Memory Corruption Attacks

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Content

- What is buffer overflow?
- Process memory layout
- Basic stack layout
- Buffer overflow attack

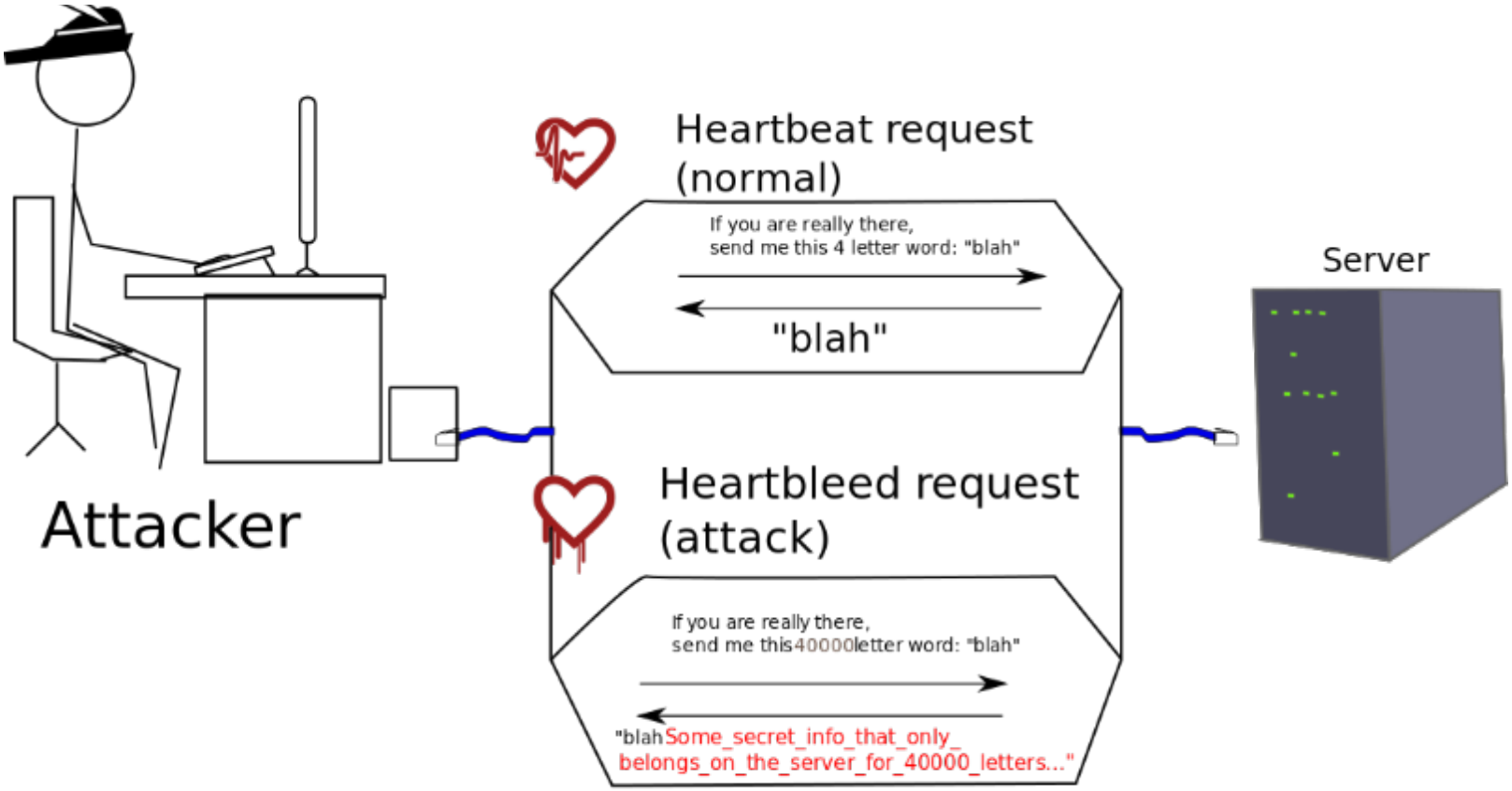
Buffer overflow

- A buffer overflow is a bug that affects low-level code, typically in C and C++ (because all strings are arrays of `char`'s)
- Buffer = contiguous memory associated with a variable or field
- A buffer overflow means **any access of a buffer outside of its allotted bounds**
  - ✓ Could be an over-*write* or over-*read*
- An attacker can perform buffer overflow attacks to do the followings:
  - ✓ Steal private information
  - ✓ Corrupt valuable information
  - ✓ Run code of the attacker's choice

Example: Heartbleed

- SSL/TLS is a core protocol for encrypted communications used by the web
- OpenSSL contains a function known as a heartbeat option. With it, a client periodically sends and receives messages to check whether both the client and the server are both still connected.
  - ✓ Discovered in March 2014. However, it has been in the released code since March 2012 (2 years old!)
- A carefully crafted packet causes OpenSSL to read and return portions of a vulnerable server's memory
  - ✓ Leaking passwords, keys, and other private information

Buffer over-read bug



https://xkcd.com/1354/

The extra data that is sent back is fetched from the server's memory, due to the bug. It could include passwords and private keys.

Control flow hijacking

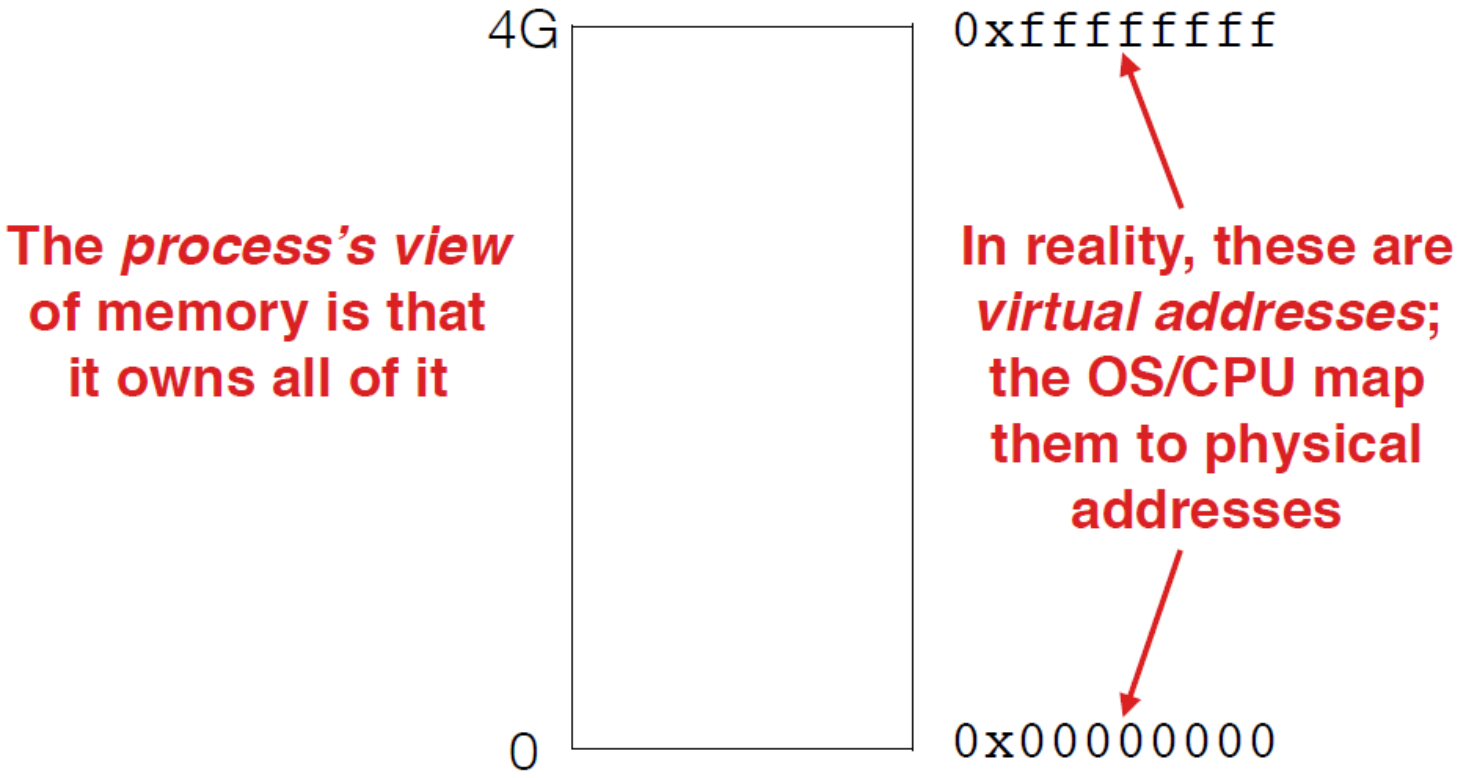
- The general idea is to overflow a buffer so that it overwrites the return address.
- When the function is done, it will jump to whatever address is on the stack.
- We put some code in the buffer and set the return address to point to it!

Problem

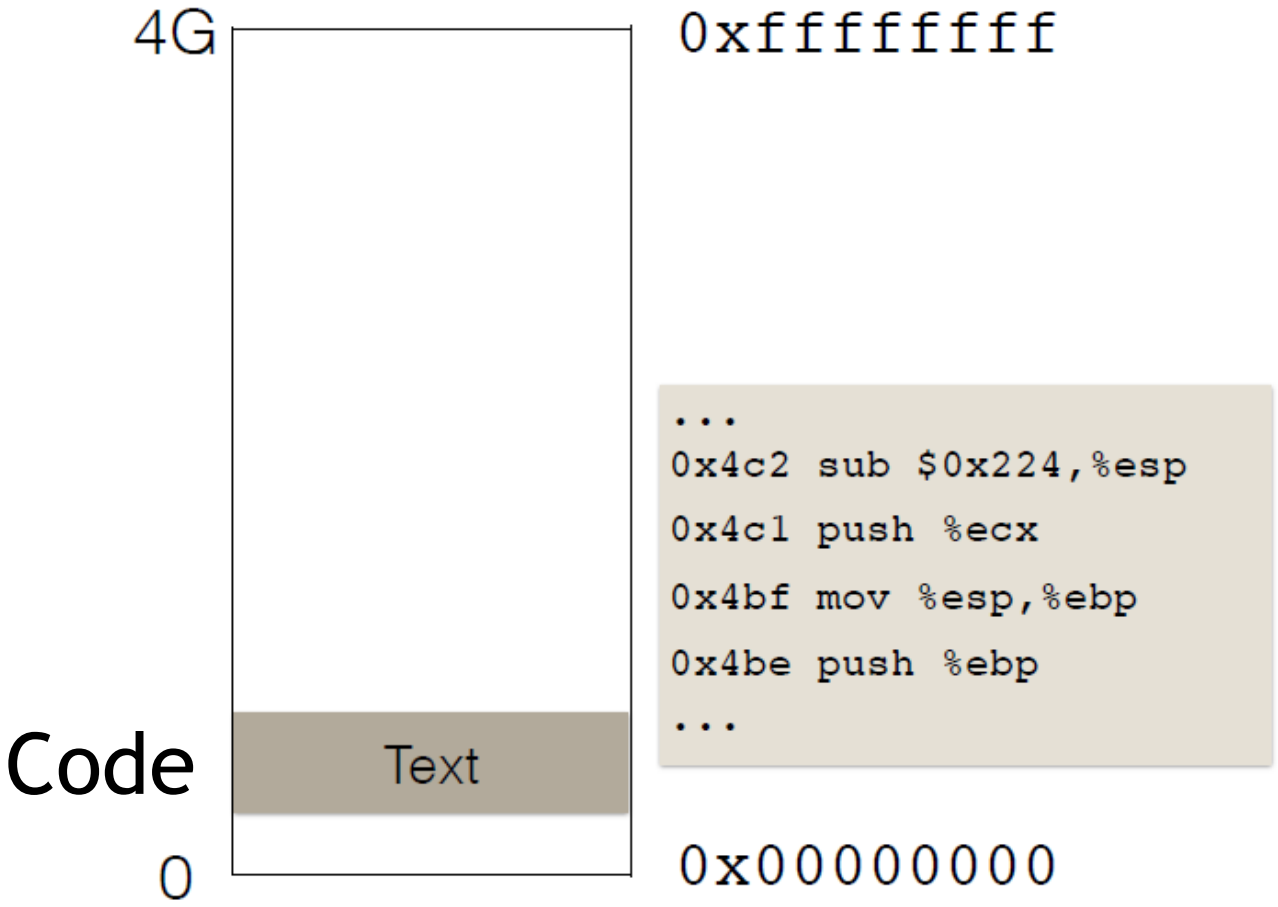
```
void foo(char *s) {
  char buf[10];
  strcpy(buf,s);
  printf("buf is %s\n",s);
}

…
foo("thisstringistolongforfoo");
```

Q. What happened? A. Segmentation fault

All programs are in memory



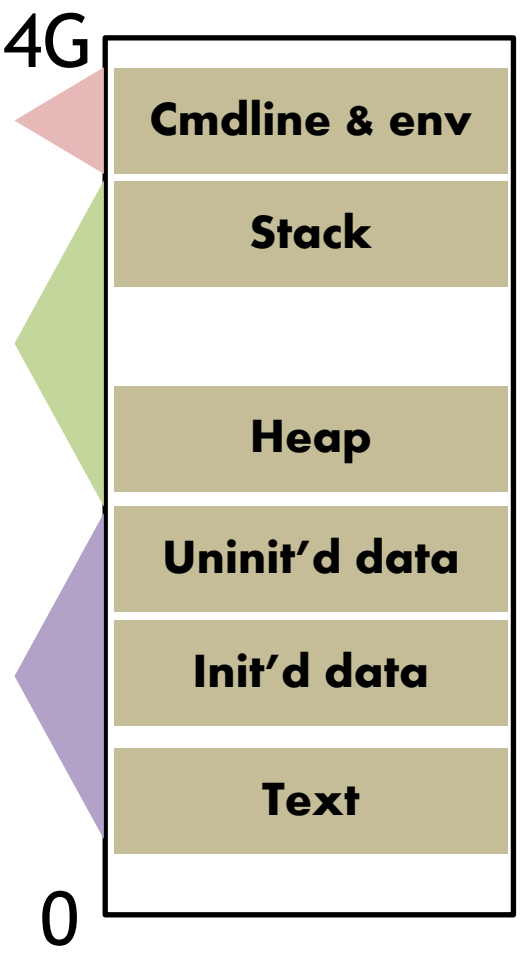
The instructions themselves are in memory



Set when process starts

Runtime

Known at compile time



0xffffffff

```
int f() {
    int x;
    …
```

```
mallloc(sizeof(long));
```

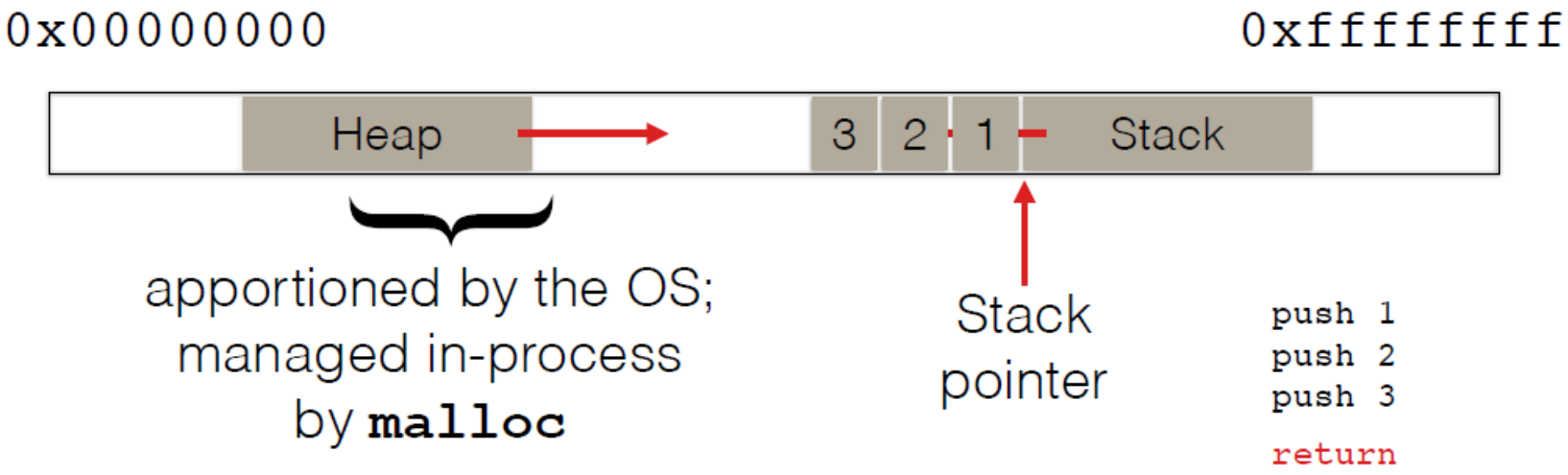
```
static int x;
```

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

0x00000000

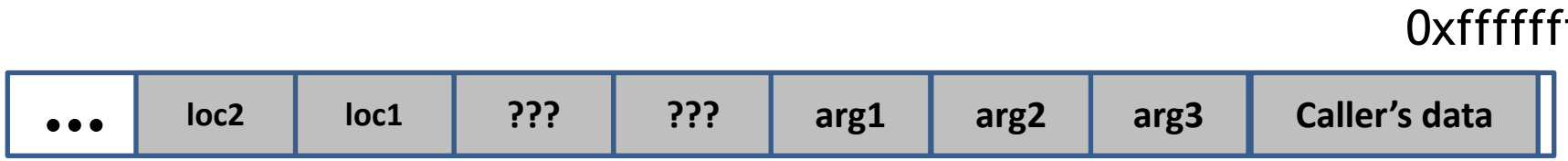
Stack and heap grow in opposite directions

Compiler emits instructions
adjust the size of the stack at run-time



Focusing on the stack for now

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

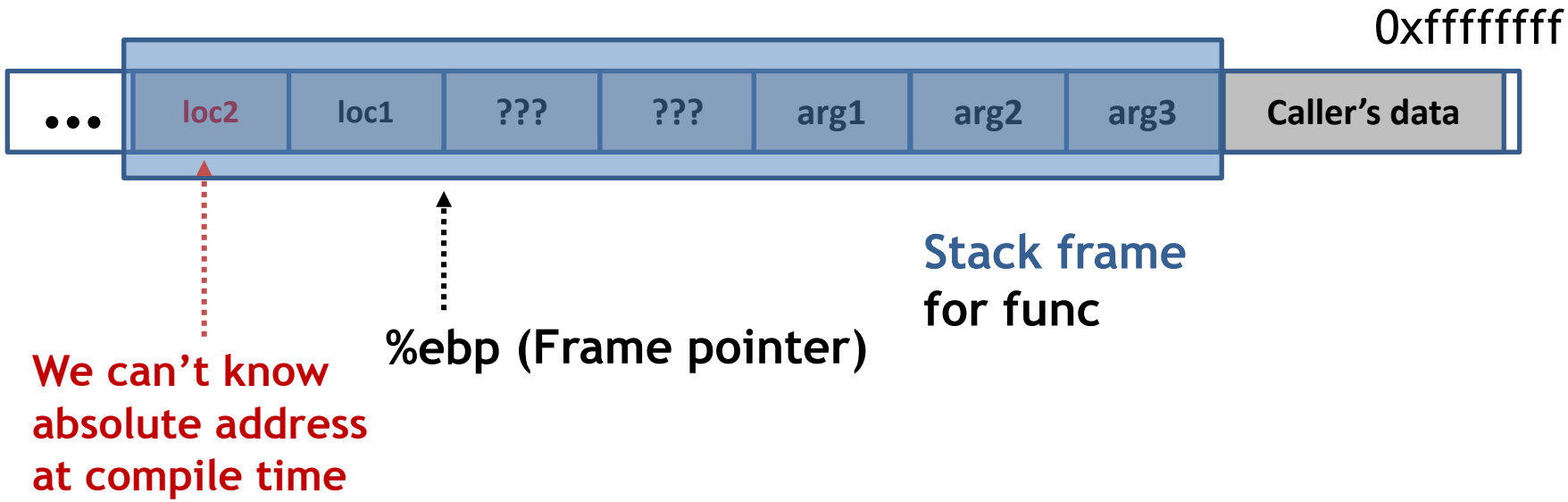


Local variables pushed in the same order as they appear in the code

Arguments pushed in reverse order of code

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

Q. Where is this loc2?



But, we can know the relative address

- loc2 is always 8bytes before ???s

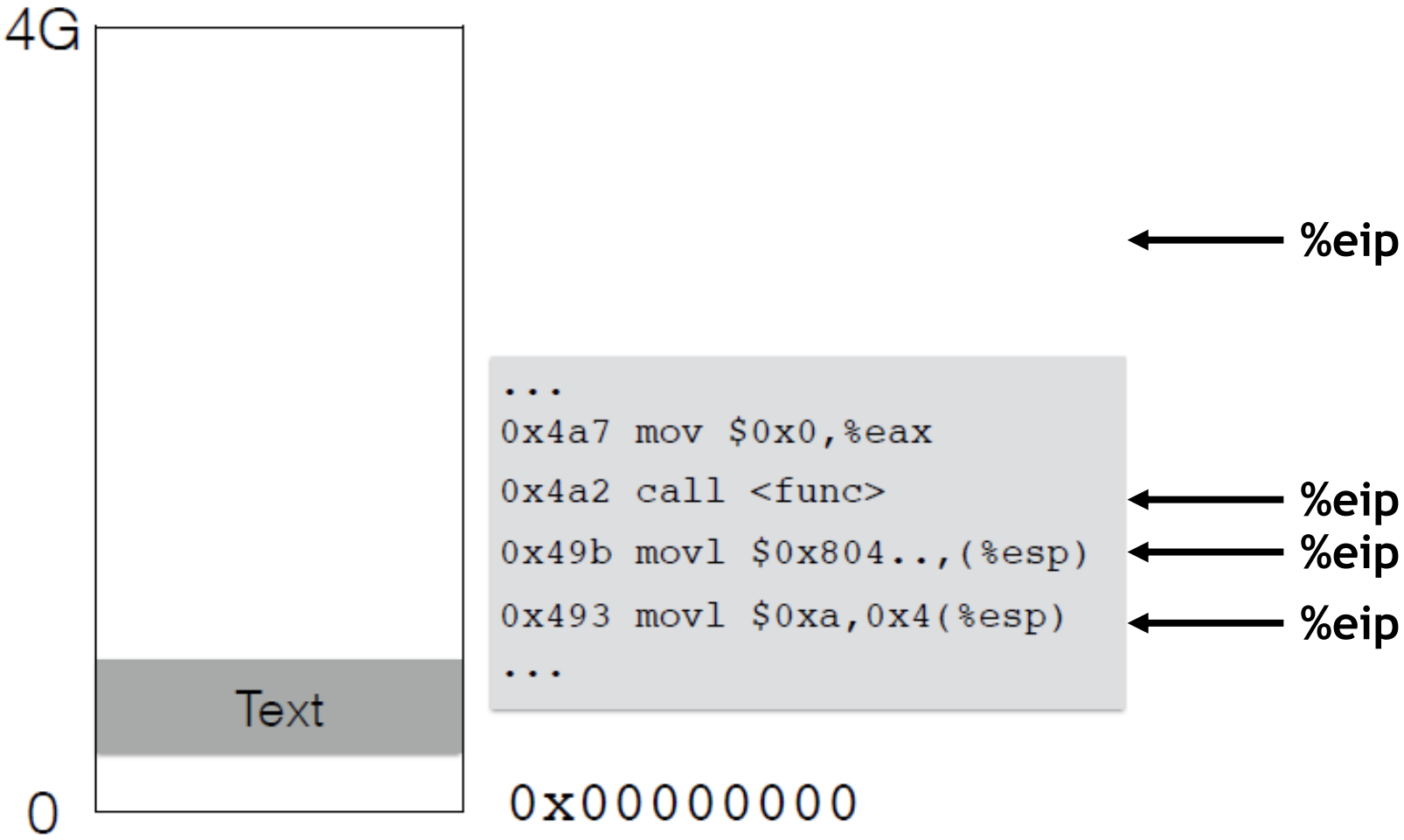
Special registers

- Frame (or Base) Pointer
  - ✓ %ebp
  - ✓ Points to 'bottom' of stack frame
  - ✓ The value of %ebp is pushed on the stack (and later restored) by the **callee** on function entry

- Stack Pointer
  - ✓ %esp
  - ✓ Points to 'top' of stack frame

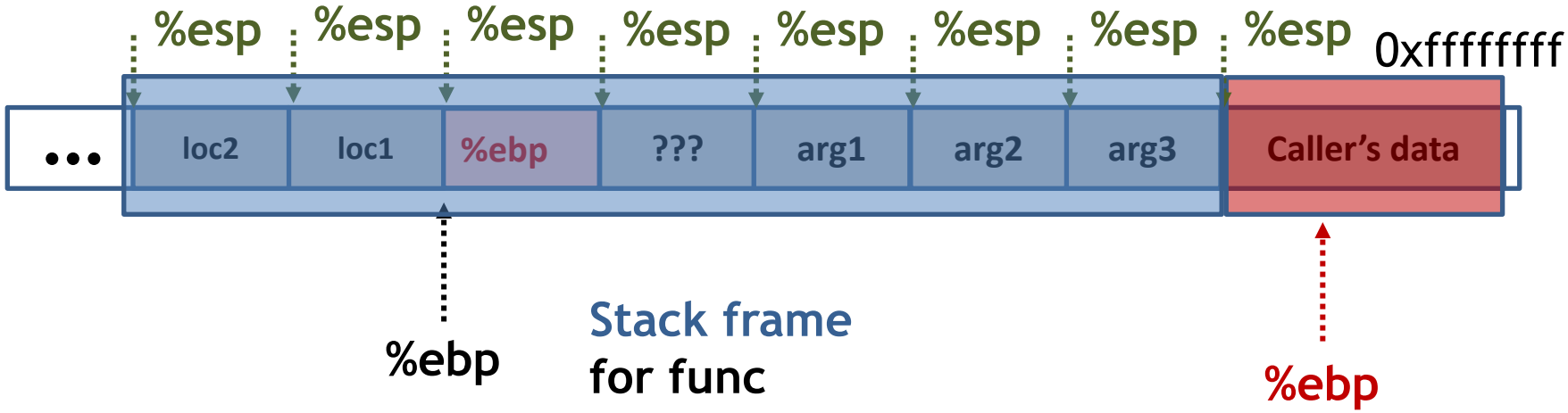
- Instruction Pointer (or program counter)
  - ✓ %eip
  - ✓ Points to the next instruction to be executed

Instructions in memory



Stack frame

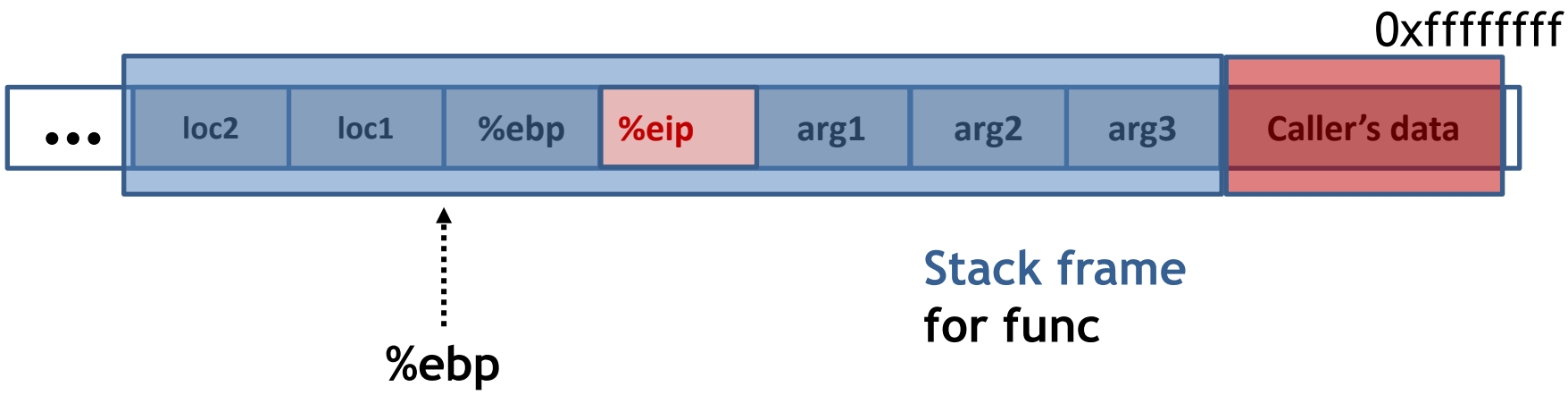
```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4]
    int  loc2;
    ...
}
```



- We need to store ??? to return
- We need to store old %ebp
- We set %ebp to current (%esp)

What is ???

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



- We also need to store old %eip Push next %eip on the stack before calling

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

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

```
void foo(char *s) {
      char buf[4];
      strcpy(buf,s);
      …
}
```

All ours!

buffer

strcpy will let you write as much as you want

```
void foo(char *s) {
        char buf[4];
        strcpy(buf,s);
        …
}
```

1. How can you load your own code into memory?
2. How can we get %eip to point to it?

Example of malicious codes

```
#include <stdio.h>

char *args[] = {"/bin/ls", NULL};

void main(void) {
  execv("/bin/ls",args);
  printf("I'm not printed\n");
}
```

- In many cases, attacker's goal is to run a **general-purpose shell**
  - ✓ Command-line prompt that gives attacker general access to the system
- The code to launch a shell is called **shellcode**

Shellcode

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

Assembly

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

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

Machine code

(Part of) your input

Loading code into memory

- It **must be the machine code** instructions (i.e., already complied and ready to run)
- You can take a code, and generate machine language.
  - It can't contain any all-zero bytes. Why?
- Copy down the individual byte values and build a string.

Sample program/string

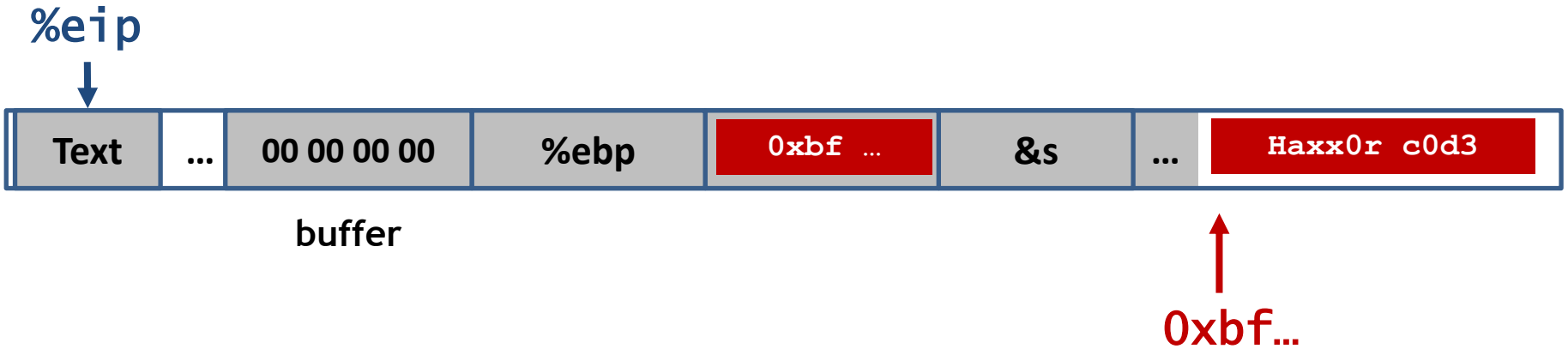
```
unsigned char cde[] =
\x31\xc0\x50\x68\x76\x08\x31\xc0\x88\x46\x07
  \x89\x46\x0c\xb0\x0b\x89\xf3\x8d\x4e\x08\x
  8d\x56\x0c\xcd\x80\x31\xdb\x89\xd8\x40\xcd
  \x80\xe8\xdc\xff\xff\xff/bin/ls
```

We use this string for buffer overflow!

Sample overflow program

```
unsigned char cde[] = "\x31\xc0\…

void foo(char *s) {
  char buf[100];
  strcpy(buf,s);
  printf(“buf is %s\n”,s);
}

int main(void) {
  printf("Running foo\n");
  foo(cde);
  printf("foo returned\n");
}
```

Hijacking the saved %eip

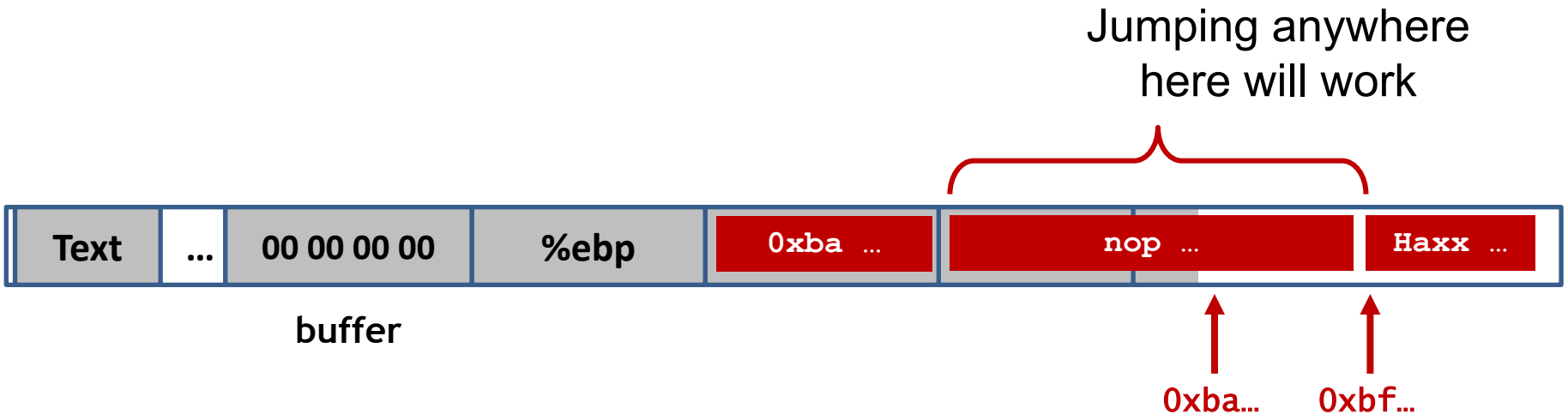


However, if we point to wrong address (i.e., 0xbd … invalid instruction), the CPU will panic

How to guess the correct 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
- Without address randomization:
  - The **stack always starts** from the same fixed address

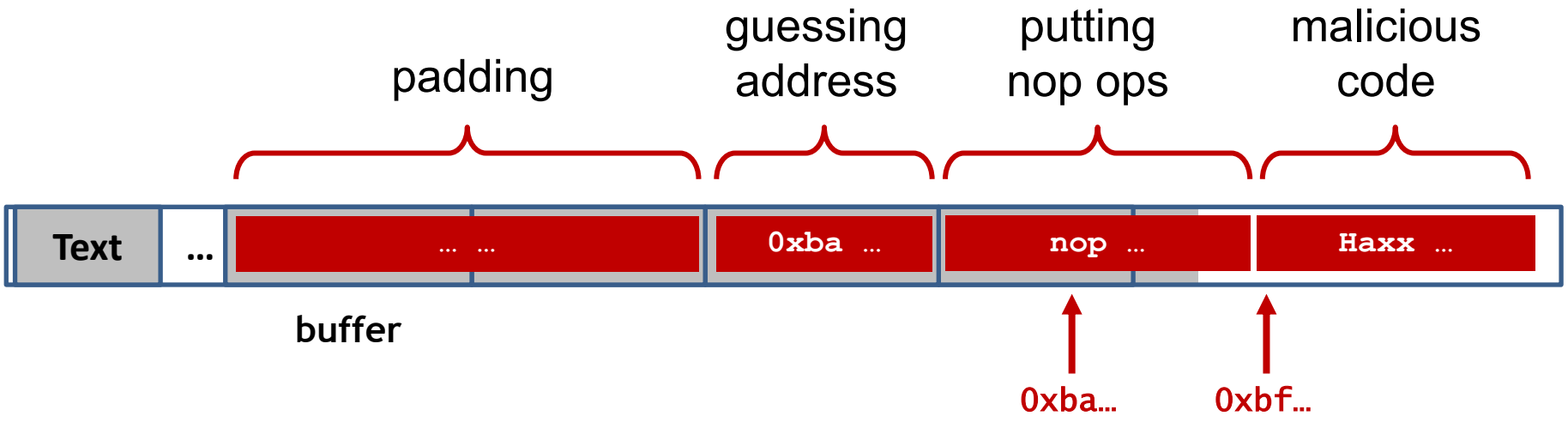
Improving our chances: nop sleds



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

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

Putting it all together



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