Systems and Networking I

Applied Computer Science and Artificial Intelligence

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

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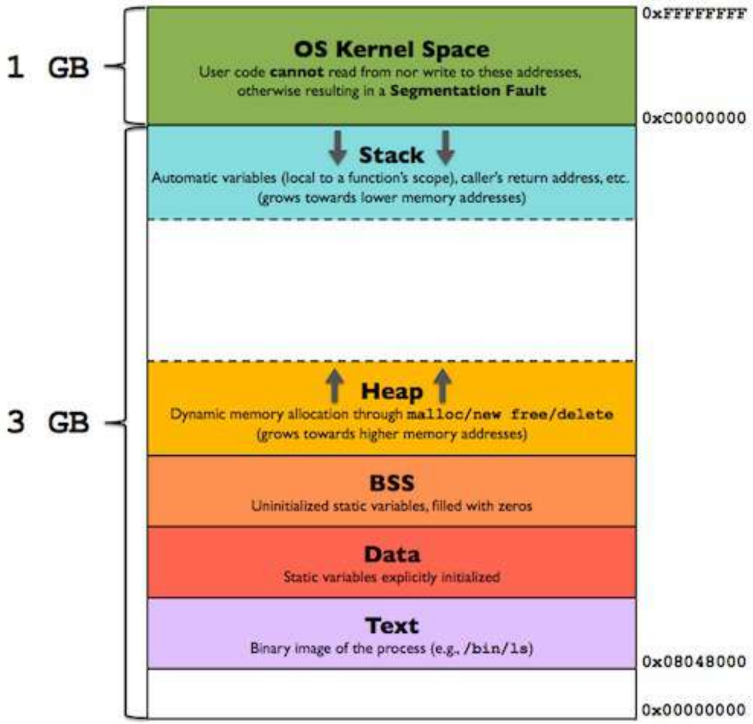
- Several processes may run the same program (e.g., multiple Google Chrome instances) but each has its own state
- A process executes one instruction at a time, sequentially

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

The OS gives the same amount of virtual address space to each process



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1 GB
OS Kernel Space
User code **cannot** read from nor write to these addresses, otherwise resulting in a **Segmentation Fault**
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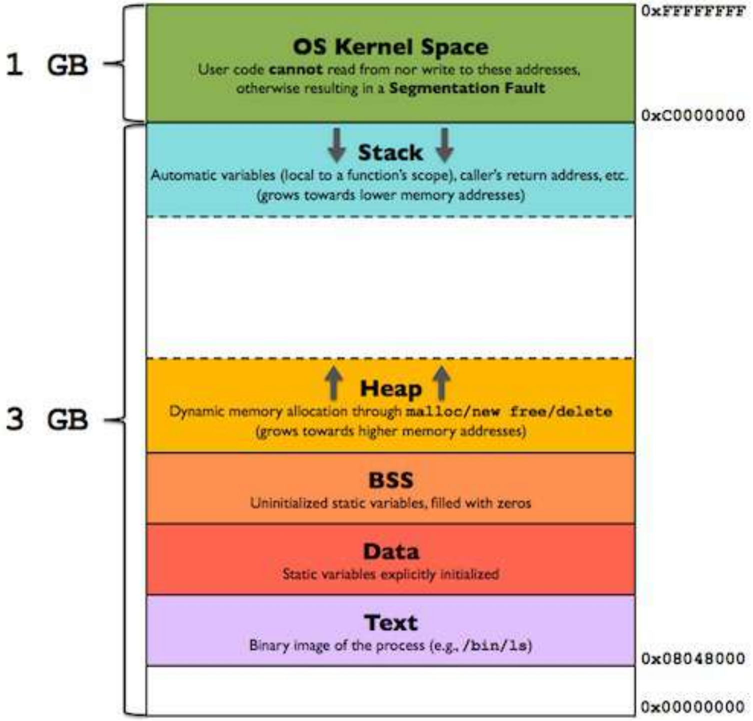
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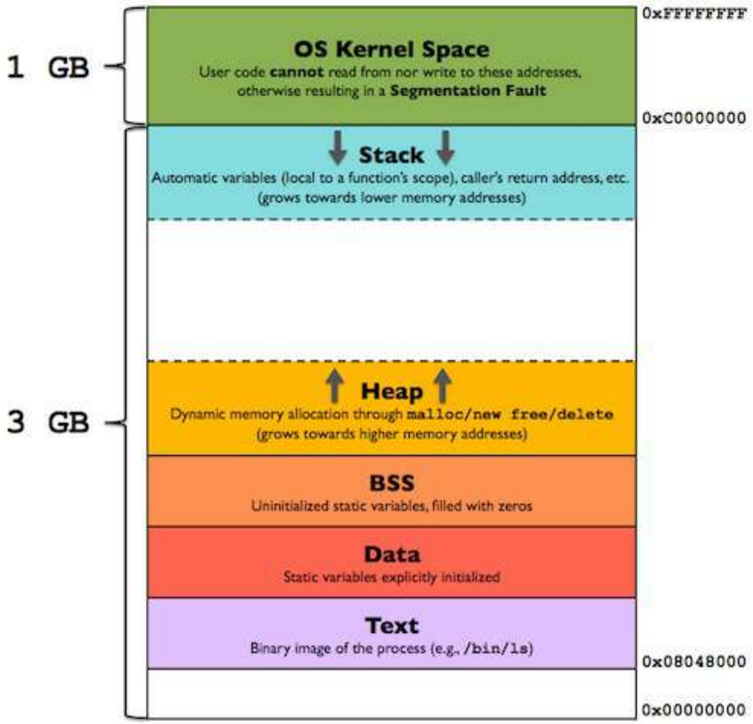
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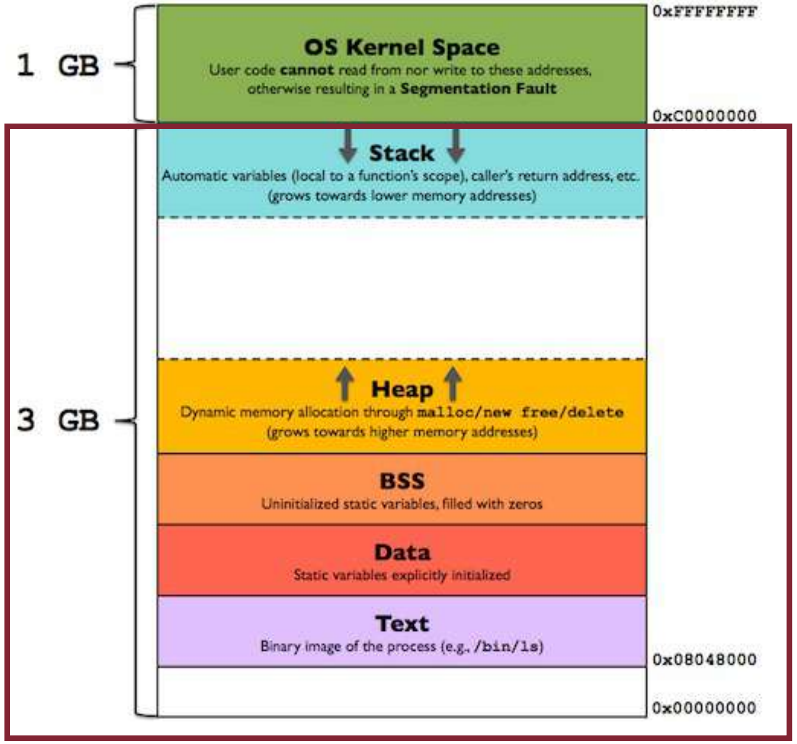
For example, on a 32-bit architecture, the virtual addresses range from 0 to 2^{32} -1

(with the exception of some addresses reserved for the OS kernel)



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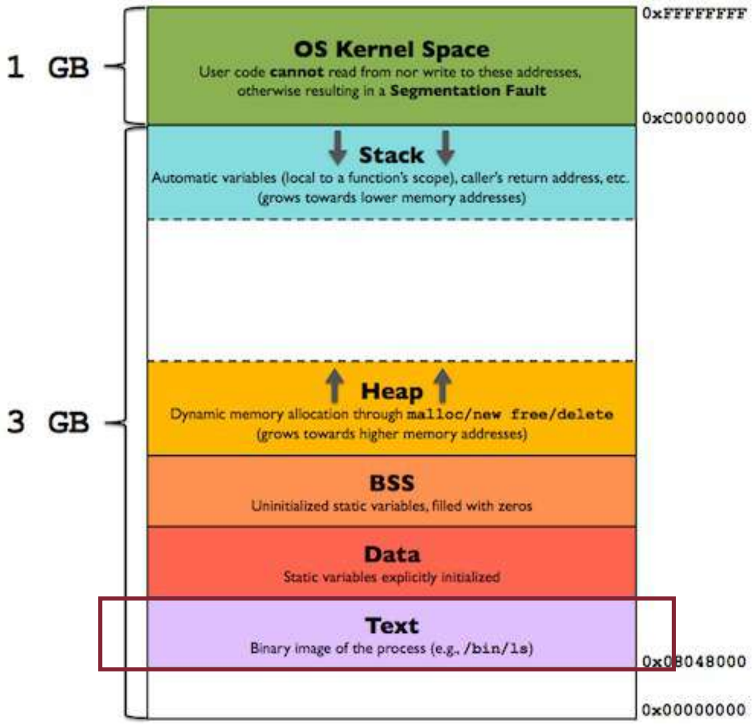
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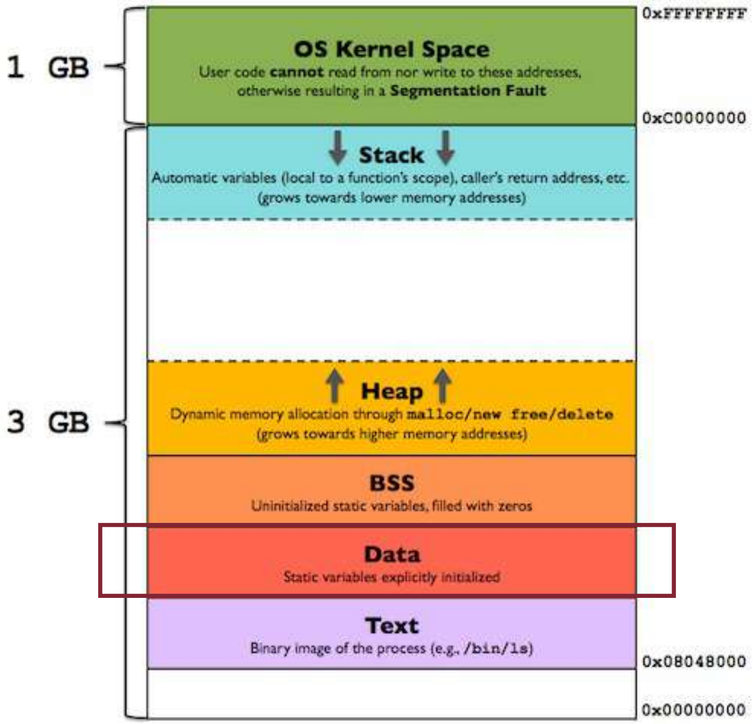
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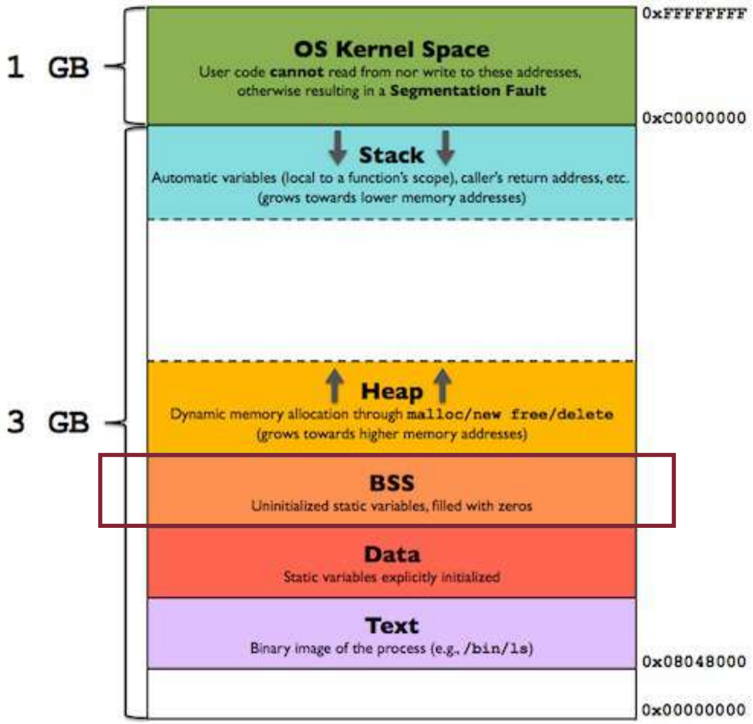

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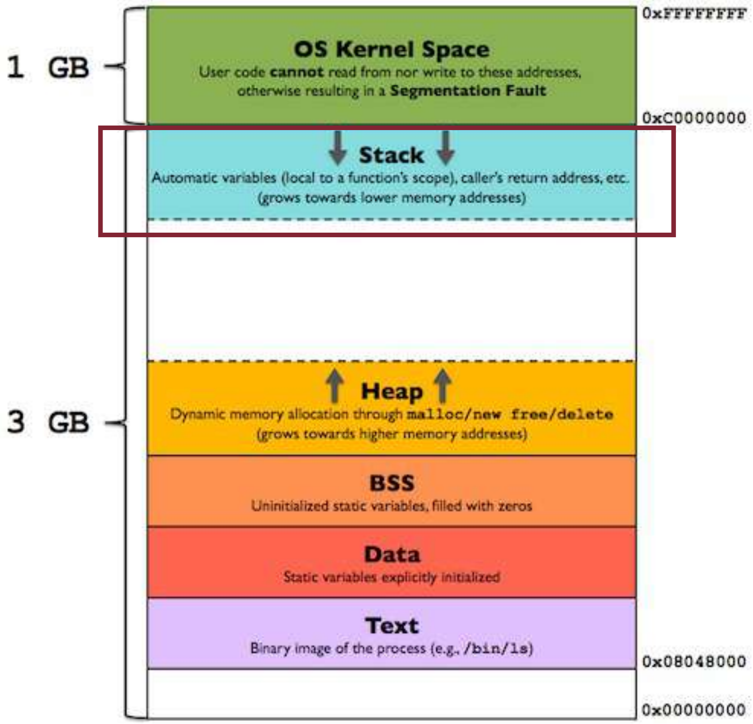
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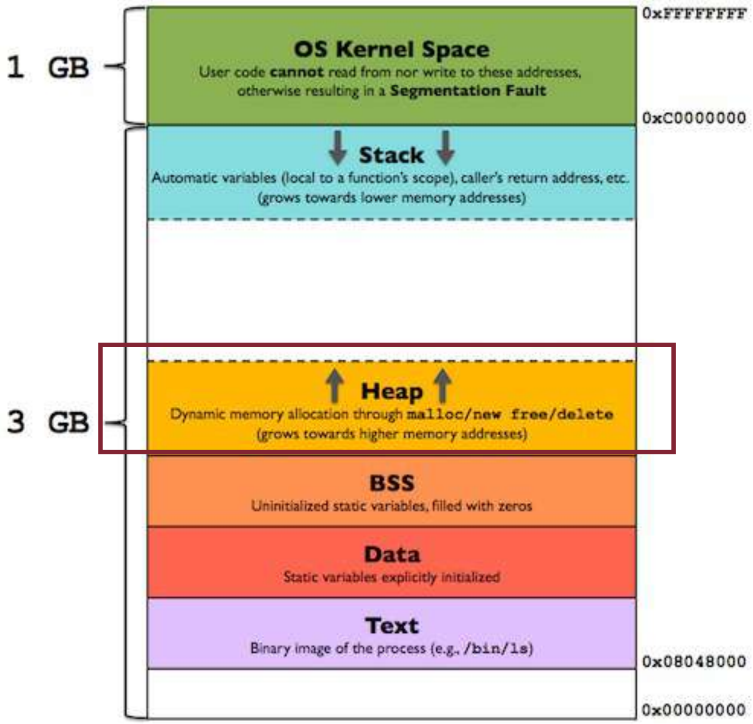

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Program vs. Process: Example

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void doSomething(int f) {
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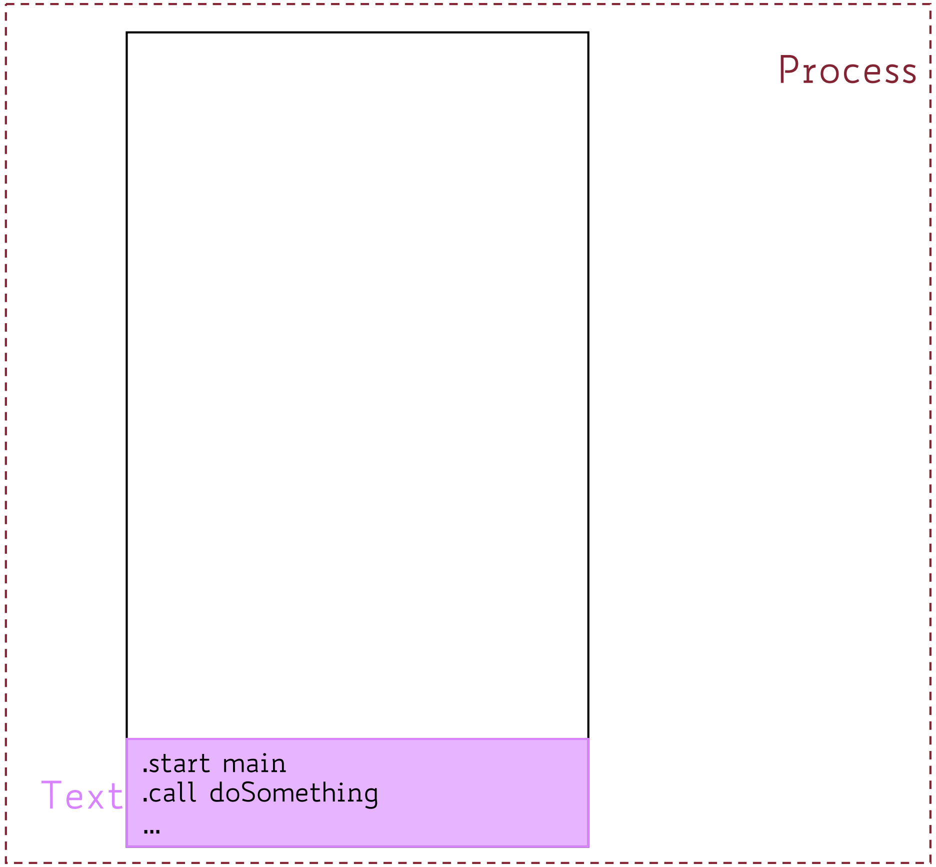

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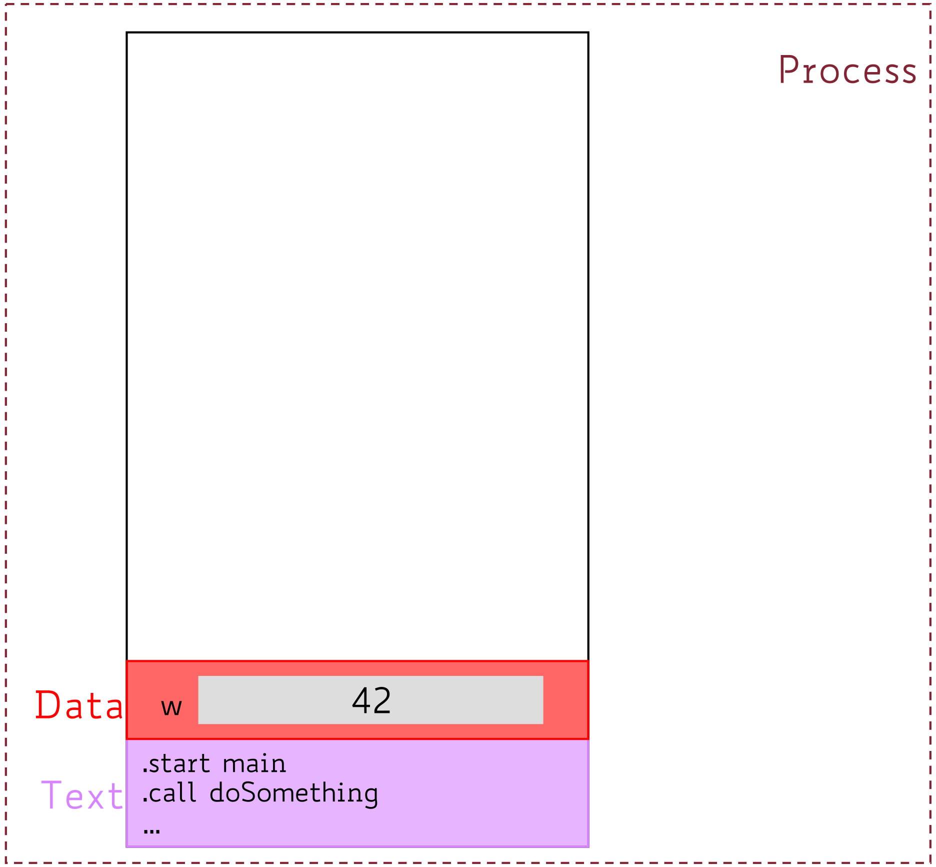

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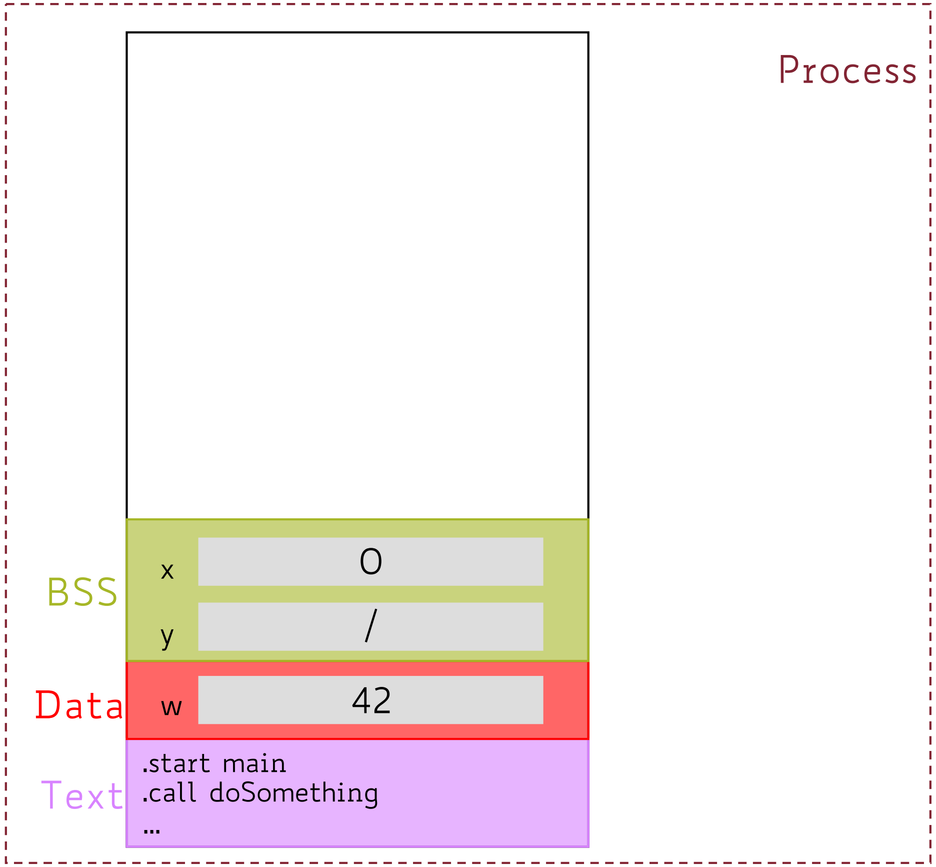

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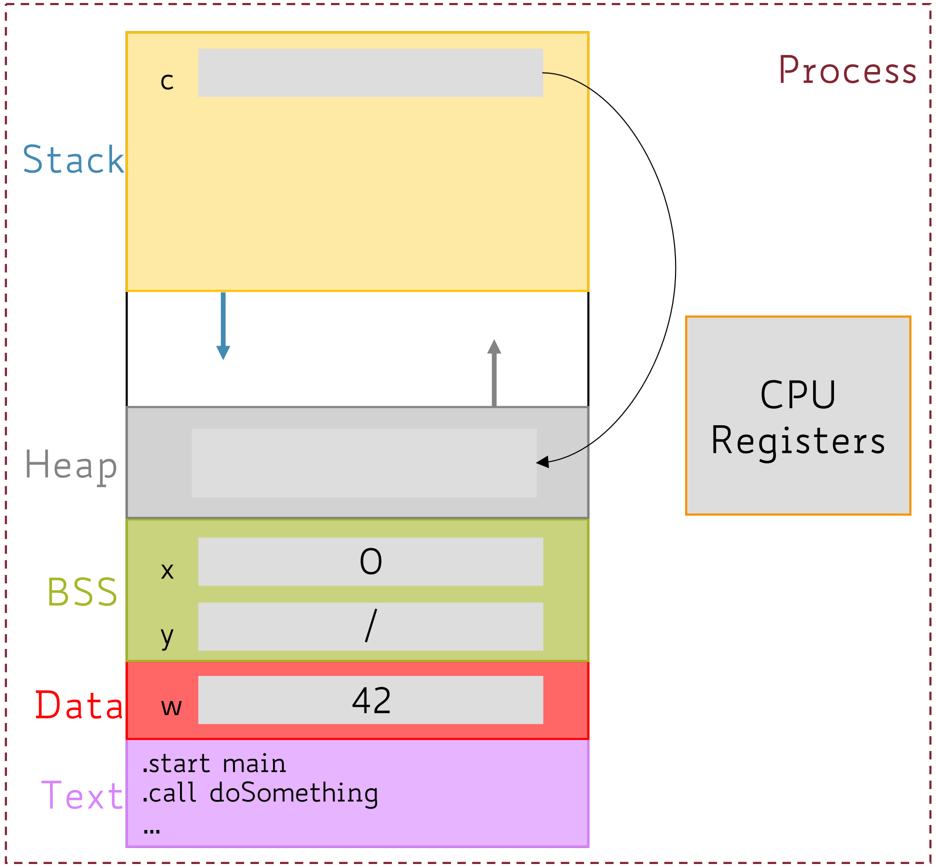

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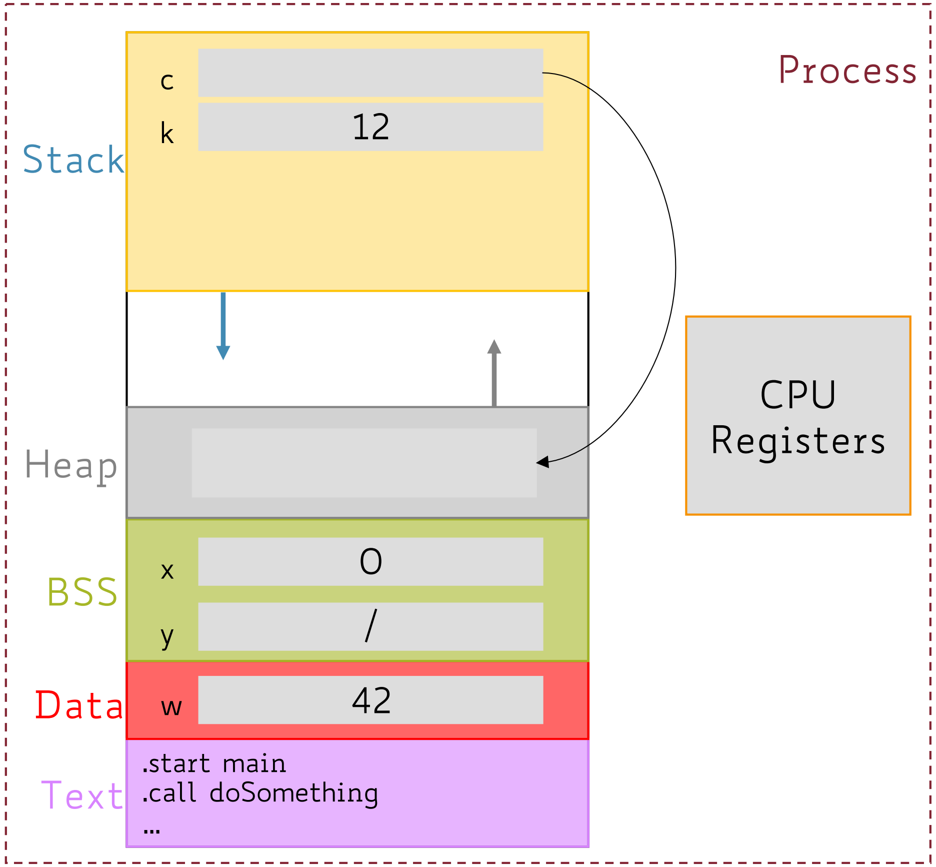

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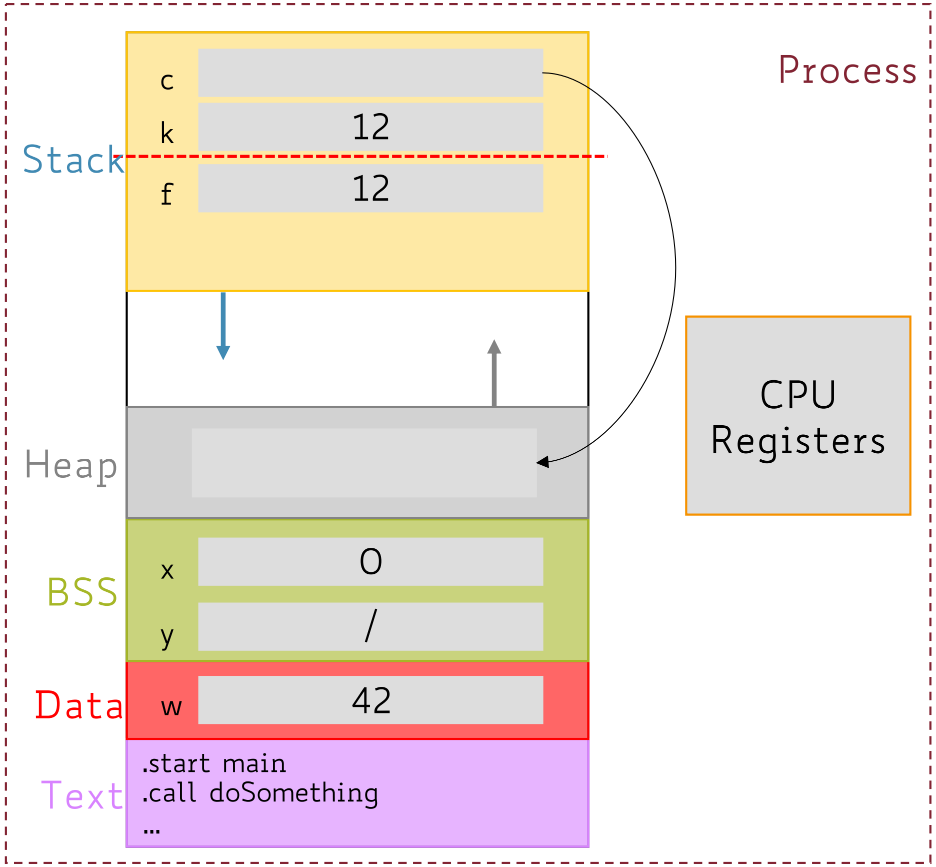

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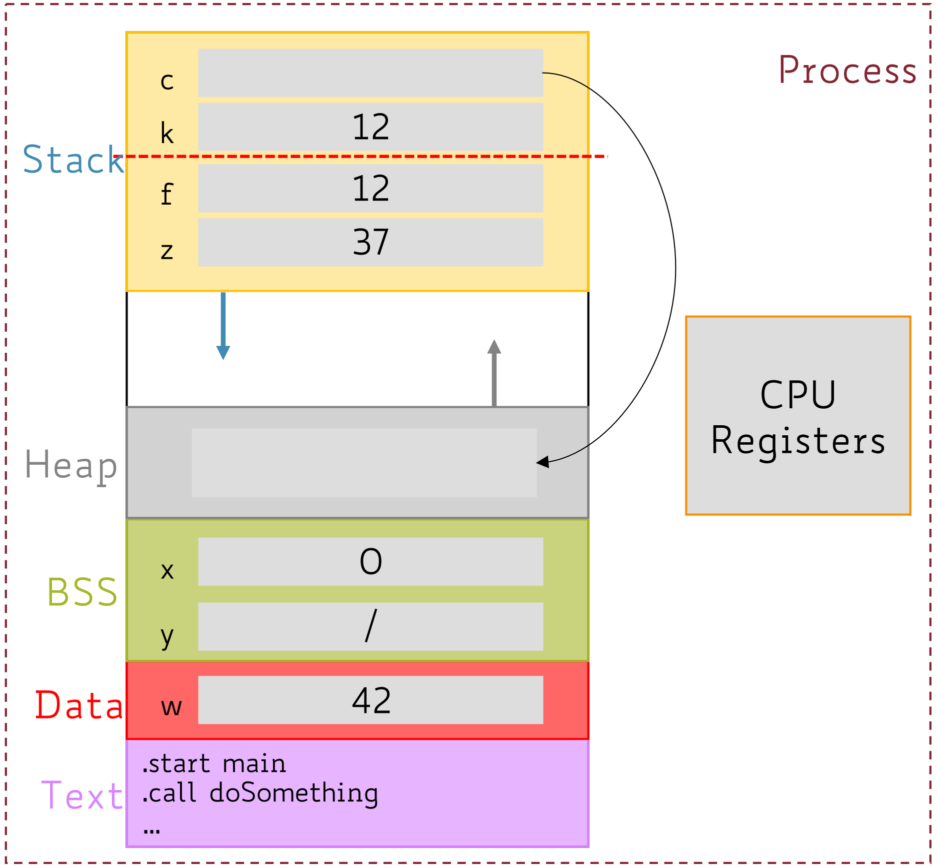

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- Stack memory conventionally grows top-down, i.e., from higher to lower memory addresses

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() {
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    foo(x, y);

void foo(a,b) {
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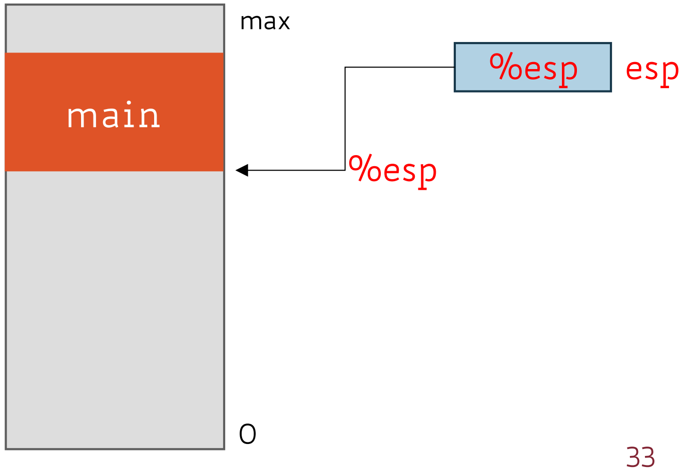

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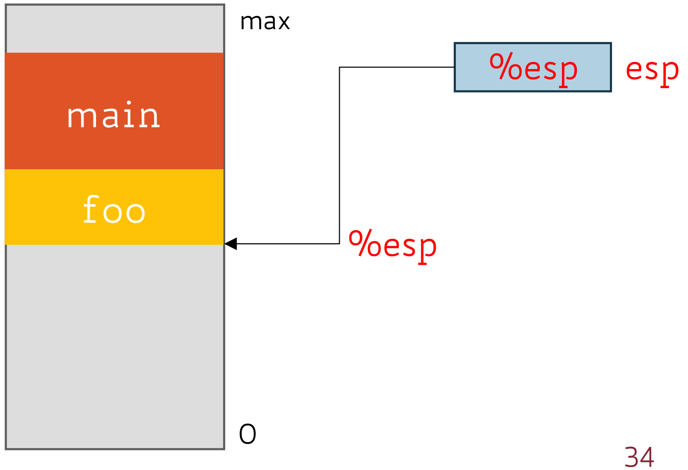

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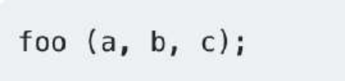
- The second and the third ones are set by the callee

Stack Frame: Parameters + Return



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foo (a, b, c);
```

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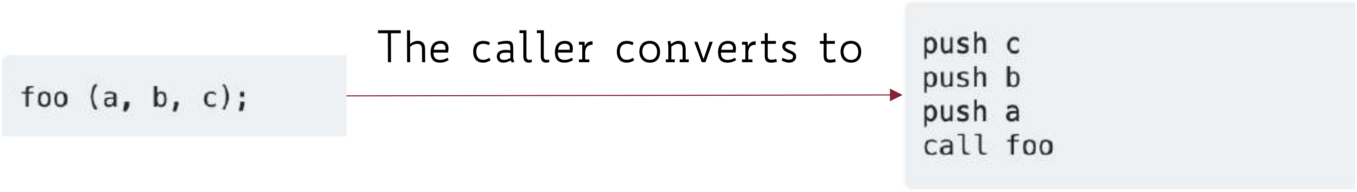

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push c
push b
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call foo
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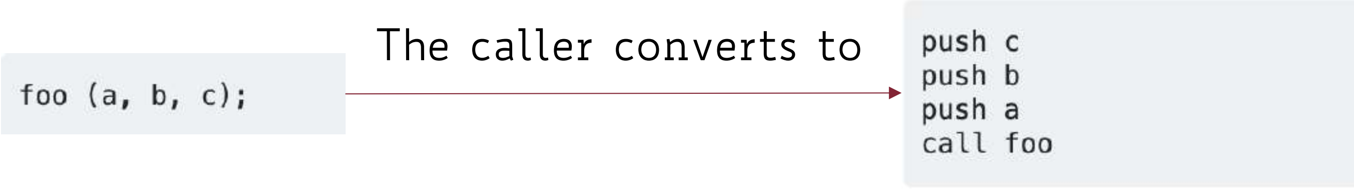

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```

The caller converts to

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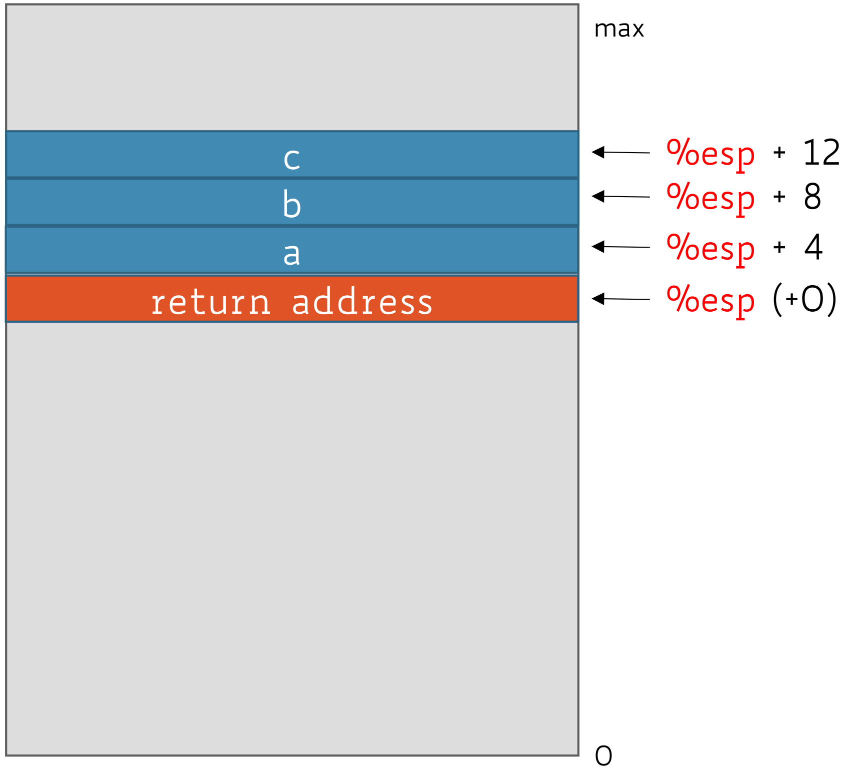
push c
push b
push a
call foo
```

- 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

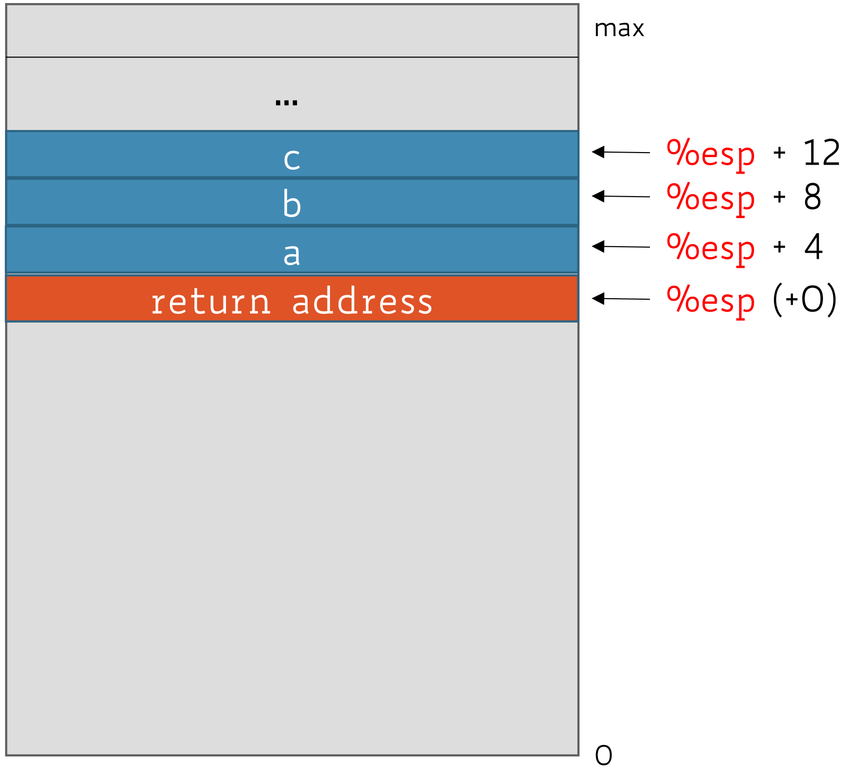


Stack Frame: Parameters + Return

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



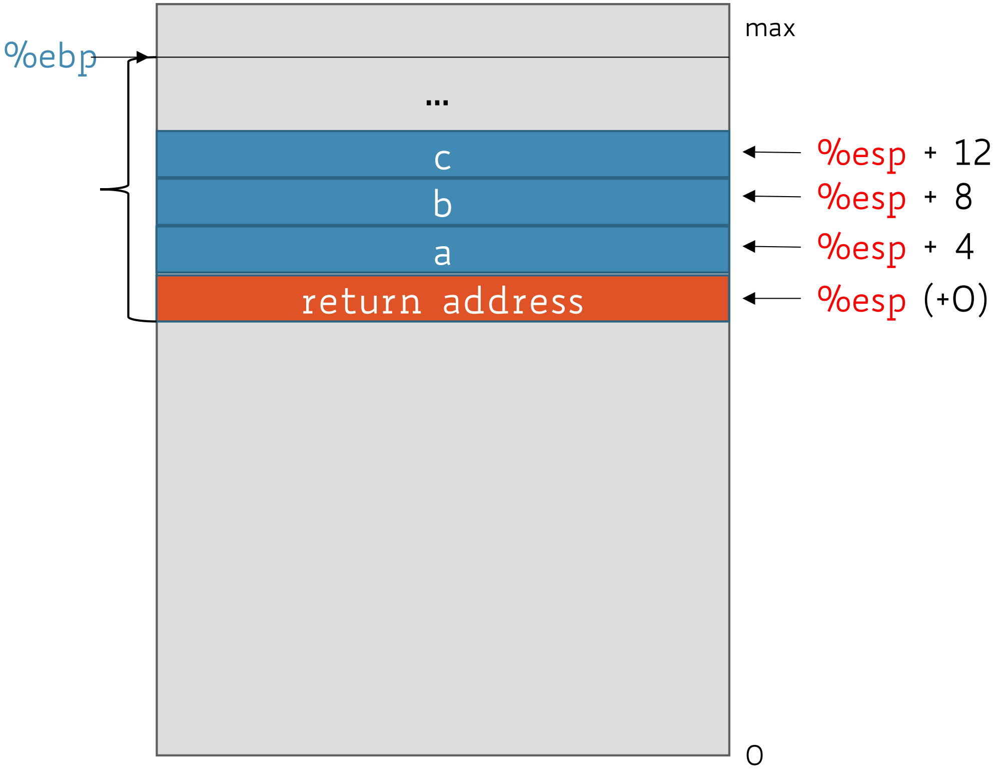
Stack Frame: Parameters + Return

Solution

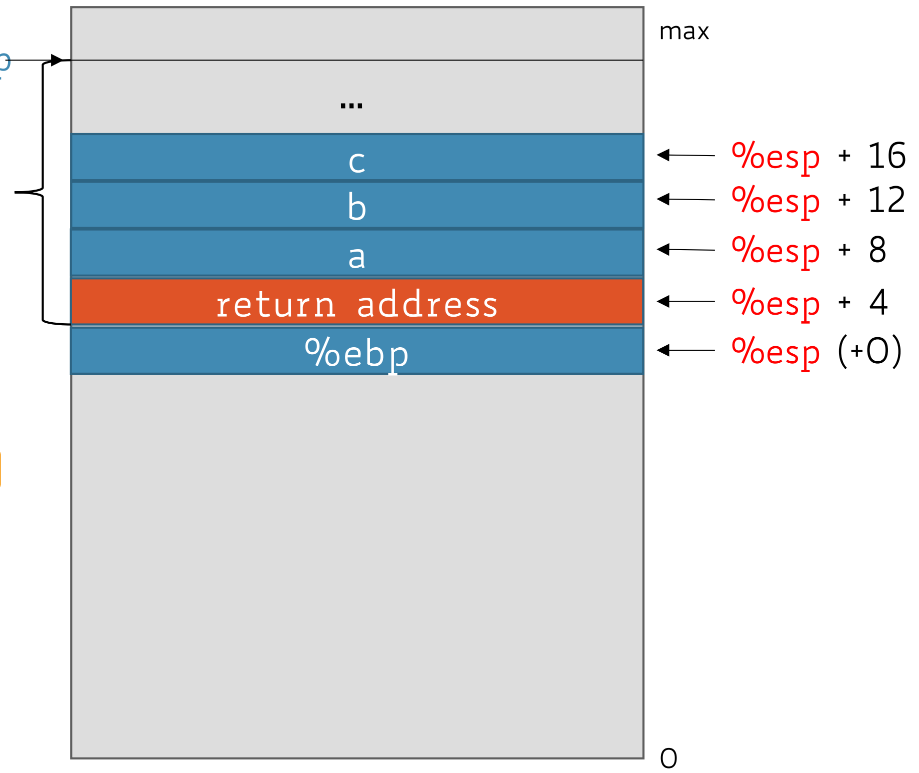
Instead of using a single pointer to the top of the stack (esp)

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

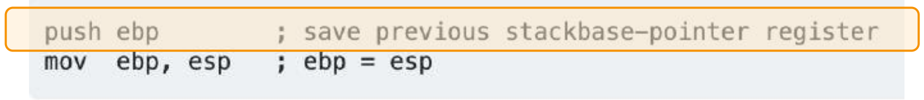
Let esp be free to change across different function calls, while keep ebp fixed within each stack frame



Stack Frame: Saving the Base Frame Pointer

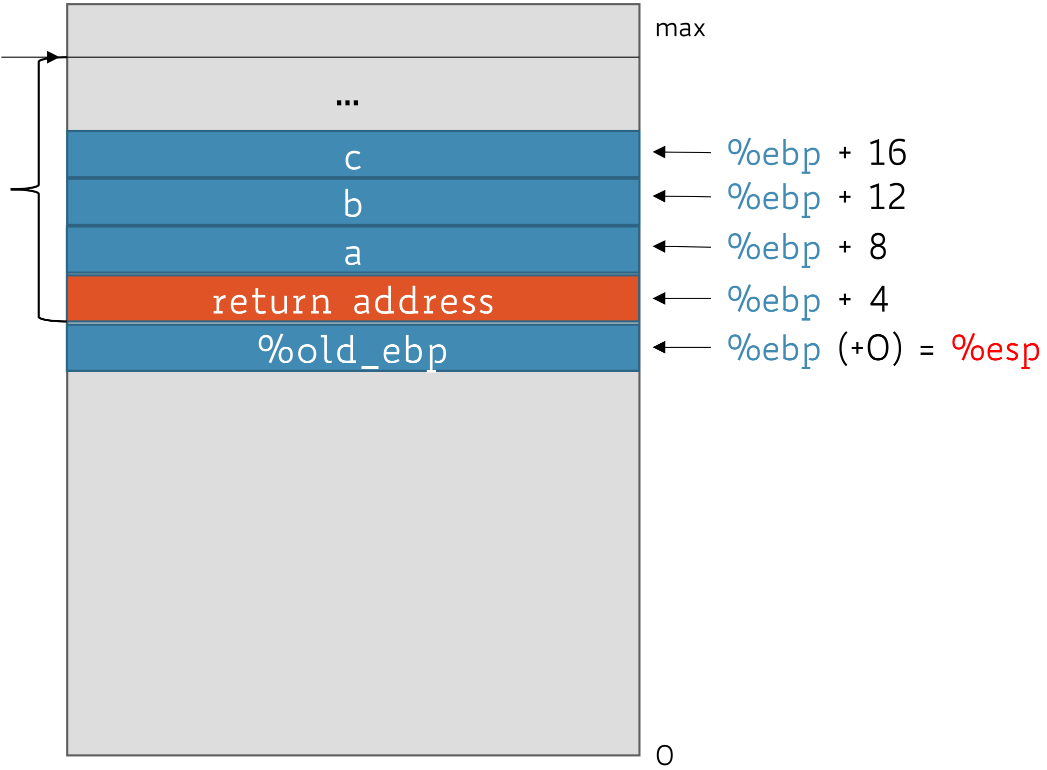


The callee first saves the current stack frame base pointer (%ebp) to the stack!

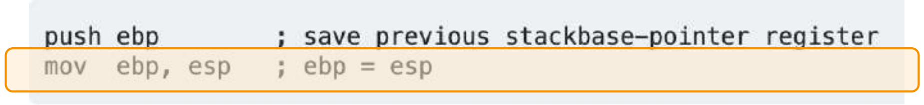


```
push ebp          ; save previous stackbase-pointer register
mov  ebp, esp     ; ebp = esp
```

Stack Frame: Saving the Base Frame Pointer



Then it sets the new base frame pointer to the current value of esp



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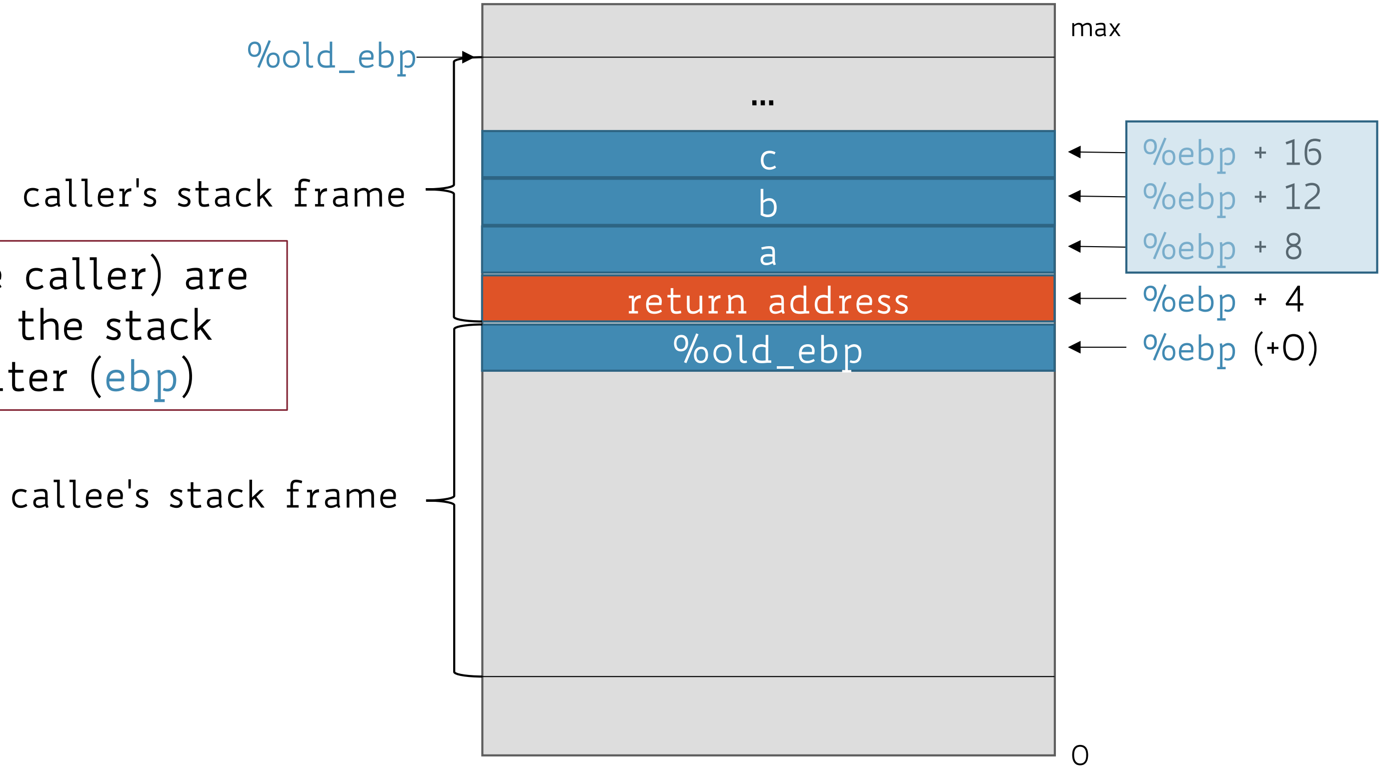
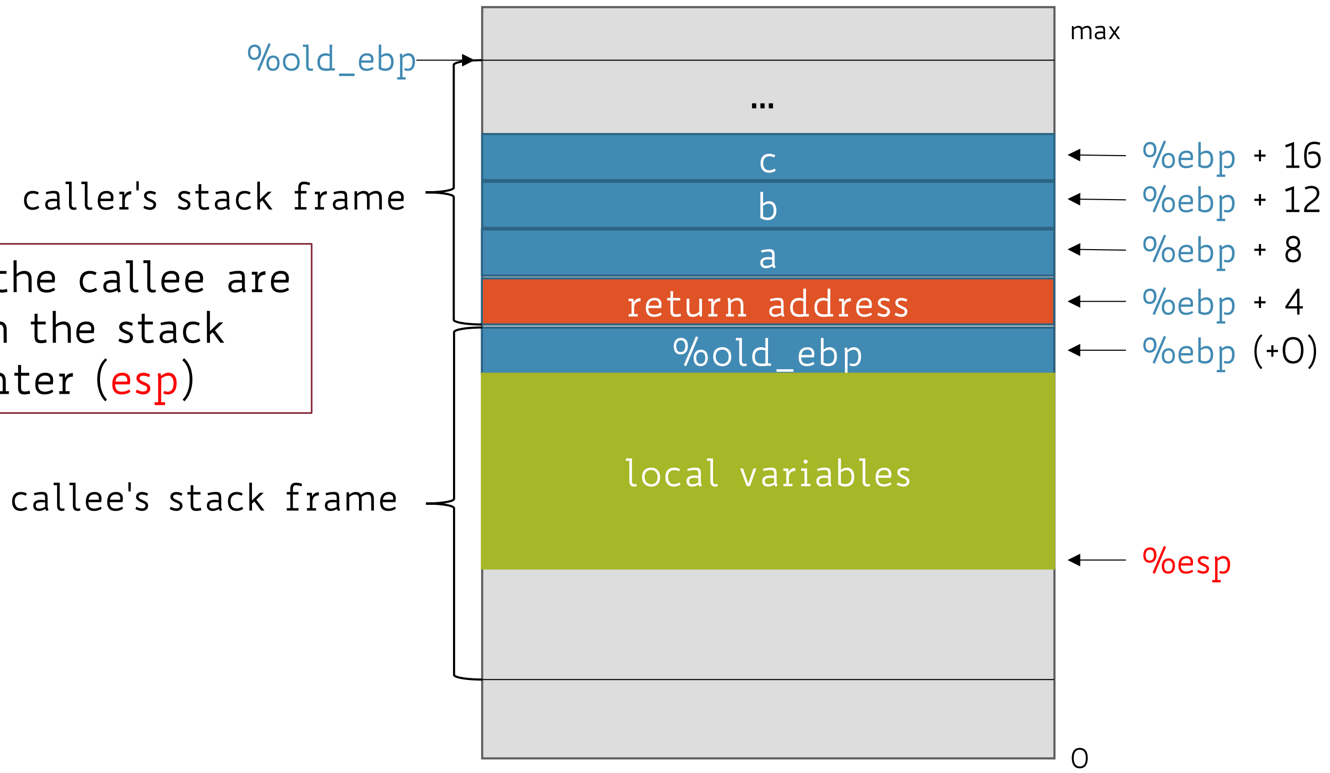
Parameters: Offset from the Base Frame Pointer



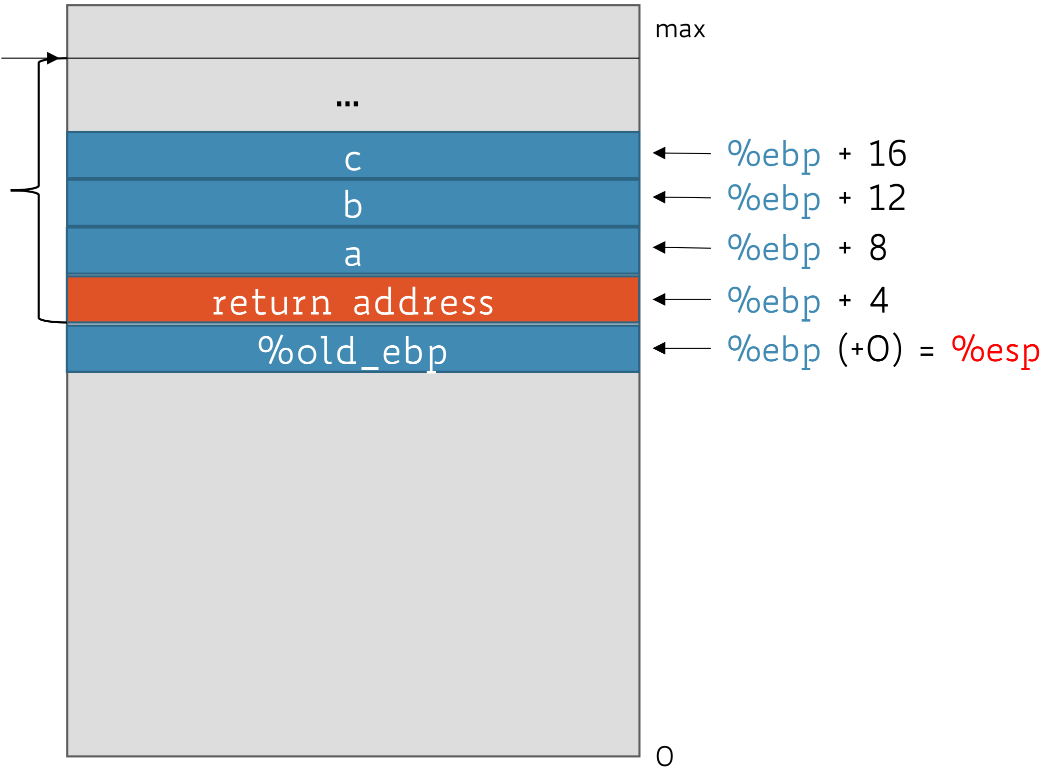
Parameters (of the caller) are accessed through the stack frame base pointer (ebp)

Local Variables: Offset from Stack Pointer

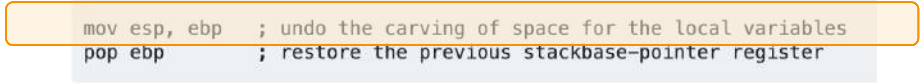
Local variables of the callee are accessed through the stack frame top pointer (esp)



Stack Frame: Cleanup and Return

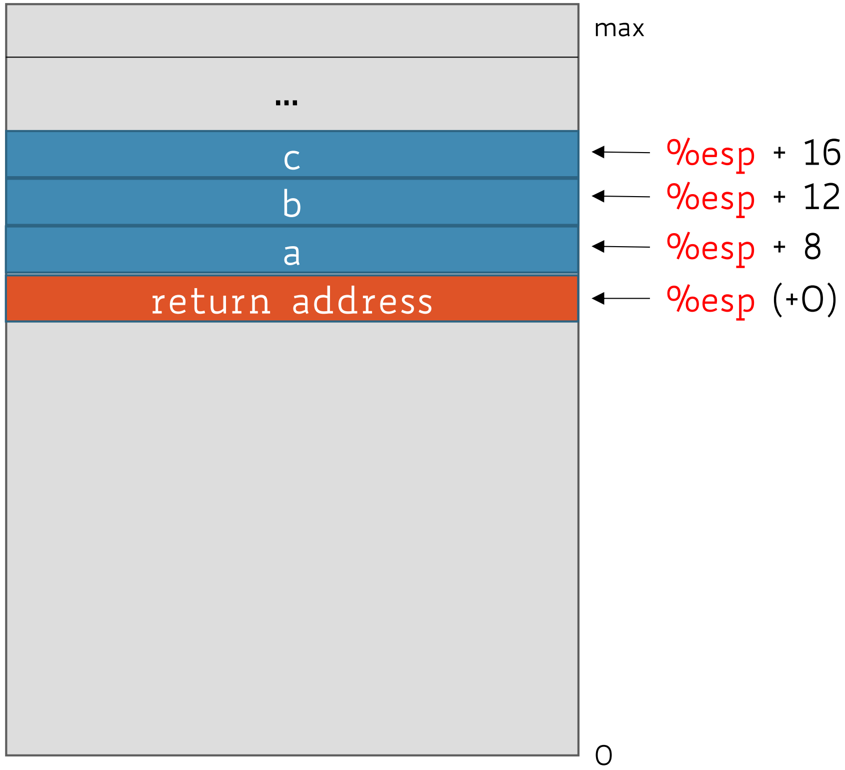


The old stack frame base pointer is restored

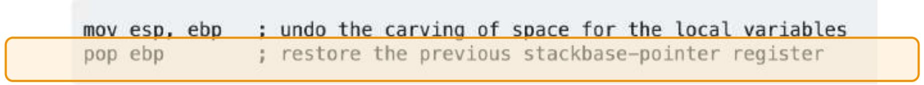


```
mov esp, ebp    ; undo the carving of space for the local variables
pop ebp         ; restore the previous stackbase-pointer register
```

Stack Frame: Cleanup and Return

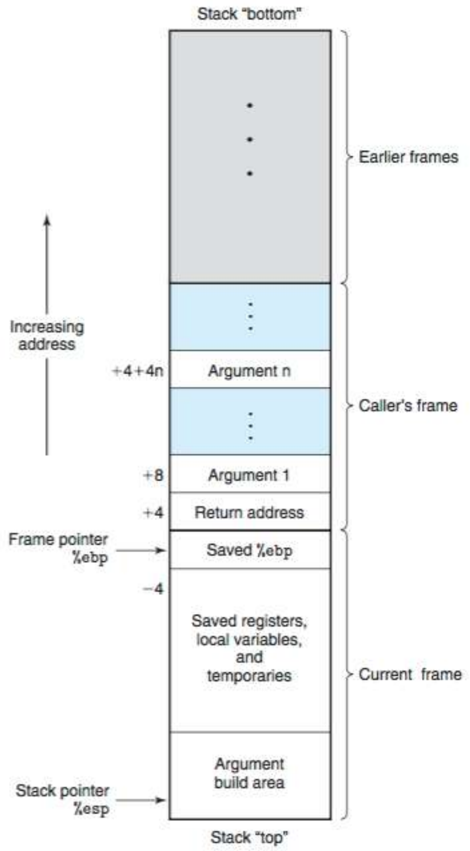


The old stack frame base pointer is restored



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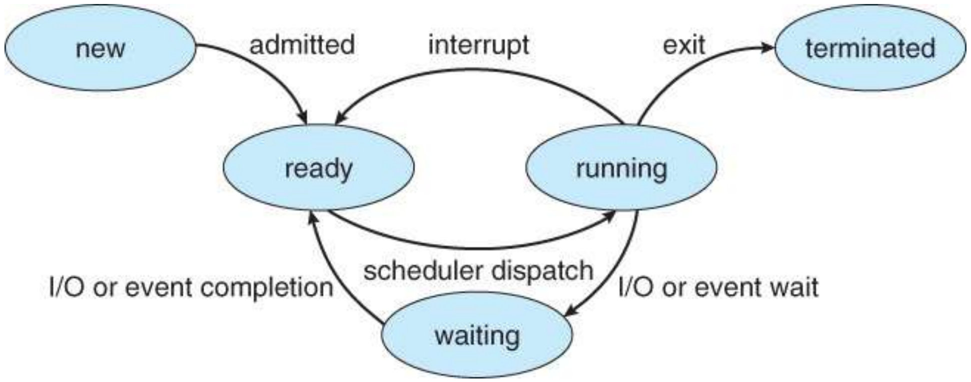
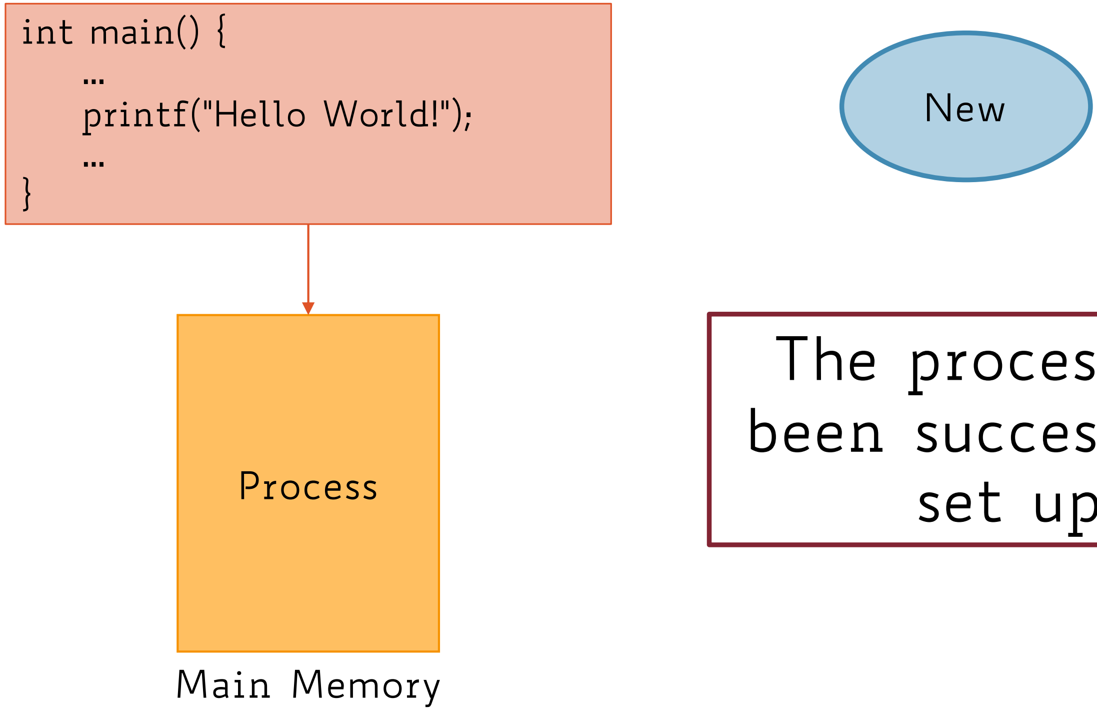
  - **Terminated** → The process is finished and the OS can destroy it

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)

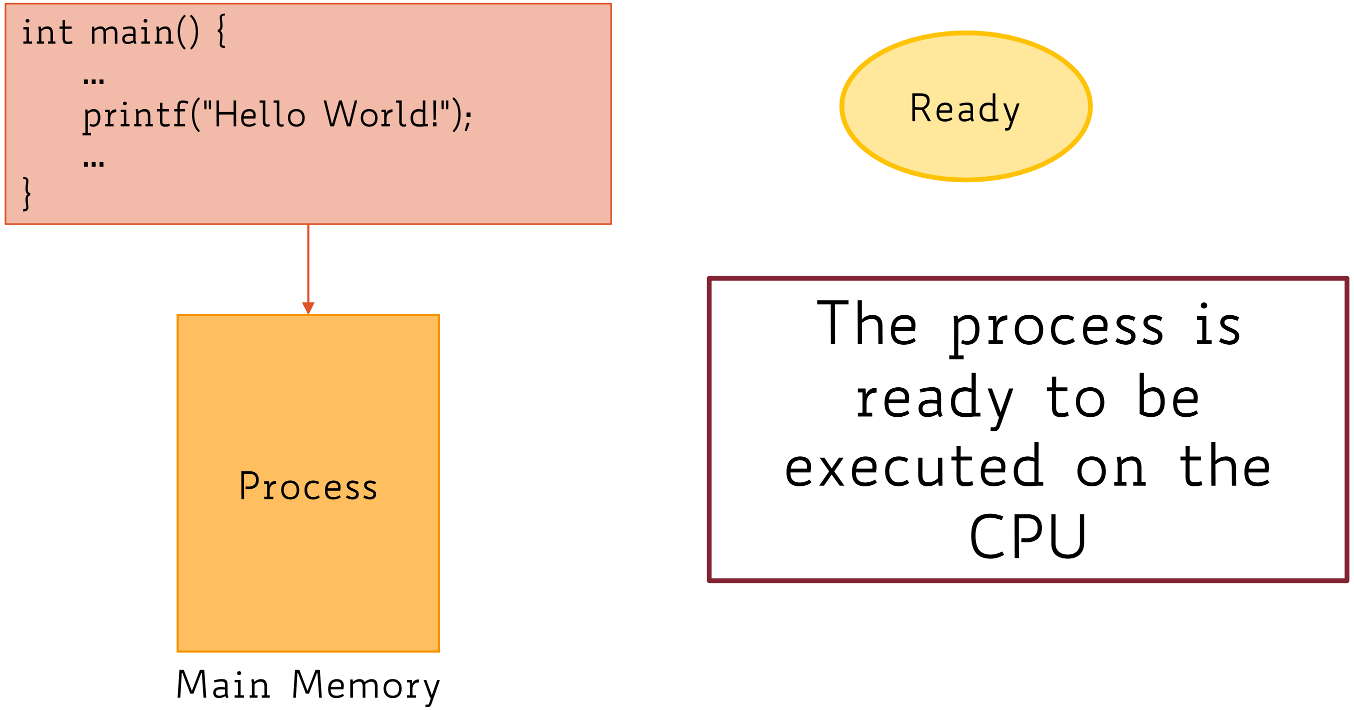
Process Execution State: Example



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

The process has been successfully set up

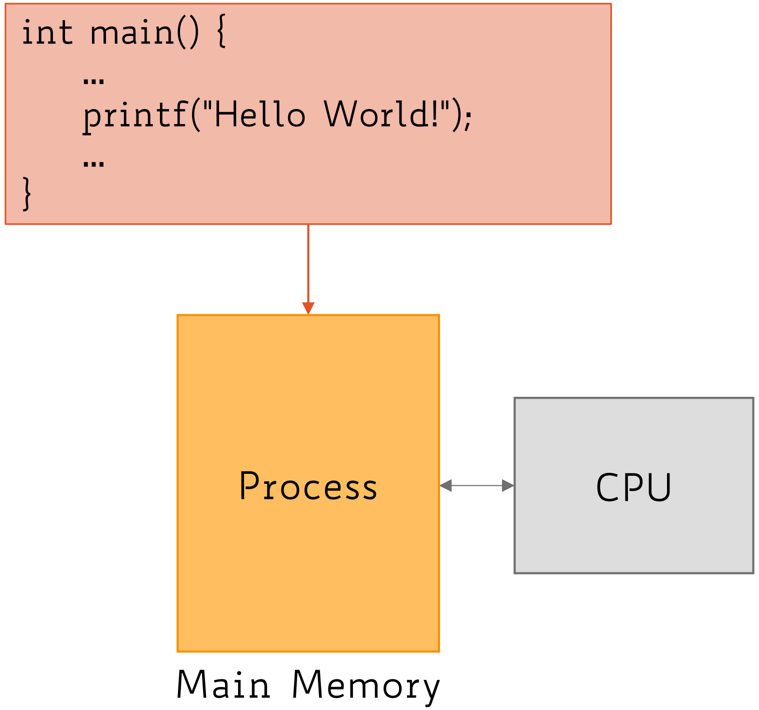
Process Execution State: Example



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

The process is ready to be executed on the CPU

Process Execution State: Example



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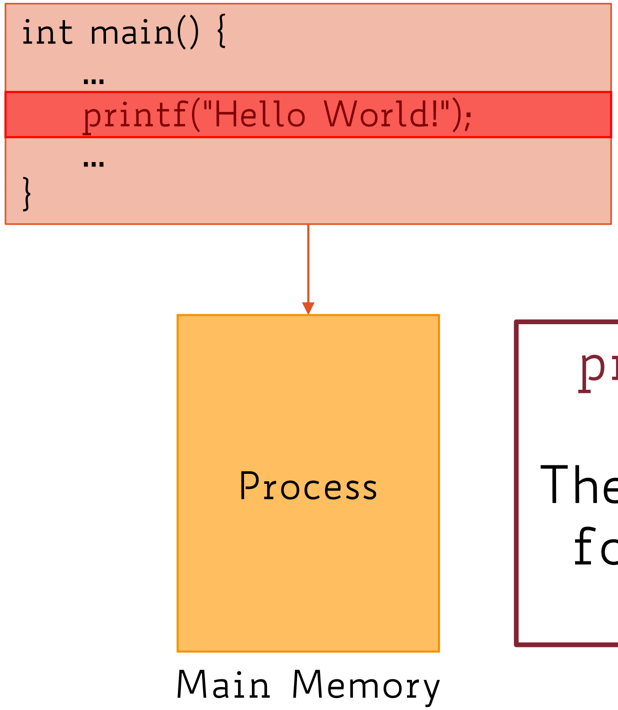
Running

The process is actually executing on the CPU

Process Execution State: Example

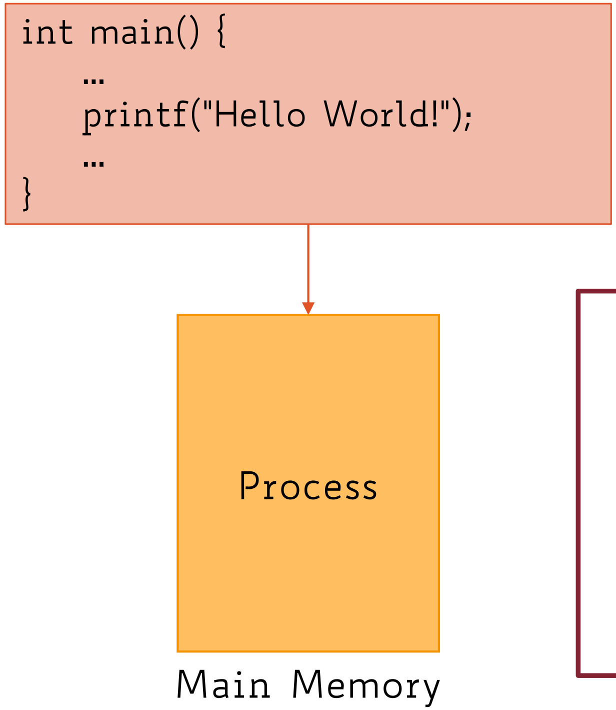


```
int main() {
    …
    printf("Hello World!");
    …
}
```

Waiting

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

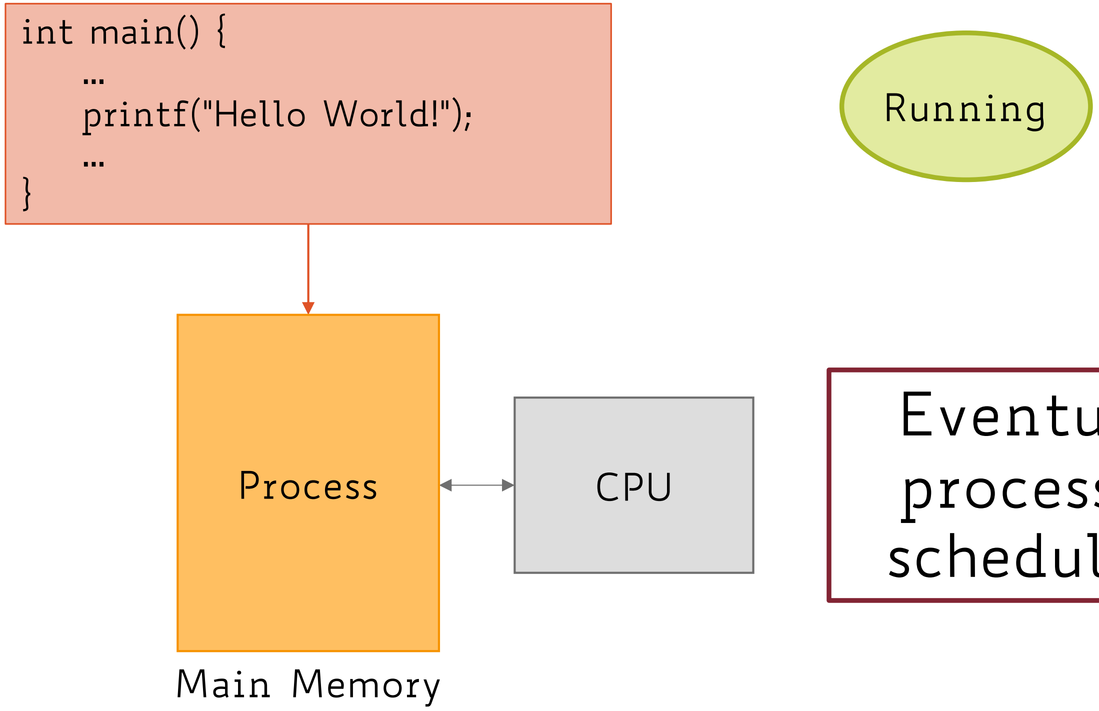


```
int main() {
    ...
    printf("Hello World!");
    ...
}
```

Ready

Once printf is done (e.g., HW interrupt) the process goes back to ready status yet it is not resumed directly!
(i.e., it is up to the OS to decide which process to schedule next)

Process Execution State: Example



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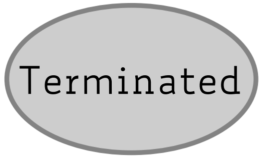
}
```

Eventually, the process will be scheduled again

Process Execution State: Example

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



Terminated

Finally, the process terminates

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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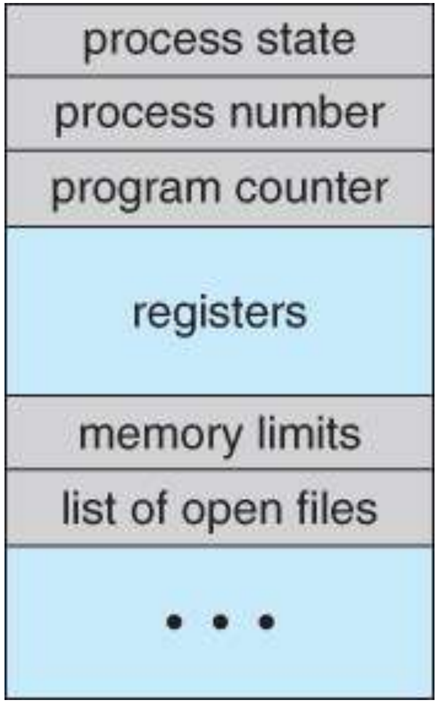
  - I/O status → list of open files

Process Control Block (PCB)



process state

process number

program counter

registers

memory limits

list of open files

• • •

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Summary

- Process is the **unit of execution** (running on a single CPU)
- OS gives every process the illusion of having a contiguous sequence of memory addresses that they can refer (**virtual address space**)
- OS keeps track of process-related information using an ad hoc data structure called Process Control Block (PCB)
- Process can be in one of **5 possible states**: **new**, **ready**, **waiting**, **running**, or **terminated**