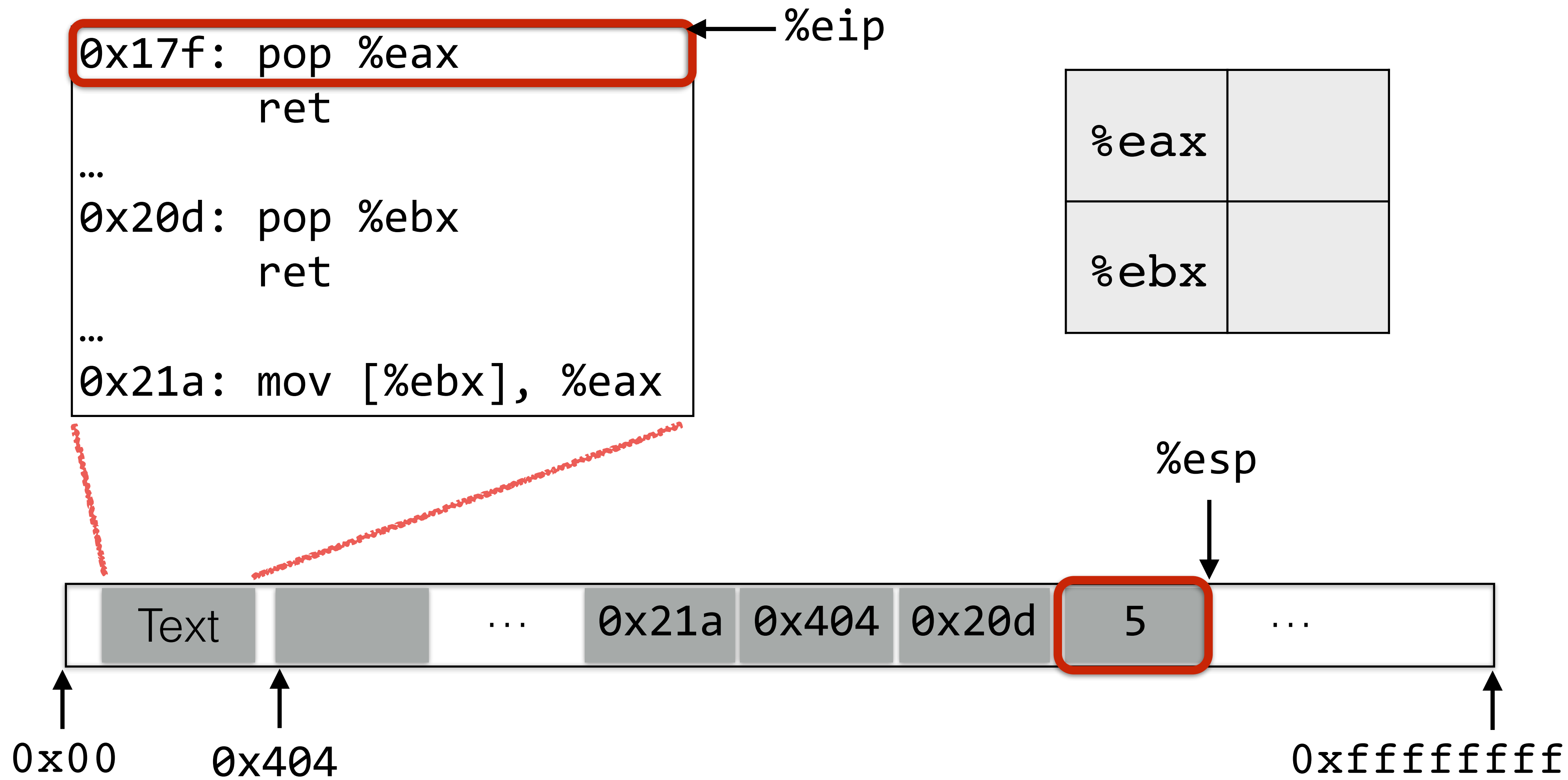

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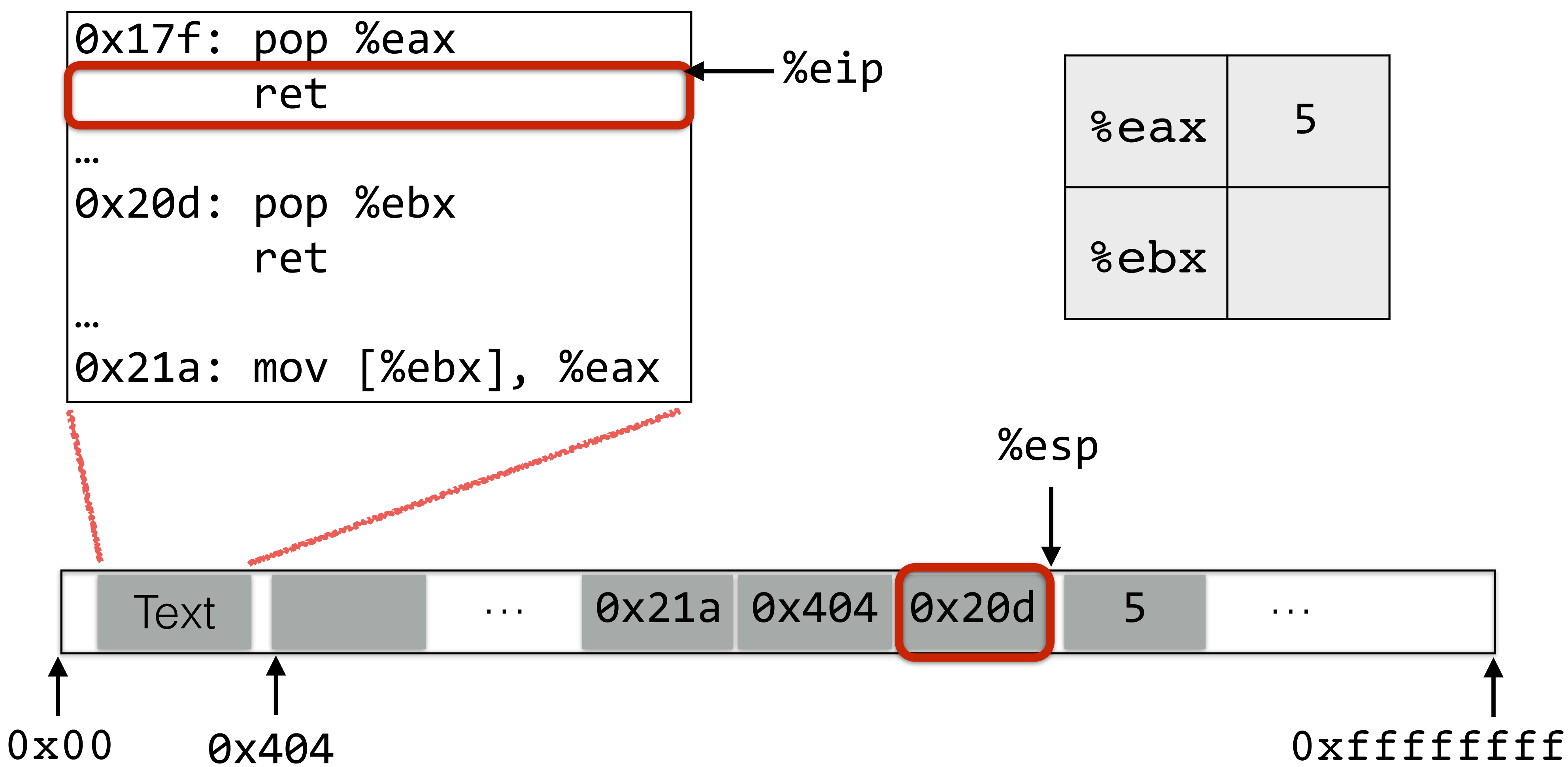

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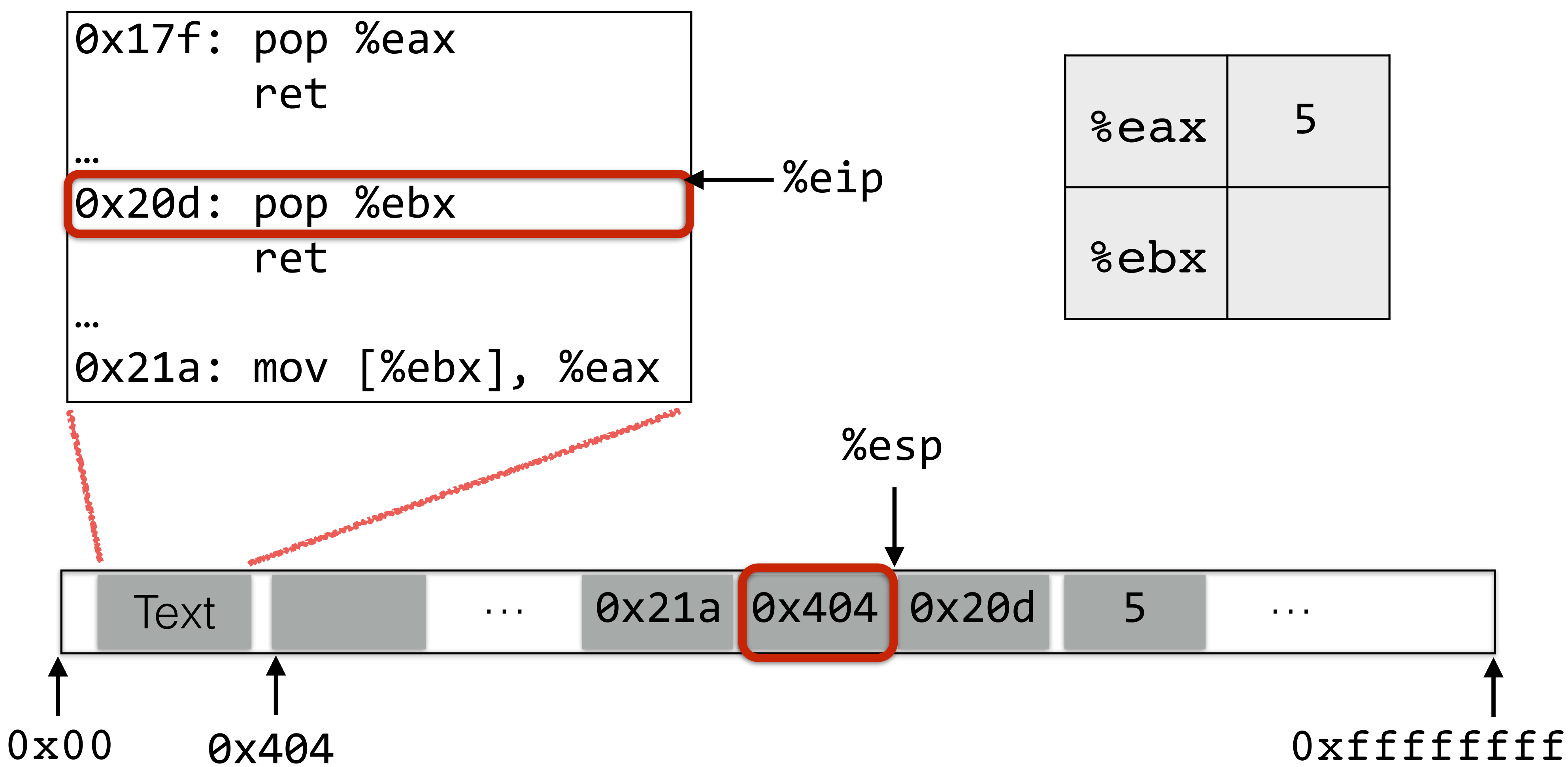

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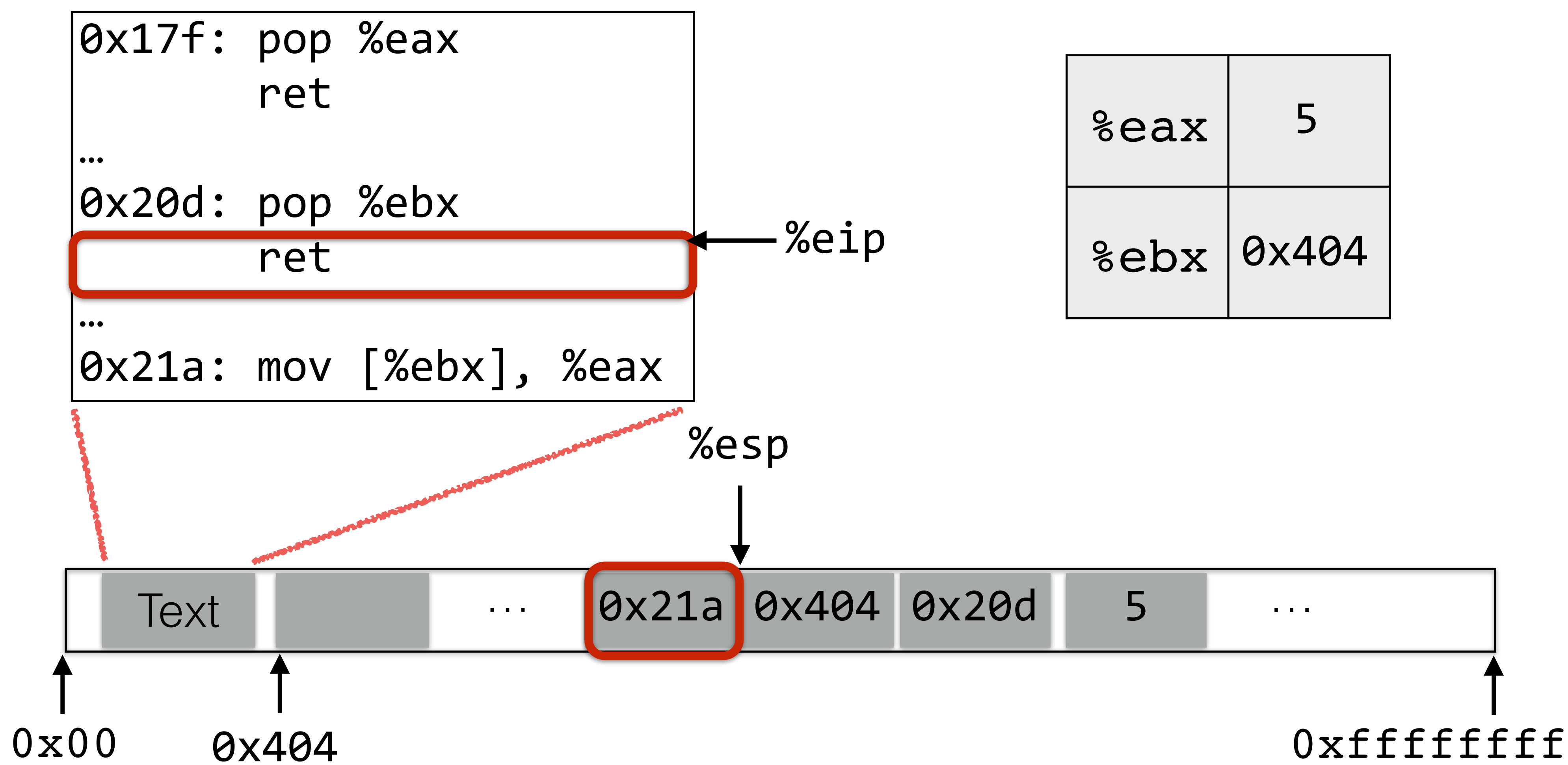

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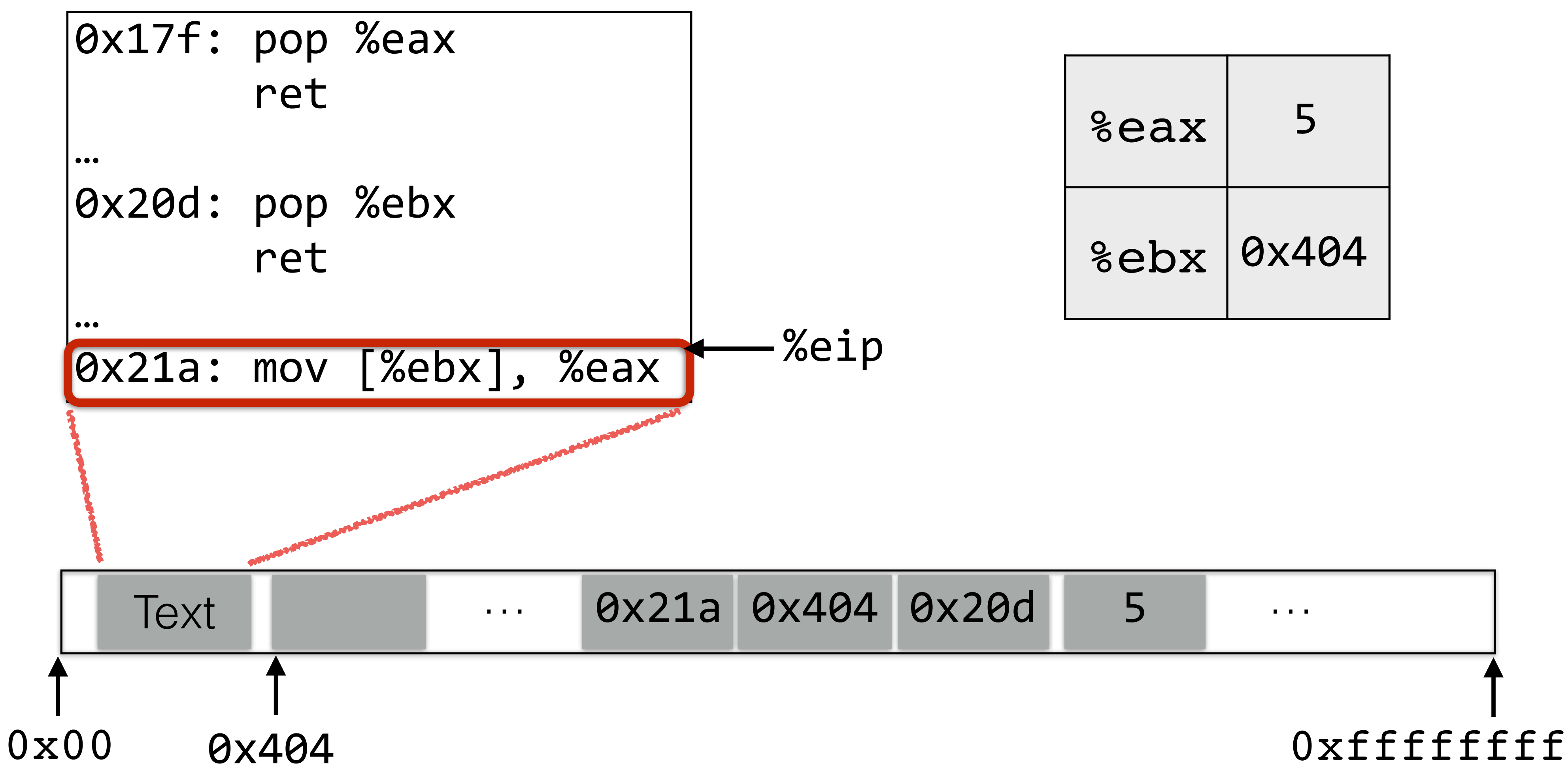

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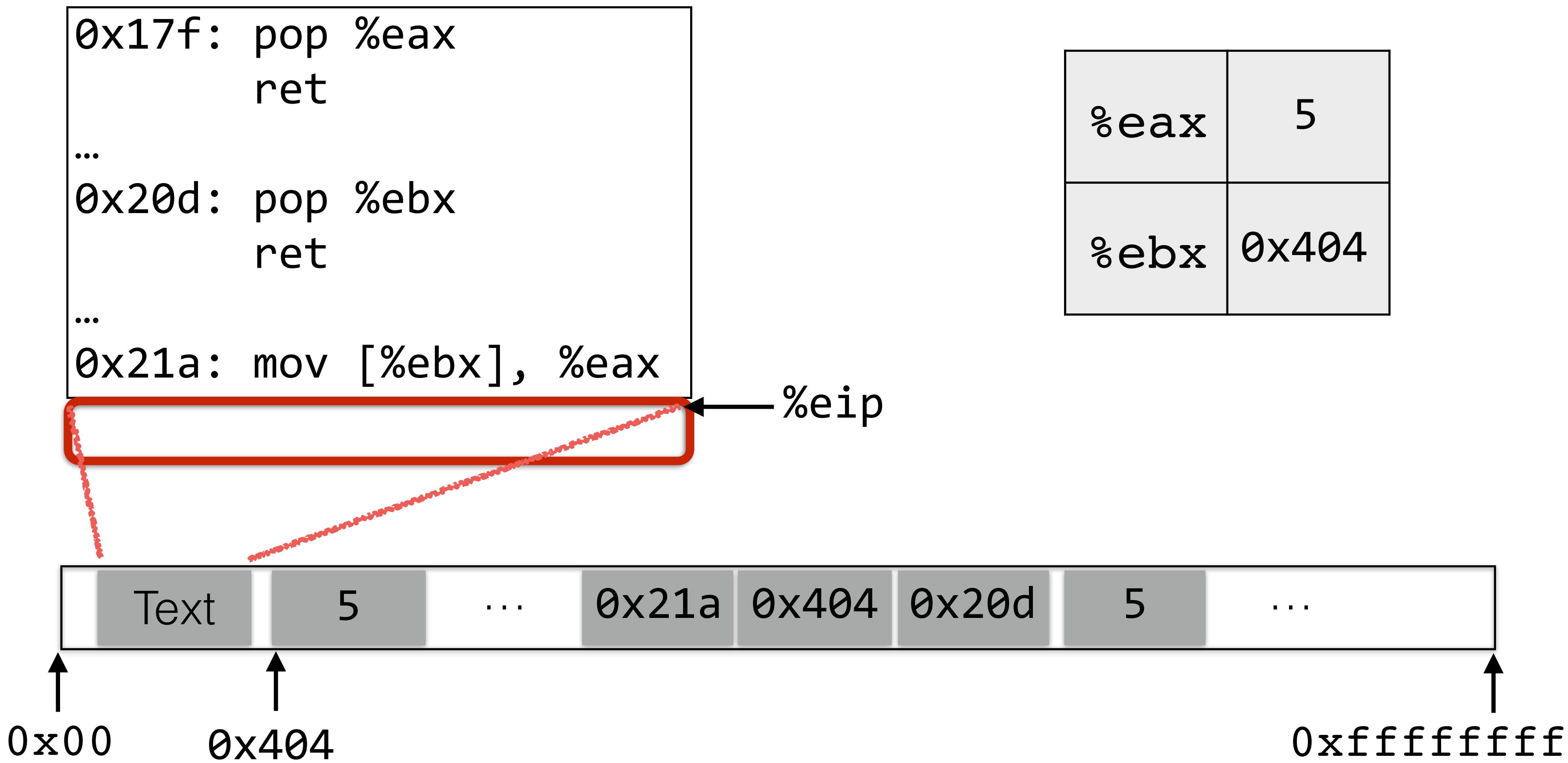

Image by Dino Dai Zovi

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  - Schwartz et al (USENIX Security '11) have automated gadget shellcode creation, though not needing/requiring Turing completeness

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http://www.scs.stanford.edu/brop/

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  - The exploit was carried out on a 64-bit executable with full stack canaries and randomization
- Conclusion: **give an inch, and they take a mile?**
- Put another way: **Memory safety is really useful!**

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    char buf[80];
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Format string vulnerabilities

`printf` format strings

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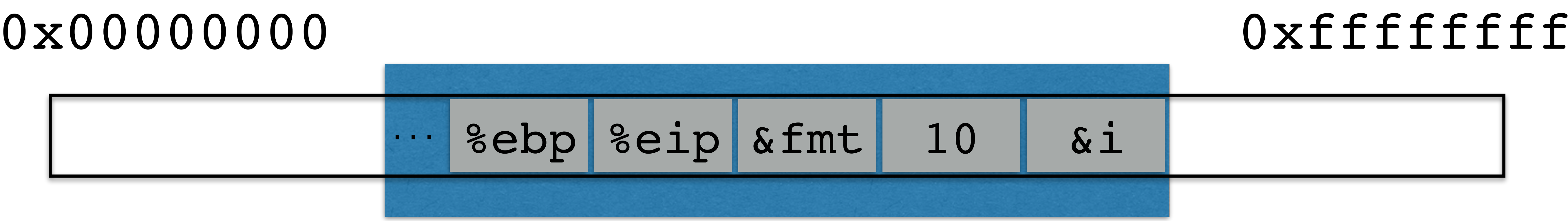

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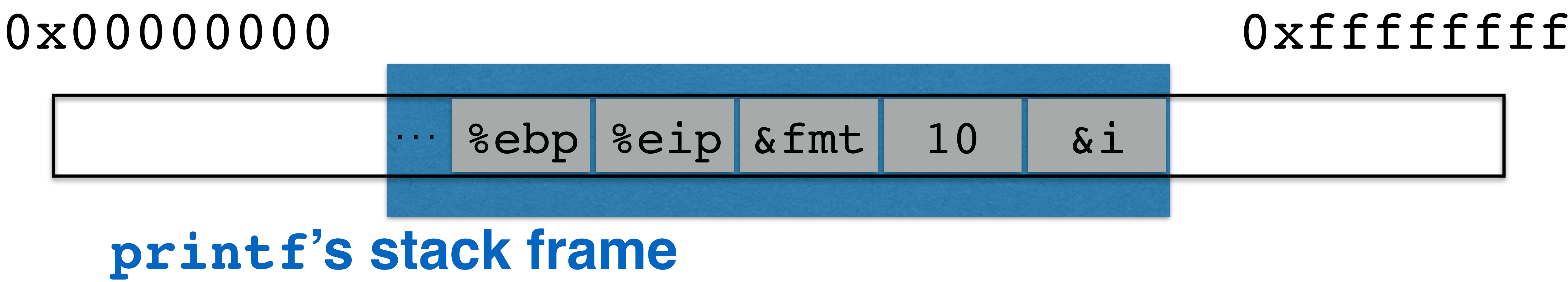

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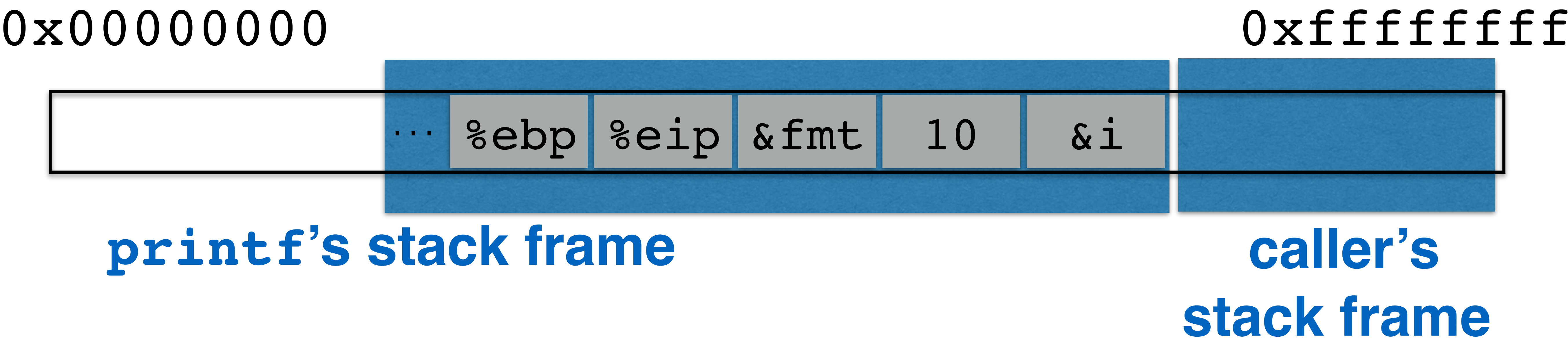

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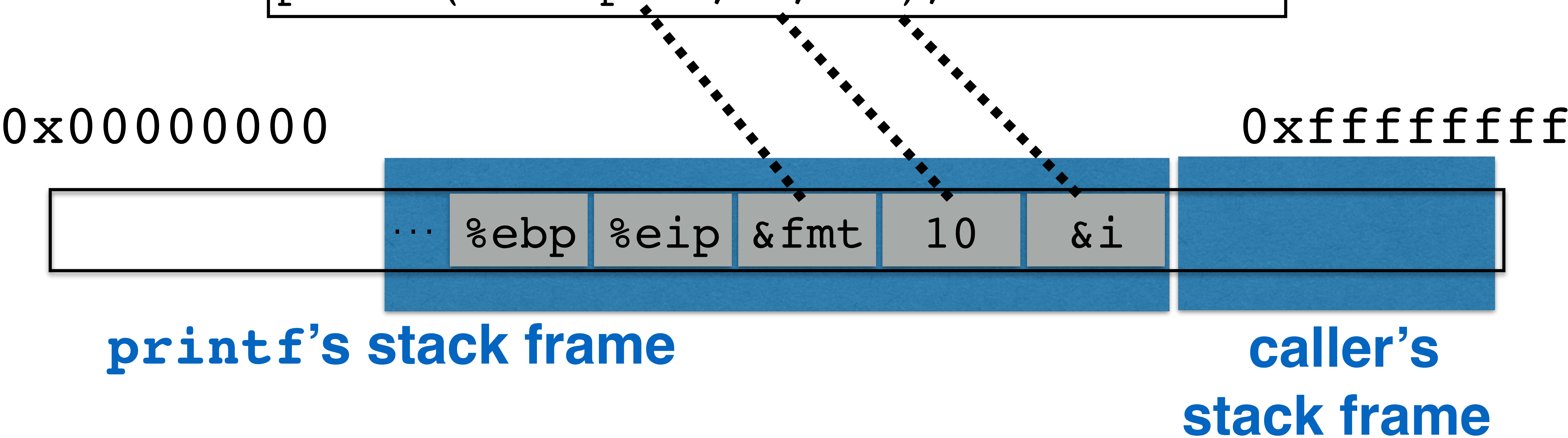

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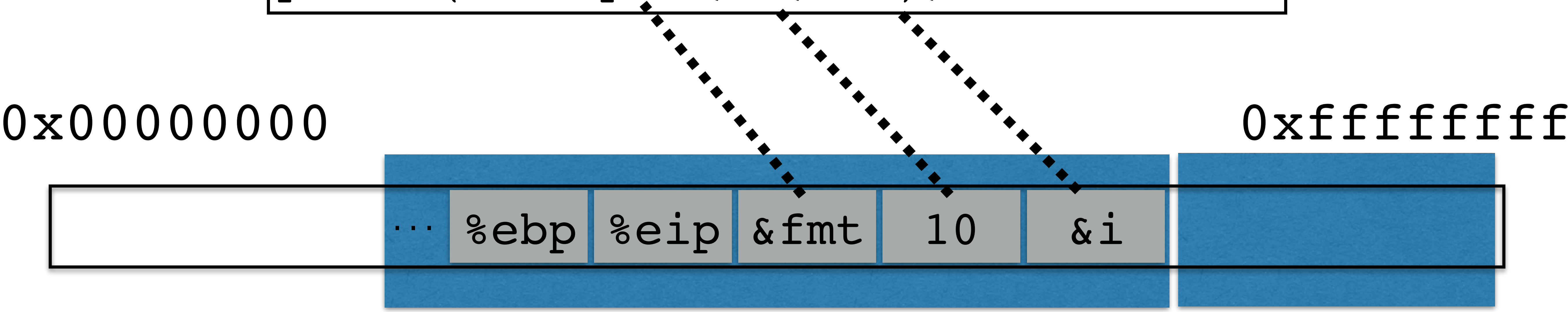

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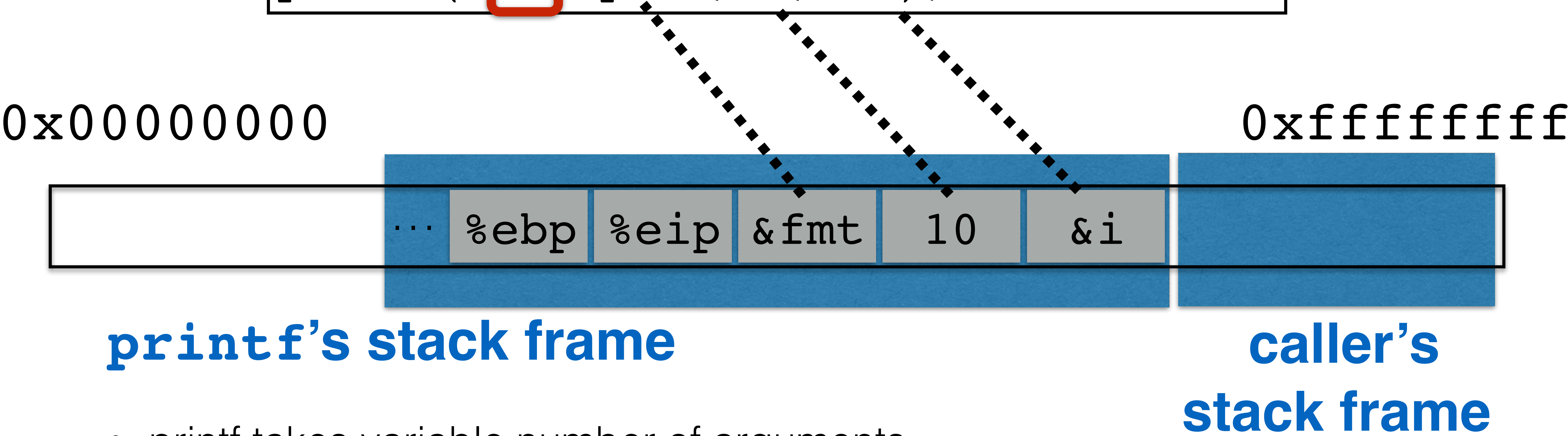

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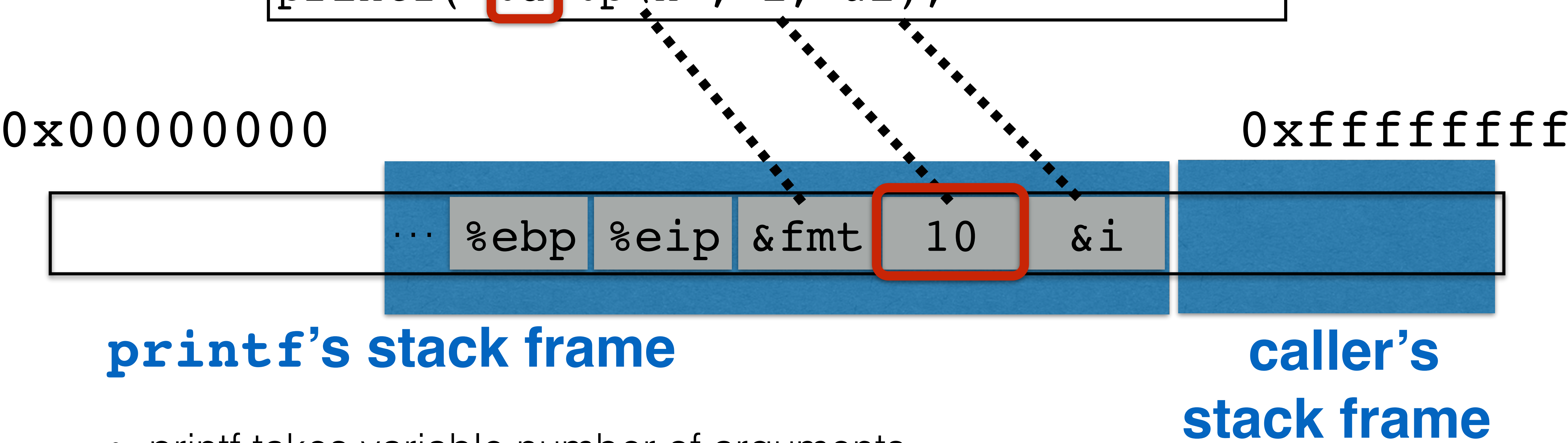

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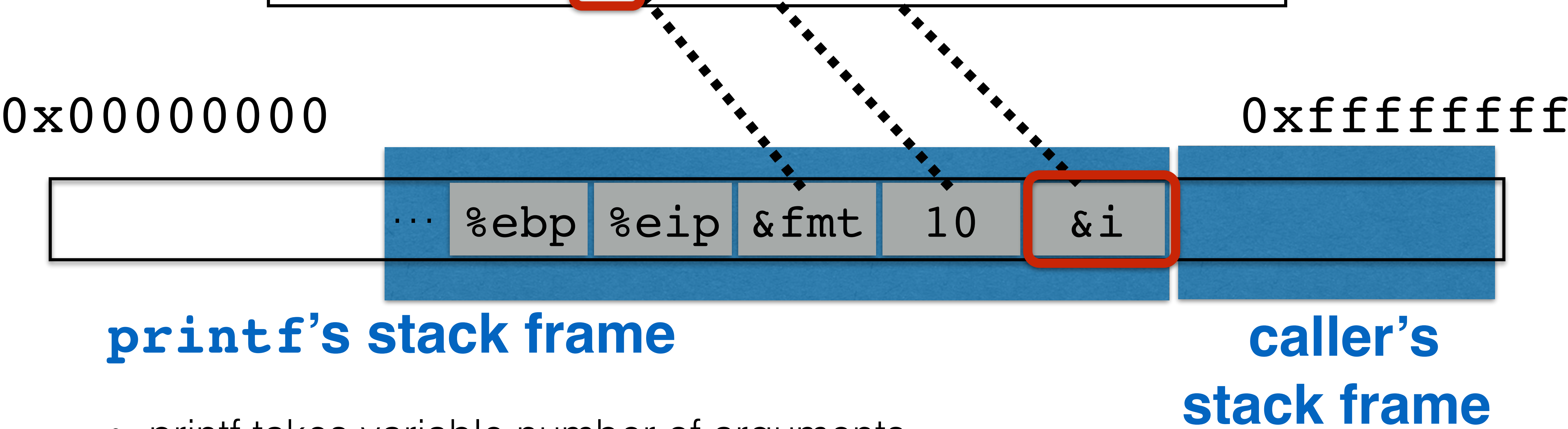
- It presumes that you called it with (at least) as many arguments as specified in the format string

`printf` format strings

```
int i = 10;
printf("%d %p\n", i, &i);
```



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```c
void vulnerable()
{
    char buf[80];
    if(fgets(buf, sizeof(buf), stdin)==NULL)
        return;
    printf(buf);
}
```

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“%d %x"

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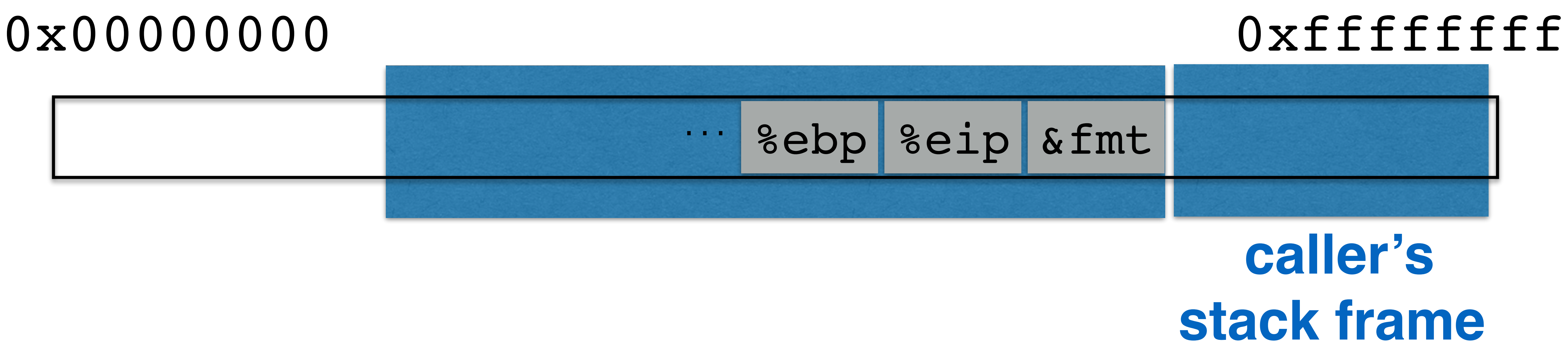

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{
    char buf[80];
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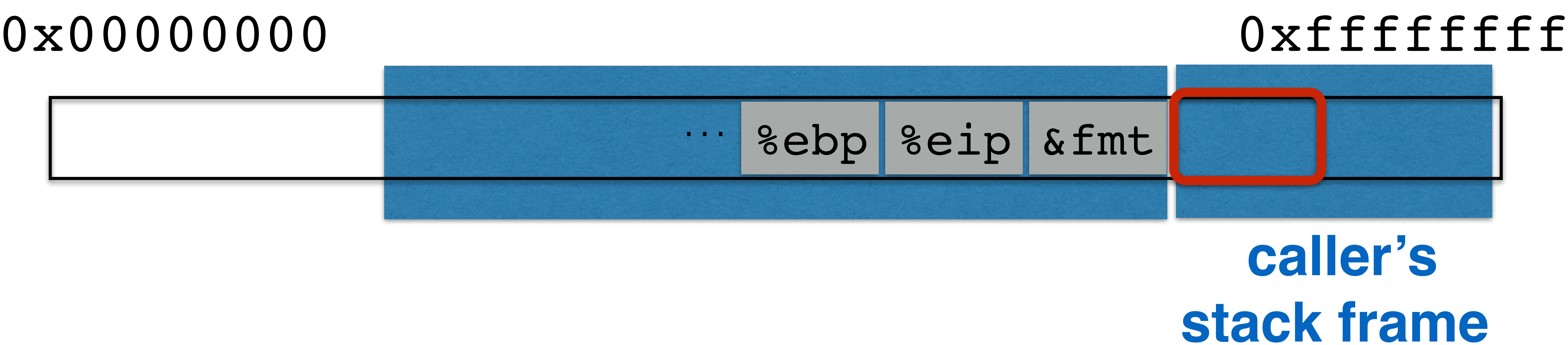

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{
    char buf[80];
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        return;
    printf(buf);
}
```

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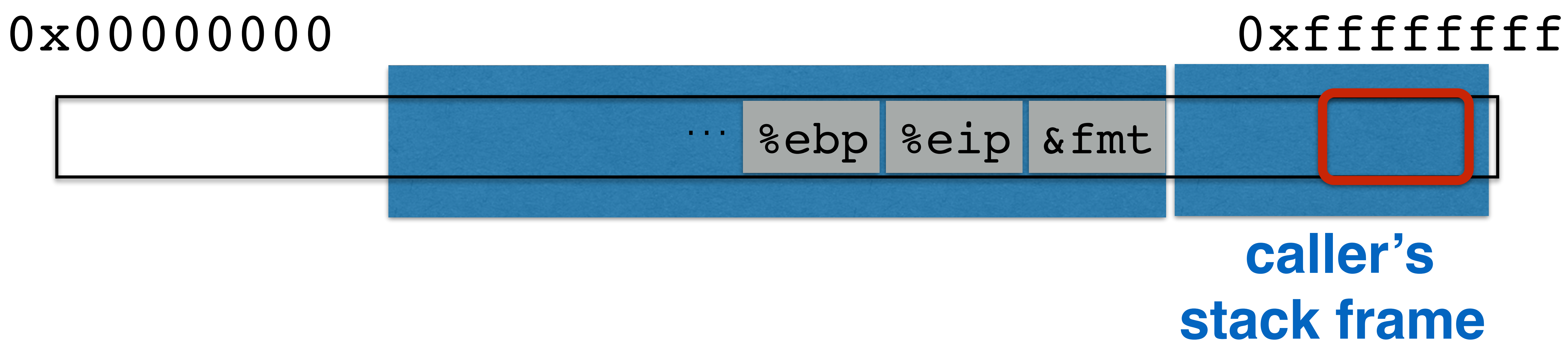

Format string vulnerabilities

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Format string vulnerabilities

- `printf("100% dml");`
  - Prints stack entry 4 byes above saved %eip
- `printf("%s");`
  - Prints bytes *pointed to* by that stack entry
- `printf("%d %d %d %d …");`
  - Prints a series of stack entries as integers

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  - Prints stack entry 4 byes above saved %eip
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- **`printf(“%08x %08x %08x %08x …”);`**

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  - Same, but nicely formatted hex

Format string vulnerabilities

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  - Same, but nicely formatted hex
- `printf("100% no way!")`

Format string vulnerabilities

- `printf(“100% dml”);`
  - Prints stack entry 4 byes above saved %eip
- `printf(“%s”);`
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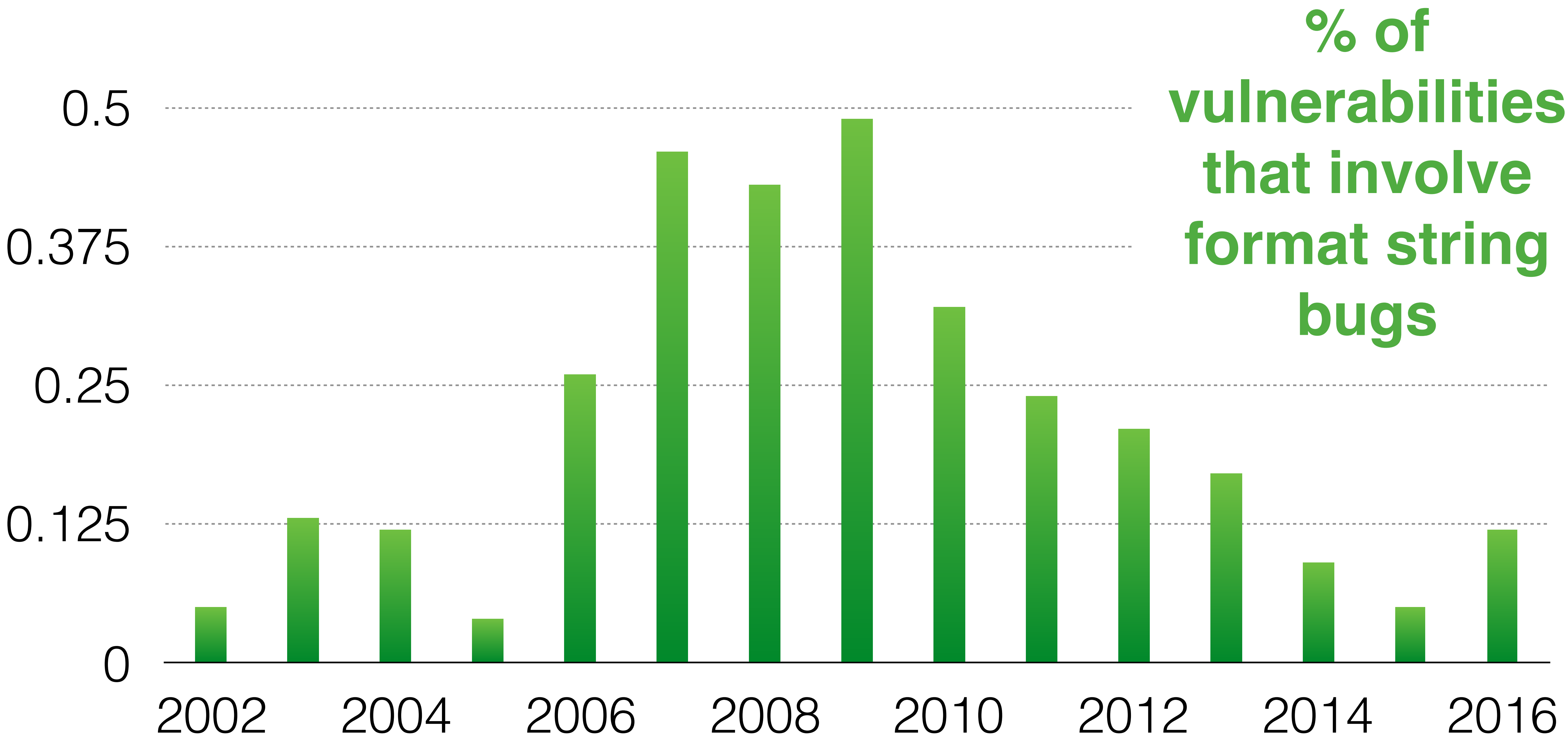
- `printf(“%d %d %d %d …”);`
  - Prints a series of stack entries as integers
- `printf(“%08x %08x %08x %08x …”);`
  - Same, but nicely formatted hex
- `printf(“100% no way!”)`
  - ***WRITES*** the number 3 to address pointed to by stack entry

Format string prevalence



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

What’s wrong with this code?

```
#define BUF_SIZE 16
char buf[BUF_SIZE];
void vulnerable()
{
    int len = read_int_from_network();
    char *p = read_string_from_network();
    if(len > BUF_SIZE) {
        printf(“Too large\n”);
        return;
    }
    memcpy(buf, p, len);
}
```

What's wrong with this code?

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char buf[BUF_SIZE];
void vulnerable()
{
    int len = read_int_from_network();
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        return;
    }
    memcpy(buf, p, len);
}
```

```
void *memcpy(void *dest, const void *src, size_t n);
```

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        return;
    }
    memcpy(buf, p, len);
}
```

```
void *memcpy(void *dest, const void *src, size_t n);
typedef unsigned int size_t;
```

What's wrong with this code?

```
#define BUF_SIZE 16
char buf[BUF_SIZE];
void vulnerable()
{   Negative
    int len = read_int_from_network();
    char *p = read_string_from_network();
    if(len > BUF_SIZE) {
        printf("Too large\n");
        return;
    }
    memcpy(buf, p, len);
}
```

```
void *memcpy(void *dest, const void *src, size_t n);
typedef unsigned int size_t;
```

What’s wrong with this code?

```
#define BUF_SIZE 16
char buf[BUF_SIZE];
void vulnerable()
{   Negative
    int len = read_int_from_network();
    char *p = read_string_from_network();
 Ok if(len > BUF_SIZE) {
        printf(“Too large\n”);
        return;
    }
    memcpy(buf, p, len);
}
```

```
void *memcpy(void *dest, const void *src, size_t n);
typedef unsigned int size_t;
```

What's wrong with this code?

```
#define BUF_SIZE 16
char buf[BUF_SIZE];
void vulnerable()
{   Negative
    int len = read_int_from_network();
    char *p = read_string_from_network();
 Ok if(len > BUF_SIZE) {
        printf("Too large\n");
        return;
    }
    memcpy(buf, p, len);
}                   Implicit cast to unsigned
```

```
void *memcpy(void *dest, const void *src, size_t n);
typedef unsigned int size_t;
```

Integer overflow vulnerabilities

What's wrong with this code?

```
void vulnerable()
{
    size_t len;
    char *buf;

    len = read_int_from_network();
    buf = malloc(len + 5);
    read(fd, buf, len);
    ...
}
```

What’s wrong with this code?

```
void vulnerable()
{
    size_t len;
    char *buf;
  HUGE
    len = read_int_from_network();
    buf = malloc(len + 5);
    read(fd, buf, len);
    ...
}
```

What's wrong with this code?

HUGE

```
void vulnerable()
{
    size_t len;
    char *buf;

    len = read_int_from_network();
    buf = malloc(len + 5); 
    read(fd, buf, len);
    ...
}
```

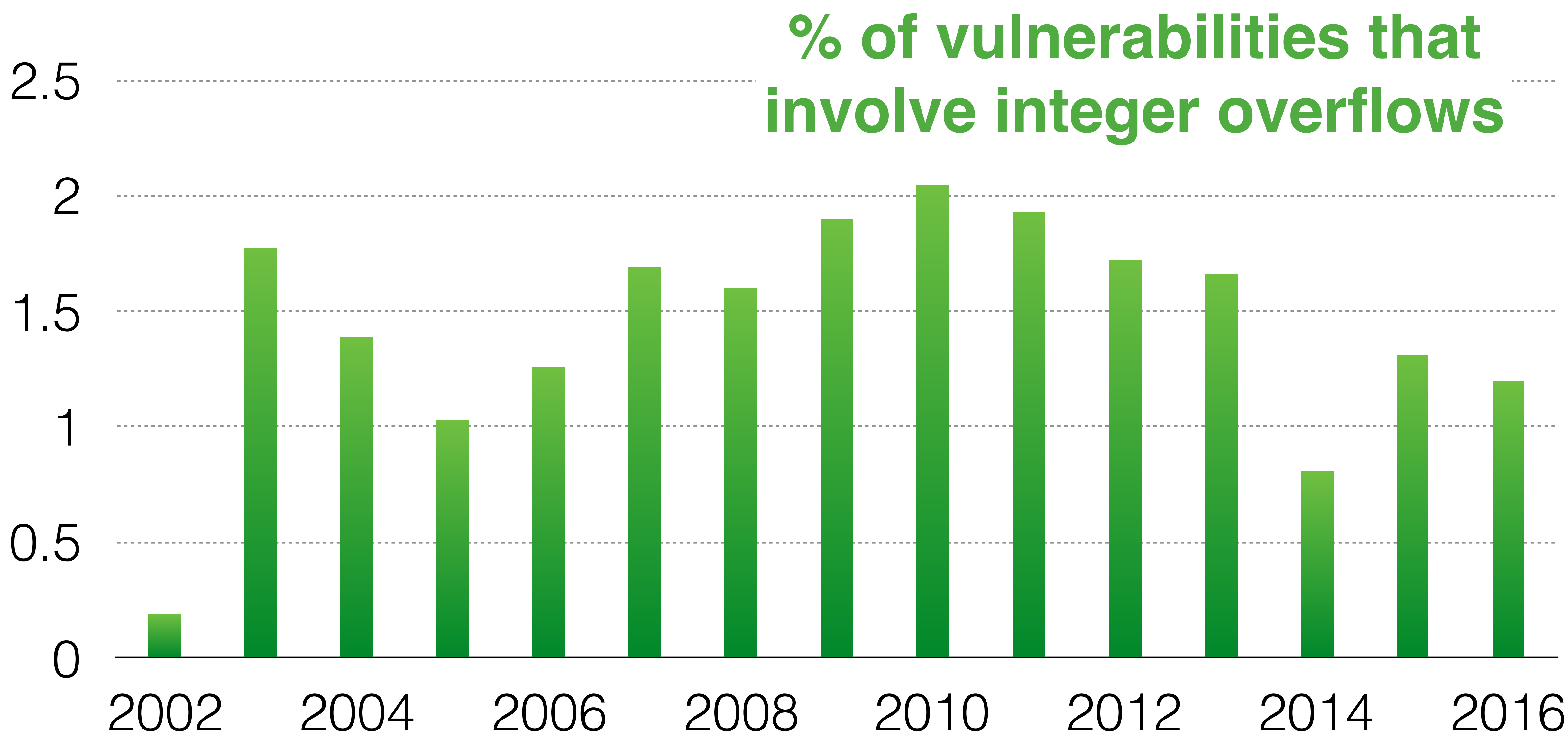
Wrap-around

What’s wrong with this code?

```
void vulnerable()
{
    size_t len;
    char *buf;
  HUGE
    len = read_int_from_network();
    buf = malloc(len + 5); Wrap-around
    read(fd, buf, len);
    ...
}
```

Takeaway: You have to know the semantics of your programming language to avoid these errors

Integer overflow prevalence



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