X86 Review
Process Layout, ISA, etc.

CS642:
Computer Security

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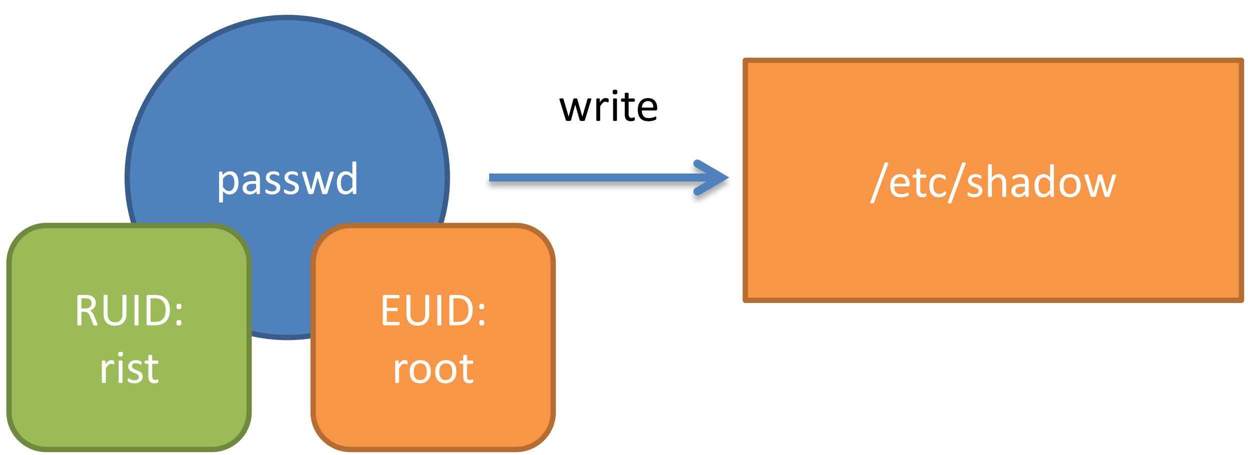
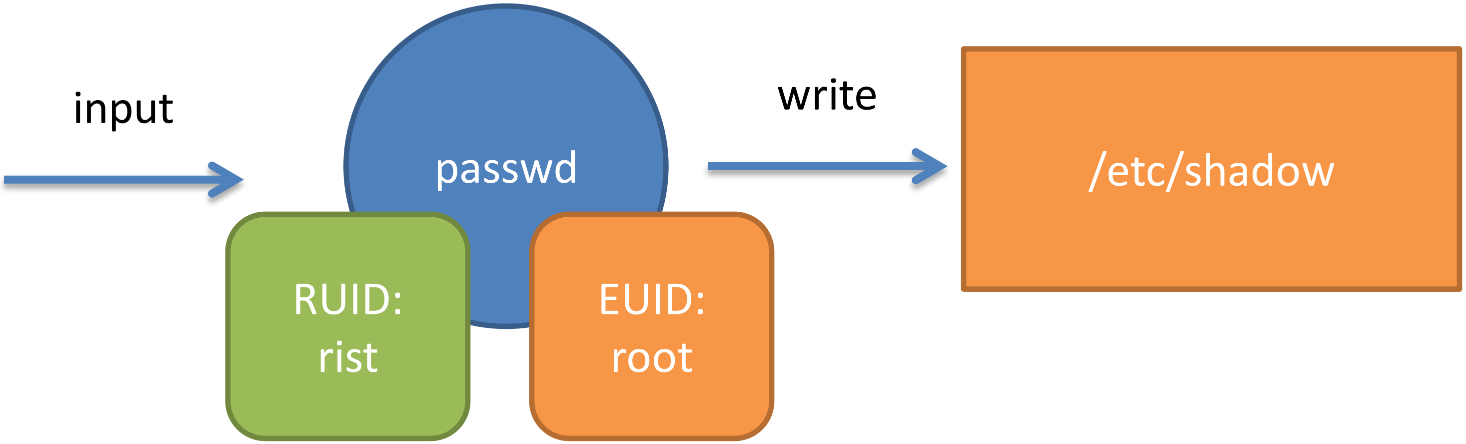
From Last Week

- ACL-based permissions (UNIX style)
  - Read, Write, eXecute can be restricted on users and groups
  - Processes (usually) run with the permissions of the invoking user
- Example:



Processes are the front line of system security

- Control a process and you get the privileges of its UID
- So how do you control a process?
  - Send specially formed input to process



Roadmap

- Today
  - Enough x86 to understand (some) process vulnerabilities
- Next Time
  - Live demo of an attack
  - How such attacks occur

Why do we need to look at assembly?

"WYSINWYX: What you see is not what you eXecute"
[Balakrishnan and Reps TOPLAS 2010]

We understand code in this form

```
int foo(){
        int a = 0;
        return a + 7;
}
```

Compiler

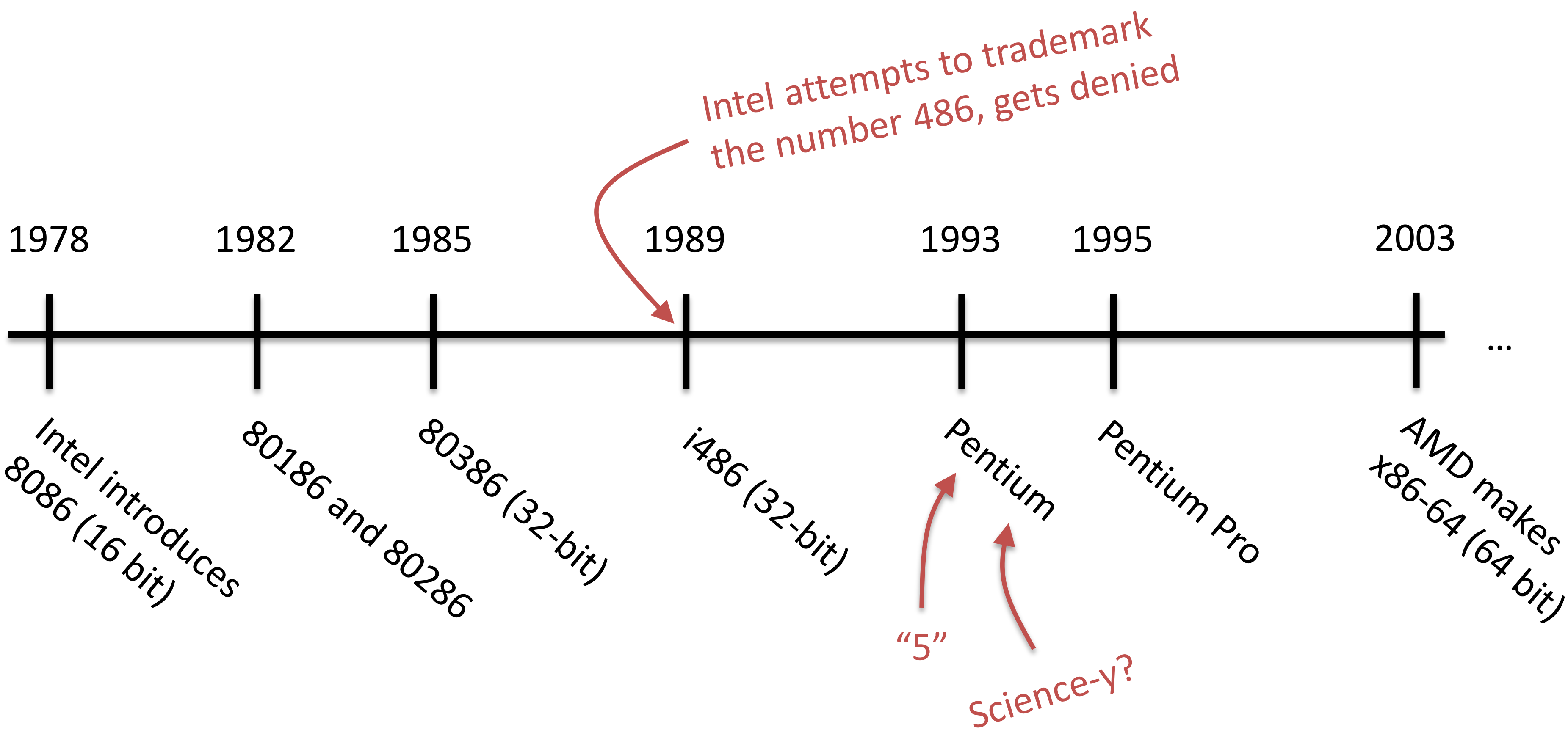
Vulnerabilities exploited in this form

```
pushl %ebp
movl  %esp, %ebp
subl  $16, %esp
movl  $0, -4(%ebp)
movl  -4(%ebp), %eax
addl  $7, %eax
leave
ret
```

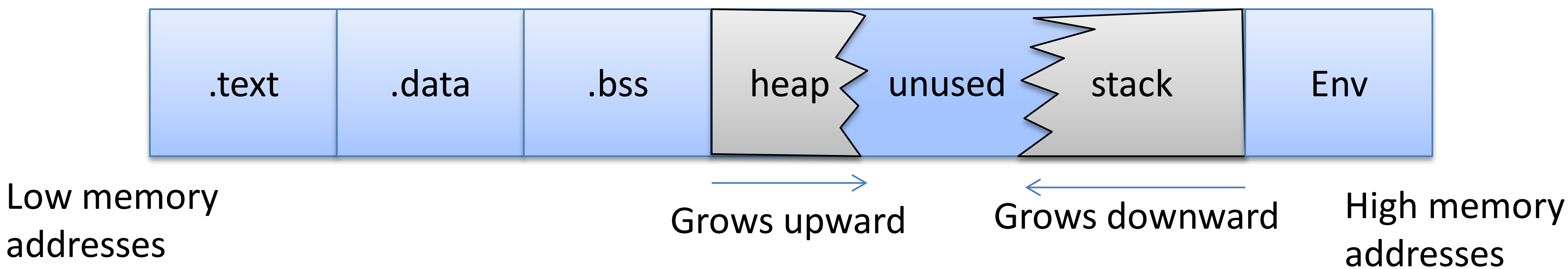
x86: Popular but crazy

- CISC (complex instruction set computing)
  - Over 100 distinct opcodes in the set
- Register poor
  - Only 8 registers of 32-bits, only 6 are general-purpose
- Variable-length instructions
- Built of many backwards-compatible revisions
  - Many security problems preventable… in hindsight

A Little History



Process memory layout



.text
- Machine code of executable

.data
- Global initialized variables

.bss
- Below Stack Section

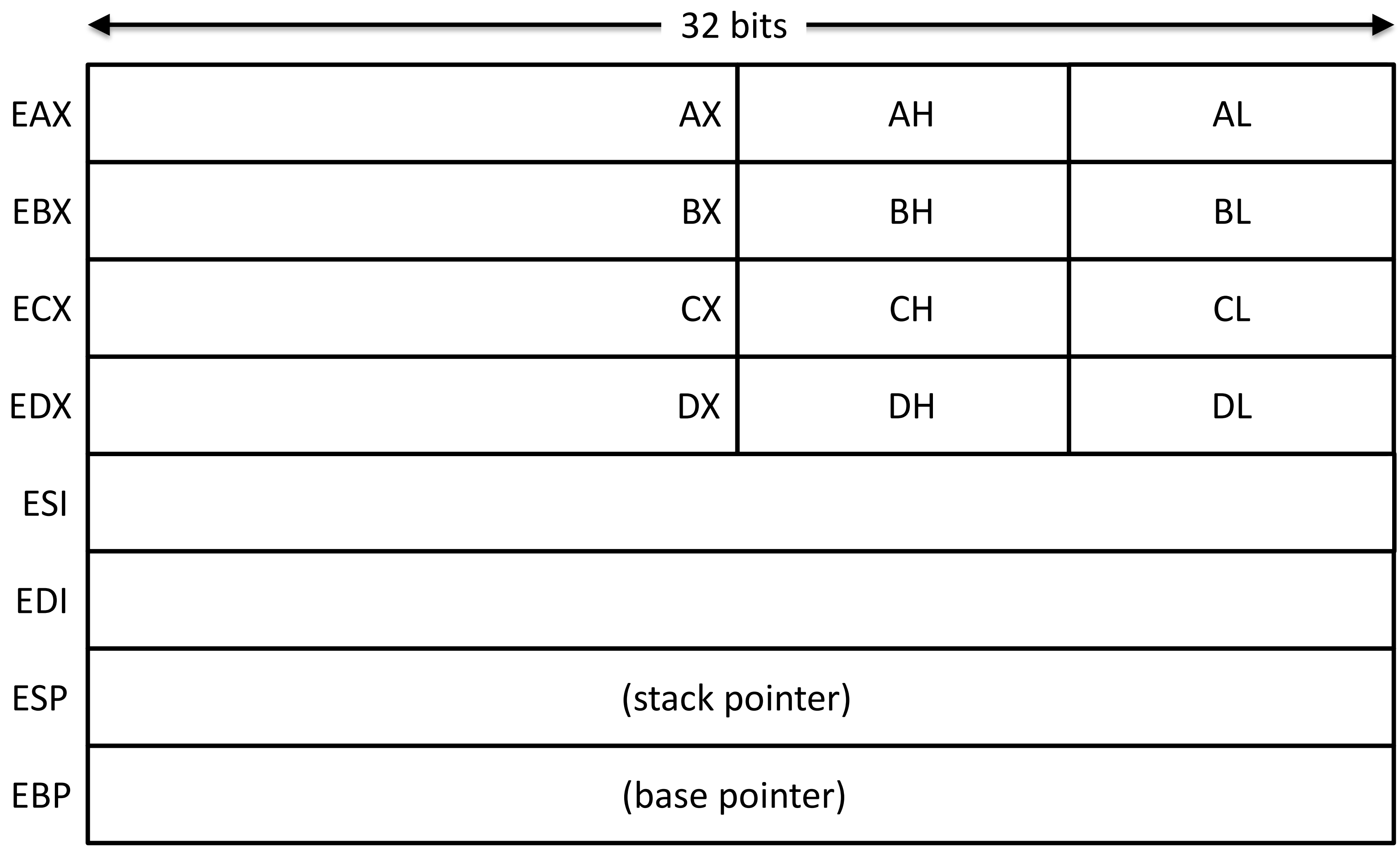
global uninitialized variables

heap
- Dynamic variables

stack
- Local variables
- Function call data

Env
- Environment variables
- Program arguments

Registers


32 bits
EAX
AX
AH
AL
EBX
BX
BH
BL
ECX
CX
CH
CL
EDX
DX
DH
DL
ESI
EDI
ESP
(stack pointer)
EBP
(base pointer)

Instruction Syntax

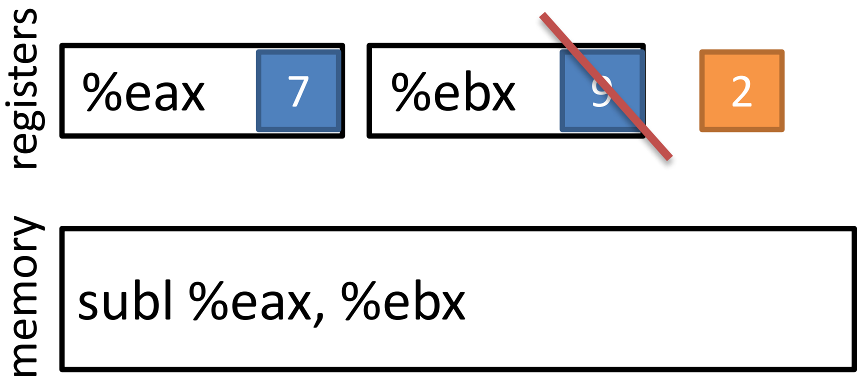
Examples:

```
subl $16, %ebx

movl (%eax), %ebx
```

- Instruction ends with data length
- opcode, src, dst
- Constants preceded by $
- Registers preceded by %
- Indirection uses ( )

Register Instructions: sub

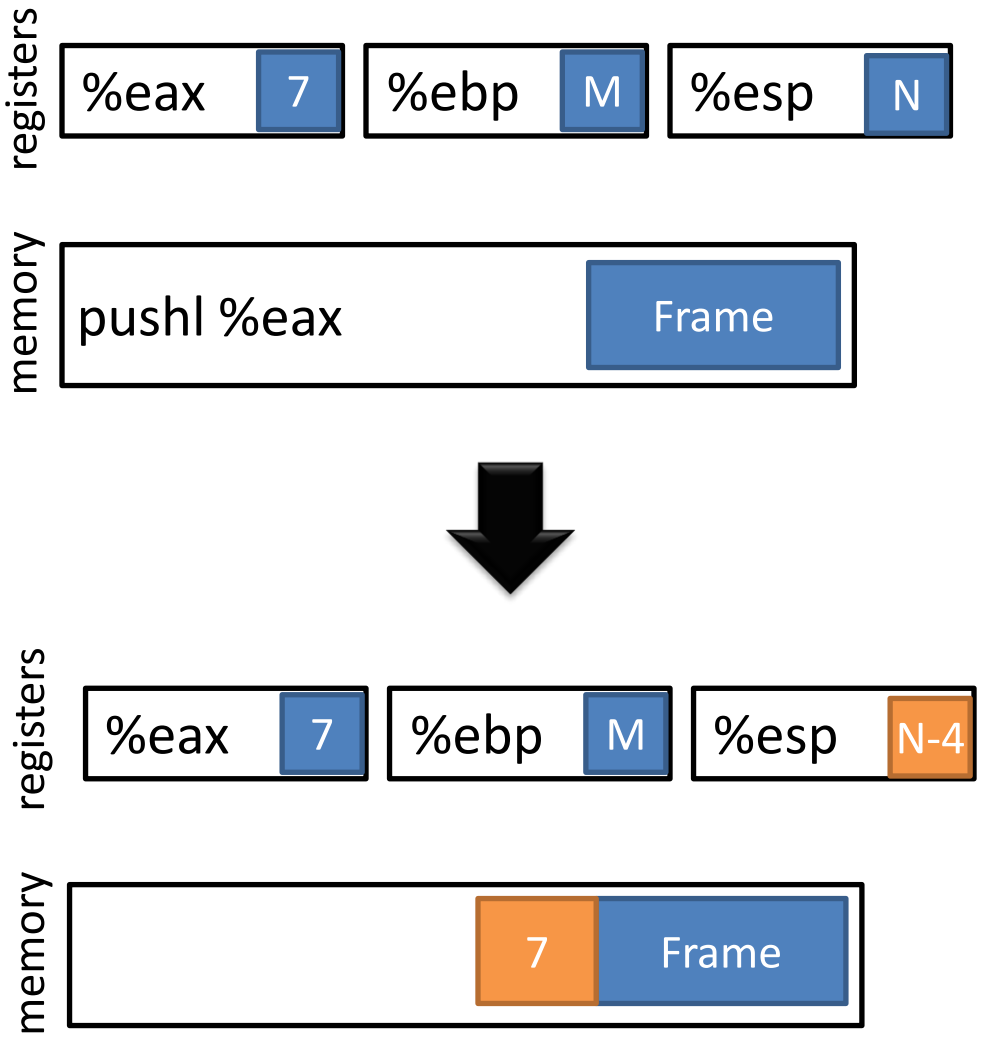


- Subtract from a register value

The Stack

- Local storage
  - Good place to keep data that doesn’t fit into registers
- Grows from high addresses towards low addresses

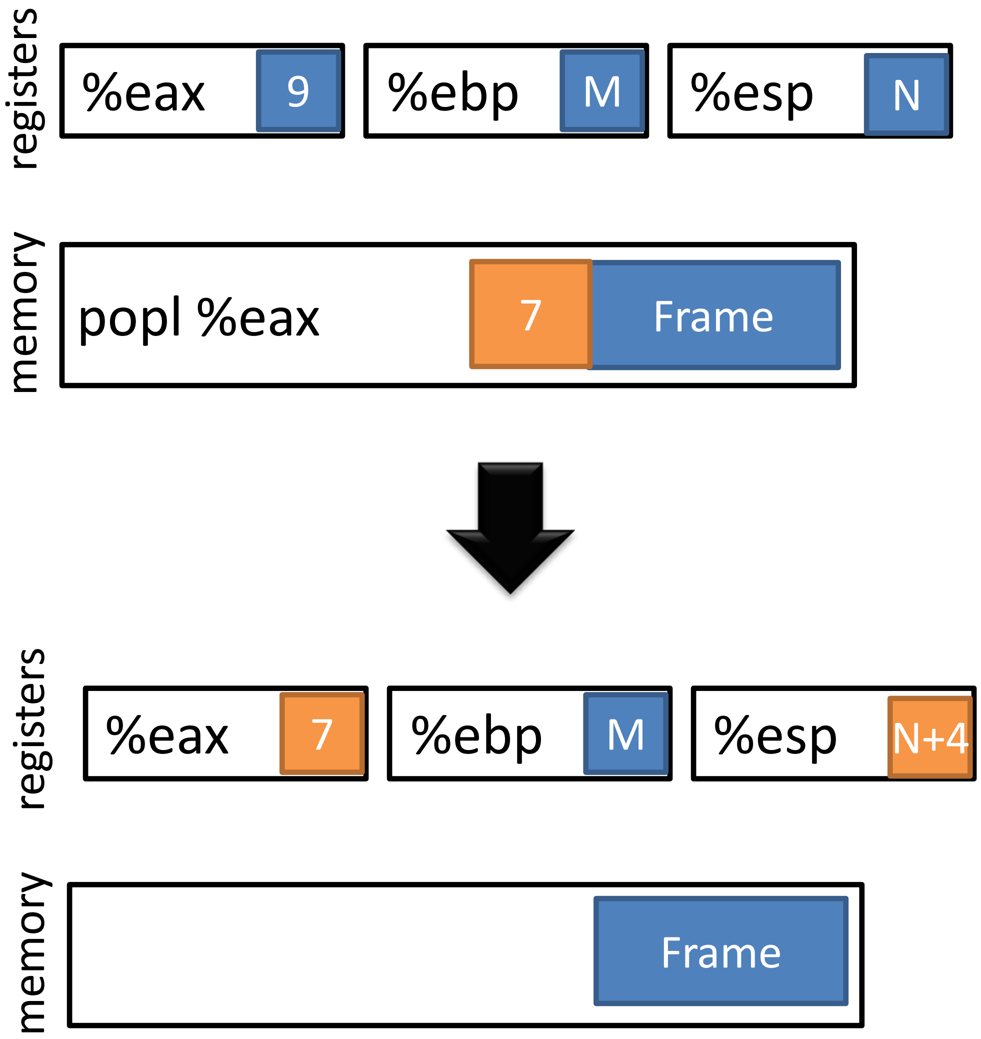
Frame Instructions: push



- Put a value on the stack
  - Pull from register
  - Value goes to %esp
  - Subtract from %esp
- Example:

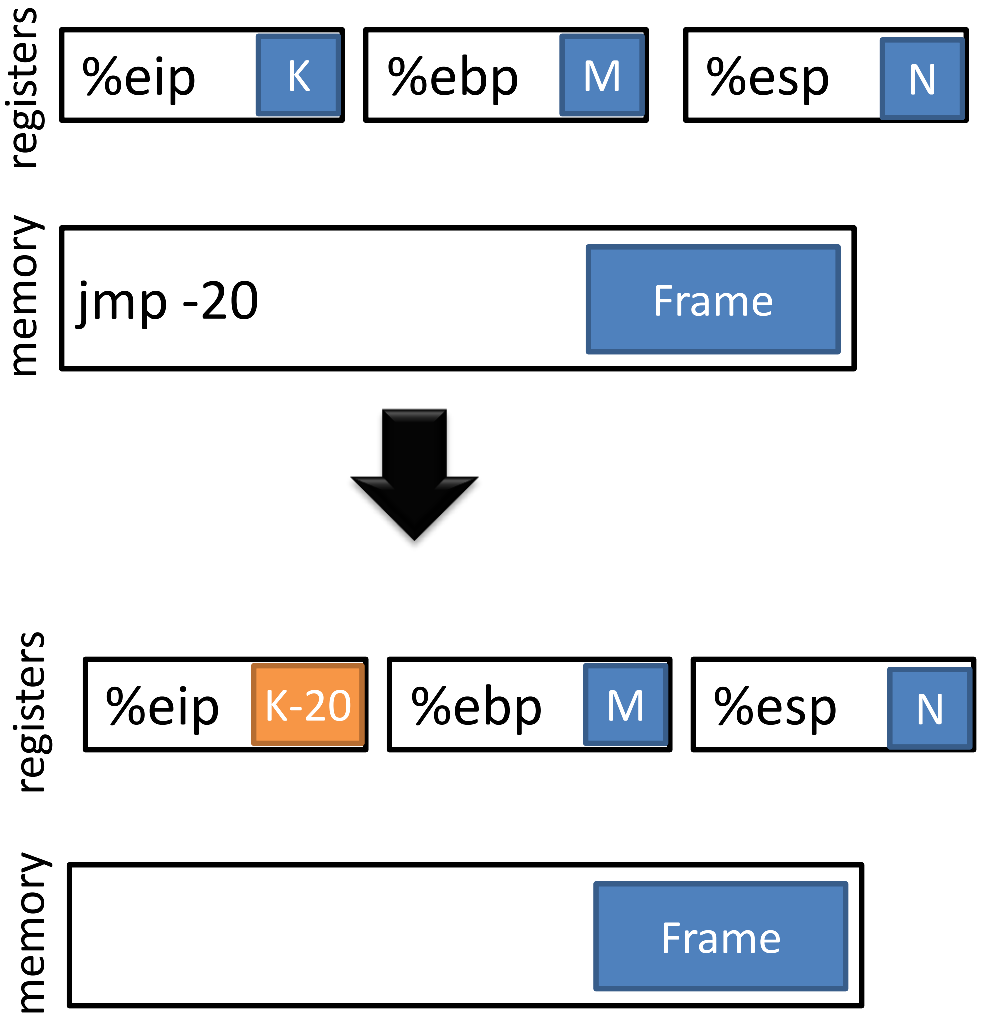
pushl %eax

Frame Instructions: pop



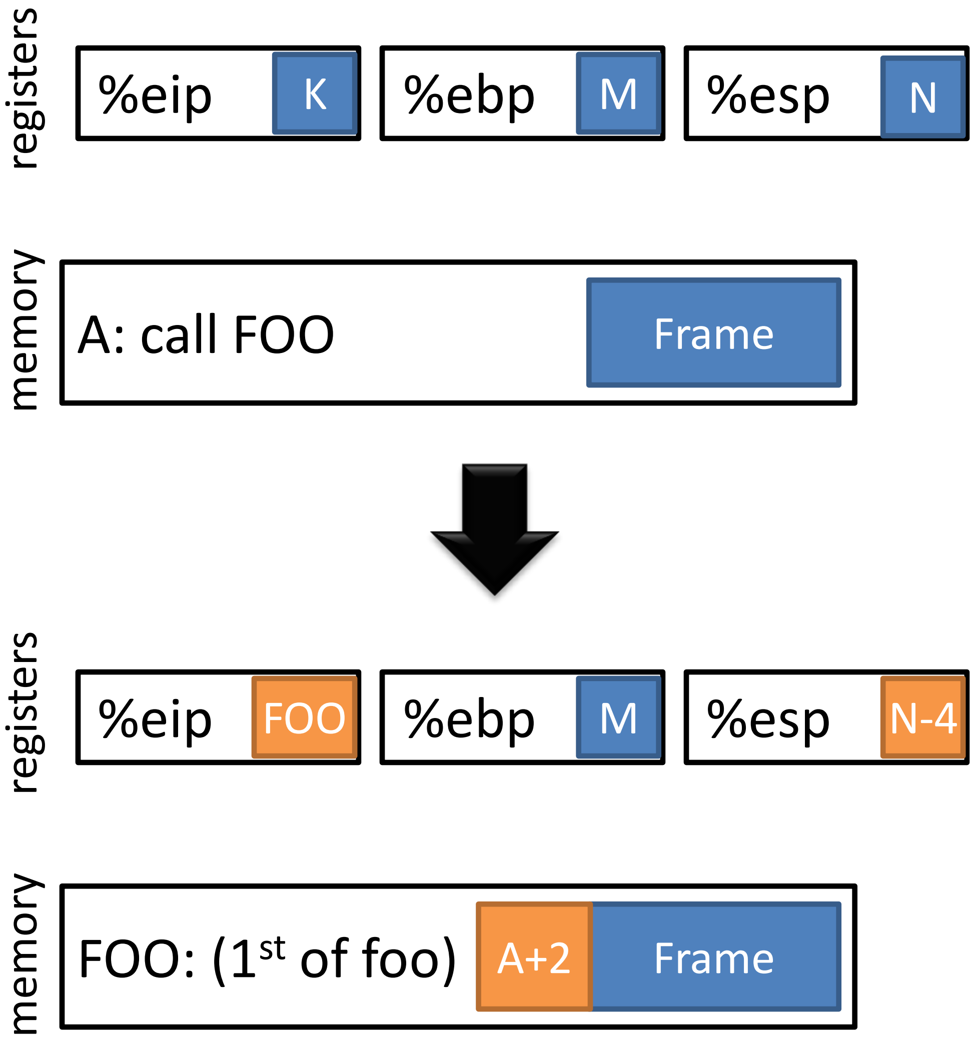
- Take a value from the stack
  - Pull from stack pointer
  - Value goes from %esp
  - Add to %esp

Control flow instructions: jmp



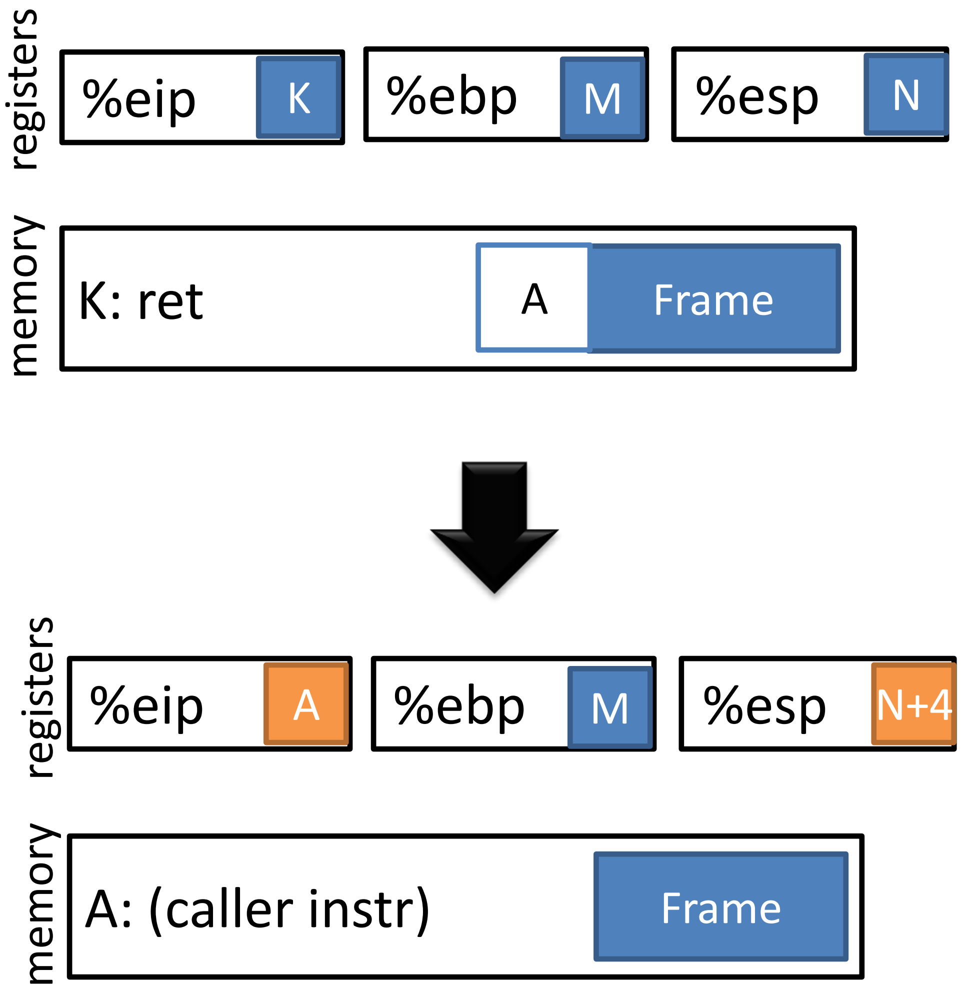
- %eip points to the currently executing instruction (in the text section)
- Has unconditional and conditional forms
- Uses relative addressing

Control flow instructions: call



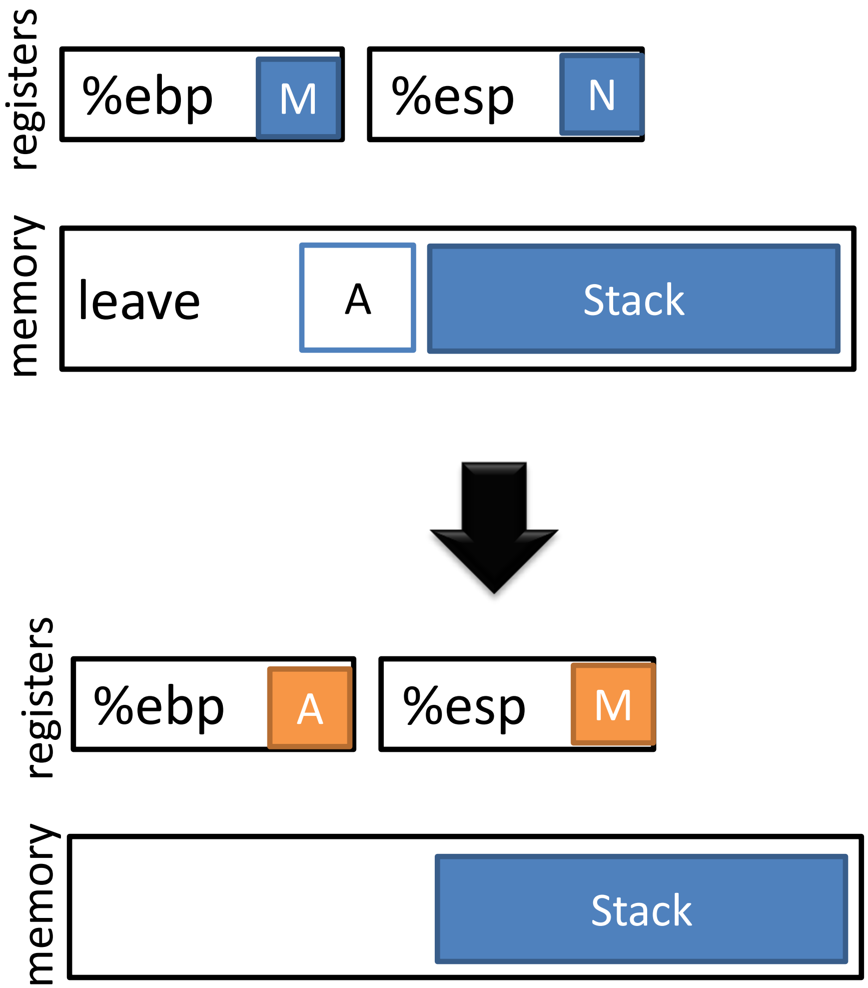
- Saves the current instruction pointer to the stack
- Jumps to the argument value

Control flow instructions: ret



- Pops the stack into the instruction pointer

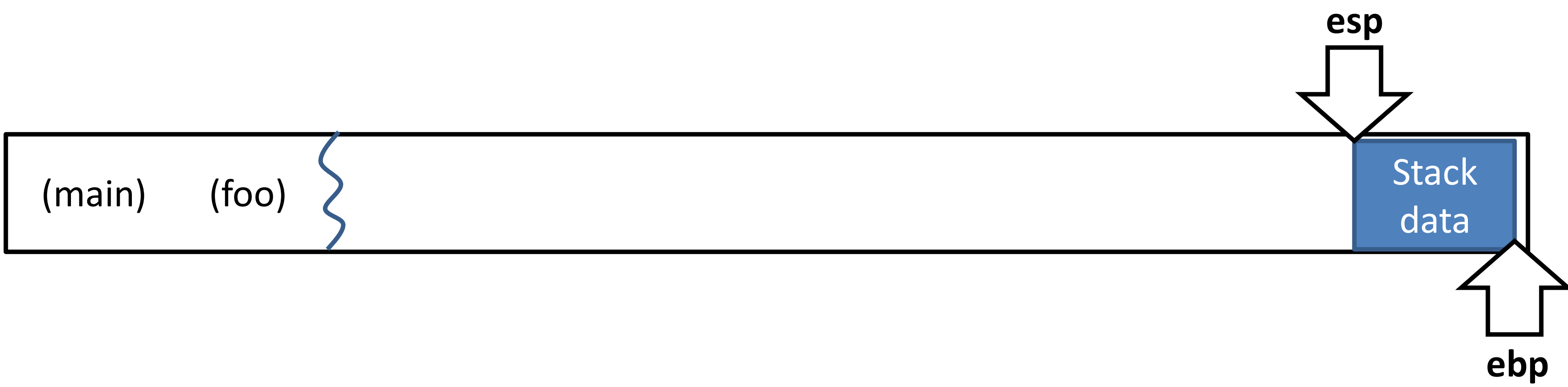
Stack instructions: leave



- Equivalent to

```
movl %ebp, %esp
popl %ebp
```

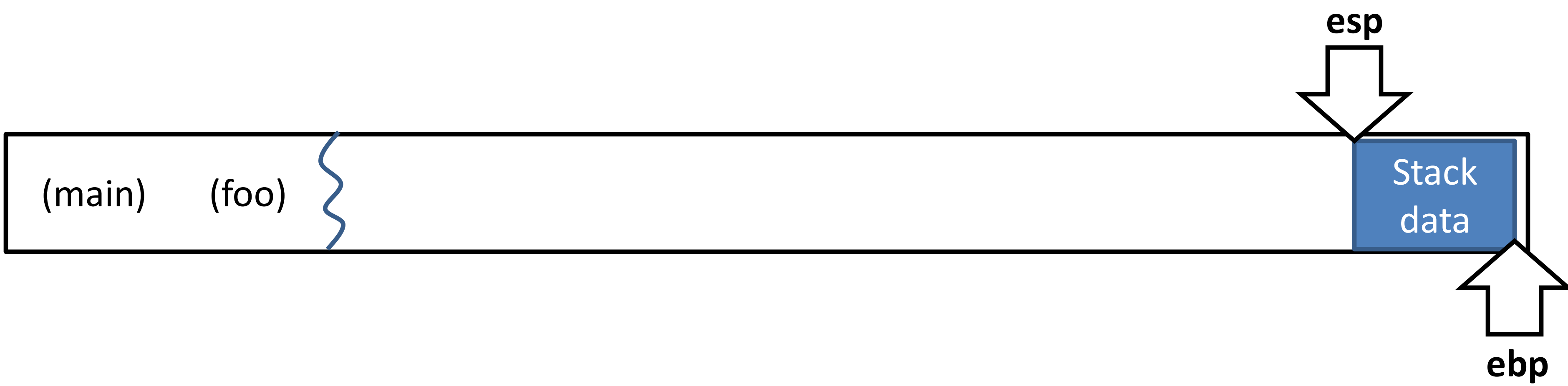
Implementing a function call

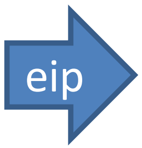



```
main:
    …
    subl    $8, %esp
    movl    $2, 4(%esp)
    movl    $1, (%esp)
    call    foo
    addl    $8, %esp
    …
```

```
foo:
    pushl   %ebp
    movl    %esp, %ebp
    subl    $16, %esp
    movl    $3, -4(%ebp)
    movl    8(%ebp), %eax
    addl    $9, %eax
    leave
    ret
```

Implementing a function call






```
main:
    …
    subl    $8, %esp
    movl    $2, 4(%esp)
    movl    $1, (%esp)
    call    foo
    addl    $8, %esp
    …
```

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    leave
    ret
```

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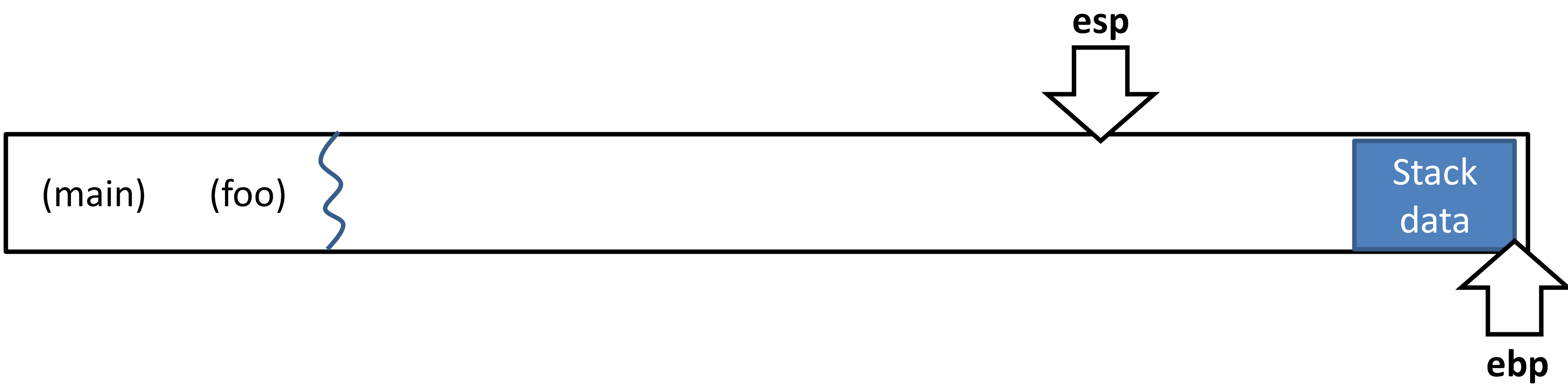


```
main:
    …
    subl    $8, %esp
    movl    $2, 4(%esp)
    movl    $1, (%esp)
    call    foo
    addl    $8, %esp
    …
```

```
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    ret
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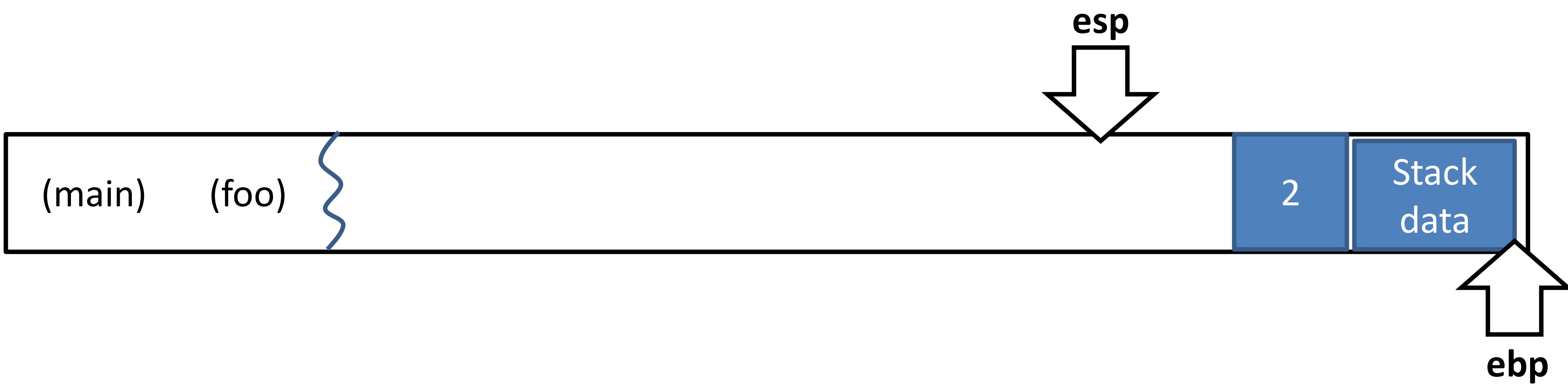
Implementing a function call

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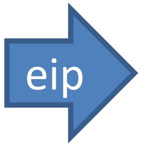
    movl    $1, (%esp)
    call    foo
    addl    $8, %esp
    …
```




```
foo:
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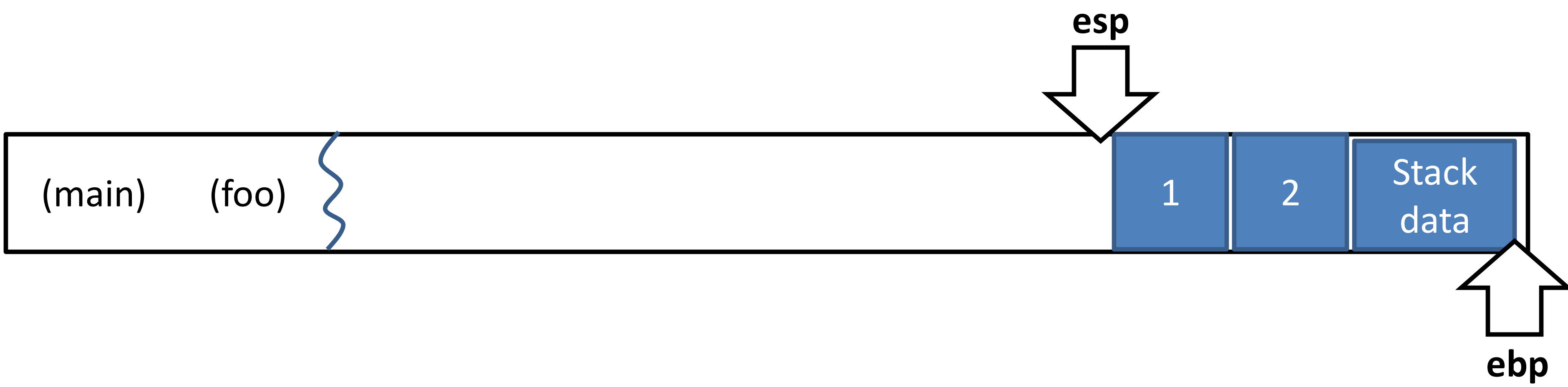
    movl    %esp, %ebp
    subl    $16, %esp
    movl    $3, -4(%ebp)
    movl    8(%ebp), %eax
    addl    $9, %eax
    leave
    ret
```

Implementing a function call

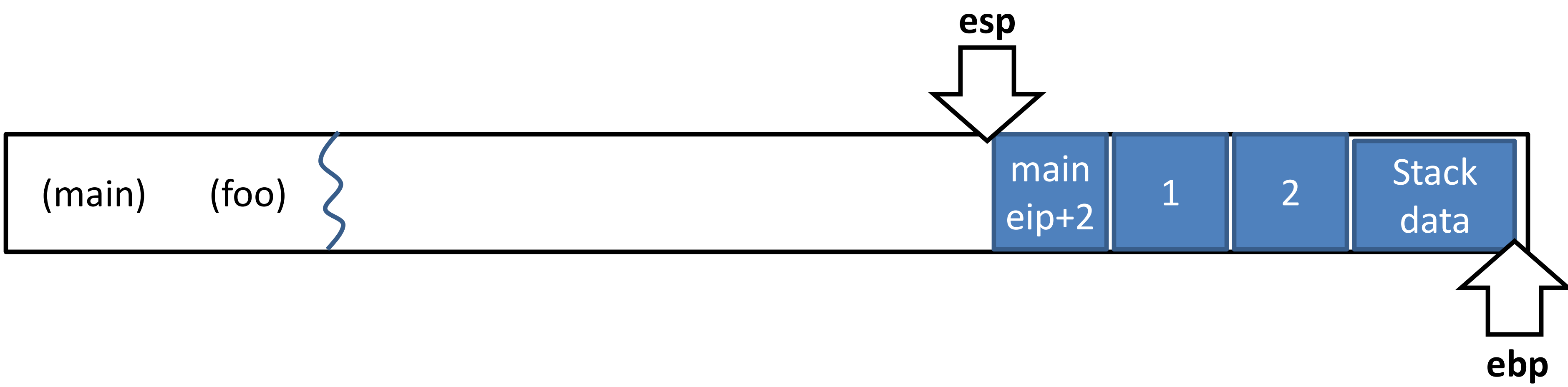



```
main:
    …
    subl    $8, %esp
    movl    $2, 4(%esp)
    movl    $1, (%esp)
    call    foo
    addl    $8, %esp
    …
```

eip

```
foo:
    pushl   %ebp
    movl    %esp, %ebp
    subl    $16, %esp
    movl    $3, -4(%ebp)
    movl    8(%ebp), %eax
    addl    $9, %eax
    leave
    ret
```

Implementing a function call




```
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    …
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    movl    $2, 4(%esp)
    movl    $1, (%esp)
    call    foo
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    …
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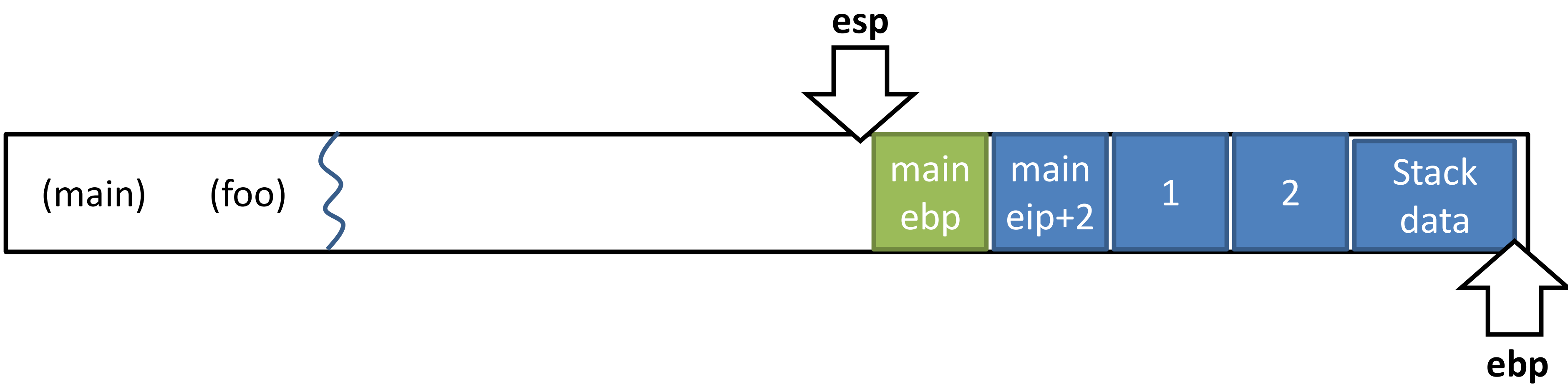


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    subl     $8, %esp
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    movl     $1, (%esp)
    call     foo
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        ret
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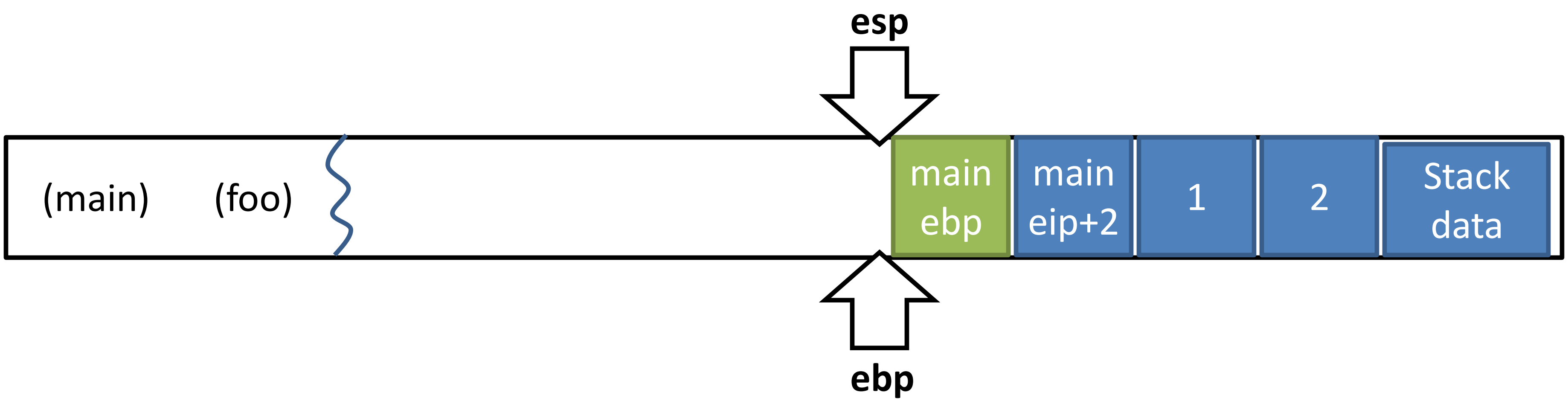


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    movl    $1, (%esp)
    call    foo
    addl    $8, %esp
    …
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```
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    movl    %esp, %ebp
eip subl    $16, %esp
    movl    $3, -4(%ebp)
    movl    8(%ebp), %eax
    addl    $9, %eax
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    ret
```

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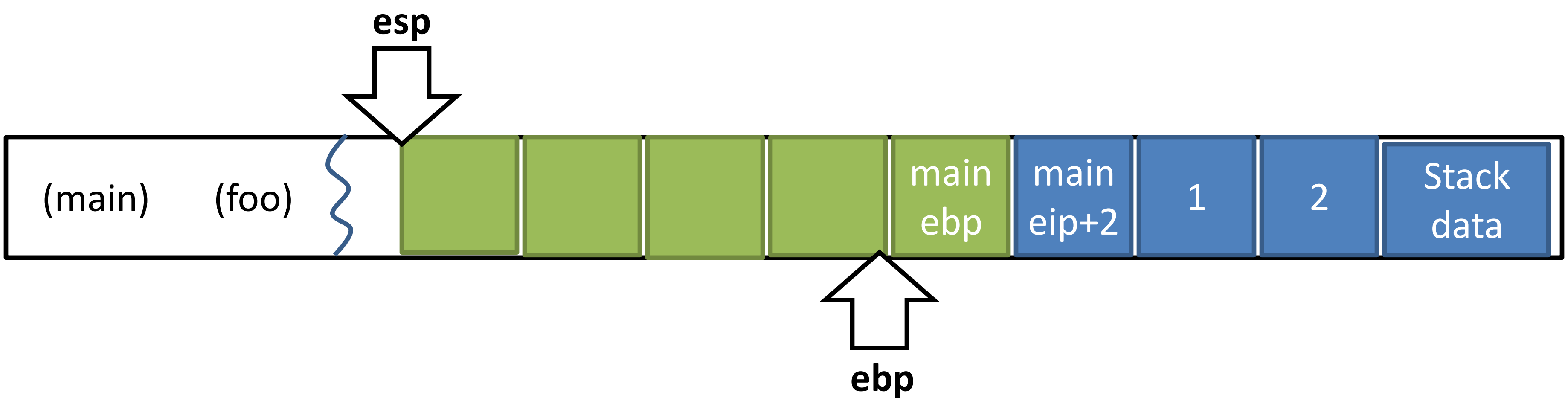


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    …
    subl    $8, %esp
    movl    $2, 4(%esp)
    movl    $1, (%esp)
    call    foo
    addl    $8, %esp
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        movl    8(%ebp), %eax
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        ret
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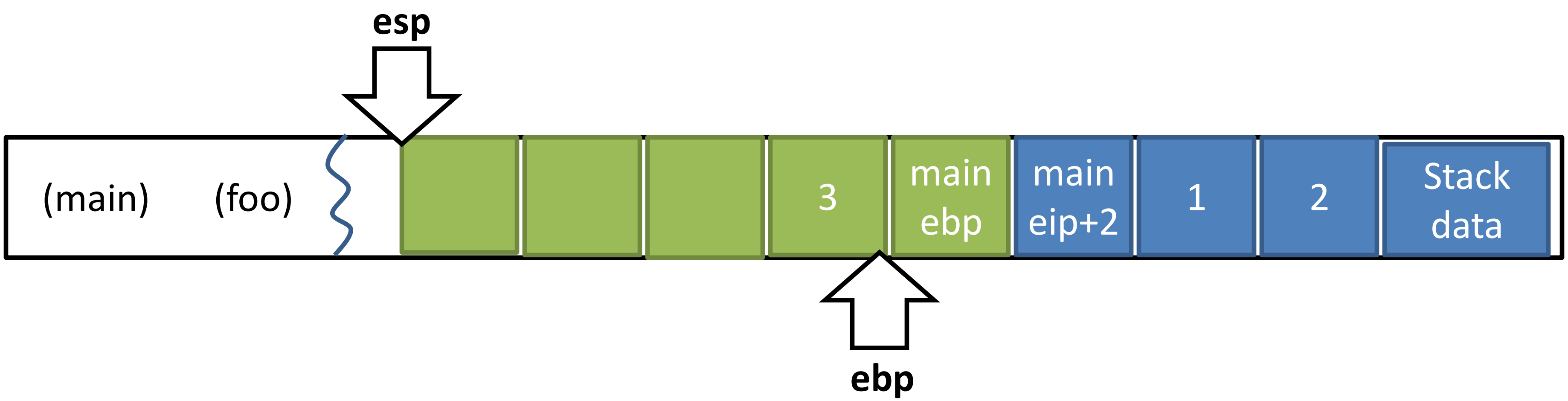


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    subl    $16, %esp
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    ret
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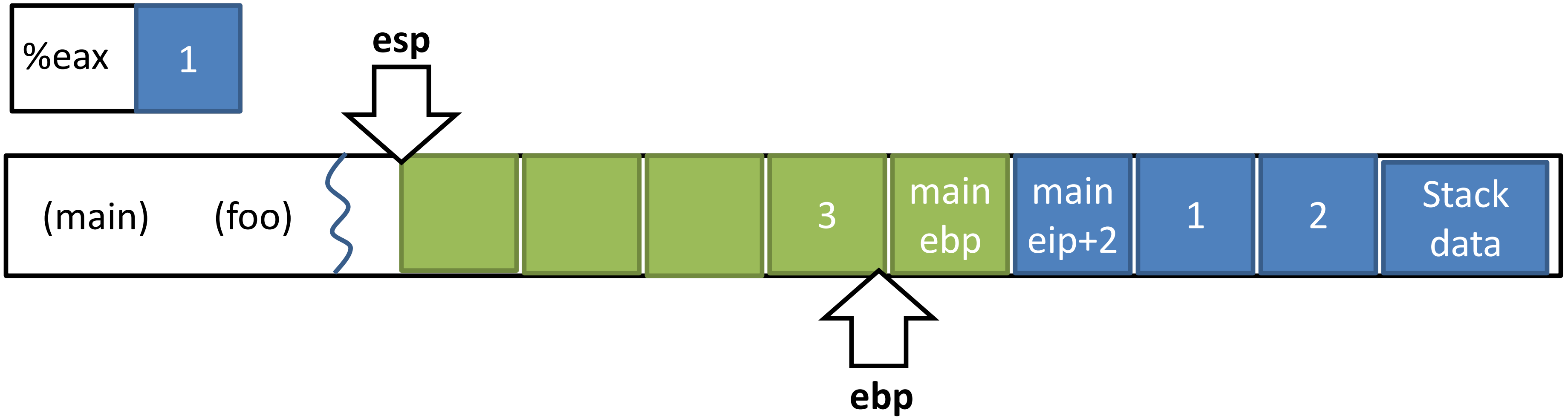
Implementing a function call

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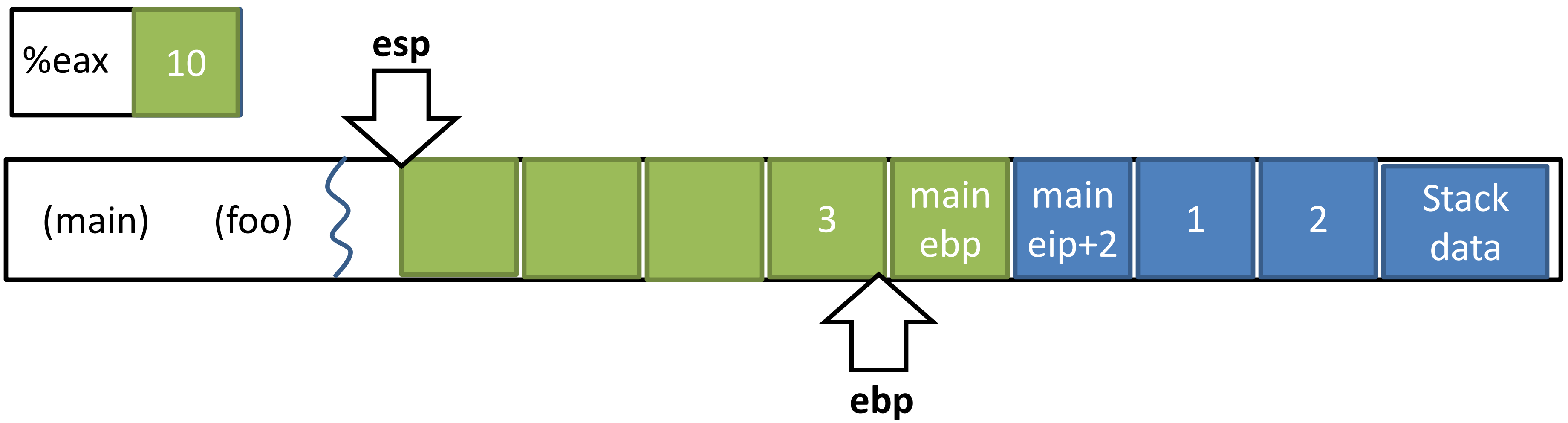
```

Implementing a function call

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    …
    subl    $8, %esp
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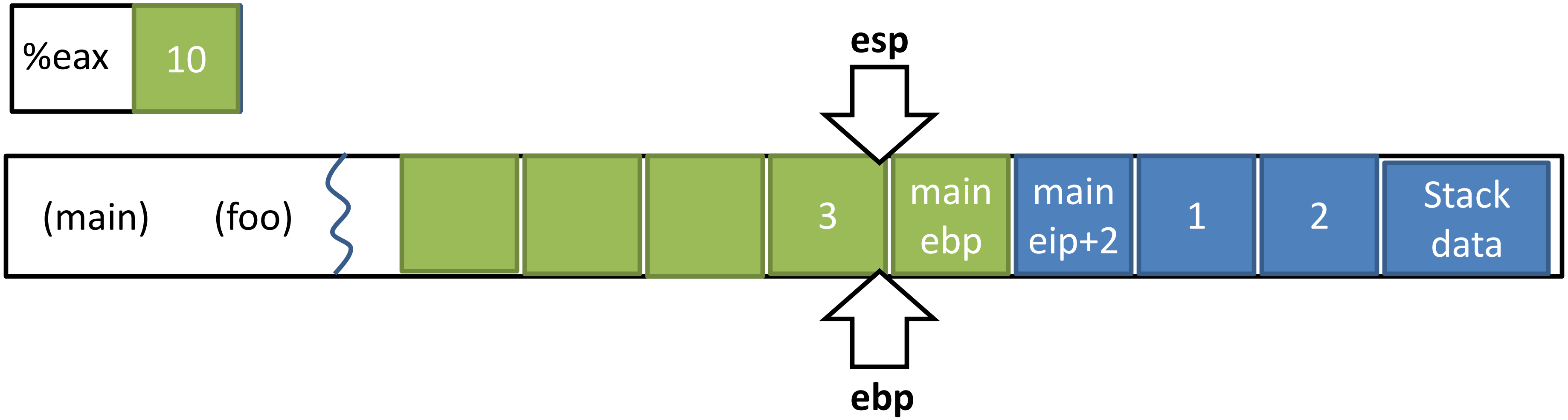
    ret
```

Implementing a function call




```
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    …
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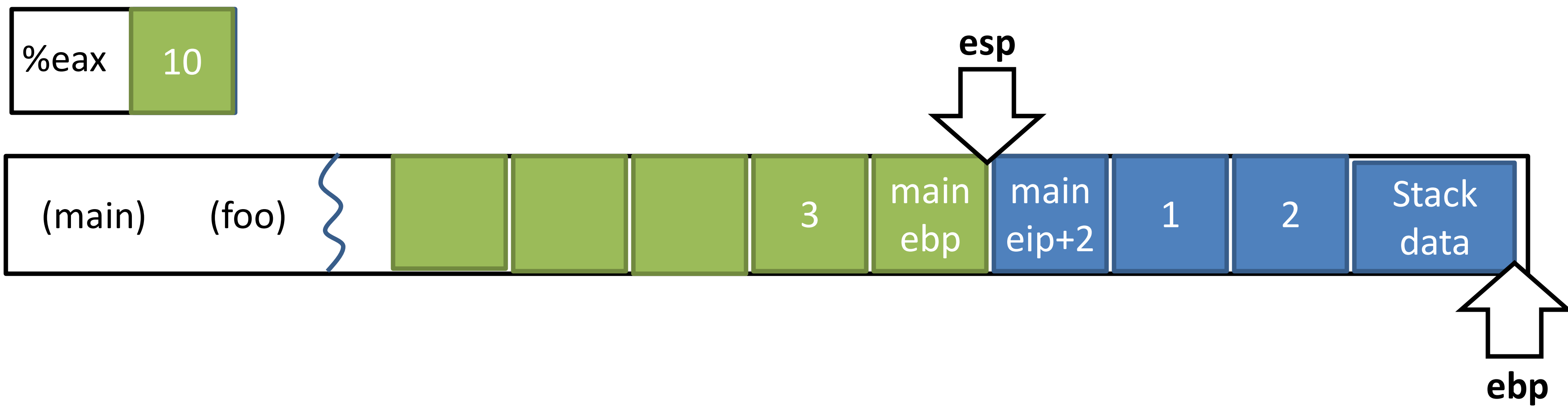
eip →   leave
        ret
```

Implementing a function call




```
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    …
    subl    $8, %esp
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    movl    $1, (%esp)
    call    foo
    addl    $8, %esp
    …
```

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    pushl   %ebp
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    subl    $16, %esp
    movl    $3, -4(%ebp)
    movl    8(%ebp), %eax
    addl    $9, %eax
    leave
eip → ret
```

Implementing a function call


```
main:
    …
    subl    $8, %esp
    movl    $2, 4(%esp)
    movl    $1, (%esp)
    call    foo
eip →  addl    $8, %esp
    …
```

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    movl    8(%ebp), %eax
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Implementing a function call


```
main:
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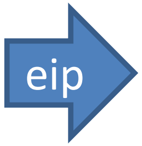
    movl    $1, (%esp)
    call    foo
    addl    $8, %esp
    …
```




```
foo:
    pushl   %ebp
    movl    %esp, %ebp
    subl    $16, %esp
    movl    $3, -4(%ebp)
    movl    8(%ebp), %eax
    addl    $9, %eax
    leave
    ret
```

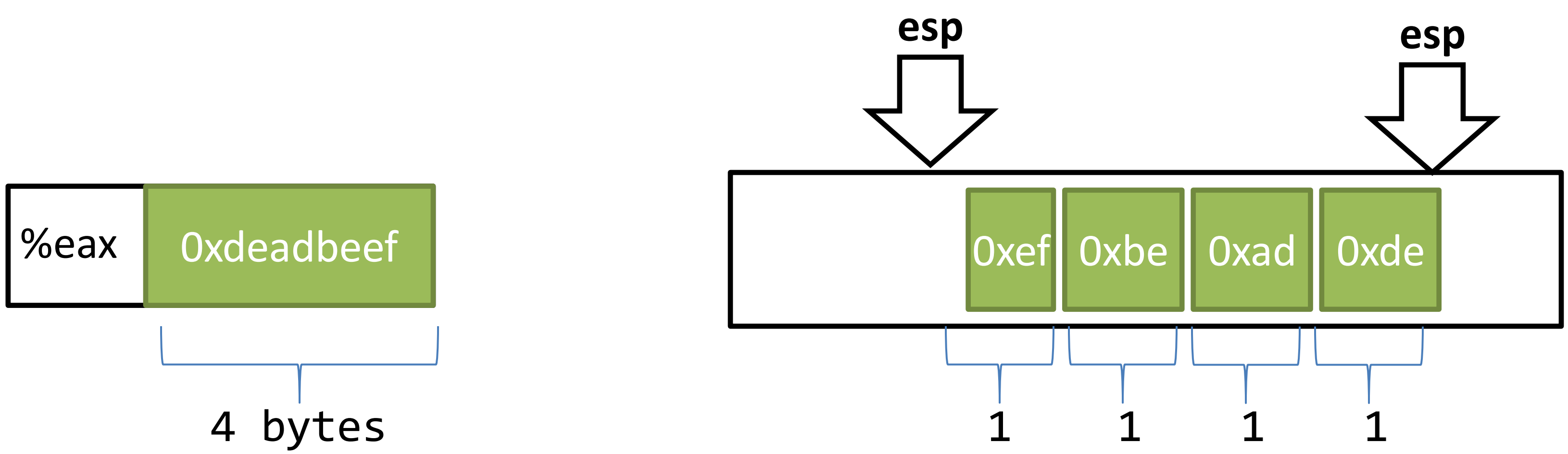
Function Calls: High level points

- Locals are organized into stack frames
  - Callees exist at lower address than the caller
- On call:
  - Save %eip so you can restore control
  - Save %ebp so you can restore data
- Implementation details are largely by convention
  - Somewhat codified by hardware

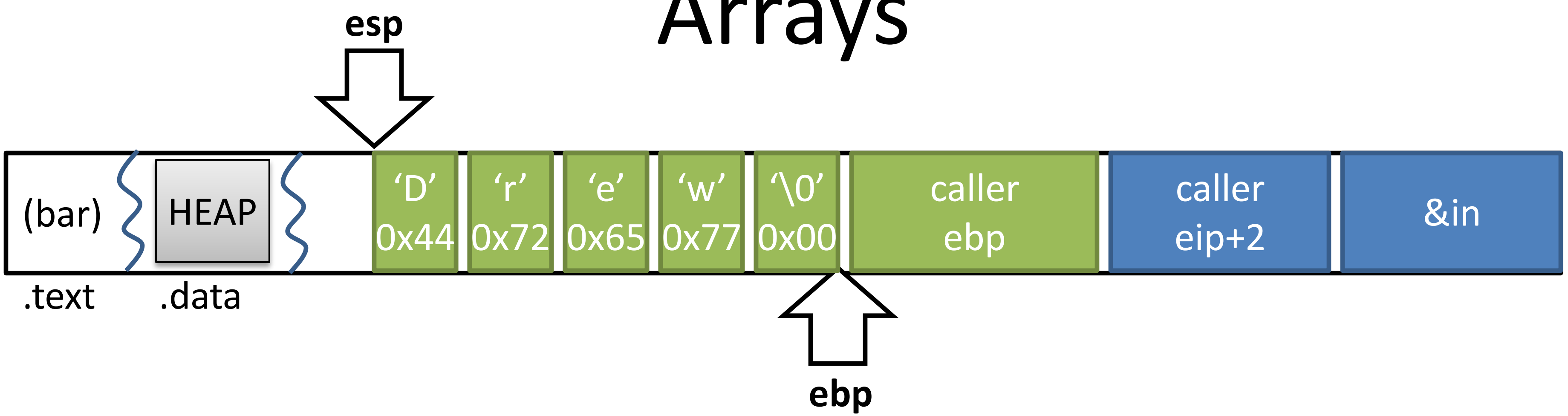
Data types / Endianness

- x86 is a little-endian architecture

```
pushl %eax
```



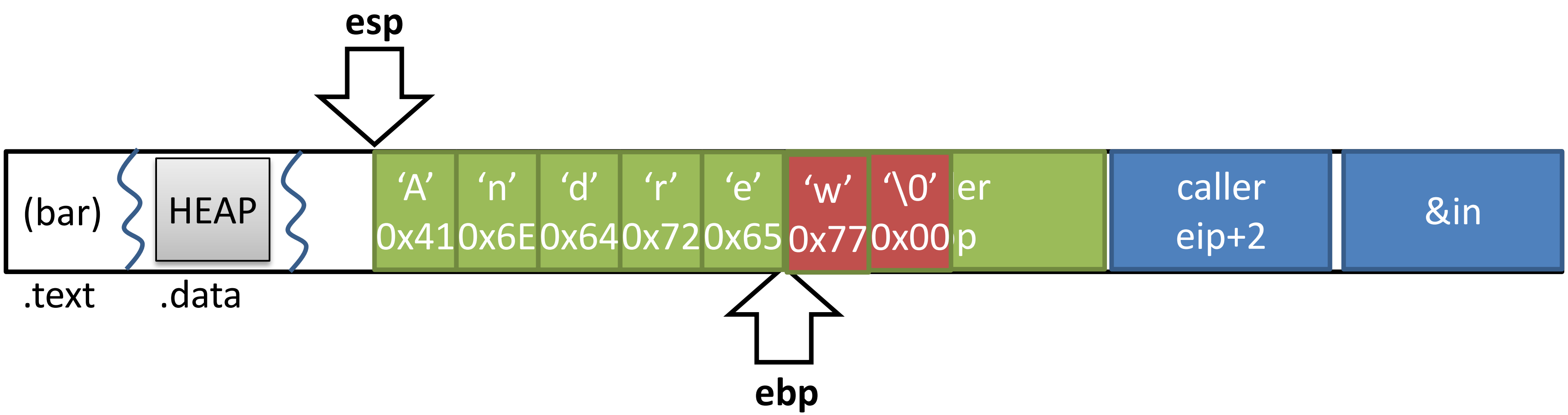
Arrays




```
void bar(char * in){
  char name[5];
  strcpy(name, in);
}
```

```
bar:
  pushl   %ebp
  movl    %esp, %ebp
  subl    $5, %esp
  movl    8(%ebp), %eax
  movl    %eax, 4(%esp)
  leal    -5(%ebp), %eax
  movl    %eax, (%esp)
  call    strcpy
  leave
  ret
```

What if you have a long name?




```
void bar(char * in){
  char name[5];
  strcpy(name, in);
}
```

```
bar:
  pushl   %ebp
  movl    %esp, %ebp
  subl    $5, %esp
  movl    8(%ebp), %eax
  movl    %eax, 4(%esp)
  leal    -5(%ebp), %eax
  movl    %eax, (%esp)
  call    strcpy
  leave
  ret
```

Buffer Overflow!

- You know it!
- I know it
- C doesn’t know it
  - In this case, the return is likely to cause a catastrophic failure upon return (seg fault)
  - If you are “lucky” the overflow might only overwrite unused locals and never manifest a bug
- Java *does* know it’s a buffer overflow
  - ArrayIndexOutOfBoundsException

Next Time

Exploiting buffer overflows

Tools: GCC

```
gcc –O0 –S program.c –o program.S –m32
```

```
gcc –O0 –g program.c –o program –m32
```

Tools: GDB

```
gdb program
(gdb) run
(gdb) disas foo
(gdb) quit
```

Tools: objdump

```
objdump –Dwrt program
```

Tools: od

```
od –x program
```

Summary

- Basics of x86
  - Process layout
  - ISA details
  - Most of the instructions that you'll need
- Introduced the concept of a buffer overflow
- Some tools to play around with x86 assembly