CS 88: Security and Privacy

03: Software Security – Buffer Overflow Attacks

01-30-2024

SWARTHMORE COLLEGE

Announcements

- Clicker registrations posted – let me know if I don’t have yours
- Please choose partnerships for Lab 1 (EdStem) – last chance.
- Reading quizzes count from this week
- Lab 0 is due today
- Midterm dates on edstem later today

Reading Quiz

Today

- What is software security
- CS 31 Recap:
  - functions and the stack
  - assembly instructions
- Stack Buffer Overflow

Software Security

When is a program secure?

A. When it does what we want it to do
B. When we ensure that bad inputs do not result in unintended functionality
C. We need B + some more safeguards (what are some examples?)
D. We can never have a secure program

When is a program secure?

- Formal approach: When it does exactly what it should
  - not more
  - not less
- But how do we know what it is supposed to do?

When is a program secure?

- Formal approach: When it does exactly what it should
  - not more
  - not less
- *But how do we know what it is supposed to do?*
  - somebody tells us (do we trust them?)
  - we write the code ourselves (what fraction of s/w have you written?)

When is a program secure?

- Pragmatic approach: when it doesn’t do bad things
- Often easier to specify a list of “bad” things:
  - delete or corrupt important files (integrity)
  - crash my system (availability)
  - send my password over the internet (confidentiality)
  - send phishing email

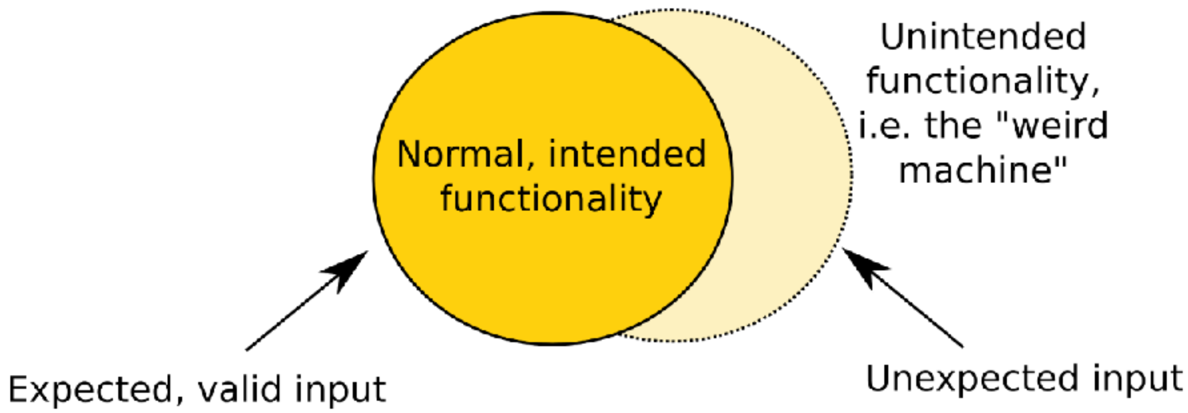
When is a program secure?

- But .. what if the program doesn’t do bad things, but could?

- is it secure?

Weird machines

- complex systems contain unintended functionality



- attackers can trigger this unintended functionality
  - i.e. they are exploiting vulnerabilities

What is a software vulnerability?

- A bug in a program that allows an unprivileged user capabilities that should be denied to them.
- There are a lot of types of vulnerabilities
  - bugs that violate “control flow integrity”
  - why? lets attacker run code on your computer!
- Typically these involve violating assumptions of the programming language or its run-time

Exploiting vulnerabilities (the start)

- Dive into low level details of how exploits work
  - How can a remote attacker get a victim program to execute their code?

- Threat model: victim code is handling input that comes from across a security boundary
  - what are examples of this?

- Security policy: want to protect integrity of execution and confidentiality of data from being compromised by malicious and highly skilled users of our system.

Today: stack buffer overflows

- Understand how buffer overflow vulnerabilities can be exploited
- Identify buffer overflows and asses their impact
- Avoid introducing buffer overflow vulnerabilities
- Correctly fix buffer overflow vulnerabilities

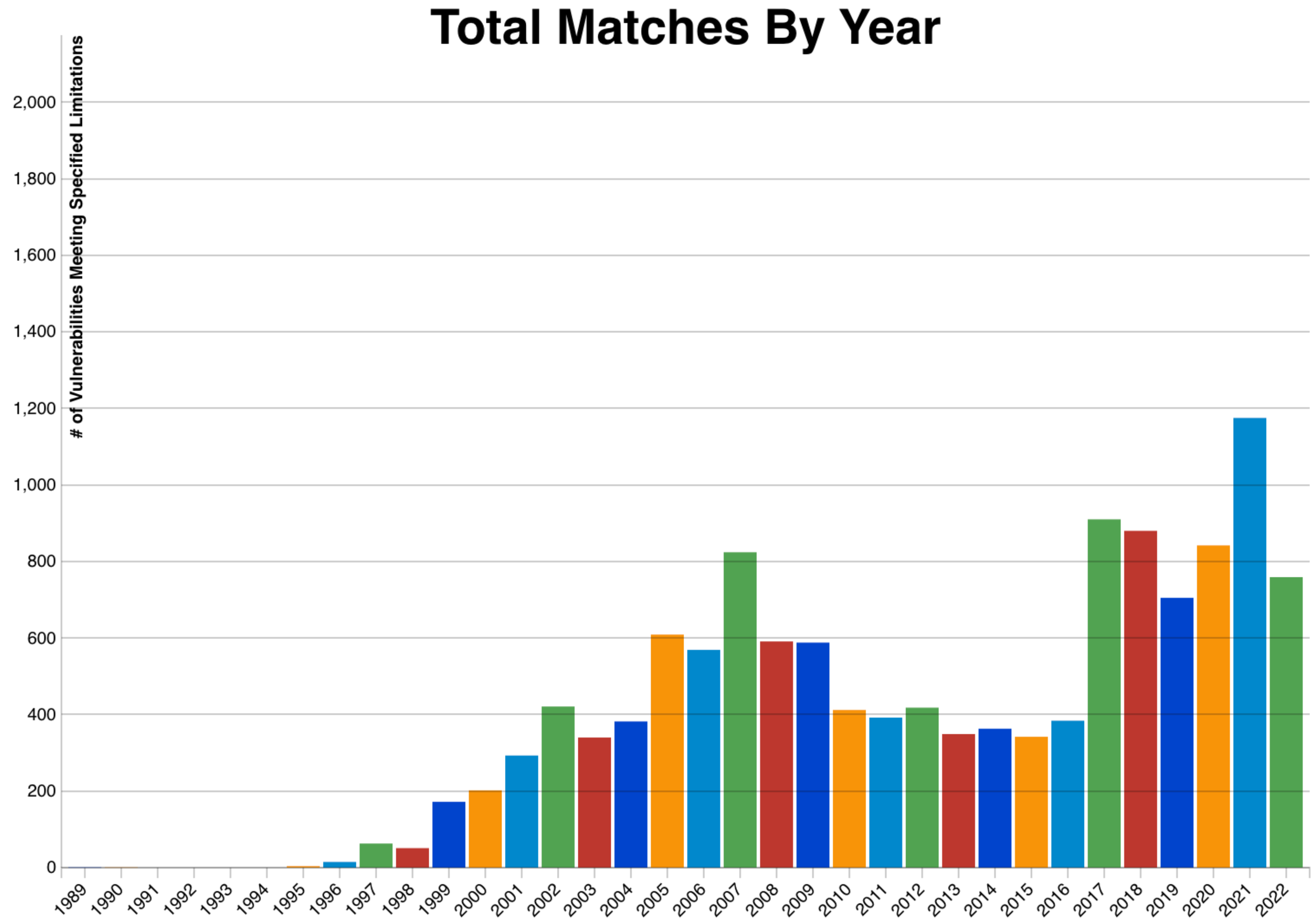
Buffer Overflows

- An anomaly that occurs when a program writes/reads data beyond the boundary of a buffer
- Canonical software vulnerability
  - ubiquitous in system software
  - OSes, web servers, web browsers
- If your program crashes with memory faults, you probably have a buffer overflow vulnerability

Search Parameters:

- Results Type: Statistics
- Keyword (text search): buffer overflow
- Search Type: Search All
- CPE Name Search: false

Common Vulnerabilities and Exposures (CVE): security flaw that is publicly known



Critical Systems are written in C/C++

- OS kernels
- High-performance servers
  - Apache, MySQL
- Embedded Systems
  - IoT deivices, “smart” vehicles, the MARs rover..

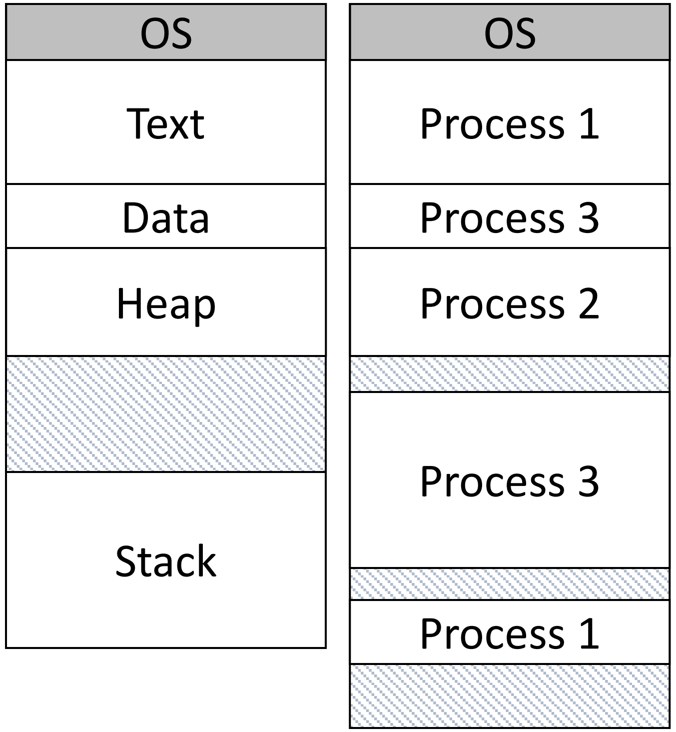
https://nvd.nist.gov/vuln/search

CS 31 Recap

Memory

- Abstraction goal: make every process think it has the same memory layout.
  - MUCH simpler for compiler if the stack always starts at 0xFFFFFFFF, etc.

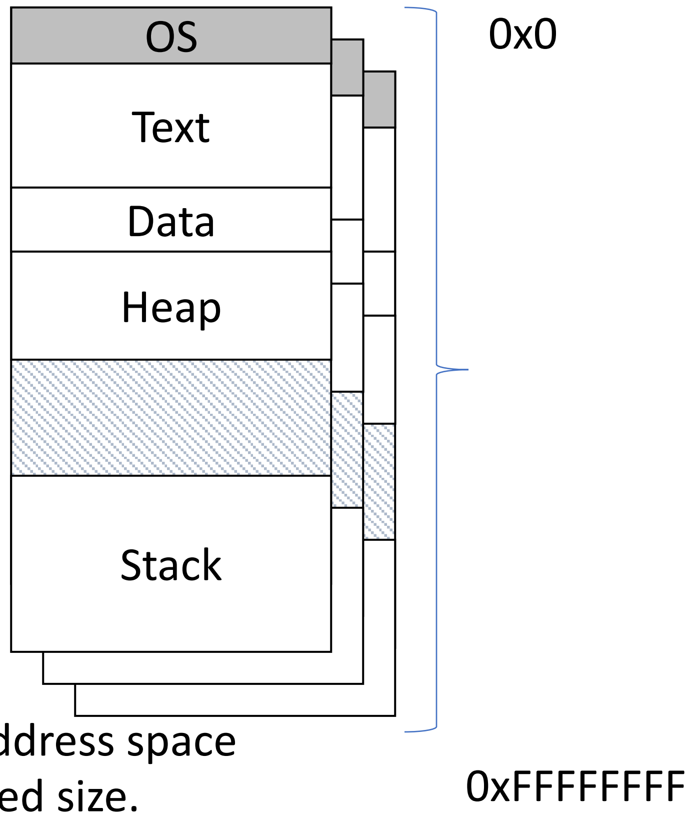
- Reality: there's only so much memory to go around, and no two processes should use the same (physical) memory addresses.



OS (with help from hardware) will keep track of who's using each memory region.

Memory Terminology

<u>Virtual (logical) Memory</u>: The abstract view of memory given to processes. Each process gets an independent view of the memory.

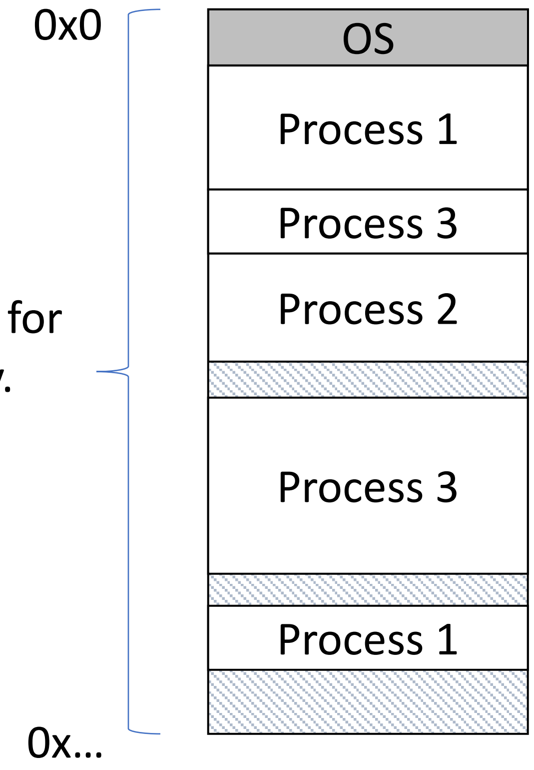


Virtual address space (VAS): fixed size.

<u>Address Space</u>: Range of addresses for a region of memory.

The set of available storage locations.

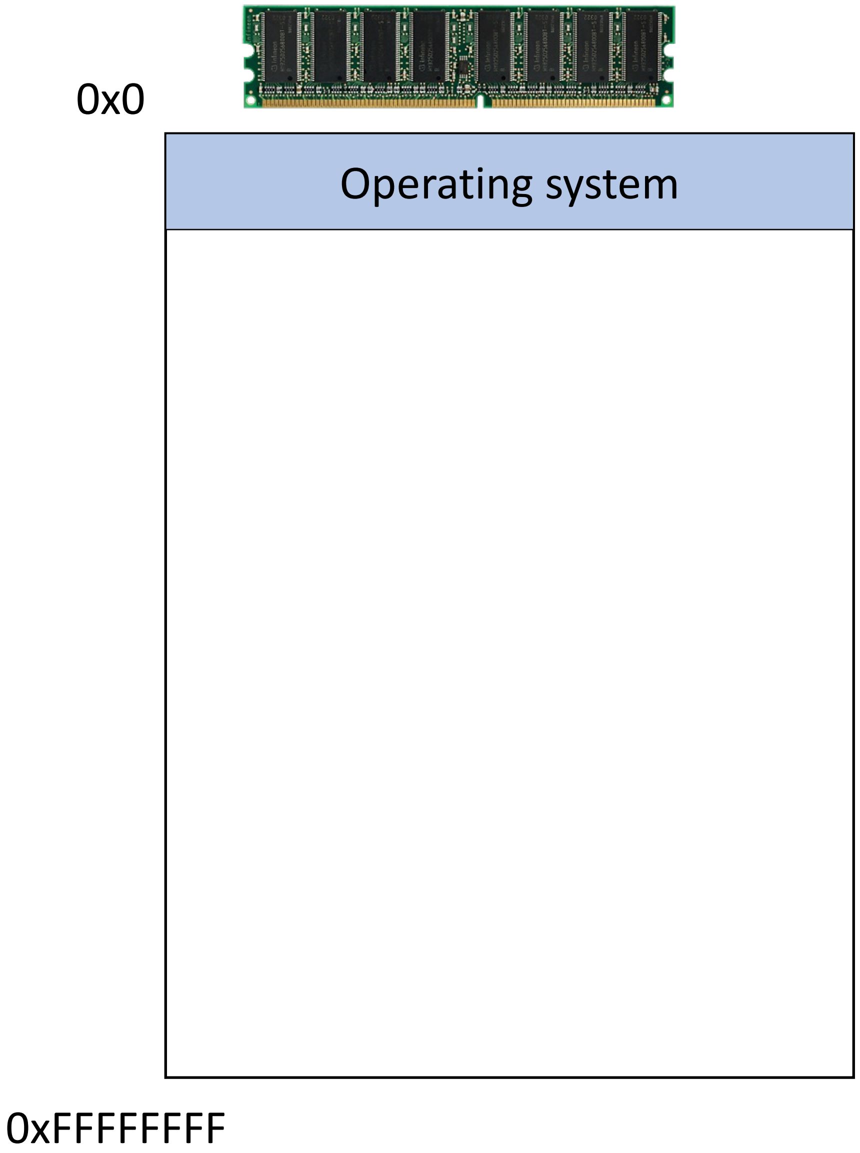
<u>Physical Memory</u>: The contents of the hardware (RAM) memory. Managed by OS. Only <u>ONE</u> of these for the entire machine!



(Determined by amount of installed RAM.)

Memory

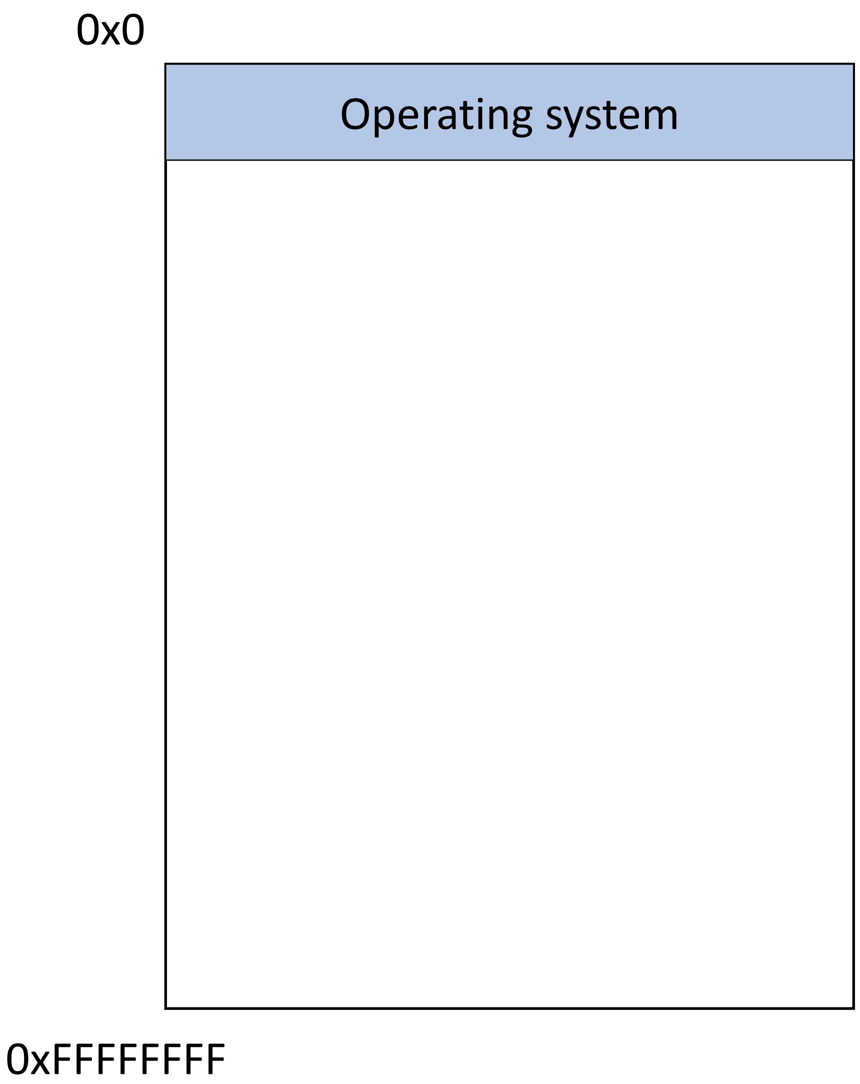
- Behaves like a big array of bytes, each with an address (bucket #).
- By convention, we divide it into regions.
- The region at the lowest addresses is usually reserved for the OS.



NULL: A special pointer value.

NULL is equivalent to pointing at memory address 0x0. This address is NEVER in a valid segment of your program's memory.

- This guarantees a segfault if you try to dereference it.
- Generally a good ideal to initialize pointers to NULL.

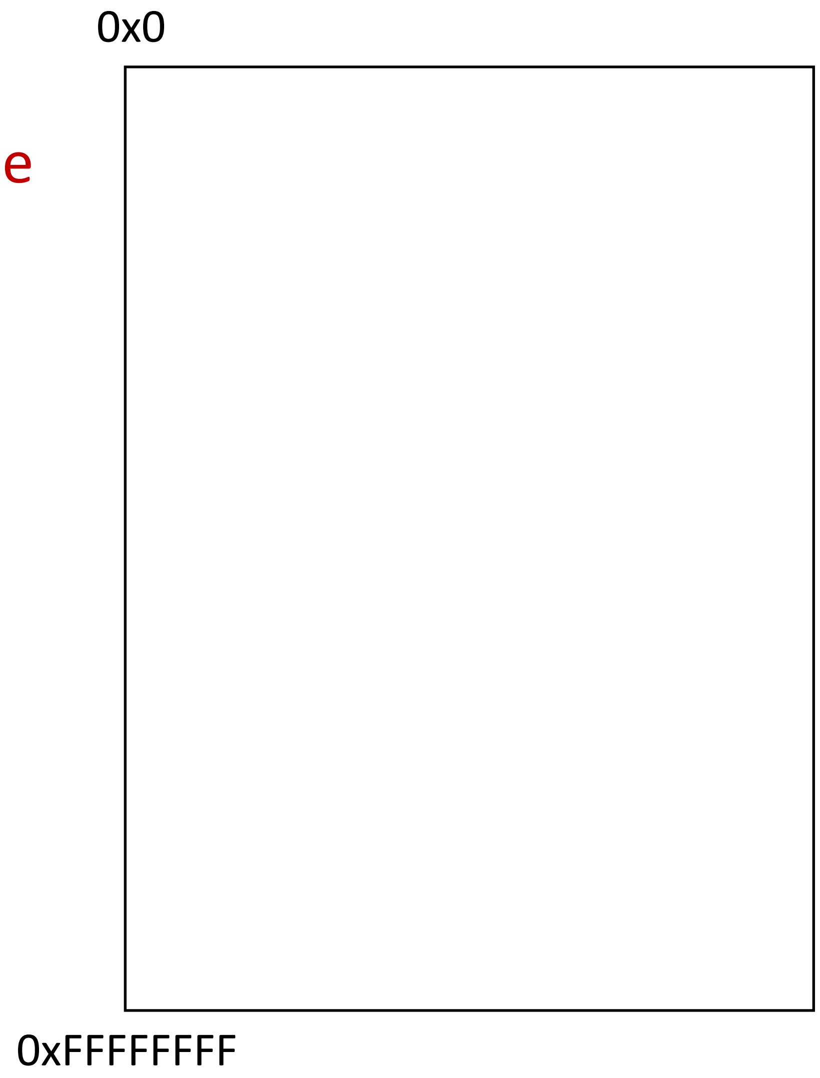


What happens if we launch an attack where we load an instruction to execute at 0x0

A. Nothing will happen, this region is mapped to the NULL pointer, which does not have any effect

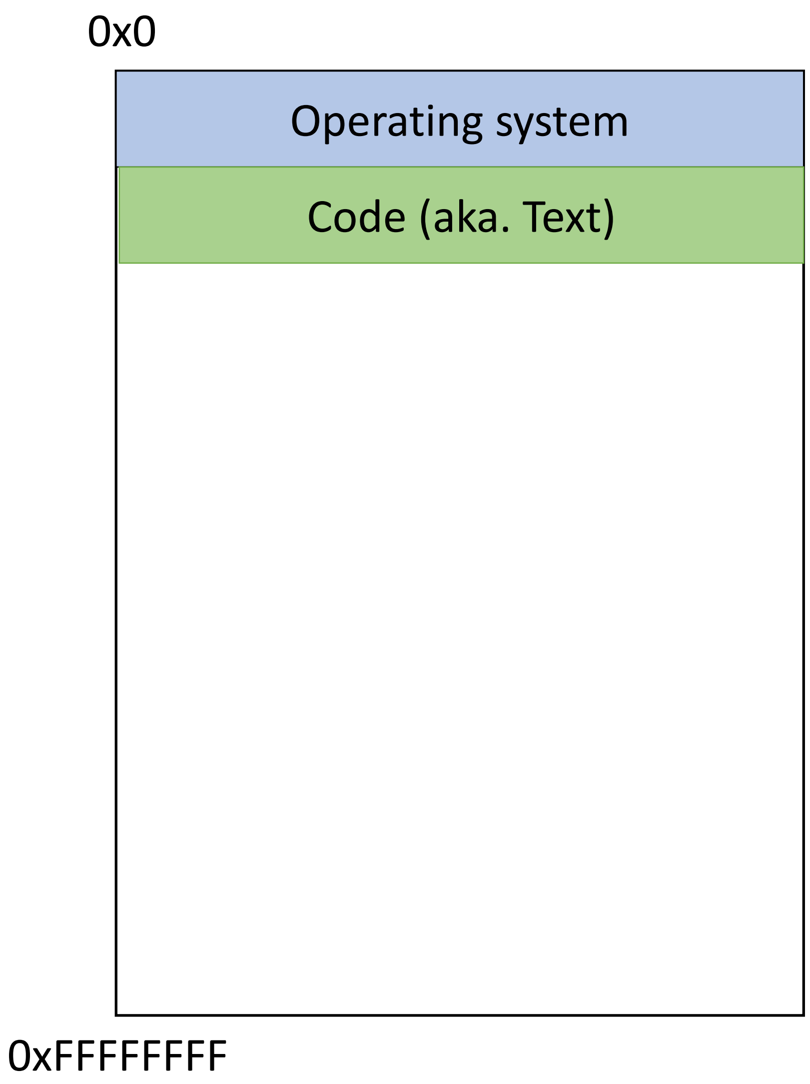
B. There will be some effect, but not necessarily devastating

C. This will have a devastating effect.



Memory - Text

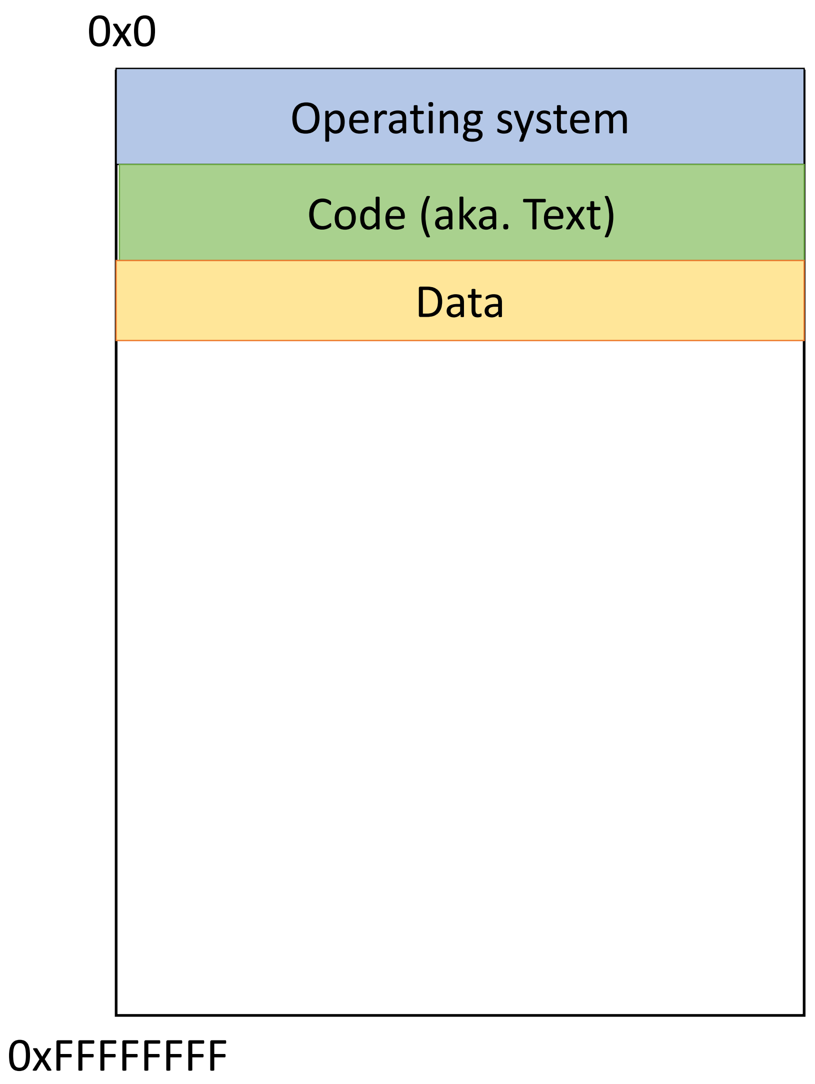
- After the OS, we store the program's code.
- Instructions generated by the compiler.



Memory – (Static) Data

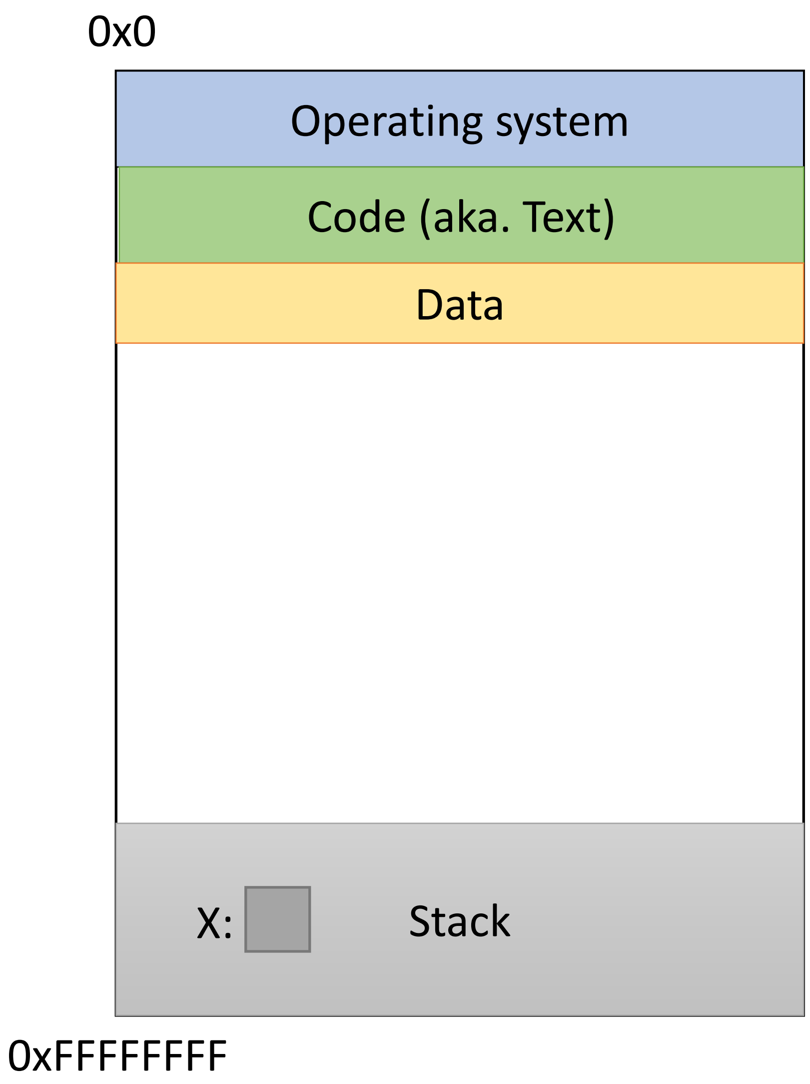
- Next, there's a fixed-size region for static data.

- This stores static variables that are known at compile time.
    - Global variables



Memory - Stack

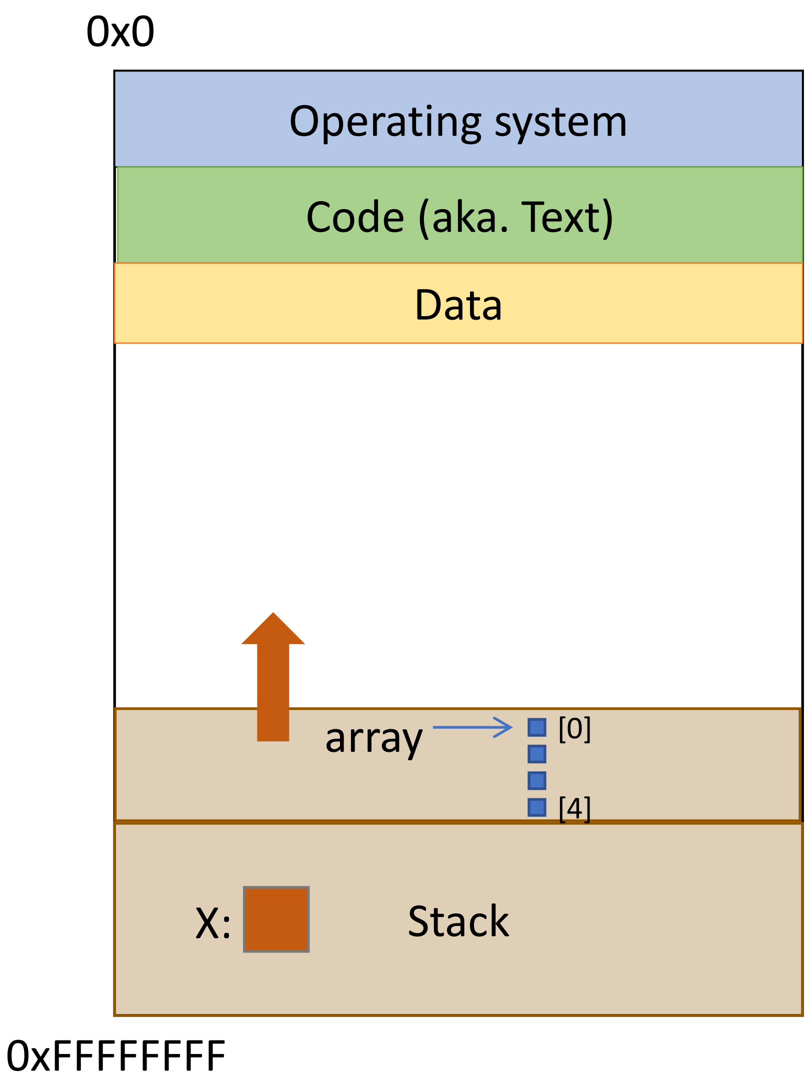
- At high addresses, we keep the stack.
- This stores local (automatic) variables.
  - The kind we've been using in C so far.
  - e.g., int x;



Memory - Stack

- The stack grows upwards towards lower addresses (negative direction).

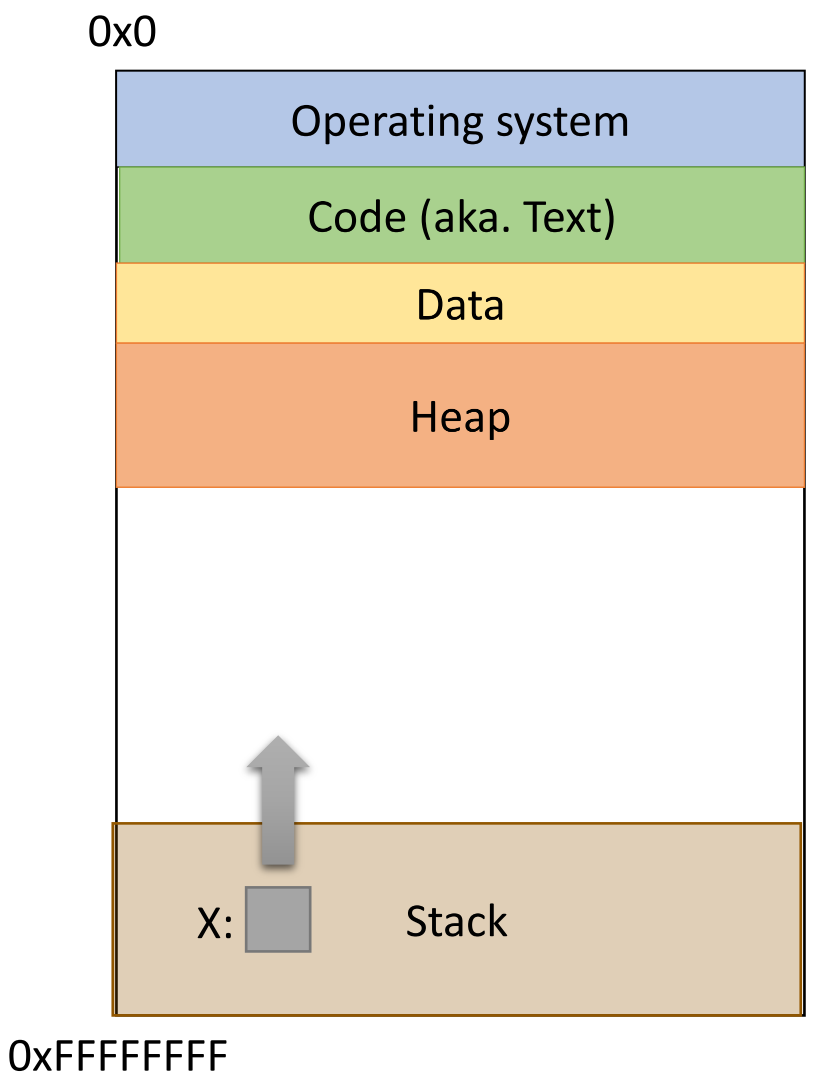
- Example: Allocating array
  - int array[4];



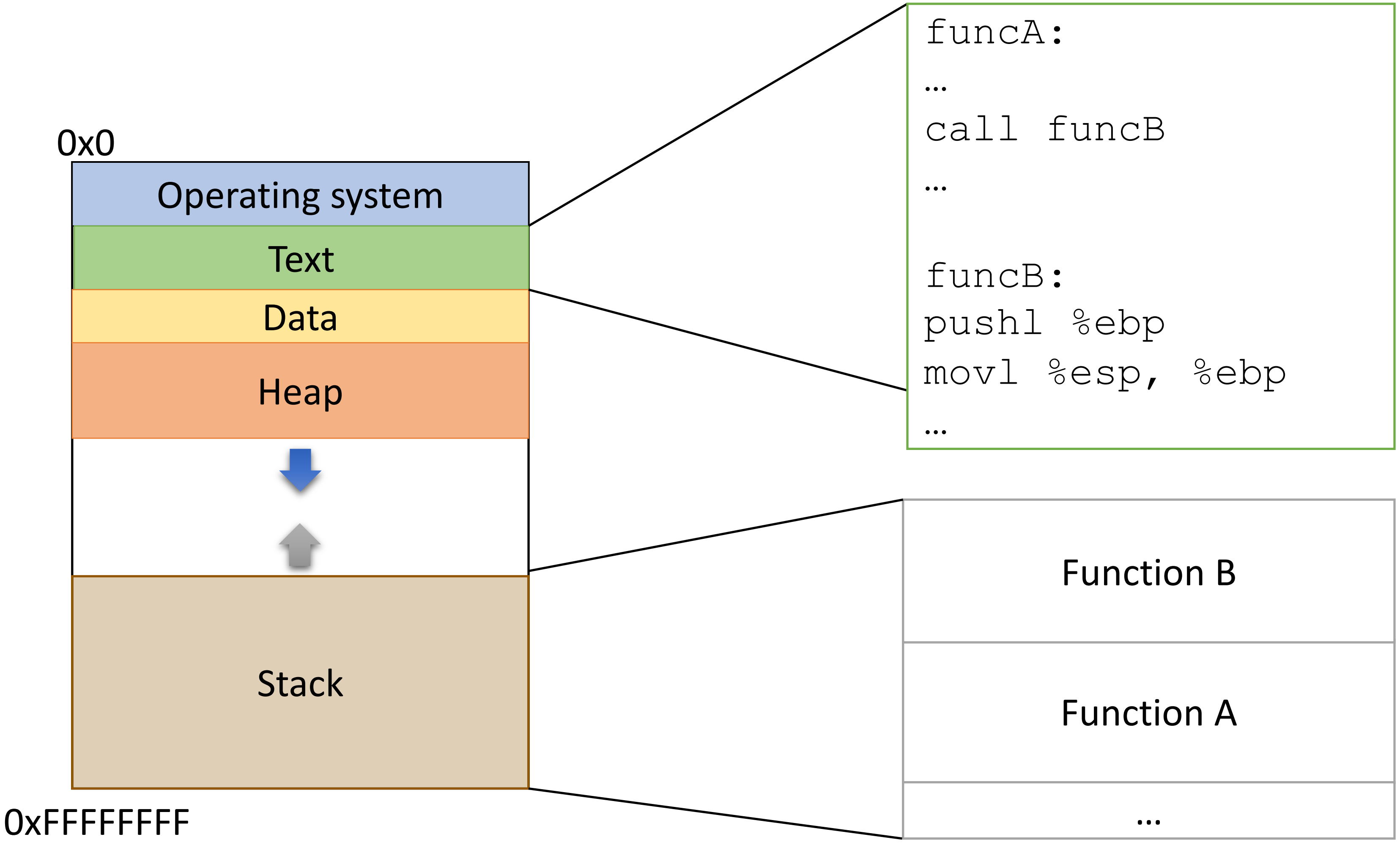
Memory - Heap

- The heap stores dynamically allocated variables.

- When programs explicitly ask the OS for memory, it comes from the heap.
  - malloc() function



Instructions in Memory



Process memory layout

.text

- Machine code of executable

.data

- Global initialized variables

.bss

- Below Stack Section

  global uninitialized vars

heap

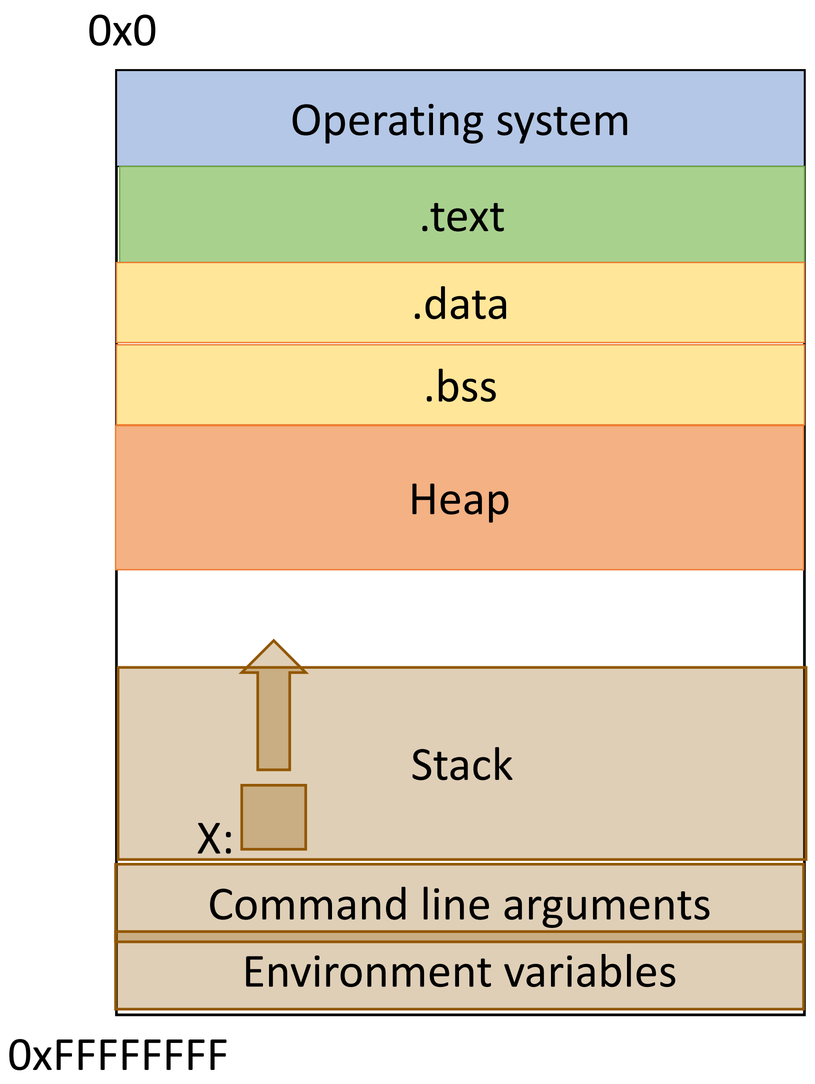
– Dynamic variables

stack

– Local variables
– Function call data

Env

– Environment variables
– Program arguments



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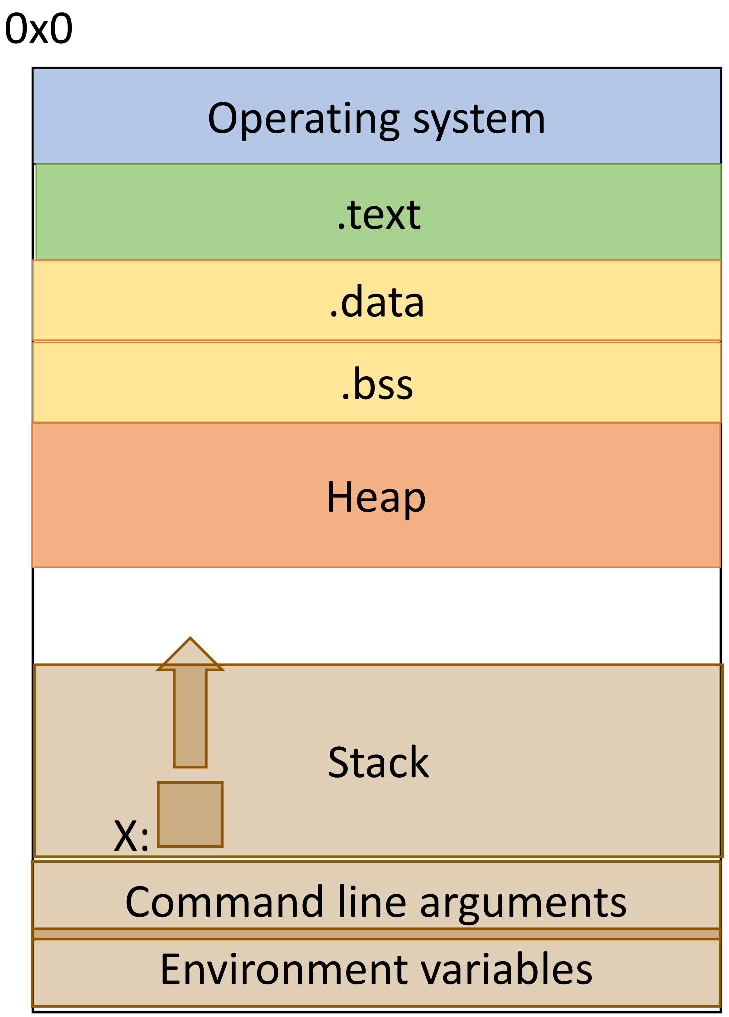
– Program arguments

```
int i = 0;
int main()
{
    char *ptr = malloc(sizeof(int));
    char buf[1024];
    int j;
    static int y; //similar to global
vars
}
```



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– Local variables
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```
int i = 0;
int main()
{
    char *ptr = malloc(sizeof(int));
    char buf[1024]
    int j;
    static int y;
}
```

- i -> data segment
- ptr -> stack
    - data allocated on heap
- buf -> stack
- j -> stack
- y -> bss

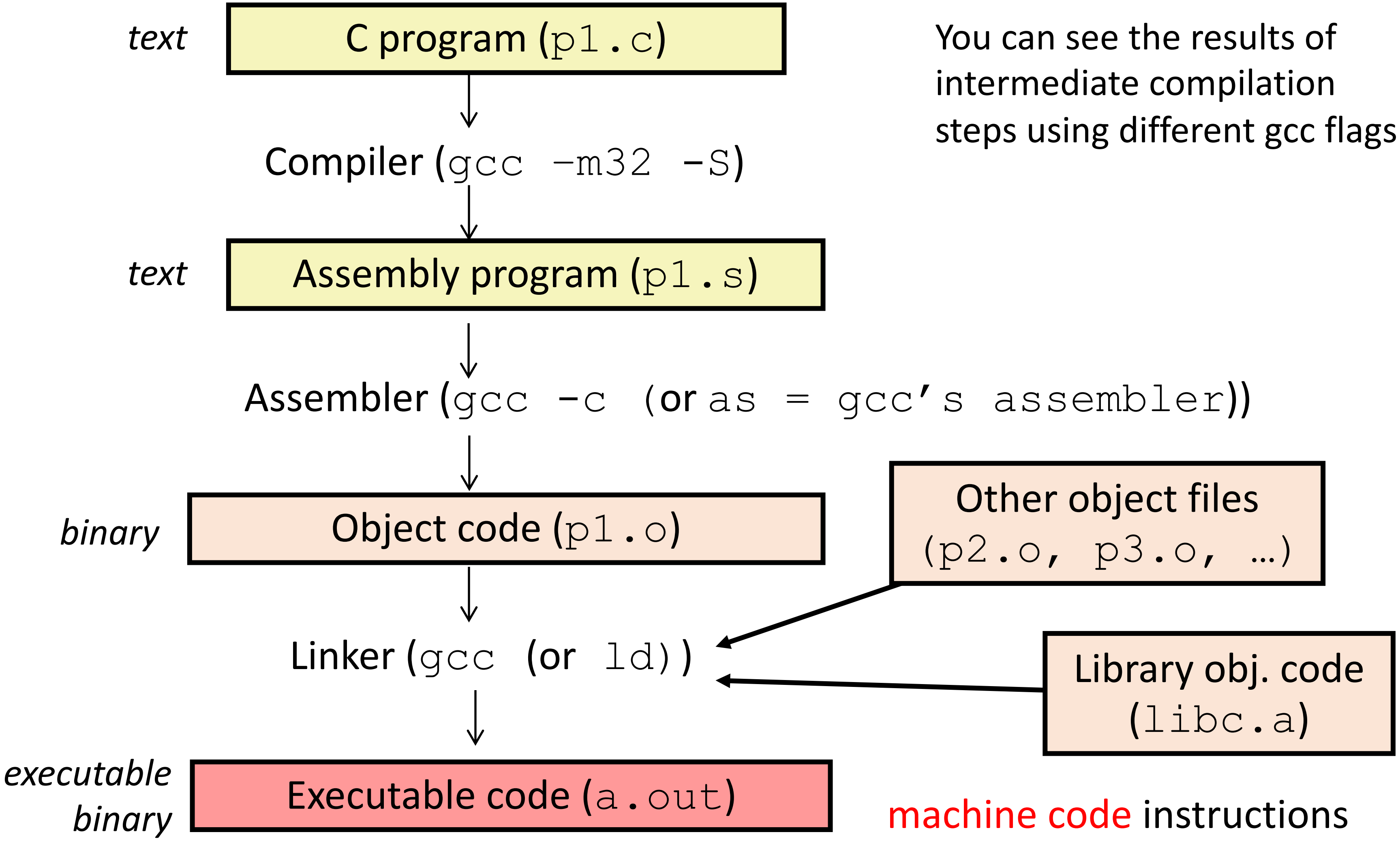
X86: The De Facto Standard

- Extremely popular for desktop computers
- Alternatives
  - ARM: popular on mobile
  - MIPS: very simple
  - Itanium: ahead of its time
- CISC
  - 100 distinct opcodes

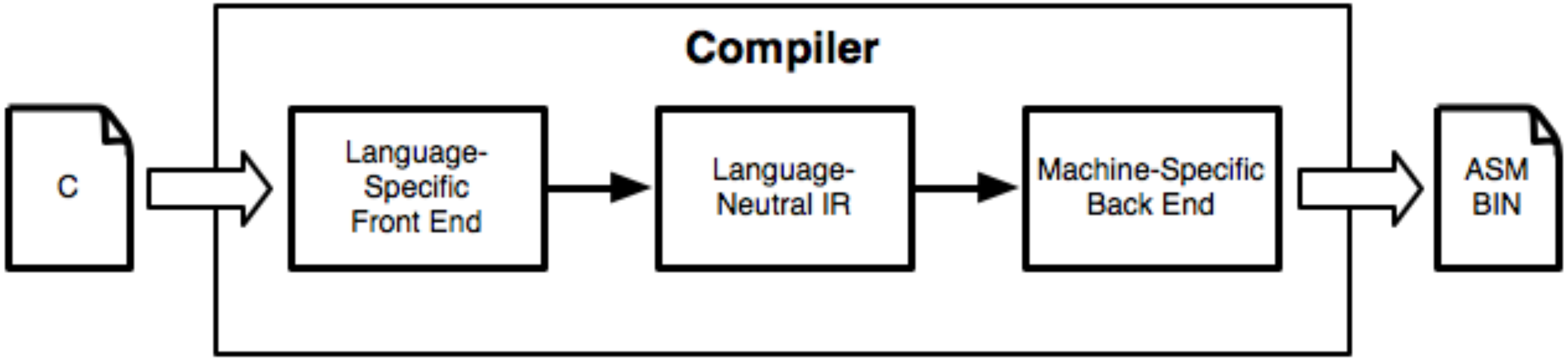
- Register poor
  - 8 registers of 32 bits
  - only 6 general purpose
- instructions are variable length
  - not aligned at 4 byte boundaries
  - lots of backward compatibilities
    - defined in late 70s
    - exploit code that no one pays attention to
- we will use 32 bit because its more convenient.

Compilation Steps (.c to a.out)

You can see the results of intermediate compilation steps using different gcc flags



Compilers



- Computers don't execute source code
    - Instead, they use machine code
- Compilers translate code from a higher level to a lower one
- In this context, C → assembly → machine code

Object / Executable / Machine Code

Assembly	**Machine Code (Hexadecimal)**
`push %ebp`	`55`
`mov  %esp, %ebp`	`89 E5`
`sub  $16, %esp`	`83 EC 10`
`movl $10, -8(%ebp)`	`C7 45 F8 0A 00 00 00`
`movl $20, -4(%ebp)`	`C7 45 FC 14 00 00 00`
`movl -4(%ebp), $eax`	`8B 45 FC`
`addl $eax, -8(%ebp)`	`01 45 F8`
`movl -8(%ebp), %eax`	`B8 45 F8`
`leave`	`C9`

Almost a 1-to-1 mapping to Machine Code
Hides some details like num bytes in instructions

Object / Executable / Machine Code

Assembly

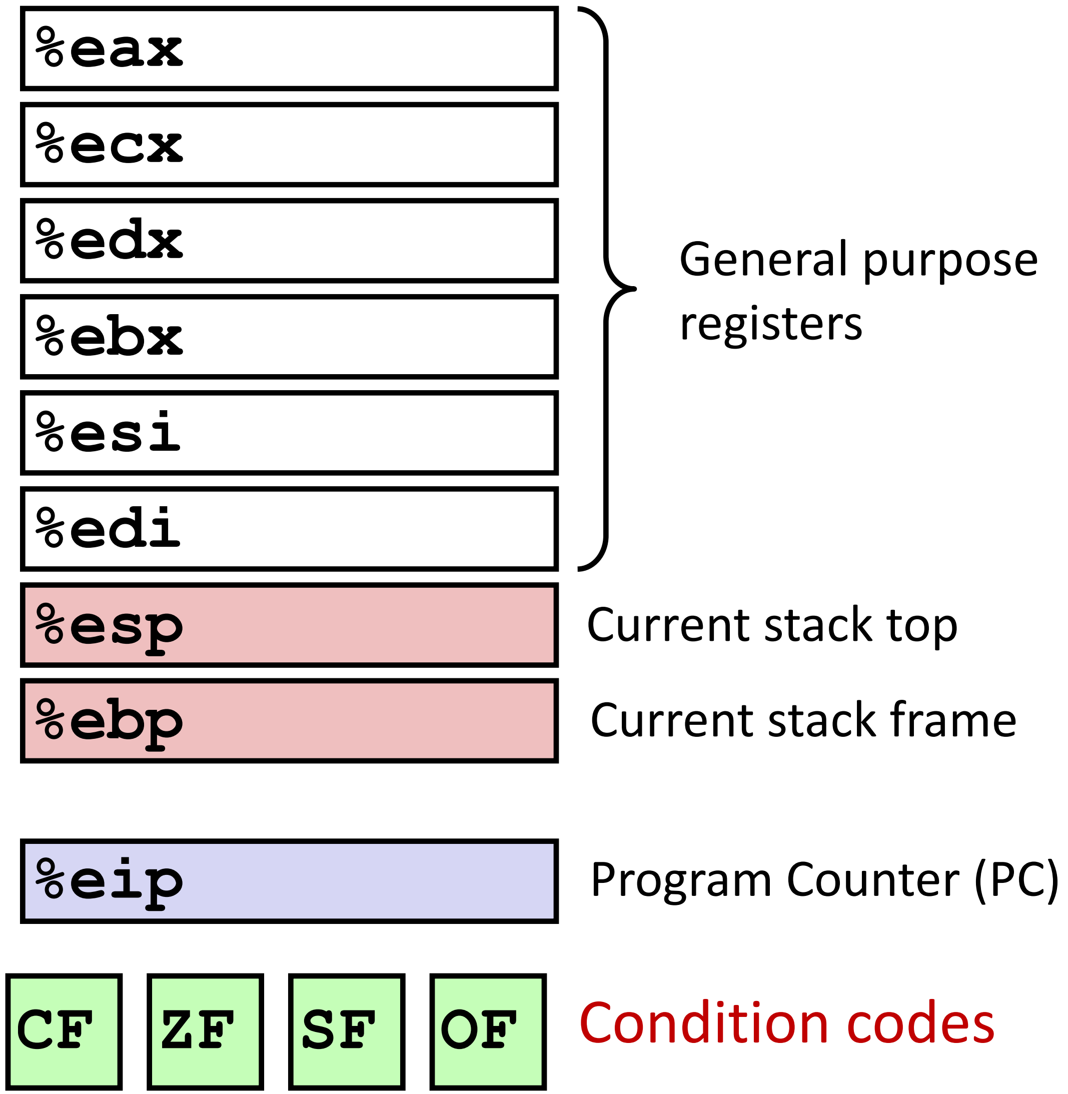
```
push %ebp
mov  %esp, %ebp
sub  $16, %esp
movl $10, -8(%ebp)
movl $20, -4(%ebp)
movl -4(%ebp), $eax
addl $eax, -8(%ebp)
movl -8(%ebp), %eax
leave
```

```
int main() {
	int a = 10;
	int b = 20;

	a = a + b;

	return a;
}
```

Processor State in Registers

Information about currently executing program

- Temporary data (%eax - %edi)
- Location of runtime stack (%ebp, %esp)
- Location of current code control point (%eip, …)
- Status of recent tests %EFLAGS (CF, ZF, SF, OF)



General purpose Registers

Register name
%eax
%ecx
%edx
%ebx
%esi
%edi
%esp
%ebp
%eip
%EFLAGS

bits: 31 16	15 8	7 0
%eax %ax	%ah	%al
%ecx %cx	%ch	%cl
%edx %dx	%dh	%dl
%ebx %bx	%bh	%bl
%esi %si		
%edi %di		
%esp %sp		
%ebp %bp		

Six are for instruction operands

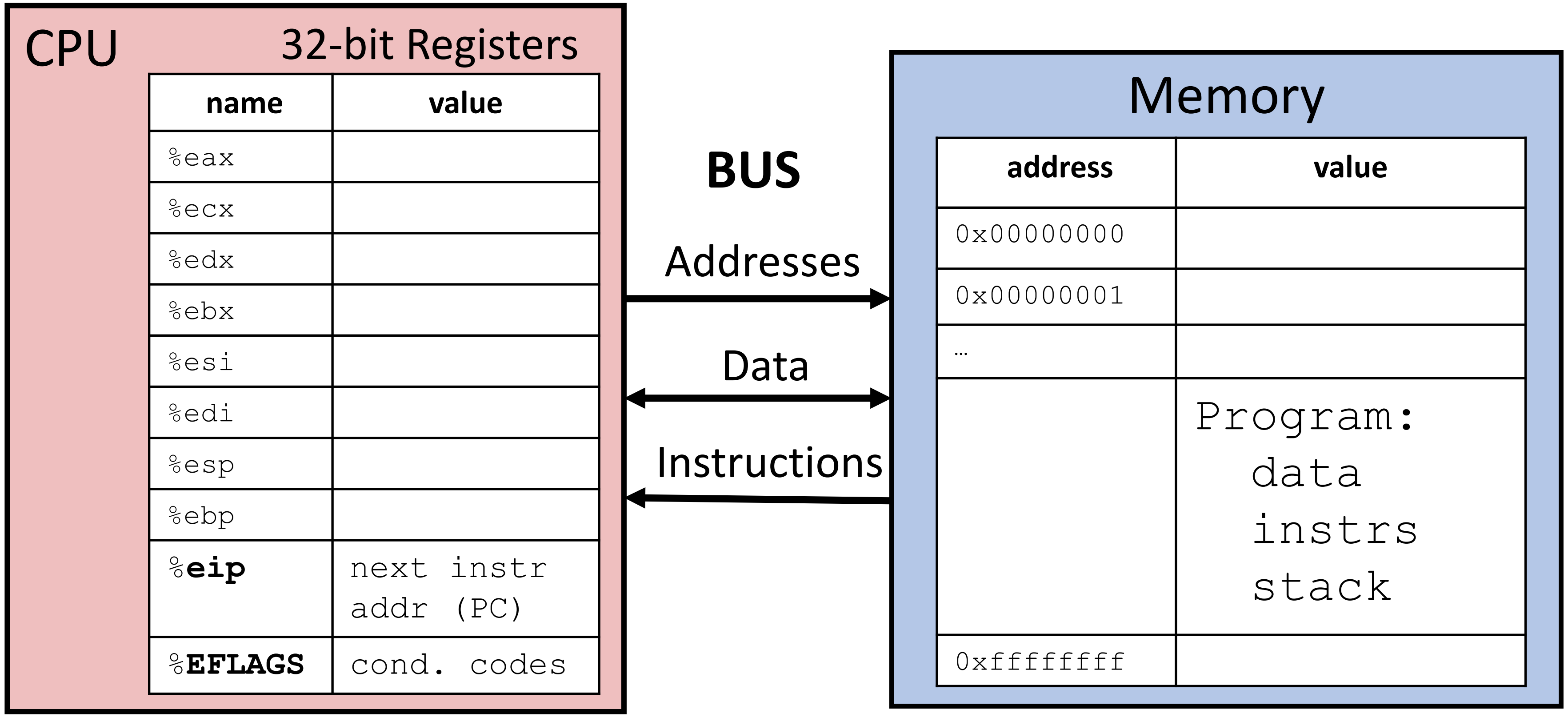
Can store 4 byte data or address value

The low-order 2 bytes %ax is the low-order 16 bits of %eax

Two low-order 1 bytes %al is the low-order 8 bits of %eax

May see their use in ops involving shorts or chars

Assembly Programmer's View of State



Registers:

PC: Program counter (%eip)

Condition codes (%EFLAGS)

General Purpose (%eax - %ebp)

Memory:

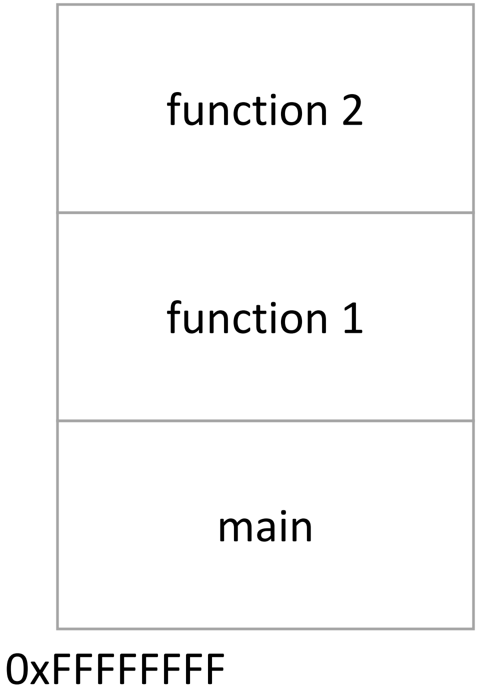
- Byte addressable array
- Program code and data
- Execution stack

Stack Frame Contents

- What needs to be stored in a stack frame?
  - Alternatively: What must a function know?

- Local variables
- Previous stack frame base address
- Function arguments
- Return value
- Return address

- Saved registers
- Spilled temporaries



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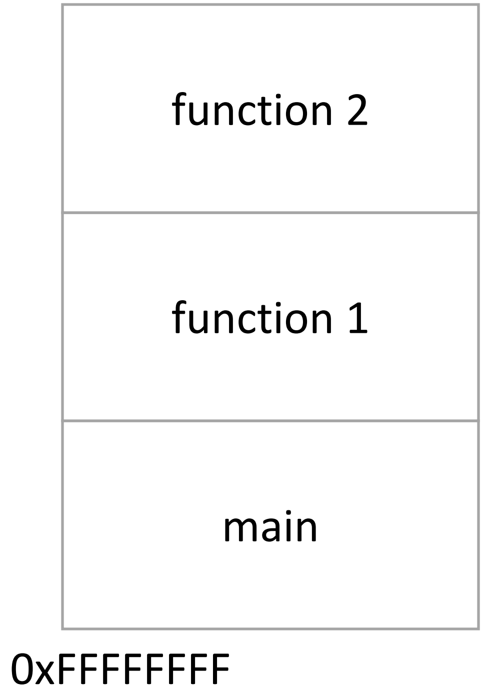
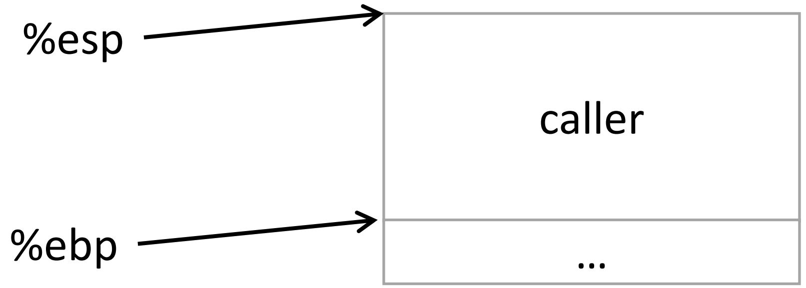


Frame Pointer

- Must maintain invariant:
  - The current function's stack frame is always between the addresses stored in %esp and %ebp

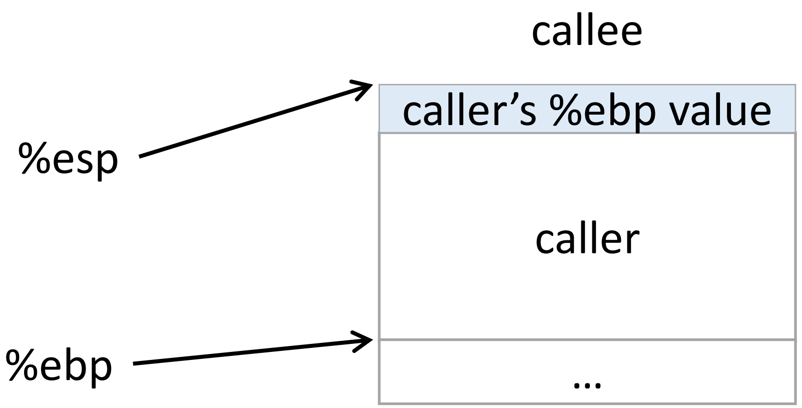
- Must adjust %esp, %ebp on call / return.



Frame Pointer

- Must maintain invariant:
  - The current function's stack frame is always between the addresses stored in %esp and %ebp

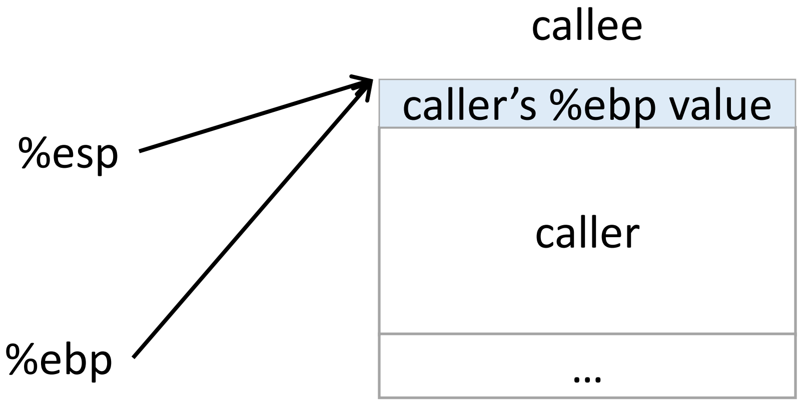
- Immediately upon calling a function:
    - pushl %ebp



Frame Pointer

- Must maintain invariant:
  - The current function's stack frame is always between the addresses stored in %esp and %ebp

- Immediately upon calling a function:
  - pushl %ebp
  - Set %ebp = %esp

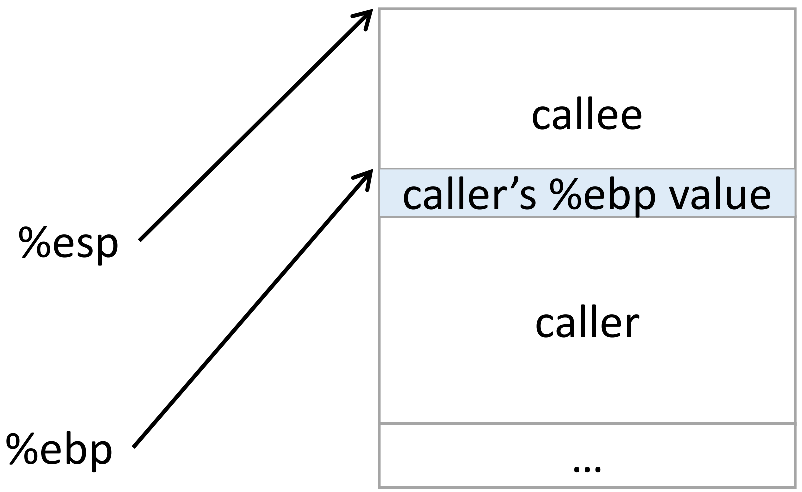


Frame Pointer

- Must maintain invariant:
  - The current function's stack frame is always between the addresses stored in %esp and %ebp

- Immediately upon calling a function:
  - pushl %ebp
  - Set %ebp = %esp
  - Subtract N from %esp

Callee can now execute.



Frame Pointer

- Must maintain invariant:
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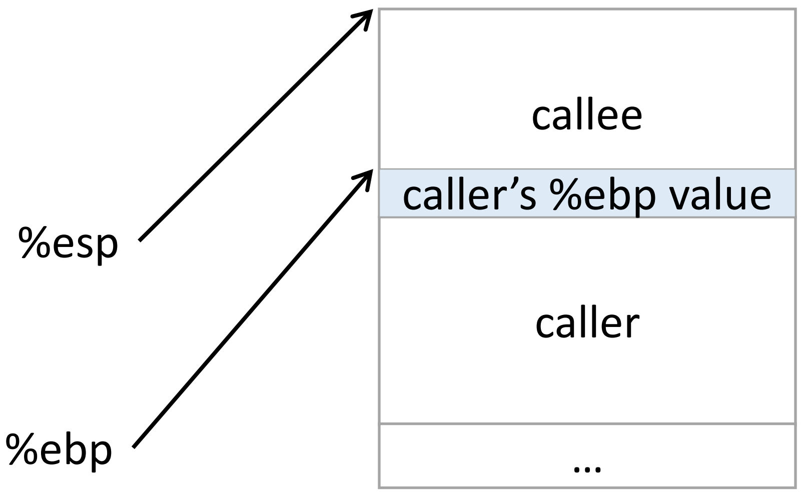
- To return, reverse this:



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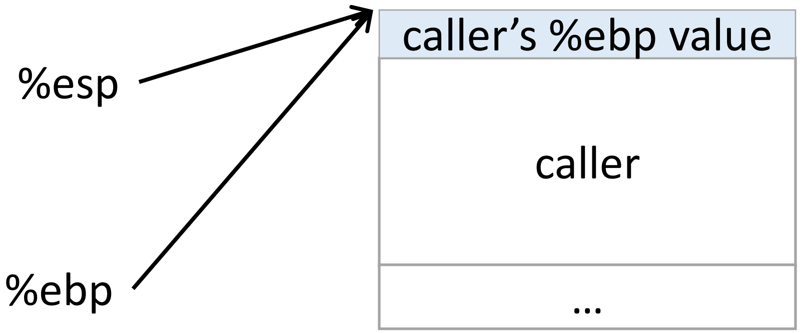

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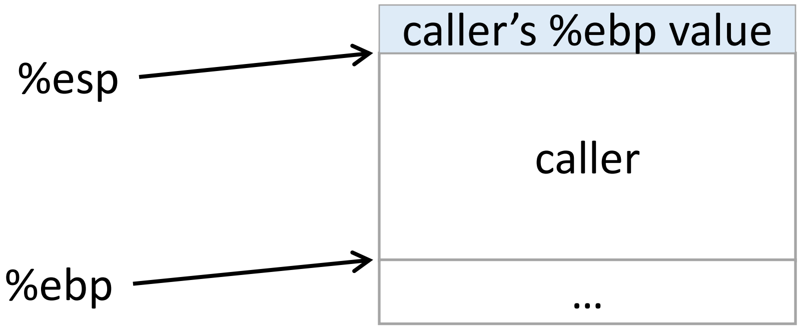


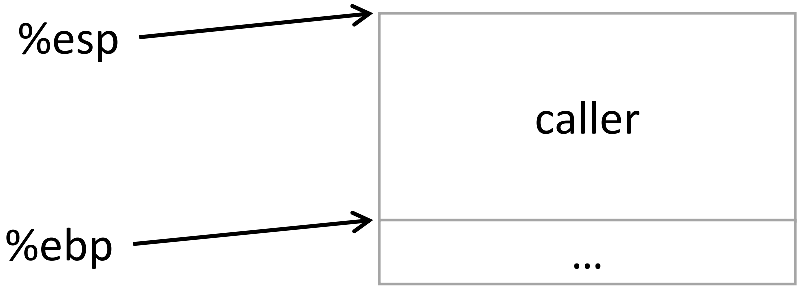
Frame Pointer

- Must maintain invariant:
  - The current function's stack frame is always between the addresses stored in %esp and %ebp

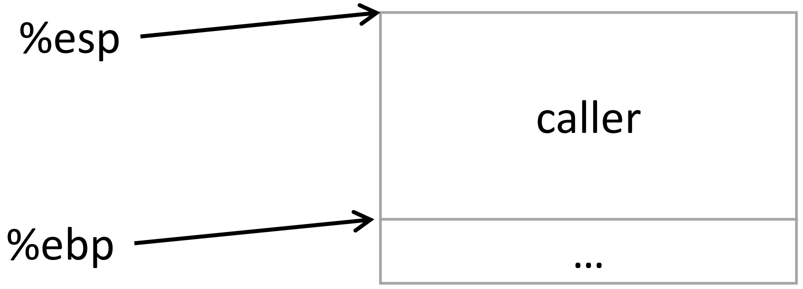
- To return, reverse this:
  - set %esp = %ebp
  - popl %ebp

IA32 has another convenience instruction for this: leave

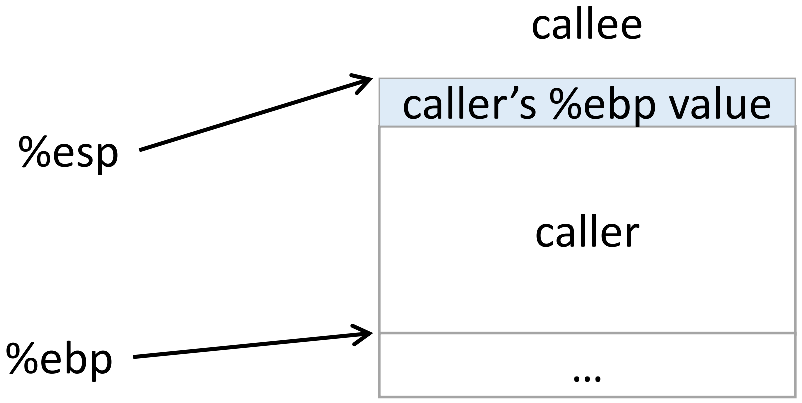
Back to where we started.



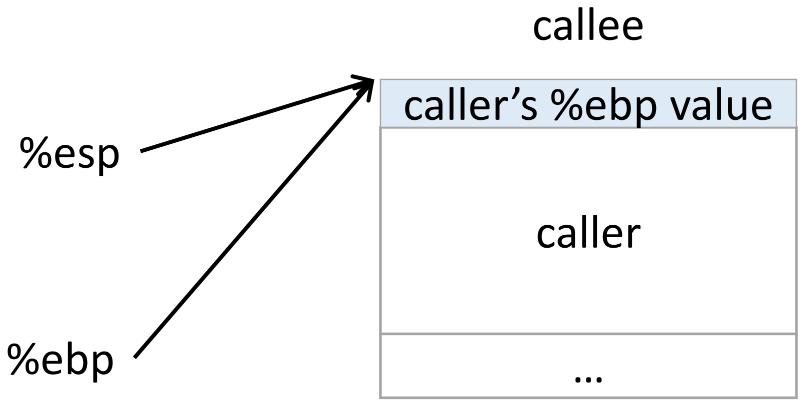
Frame Pointer: Function Call



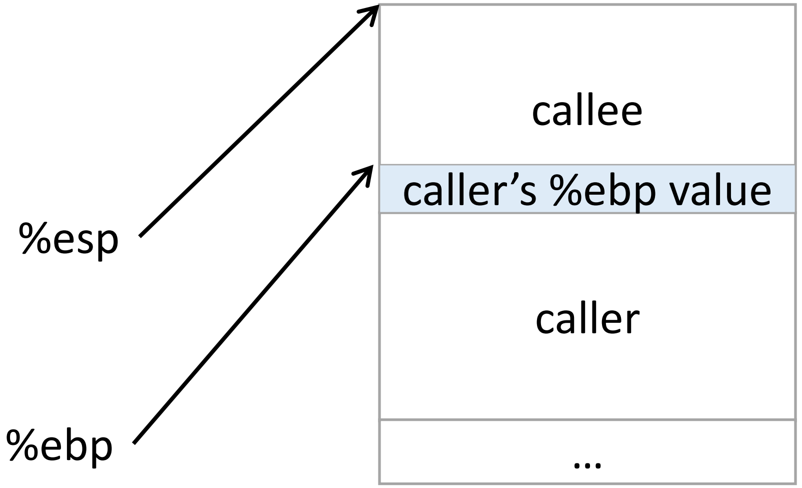
Initial state



pushl %ebp (store caller's frame pointer)

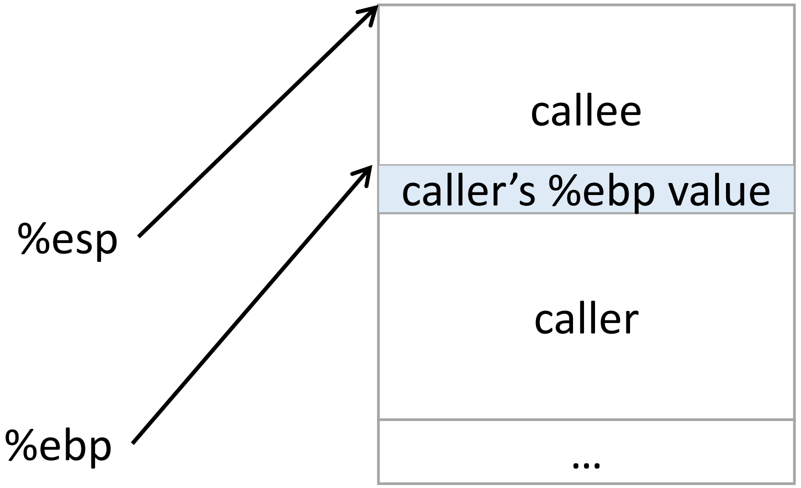


movl %esp, %ebp
(establish callee's frame pointer)

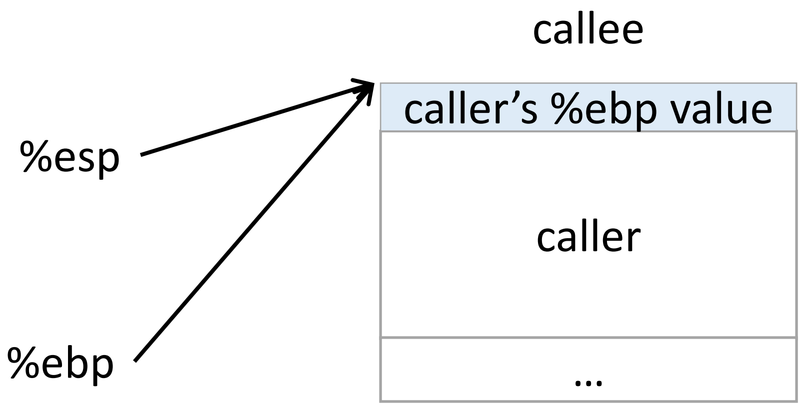


subl $SIZE, %esp
(allocate space for callee's locals)

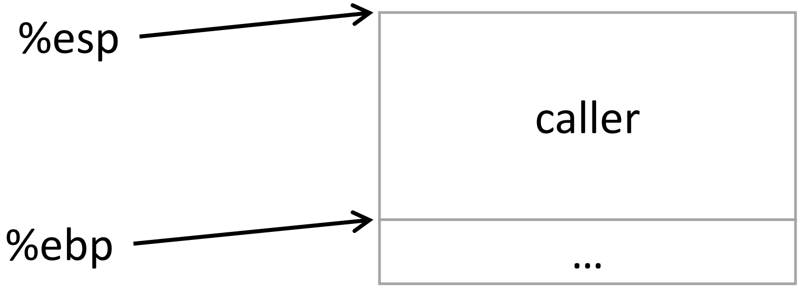
Frame Pointer: Function Return



Want to restore caller's frame.



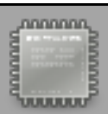
movl %ebp, %esp
(restore caller's stack pointer)



popl %ebp (restore caller's frame pointer)

IA32 provides a convenience instruction that does all of this:
`leave`

Functions and the Stack



Program Counter (%eip)

1. pushl %eip
2. jump funcB
3. (execute funcB)

Text Memory Region

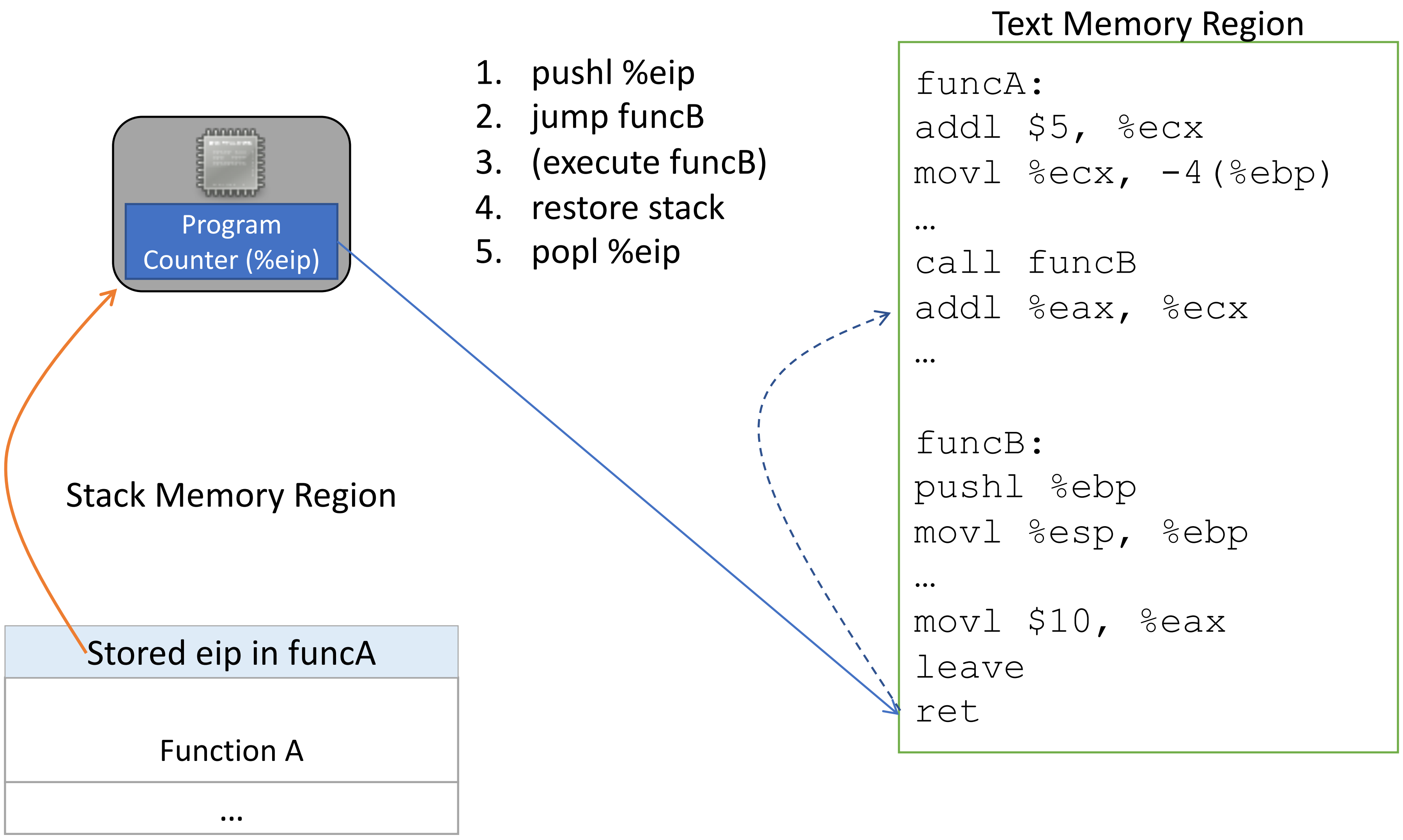
```
funcA:
addl $5, %ecx
movl %ecx, -4(%ebp)
…
call funcB
addl %eax, %ecx
…

funcB:
pushl %ebp
movl %esp, %ebp
…
movl $10, %eax
leave
ret
```

Stack Memory Region

Function B
Stored eip in funcA
Function A
…

Functions and the Stack



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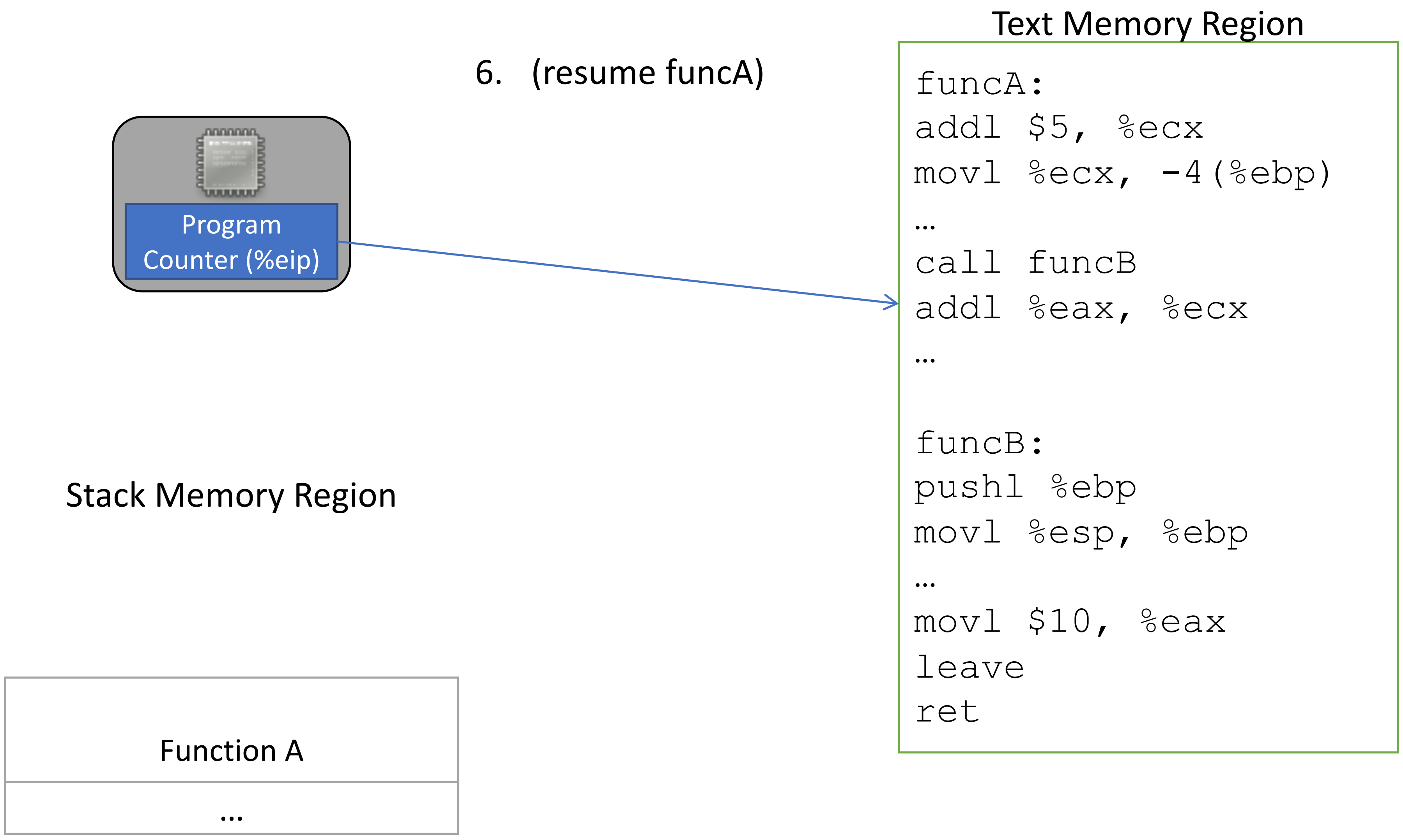
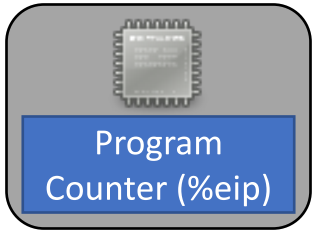


Functions and the Stack



1. pushl %eip
2. jump funcB
3. (execute funcB)
4. restore stack
5. popl %eip
6. (resume funcA)

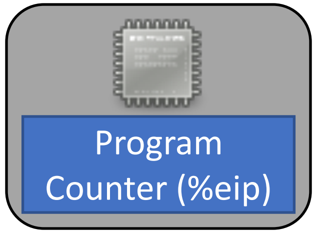
Stack Memory Region

Stored eip in funcA
Function A
…

Text Memory Region

```
funcA:
addl $5, %ecx
movl %ecx, -4(%ebp)
…
call funcB
addl %eax, %ecx
…

funcB:
pushl %ebp
movl %esp, %ebp
…
movl $10, %eax
leave
ret
```

Functions and the Stack



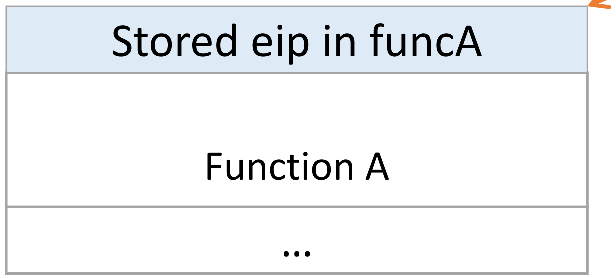
1. pushl %eip
2. jump funcB
3. (execute funcB)
4. restore stack
5. popl %eip
6. (resume funcA)

call (steps 1–2)

leave (step 4)

ret (step 5)

Stack Memory Region



Return address:

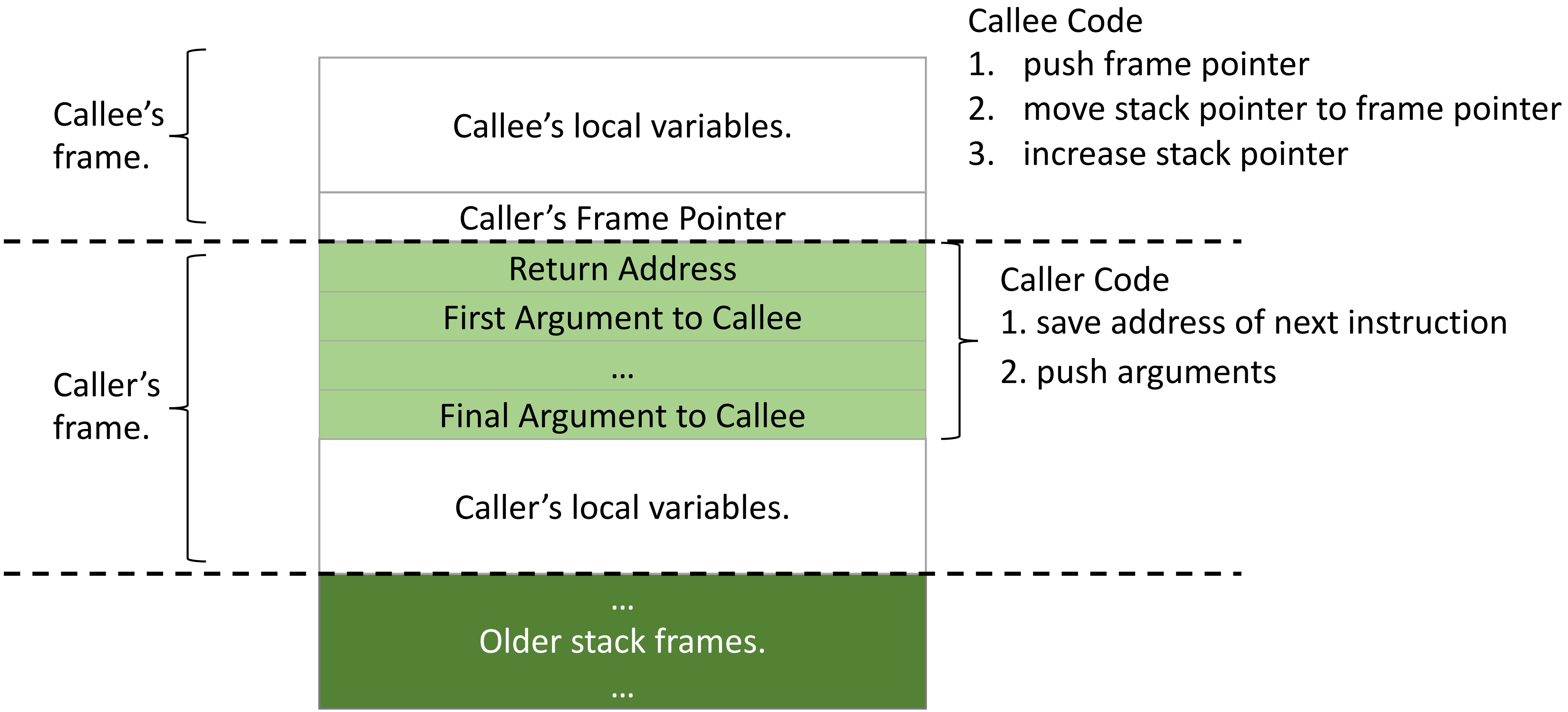
Address of the instruction we should jump back to when we finish (return from) the currently executing function.

Register Convention

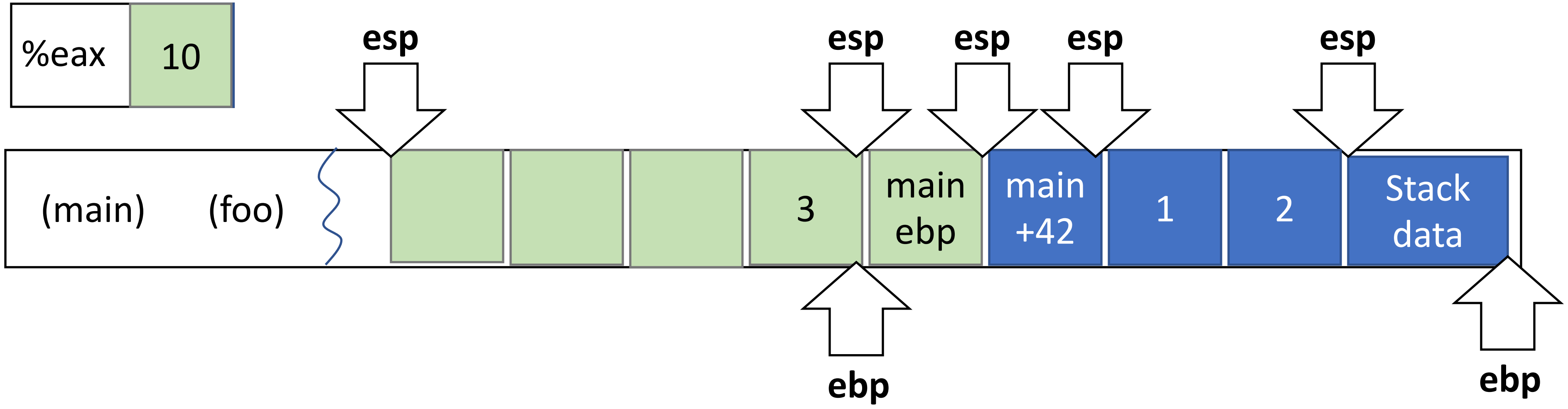
- Caller-saved: %eax, %ecx, %edx
  - If the caller wants to preserve these registers, it must save them prior to calling callee
  - callee free to trash these, caller will restore if needed

- Callee-saved: %ebx, %esi, %edi
  - If the callee wants to use these registers, it must save them first, and restore them before returning
  - caller can assume these will be preserved

Putting it all together…



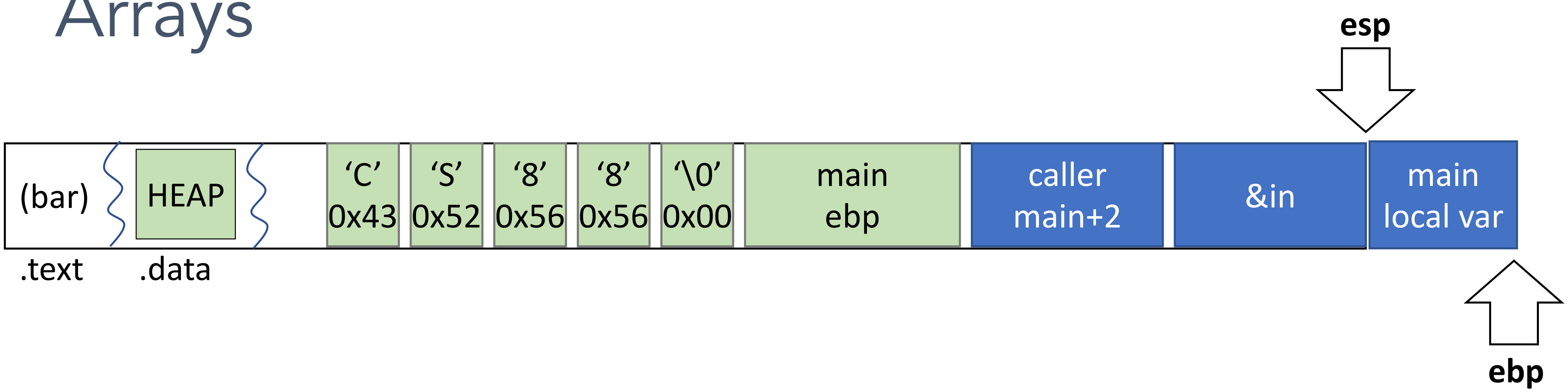
Implementing a function call




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

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

Arrays

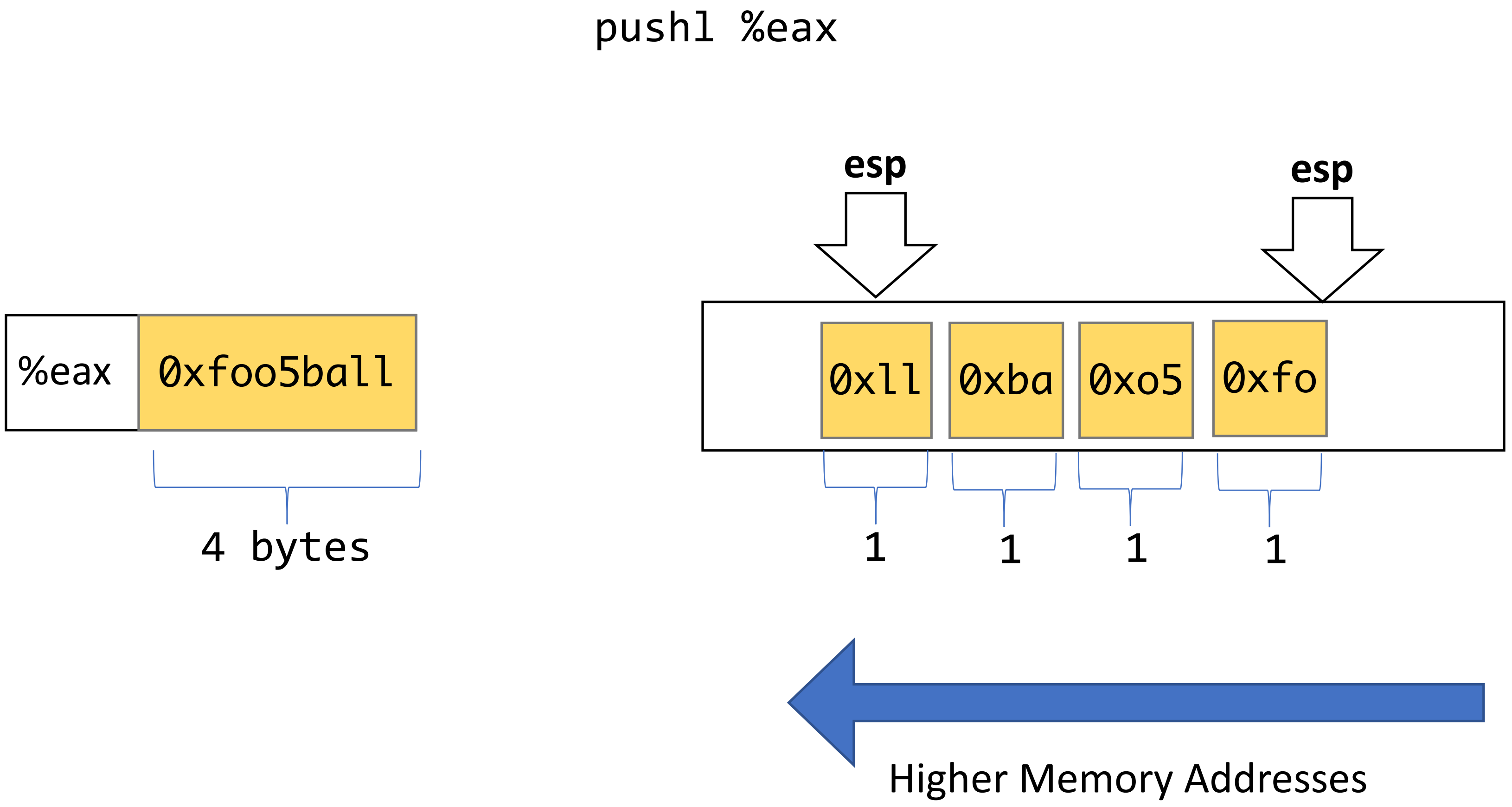



```
void main(){
   bar("CS88);
}

void bar(char * in){
  char name[5]; // "CS88"
  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
```

Data types / Endianness

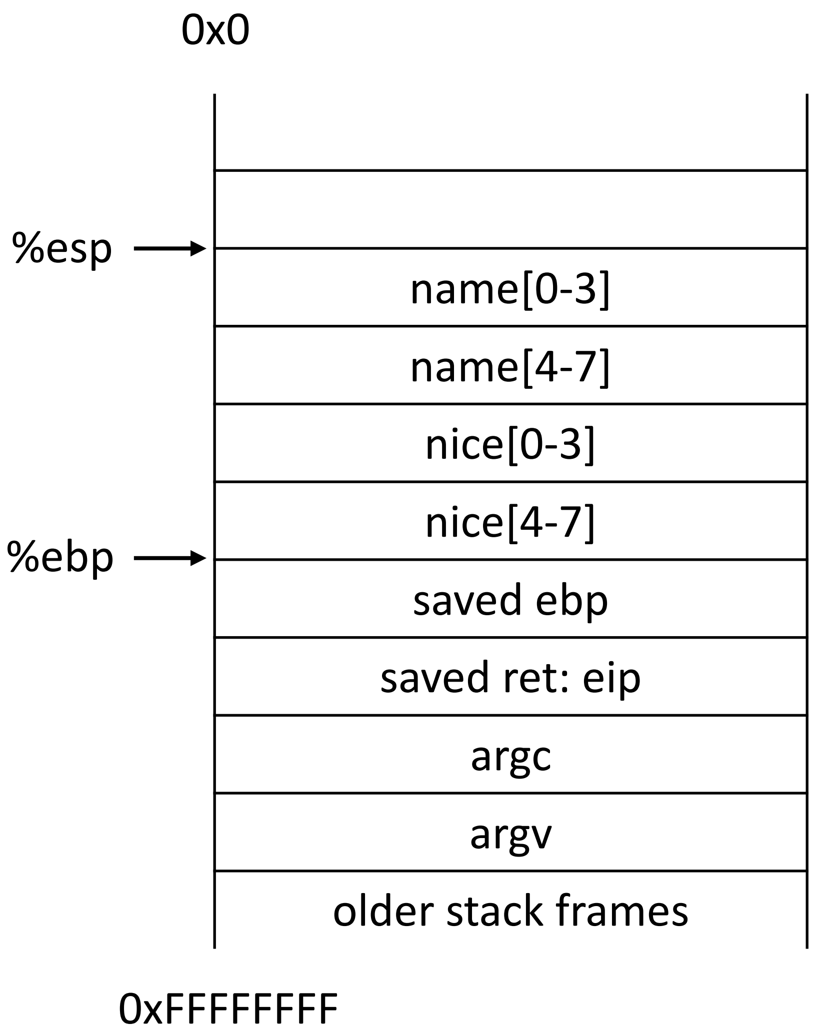
x86 is a little-endian architecture



Buffer Overflows

Example 1

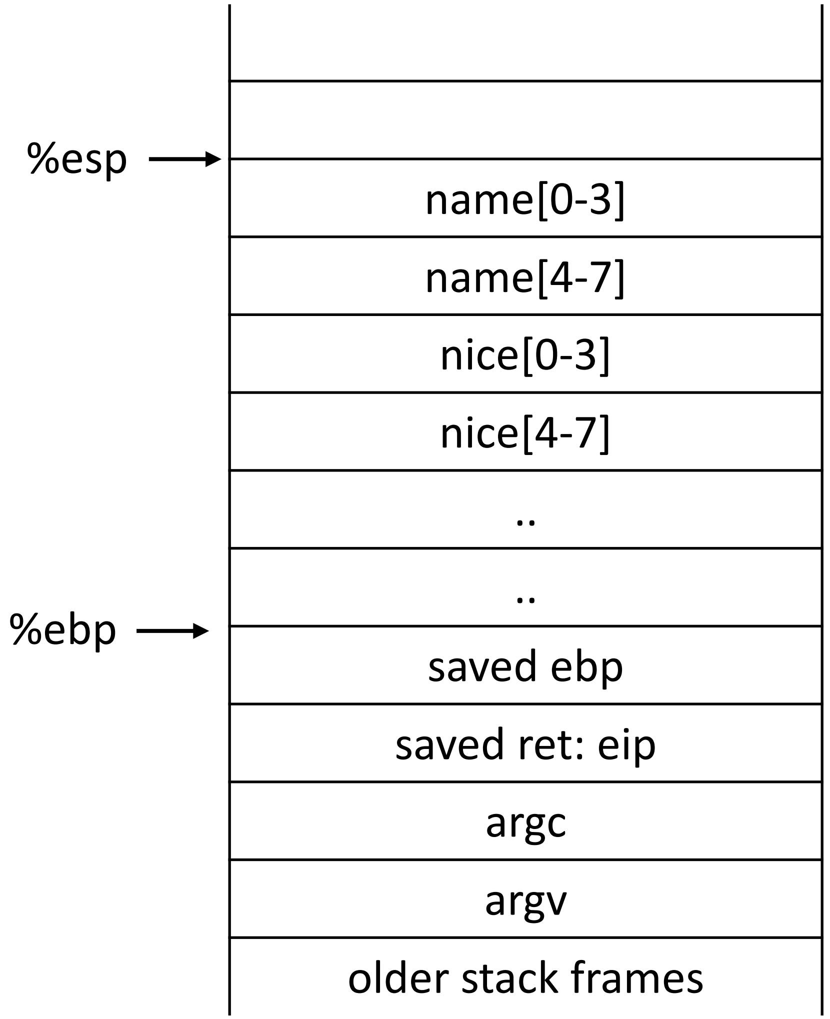
```c
#include <stdio.h>
#include <string.h>

int main(int argc, char**argv){
    char nice[] = “is nice.”;
    char name[8];
    gets(name);
    printf(“%s %s\n”, name, nice);
    return 0;
}
```



Function call stack

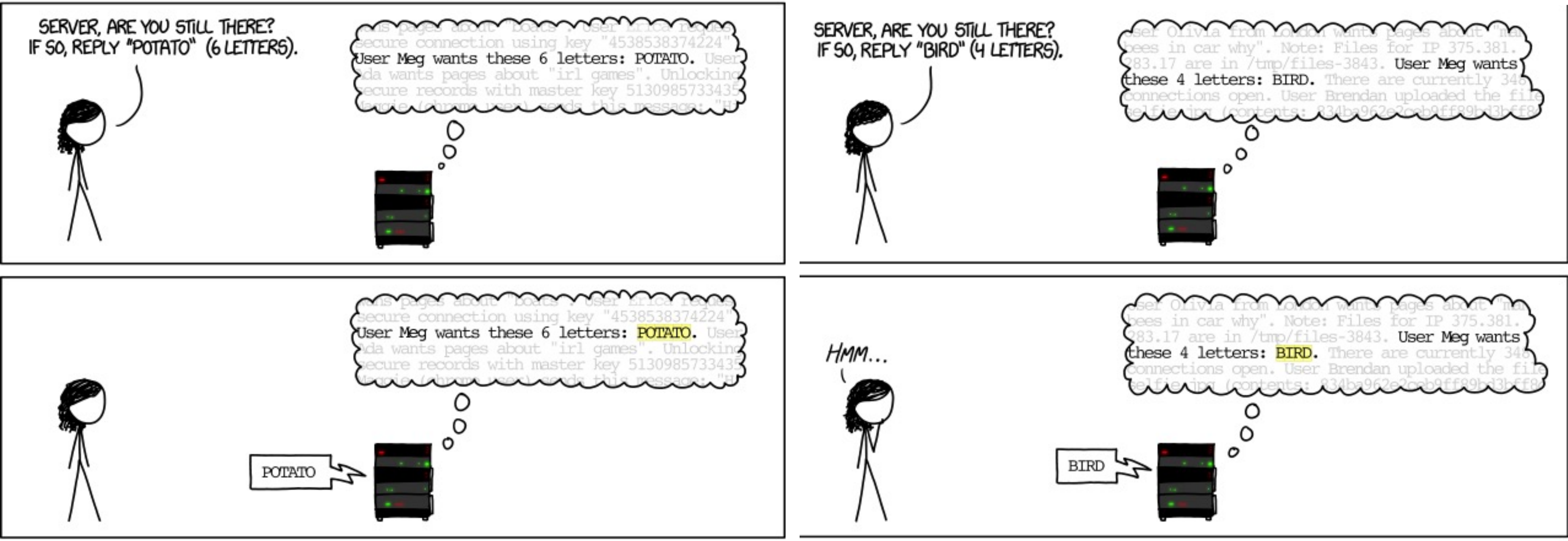
What happens if we read a long name?

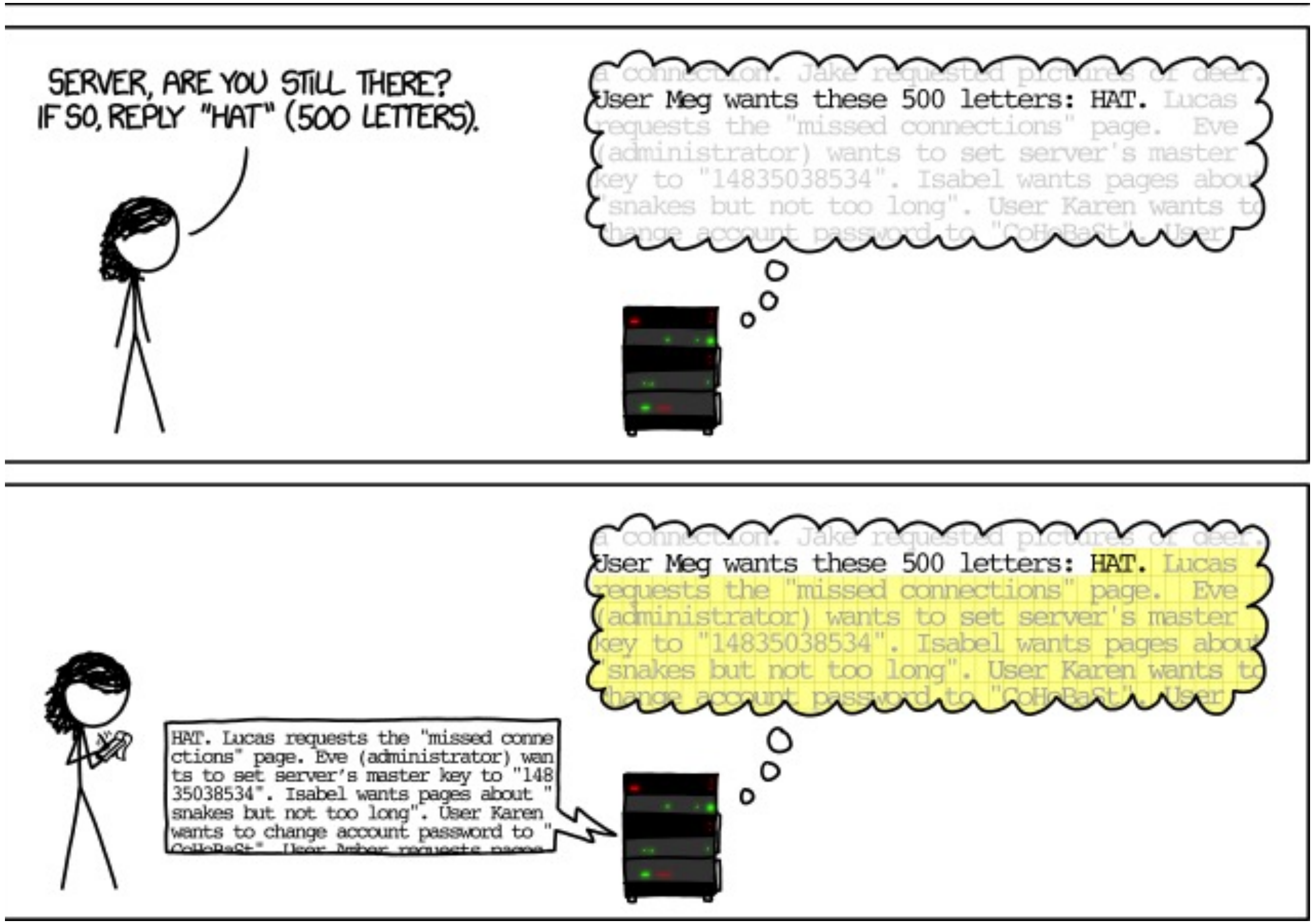
```c
#include <stdio.h>
#include <string.h>

int main(int argc, char**argv){
    char nice[] = “is nice.”;
    char name[8];
    gets(name);
    printf(“%s %s\n”, name, nice);
    return 0;
}
```



A. Nothing bad will happen
B. Something nonsensical will result
C. Something terrible will result

HOW THE HEARTBLEED BUG WORKS:



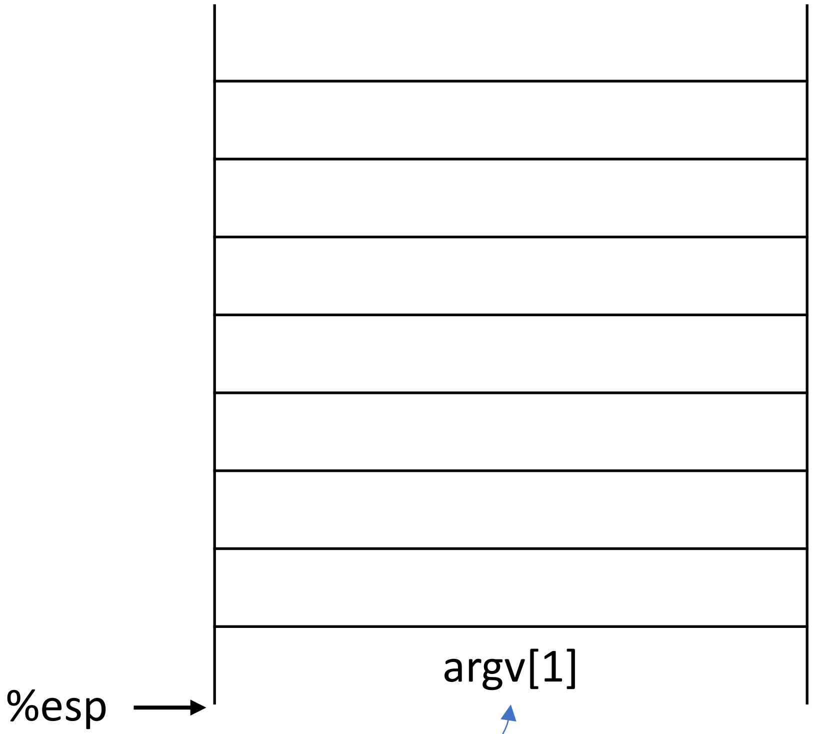

SERVER, ARE YOU STILL THERE? IF SO, REPLY "HAT" (500 LETTERS).
User Meg wants these 500 letters: HAT. Lucas requests the "missed connections" page. Eve (administrator) wants to set server's master key to "14835038534". Isabel wants pages about "snakes but not too long". User Karen wants to
User Meg wants these 500 letters: HAT. Lucas requests the "missed connections" page. Eve (administrator) wants to set server's master key to "14835038534". Isabel wants pages about "snakes but not too long". User Karen wants to
HAT. Lucas requests the "missed conne
ctions" page. Eve (administrator) wan
ts to set server's master key to "148
35038534". Isabel wants pages about "
snakes but not too long". User Karen
wants to change account password to "

Buffer Overflow example

```
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```

Buffer Overflow example

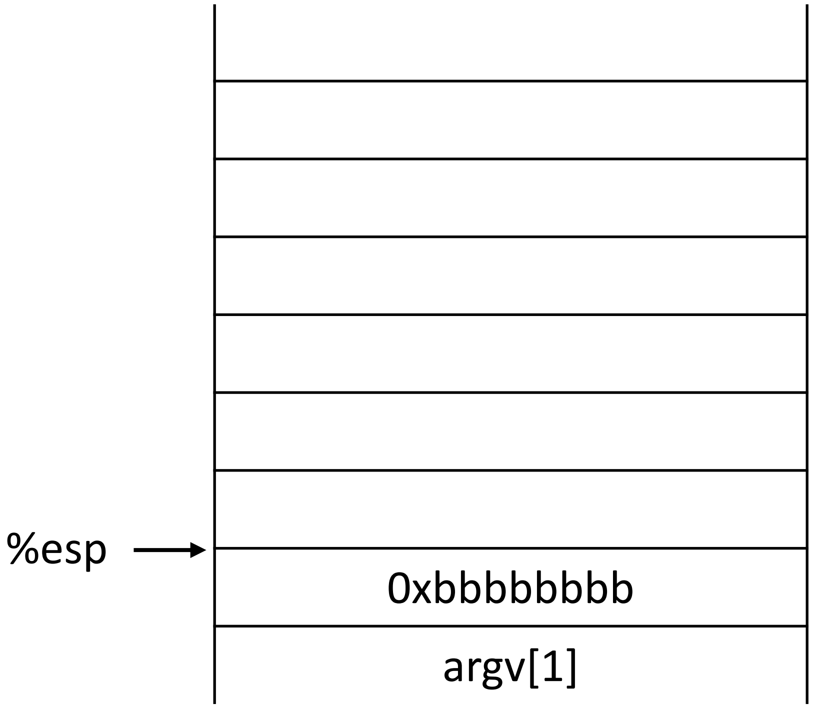
```
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



Load function arguments starting with the last argument

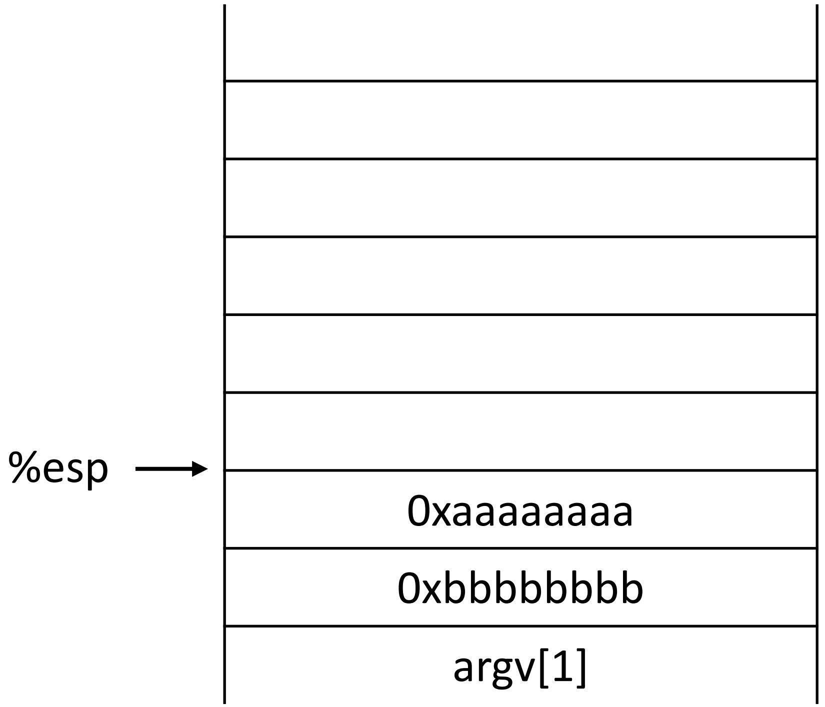
Buffer Overflow example

```c
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



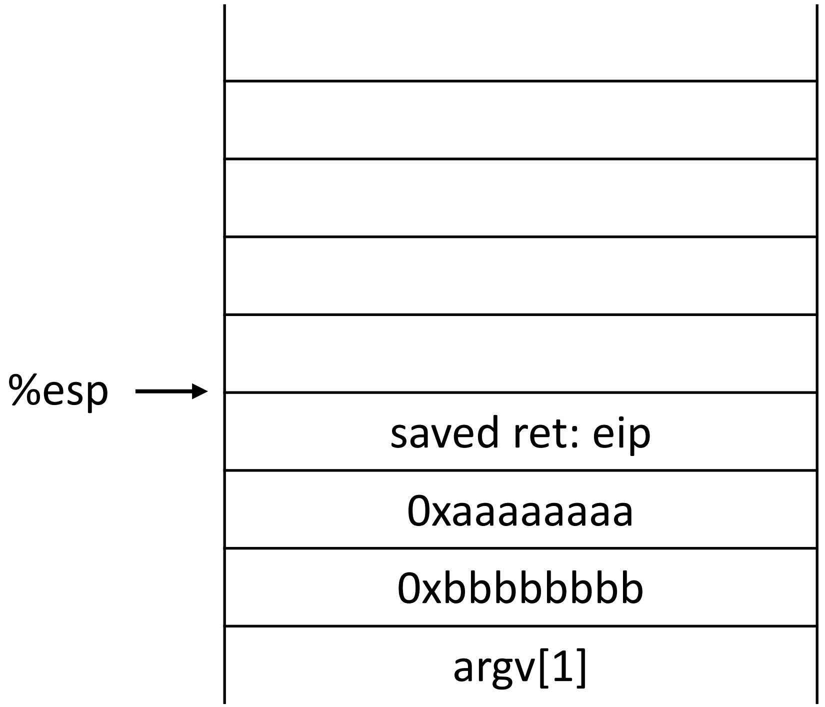
Buffer Overflow example

```
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



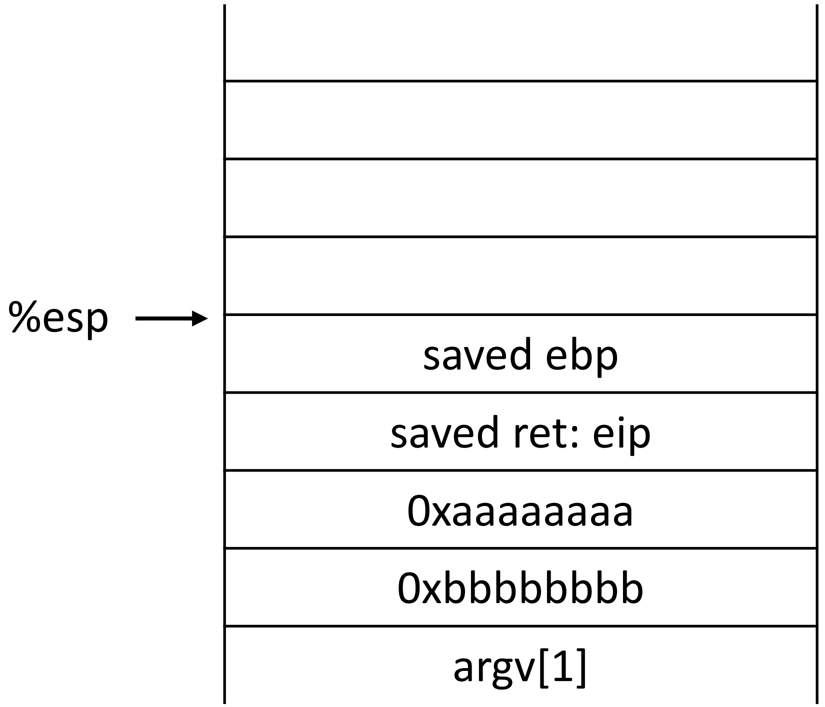
Buffer Overflow example

```
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



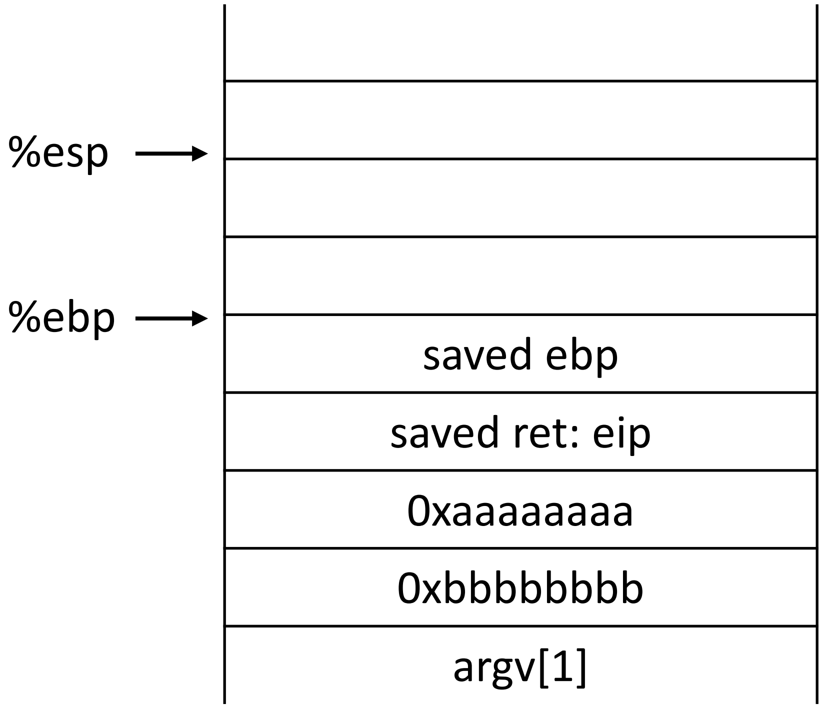
Buffer Overflow example

```c
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



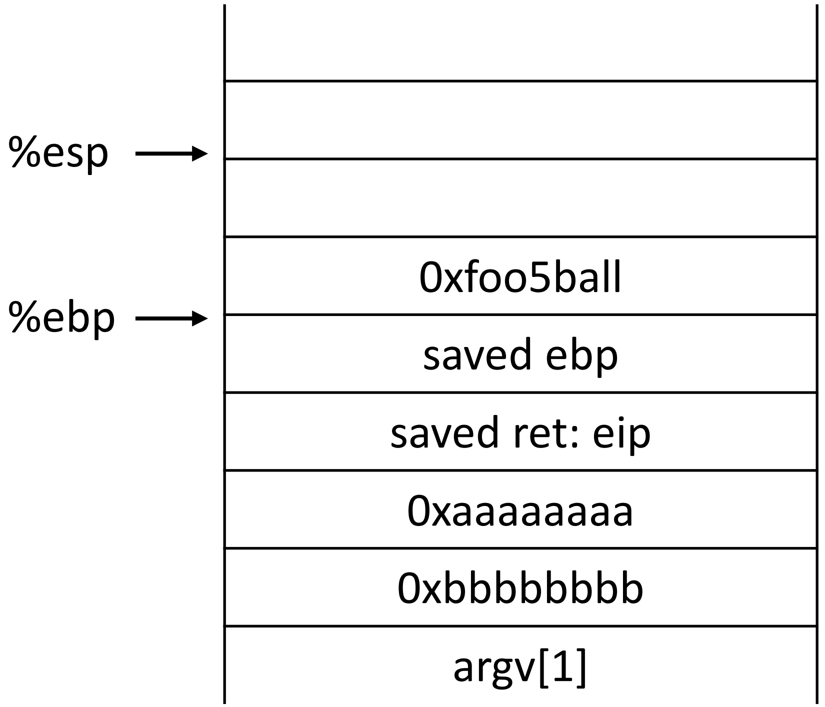
Buffer Overflow example

```
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



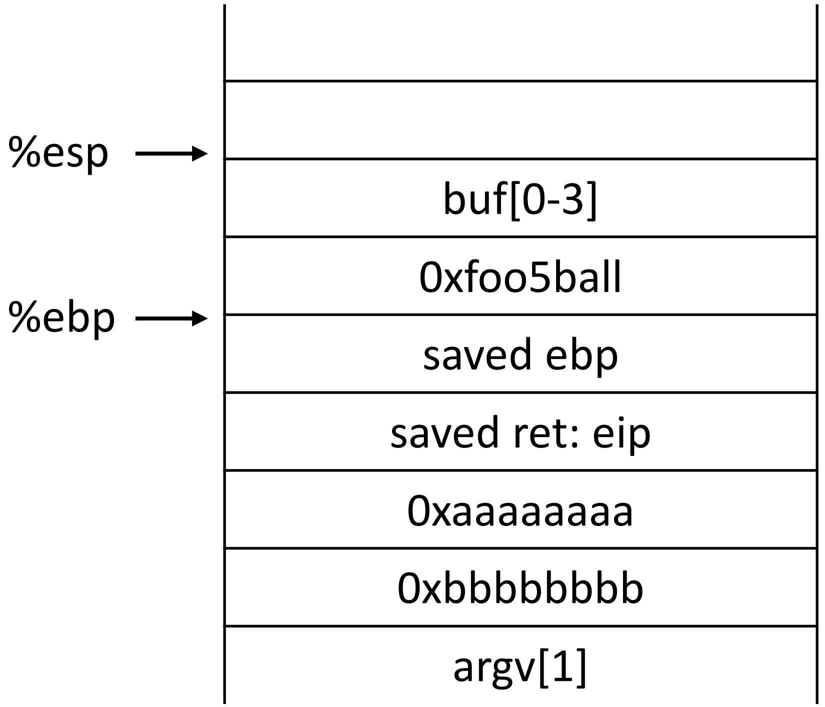
Buffer Overflow example

```
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



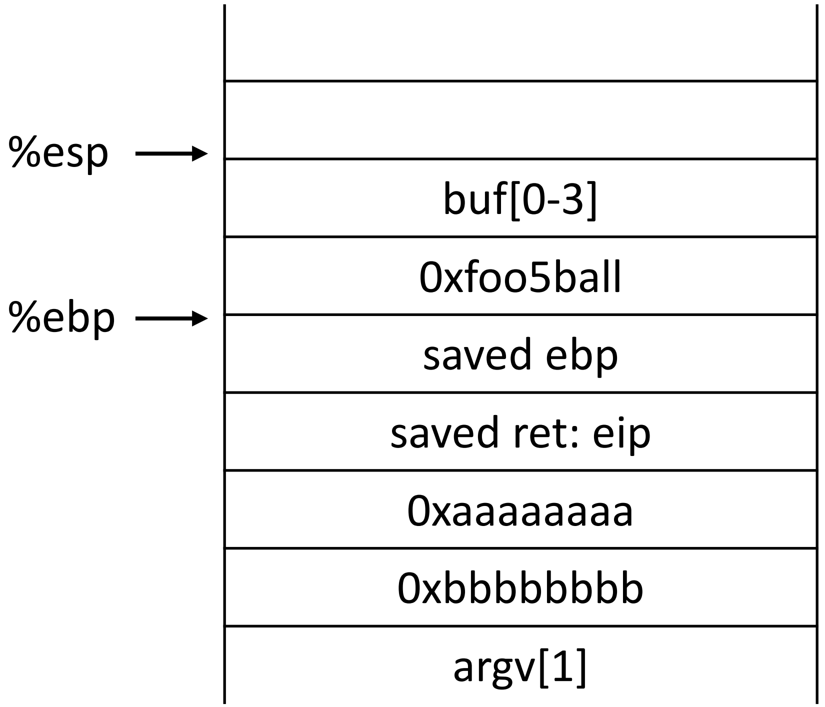
Buffer Overflow example

```c
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



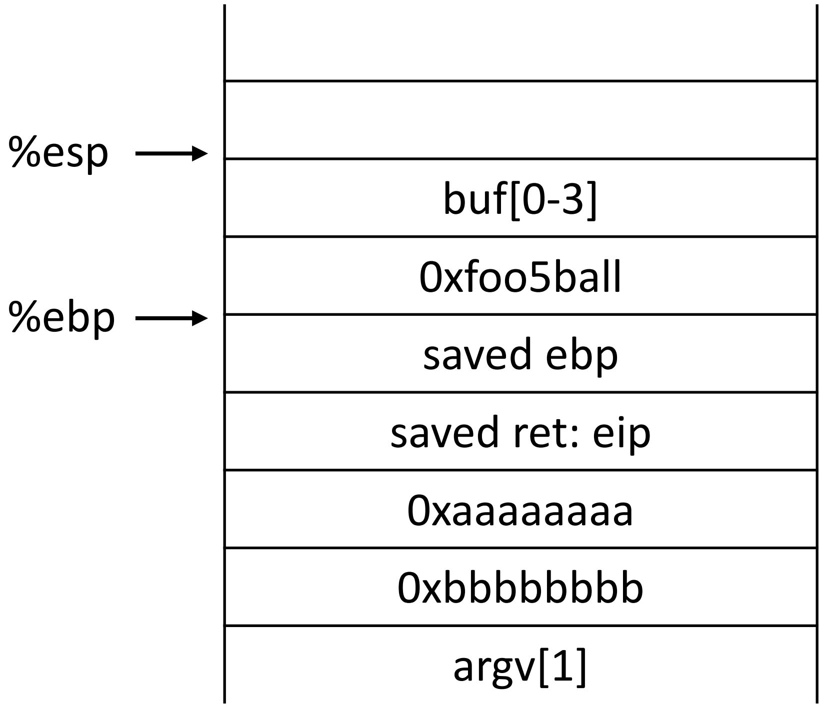
Buffer Overflow example

```c
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



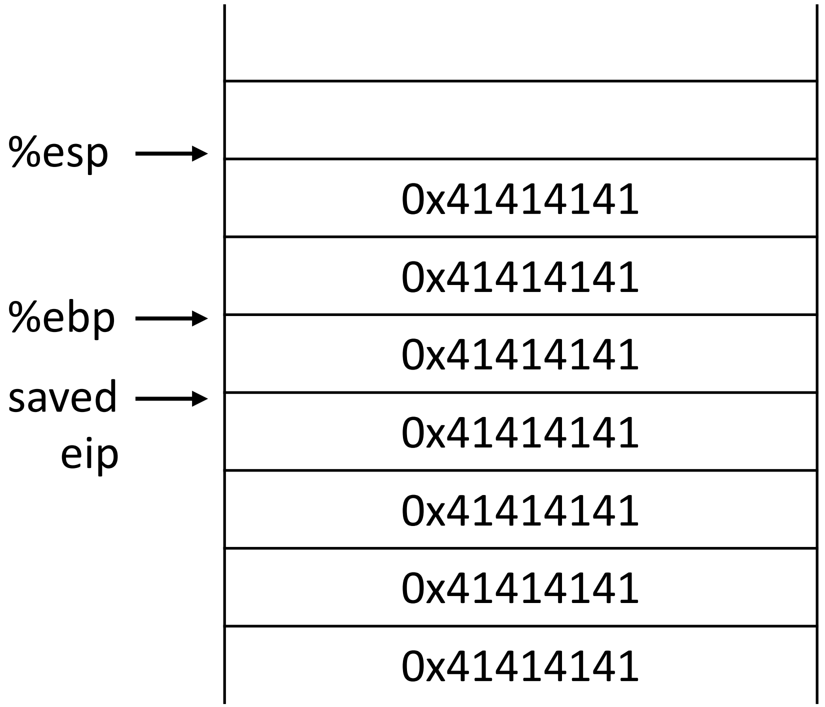
Buffer Overflow example: If the first input is "AAAAAAAAAAAAAAAA"

```c
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



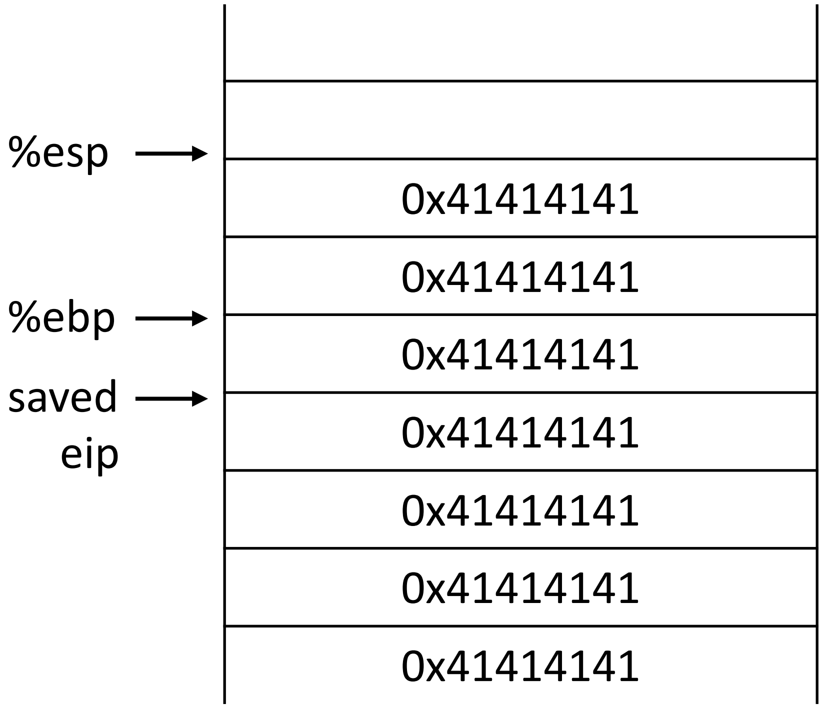
Buffer Overflow example: If the first input is "AAAAAAAAAAAAAAAA"

```c
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



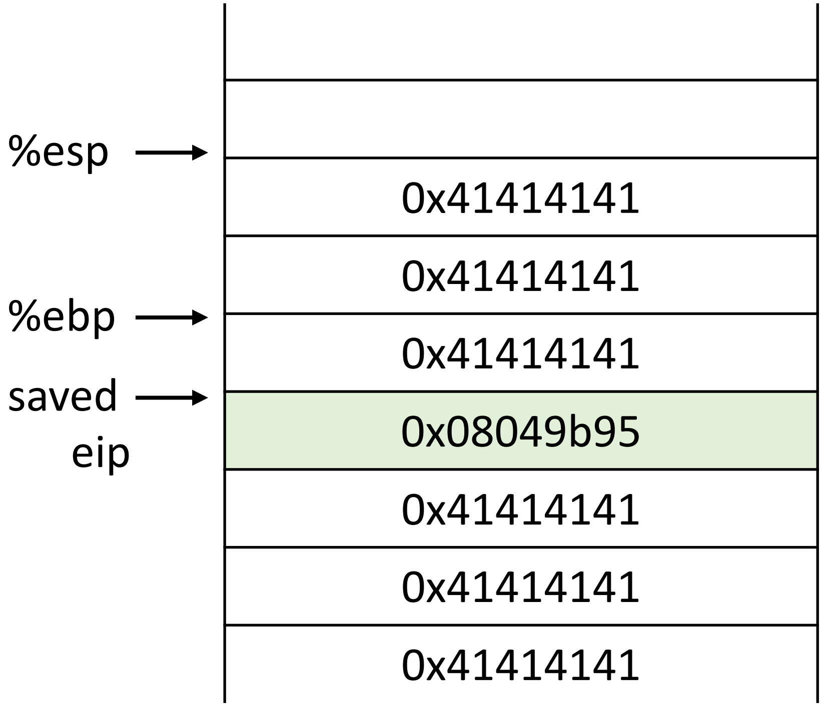
Buffer Overflow example: If the first input is “AAAAAAAAAAAAAAAA”

```c
#include <stdio.h>
#include <string.h>

void foo() { 0x08049b95
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



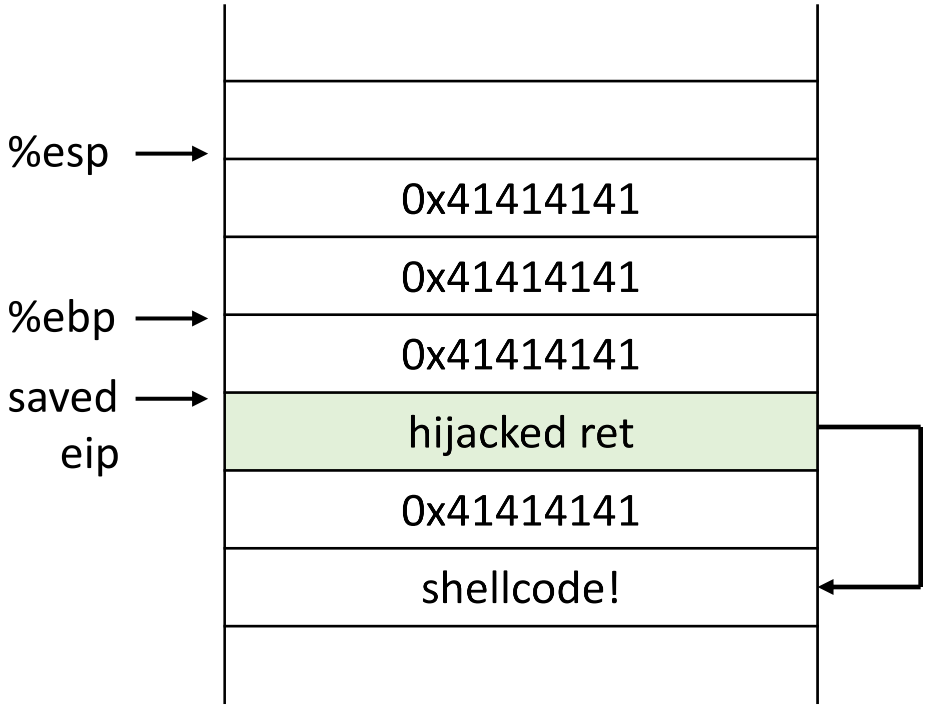
Buffer Overflow example: If the first input is “AAAAAAAA\x95\x9b\x04\x08”

```c
#include <stdio.h>
#include <string.h>

void foo() { 0x08049b95
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



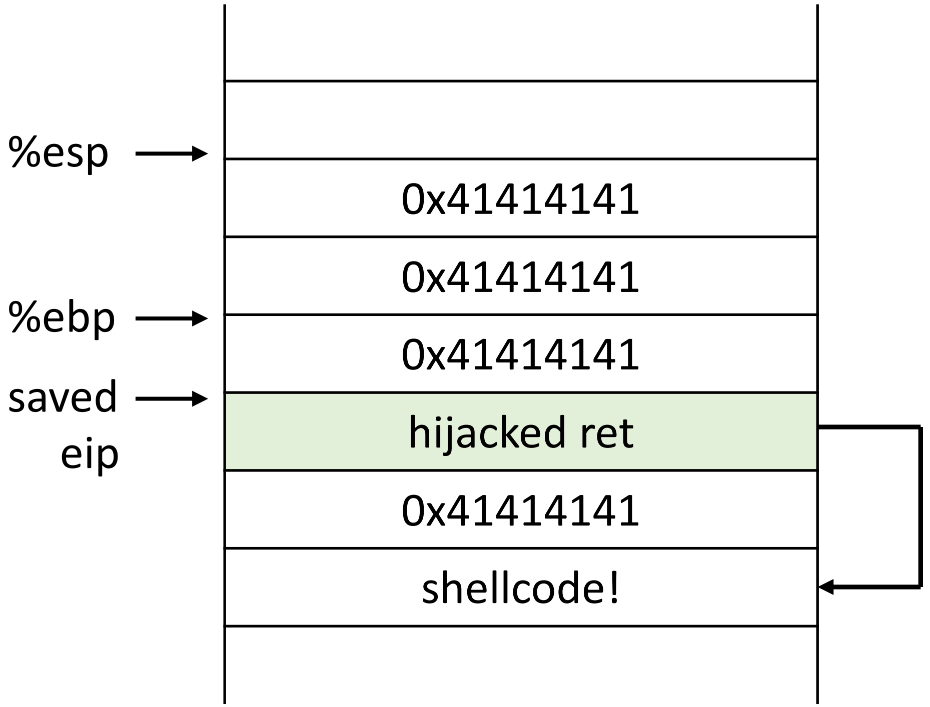
Better Hijacking Control

```c
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



Better Hijacking Control

```
#include <stdio.h>
#include <string.h>

void foo() {
  printf("hello all!!\n");
  exit(0);
}

void func(int a, int b, char *str) {
  int c = 0xfoo5ball ;
  char buf[4];
  strcpy(buf,str);
}

int main(int argc, char**argv) {
  func(0xaaaaaaaa,0xbbbbbbbb,argv[1]);
  return 0;
}
```



Jump to attacker supplied code where?

- put code in the string
- jump to start of the string

Shellcode

- Type of control flow hijack: taking control of the instruction pointer
- Small code fragment to which we transfer control
- Shellcode used to execute a shell

Shellcode

```
int main(void) {
  char* name[1];
  name[0] = "/bin/sh";
  name[1] = NULL;
  execve(name[0], name, NULL);
  return 0;
}
```

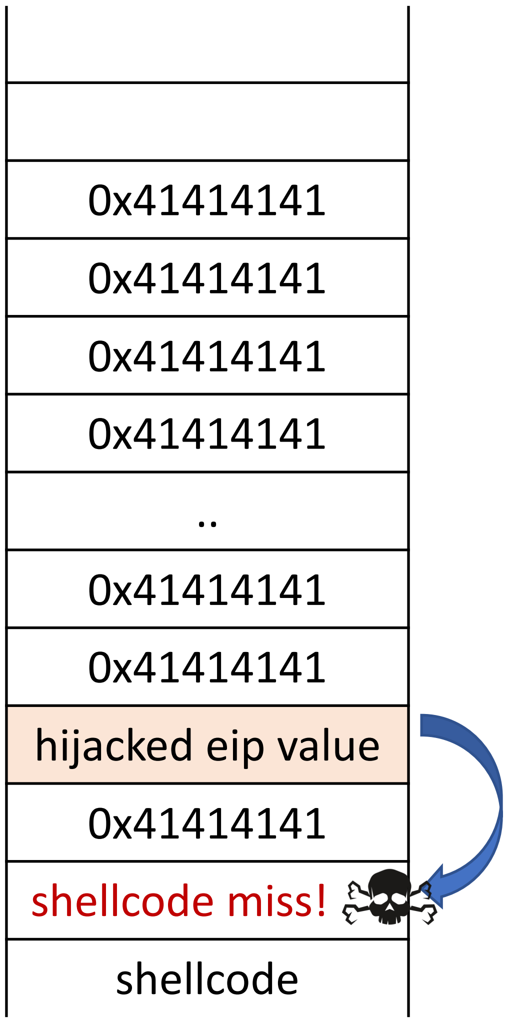
How do we transfer this to code?
Take the compiled assembly?

Payload is not always robust

Exact address of the shellcode start is not always easy to guess

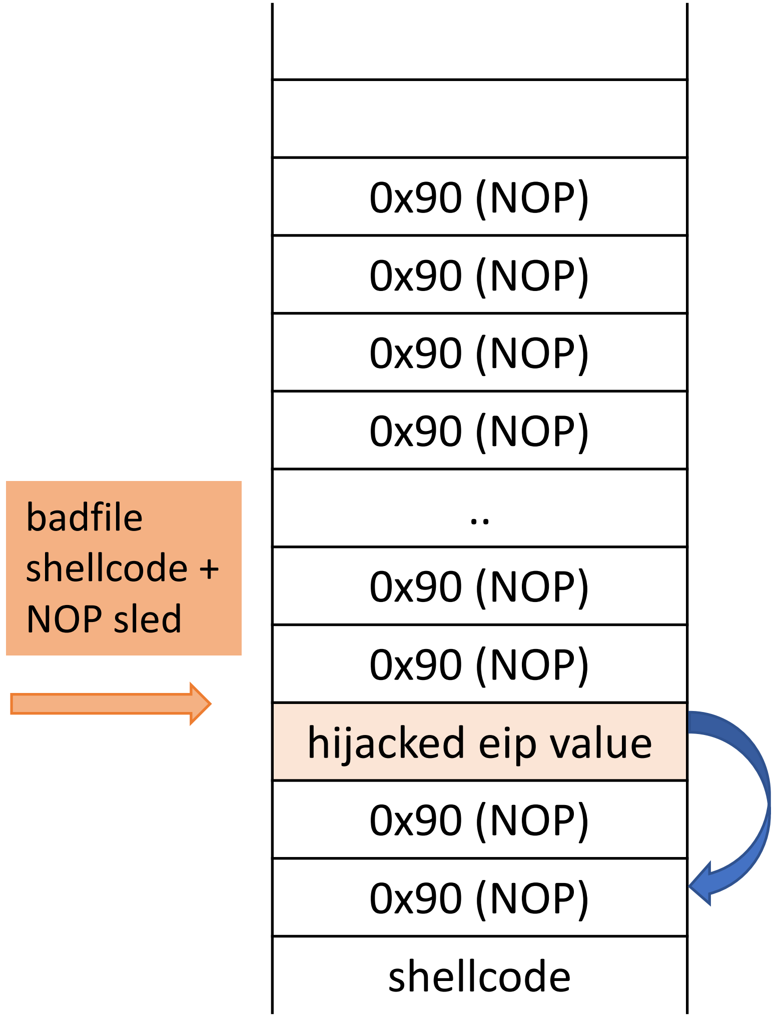
Miss? Segfault

Fix? NOP Sled!



NOP Sled!

- NOP instruction: 0x90
- NOP sleds are used to pad out exploits
  - Composed of instruction sequences that don't affect proper execution of the attack
  - Classically the NOP instruction (0x90), but not restricted to that
- Why are the called sleds?
  - Execution *slides* down the NOPs into your payload
  - Overwritten return address can be less precise, so long as we land somewhere in the NOP sled

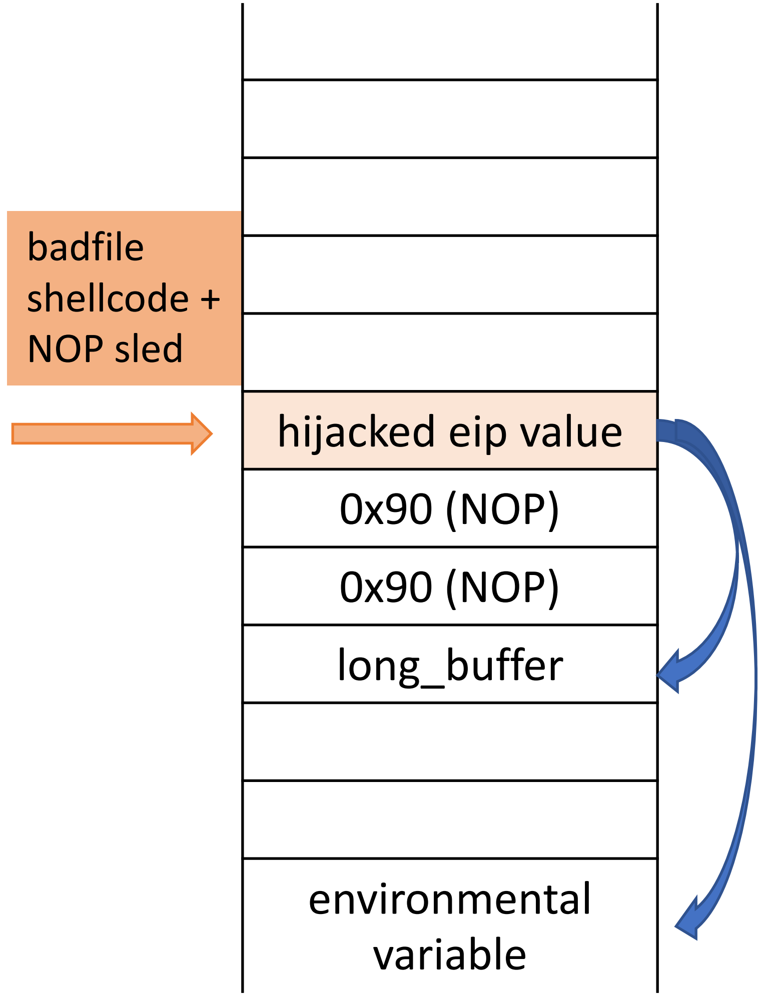


Small Buffers

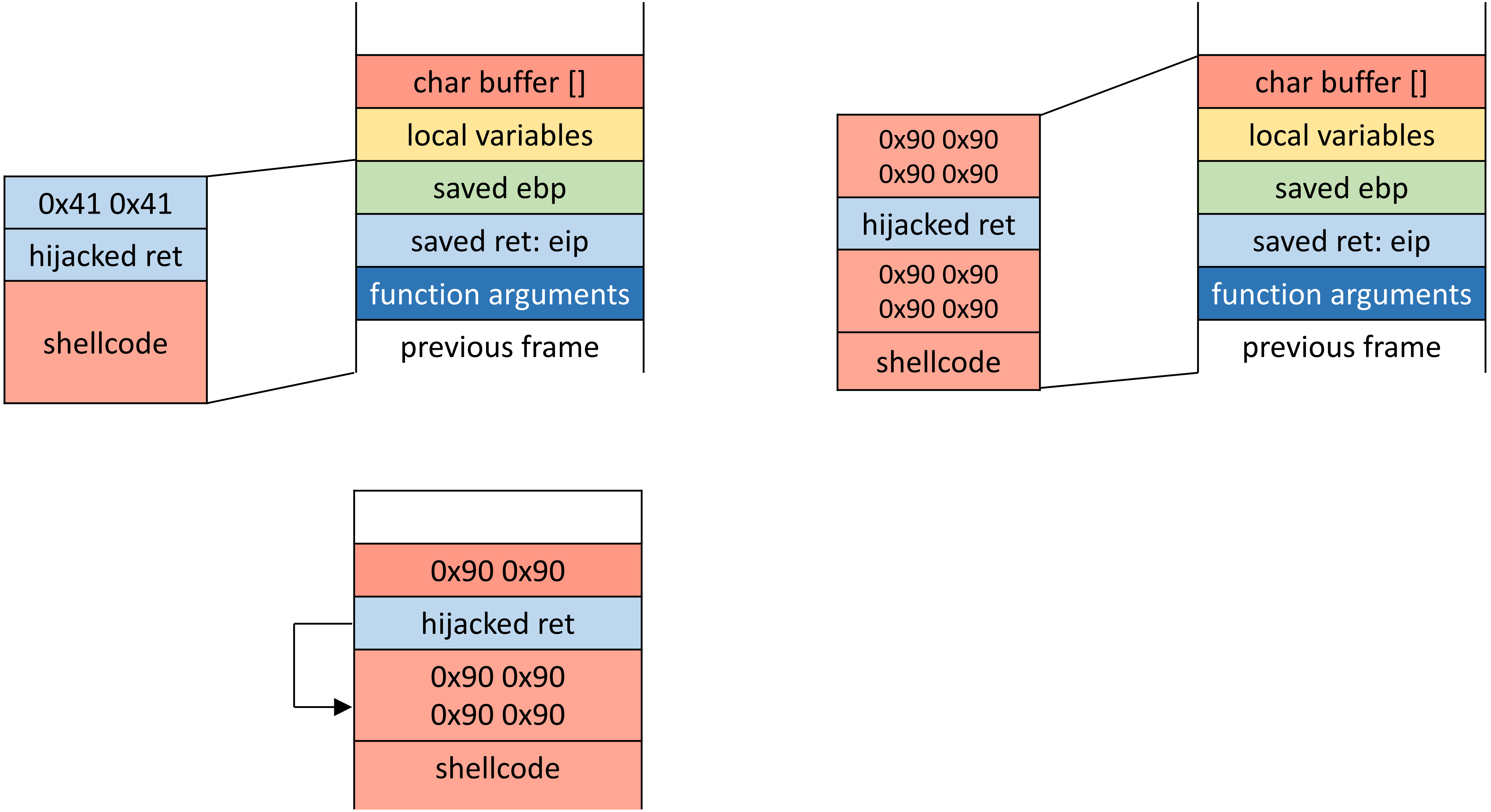
Buffer can be too small to hold exploit Code

Store exploit code in:

- an environmental variable
- or another buffer allocated on the stack
- redirect return address accordingly



Putting it all together



Summary: Stack Code Injection

- Executable attack code is stored on stack, inside the buffer containing attacker's string
  - Stack memory is supposed to contain only data, but…
- For the basic stack-smashing attack, overflow portion of the buffer must contain correct address of attack code in the RET position
  - The value in the RET position must point to the beginning of attack assembly code in the buffer
    - Otherwise application will crash with segmentation violation
  - Attacker must correctly guess in which stack position his buffer will be when the function is called