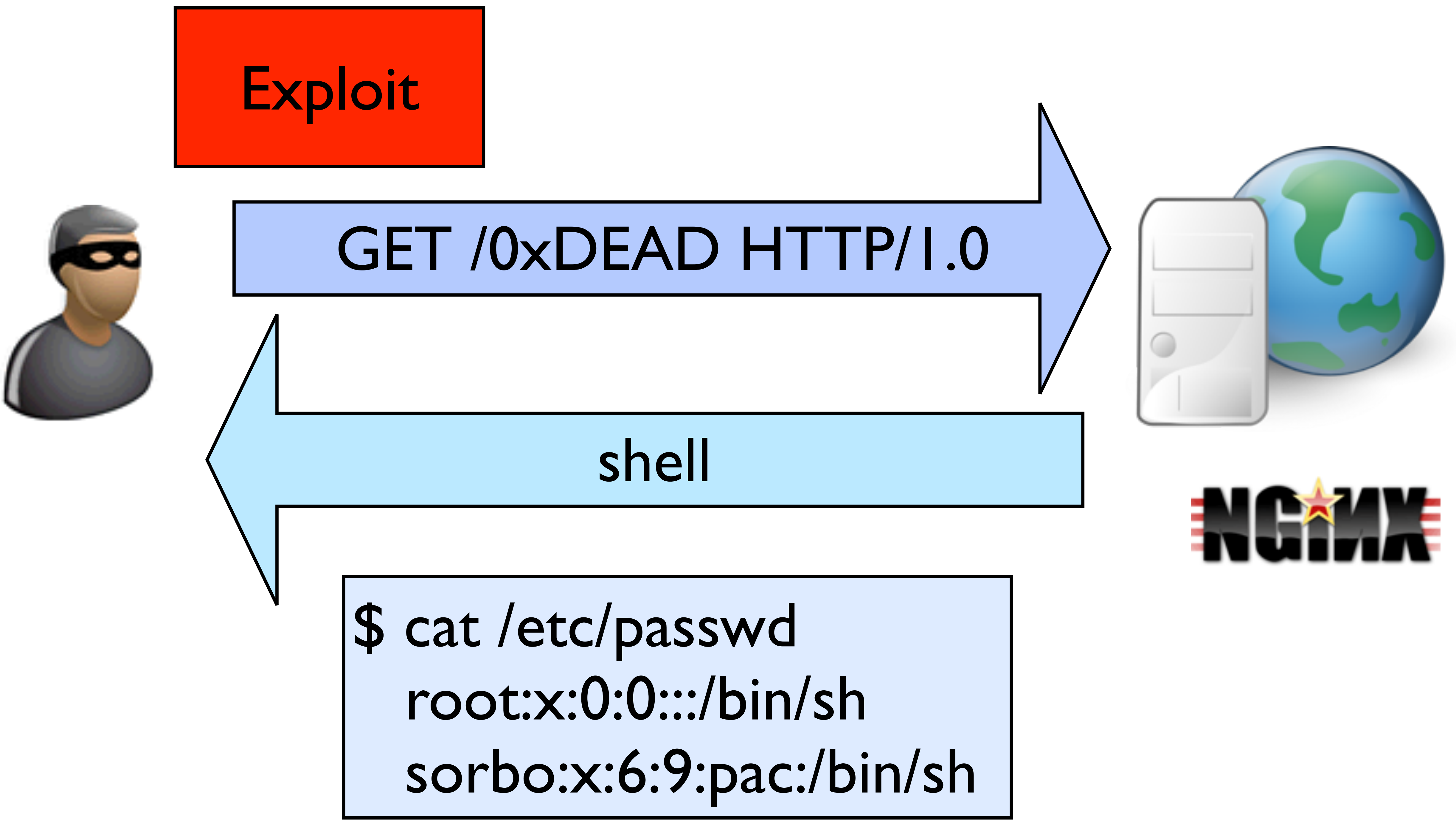
Hacking Blind

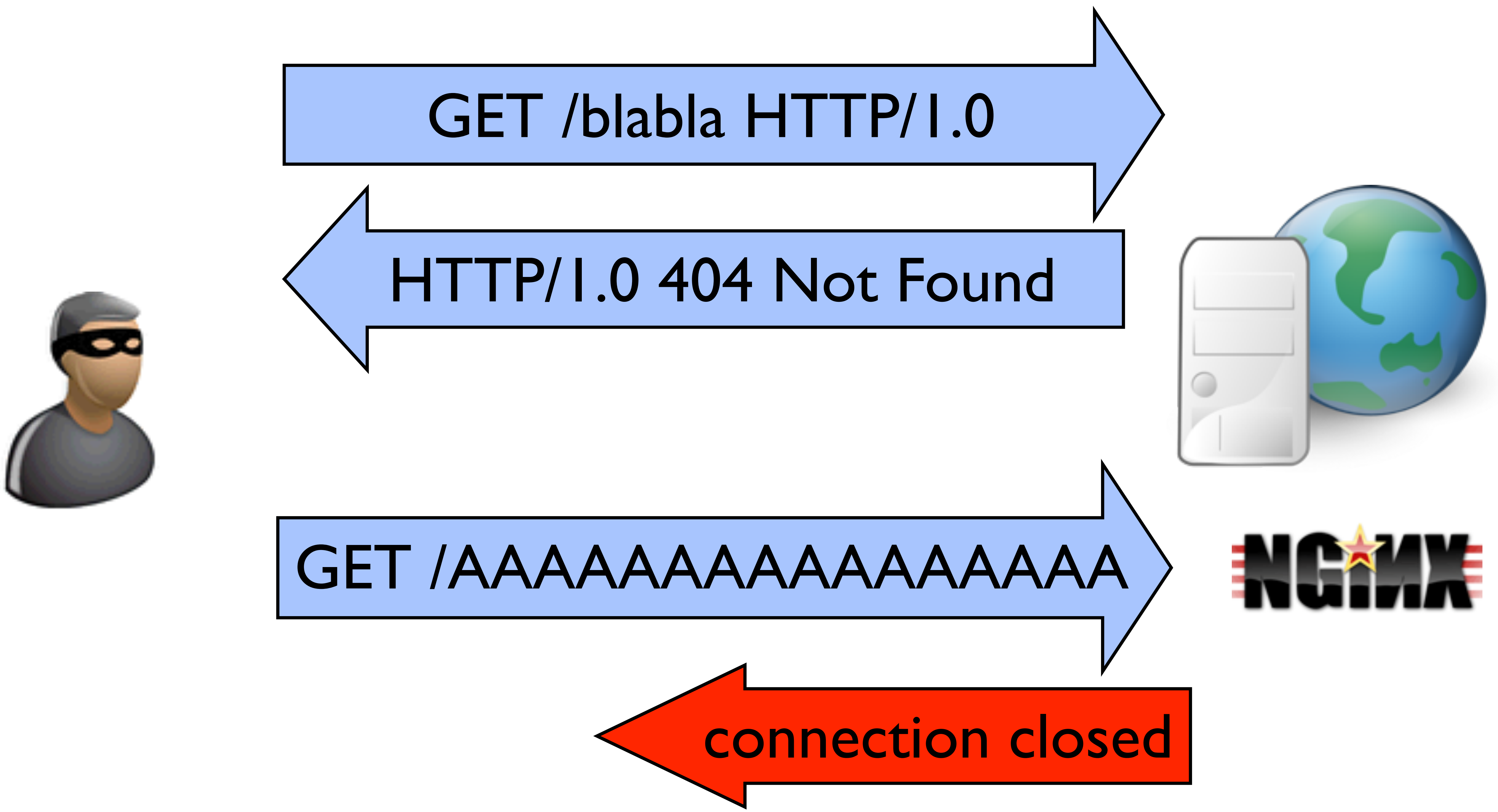
Andrea Bittau, Adam Belay, Ali Mashtizadeh,
David Mazières, Dan Boneh

Stanford University

Hacking 101


Exploit
GET /0xDEAD HTTP/1.0
shell
NGINX
$ cat /etc/passwd
root:x:0:0:::/bin/sh
sorbo:x:6:9:pac:/bin/sh

Crash or no Crash?
Enough to build exploit



Don't even need to know what application is running!

Exploit scenarios:

1. Open source
2. Open binary
3. Closed-binary (and source)

????

Attack effectiveness

- Works on 64-bit Linux with ASLR, NX and canaries

Server	Requests	Time (mins)
nginx	2,401	1
MySQL	3,851	20
Toy proprietary service (unknown binary and source)	1,950	5

Attack requirements

1. Stack vulnerability, and knowledge of how to trigger it.
2. Server process that respawns after crash
   - E.g., nginx, MySQL, Apache, OpenSSH, Samba.

Background Outline

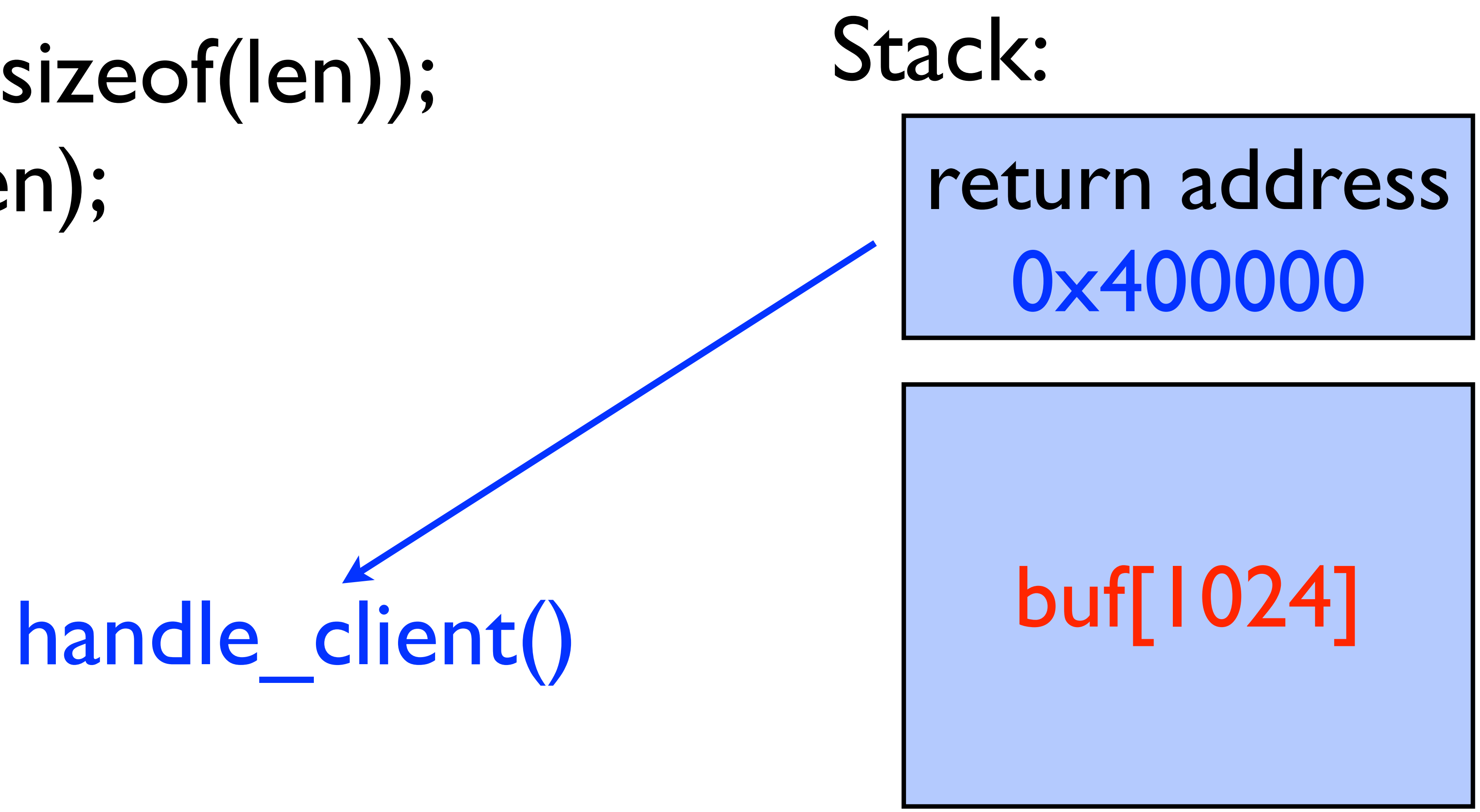
- Stack Vulnerabilities
- No-eXecute memory (NX)
- Return-Oriented Programming (ROP)
- Address Space Layout Randomization (ASLR)

Stack vulnerabilities

```
void process_packet(int s) {
    char buf[1024];
    int len;

    read(s, &len, sizeof(len));
    read(s, buf, len);

    return;
}
```



Stack vulnerabilities

```
void process_packet(int s) {
    char buf[1024];
    int len;

    read(s, &len, sizeof(len));
    read(s, buf, len);

    return;
}
```

handle_client()

Stack:

return address
0x400000

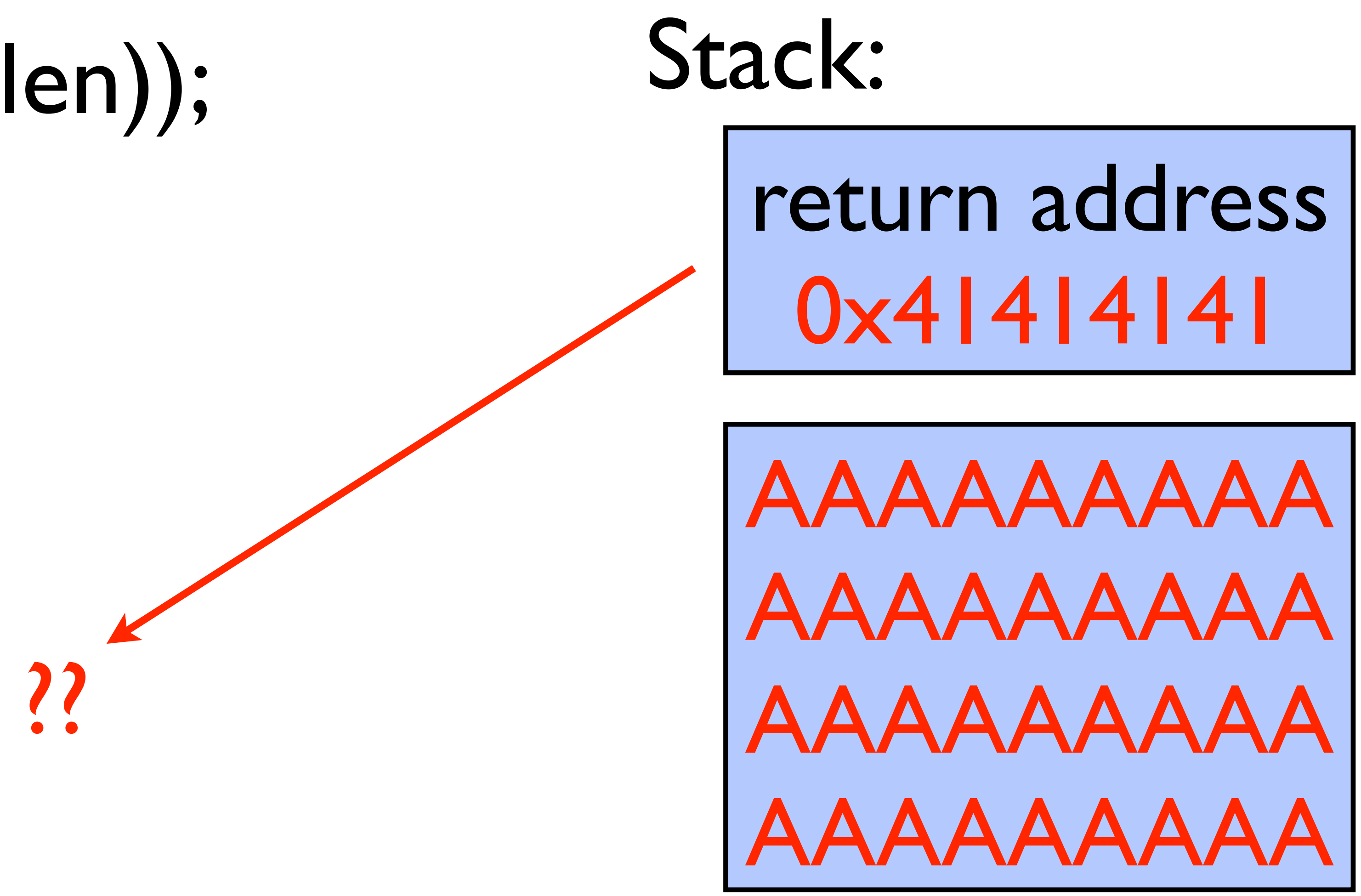
AAAAAAAAA
AAAAAAAAA
AAAAAAAAA
AAAAAAAAA

Stack vulnerabilities

```
void process_packet(int s) {
    char buf[1024];
    int len;

    read(s, &len, sizeof(len));
    read(s, buf, len);

    return;
}
```

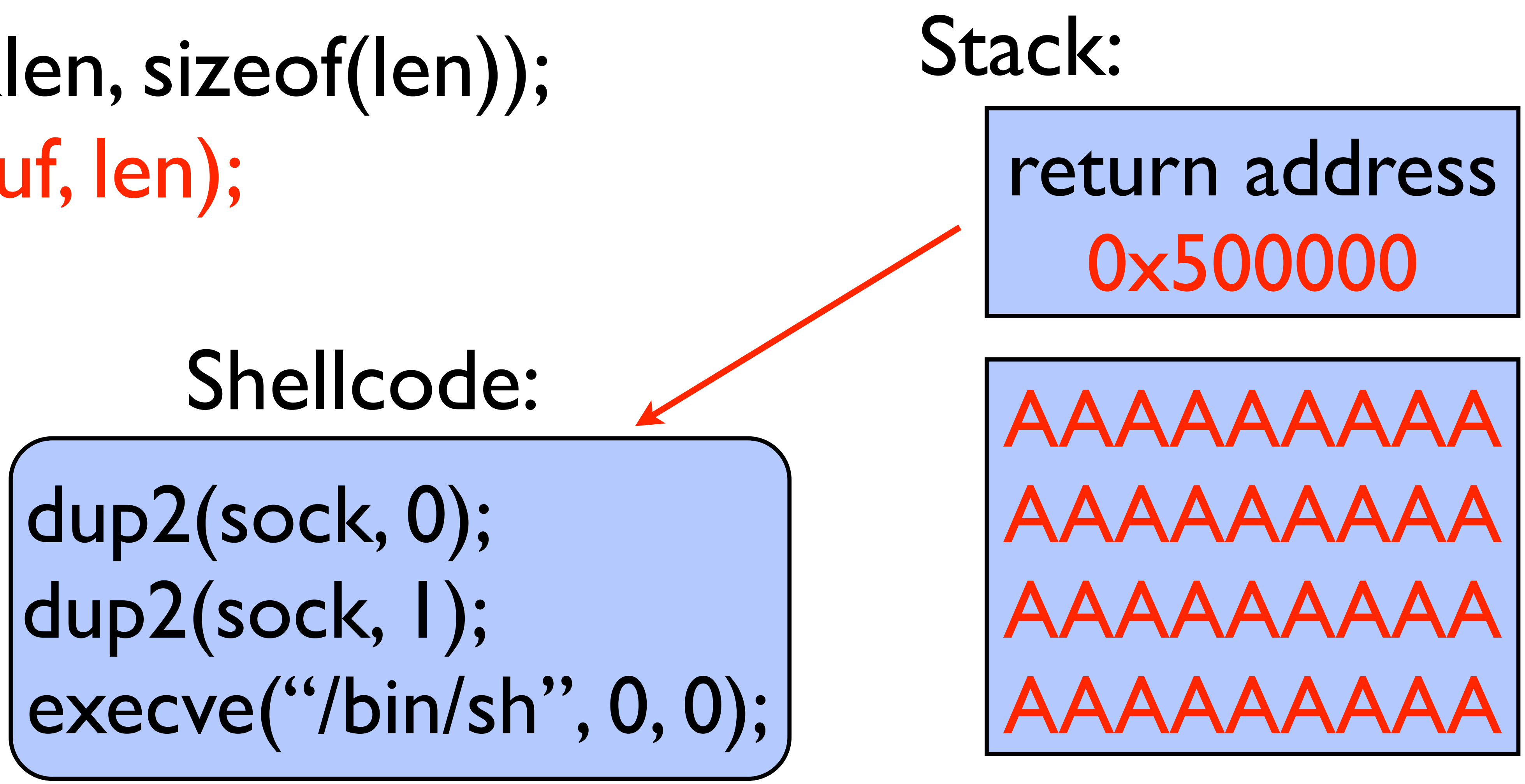


Stack vulnerabilities

```
void process_packet(int s) {
    char buf[1024];
    int len;

    read(s, &len, sizeof(len));
    read(s, buf, len);

    return;
}
```



Stack vulnerabilities

```
void process_packet(int s) {
    char buf[1024];
    int len;

    read(s, &len, sizeof(len));
    read(s, buf, len);

    return;
}
```

Shellcode:

```
dup2(sock, 0);
dup2(sock, 1);
execve("/bin/sh", 0, 0);
```

Stack:

return address
0x600000

0x1029827189
123781923719
823719287319
879181823828

Exploit protections

void pro
char
int le

rea
rea

return;
}

Stack:

return address
0x600000

0x1029827189
123781923719
823719287319
879181823828

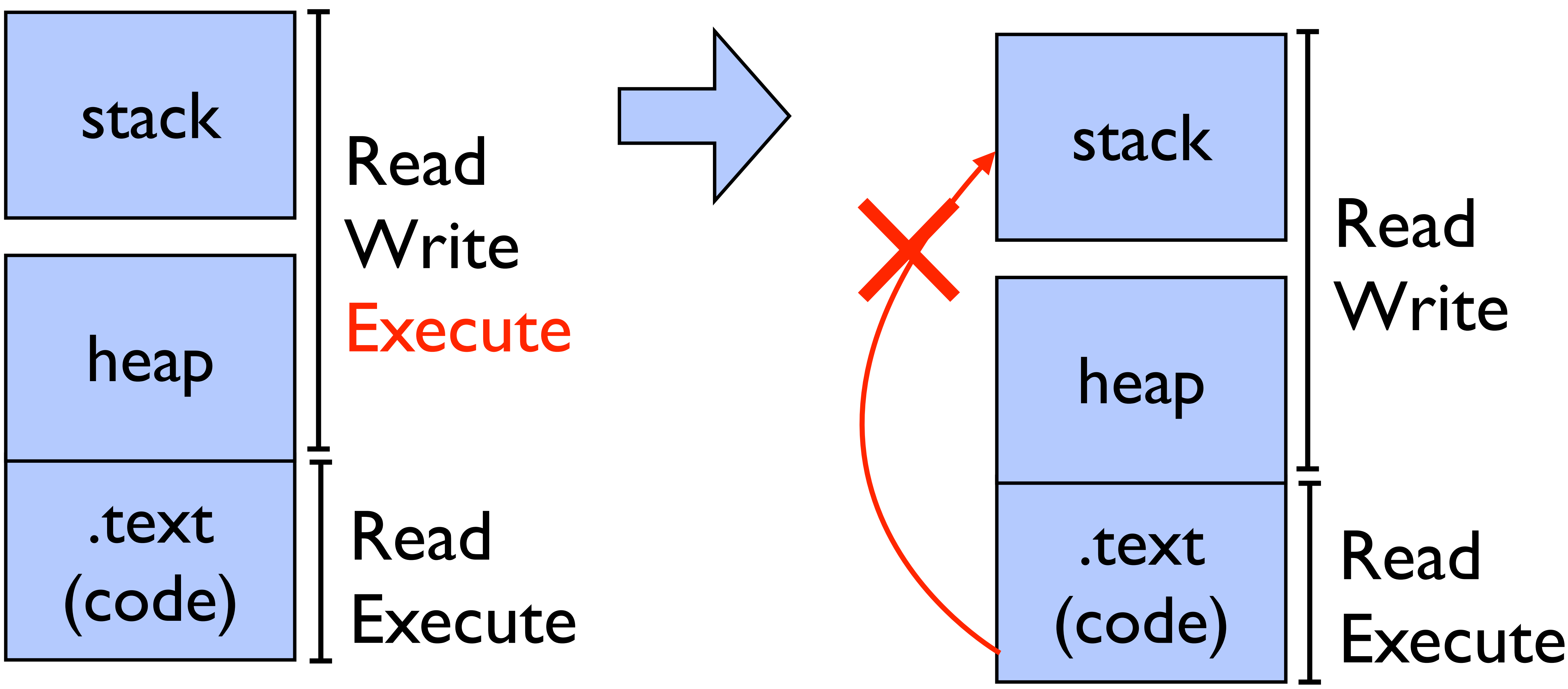
Shellcode:

dup2(sock, 0);
dup2(sock, 1);
execve("/bin/sh", 0, 0);

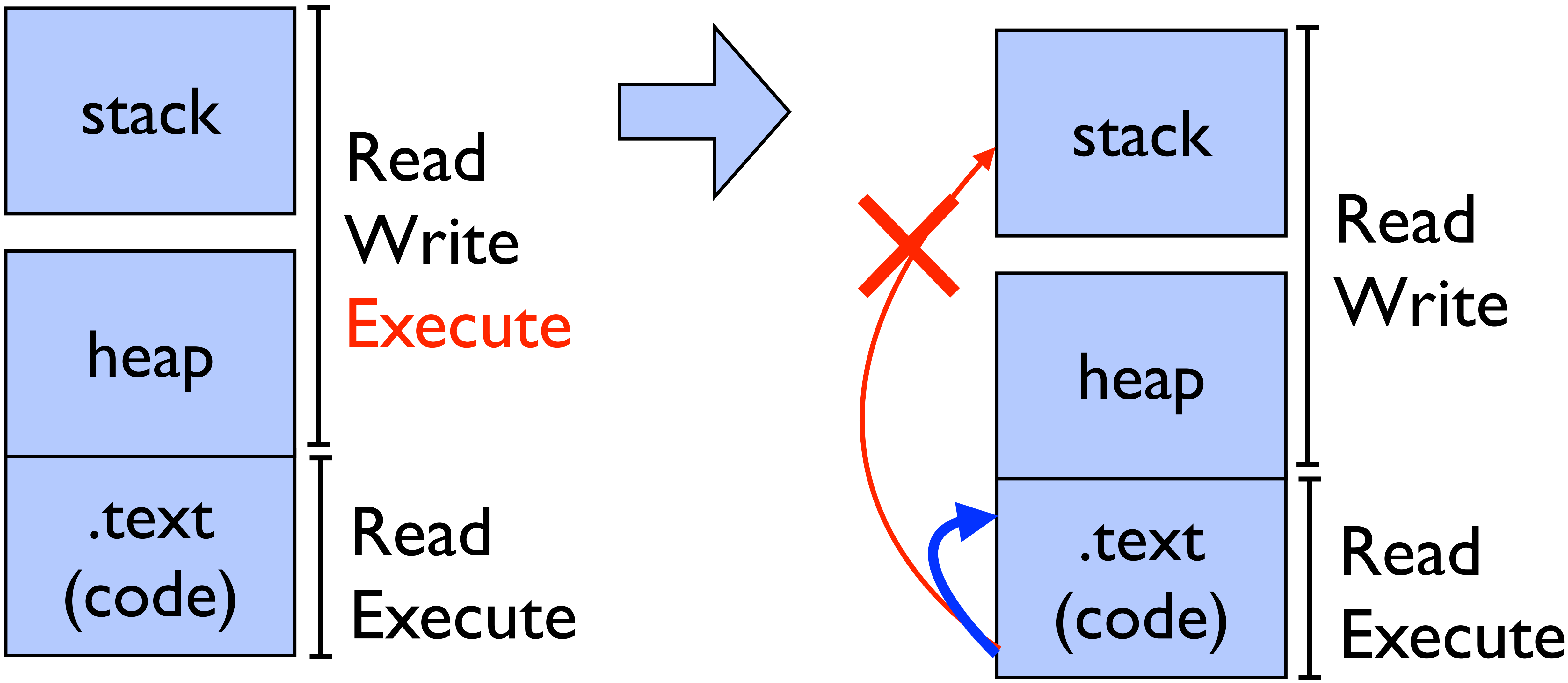
1. Make stack non-executable (NX)

2. Randomize memory addresses (ASLR)

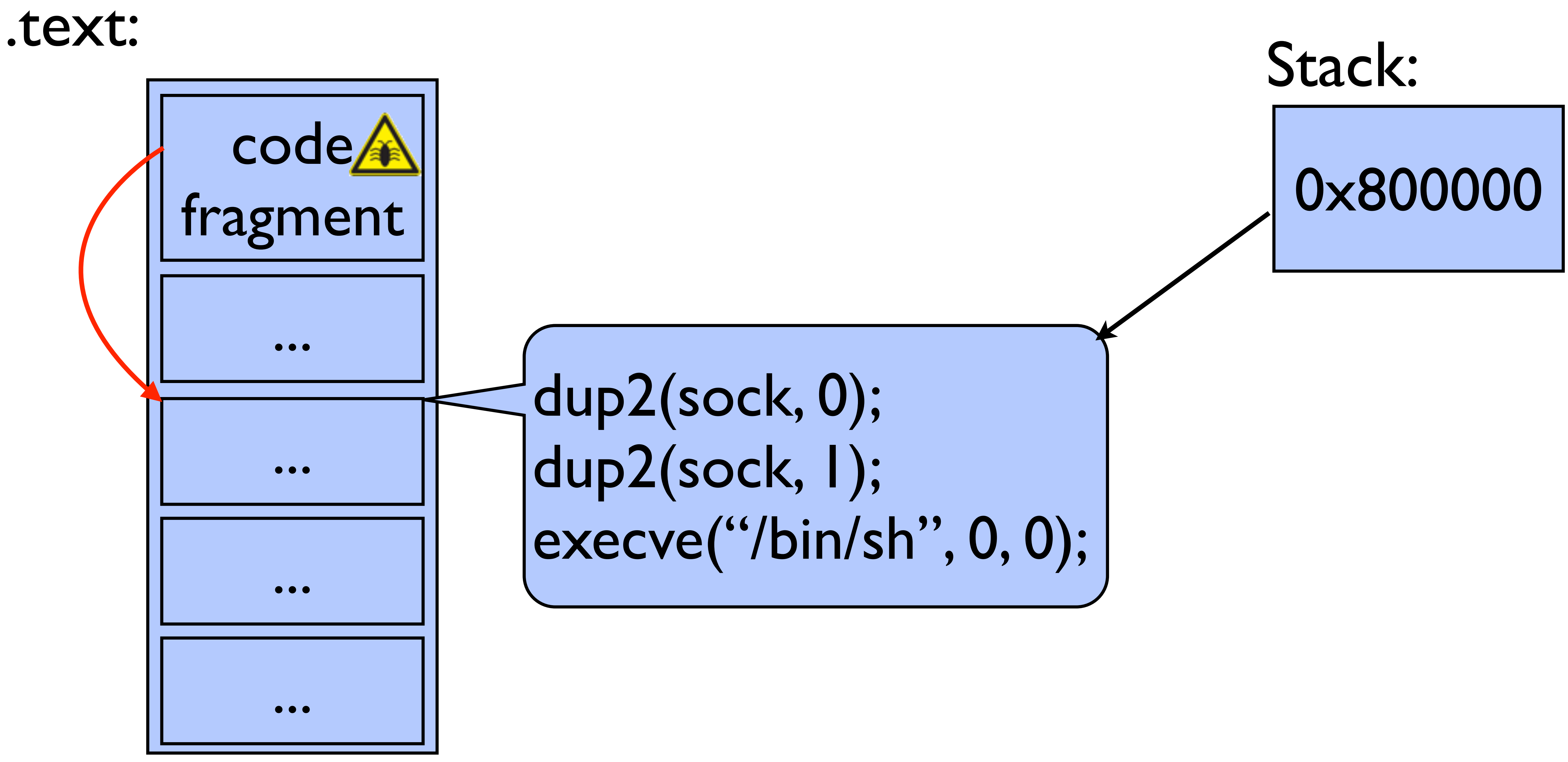
Non-eXecutable (NX) memory



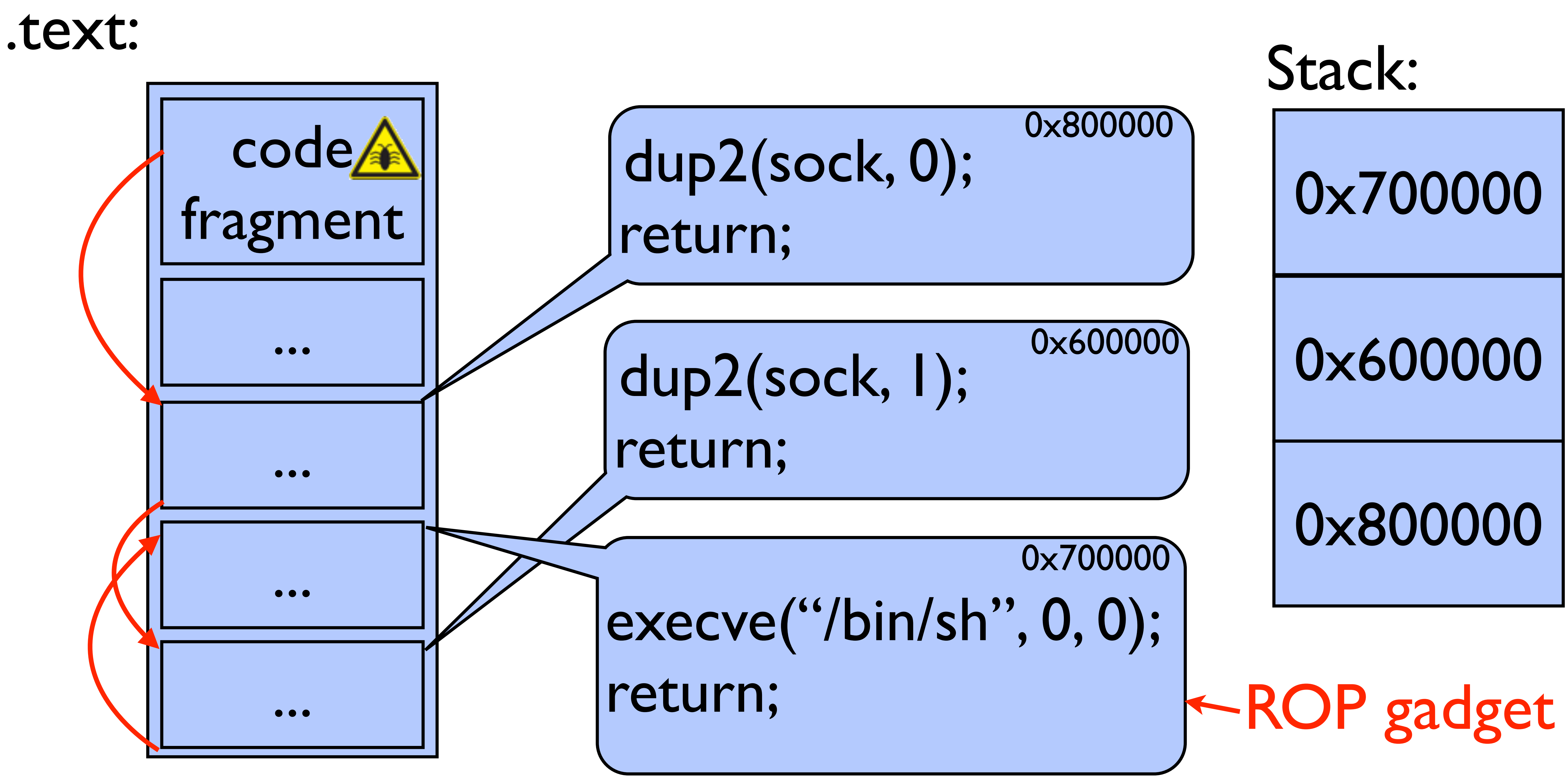
Non-eXecutable (NX) memory



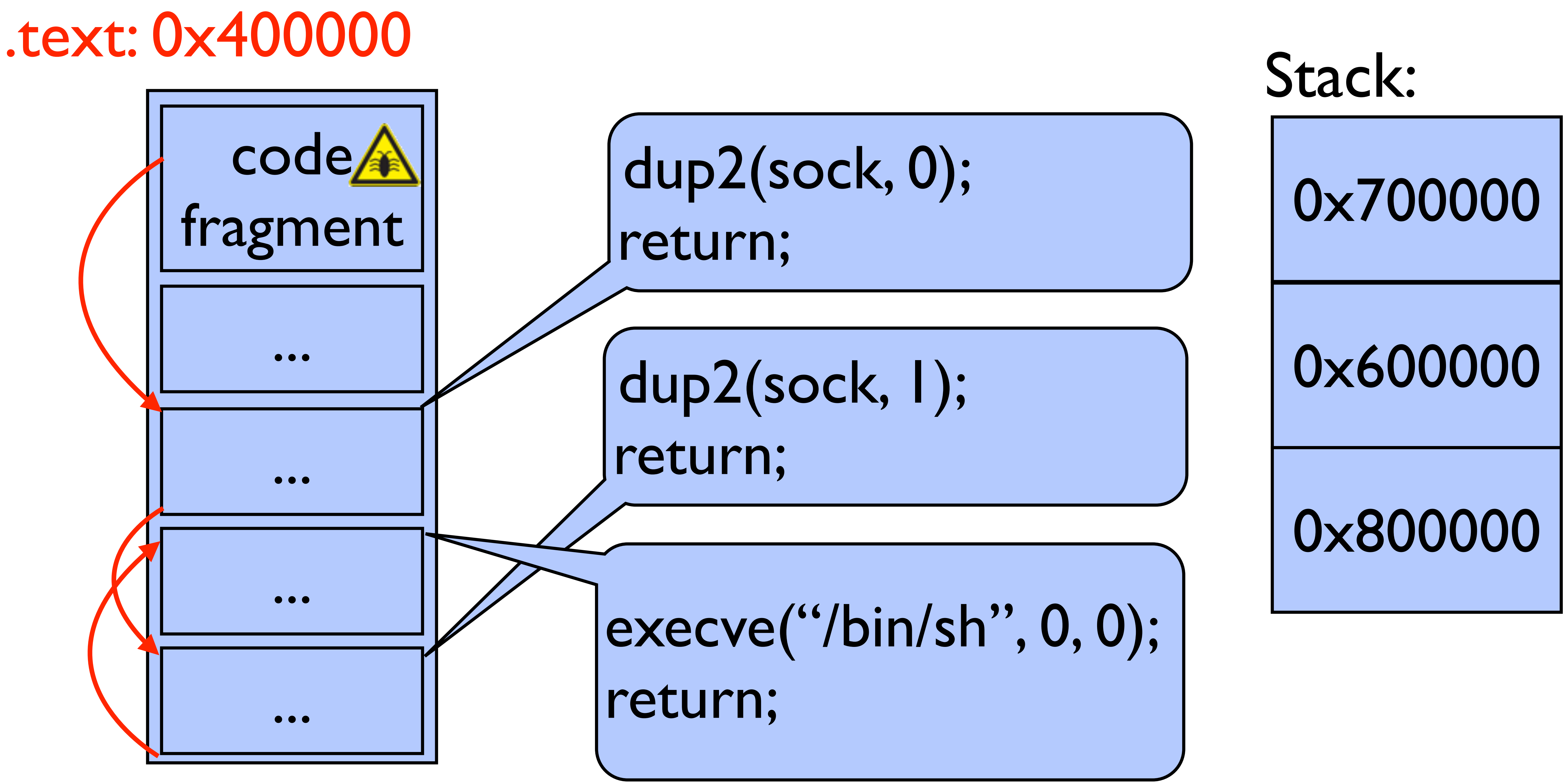
Return-Oriented Programming (ROP)



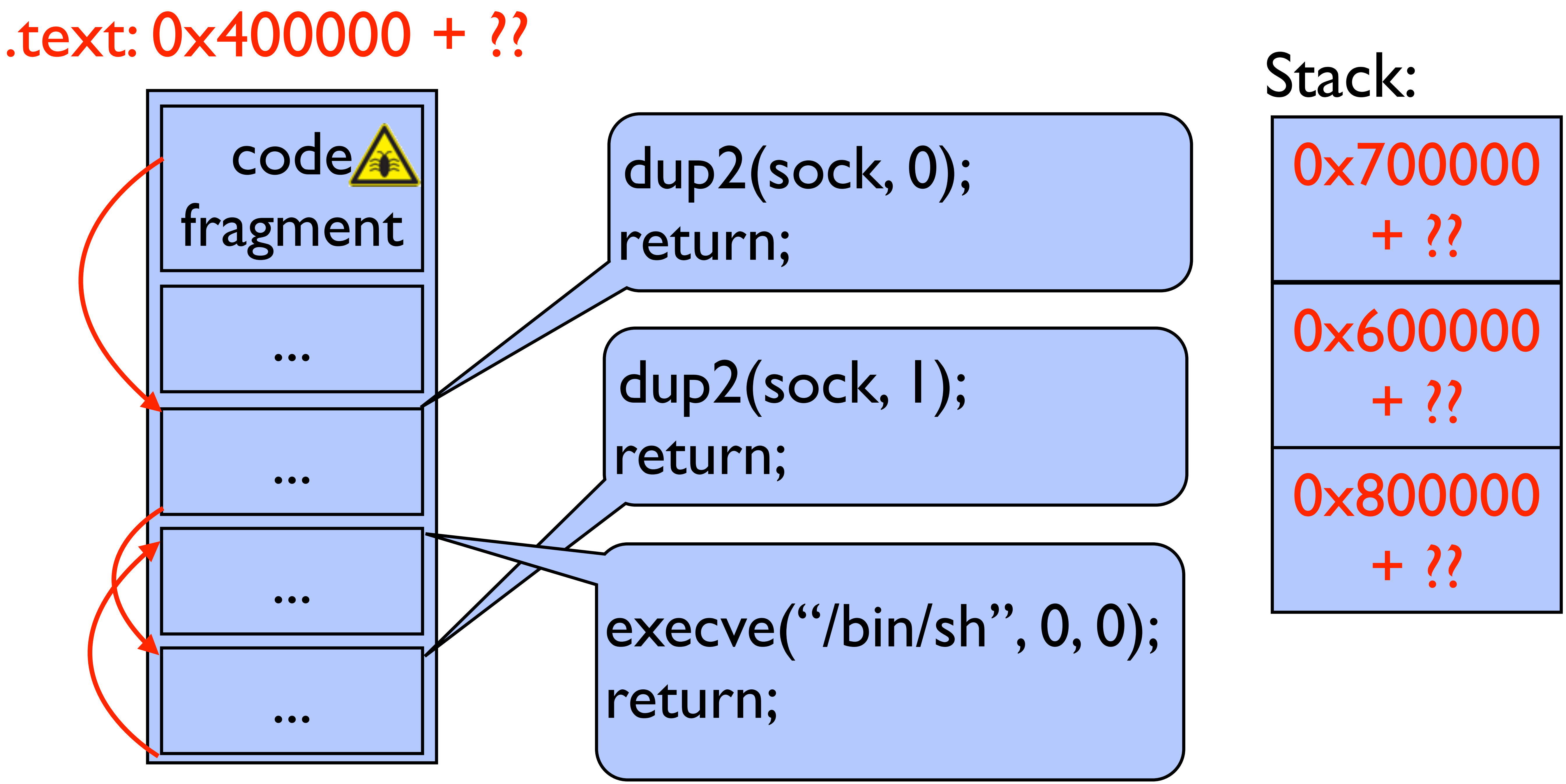
Return-Oriented Programming (ROP)



Address Space Layout Randomization (ASLR)



Address Space Layout Randomization (ASLR)



Exploit requirements today

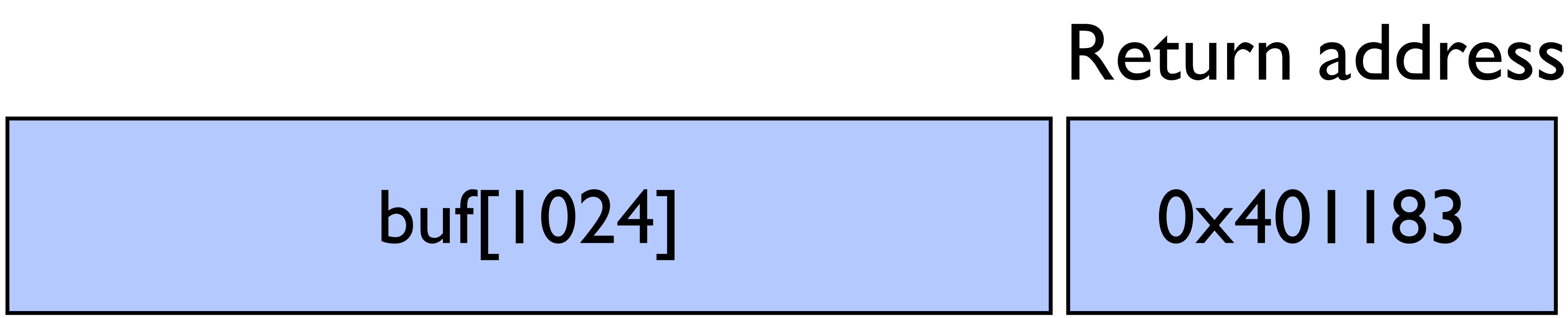
1. Break ASLR.
2. Copy of binary (find ROP gadgets / break NX).
   - Is it even possible to hack unknown applications?

Blind Return-Oriented Programming (BROP)

1. Break ASLR.
2. Leak binary:
   - Remotely find enough gadgets to call write().
   - write() binary from memory to network to disassemble and find more gadgets to finish off exploit.

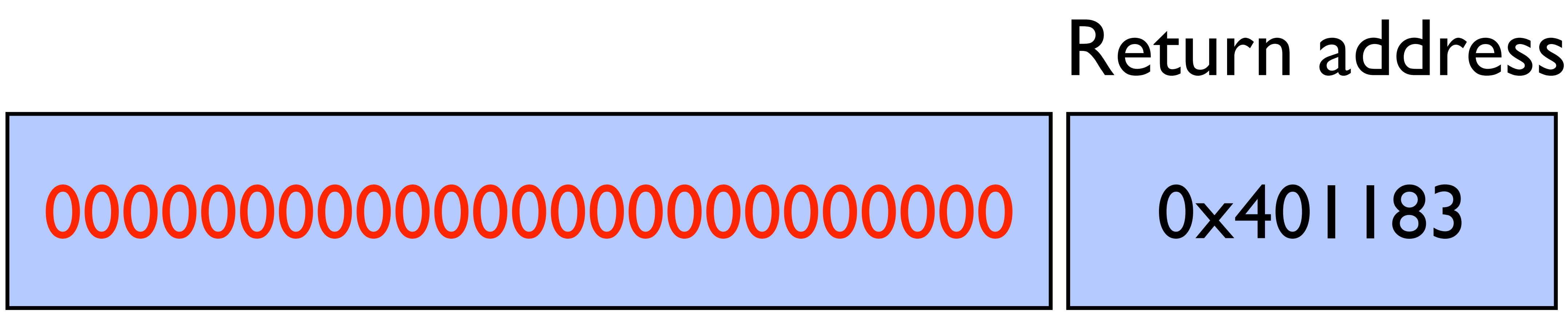
Defeating ASLR: stack reading

- Overwrite a single byte with value X:
  - No crash: stack had value X.
  - Crash: guess X was incorrect.
- Known technique for leaking canaries.



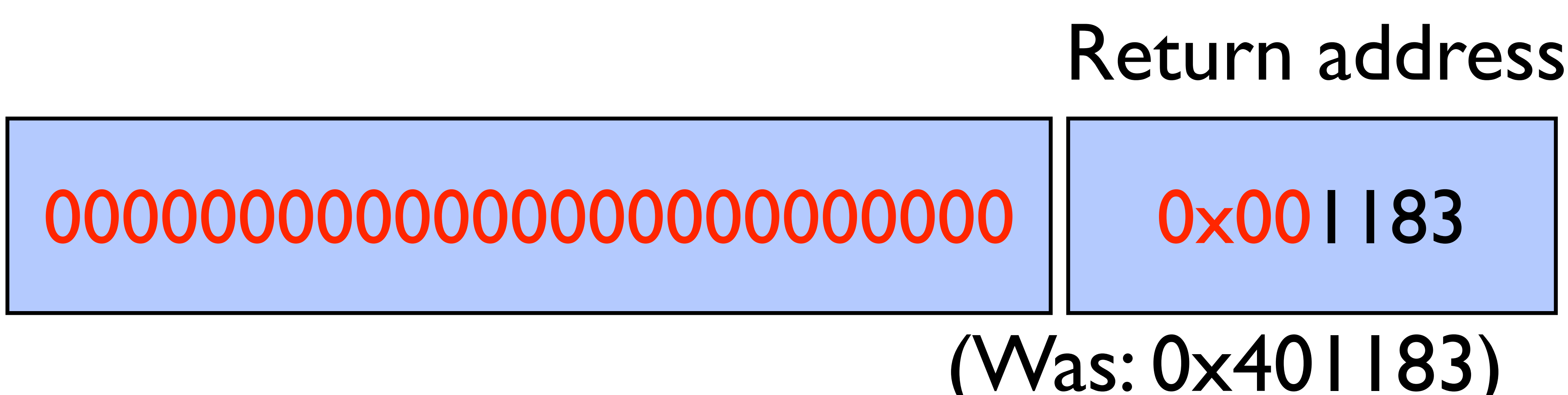
Defeating ASLR: stack reading

- Overwrite a single byte with value X:
  - No crash: stack had value X.
  - Crash: guess X was incorrect.
- Known technique for leaking canaries.



Defeating ASLR: stack reading

- Overwrite a single byte with value X:
  - No crash: stack had value X.
  - Crash: guess X was incorrect.
- Known technique for leaking canaries.



Defeating ASLR: stack reading

- Overwrite a single byte with value X:
  - No crash: stack had value X.
  - Crash: guess X was incorrect.
- Known technique for leaking canaries.

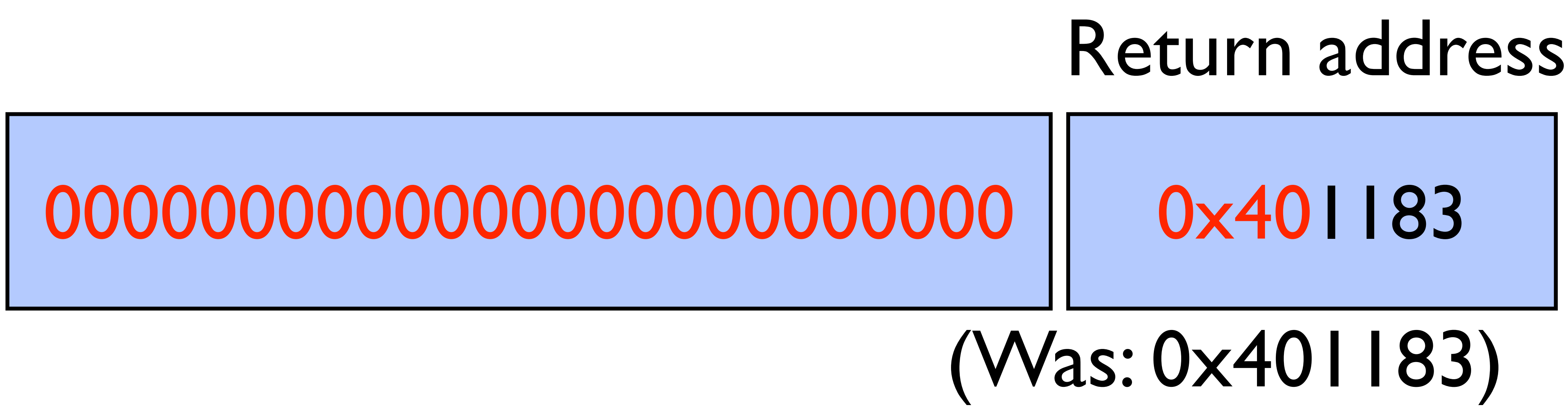
Return address

0000000000000000000000000000	0x011183

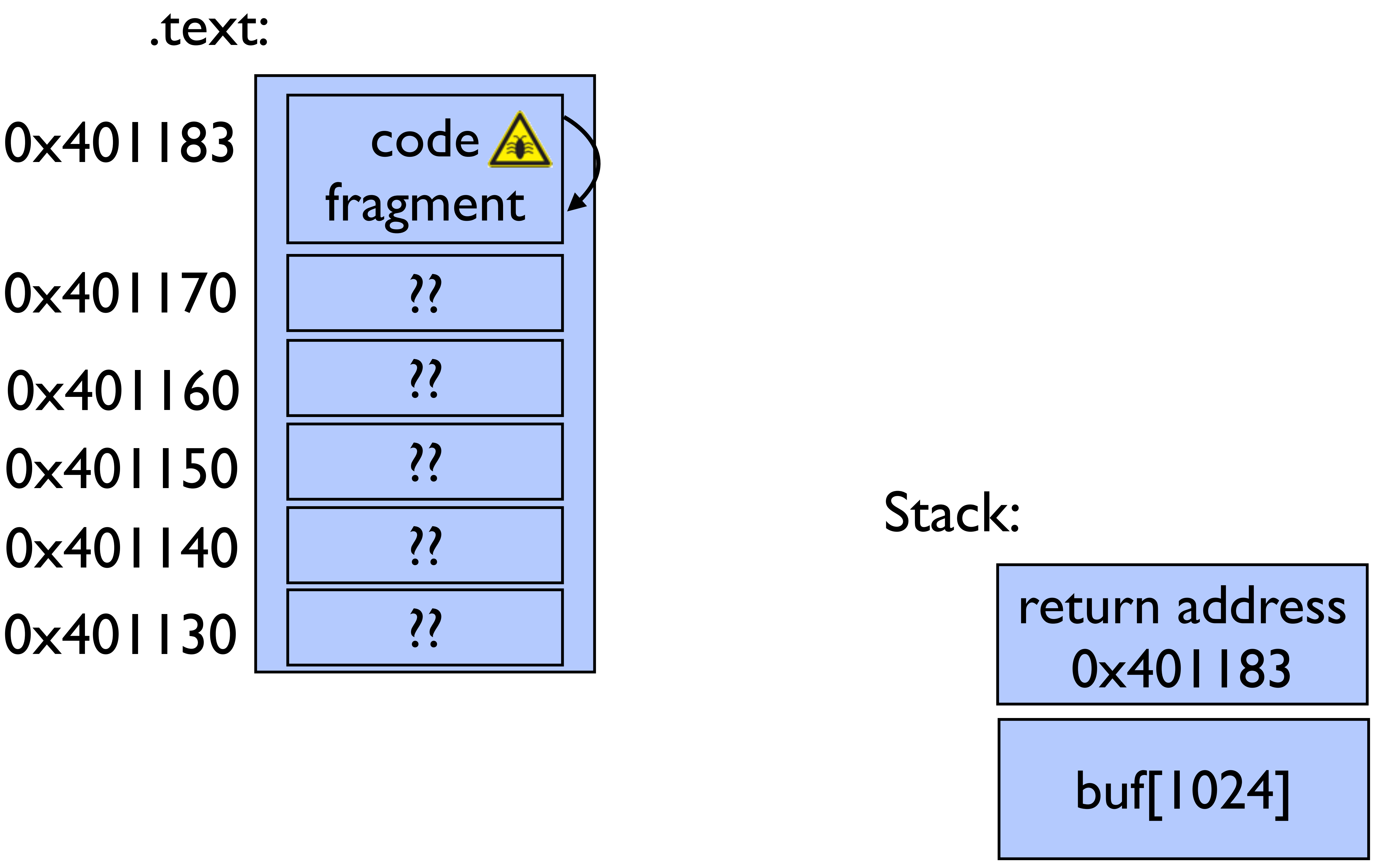
(Was: 0x401183)

Defeating ASLR: stack reading

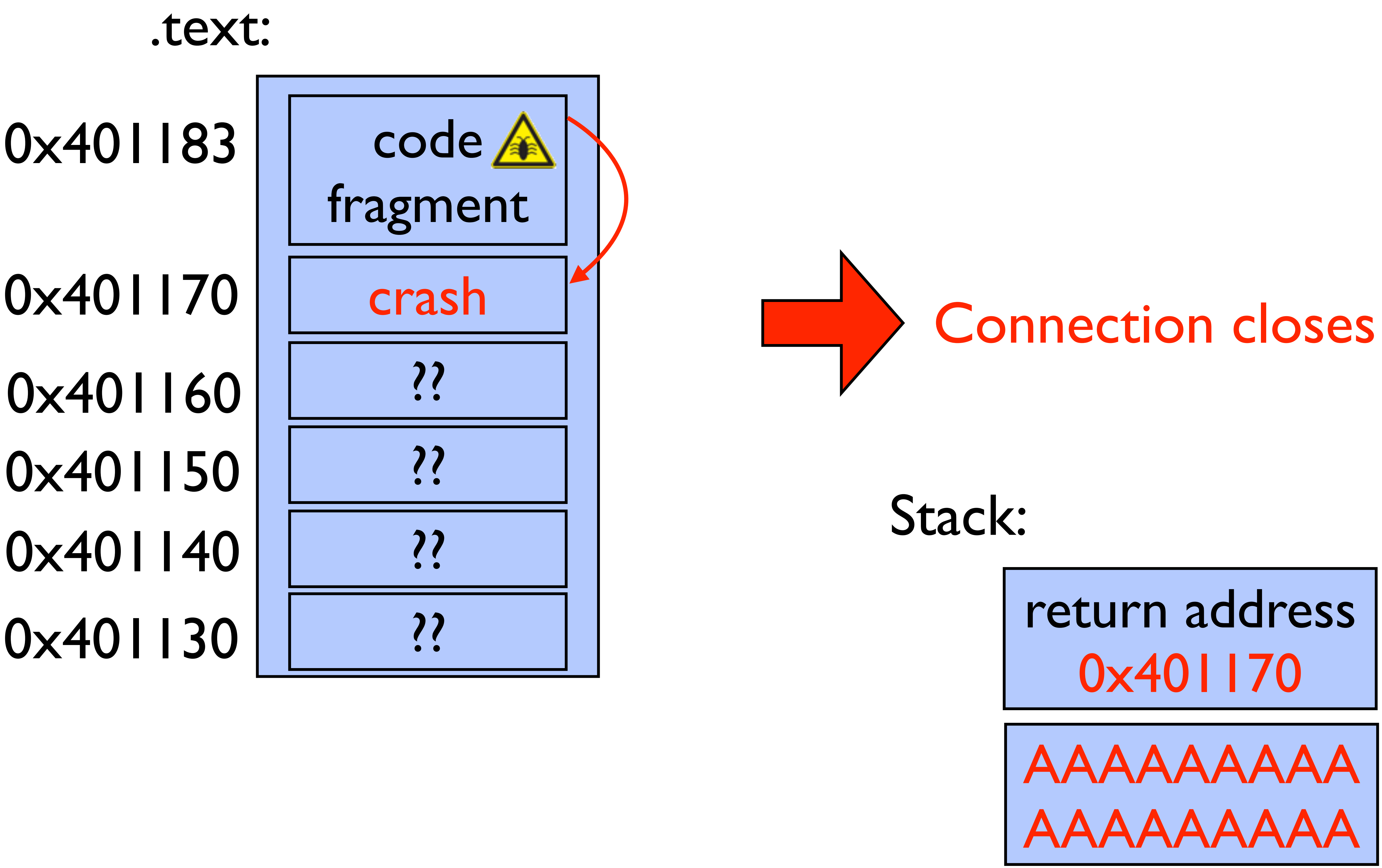
- Overwrite a single byte with value X:
  - No crash: stack had value X.
  - Crash: guess X was incorrect.
- Known technique for leaking canaries.



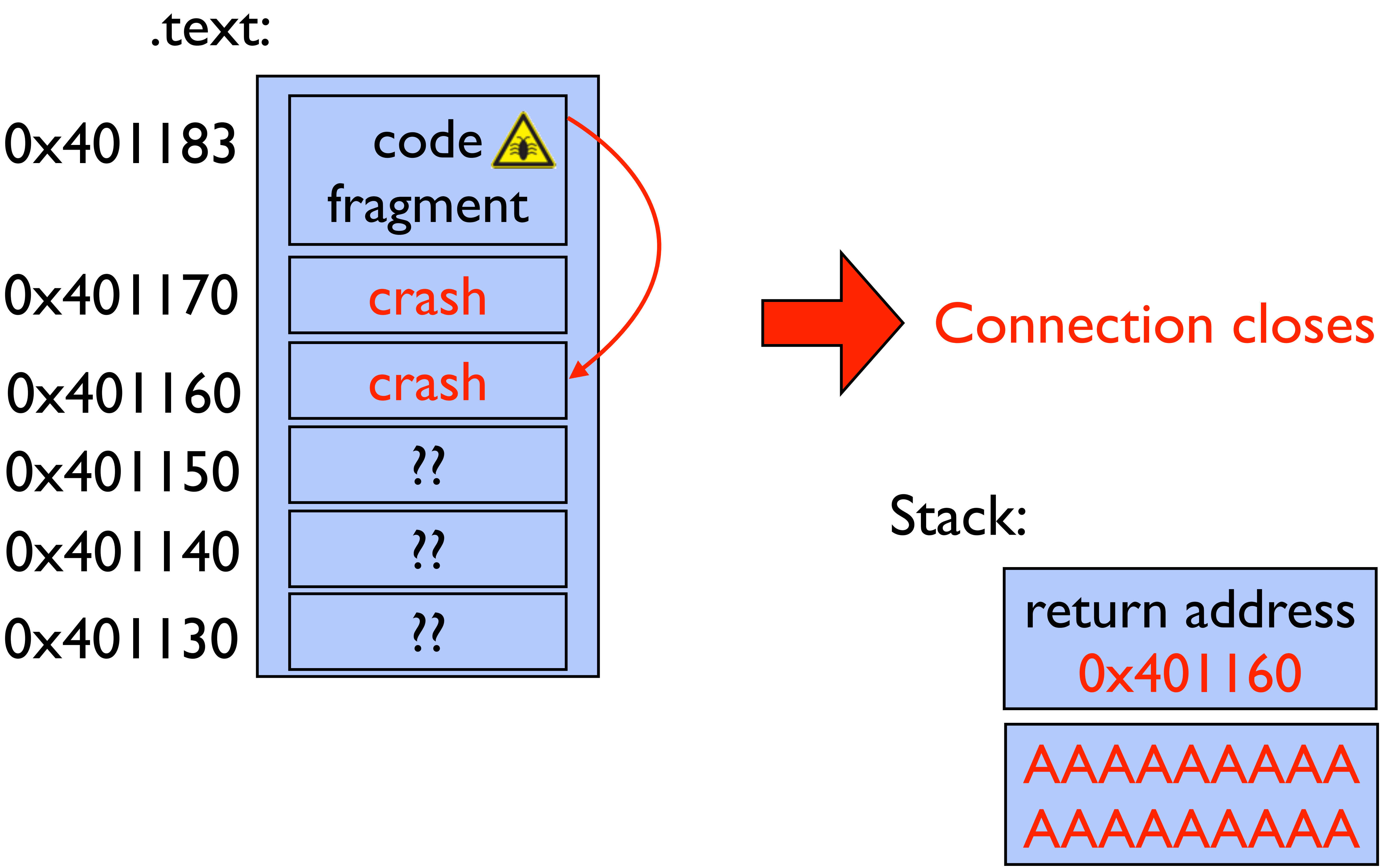
How to find gadgets?



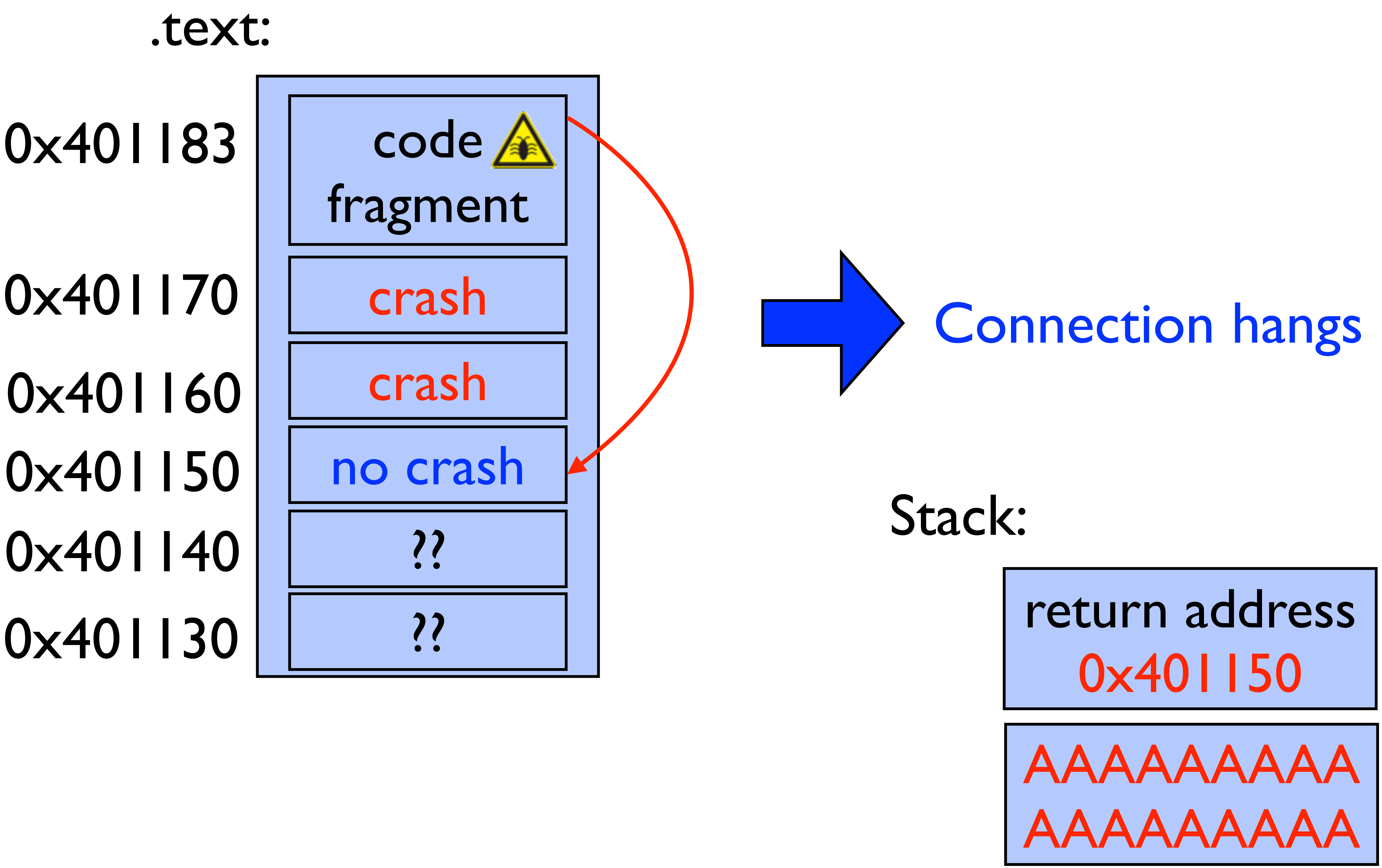
How to find gadgets?



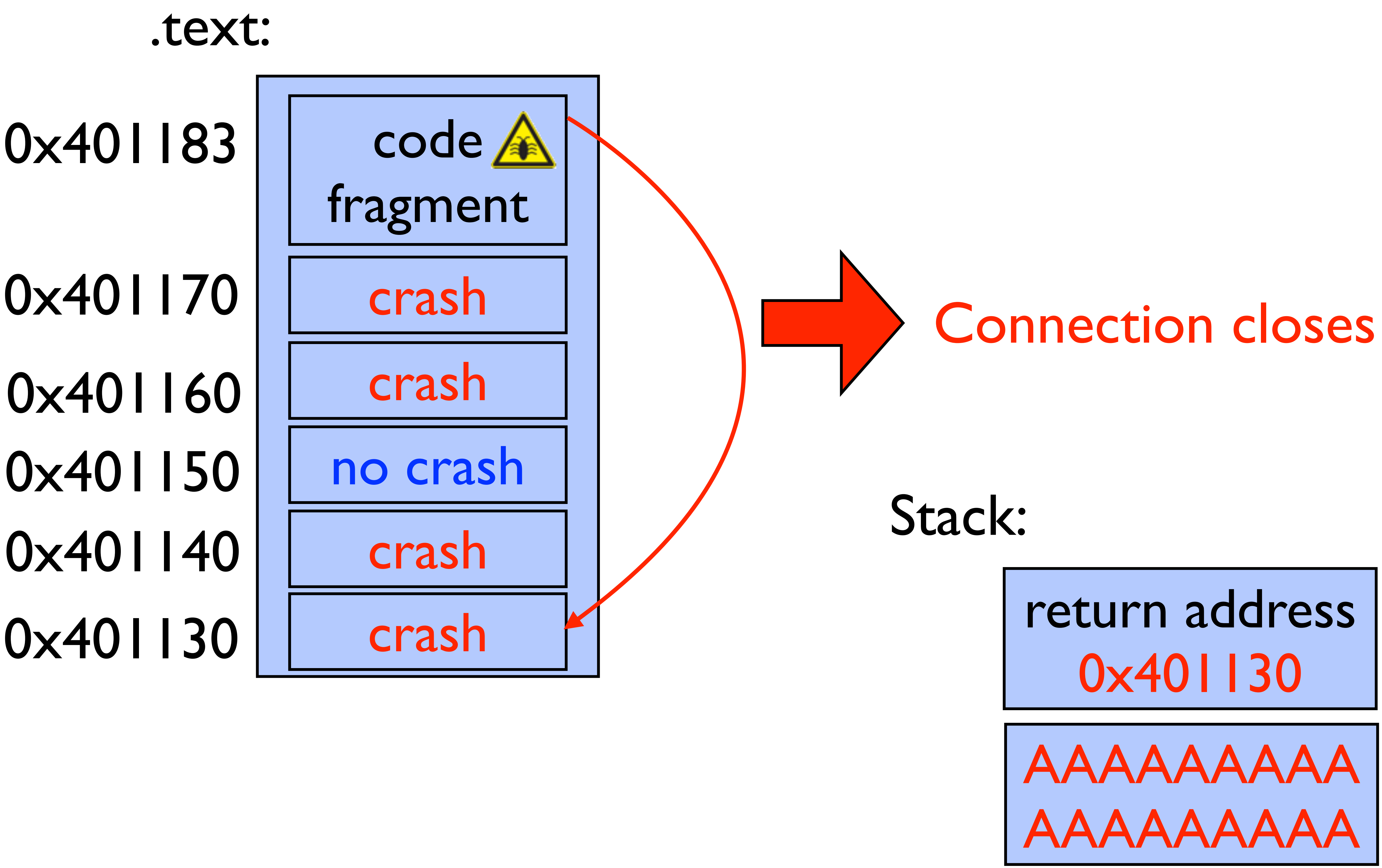
How to find gadgets?



How to find gadgets?



How to find gadgets?



Three types of gadgets

Stop gadget

```
sleep(10);
return;
```

- Never crashes

Crash gadget

```
abort();
return;
```

- Always crashes

Useful gadget

```
dup2(sock, 0);
return;
```

- Crash depends on return

Three types of gadgets

Stop gadget

```
sleep(10);
return;
```

- Never crashes

Crash gadget

```
abort();
return;
```

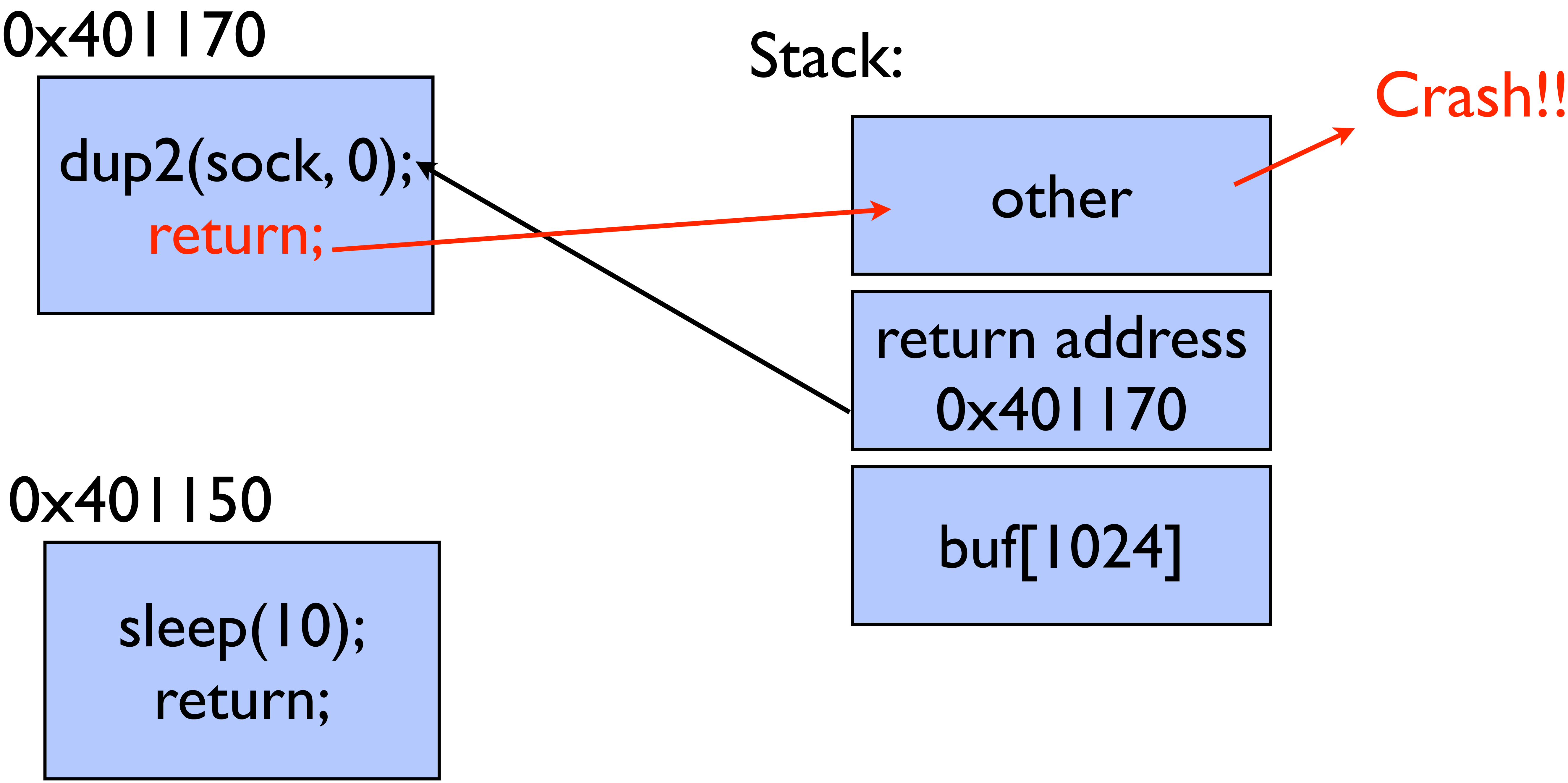
- Always crashes

Useful gadget

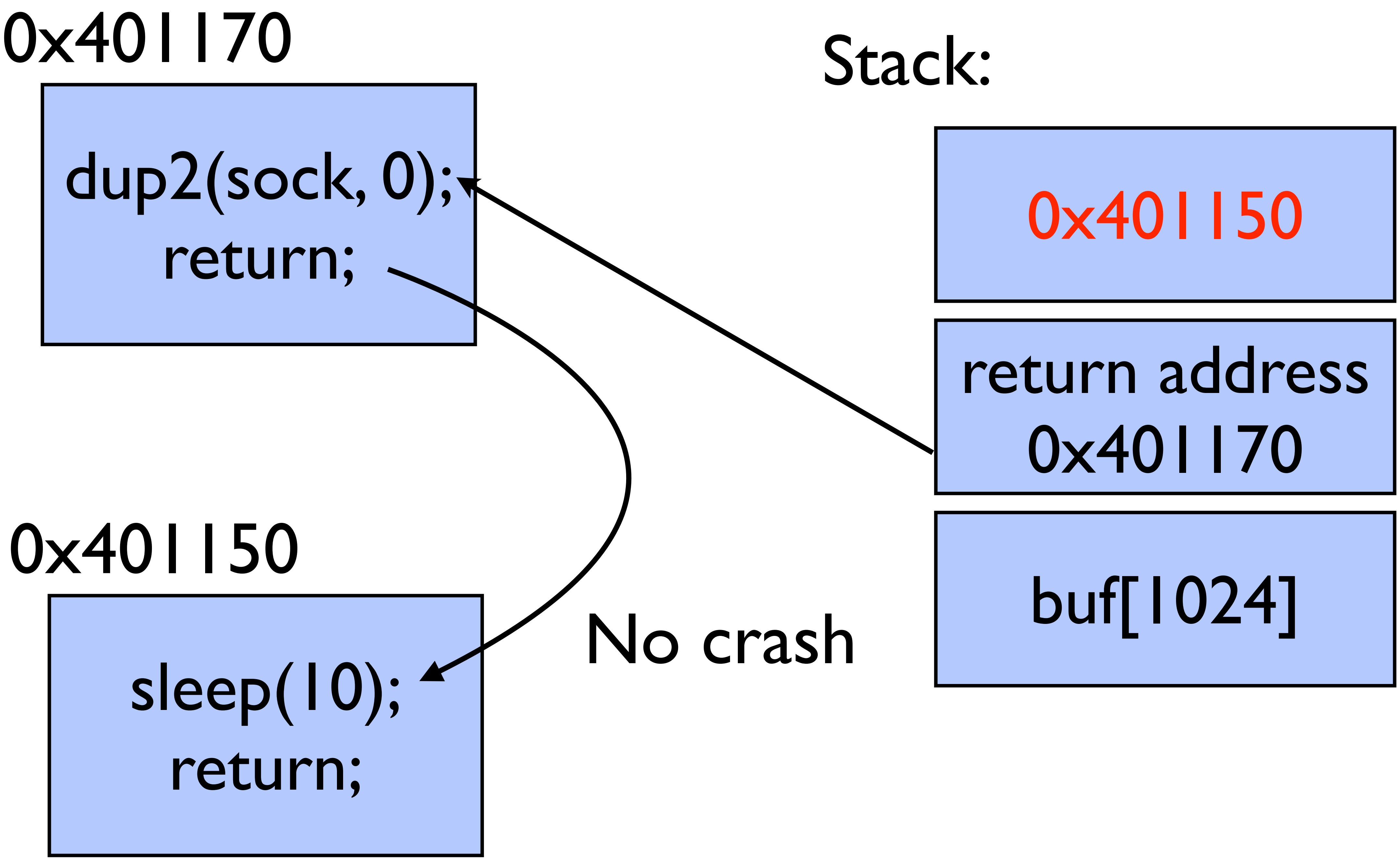
```
dup2(sock, 0);
return;
```

- Crash depends on return

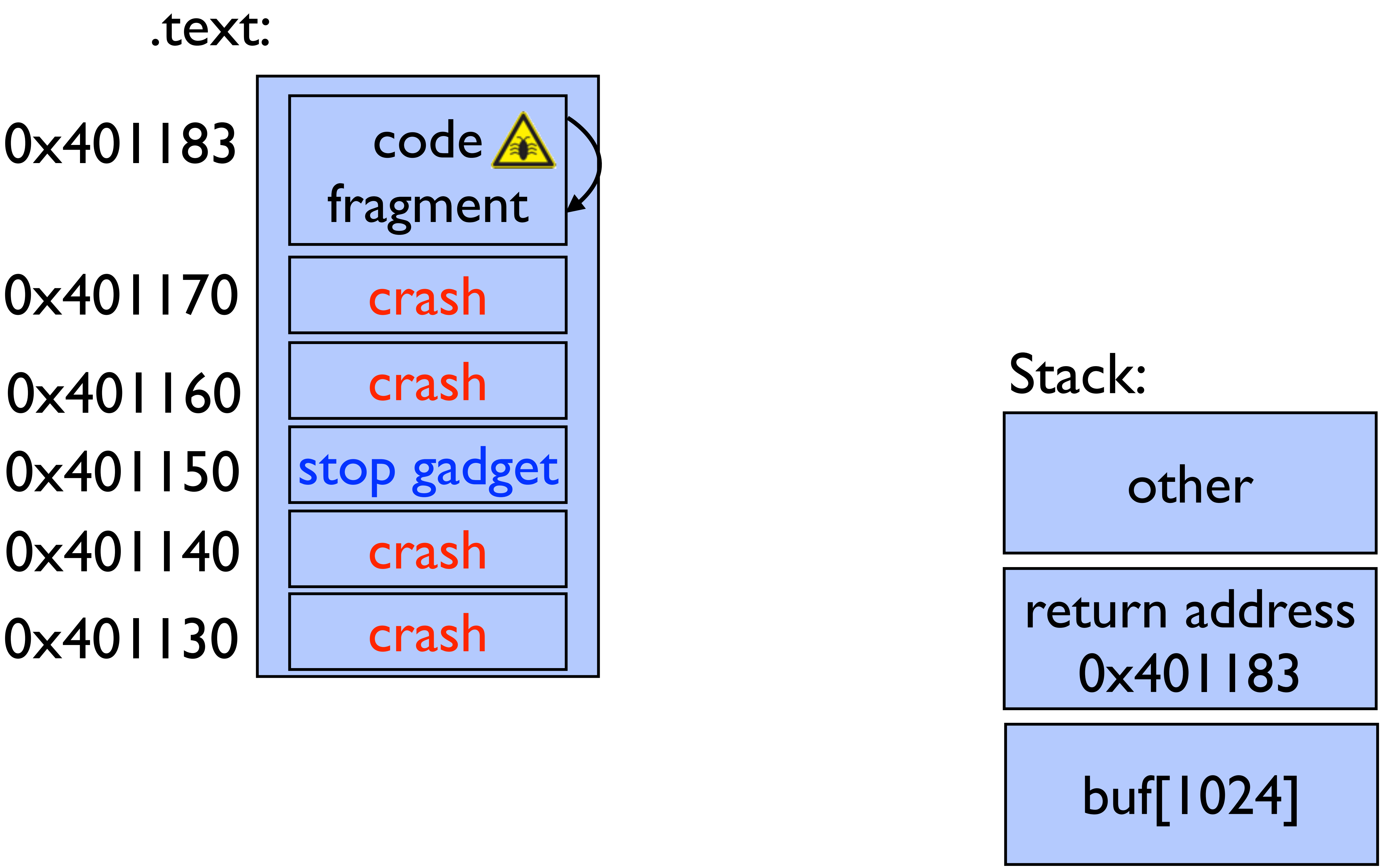
Finding useful gadgets



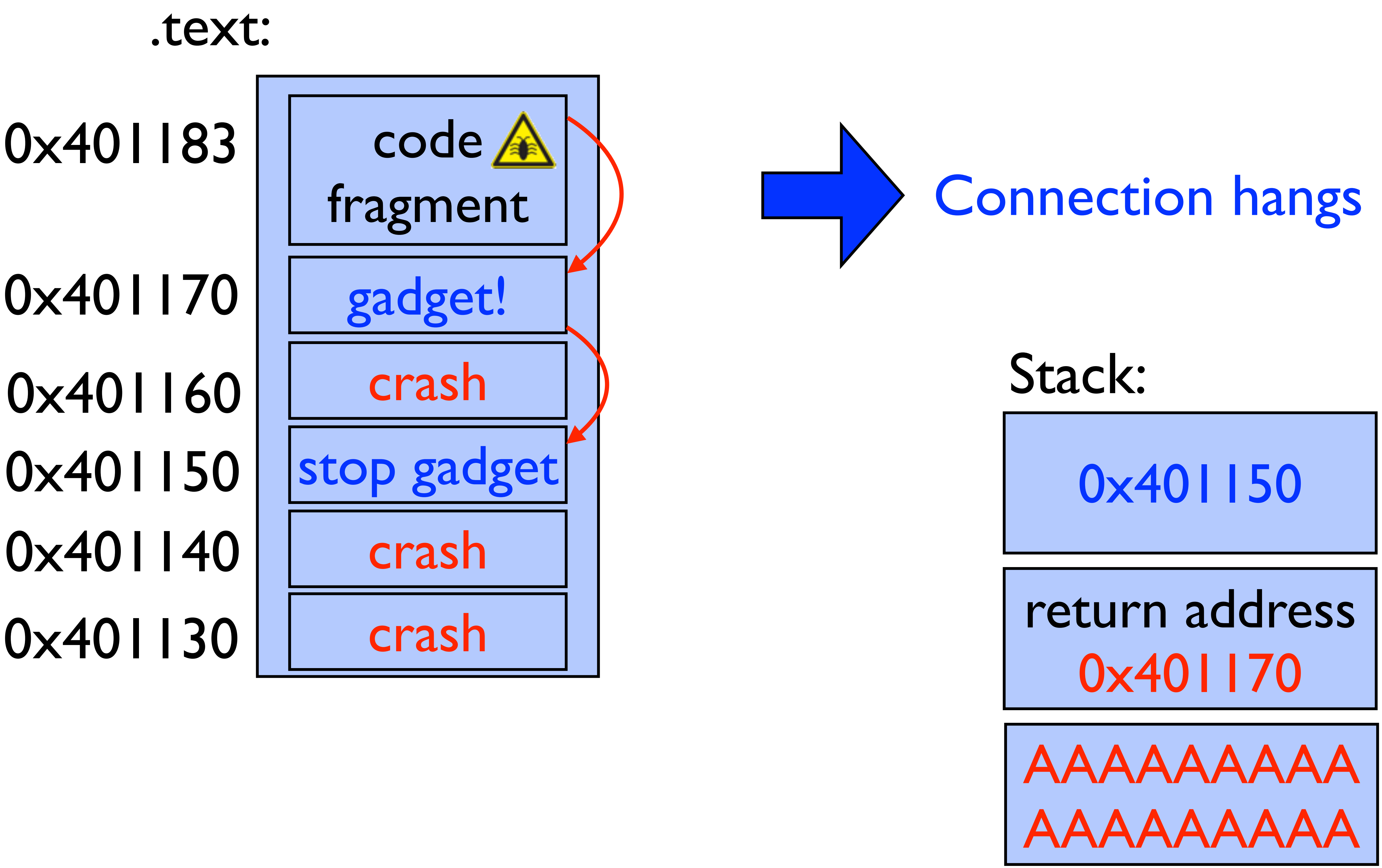
Finding useful gadgets



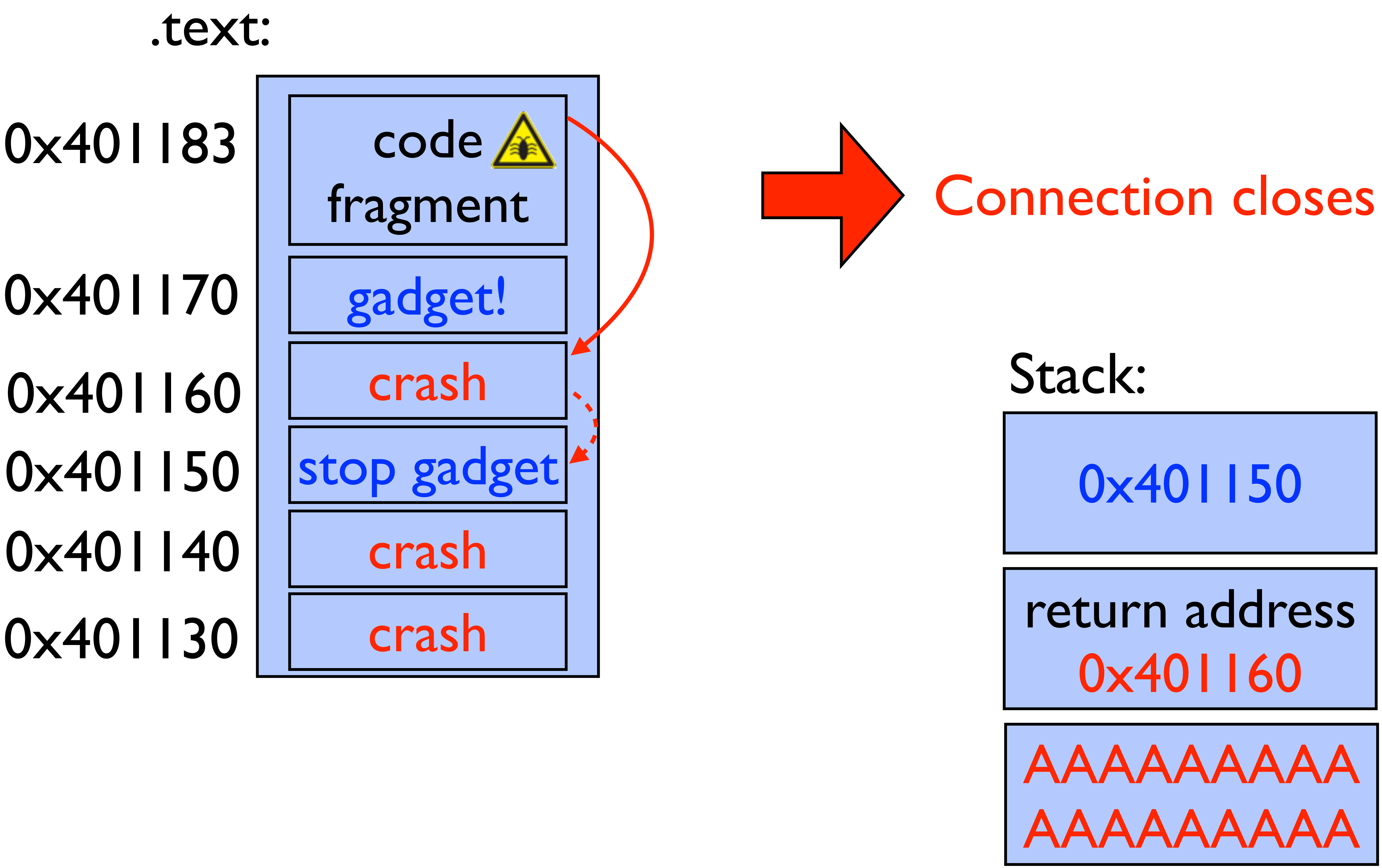
How to find gadgets?



How to find gadgets?



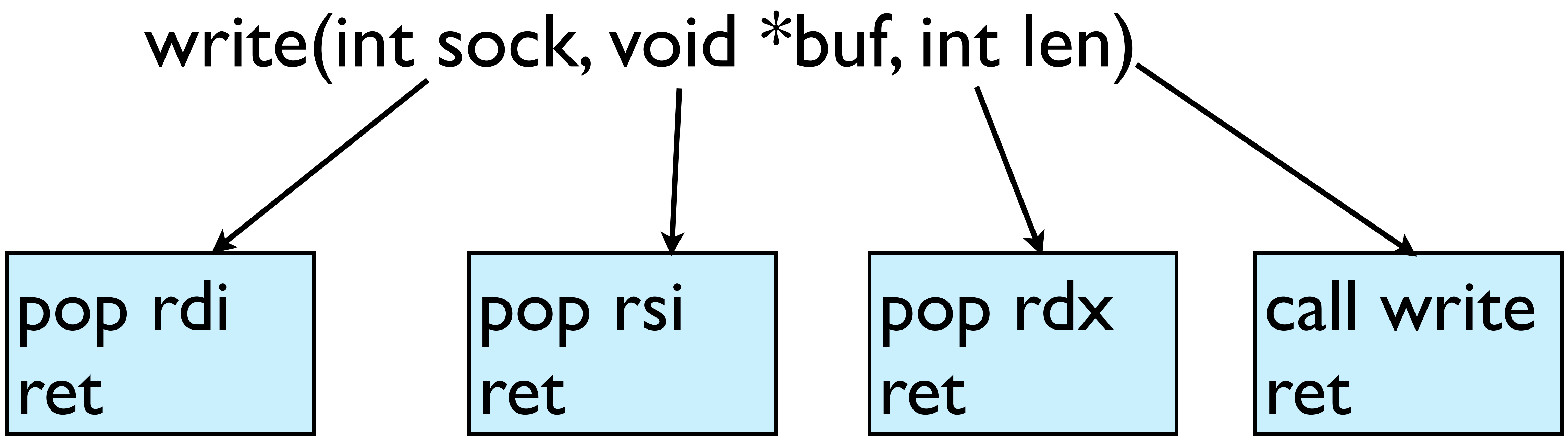
How to find gadgets?



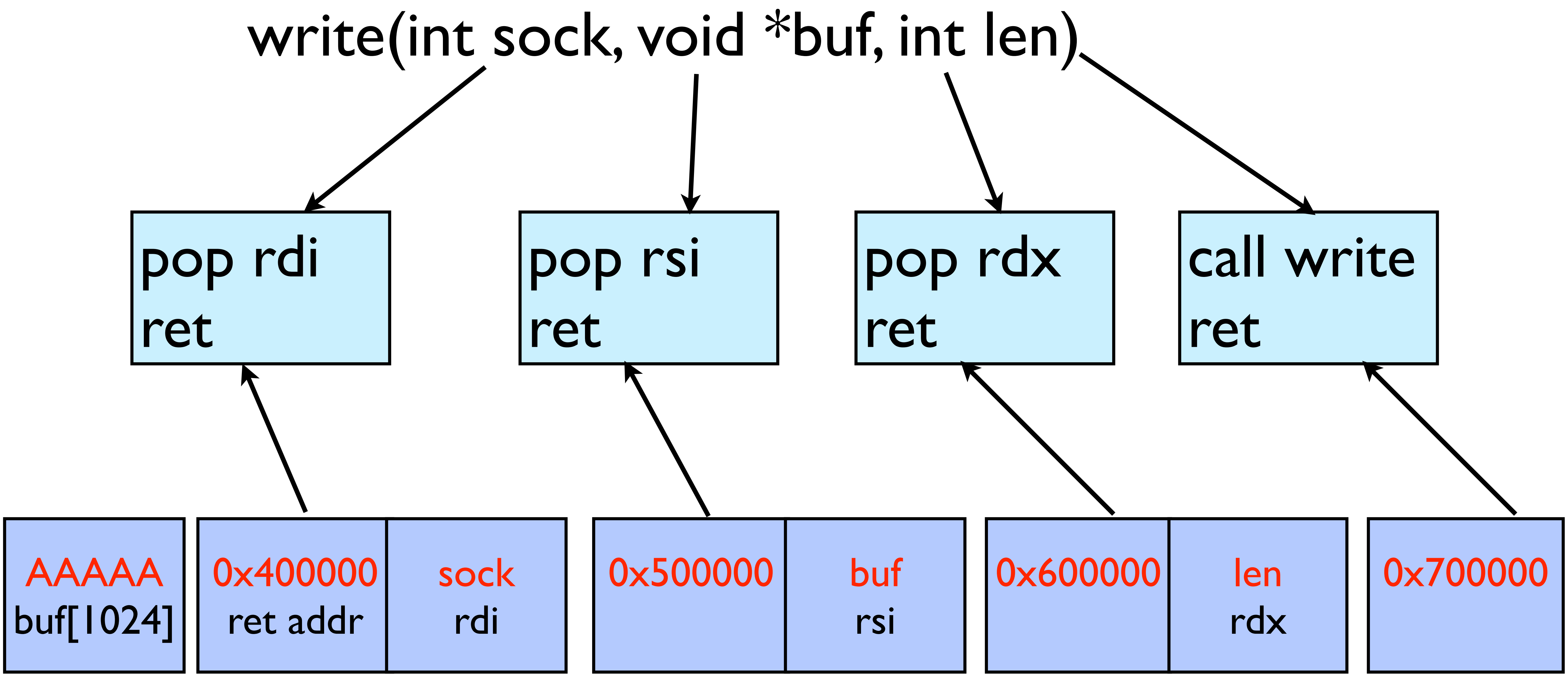
What are we looking for?

write(int sock, void *buf, int len)

What are we looking for?



What are we looking for?



Pieces of the puzzle

stop gadget
[call sleep]

pop rsi
ret

pop rdi
ret

pop rdx
ret

call write
ret

Pieces of the puzzle

stop gadget
[call sleep]

pop rsi
ret

pop rdi
ret

call strcmp
ret

call write
ret

Pieces of the puzzle

stop gadget
[call sleep]

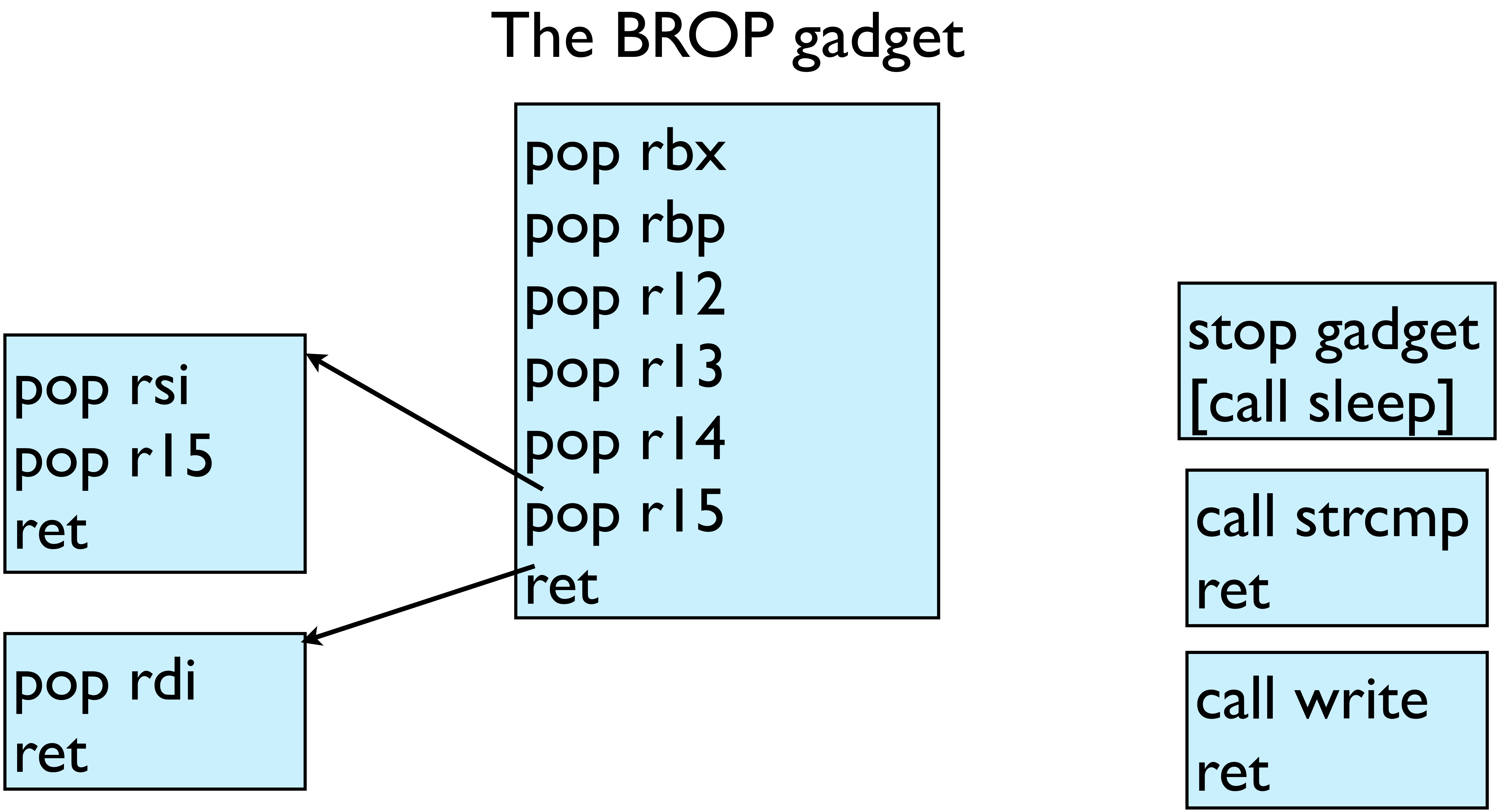
pop rsi
ret

call strcmp
ret

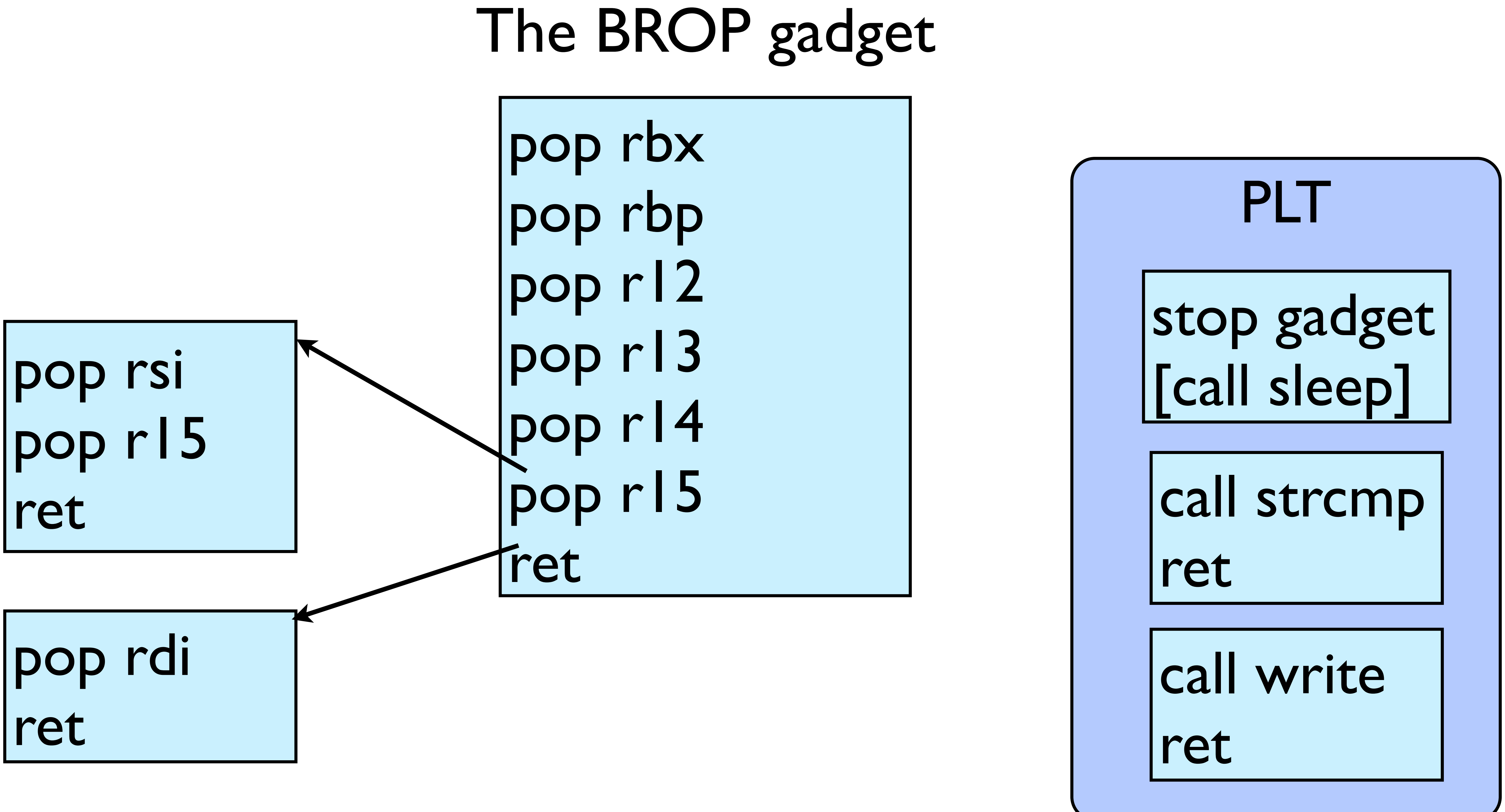
pop rdi
ret

call write
ret

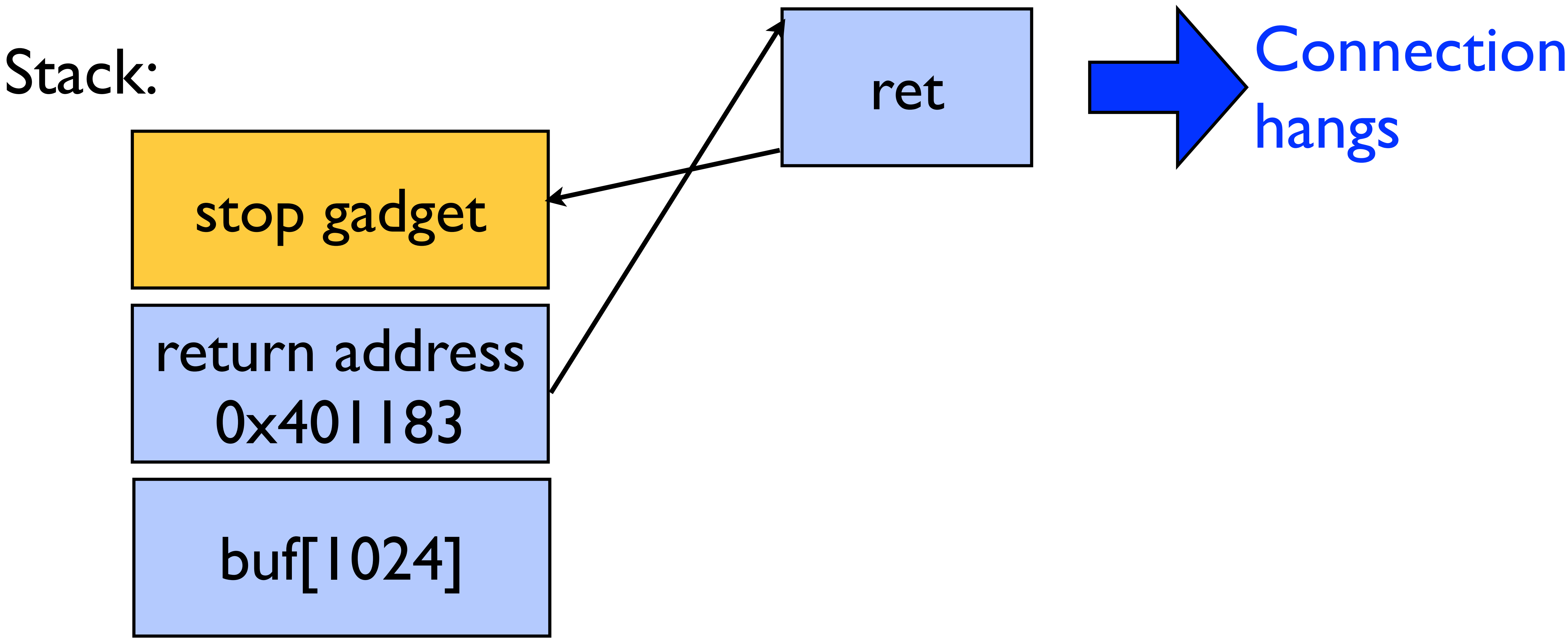
Pieces of the puzzle



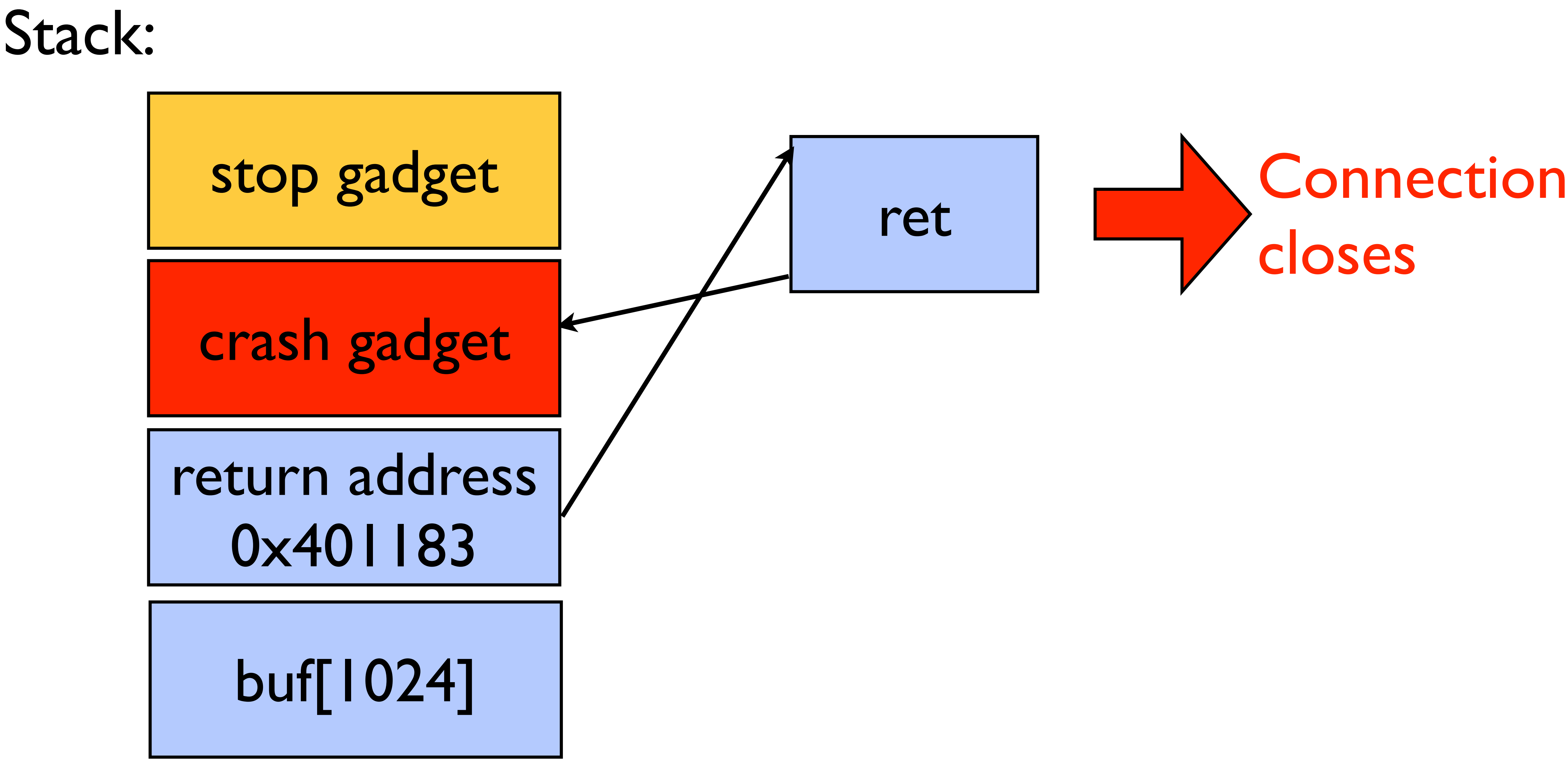
Pieces of the puzzle



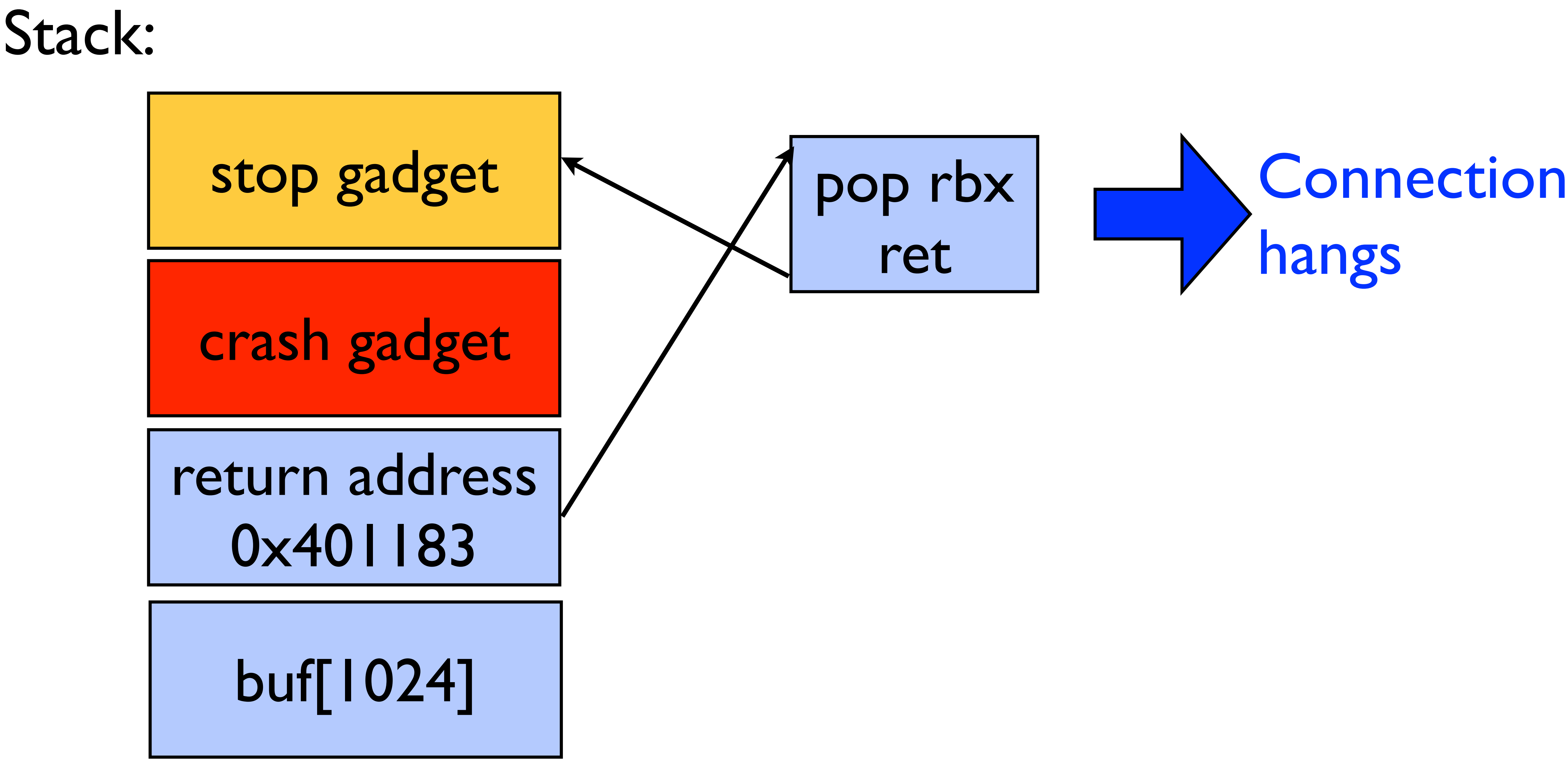
Finding the BROP gadget



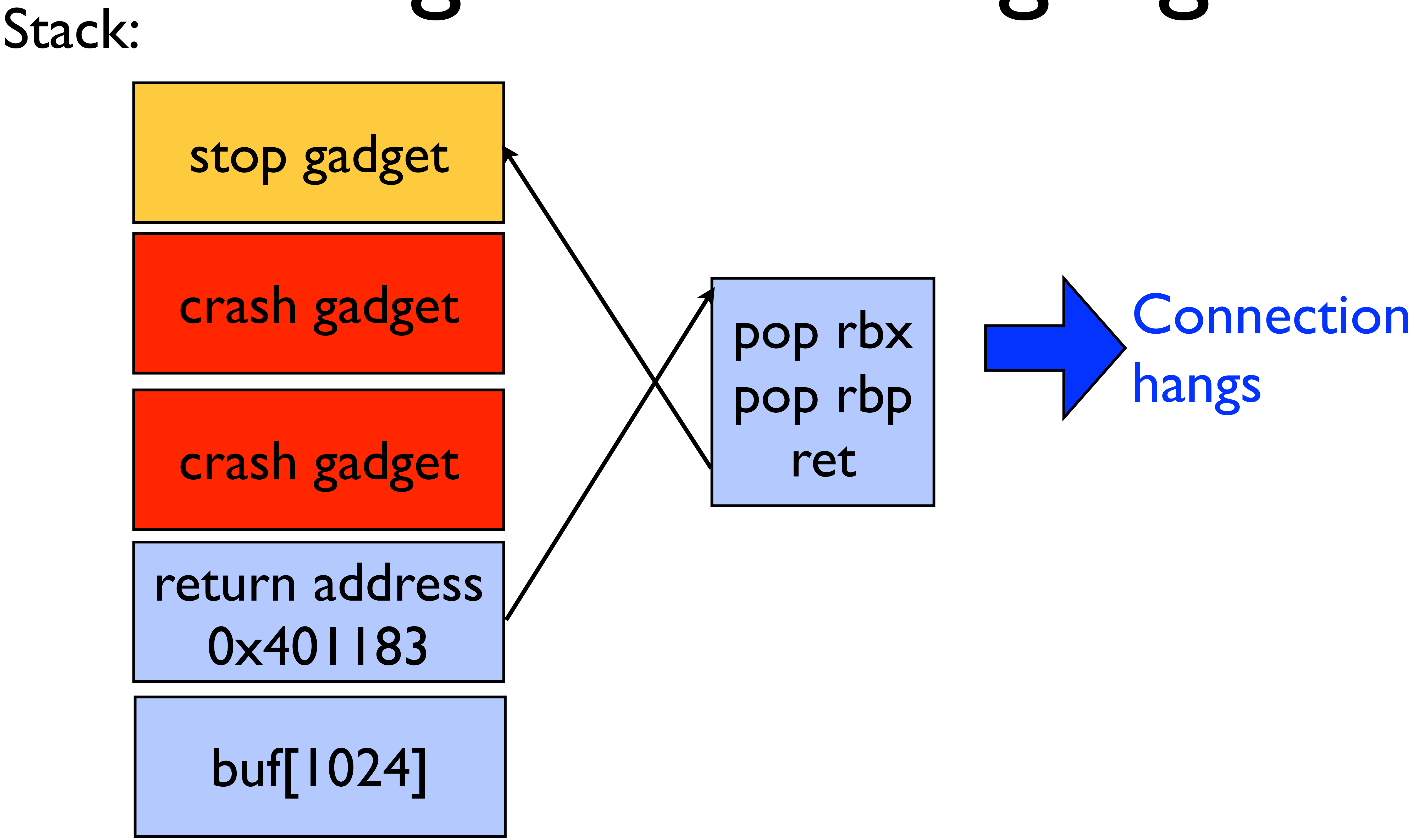
Finding the BROP gadget



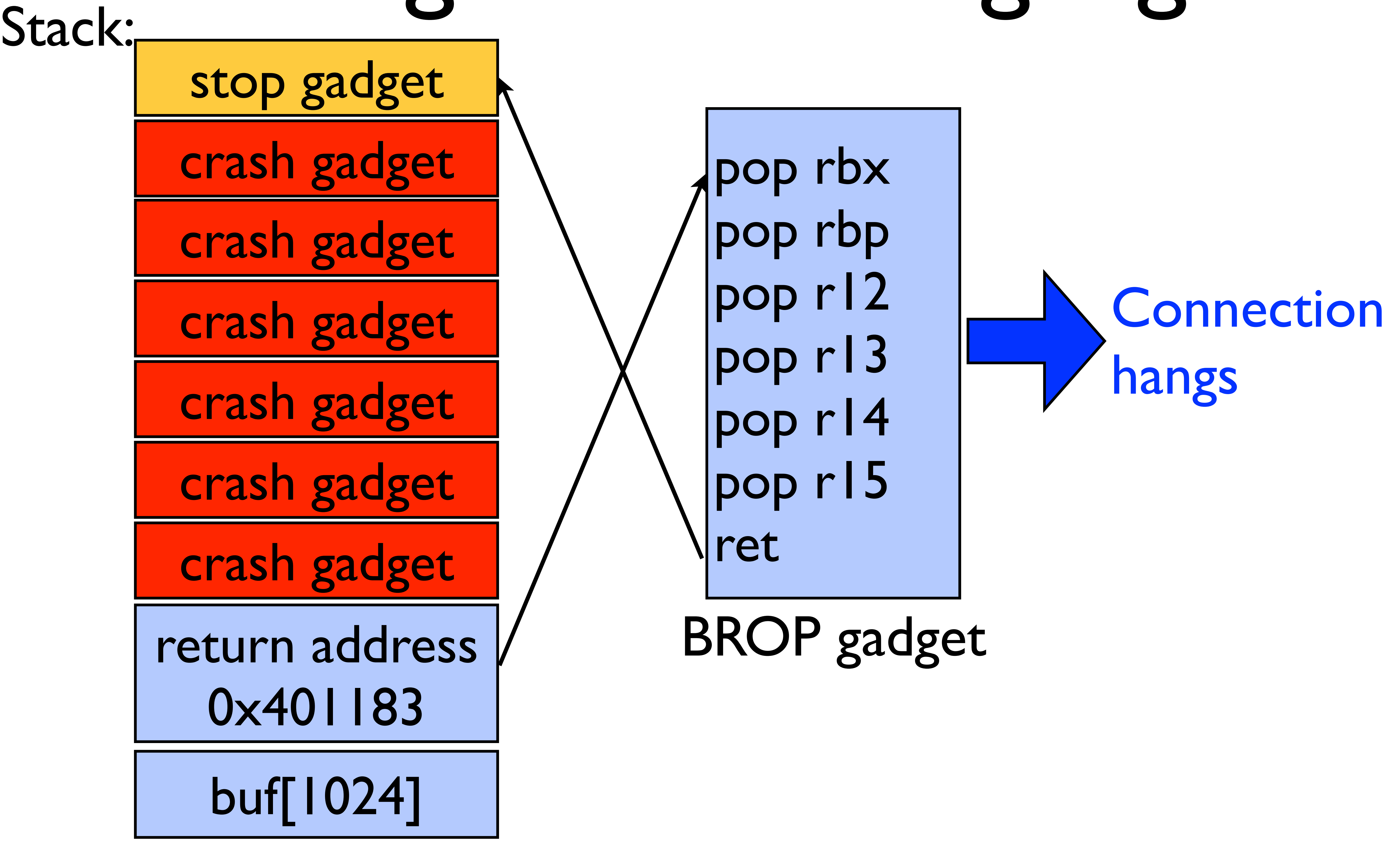
Finding the BROP gadget



Finding the BROP gadget



Finding the BROP gadget

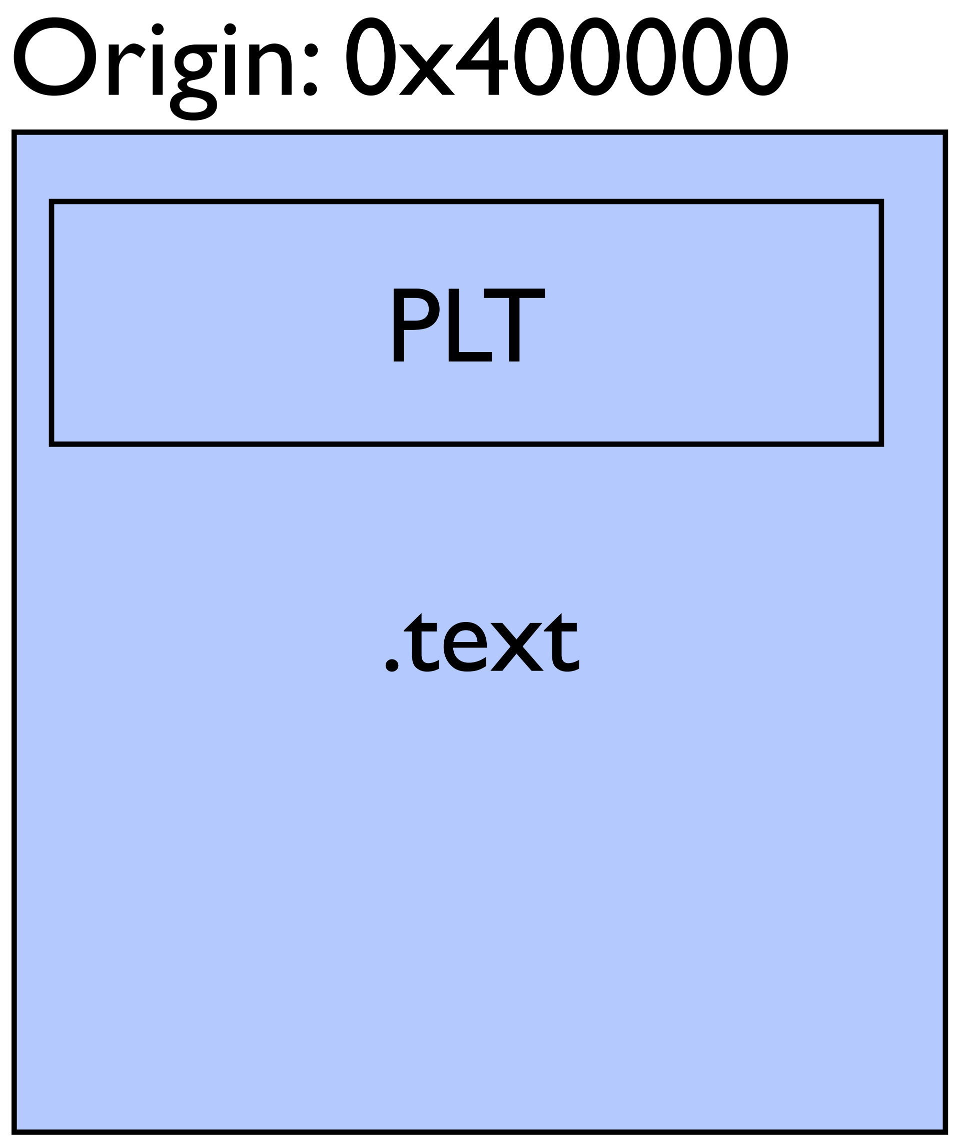


Attack so far

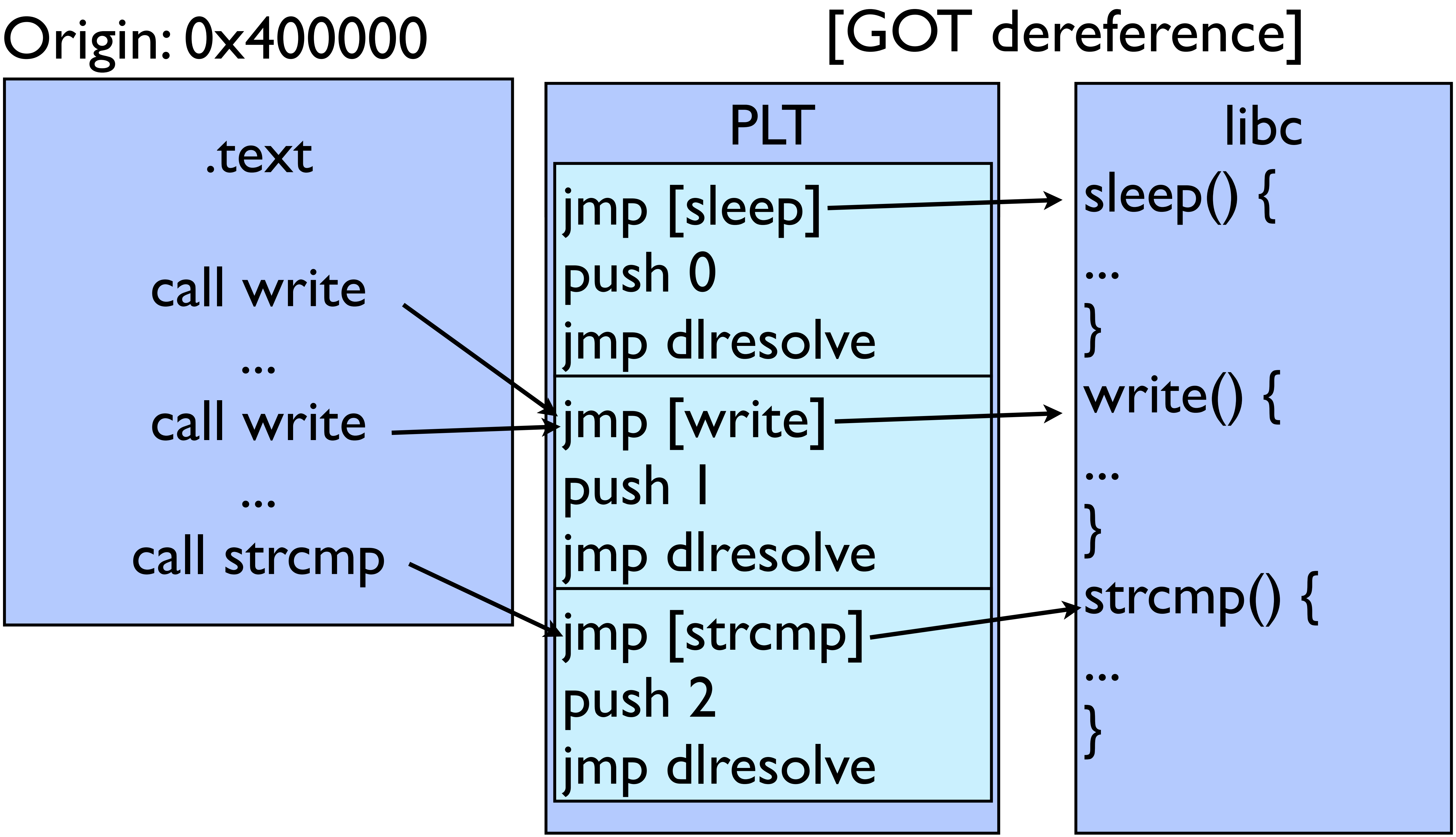
- Can control first two arguments to calls (using BROP gadget).
- Need to control third argument (using call strcmp).
- Need to find call write

Procedure Linking Table (PLT)

Procedure Linking Table (PLT)



Procedure Linking Table (PLT)



Finding the PLT

- Toward beginning of .text
- Each entry is 0x10 bytes apart, 0x10 aligned
- Most don’t crash: syscalls - return EFAULT on bad args.
- Can check if entry + 6 succeeds too (dlresolve slow path)

Fingerprinting strcmp

arg1	arg2	result
readable	0x0	crash
0x0	readable	crash
readable	readable	nocrash

- Use return address (.text) as readable

Can now control three arguments:
strcmp sets RDX to length of string

Finding write

- strcmp(origin, origin) // sets RDX / write length to 7 - ELF header.
- set rdi to socket number, rsi to origin/addr
- try calling candidate PLT function.
- check if data received on socket.
- chain writes with different FD numbers to find socket. Use multiple connections.

Launching a shell

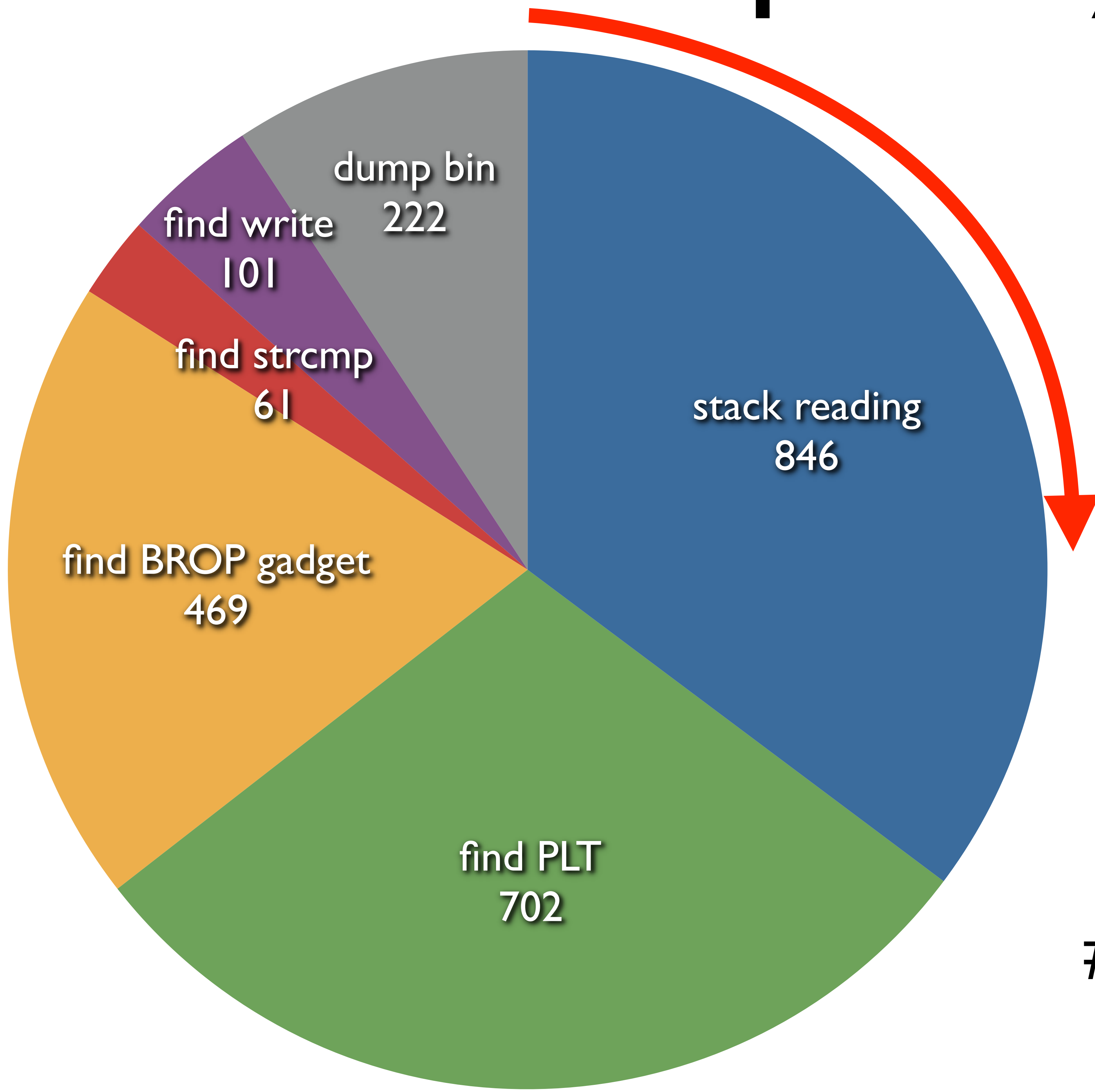
1. dump binary to network - not blind anymore!
2. dump symbol table to find PLT calls.
3. redirect stdin/out to socket:
   - dup2(fd, 0);
   - close(0); fcntl(sock, F_DUPFD, 0);
4. read() “/bin/sh” from socket to writable
   - writable can be environ (from symbol table)
5. execve(“/bin/sh”, 0, 0)

Braille

- Fully automated: from crash to shell.
- 2,000 lines of Ruby.
- Needs function that will trigger overflow:
  - nginx: 68 lines.
  - mysql: 121 lines.
  - proprietary service: 35 lines.

```
try_exp(data) → true  crash
                false no crash
```

Attack complexity



# of requests
for nginx

BROP conclusions

- It’s scary what a motivated attacker can do: e.g., hack unknown binaries.
- Hackers can get past point solutions - need principled solutions:
  - OS: rerandomize ASLR & canaries per-fork
  - Compiler: Encrypt or MAC pointers?
  - Application: Dune (privilege separation)?