CS 461 / ECE 422
Discussion #1

x86 Assembly Review

Paul Murley – pmurley2@illinois.edu

8/28/19

Overview

- Introductions
- Discussion Structure
- MPs - What to expect
- Review – Assembly Programming and Memory Structure

Discussion Sections

- Attendance recommended but not required
- Time will mostly be spent on topics that will help with the MPs
- Questions encouraged*
  - If you have a longer, specific question (e.g., your code is not working for the MP and you are not sure why), you should come to office hours rather than staying after discussion
- No screens policy does not apply in discussion section (but please be courteous)

Structure of an MP (Project)

- 5 MPs, each MP lasts about 2 – 2.5 weeks
- Split into two parts (Checkpoint 1 and Checkpoint 2)
- Scored out of 120 points (C1: 20pts, C2: 100pts)
- Checkpoint 1 will be ***significantly*** easier/faster to complete when compared Checkpoint 2
    - What does this mean?
- Emphasis: **NO LATE SUBMISSIONS ACCEPTED**

MP Handout and Submission: Git

MP Handout and Submission: Git

- Create your personal Git repository for this course (if you haven’t already):
  1. Follow link (also found on either Piazza or course website):

     https://edu.cs.illinois.edu/create-ghe-repo/cs461-fa19/

  2. Log in with your netid/password
  3. That’s it! Your repository is now available at:

     https://github-dev.cs.Illinois.edu/cs461-fa19/<netid>

MP Submission/Handout Workflow

- Empty/skeleton files for each MP will be pushed to your repository as a new branch
  - Branch will be named for the MP topic (e.g., “AppSec”)
  - You should immediately merge this branch into your master branch

- You will submit MPs by committing and pushing your completed files to master
  - The autograder will read from the master branch only!

MP1: Application Security

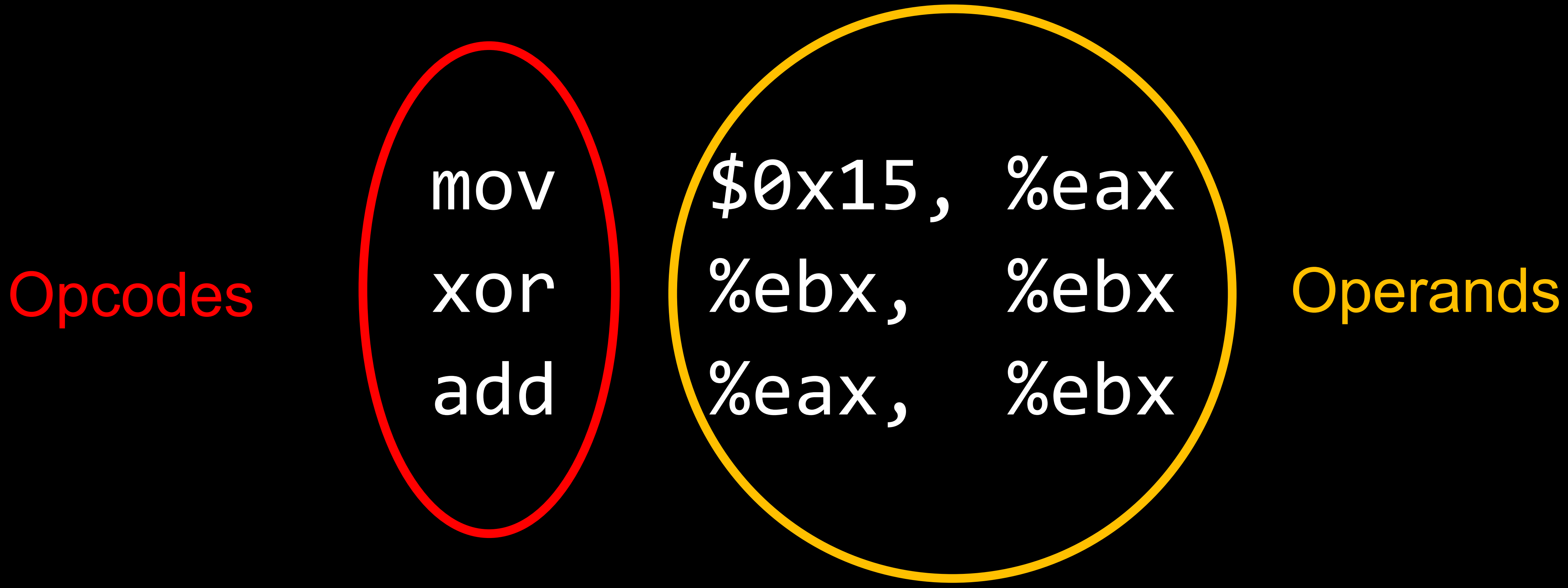
- Released: Monday, 9/2 @ 6:00pm
- Involves understanding and exploiting programs using buffer overflows, integer overflows, format string vulnerabilities, etc.
- The entire MP will be done inside of a virtual machine that we will provide to you
  - You will be expected to install virtualization software (VirtualBox) on your own computer in order to run this VM. If you don’t have a computer that can handle this, contact course staff and we will help provide a working environment.

Questions before we move on?

Review: x86 Assembly

```
mov   $0x15, %eax
xor   %ebx,  %ebx
add   %eax,  %ebx
```

Review: x86 Assembly

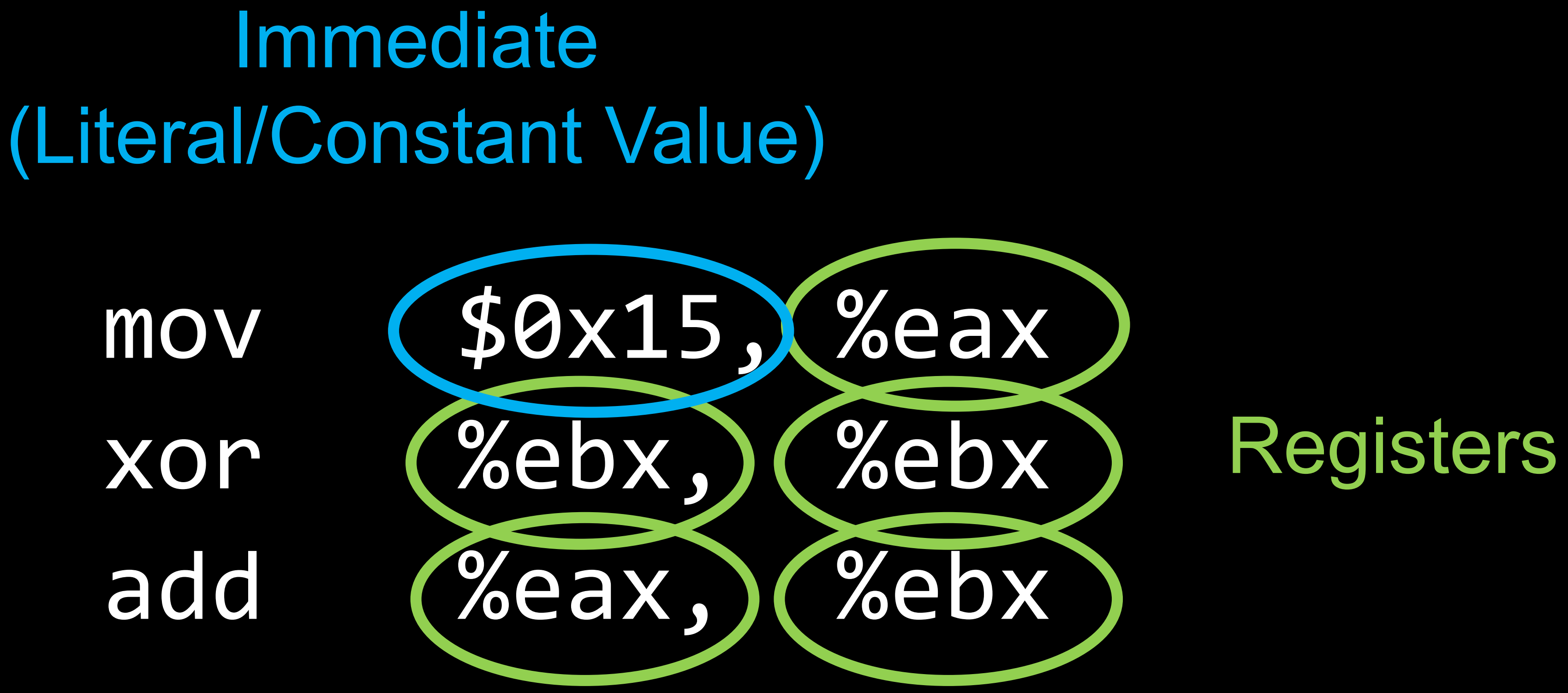


```
mov  $0x15, %eax
xor  %ebx,  %ebx
add  %eax,  %ebx
```

Opcodes

Operands

Review: x86 Assembly



Immediate
(Literal/Constant Value)

```
mov   $0x15, %eax
xor   %ebx,  %ebx
add   %eax,  %ebx
```

Registers

Commonly Used x86 Registers

General purpose registers

- EAX - Return value
- EBX
- ECX - Loop counter
- EDX
- EDI - Repeated destination
- ESI - Repeated source

Special Registers

- EBP – Frame pointer/Base pointer
- ESP - Stack pointer
- EIP - Program counter
- EFLAGS - Status of previous operations (used in conditionals)

x86 Assembly Syntax

There are two main variants of x86 syntax:

Intel

- `add eax, [ebx+4]`
- Mnemonic, then operands
- Destination operand first, then source
- Brackets indicate memory access

AT&T (GAS)

- `add 4(%ebx), %eax`
- Mnemonic, then operands
- Source operand first, then destination
- Parentheses indicate memory access

x86 Assembly Syntax

There are two main variants of x86 syntax:

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- `add eax, [ebx+4]`
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AT&T (GAS)

- `add 4(%ebx), %eax`
- Mnemonic, then operands
- Source operand first, then destination
- Parentheses indicate memory access

In this course, we use AT&T (GAS) syntax exclusively.

AT&T Memory Address Calculation

Write it:

```
displacement (base_reg, offset_reg, multiplier)
```

Calculate it:

```
base_reg + displacement + (offset_reg*multiplier)
```

```
mov   8 (%ebp), %eax          # Mem[EBP+8] to eax
mov  12 (,%edx,4), %eax       # Mem[EDX*4+12] to eax
```

Notice that not all fields are required!

Common x86 Instructions (Opcodes) (1)

Arithmetic Operations

- `add`, `sub` - add/subtract data in first operand to/from second
- `inc`, `dec` - increment/decrement operand
- `neg` - change sign of operand

Logical Operations

- `and`, `or`, `xor` - bitwise and/or/xor
- `not` - flip all of the bit values
- `shl`, `shr` - shift bits left/right

Common x86 Instructions (Opcodes) (2)

Transfer Instructions

- `mov` - copy data from first operand to second
- `lea` - compute address and store it in second operand (does NOT access memory)
- `push` - Push the operand onto the stack (see later slides)
- `pop` - Pop a value off the top of the stack into the operand

Common x86 Instructions (Opcodes) (3)

Transfer Instructions

- `jmp` – jump to label or address specified by operand
- `je` - jump if equal
- `jne` - jump if not equal
- `jz` - jump if zero
- `jg` - jump if greater than
- `jl` - jump if less than
- `jle/jge` - jump if equal or less than/greater than

For conditional jumps, EFLAGS is used. EFLAGS is a register set by the CMP and TEST instructions (and all other arithmetic instructions)

Common Instructions – Exercise 1

```
xor %eax, %eax              # eax = eax ^ eax

add $3, %eax                # eax = eax + 3

dec %eax                    # eax = eax - 1

shl $3, %eax                # eax = eax << 3

lea 4(, %eax, 4), %eax      # eax = 4 * eax + 4
```

What is in EAX?

Common Instructions – Exercise 2

```
mov   $11,%eax           11 -> eax

mov   $12,%ebx           12 -> ebx

mov   $8,%ecx            8 -> ecx

add   %ecx,%ebx          ebx = ebx + ecx

sub   %ecx,%eax          eax = eax - ecx
```

What is in EAX?

Common Instructions – Exercise 3

9 -> EAX

0 -> EBX

ECX -> EDX

M[ECX] -> EBX

M[EDX+4] -> EAX

Remember:

Opcode-Source-Destination

Address calculation:

displacement(base_reg, offset_reg, multiplier)

Translate into valid AT&T Assembly

Common Instructions – Exercise 3

9 -> EAX	mov	$9, %eax
0 -> EBX	xor	%ebx, %ebx
ECX -> EDX	mov	%ecx, %edx
M[ECX] -> EBX	mov	(%ecx), %ebx
M[EDX+4] -> EAX	mov	4(%edx), %eax

Translate into valid AT&T Assembly

GAS/AT&T Memory Syntax Example

```
typedef struct {
  int a, b, c, d;
} foo_t;
foo_t my_foos[10];
```

```
my_foos[5].c = 461;
```

```
mov my_foos, %ebx
mov $5, %ecx
mov $461, 8(%ebx, %ecx, 16)
```

32-bit x86 ISA

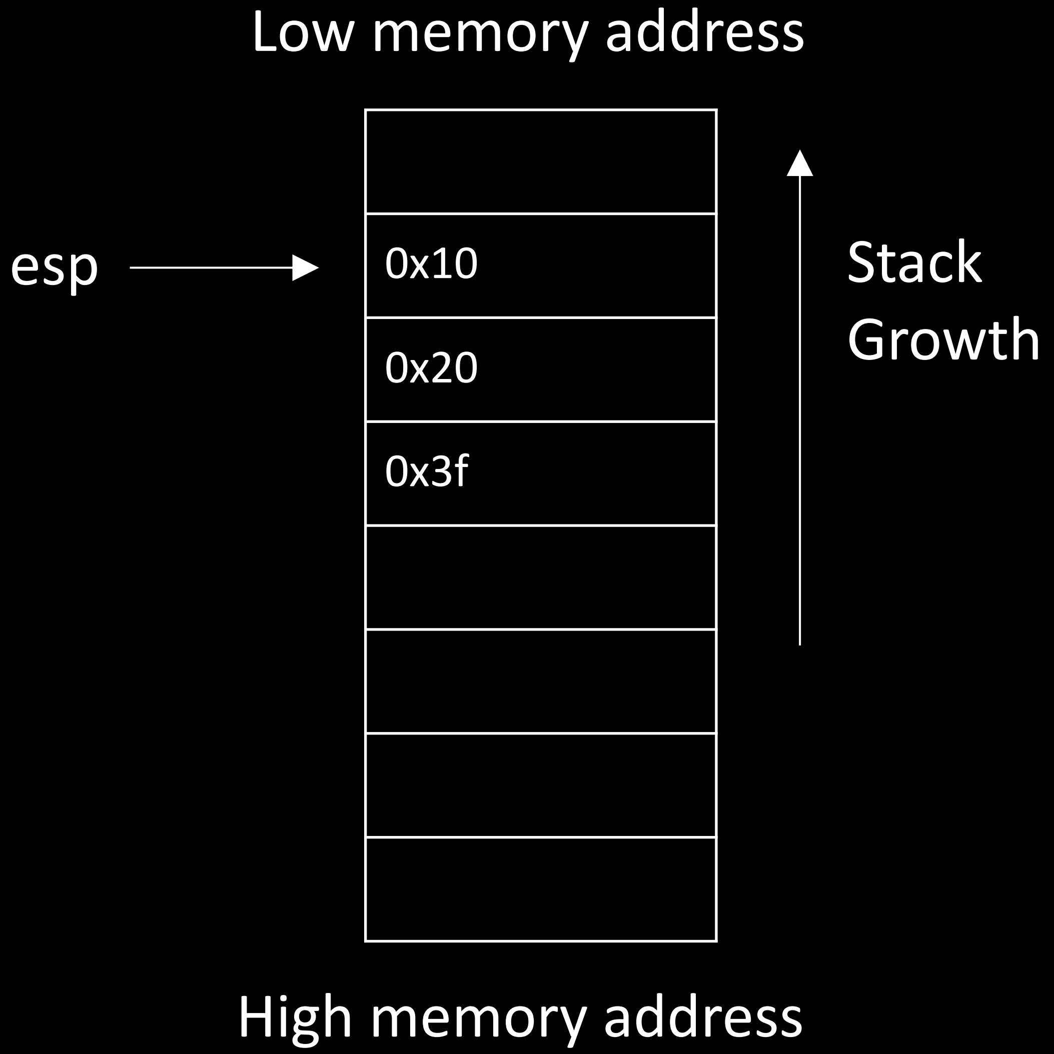
- 1 byte = 8 bits
- char -> 1 byte
- integer -> 4 bytes
- word -> 2 bytes (in gdb, word -> 4 bytes)
- Memory address -> 4 bytes
- Pointer -> 4 bytes
- Registers -> 4 bytes
- Each memory location -> 1 byte

The Stack

- Stores working data (local variables, function arguments, return addresses, etc)
- Last-in First-out (LIFO) structure
- Grows downwards (towards lower memory addresses)
- Manipulated with `push` and `pop` instructions

The Stack

- ESP (stack pointer) points to the top of the stack



Low memory address

esp

0x10

0x20

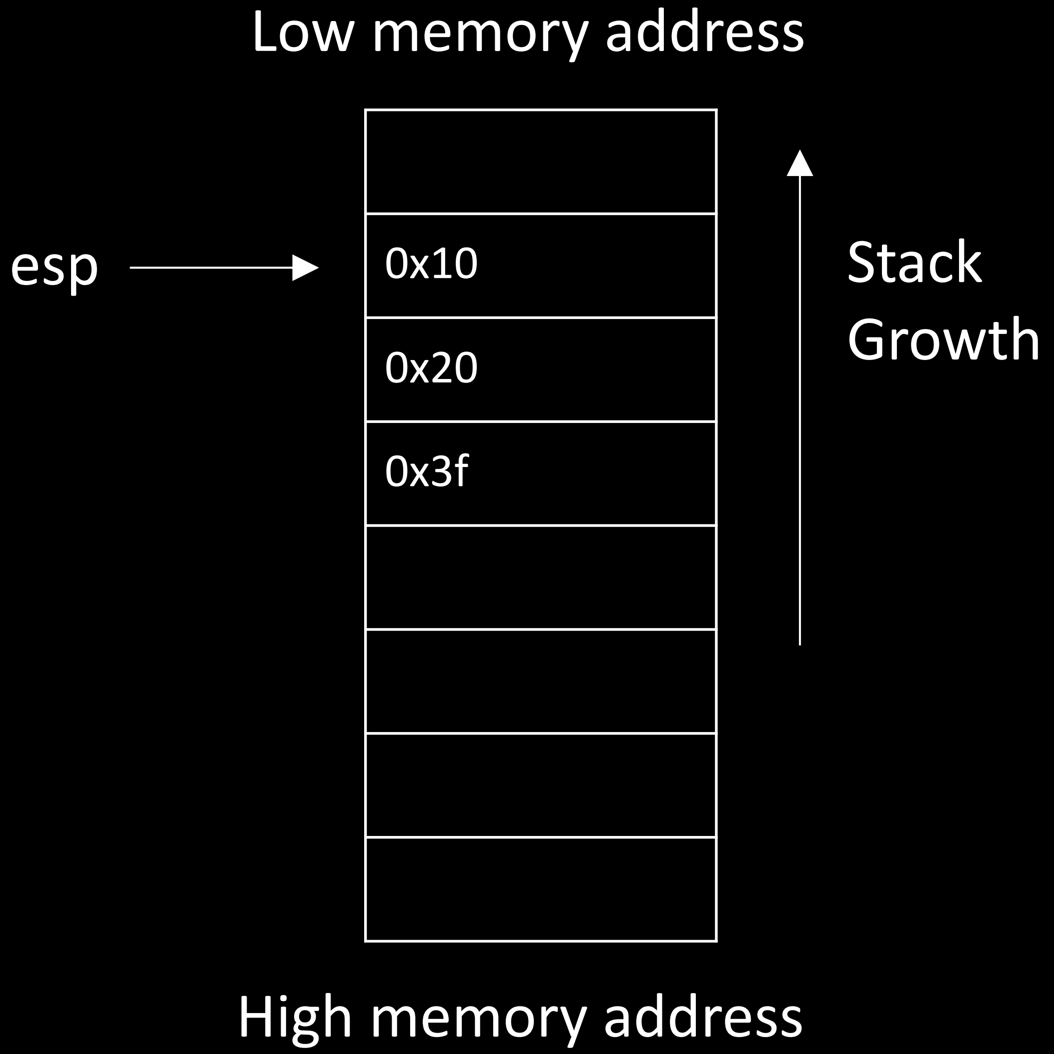
0x3f

Stack Growth

High memory address

The Stack

- ESP (stack pointer) points to the top of the stack
- push instruction decrements ESP (subtracts), and then writes to the top of the stack



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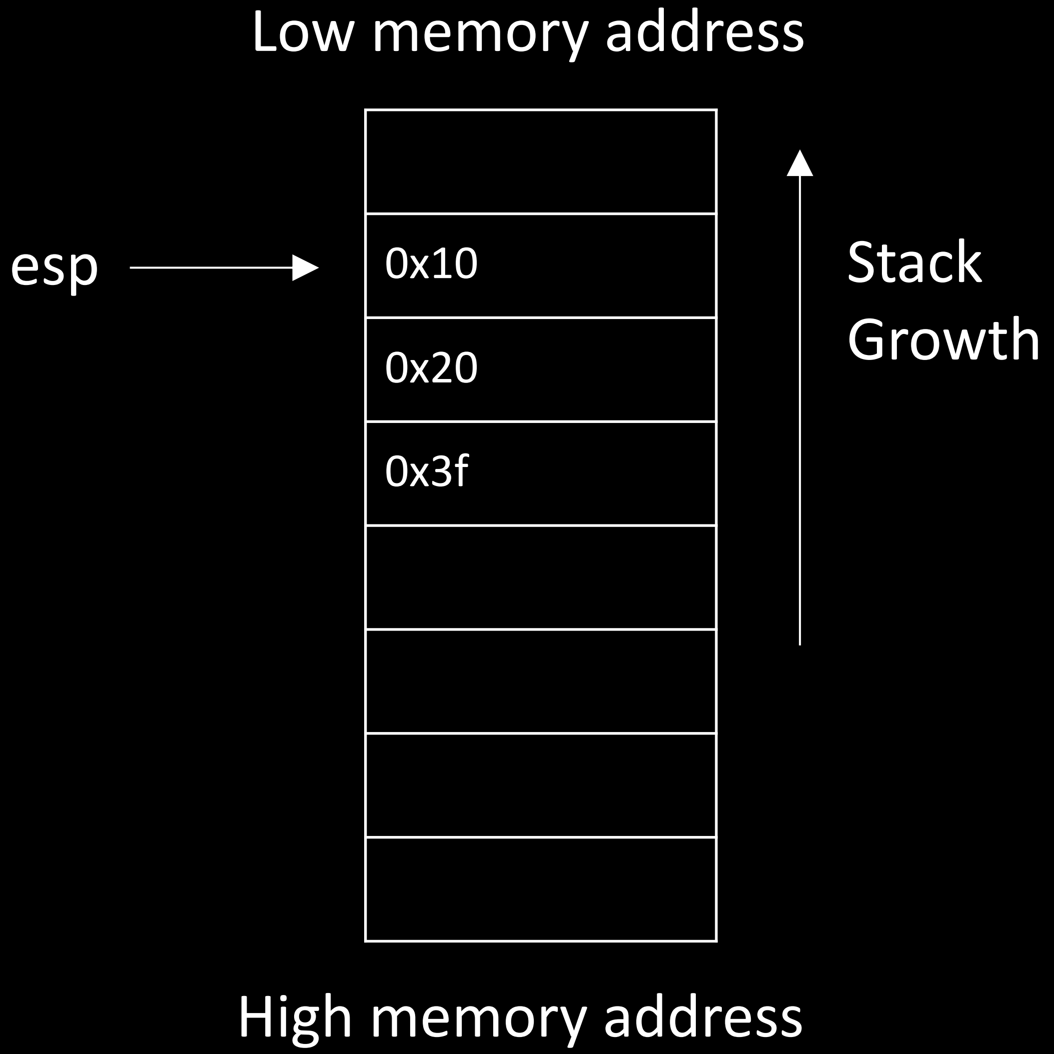
- `push` instruction decrements ESP (subtracts), and then writes to the top of the stack
    - Example: `push 0x4e`



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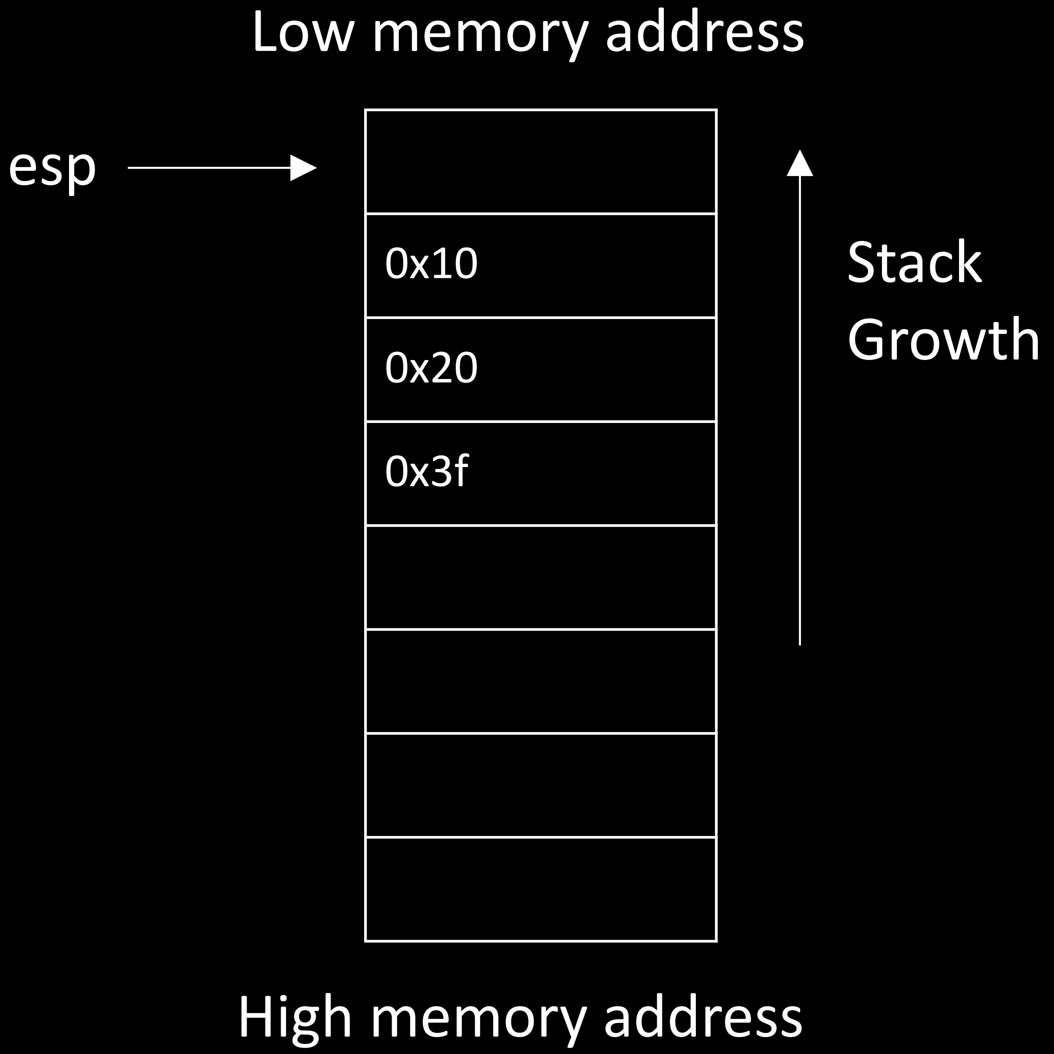

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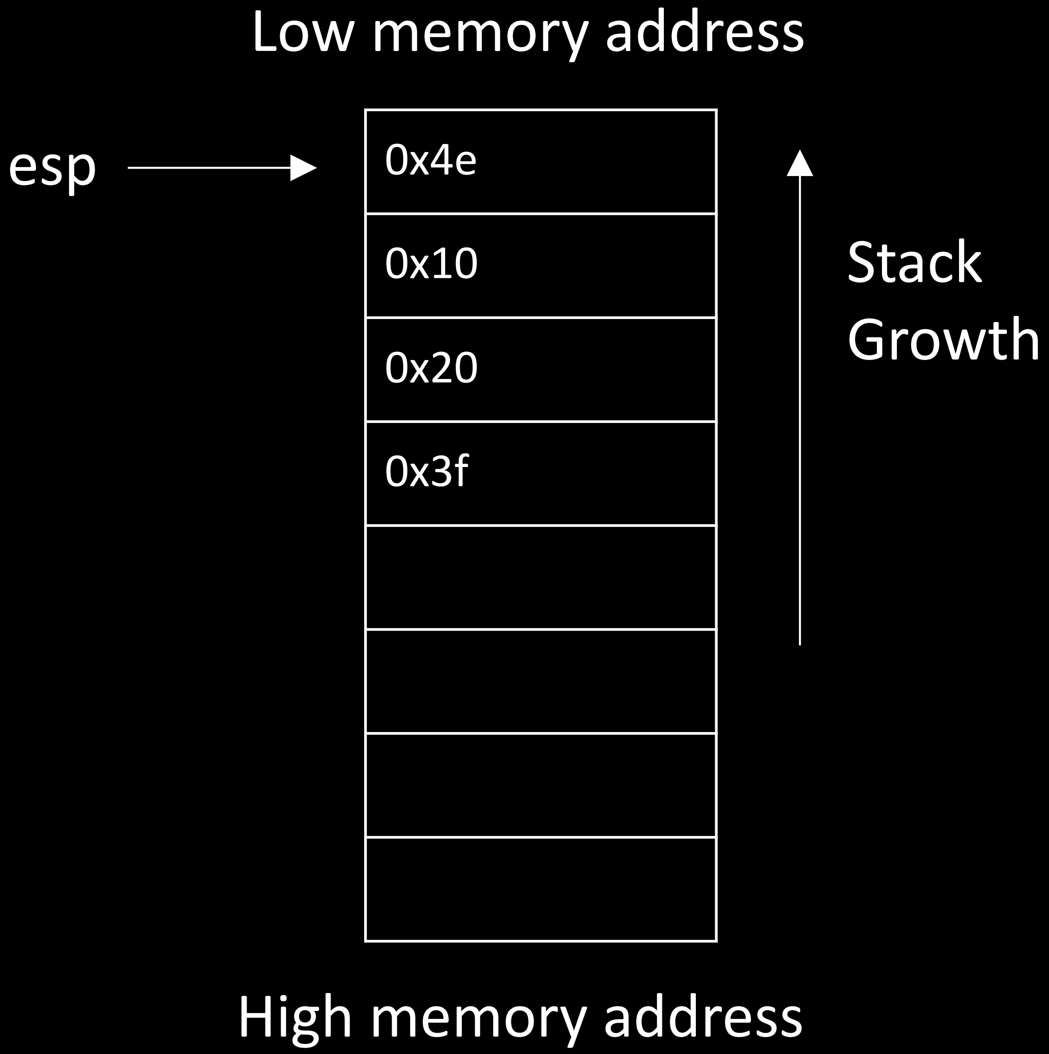

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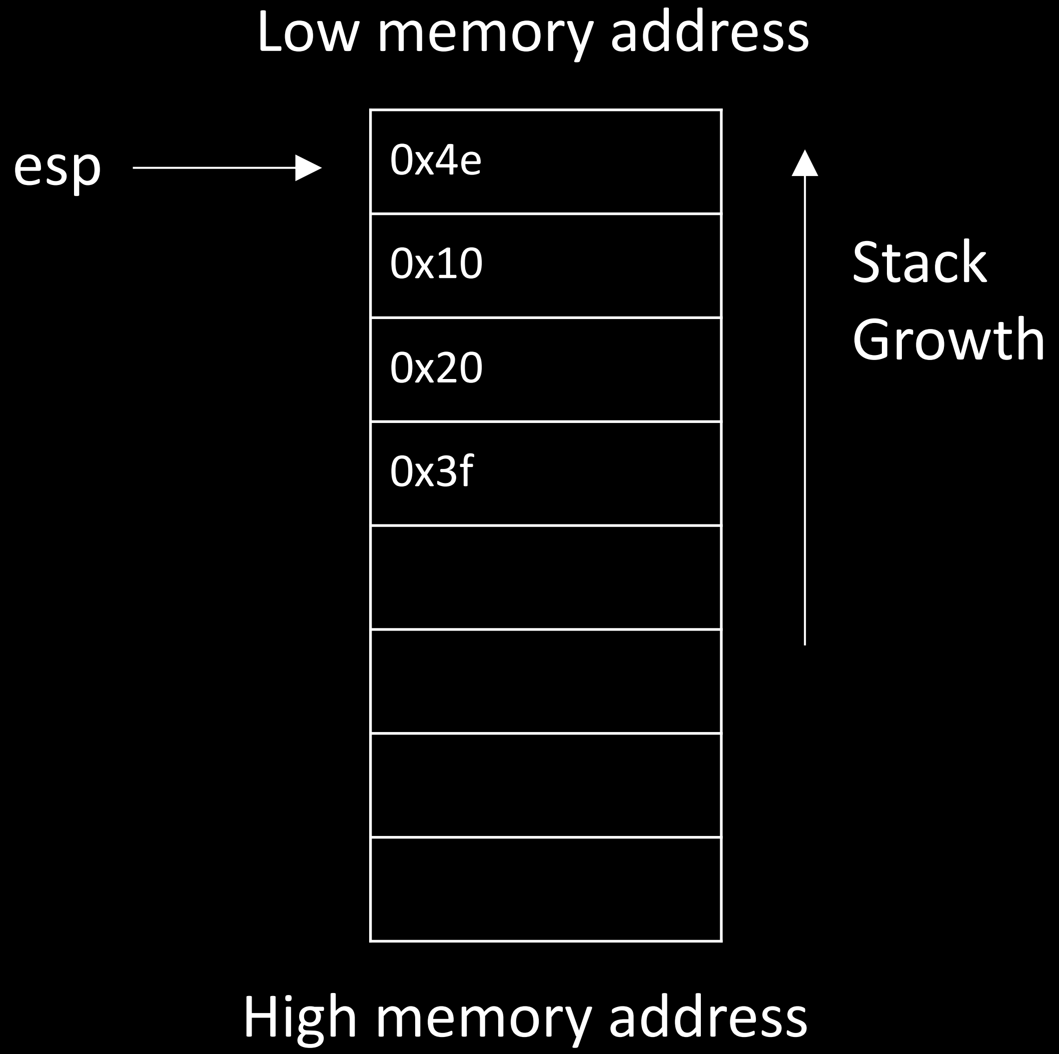

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High memory address

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- push instruction decrements ESP (subtracts), and then writes to the top of the stack
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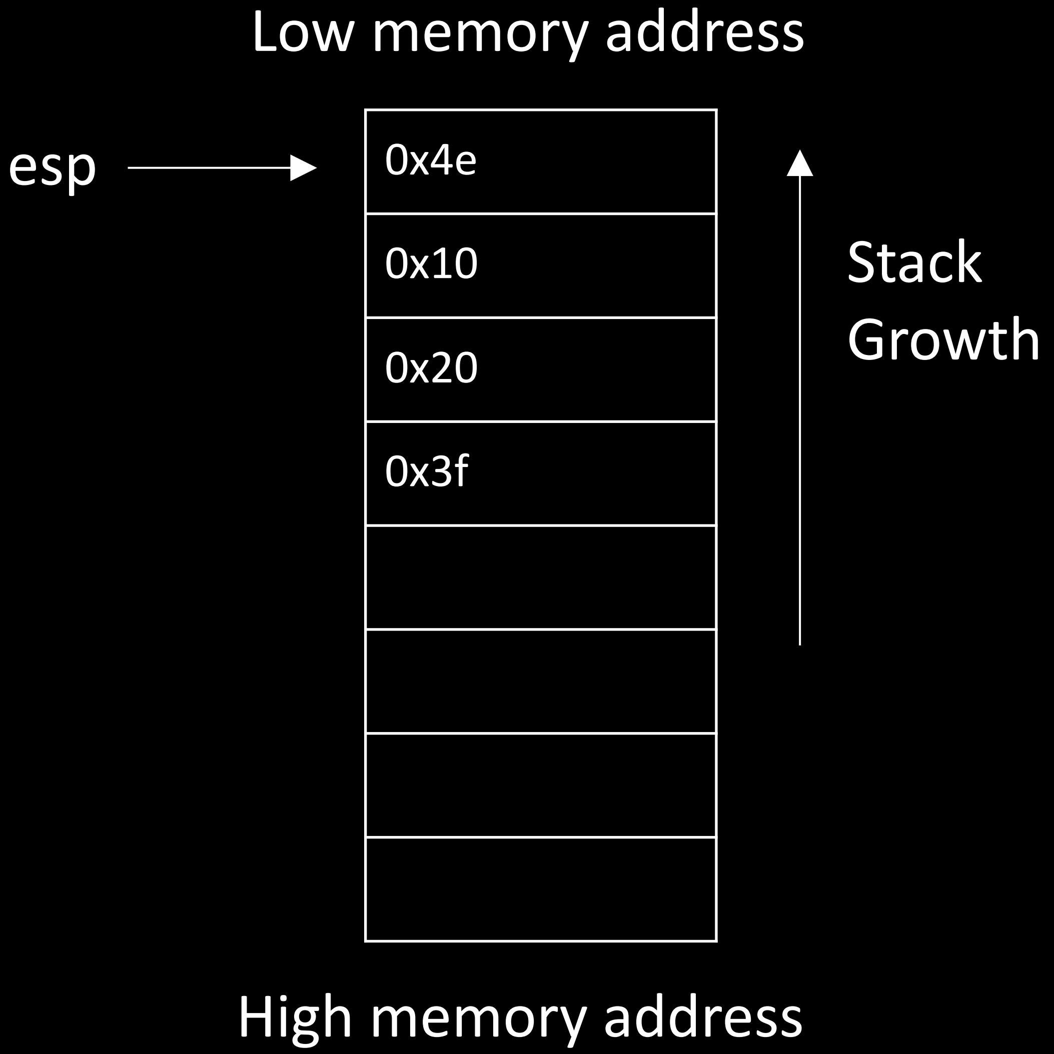
- pop instruction reads the value on top of the stack and then decrements ESP
  - Example: `pop %eax`



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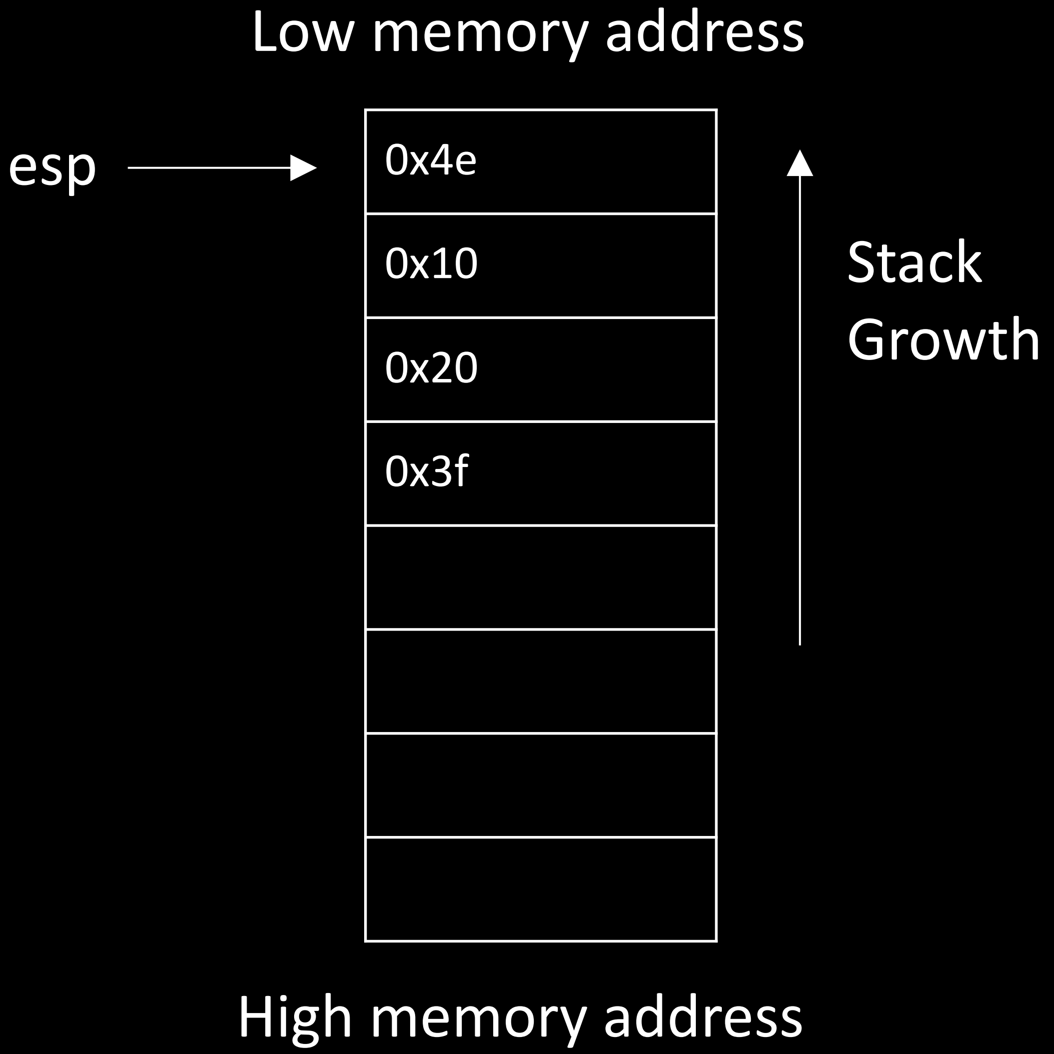
  - Example: `pop %eax` (%eax ⇐ 4)



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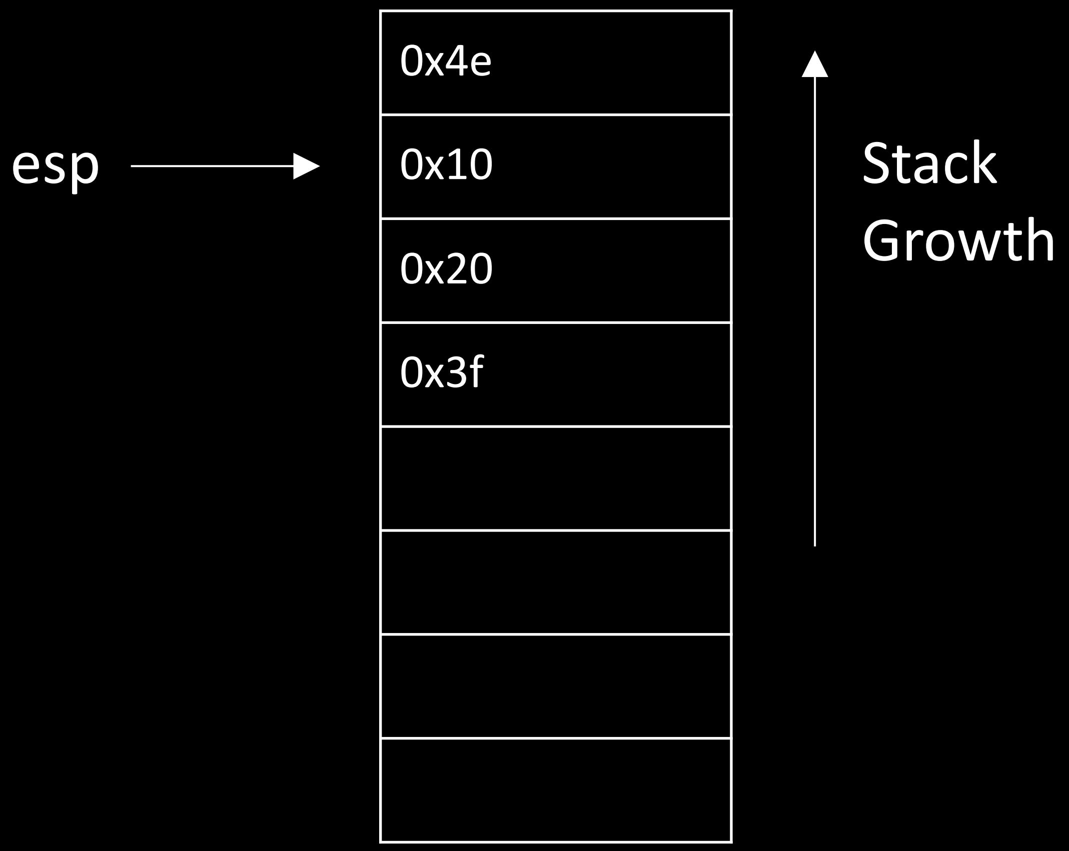

High memory address

Stack Frames

```
void bar {
     int a = 5;  // (push $5)
     int b = 10; //(push $10)
     foo(11,12);
}
```

Stack Frames

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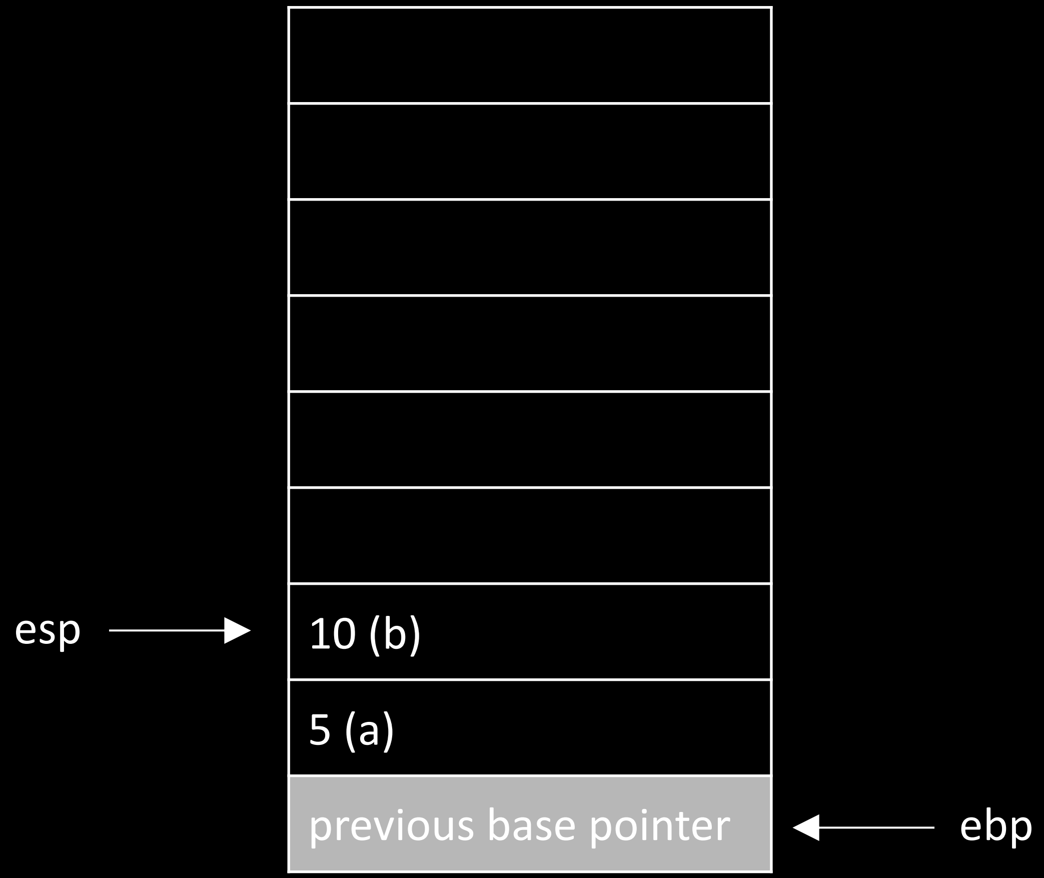

esp

10 (b)

5 (a)

previous base pointer

ebp

Stack Frames

```
void bar {
     int a = 5;  // (push $5)
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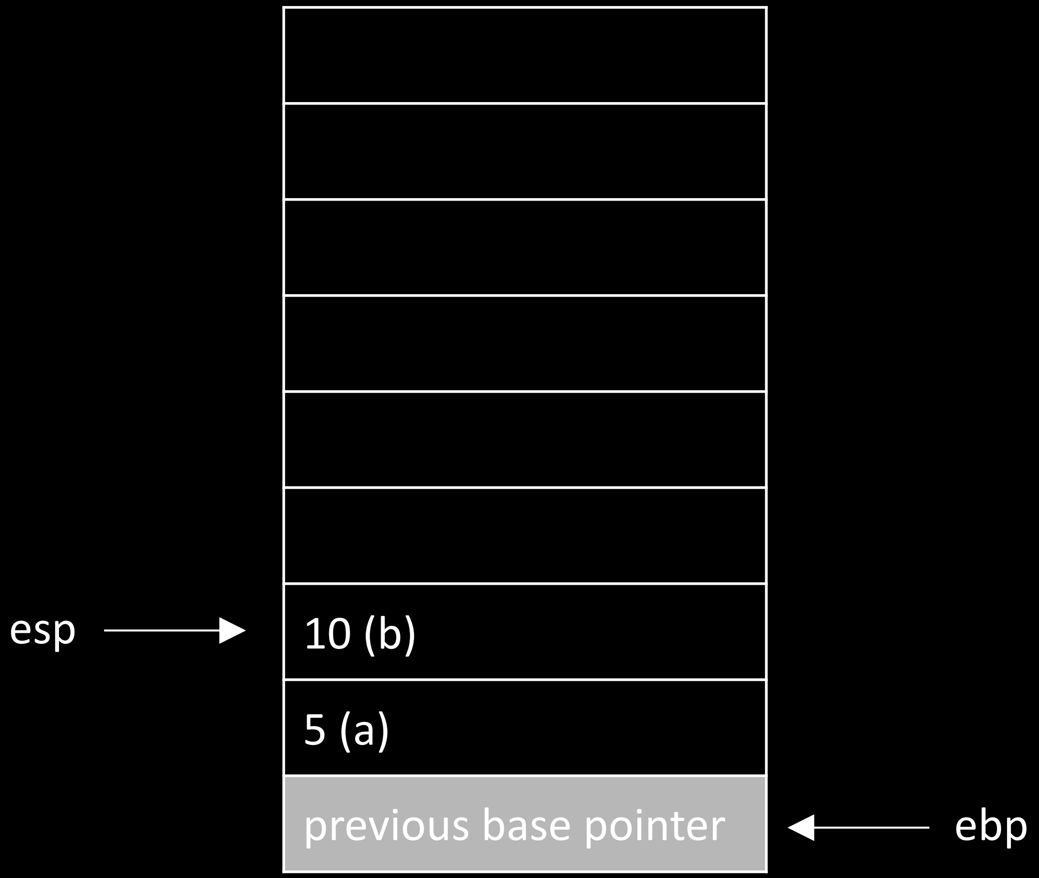

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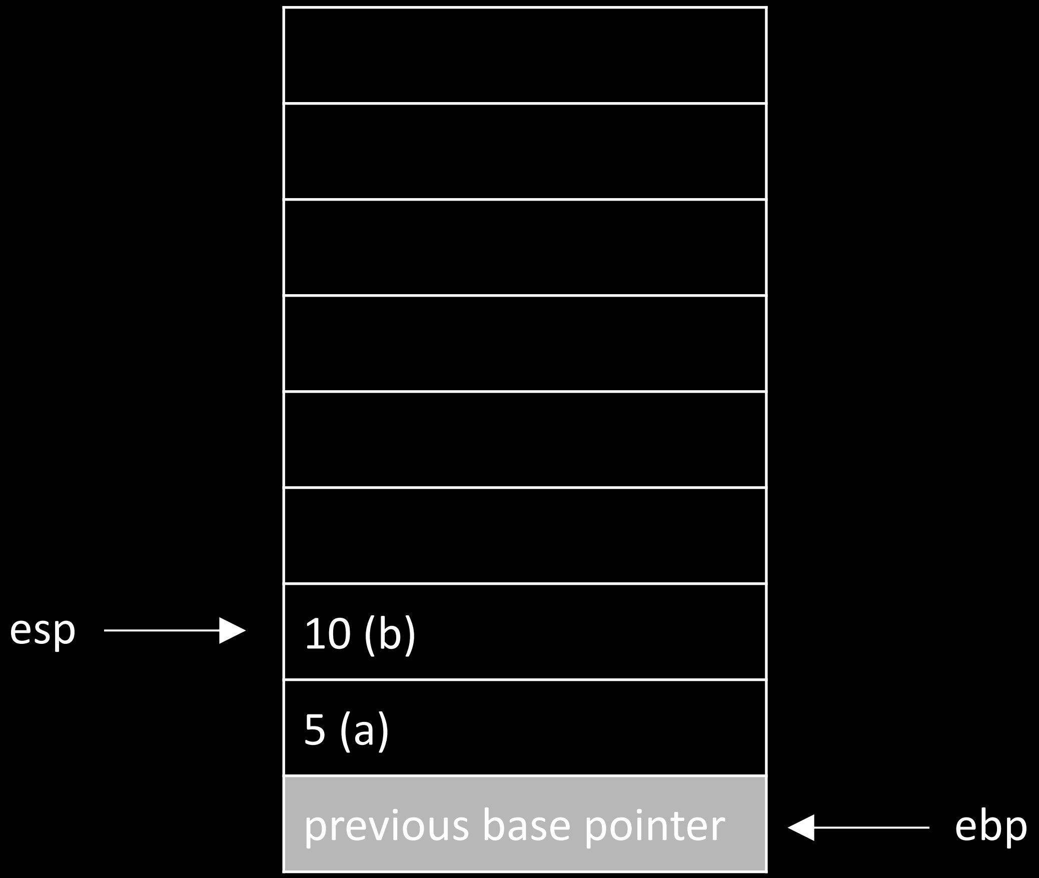
2. Set up arguments for foo()
   - Example: foo() takes 2 arguments, so we need to:

     `push $11, push $12`



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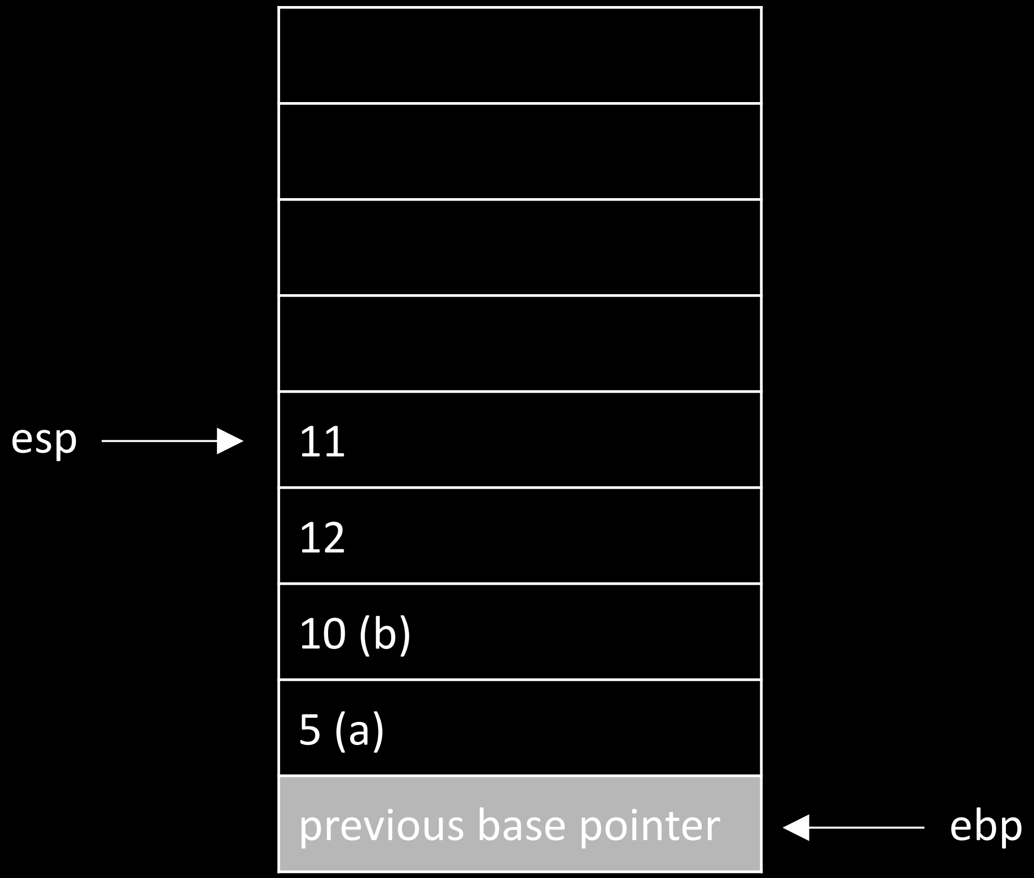

esp → 11

12

10 (b)

5 (a)

previous base pointer ← ebp

Stack Frames

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void bar {
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1. Do stuff in bar()
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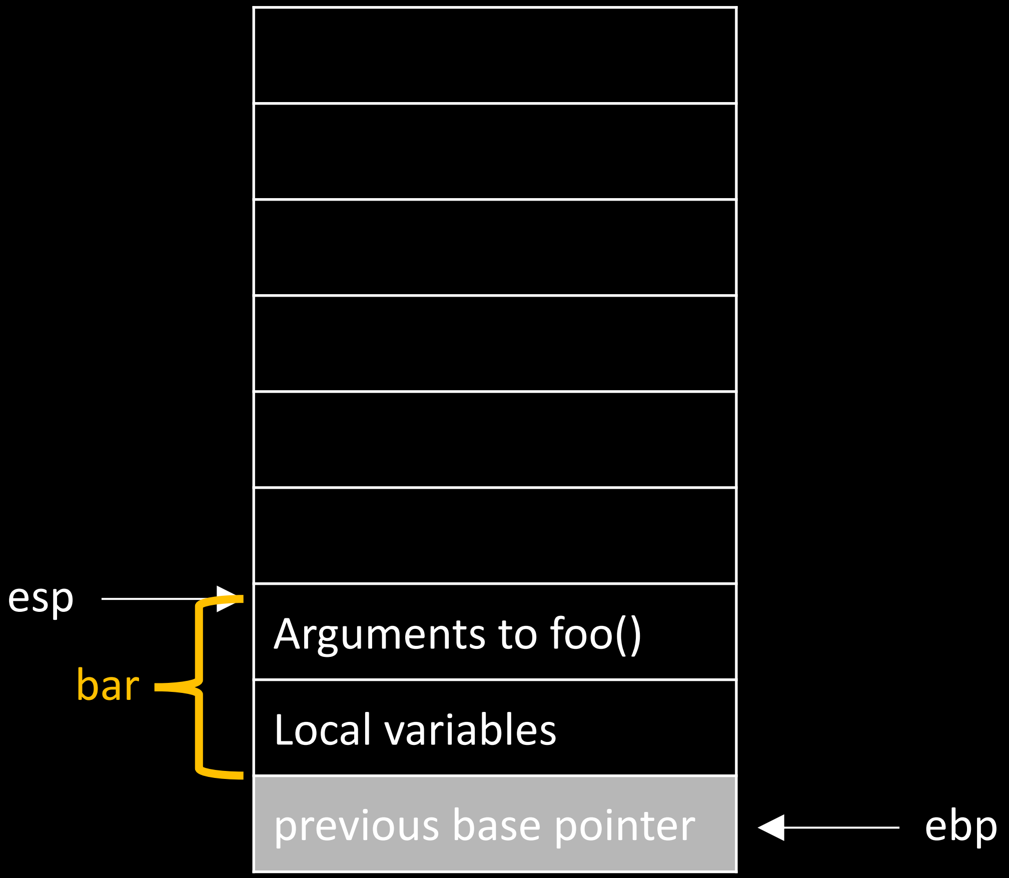

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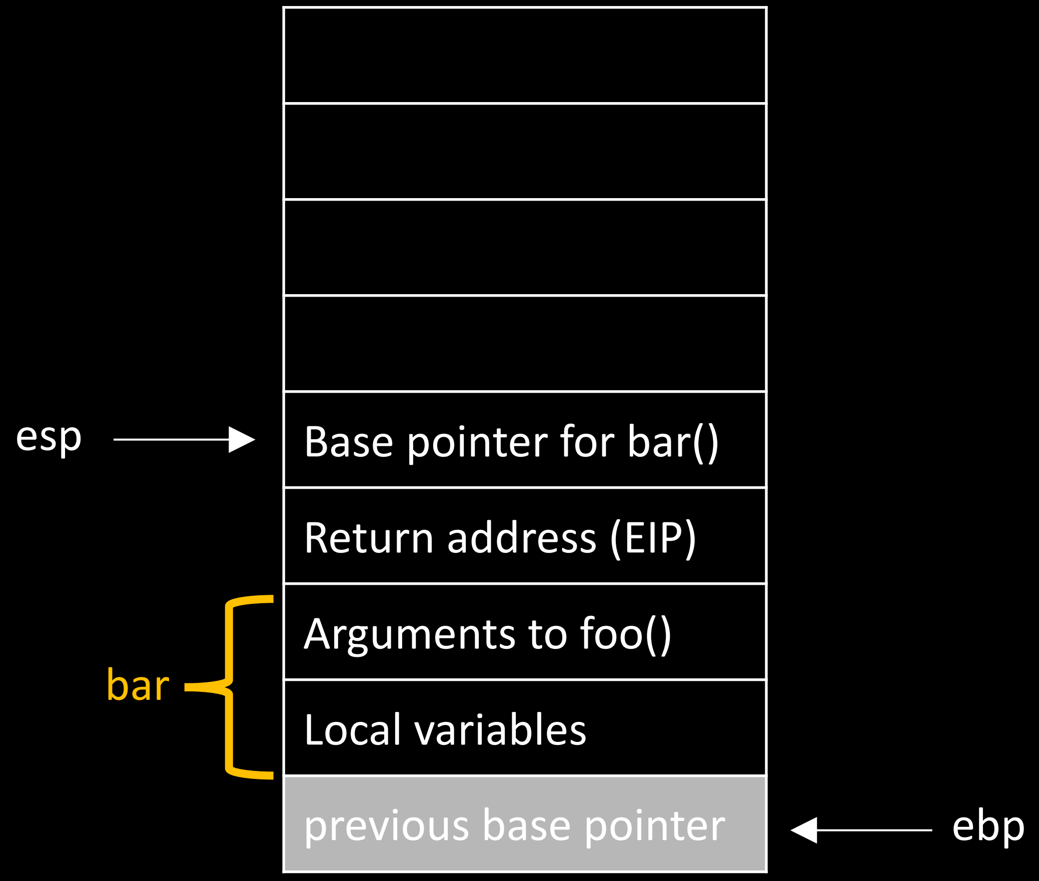

esp

Base pointer for bar()

Return address (EIP)

Arguments to foo()

Local variables

bar

previous base pointer

ebp

Stack Frames

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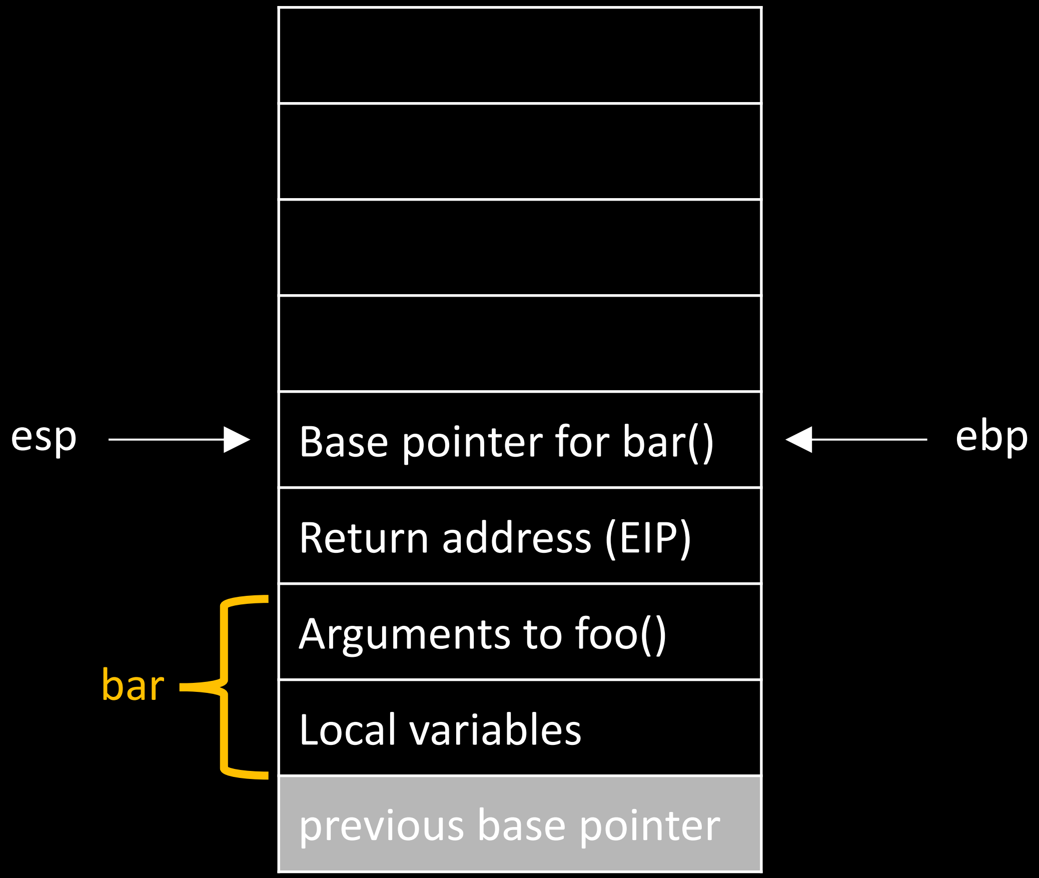

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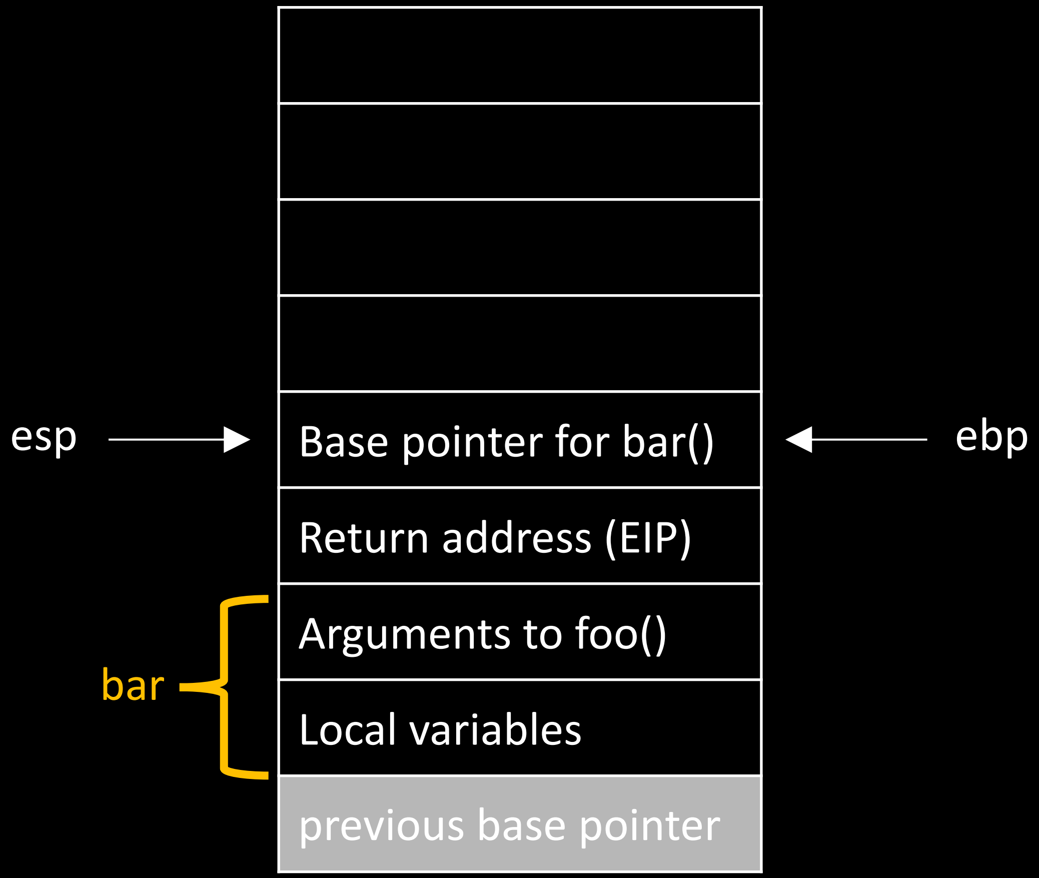
4. Do stuff in foo()



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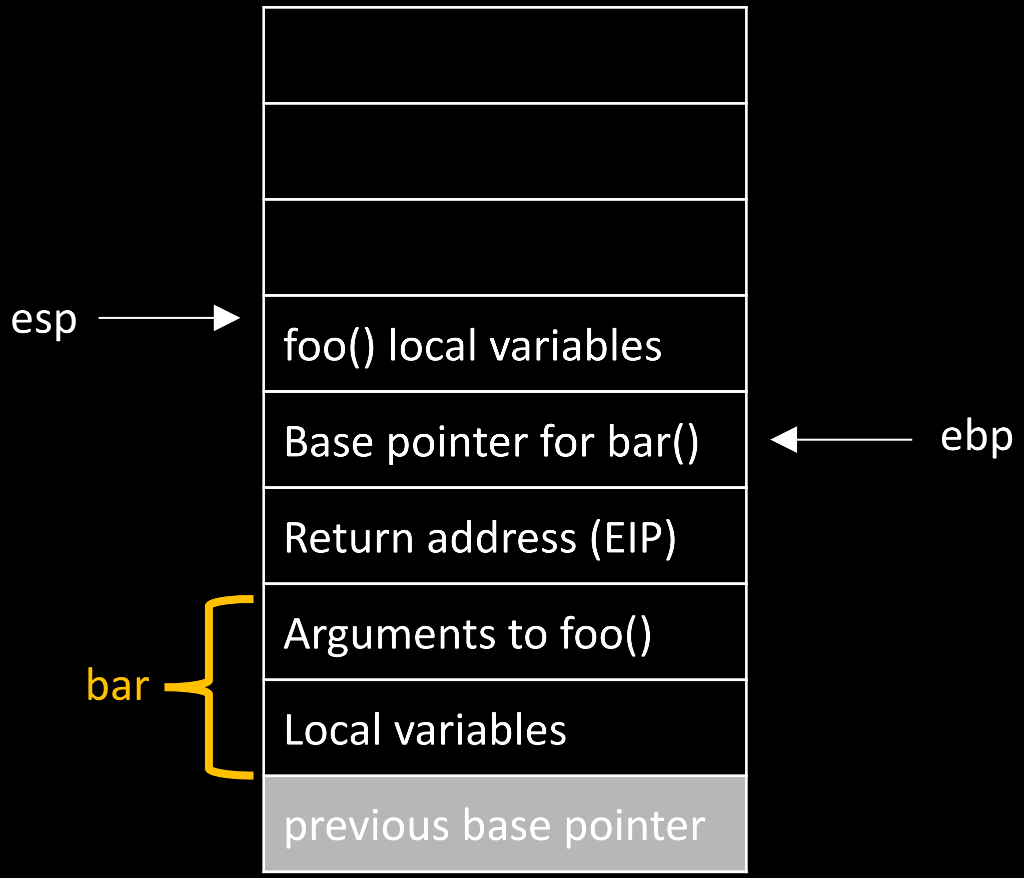

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foo() local variables

Base pointer for bar()

ebp

Return address (EIP)

Arguments to foo()

bar

Local variables

previous base pointer

Stack Frames

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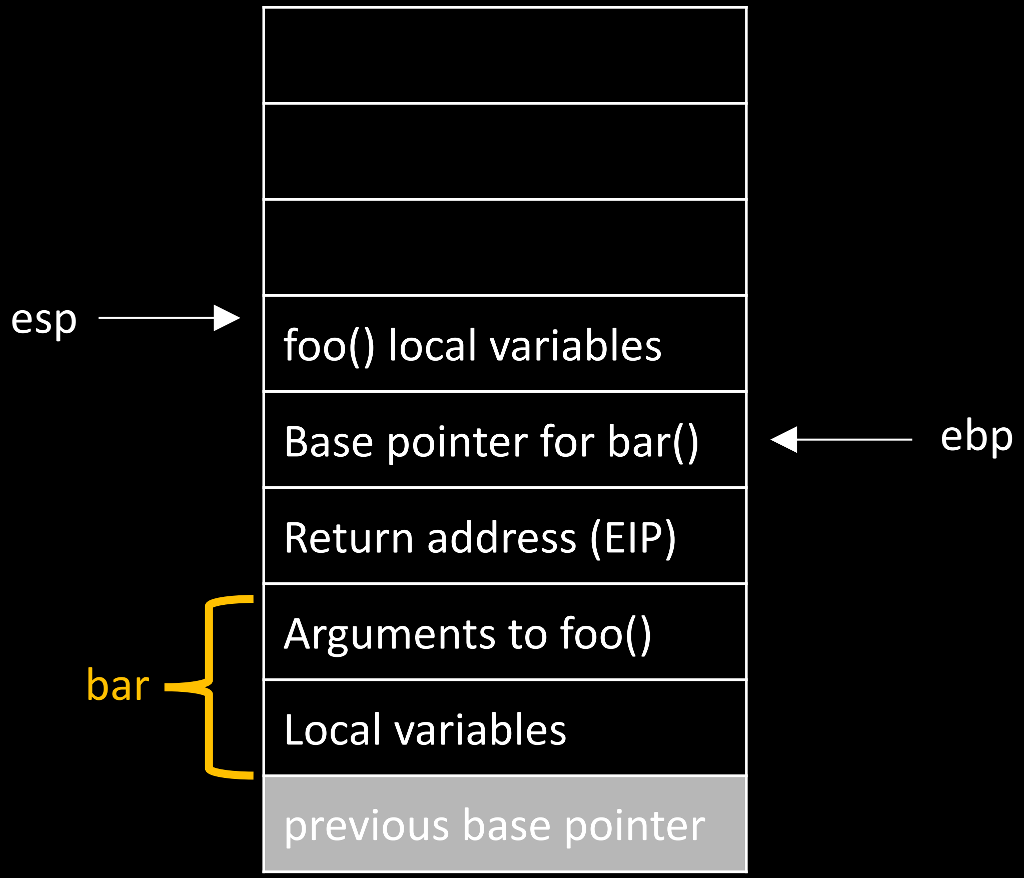

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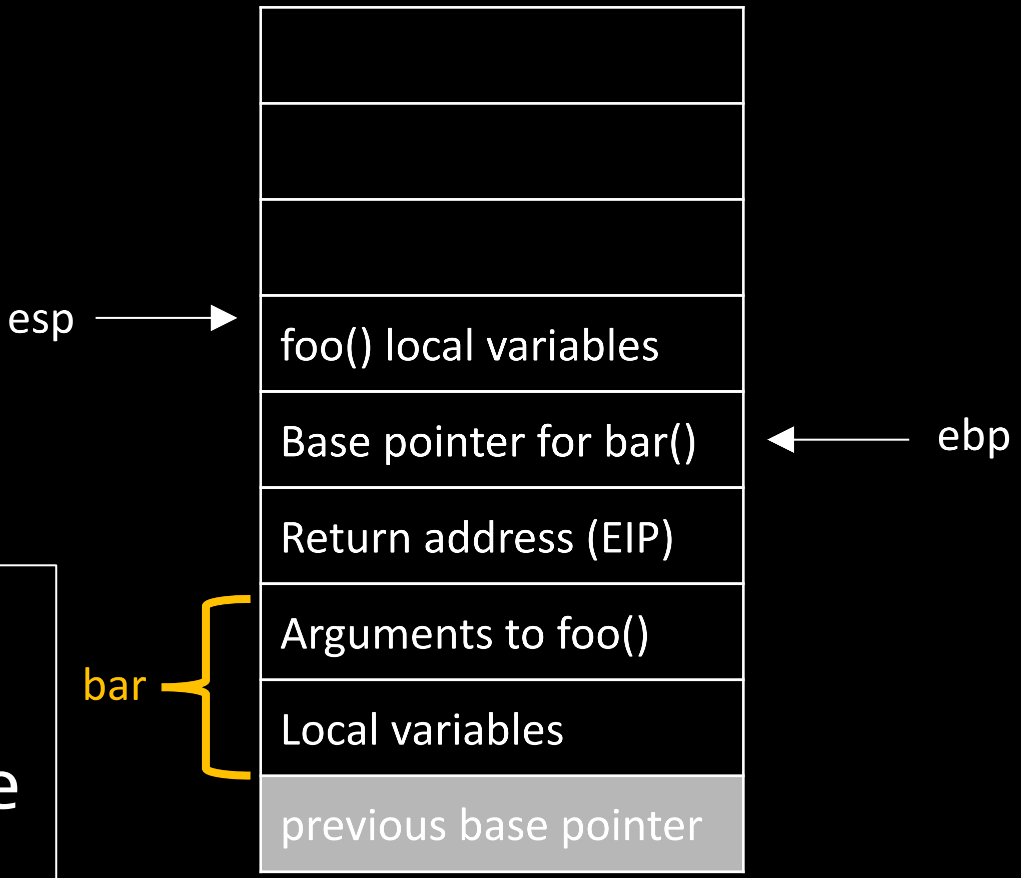
```
foo:
    …
    leave
    ret
```



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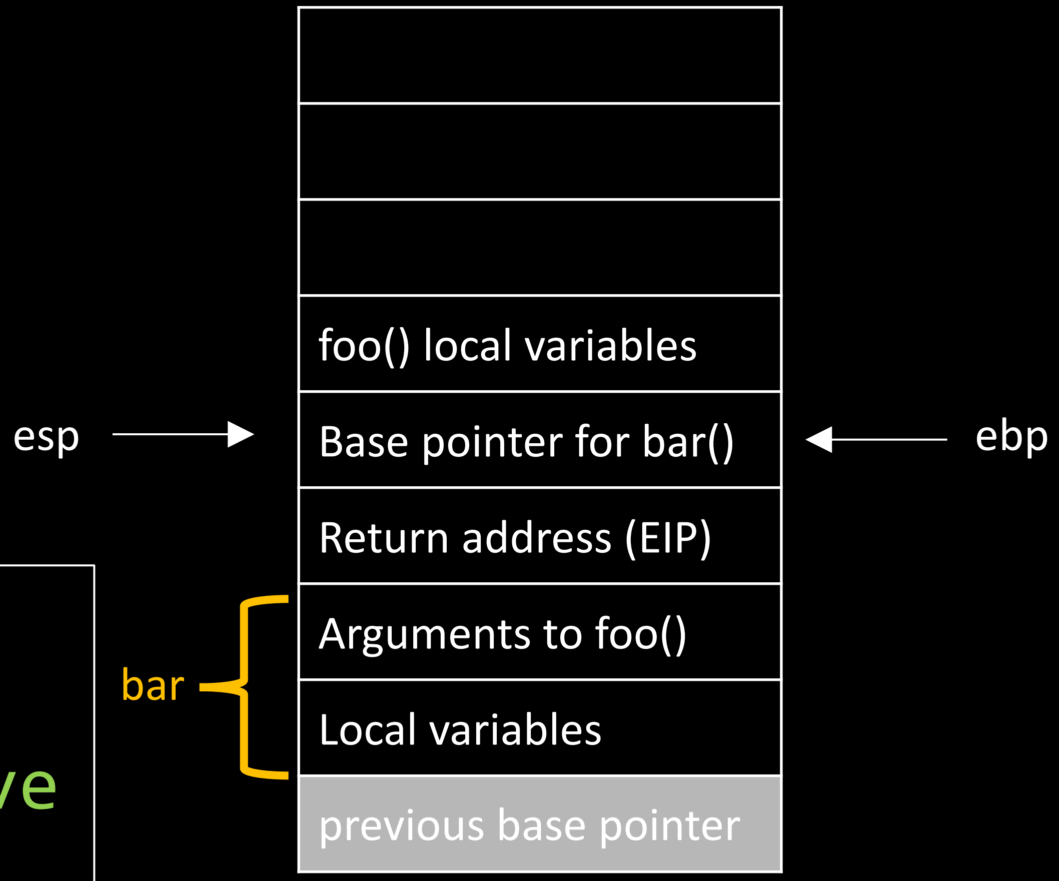

foo() local variables

Base pointer for bar()

Return address (EIP)

Arguments to foo()

Local variables

previous base pointer

Stack Frames

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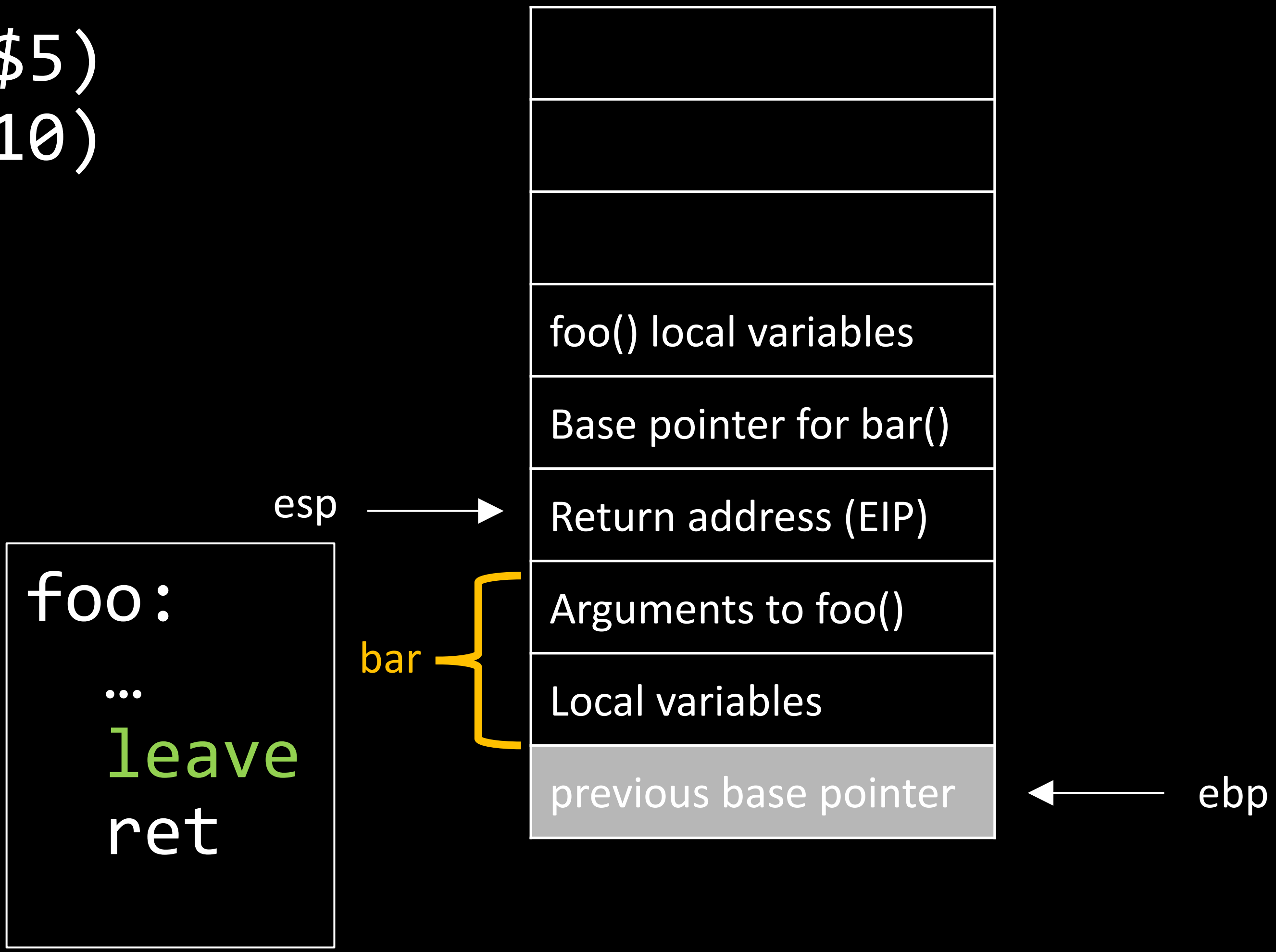

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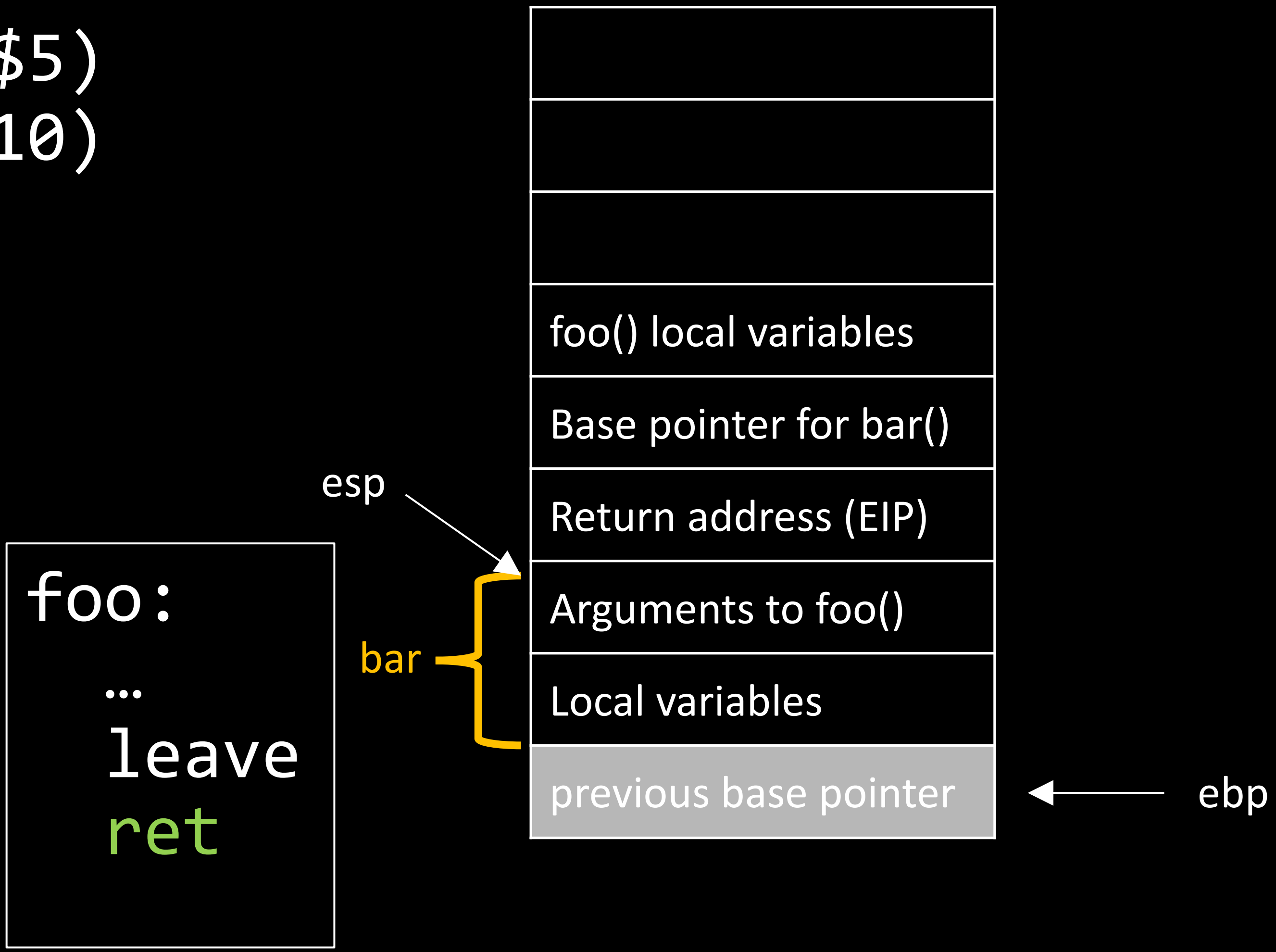

```
foo:
    …
    leave
    ret
```

Exercise: Translate to x86 Assembly

```
int func() {
    int a = 3;
    addnumbers(2, 6);
}

int addnumbers(int x, int y) {
    int b = 1;
    b = x + y;
    return b;
}
```

Possible Solution

```
func:
  push %ebp
  mov %esp,%ebp
  push $3 //int a = 3;
  push $6 //addnumbers(2,6);
  push $2
  call addnumbers
  leave
  ret
```

```
addnumbers:
  push %ebp
  mov %esp, %ebp
  push $1   //int b = 1;
  mov 8(%ebp), %eax
  add 12(%ebp),%eax
  mov %eax,(%esp)
  leave
  ret
```

Final Reminders

- MP1 Release: Monday, 9/2 @ 6:00pm
- Office Hours
  - Every weeknight from 5:00pm-7:00pm (starting 9/3)
  - Room: Siebel 4405
- Discussion Next Week
  - gdb tutorial
  - MP1 Checkpoint 1 Tips
- Contact
  - Paul Murley
  - pmurley2@illinois.edu
  - CSL 445