COSC 366
Intro to Computer Security

Lecture 04
Software Security

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Fall 2024

Today's Class

- Software security overview
- Refresher: function calls, memory layout

Overview

Why Software Security First

- Programs and their code are the basis of computing
- Most people today use off the shelf programs
- Programs are written by humans
- Flaws occur regularly or sporadically despite testing

What We Will Study

- Unintentional programming oversights

  - benign program flaws are often exploited for malicious impact

  - when this happens, which of CIA is compromised?

  - usually a stepping stone to something bigger

- Malicious programs - malware

Unintentional Programming Oversights

- Buffer overflow
- Other programming oversights
- Countermeasures

The Most Infamous: Buffer Overflow

- A buffer overflow is a bug that affects low-level language, typically C and C++
- A program with bug will normally just crash
  - In terms of CIA, what does it compromise?
- If under malicious attack, it can be exploited to
  - steal private information
  - corrupt valuable information
  - inject and execute code of the attacker's choice

What Is Buffer Overflow

- What is buffer

    - contiguous memory associated with a variable or field

    - e.g., when you type in something, it's held in the buffer before being processed

    - common in C: null-terminated strings that are arrays of chars

- What is buffer overflow

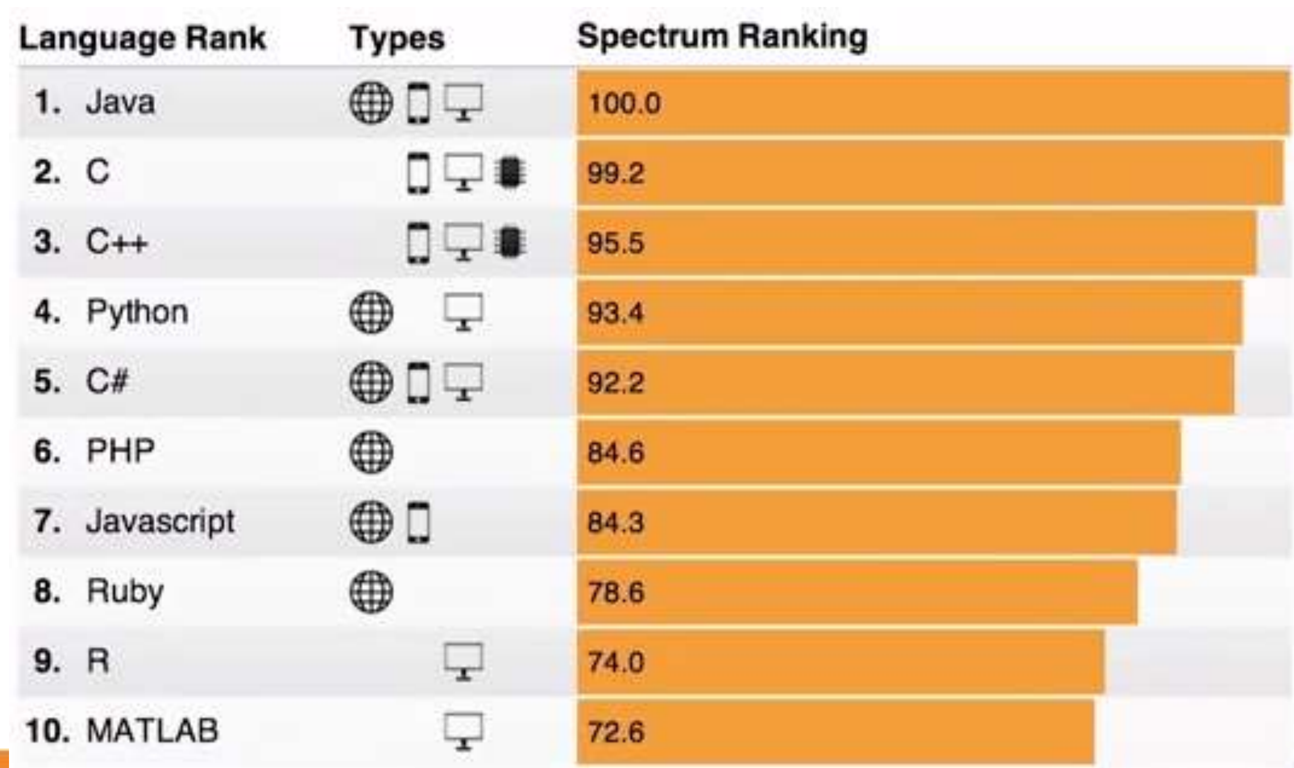
    - read/write more than a buffer can hold

- Where are the extra data go?

    - we will find out

Why Do We Study It

- It has a long history and gives a good lesson
- It is still very relevant today
  - C and C++ are still popular
  - buffer overflows still occur regularly



Critical Systems in C/C++

- Most OS kernels and utilities
  - fingerd, X window server, shell
- Many high-performance servers
  - Microsoft IIS, Apache httpd, nginx
  - Microsoft SQL server, MySQL, redis
- Many embedded systems
  - industrial control systems (e.g., SCADA), automobiles, airplanes, smartphones

History of Buffer Overflows

- 1988: Morris worm
  - 10% of the Internet (6,000 machines) infected
- 2001: CodeRed: exploited MS-IIS server
  - 300,000 machines infected in 14 hours
- 2003: SQL Slammer: exploited MS-SQL server
  - 75,000 machines infected in 10 minutes
- 2014: Heartbleed
  - 17% (half a million) secure web servers infected upon disclosure

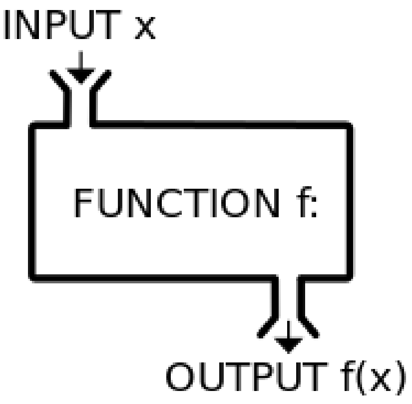
Refresher

- What are function calls?
- How is program data laid out in memory
- What does call stack look like
- What effect does calling (and returning from) a function have on memory?
- We will use x86 32-bit Linux processor model as example

FUNCTION

What's function?

- Assigns to each element of *X* exactly one element of *Y*
- A group of statements that together perform a task.
- Every C program has at least one function, which is main(), and all the most trivial programs can define additional functions.



Function

```
int x = 100;
int main()
{
   // data stored on stack
   int   a=2;
   float b=2.5;
   static int y;

   // allocate memory on heap
   int *ptr = (int *) malloc(2*sizeof(int));

   // values 5 and 6 stored on heap
   ptr[0]=5;
   ptr[1]=6;

   // deallocate memory on heap
   free(ptr);
   return 1;
}
```

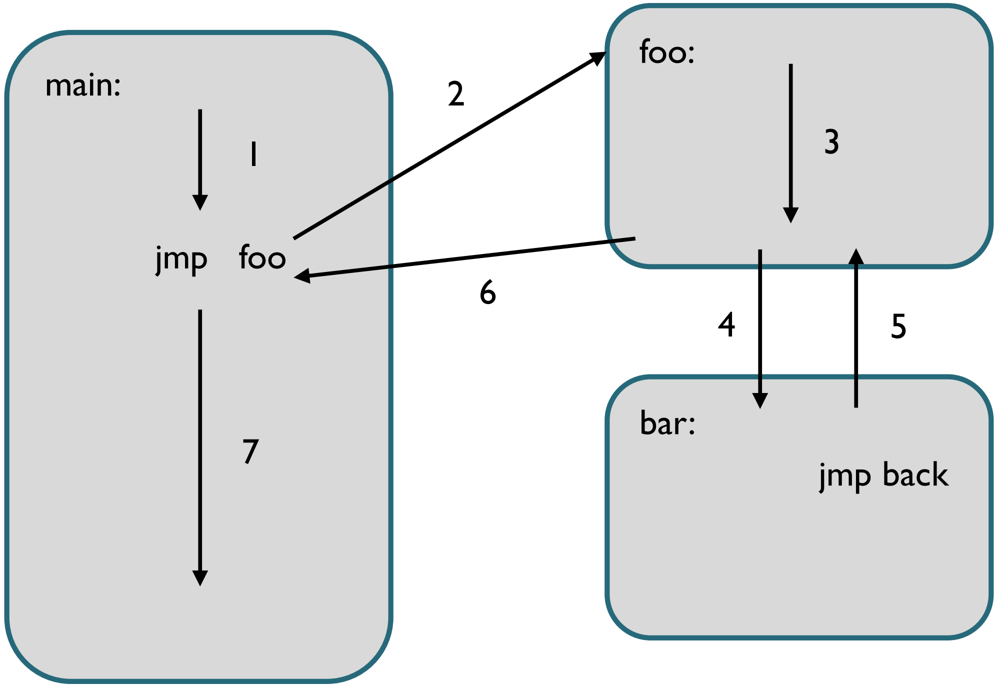
- Function name
  - Main
- Arguments
  - none
- Local variables
  - E.g., a, b
- Return address
  - Invisible
- Return value
  - 1

Function call/return

```
foo(...) {
      …
      bar();
      …
}
```

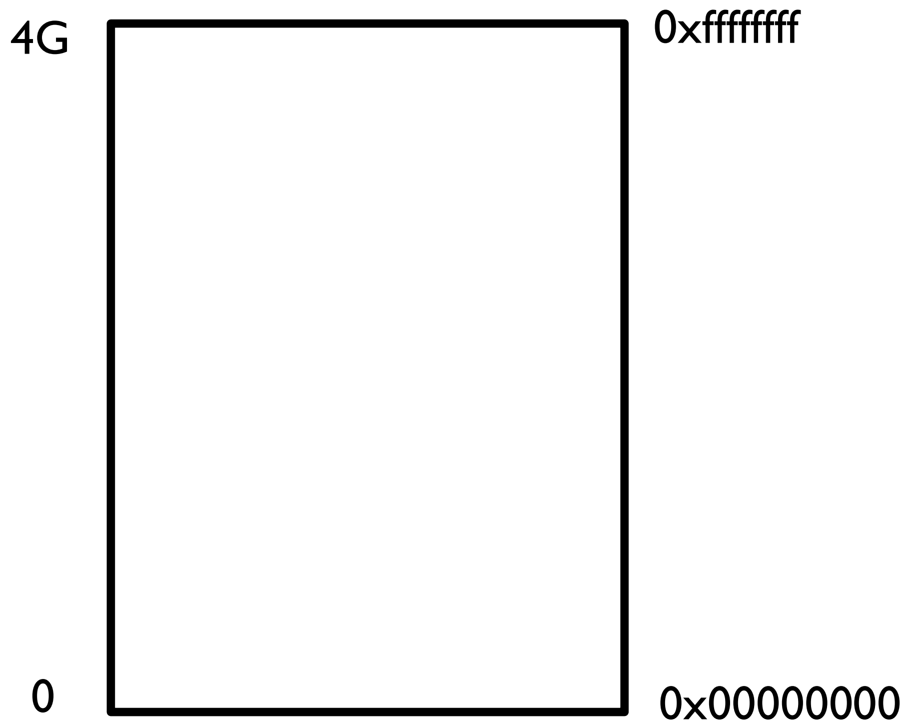
```
bar(...) {
      …
      …
}
```

```
main(...) {
      …
      foo(…);
      …
}
```



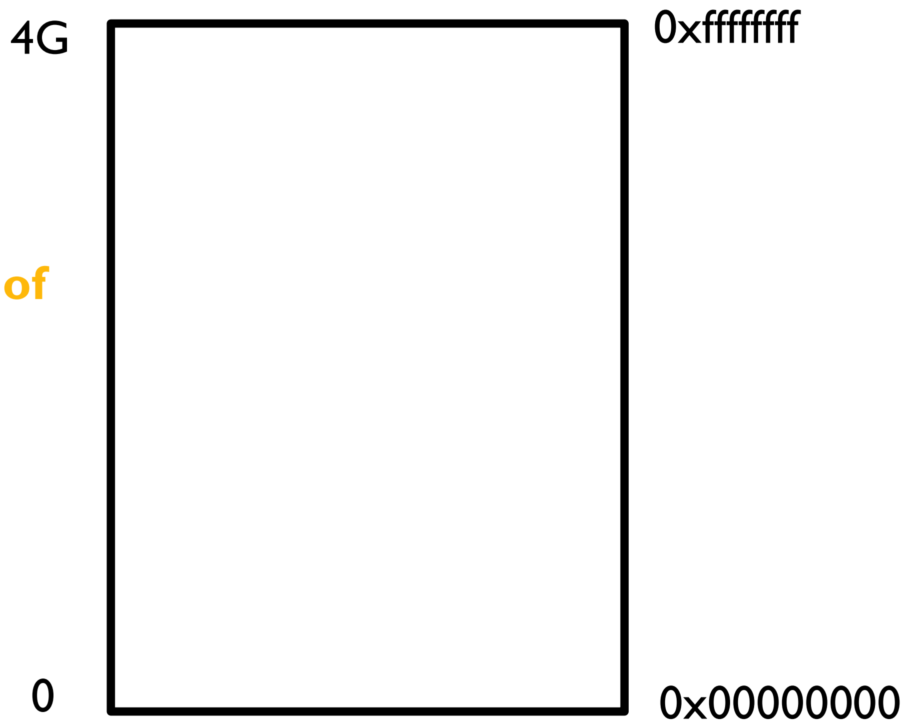
MEMORY LAYOUT

All programs are stored in memory



All programs are stored in memory

The process's view of memory is that it owns all of it



Can the 32-bit system have more than this memory space?

Wait!

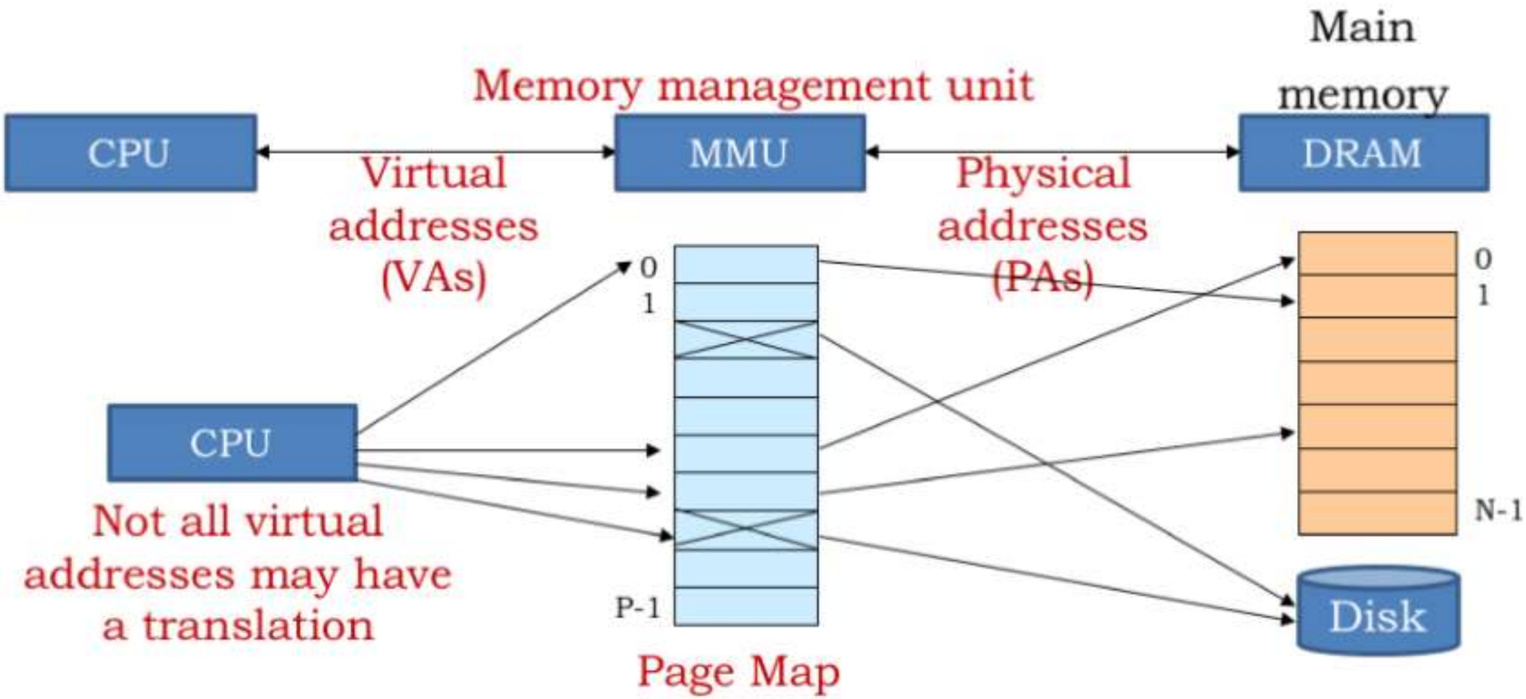
- How would it be possible for two programs to run at the same time on your Windows or MacOS?
  - May conflict your program with other programs
  - You have a limited memory like 4GB, your program needs more memory space than 4GB.
  - How can we overcome this challenge?

Virtual Memory

- Freeing applications from having to manage a shared memory space.
  - You don't worry about managing memory (at low level) when programming → Process isolation, simplifying application writing, simplifying compilation, linking, loading

- Able to conceptually use more memory than might be physically available

Virtual Memory



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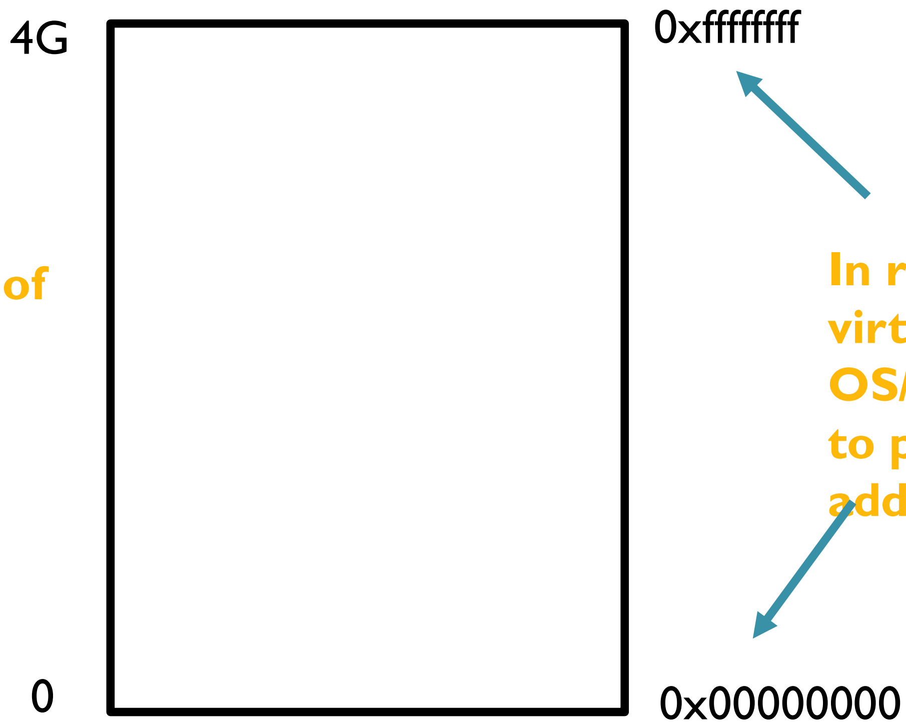
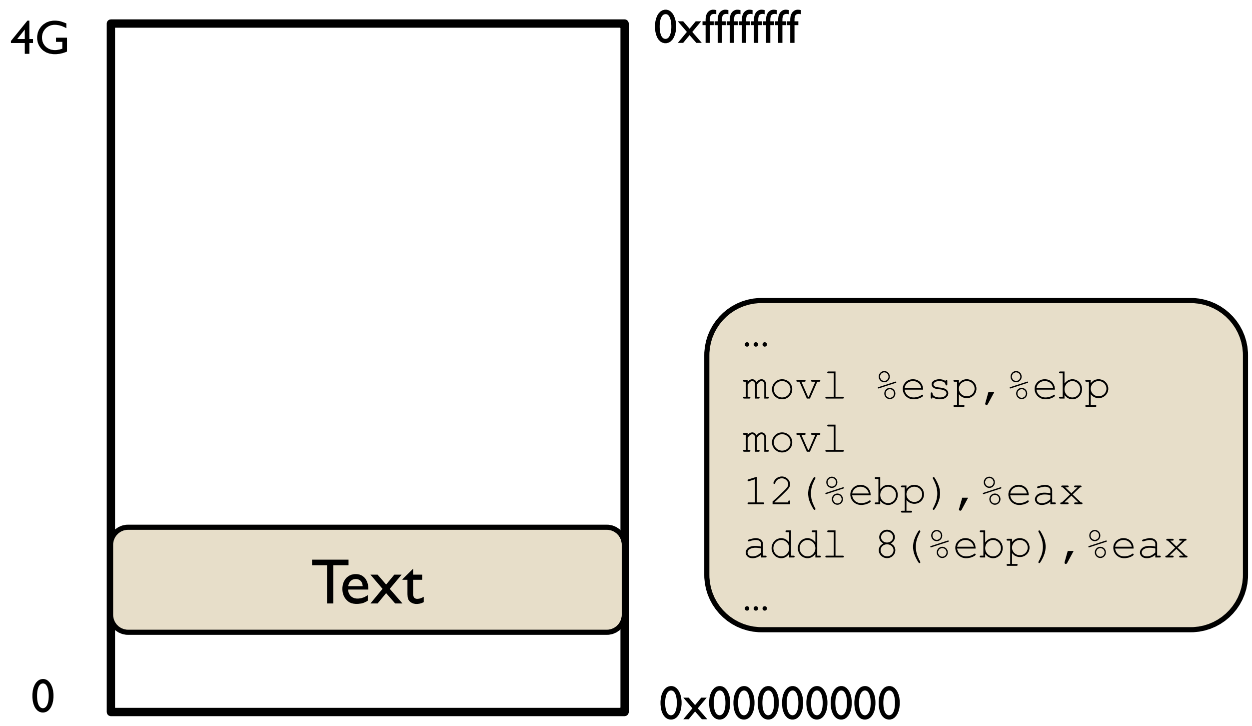


In reality, these are virtual address; the OS/CPU map them to physical addresses.

The instructions are stored in memory



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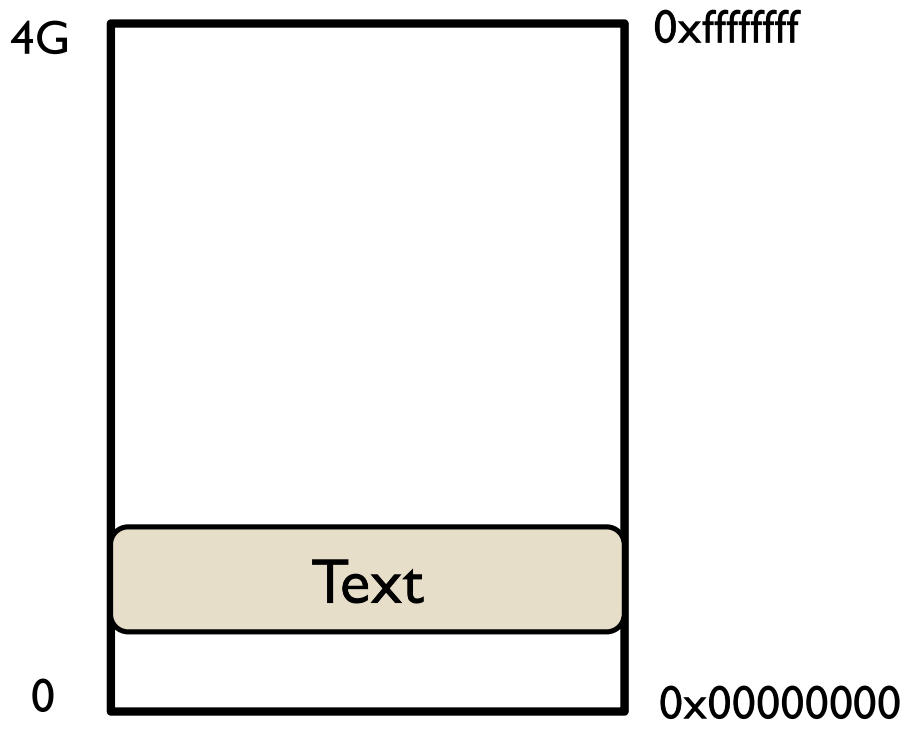
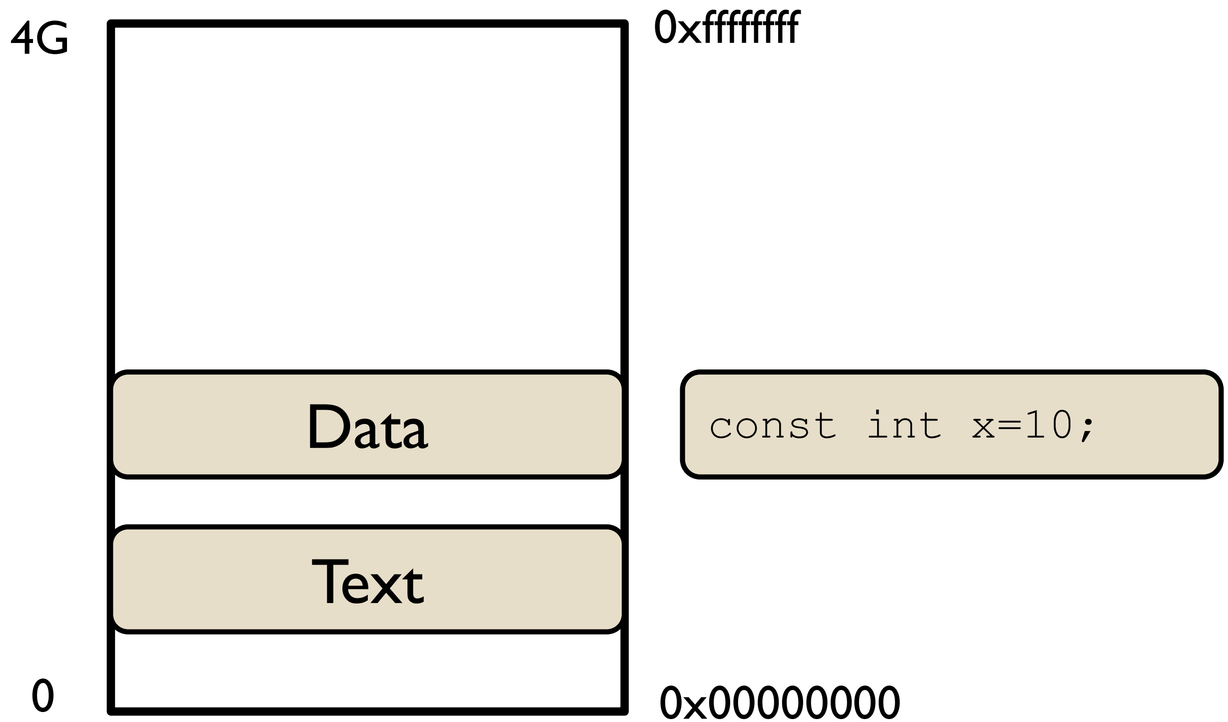


Data are stored in memory



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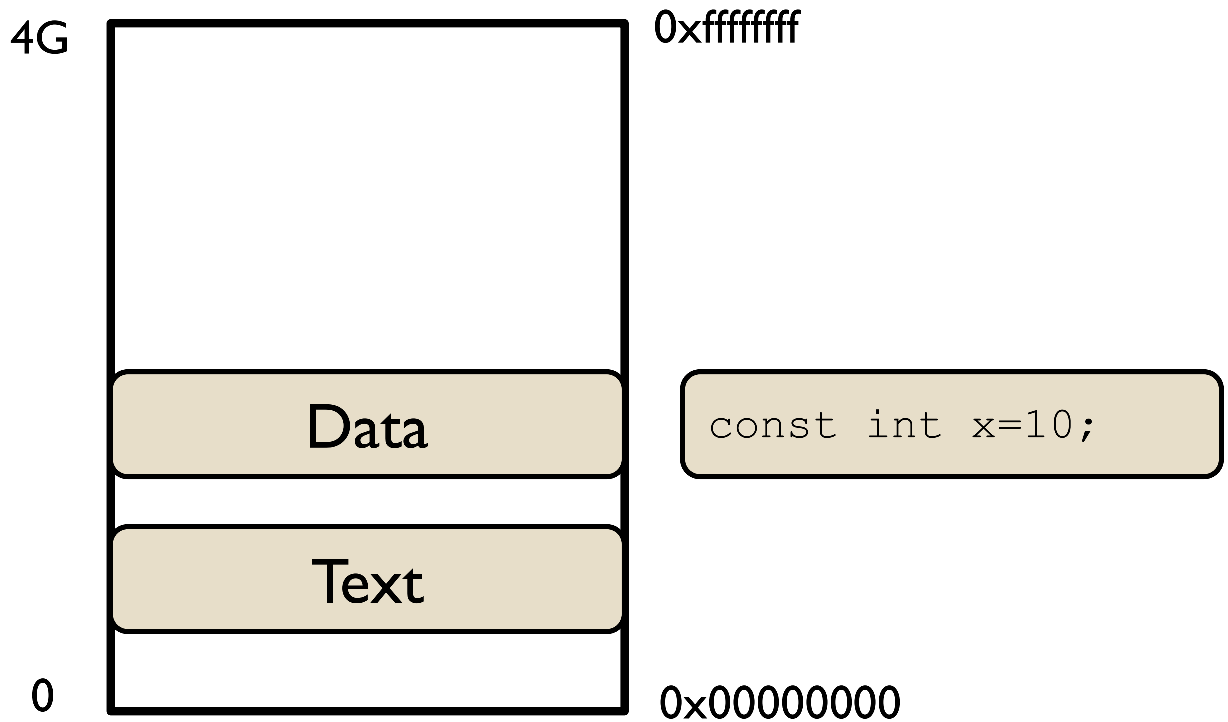

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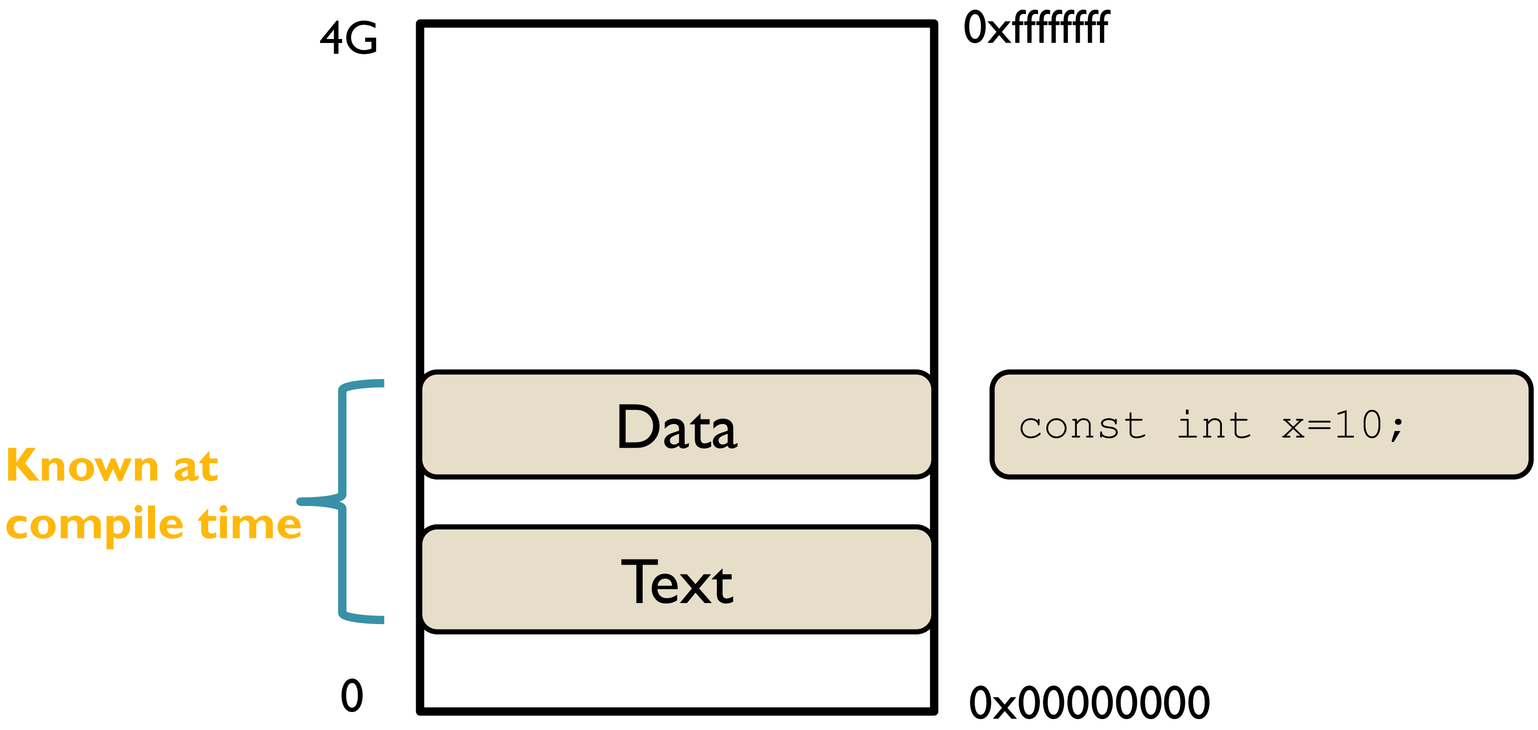
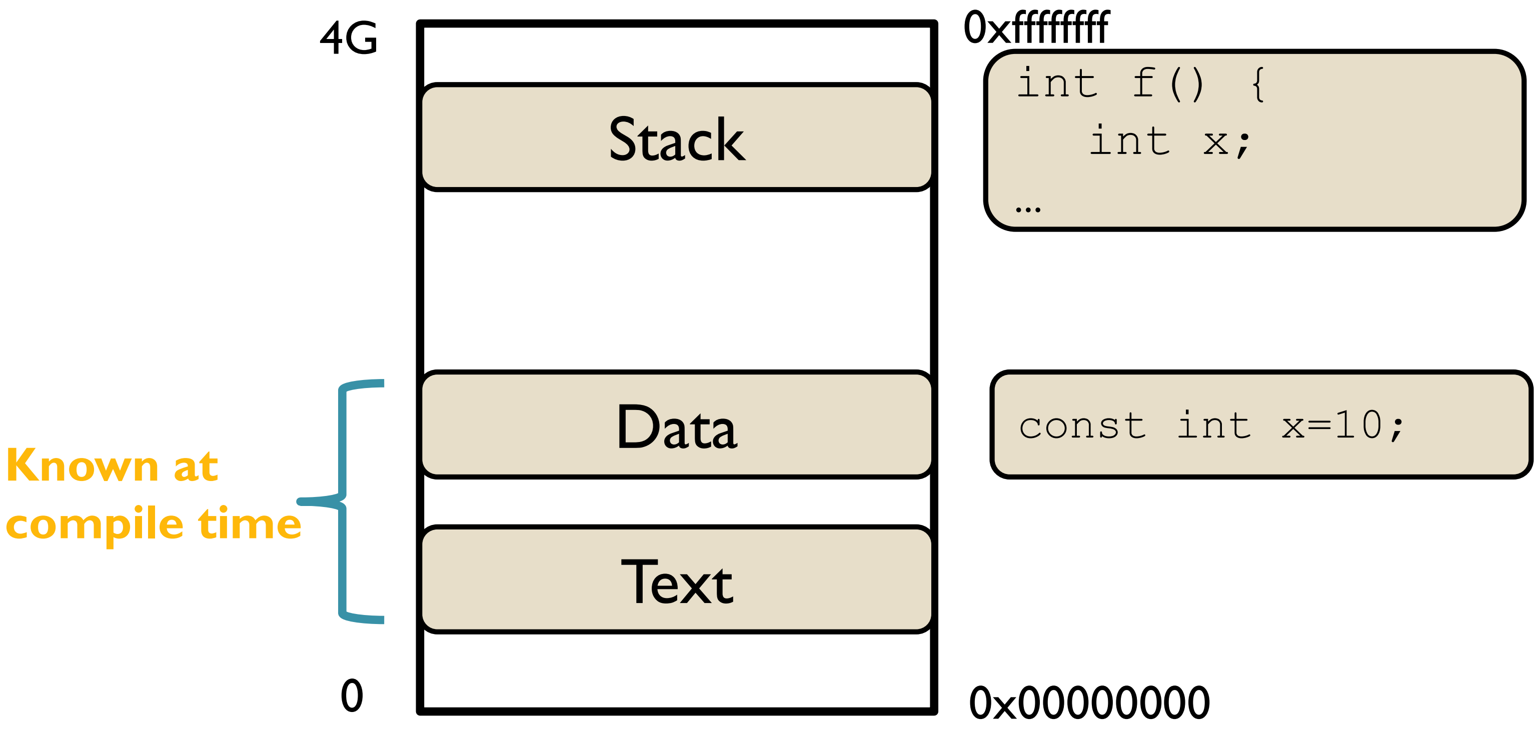
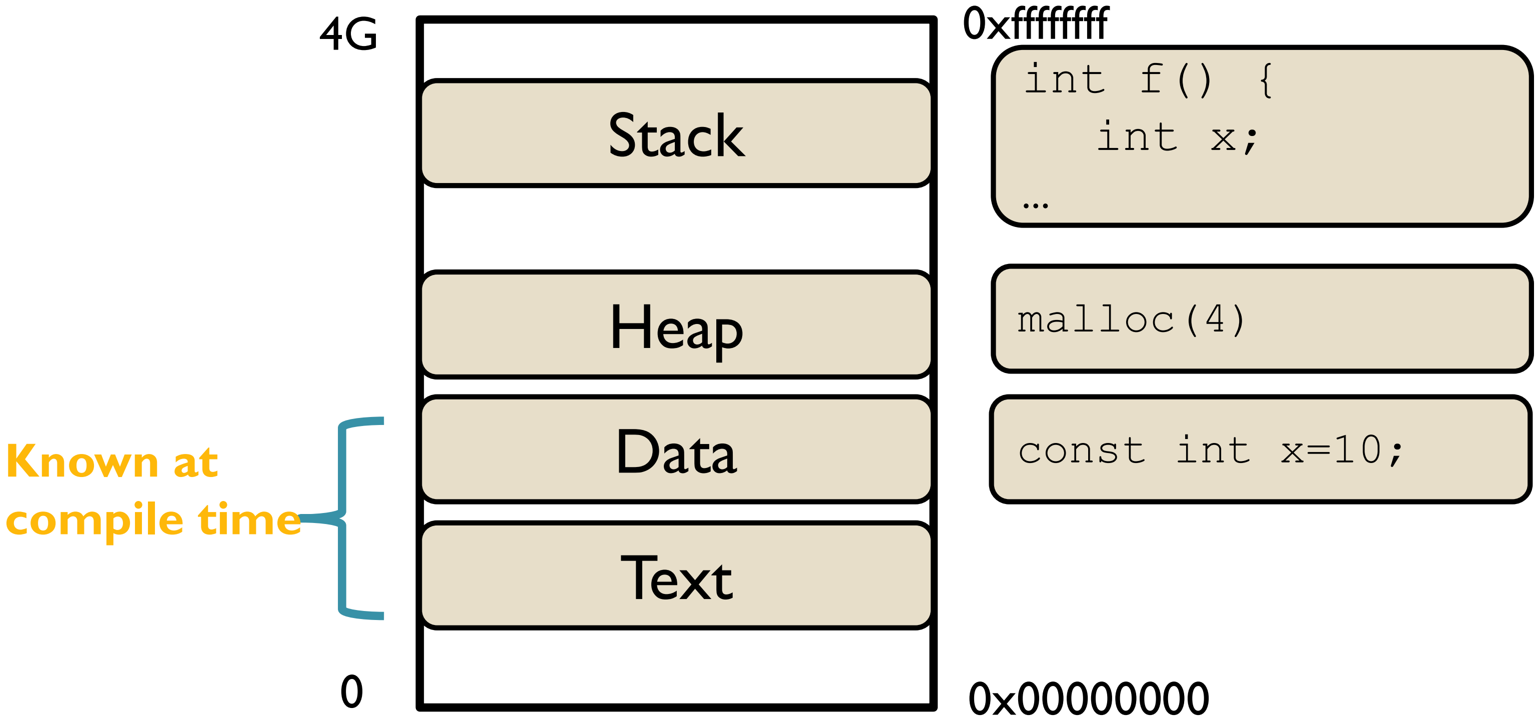


Stack (Local variables)



Heap (Dynamic memory)



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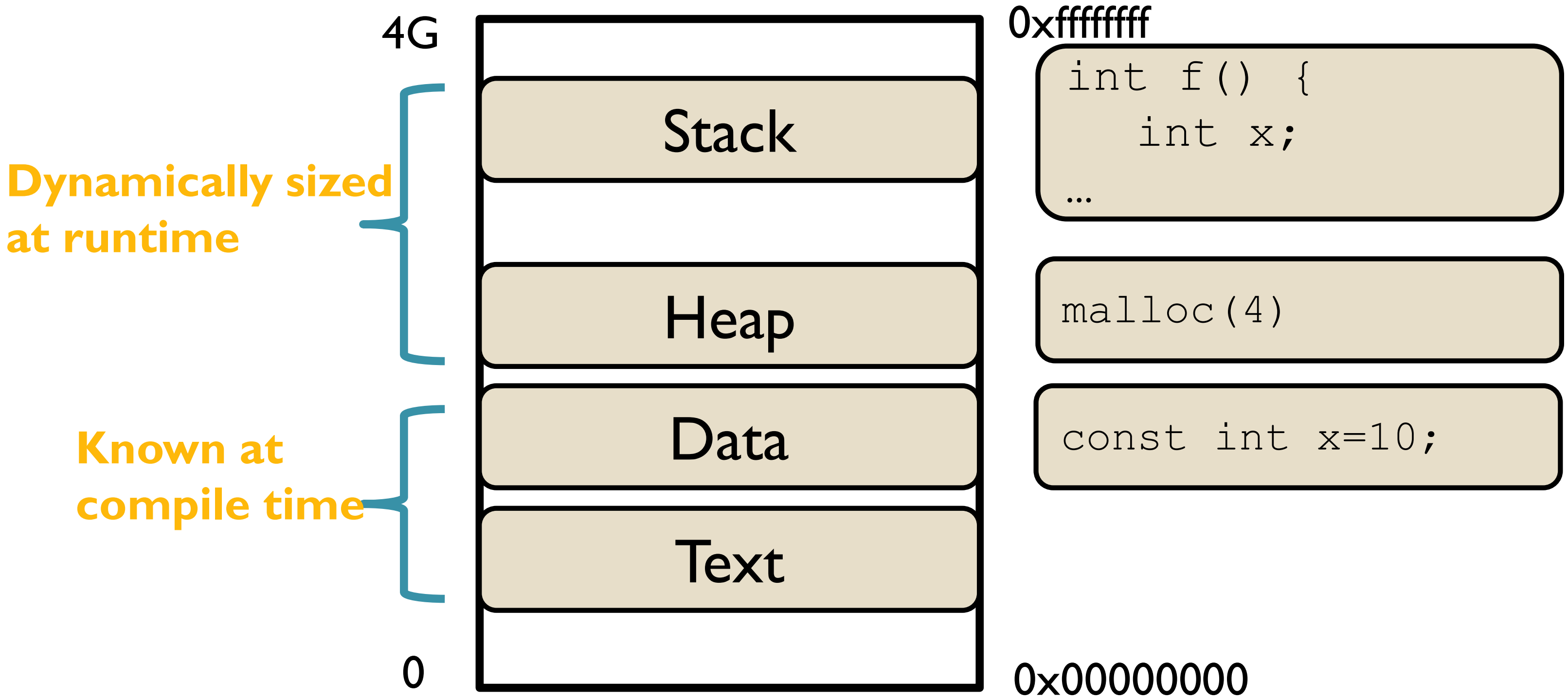
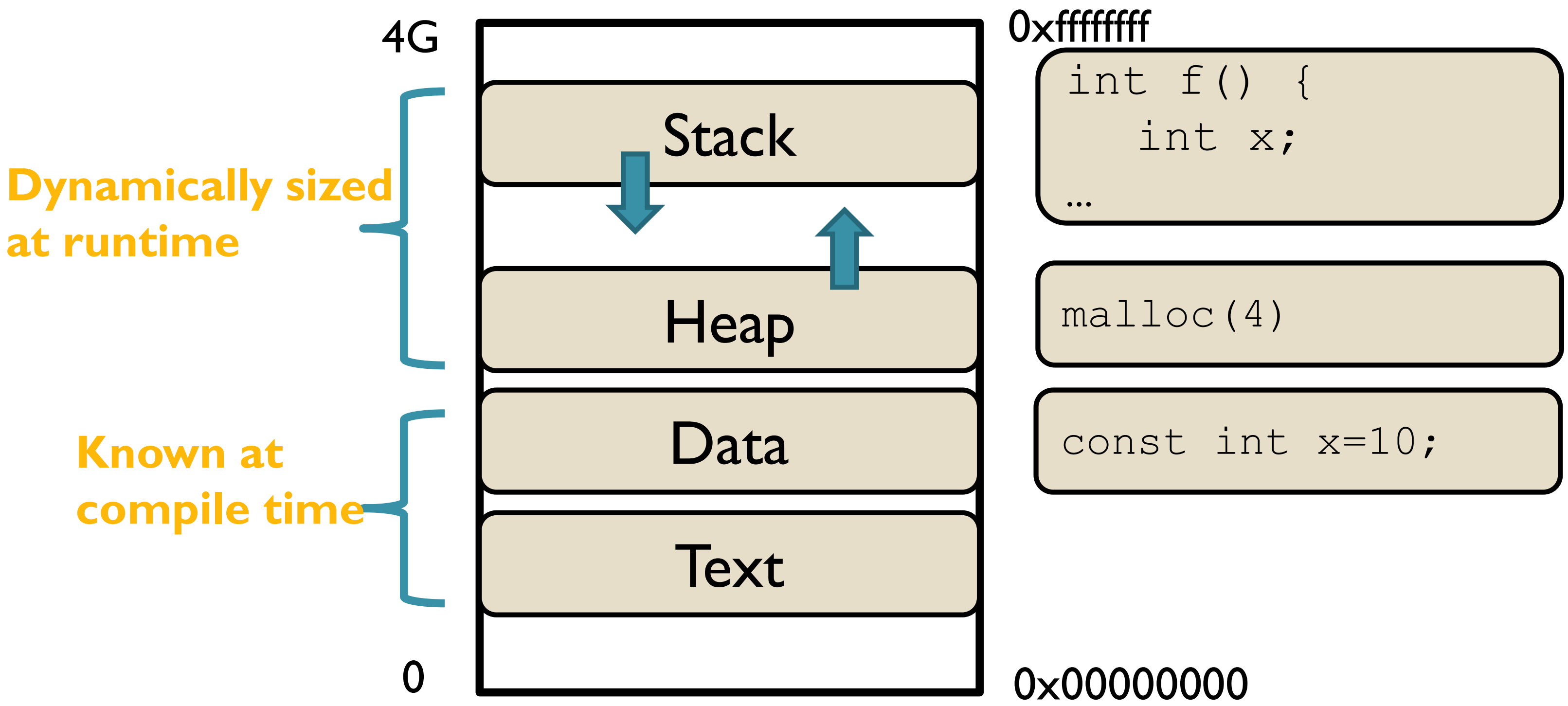


Stack & Heap grow in opposite directions



Program Memory Stack

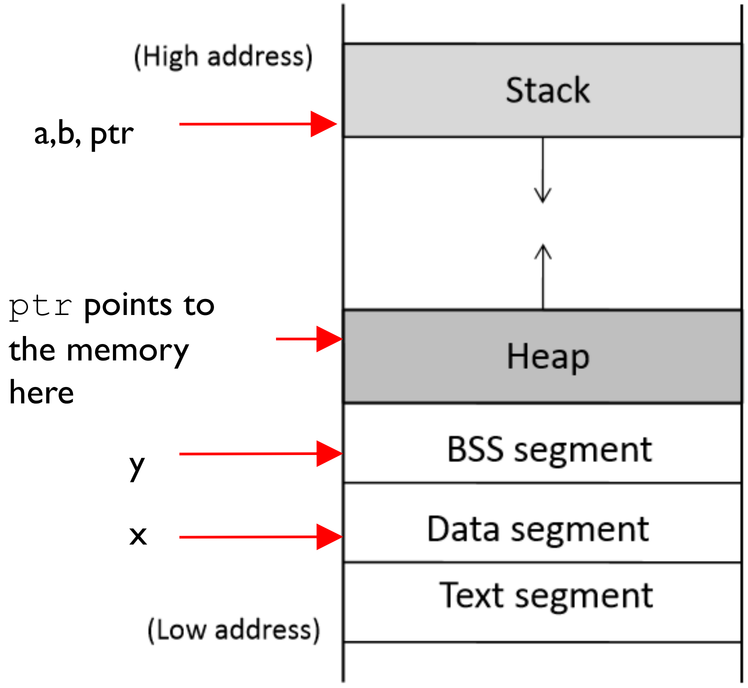
```
int x = 100;
int main()
{
   // data stored on stack
   int   a=2;
   float b=2.5;
   static int y;

   // allocate memory on heap
   int *ptr = (int *) malloc(2*sizeof(int));

   // values 5 and 6 stored on heap
   ptr[0]=5;
   ptr[1]=6;

   // deallocate memory on heap
   free(ptr);

   return 1;
}
```

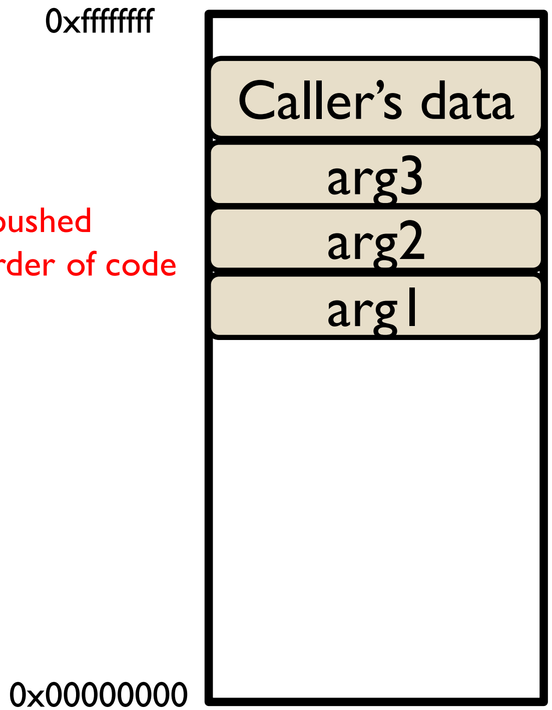


STACK LAYOUT

Stack layout when calling function

```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4]
    int  loc2;
    int  loc3;
    ...
}
```

Arguments pushed
in reverse order of code



Stack layout when calling function

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{
    char loc1[4]
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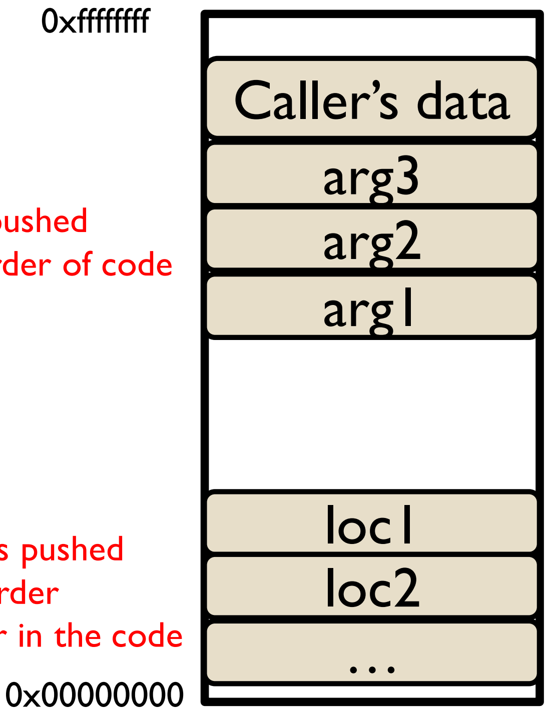
    ...
}
```

Arguments pushed
in reverse order of code

Local variables pushed
in the same order
as they appear in the code



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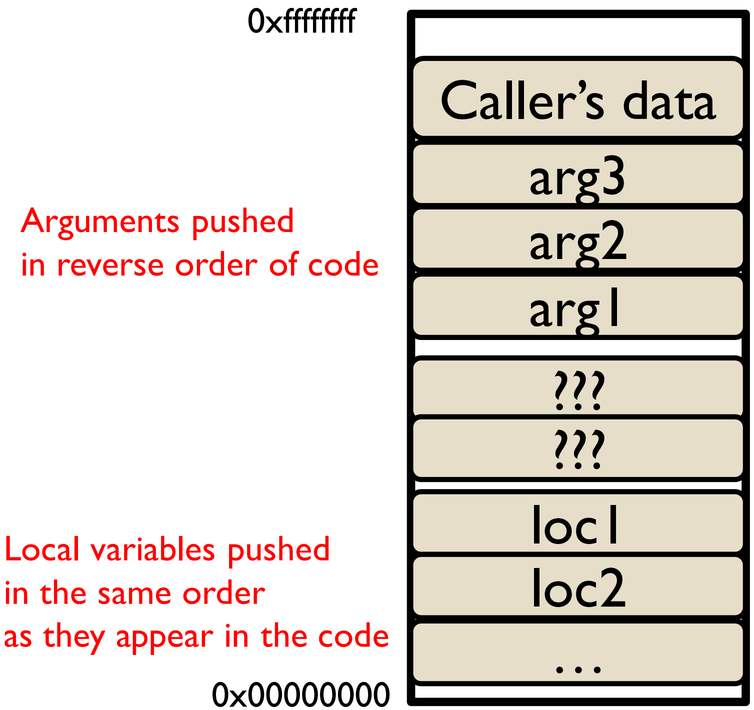

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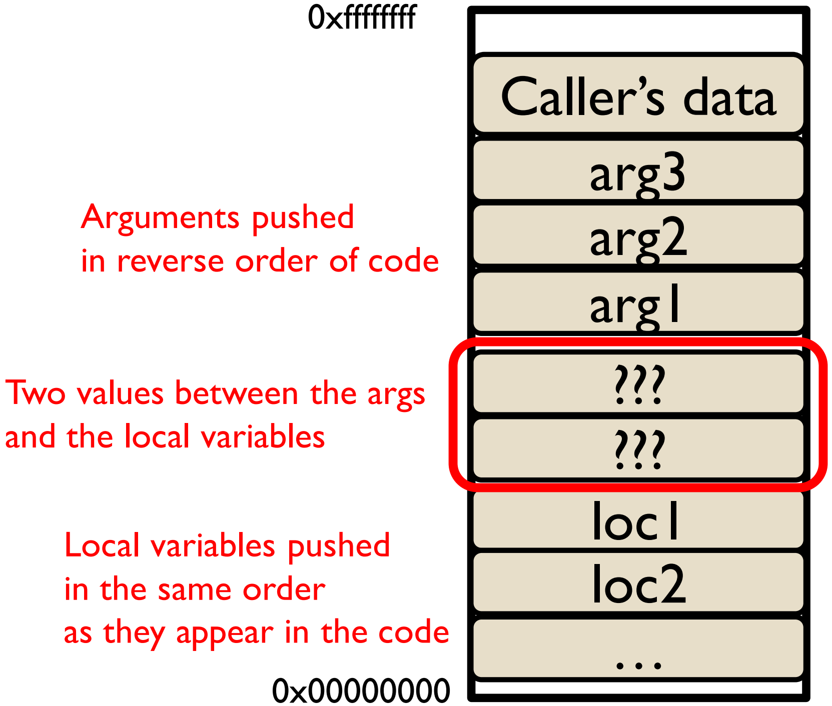
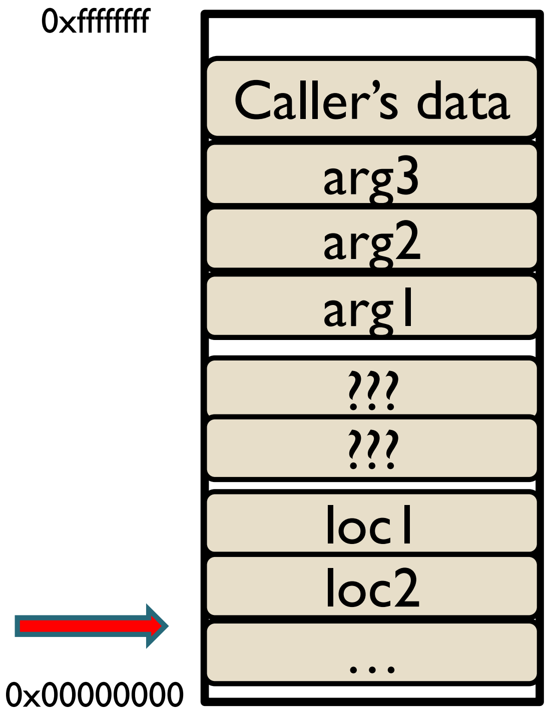


EBP (EXTENDED BASE POINTER)

What's the addr. of loc2?

```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4]
    int  loc2;
    int  loc3;
    ...
}
```

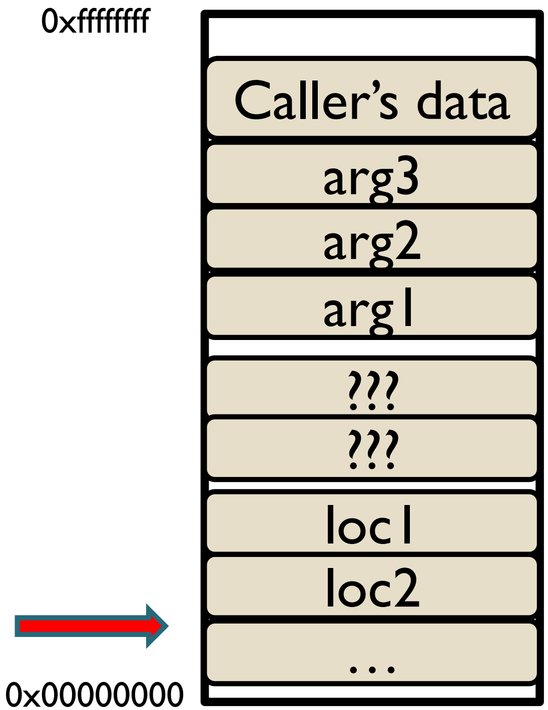
Q) Where is loc2?
What's the specific address?



What’s the addr. of loc2?

```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4]
    int  loc2;
    int  loc3;
    ...
}
```

Q) Where is loc2?
What’s the specific address?
A) We don’t know before running
since undecidable at compile time



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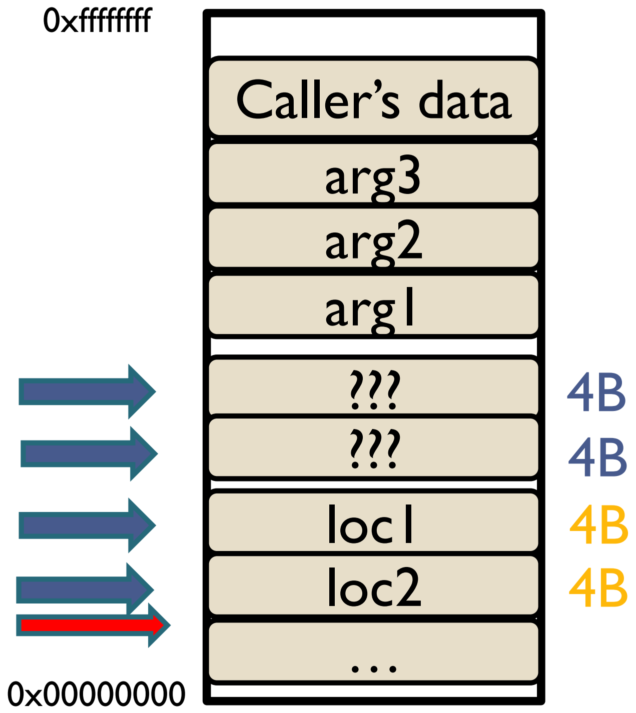
Q) Where is loc2?
What's the specific address?
A) But we can know loc2 is always
8bytes before "???"s ➔ addr of ??? - 8B



EBP (Base Pointer)

```
void func(char *arg1, int arg2, int arg3)
{
    char loc1[4]
    int  loc2;
    int  loc3;
    ...
}
```

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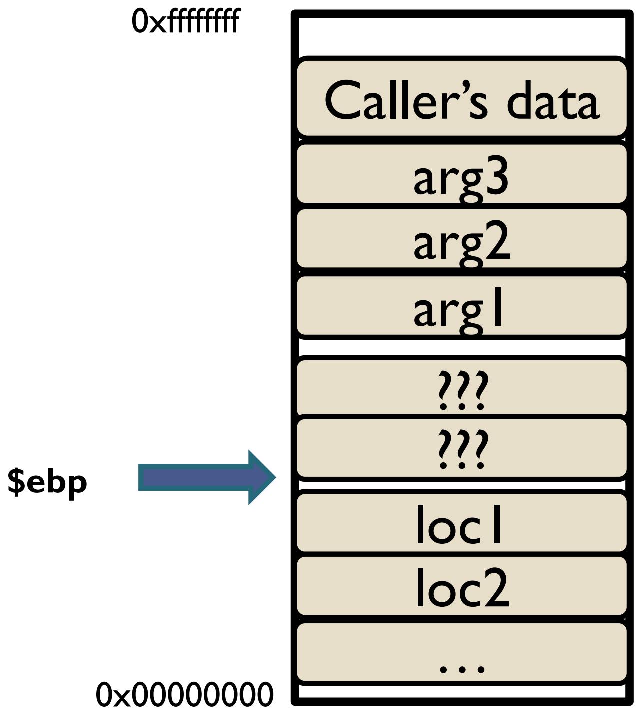

EBP (Base Pointer): Notation

- %ebp: A memory address
- (%ebp): The value at memory address %ebp (like dereferencing a pointer)

EBP (Base Pointer)

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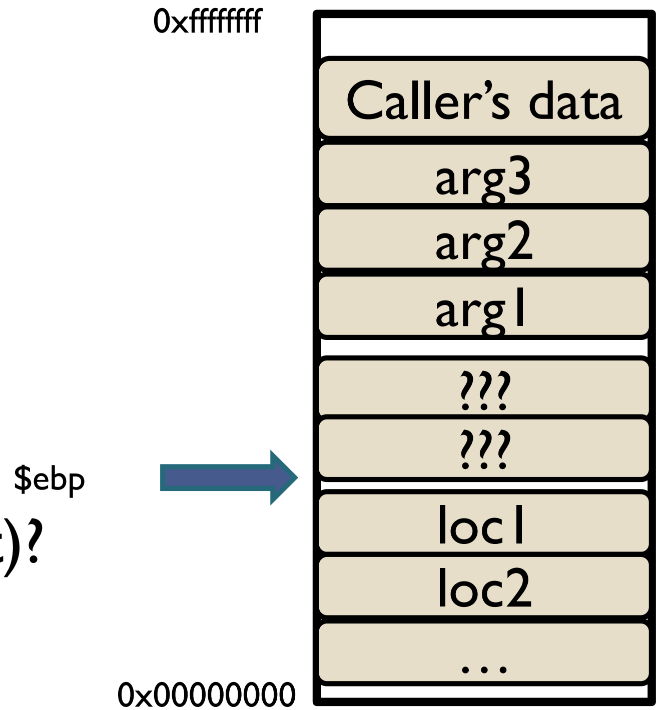

Q) where is loc2?
What's the specific address (and content)?

A) -8 (%ebp)

Stack layout when calling function

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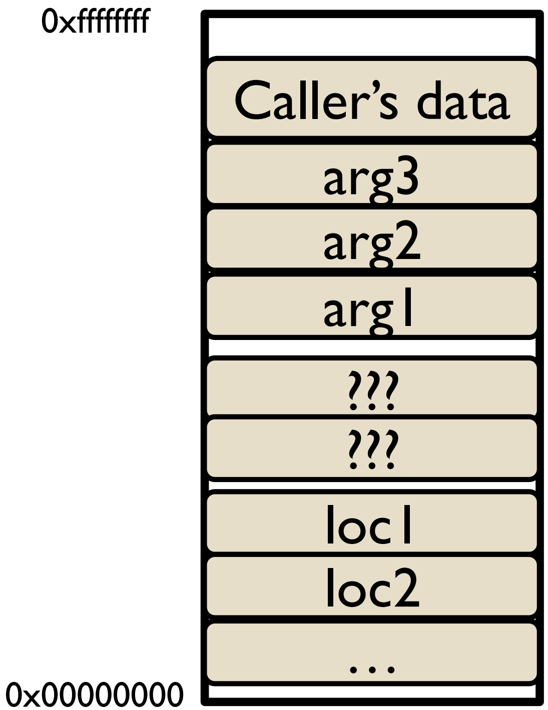
}
```



Q) What are "???"?

First, we need $ebp

Stack layout when calling function

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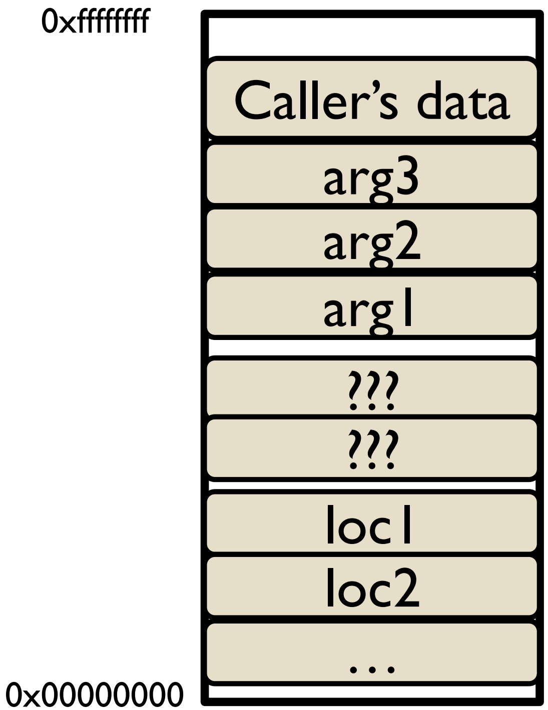


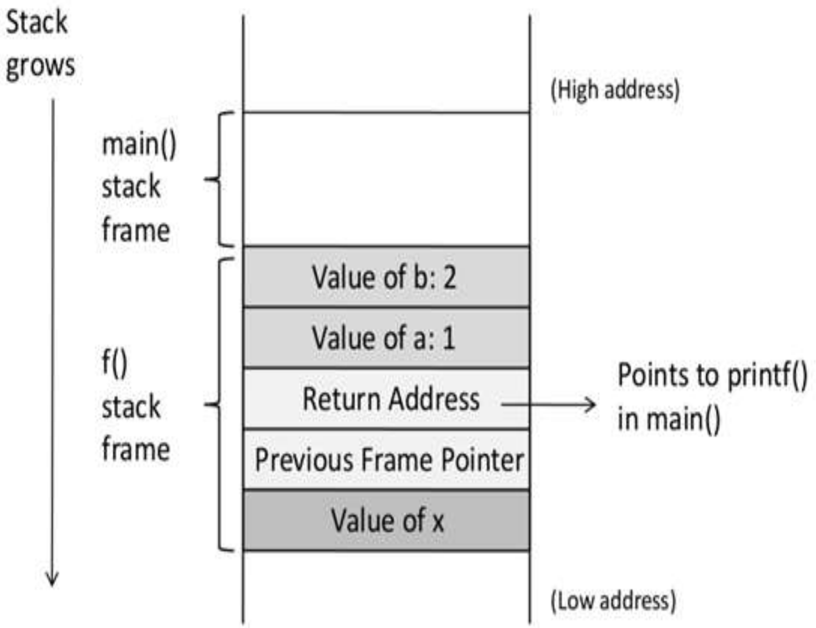
Q) What are "???" ?

First, we need $ebp

Second, we need a return address

Function Call Stack

```
void f(int a, int b)
{
  int x;
}
void main()
{
  f(1,2);
  printf("hello world");
}
```



Order of the function arguments in stack

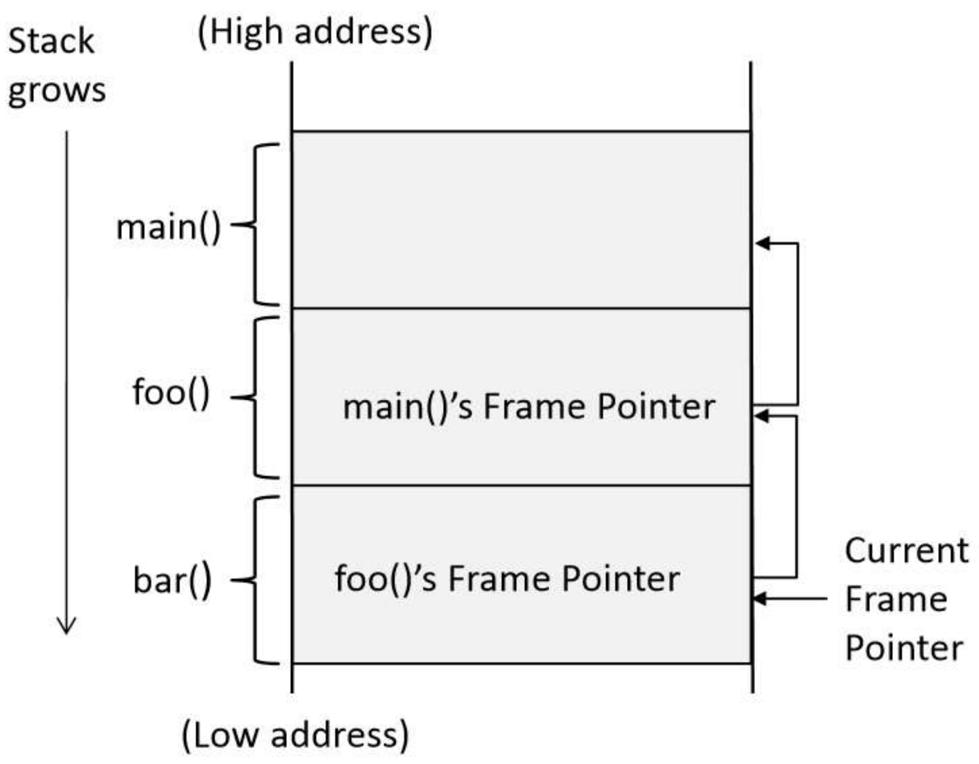
```
void func(int a, int b)
{
   int x, y;

   x = a + b;
   y = a - b;
}
```

Can you tell why are +12, +8 and -8 listed here?

```
movl     12(%ebp), %eax      ; b is stored in %ebp + 12
movl     8(%ebp), %edx       ; a is stored in %ebp + 8
addl     %edx, %eax
movl     %eax, -8(%ebp)      ; x is stored in %ebp - 8
```

Stack Layout for Function Call Chain



main()

foo()

bar()

Heap

```
int x = 100; // In Data segment
int main() {
    int a = 2; // In Stack
    float b = 2.5;// In Stack
    static int y;// In BSS

   // Allocate memory on Heap
    int *ptr = (int *) malloc(2*sizeof(int));
   // values 5 and 6 stored on heap
   ptr[0] = 5;// In Heap
   ptr[1] = 6;// In Heap
   free(ptr);
   return 1;
}
```

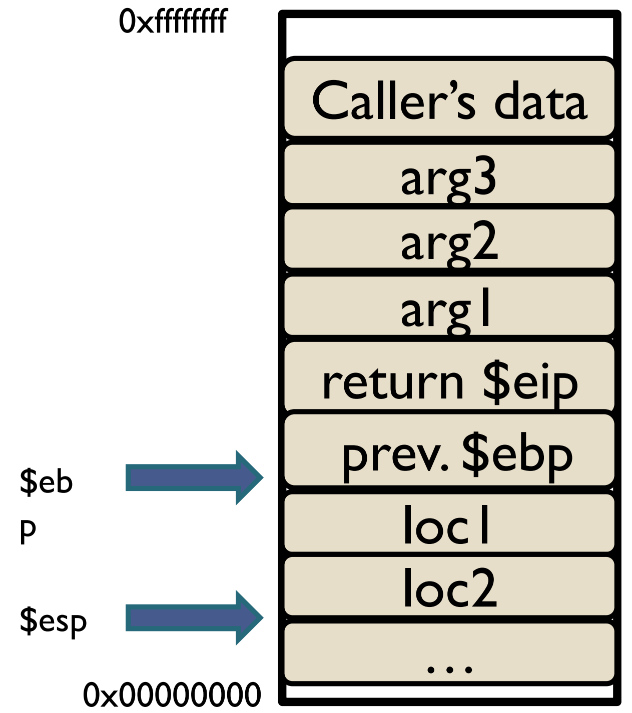
Returning from functions

In C

```
return;
```

In compiled assembly

```
leave:  mov %esp %ebp
        pop %ebp
ret:    pop %eip
```



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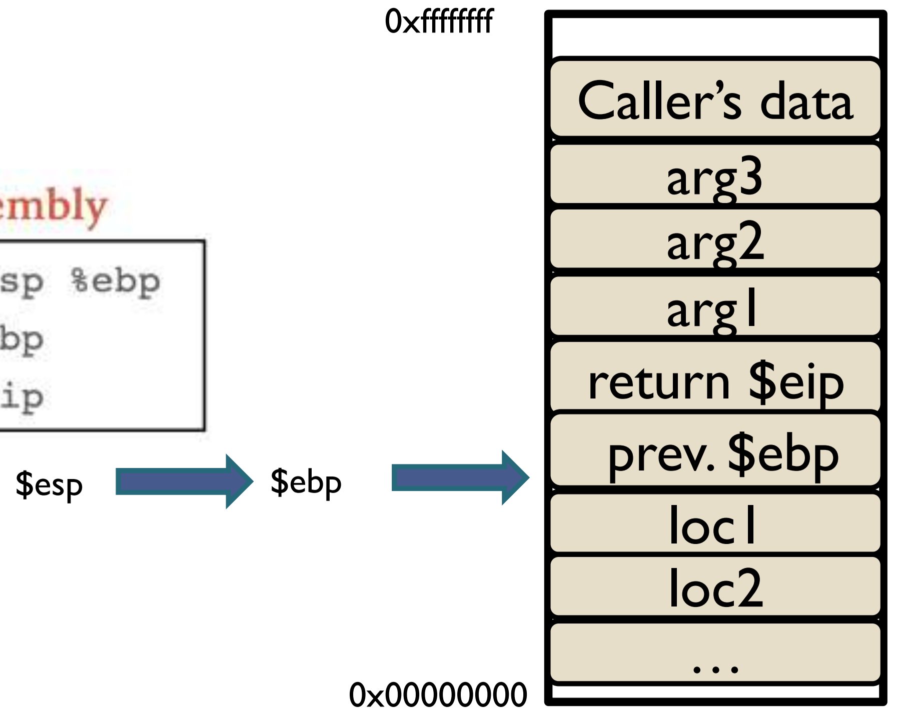

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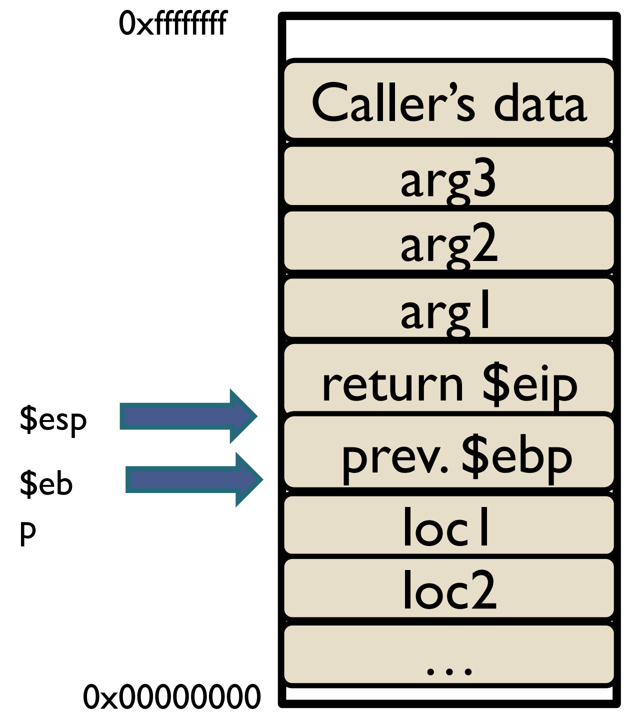

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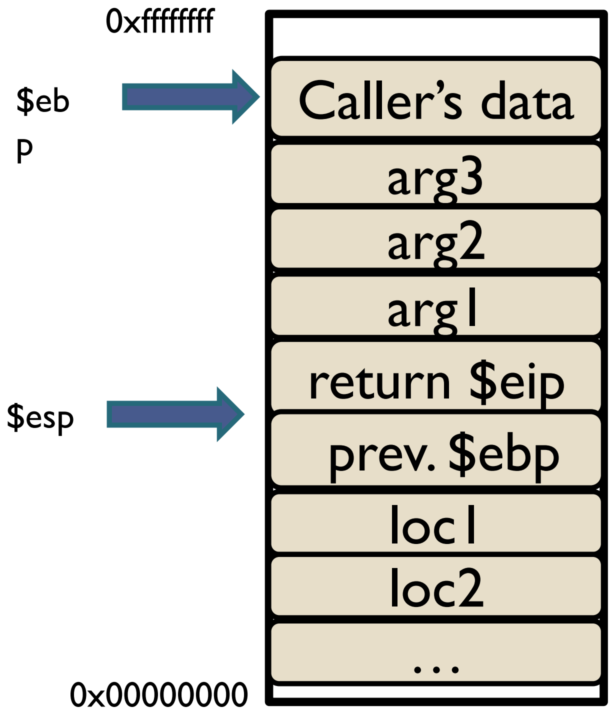

Returning from functions

In C

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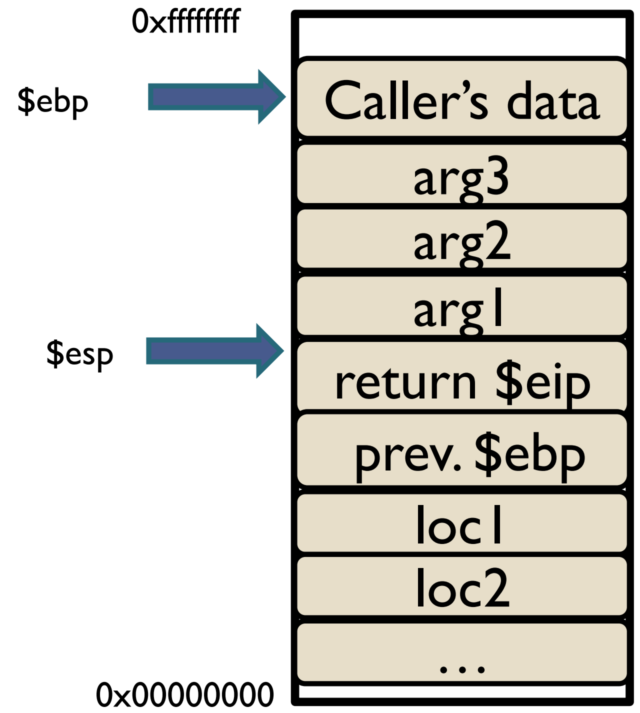
```

1. The next instruction is to “remove” the arguments off the stack
2. And now we’re back where we started



Stack & functions: Summary

Calling function (before calling):

1. **Push arguments** onto the stack (in reverse)
2. **Push the return address**, i.e., the address of the instruction you want run after control returns to you: e.g., %eip + 2
3. **Jump to the function's address**

Stack & functions: Summary

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Called function (when called):

1. **Push the old frame pointer** onto the stack: push %ebp
2. **Set frame pointer** %ebp to where the end of the stack is right now: %ebp=%esp
3. **Push local variables** onto the stack; access them as offsets from %ebp

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Called function (when returning)

1. **Reset the previous stack frame**: %esp = $ebp; pop %ebp
2. **Jump back to return address**: pop %eip