

Systems and Networking I

Applied Computer Science and Artificial Intelligence
2024-2025



SAPIENZA
UNIVERSITÀ DI ROMA

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The Big Picture So Far

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 - abstract from actual physical (HW) resources
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 - abstract from actual physical (HW) resources
 - ease the interaction between users and HW resources
- Different OS designs depending on how those services are implemented
 - monolithic, layered, microkernel, hybrid, etc.

Part II: Process Management

Program vs. Process

- A **program** is an executable file which resides on the persistent memory (e.g., disk),
 - contains only the set of instructions to accomplish a specific job
 - e.g., the `ls` program is an executable file stored at `/bin/ls` on the disk of a UNIX-like OS

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`program` → "static/passive" vs. `process` → "dynamic/active"

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Process

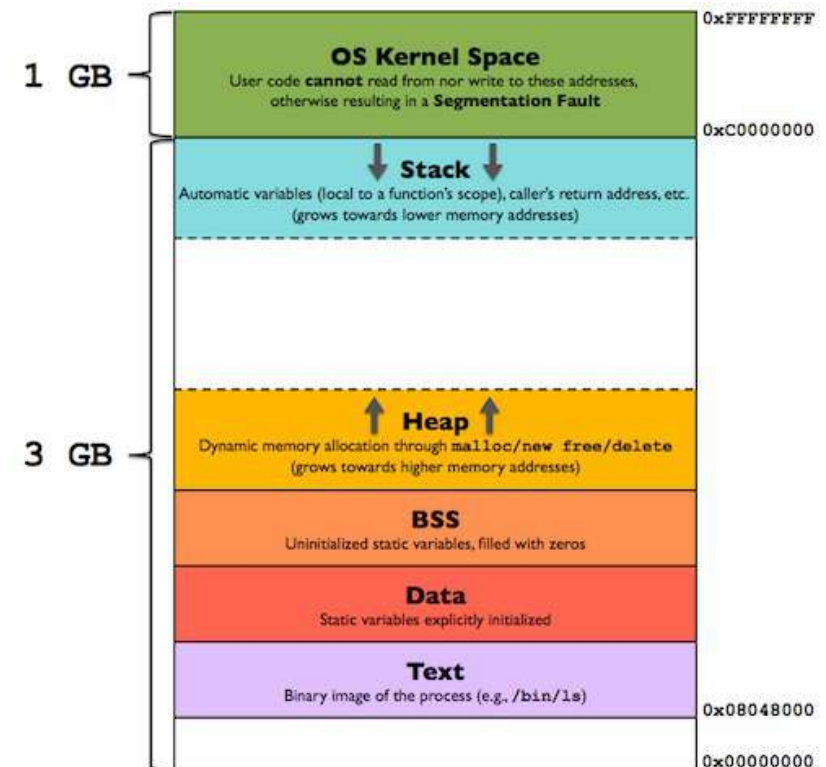
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- A process executes one instruction at a time, sequentially

OS Process Management

- How are processes represented in the OS?
- What are the possible states a process may be in and how the system moves from one state to another?
- How are processes created in the OS?
- How do processes communicate with each other?

Process: Virtual Address Space Layout

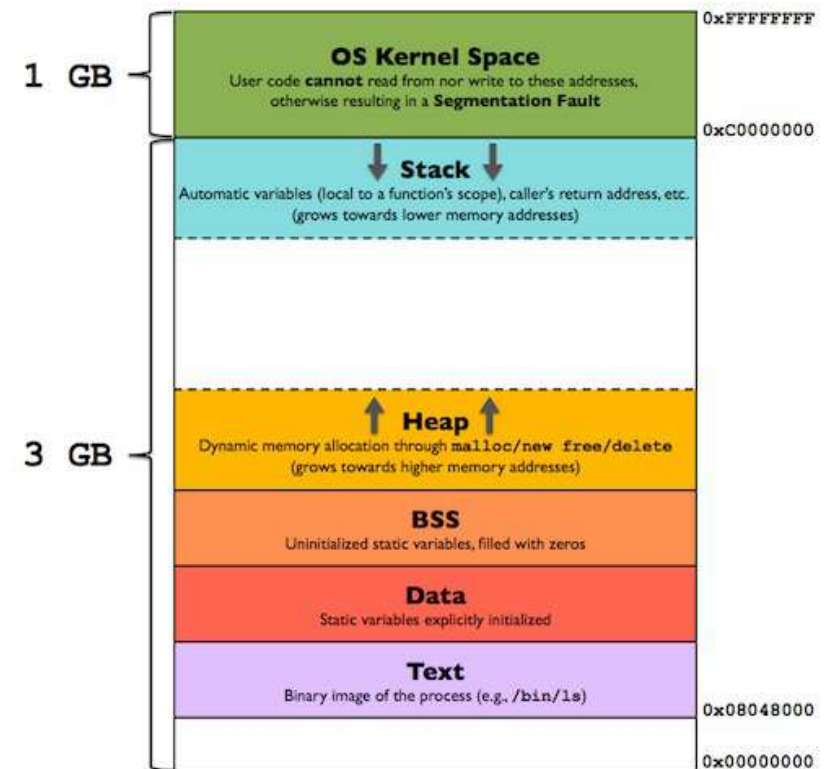
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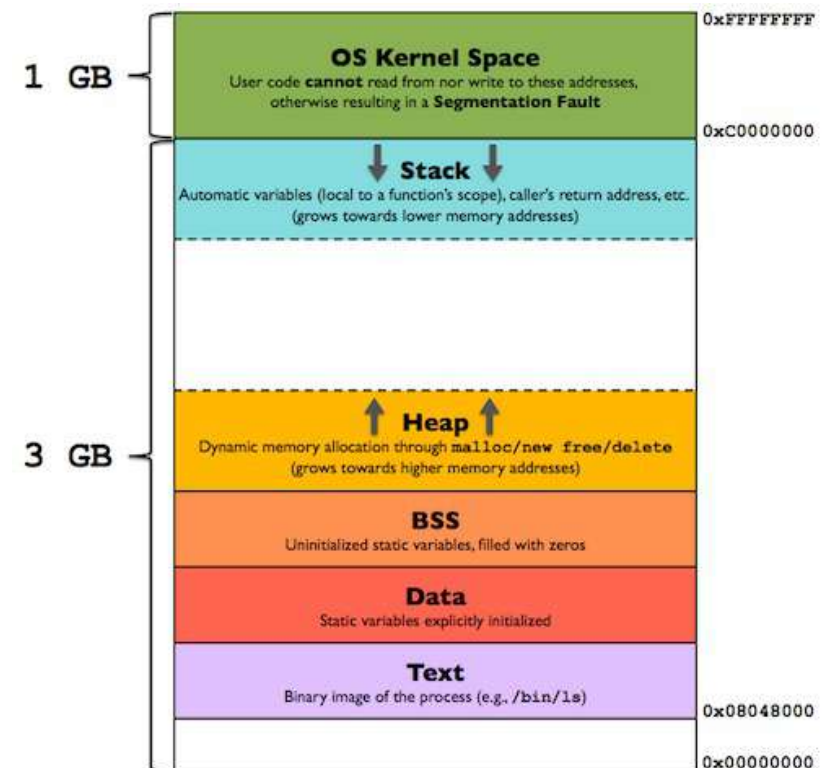


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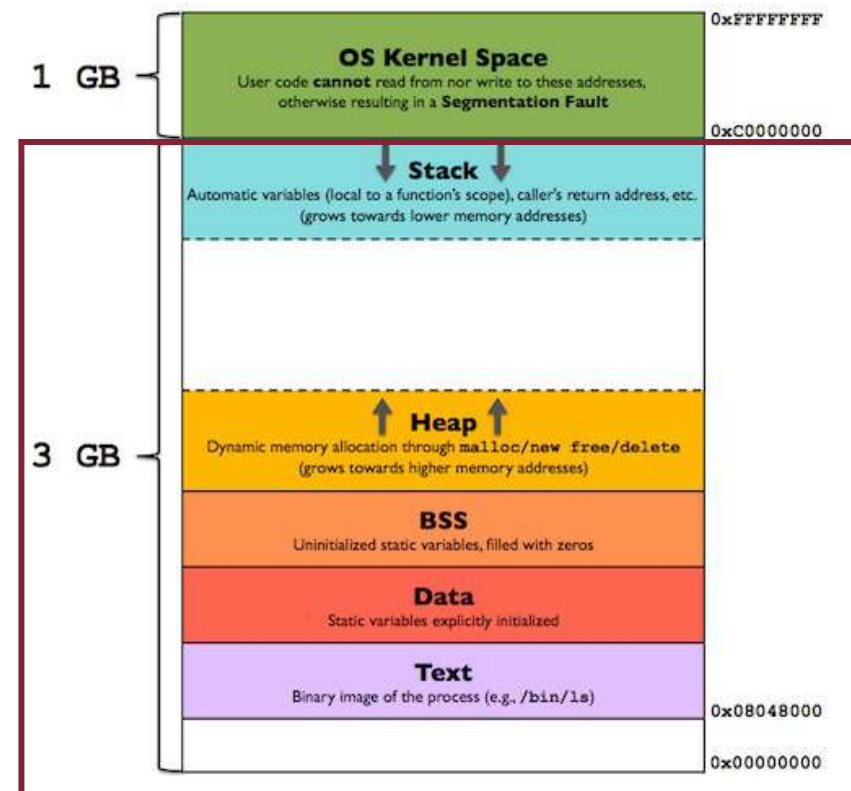
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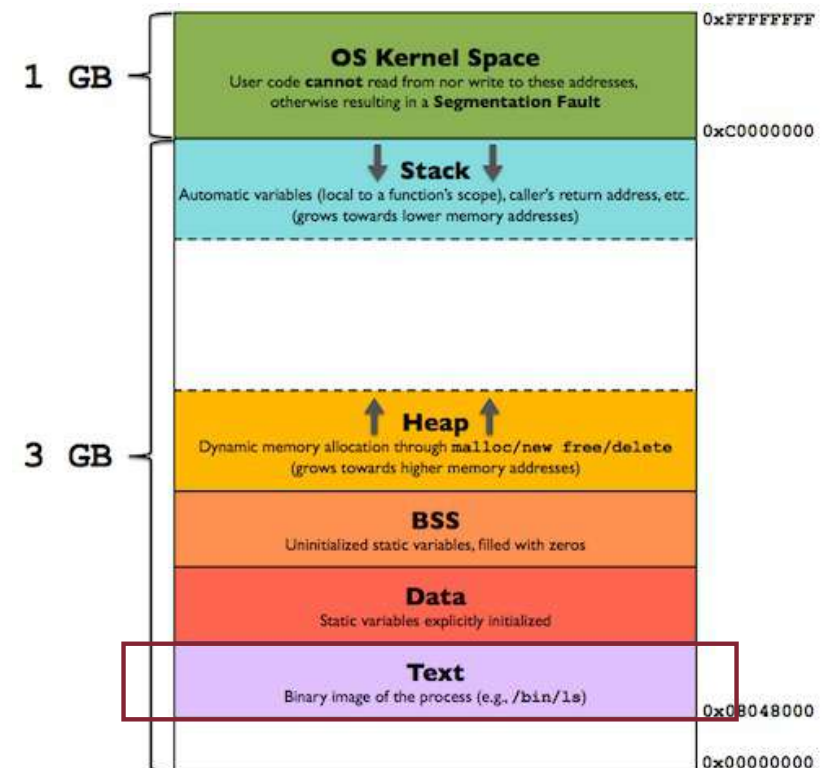
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For example, on a 32-bit architecture, the virtual addresses range from 0 to $2^{32} - 1$ (with the exception of some addresses reserved for the OS kernel)



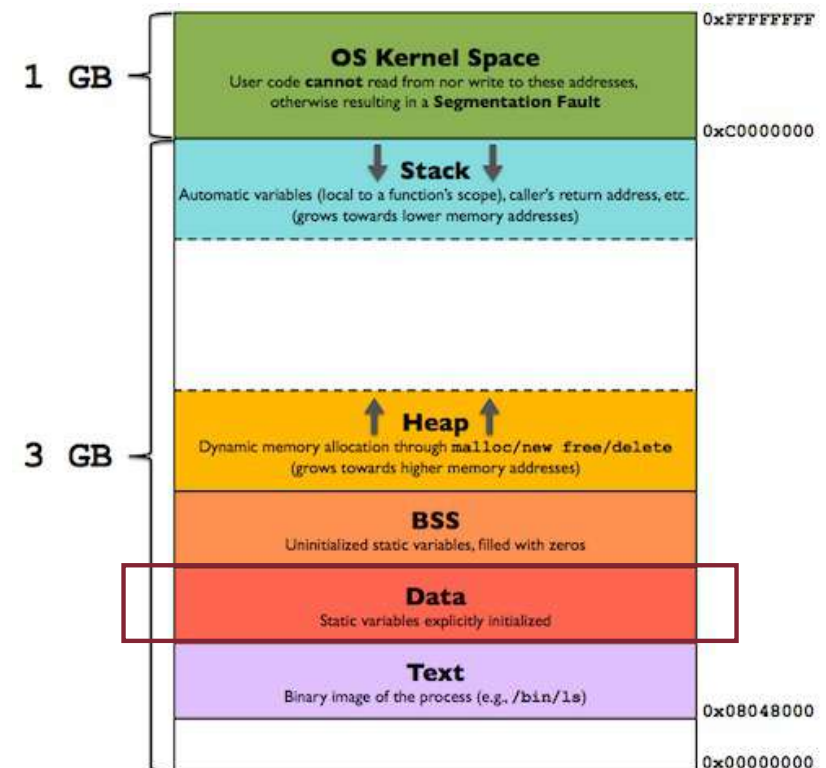
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- **Text** → contains executable instructions



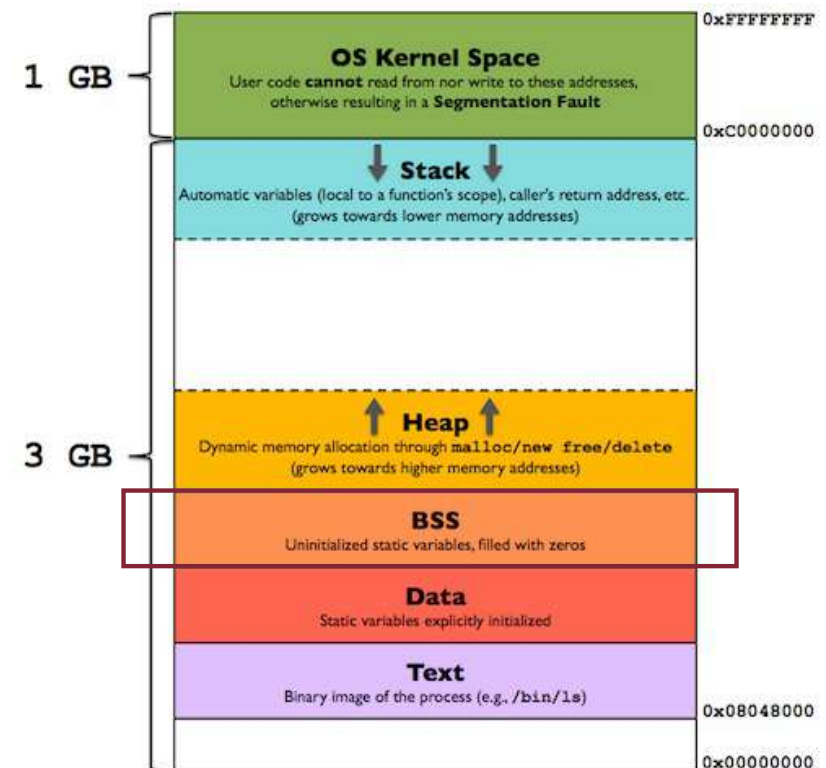
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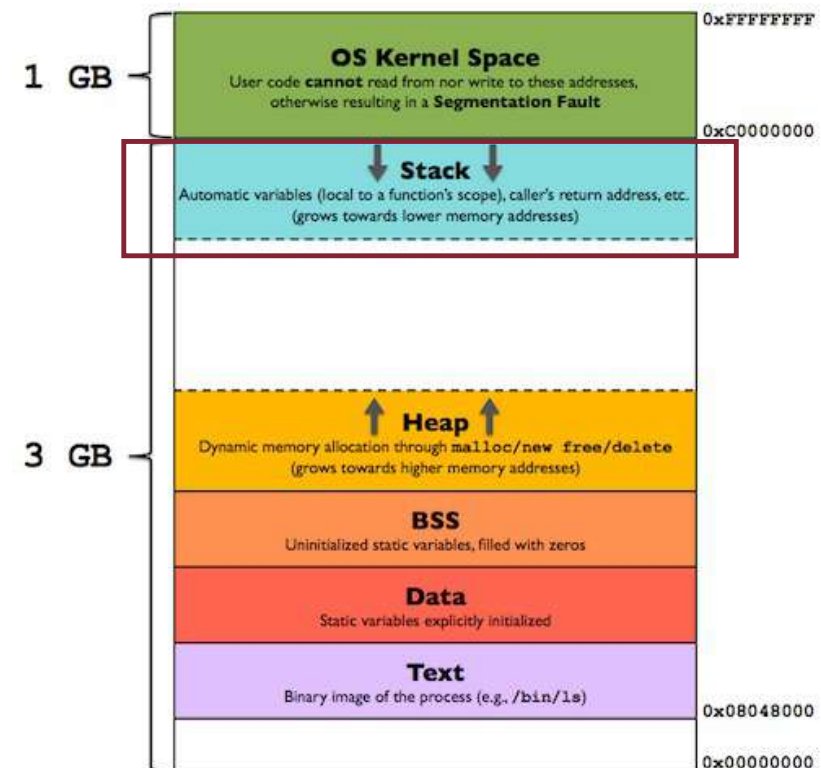
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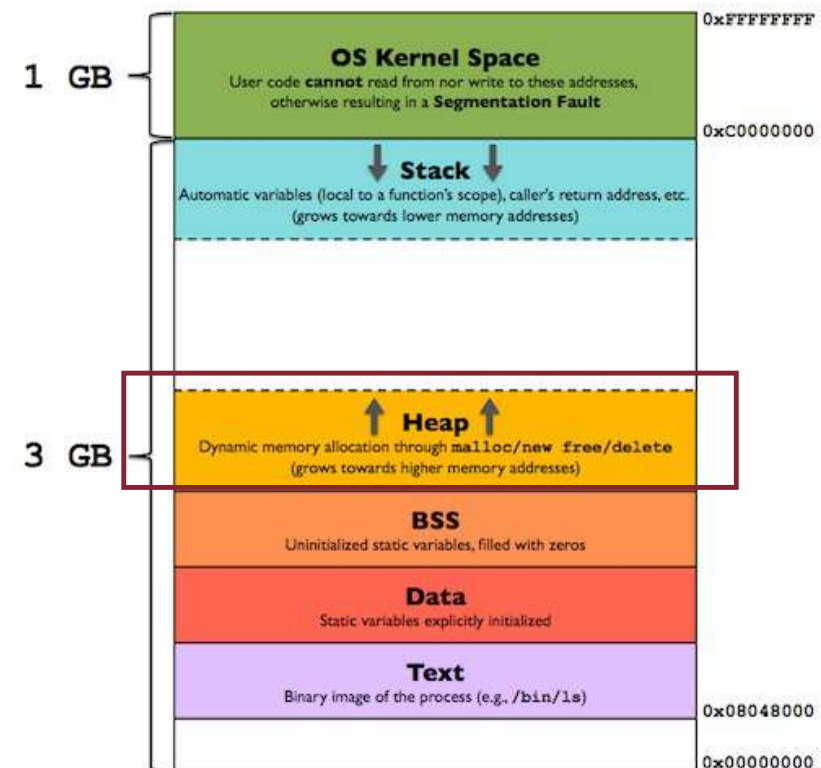
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- Heap → used for dynamic allocation



Program vs. Process: Example

Program

```
int w = 42;
int x = 0;
float y;

void doSomething(int f) {
    int z = 37;
    z += f;
    ...
}

int main() {
    char* c = malloc(128);
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Process

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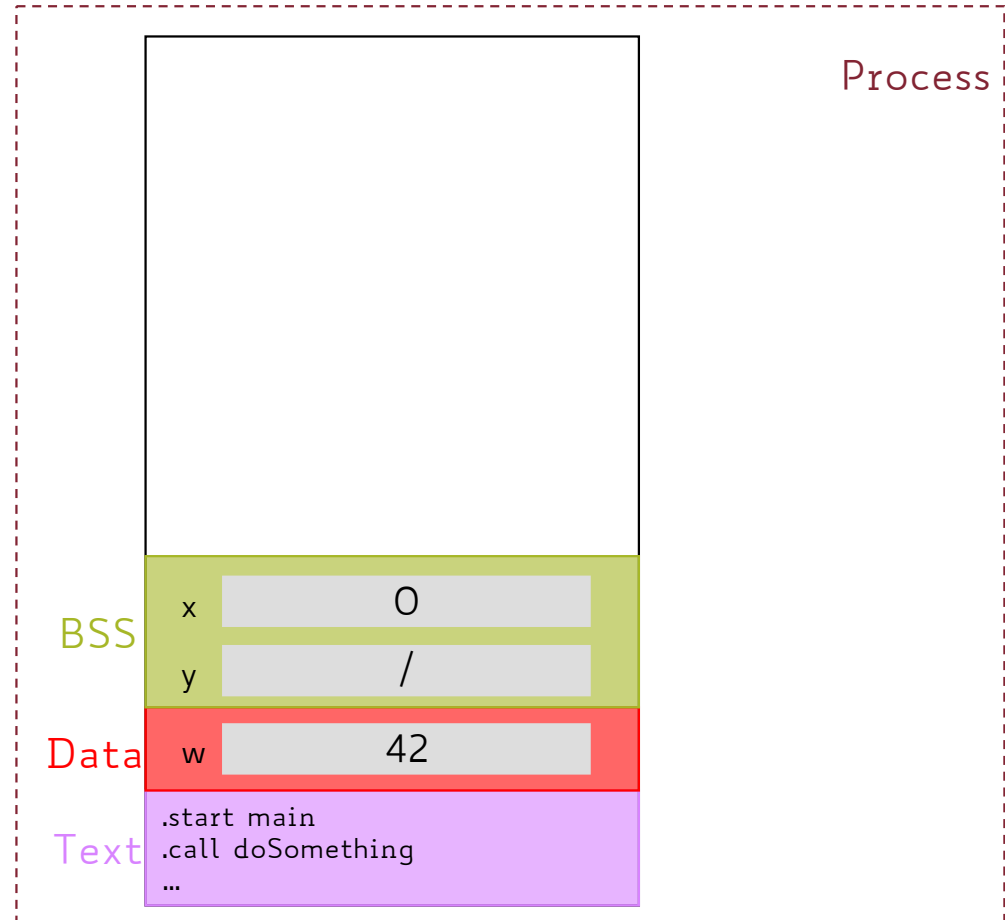
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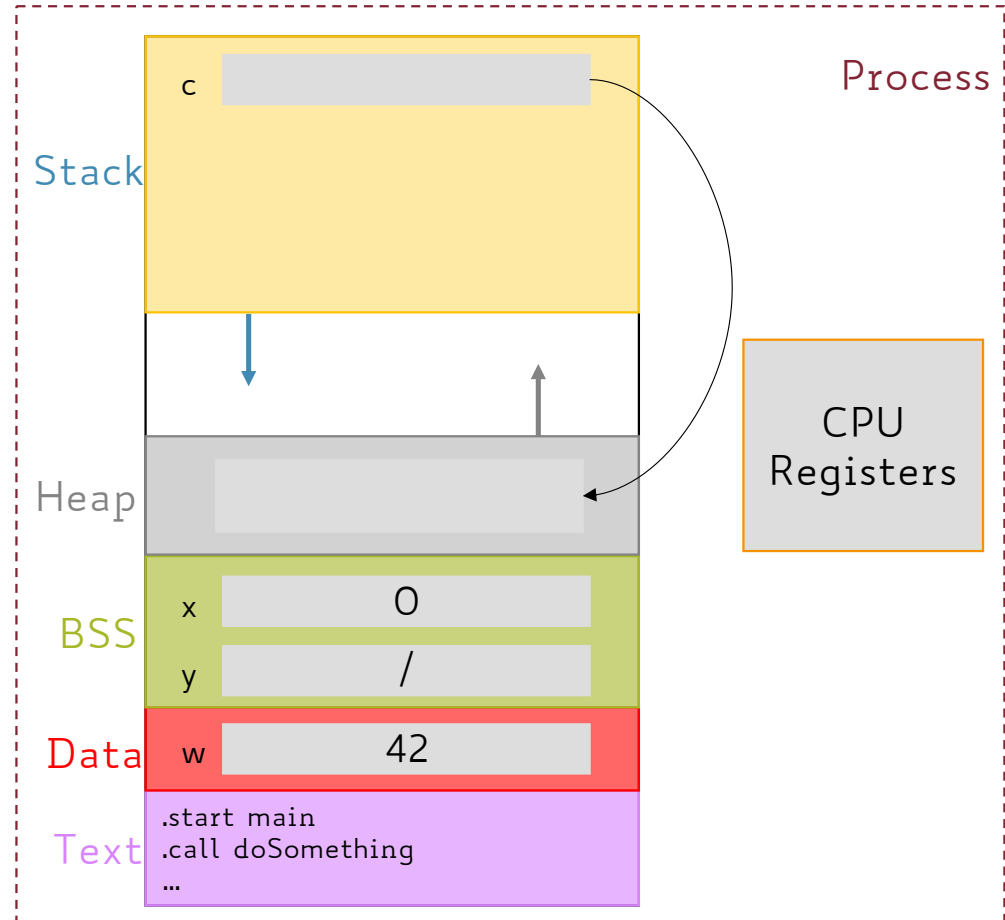
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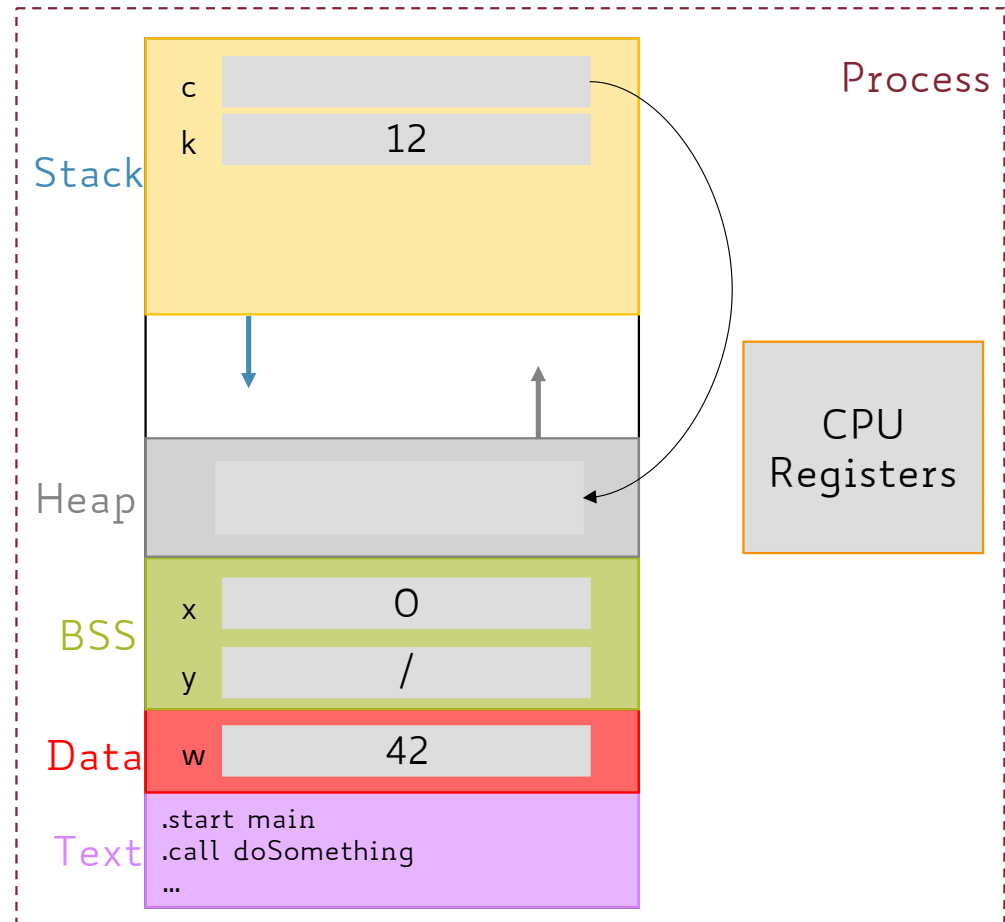
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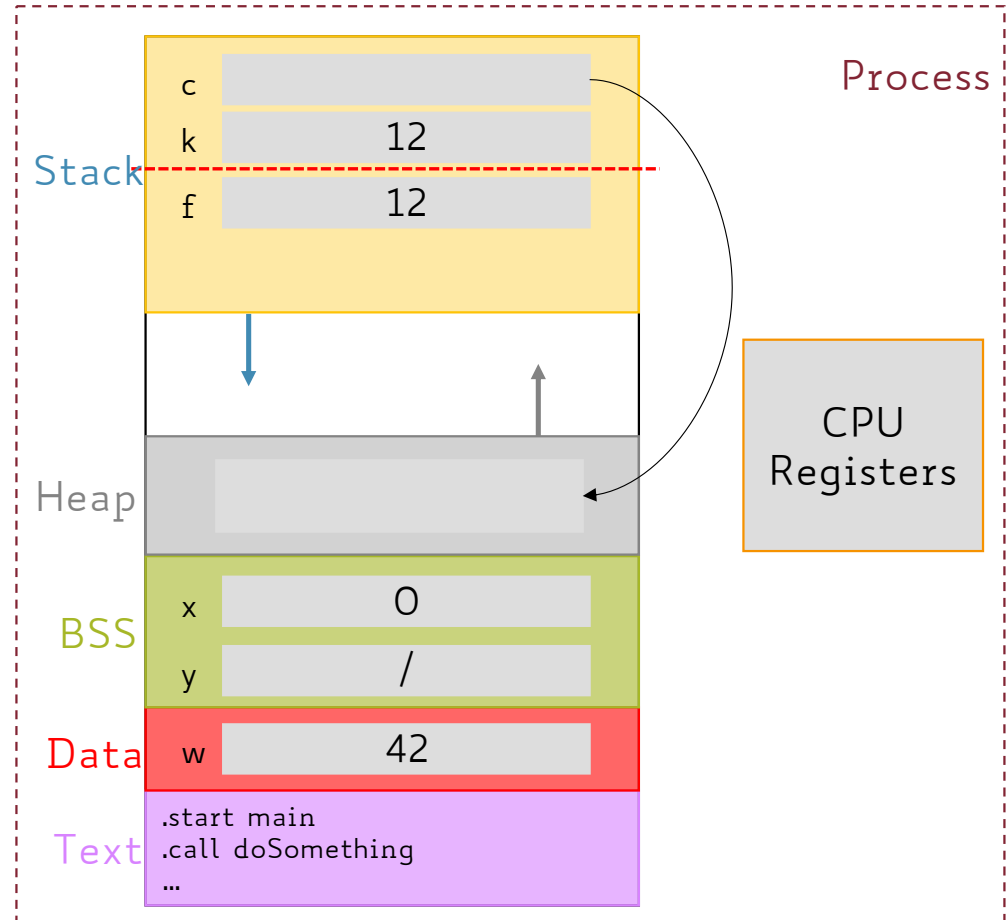
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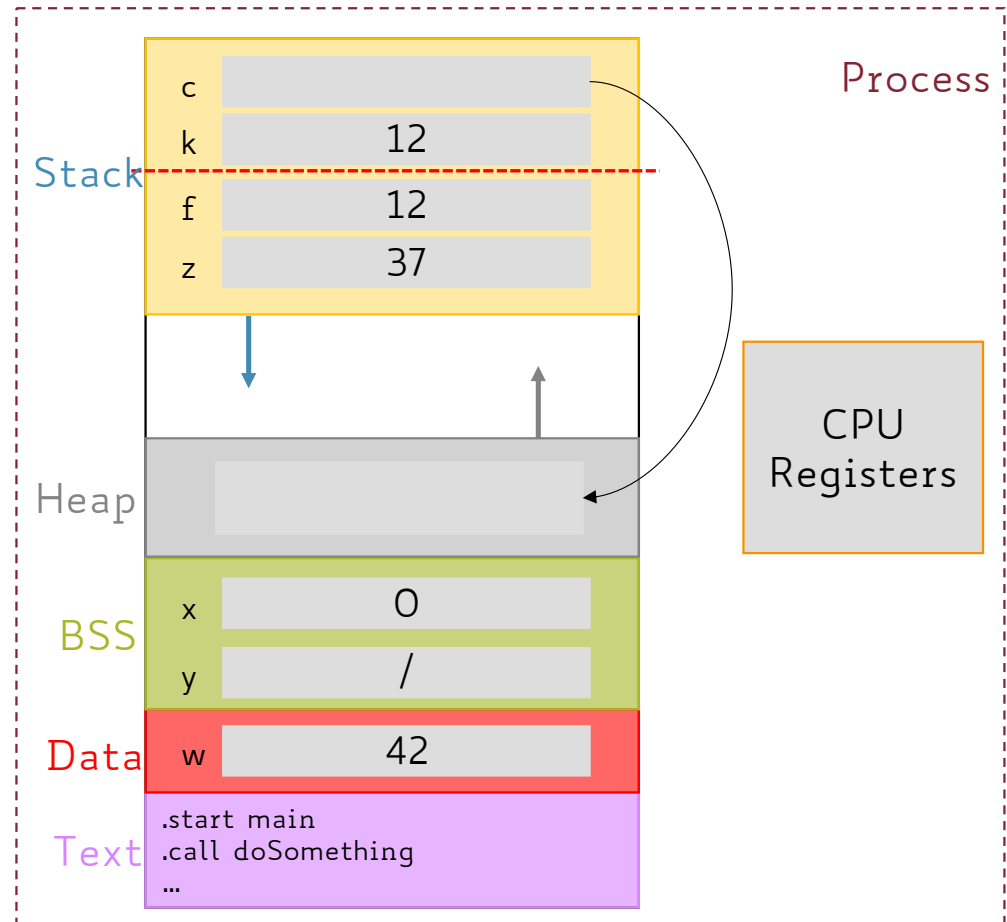
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 - **push** → used to place items onto the stack
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Stack

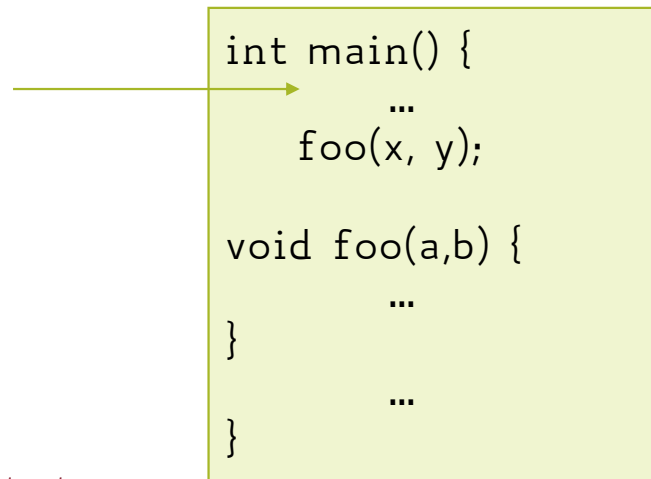
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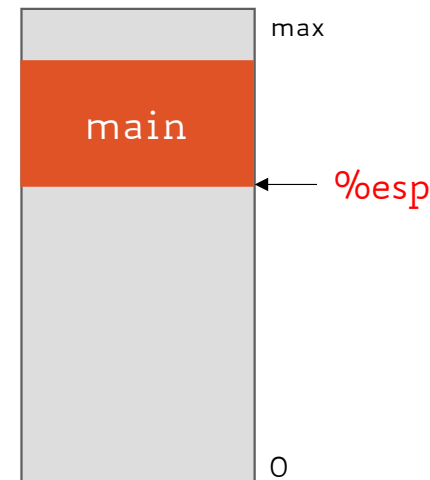
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- Stack memory conventionally grows top-down, i.e., from higher to lower memory addresses

Function Call: Stack Frame

- Each function uses a portion of the stack, called **stack frame**
- At every point in time, multiple stack frames may simultaneously exist, due to several nested function calls, yet only one is **active**



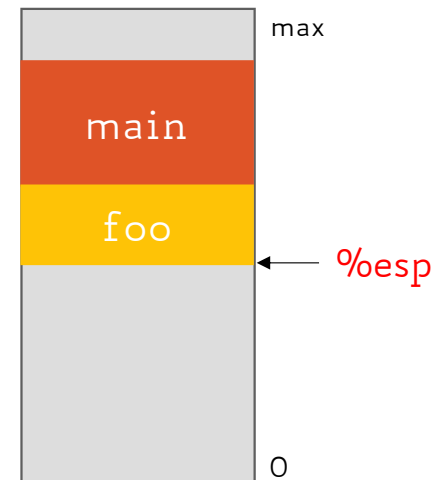
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int main() {  
    ...  
    foo(x, y);  
  
    void foo(a,b) {  
        ...  
    }  
    ...  
}
```



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- The second and the third ones are set by the **callee**

Stack Frame: Parameters + Return

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foo (a, b, c);
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The caller converts to

```
push c  
push b  
push a  
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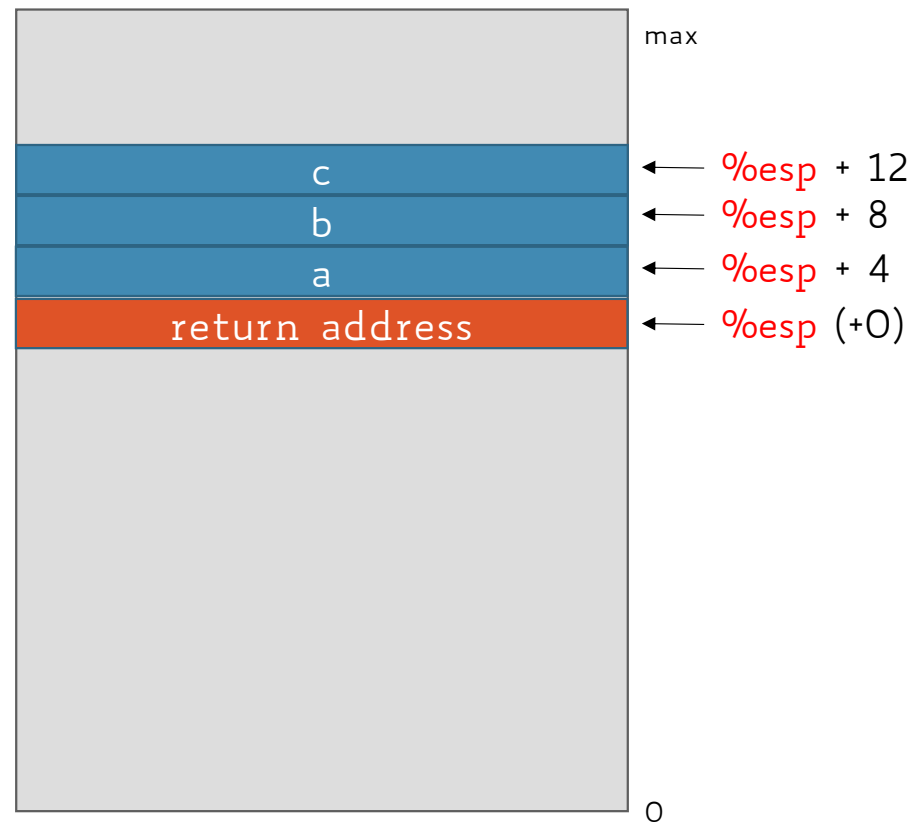
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```

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push b  
push a  
call foo
```

- Each item is pushed onto the stack, the stack grows down
- The value of **esp** register is decremented by, say, 4 bytes (i.e., in 32-bit machines), and the item is copied to the memory location pointed to by it
- The **call** instruction will implicitly push the return address on the stack

Stack Frame: Parameters + Return

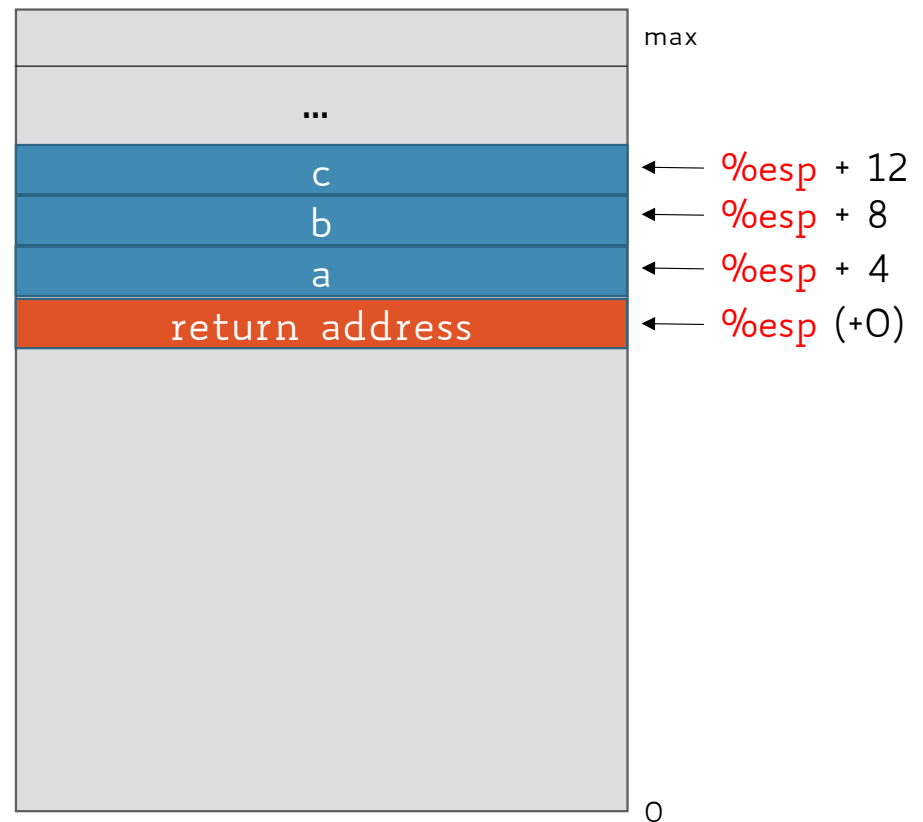


Stack Frame: Parameters + Return

Problem!

The `esp` pointer gets always updated as the stack grows

It is hard for the callee to access the actual parameters without a fixed reference on the stack



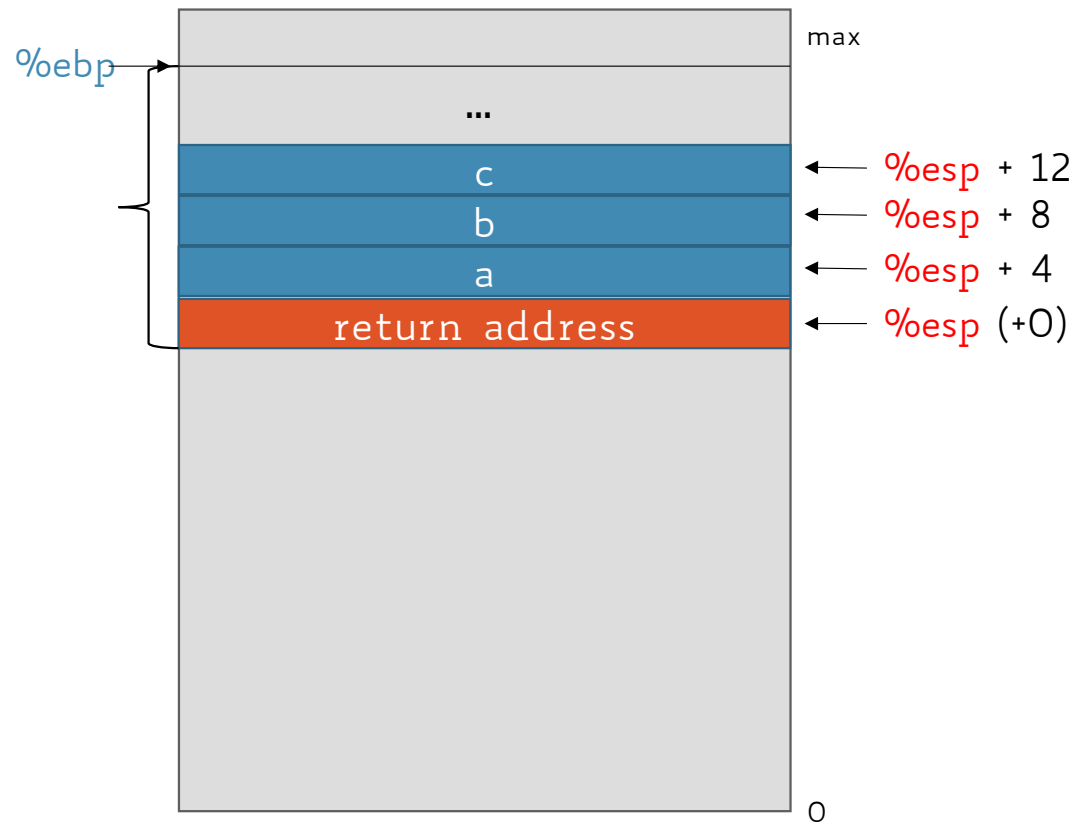
Stack Frame: Parameters + Return

Solution

Instead of using a single pointer to the top of the stack (**esp**)

Use an additional pointer to the bottom (base) of the stack (**ebp**)

Let **esp** be free to change across different function calls, while keep **ebp** fixed within each stack frame

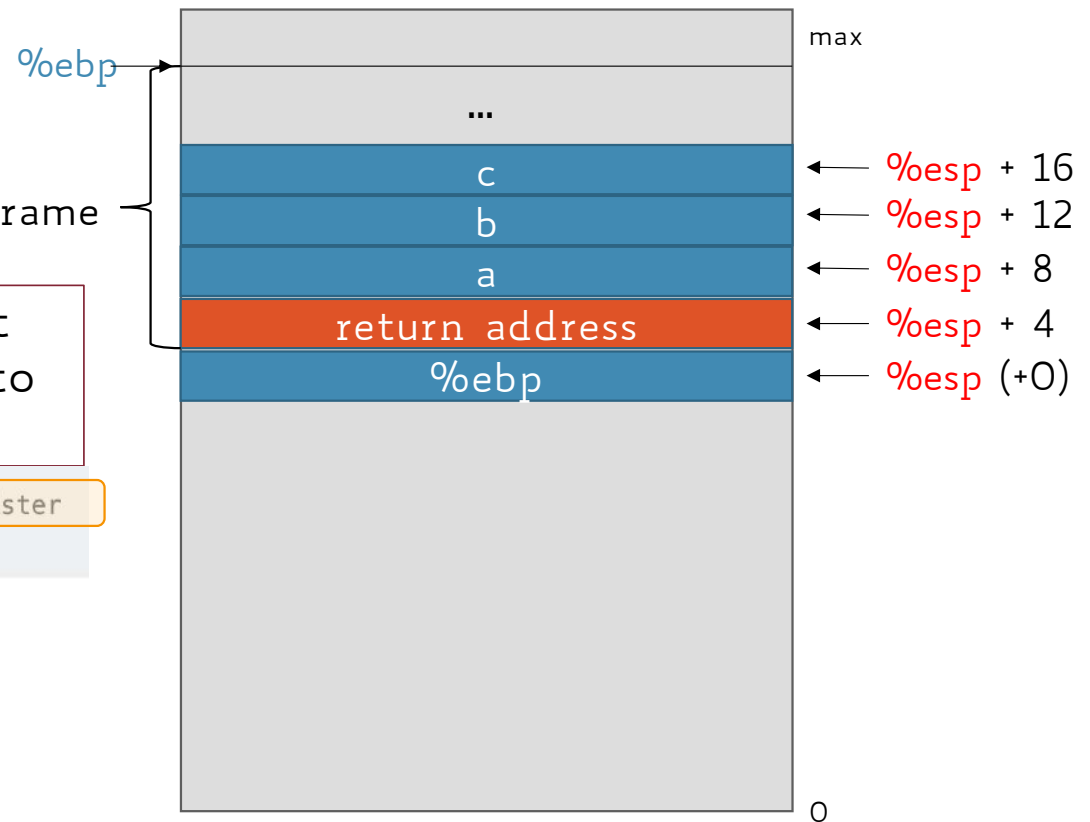


Stack Frame: Saving the Base Frame Pointer

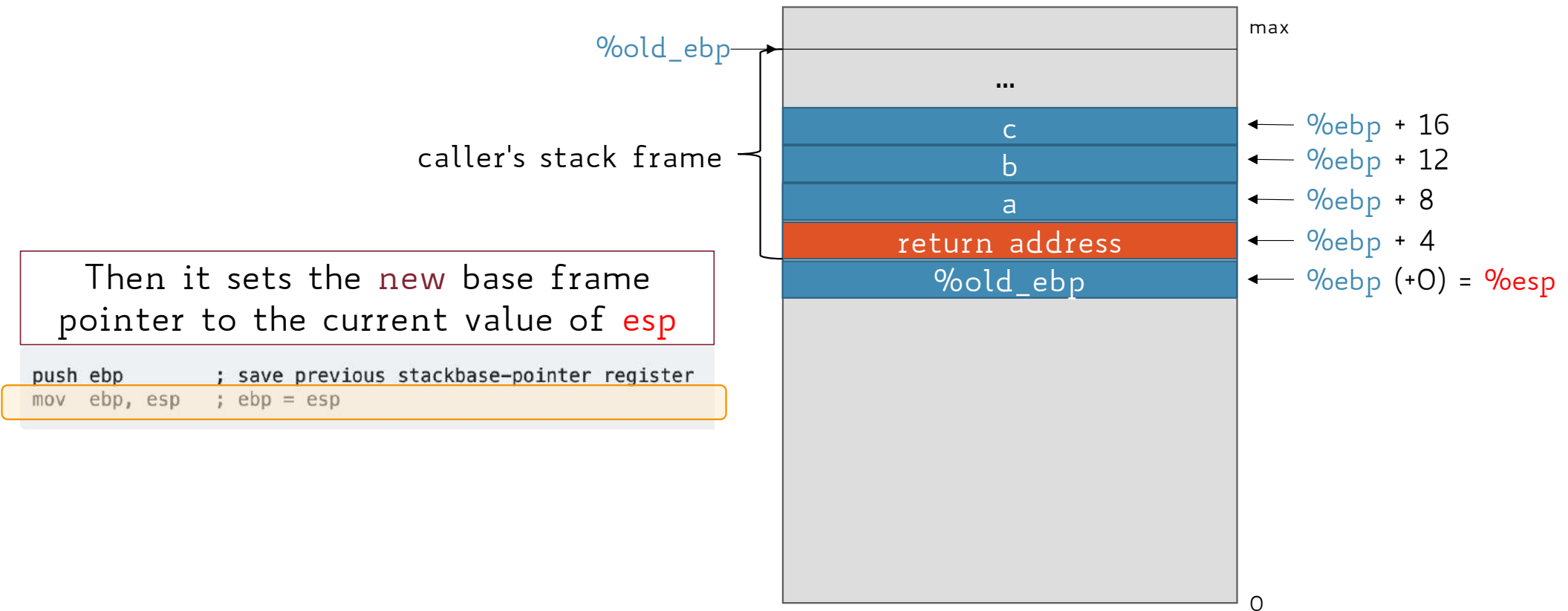
The callee first saves the current stack frame base pointer (`%ebp`) to the stack!

```
push ebp    ; save previous stackbase-pointer register
mov  ebp, esp ; ebp = esp
```

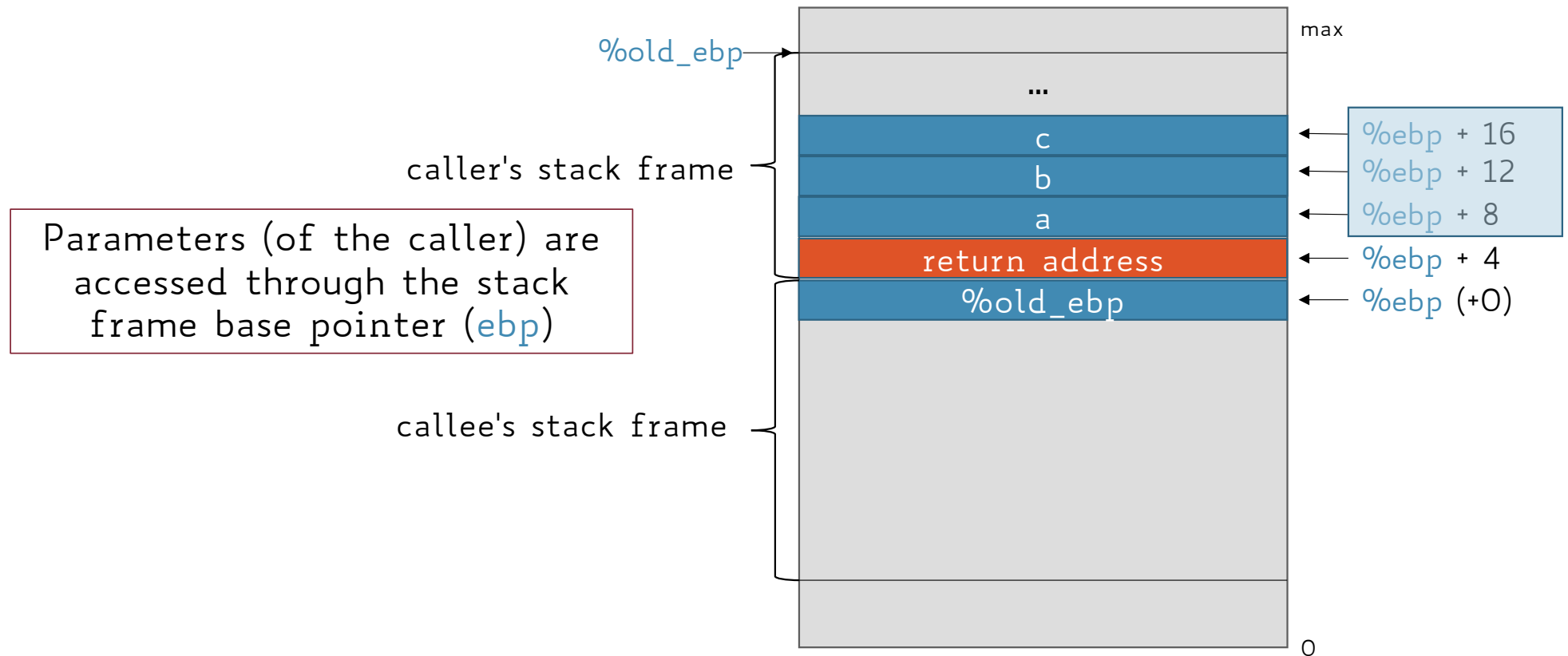
caller's stack frame



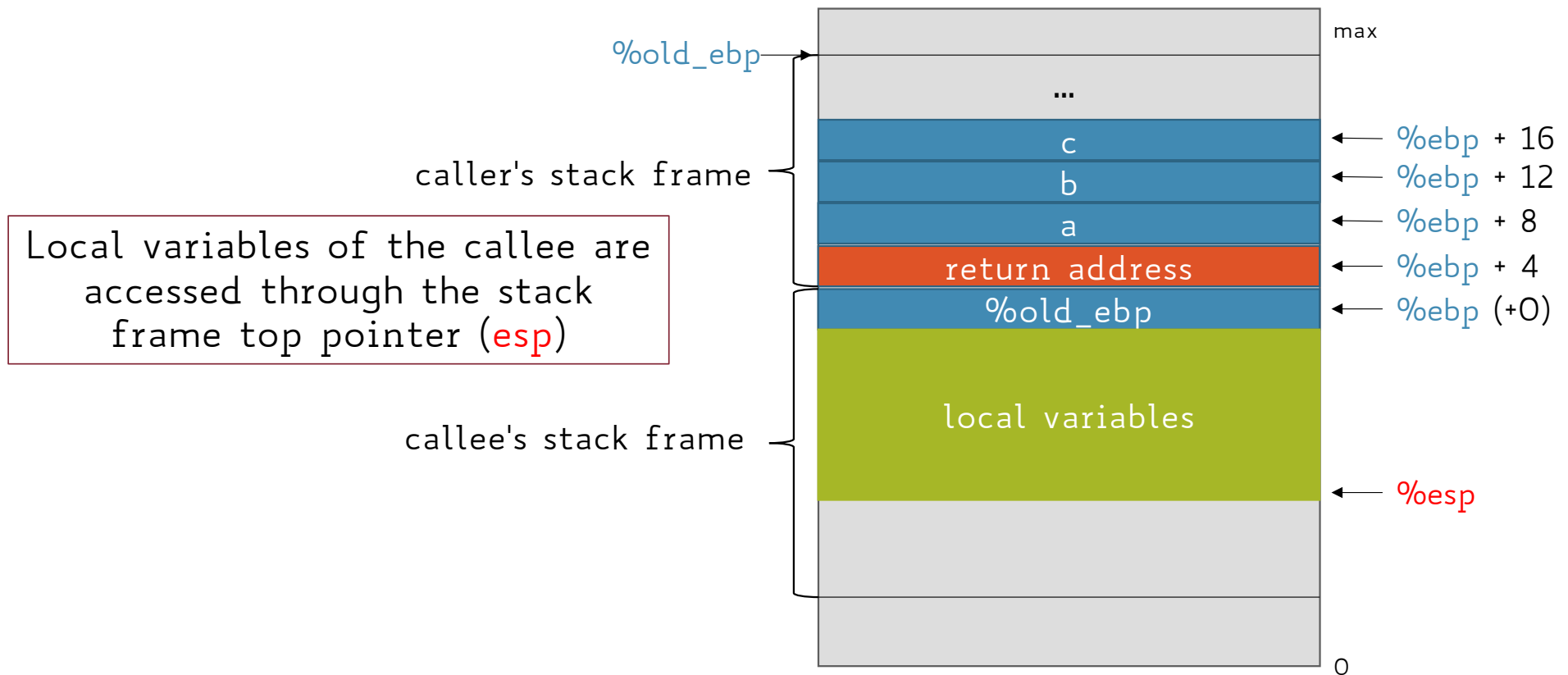
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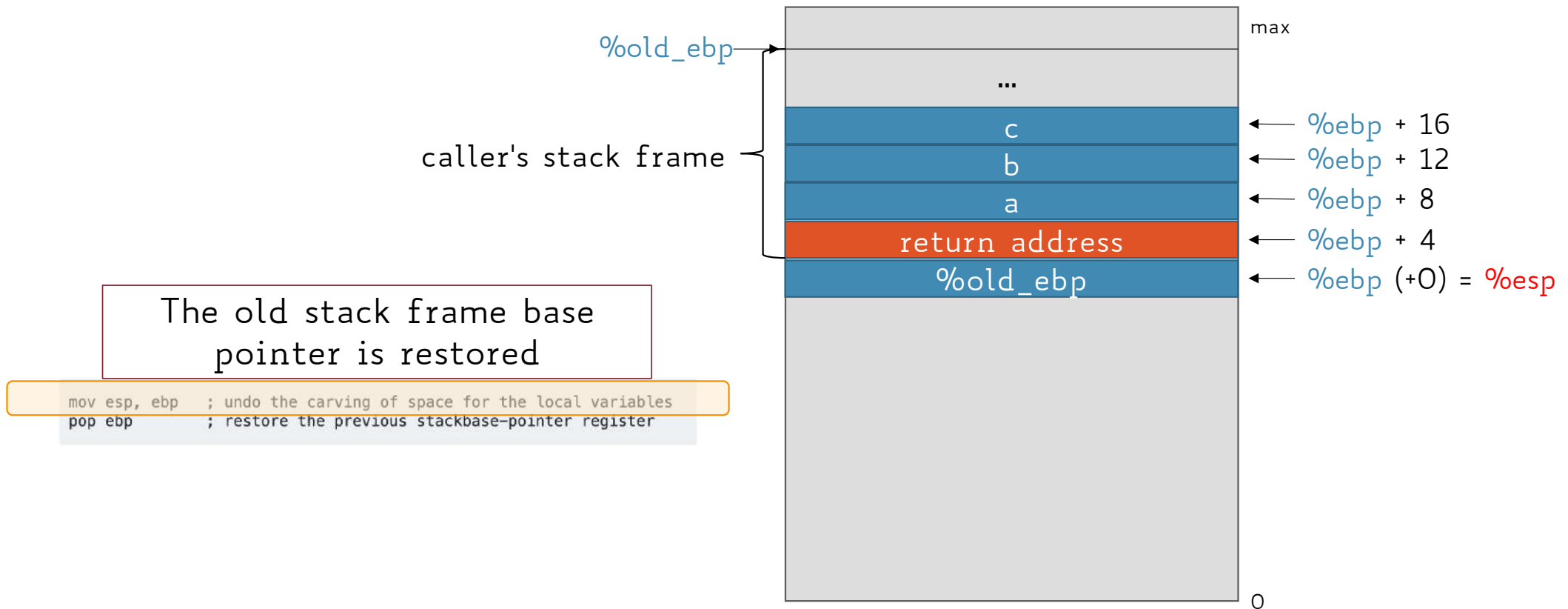
Parameters: Offset from the Base Frame Pointer



Local Variables: Offset from Stack Pointer



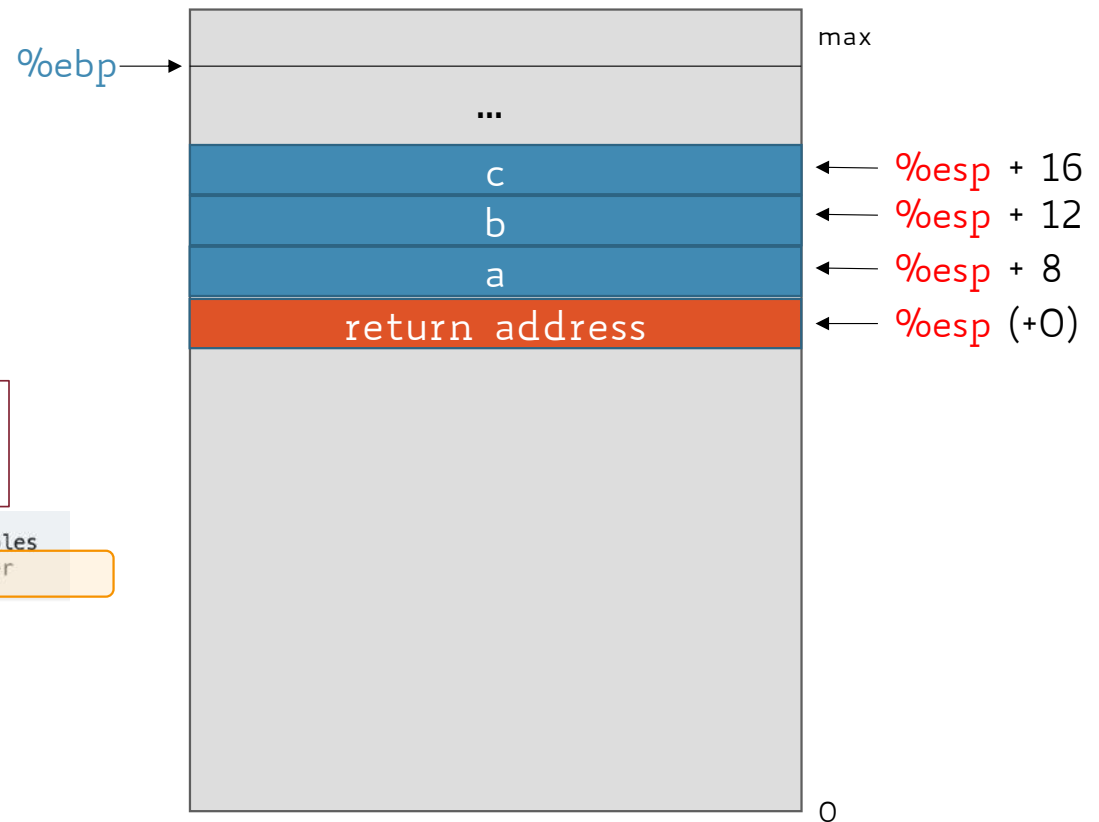
Stack Frame: Cleanup and Return



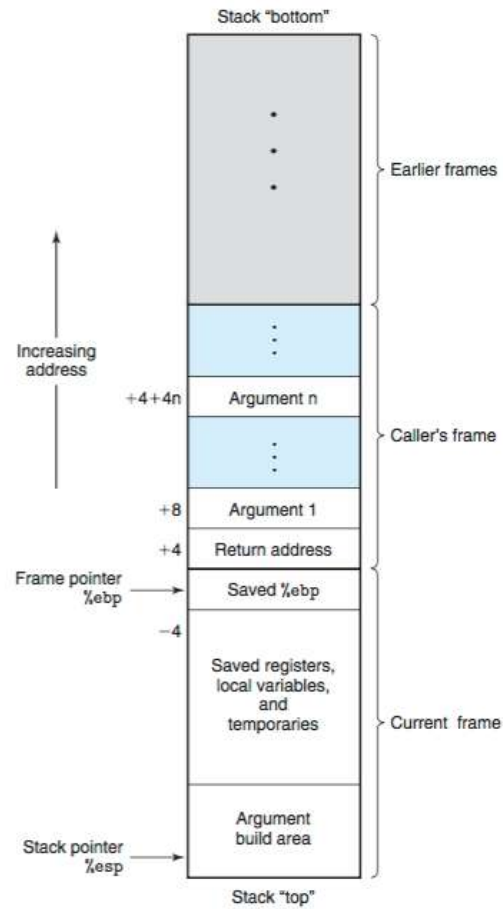
Stack Frame: Cleanup and Return

The old stack frame base pointer is restored

```
mov esp, ebp : undo the carving of space for the local variables
pop ebp      ; restore the previous stackbase-pointer register
```



Stack: Outline



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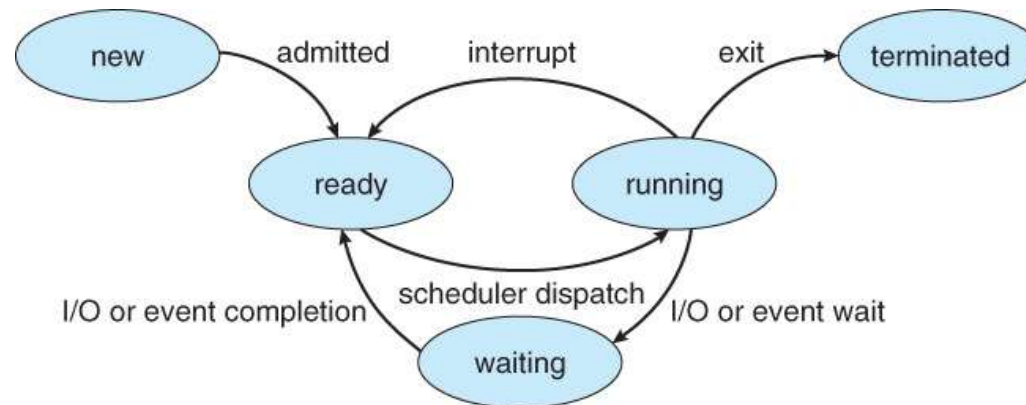
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 - **Terminated** → The process is finished and the OS can destroy it

Process Execution State Diagram



- As the process executes, it moves from state to state depending on:
 - program actions (e.g., system calls)
 - OS actions (e.g., scheduling)
 - external actions (e.g., interrupts)

Process Execution State: Example

```
int main() {  
    ...  
    printf("Hello World!");  
    ...  
}
```



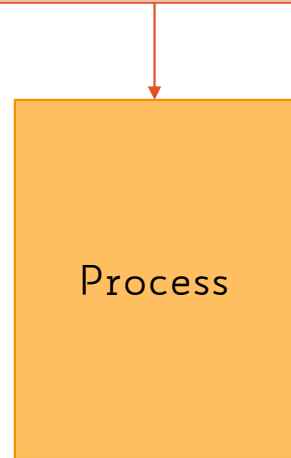
Main Memory



The process has
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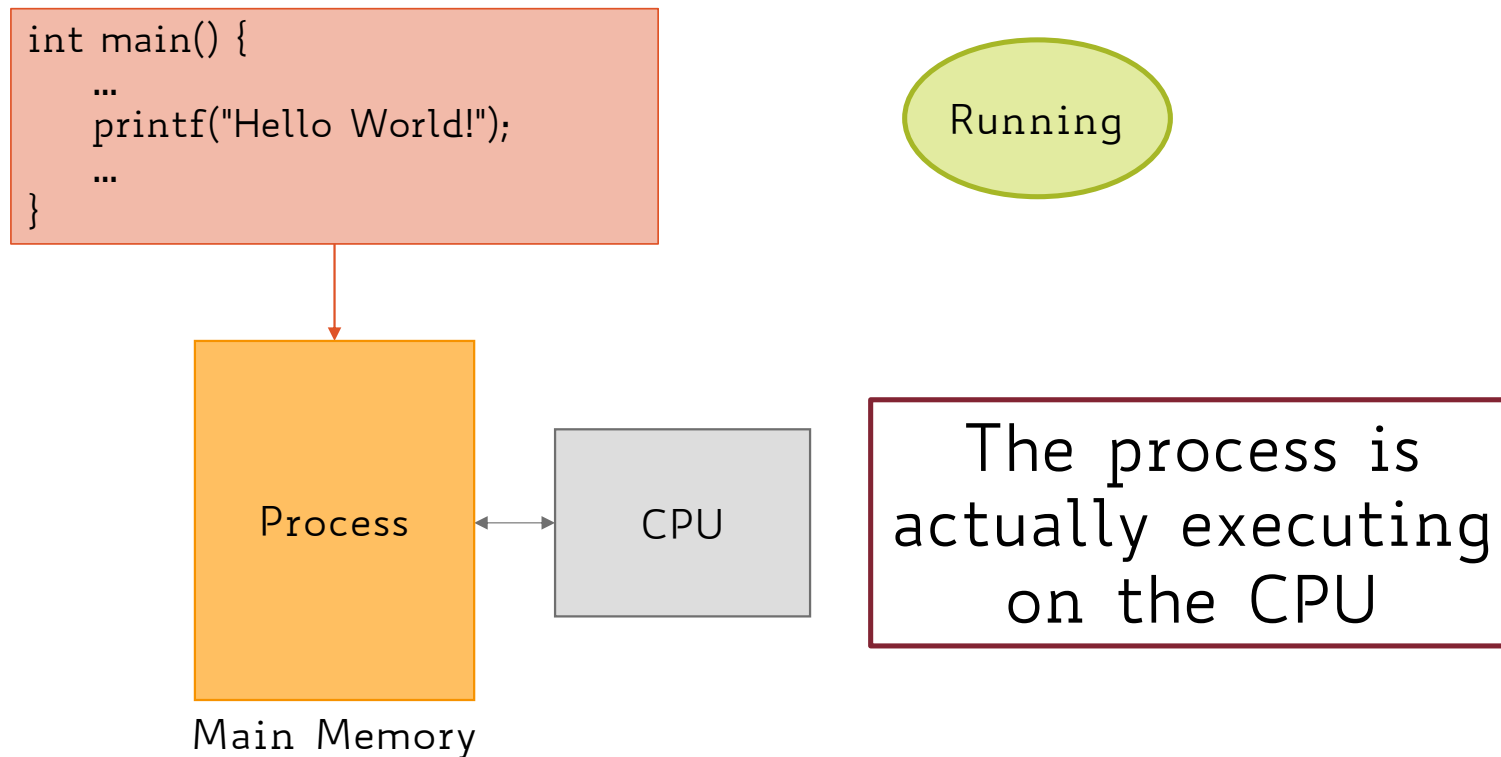


Main Memory

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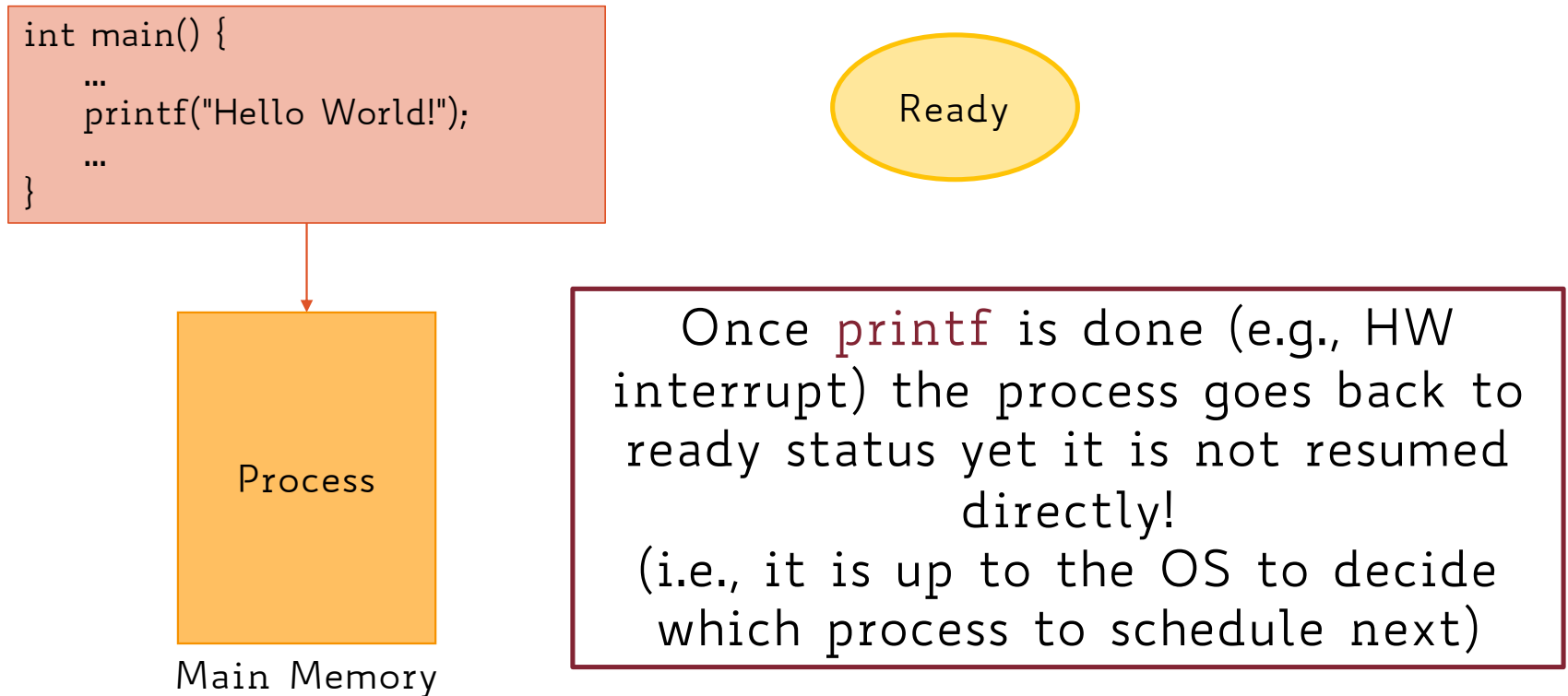
Waiting



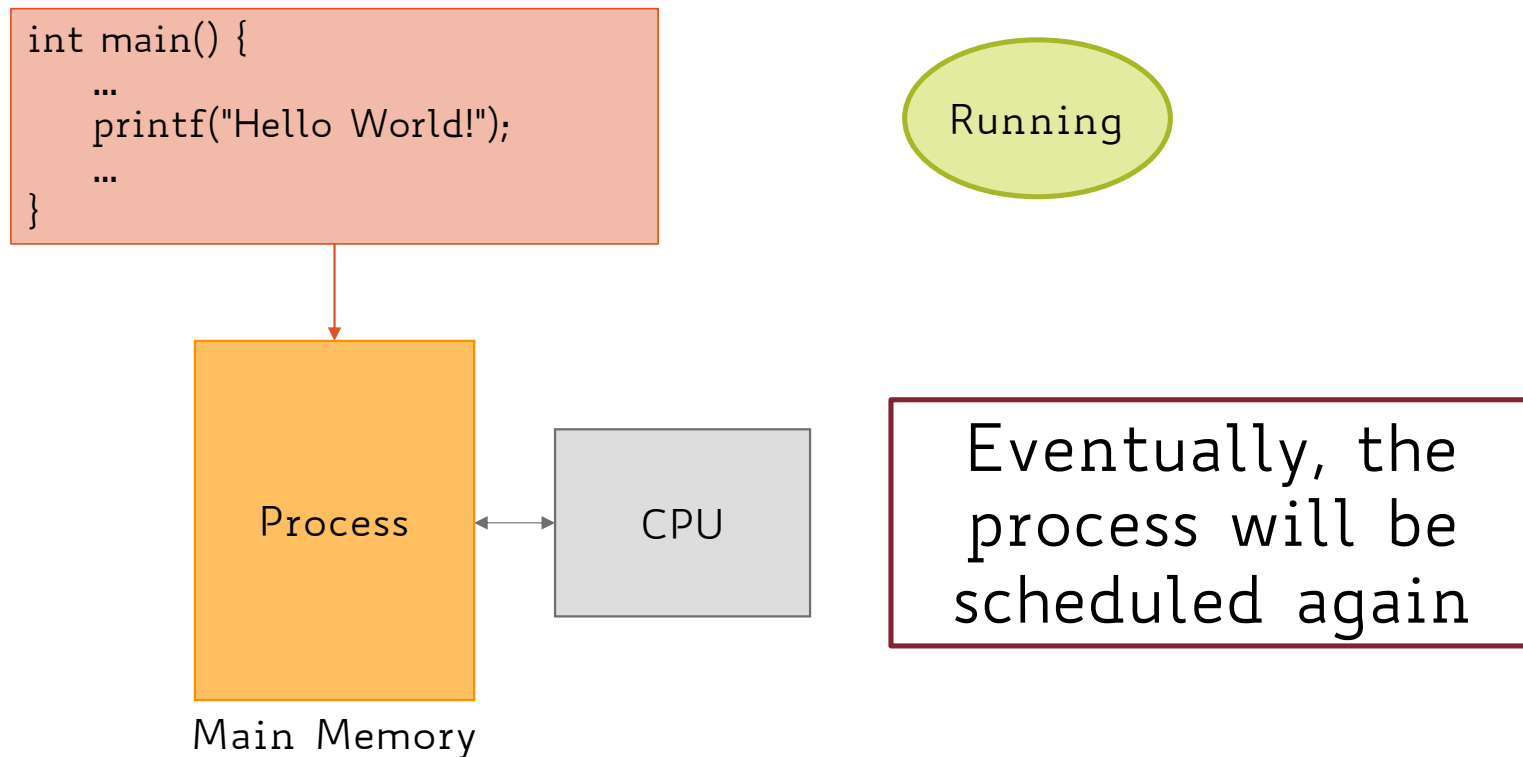
Main Memory

`printf` delegates off to a **blocking** I/O system call:
The current process is suspended in order for the OS to schedule another process which is ready to run

Process Execution State: Example



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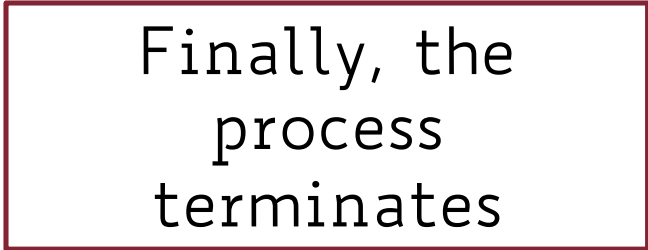


Process Execution State: Example

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```

A gray oval with a black border containing the word "Terminated".

Terminated

A white rectangle with a black border containing the text "Finally, the process terminates".

Finally, the
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Blocking vs. Non-Blocking Calls (Again!)

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NOTE:

the whole system is **not** blocked, only the process which has requested the blocked call is!

Process State

- At least, process state consists of the following:
 - the code of the running program
 - the static data of the running program
 - the program counter (PC) indicating the next instruction to execute
 - CPU registers
 - the program's call chain (stack) along with frame and stack pointers
 - the space for dynamic memory allocation (heap) along with the heap pointer
 - the set of resources in use (e.g., open files)
 - the process execution state (ready, running, etc.)

Process Control Block (PCB)

- The main data structure used by the OS to keep track of any process
- The PCB keeps track of the execution state and location of a process
- The OS allocates a new PCB upon the creation of a process and places it into a state queue
- The OS deallocates a PCB as soon as the associated process terminates

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 - Accounting information → user and kernel CPU time consumed, owner

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 - Process number (i.e., unique identifier)
 - Program Counter (PC) + Stack Pointer (SP) + general purpose registers
 - CPU scheduling information → priority and pointers to state queues
 - Memory management information → page tables
 - Accounting information → user and kernel CPU time consumed, owner
 - I/O status → list of open files

Process Control Block (PCB)



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- Process can be in one of **5 possible states**: **new**, **ready**, **waiting**, **running**, or **terminated**