Sistemi Operativi I

Corso di Laurea in Informatica

2022-2023

Gabriele Tolomei

Dipartimento di Informatica

Sapienza Università di Roma

tolomei@di.uniroma1.it

SAPIENZA
UNIVERSITÀ DI ROMA

The Big Picture So Far

- We have presented a number of services the OS provides to
  - abstract from actual physical (HW) resources
  - ease the interaction between users and HW resources

The Big Picture So Far

- We have presented a number of services the OS provides to
  - 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 needed 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

Program vs. Process

- A program is an executable file which resides on the persistent memory (e.g., disk),
  - contains only the set of instructions needed 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
- A process is a particular instance of a program when loaded to main memory
  - e.g., multiple instances of the **`ls`** program above, thus multiple processes for the same program

Program vs. Process

- A program is an executable file which resides on the persistent memory (e.g., disk),
  - contains only the set of instructions needed 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
- A process is a particular instance of a program when loaded to main memory
  - e.g., multiple instances of the **`ls`** program above, thus multiple processes for the same program

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

Process

- A process is the OS abstraction of a running program (unit of execution)

Process

- A process is the OS abstraction of a running program (unit of execution)
- Process is dynamic, whilst a program is static (code and data only)

Process

- A process is the OS abstraction of a running program (unit of execution)
- Process is dynamic, whilst a program is static (code and data only)
- Several processes may run the same program (e.g., multiple Google Chrome instances) but each has its own state

Process

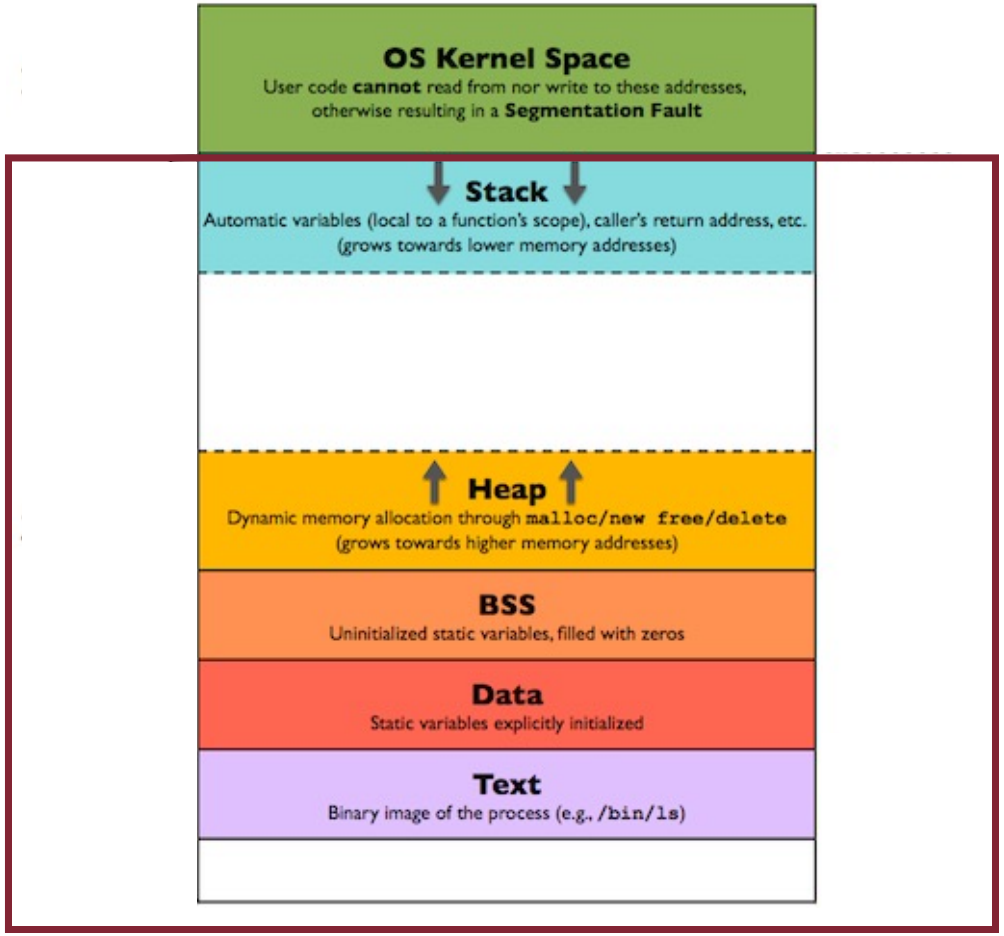
- A process is the OS abstraction of a running program (unit of execution)
- Process is dynamic, whilst a program is static (code and data only)
- Several processes may run the same program (e.g., multiple Google Chrome instances) but each has its own state
- A process executes one instruction at a time, 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

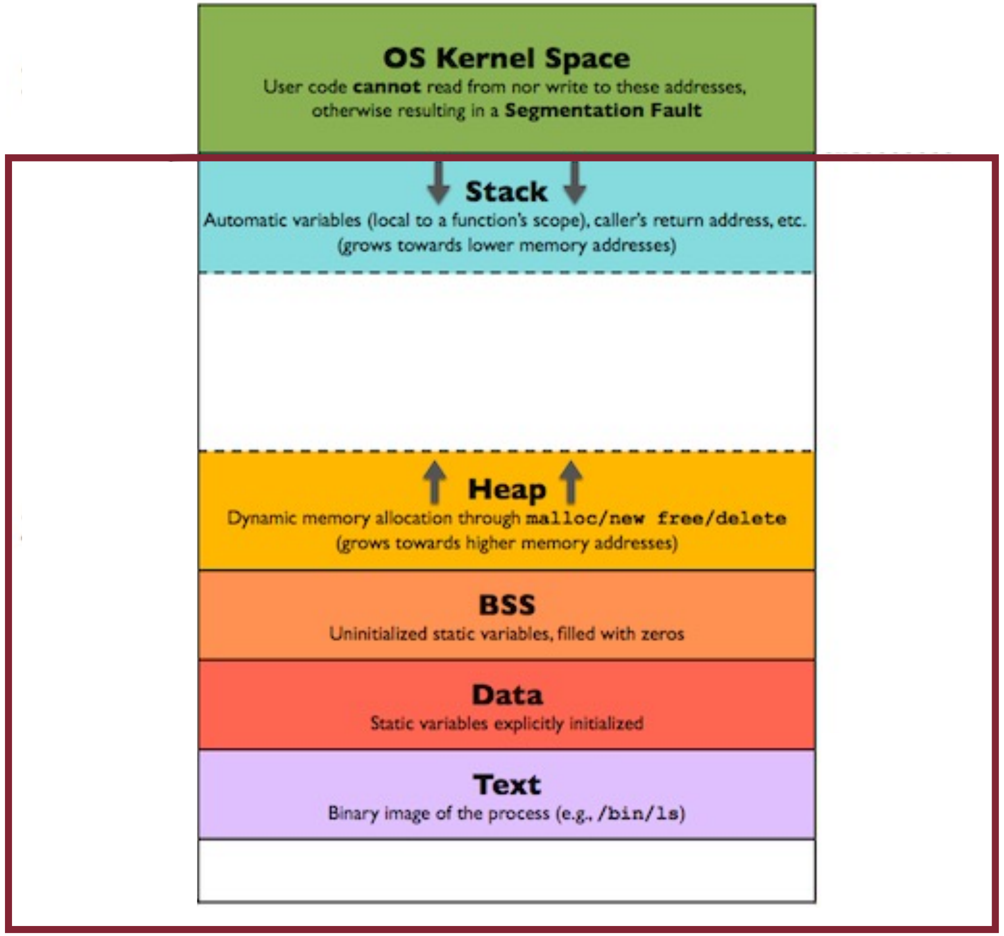
The OS gives the same amount of virtual address space to each process



Process: Virtual Address Space Layout

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

The virtual address space is an **abstraction** of the physical memory address space

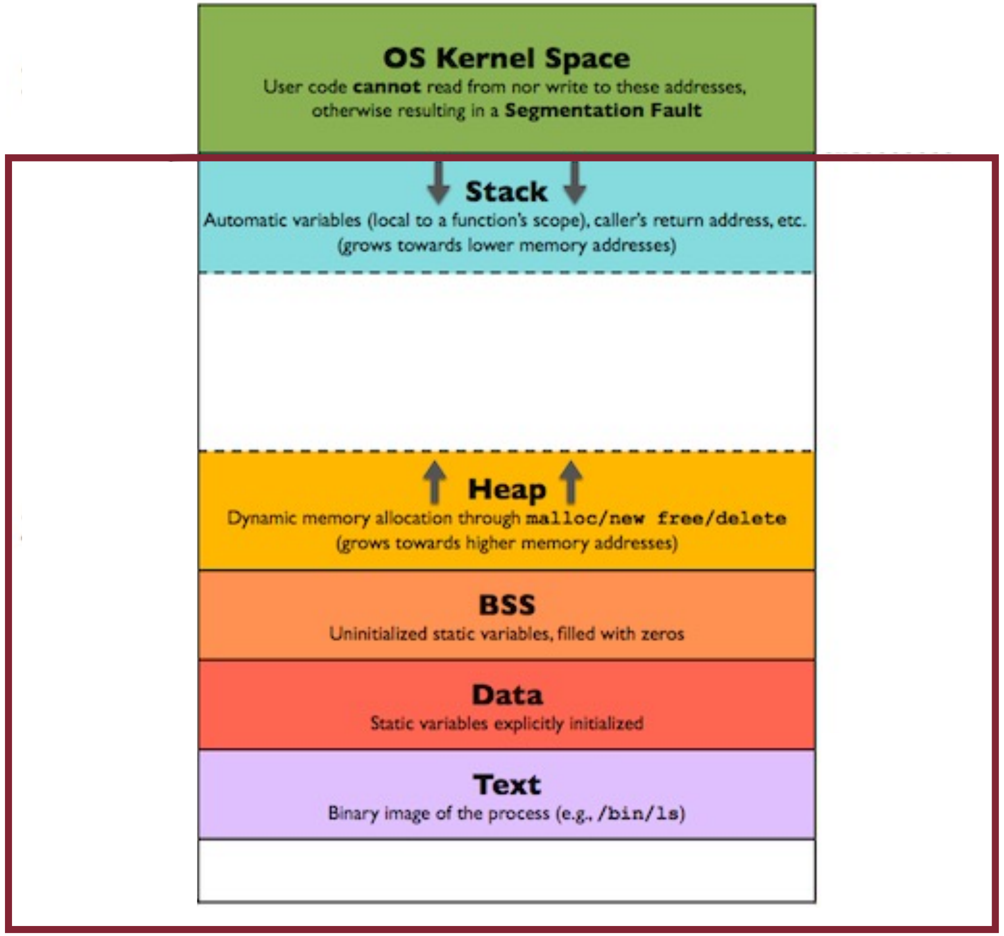


Process: Virtual Address Space Layout

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

The virtual address space is an abstraction of the physical memory address space

The range of valid virtual addresses that a process can generate is machine-dependent



Process: Virtual Address Space Layout

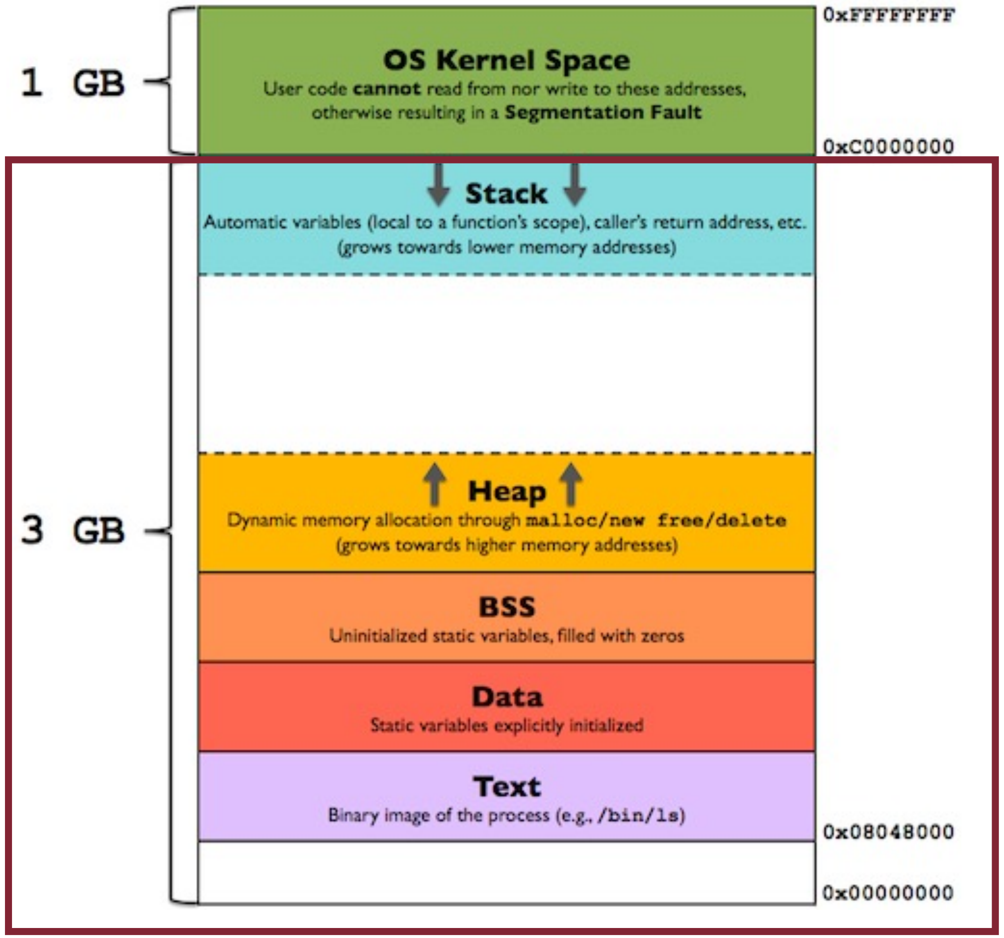
The OS gives the same amount of **virtual address space** to each process

The virtual address space is an **abstraction** of the physical memory address space

The range of valid virtual addresses that a process can generate is **machine-dependent**

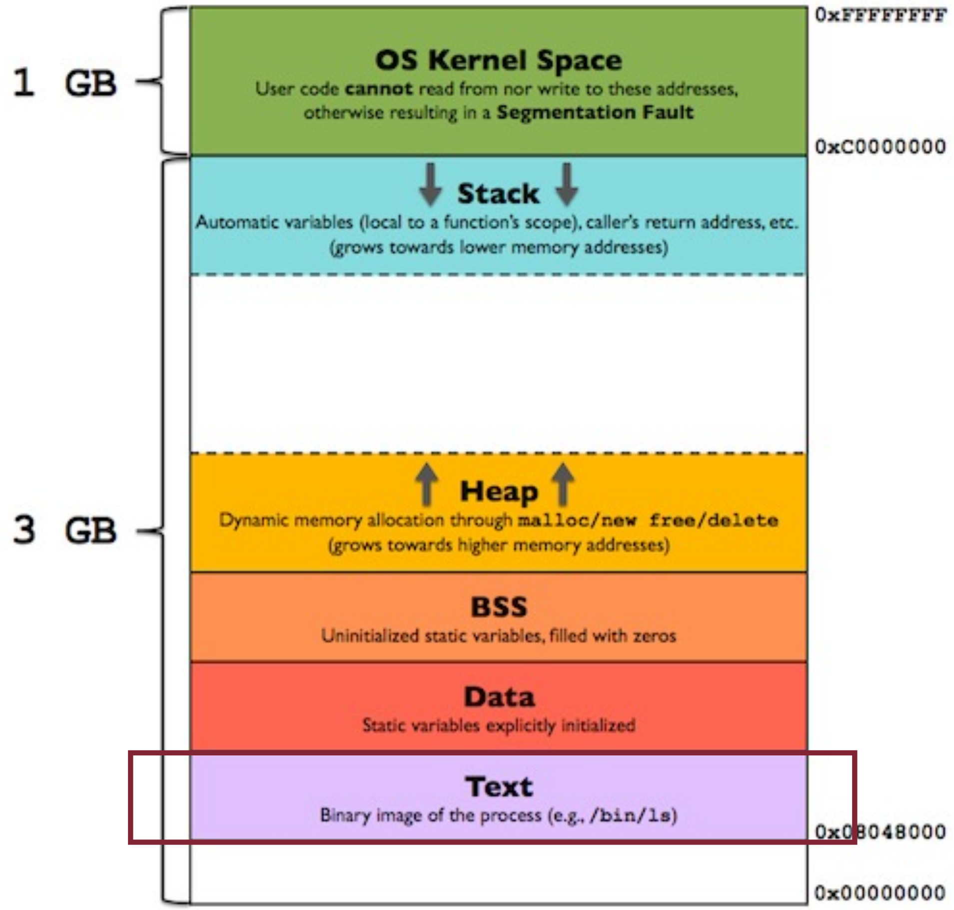
For example, on a 32-bit architecture, the virtual addresses range from 0 to 2^{32} -1

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



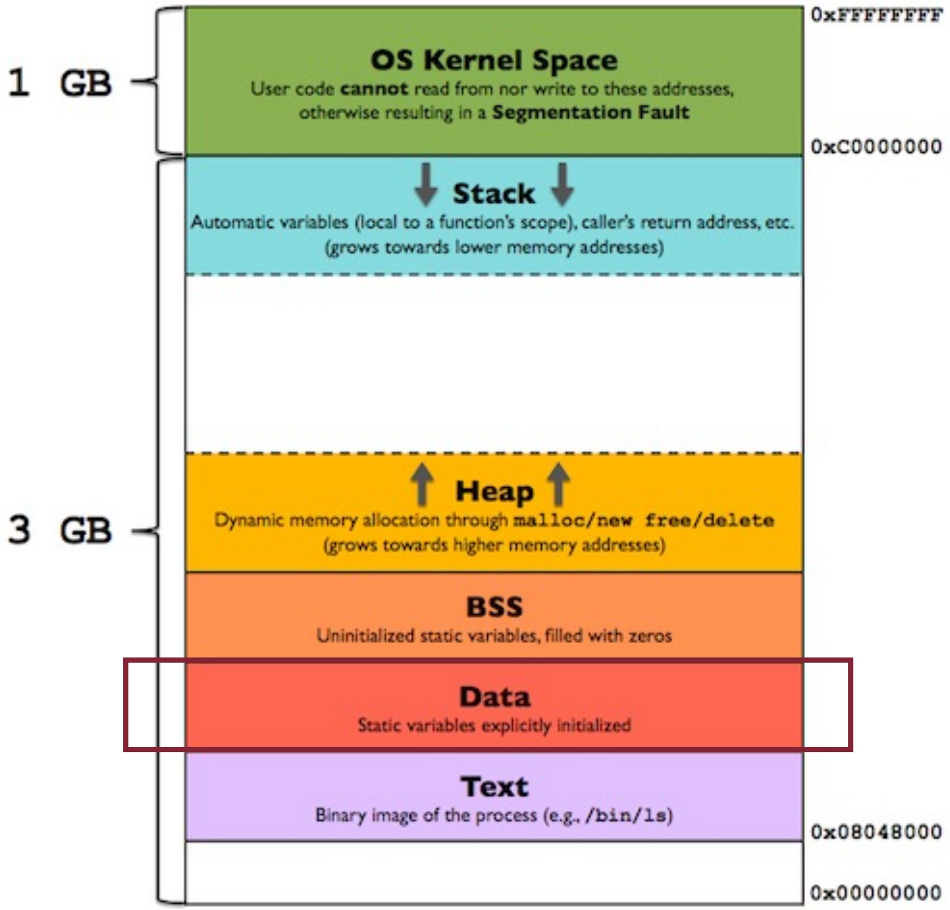
Process: Virtual Address Space Layout

- Text → contains executable instructions



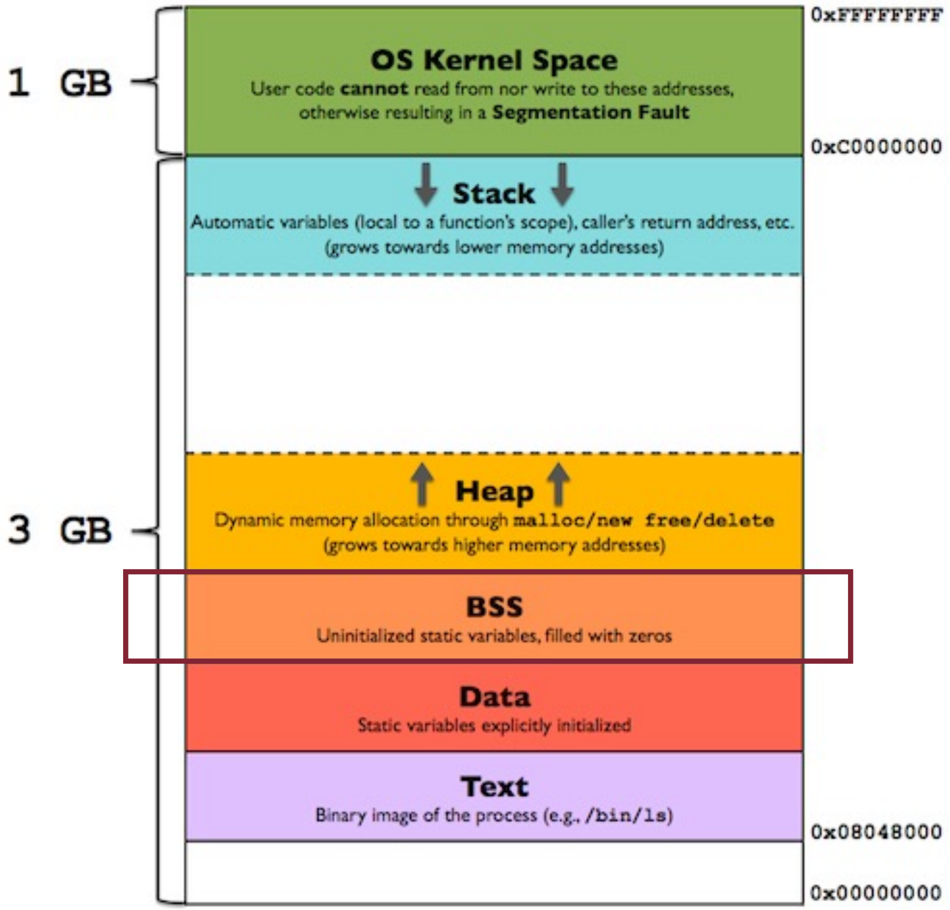
Process: Virtual Address Space Layout

- Text → contains executable instructions
- Data → global and static variable (initialized)



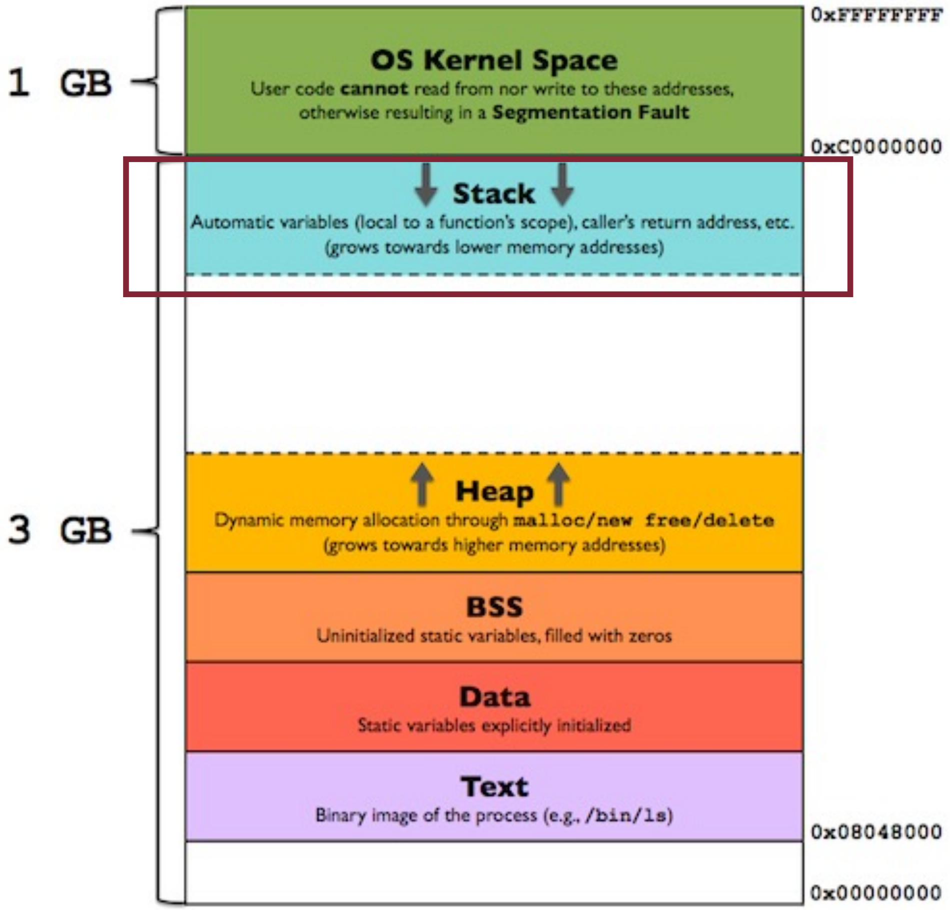
Process: Virtual Address Space Layout

- Text → contains executable instructions
- Data → global and static variable (initialized)
- BSS → global and static variable (uninitialized or initialized to 0)



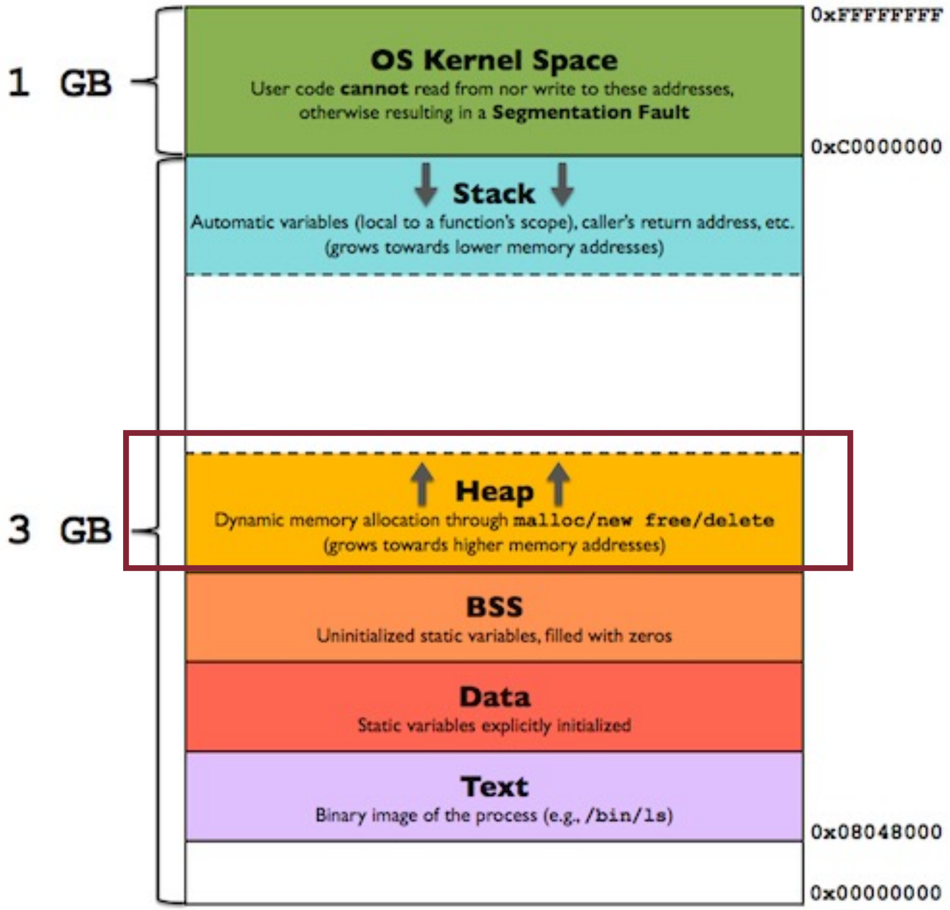
Process: Virtual Address Space Layout

- Text → contains executable instructions
- Data → global and static variable (initialized)
- BSS → global and static variable (uninitialized or initialized to 0)
- Stack → LIFO structure used to store all the data needed by a function call (stack frame)



Process: Virtual Address Space Layout

- Text → contains executable instructions
- Data → global and static variable (initialized)
- BSS → global and static variable (uninitialized or initialized to 0)
- Stack → LIFO structure used to store all the data needed by a function call (stack frame)
- 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);
    int k = 12;
    doSomething(k);
    …
}
```

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);
    int k = 12;
    doSomething(k);
    …
}
```

Process

Text

```
.start main
.call doSomething
…
```

Program vs. Process: Example

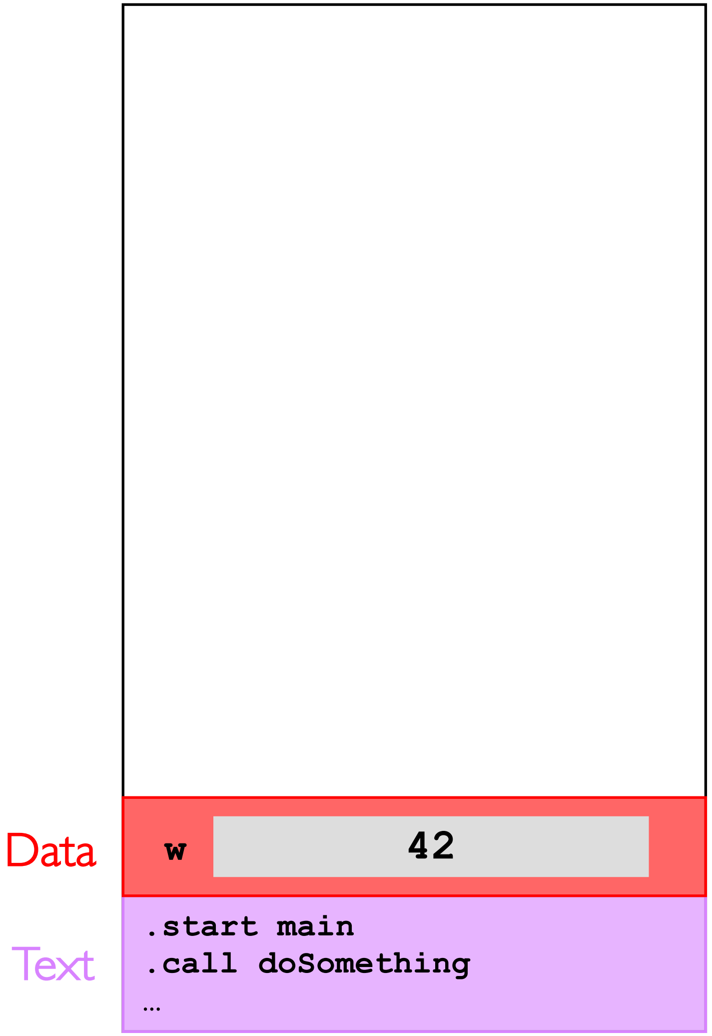
Program

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

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

int main() {
    char* c = malloc(128);
    int k = 12;
    doSomething(k);
    …
}
```

Process



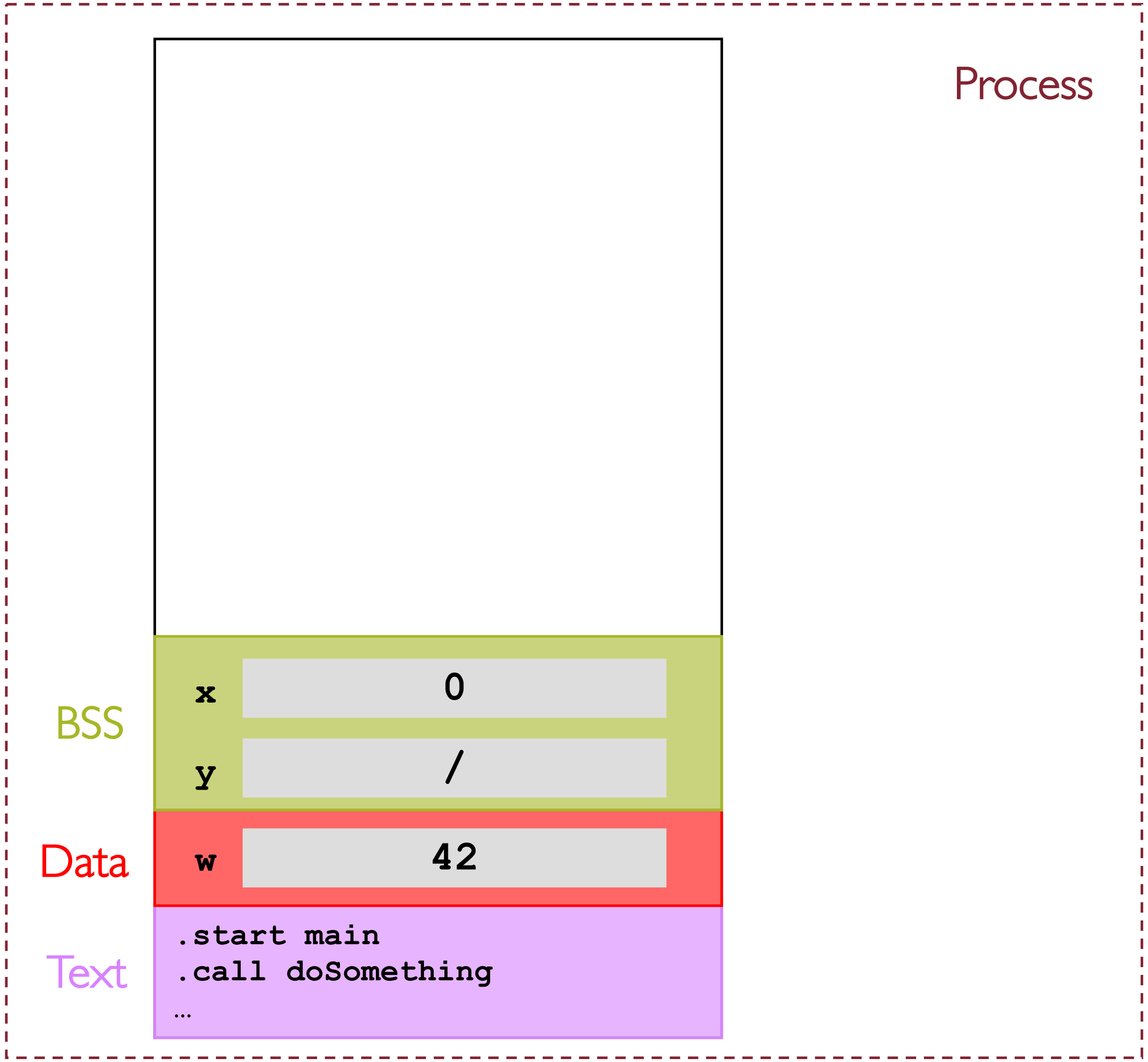
Program vs. Process: Example

Program

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

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

int main() {
    char* c = malloc(128);
    int k = 12;
    doSomething(k);
    …
}
```



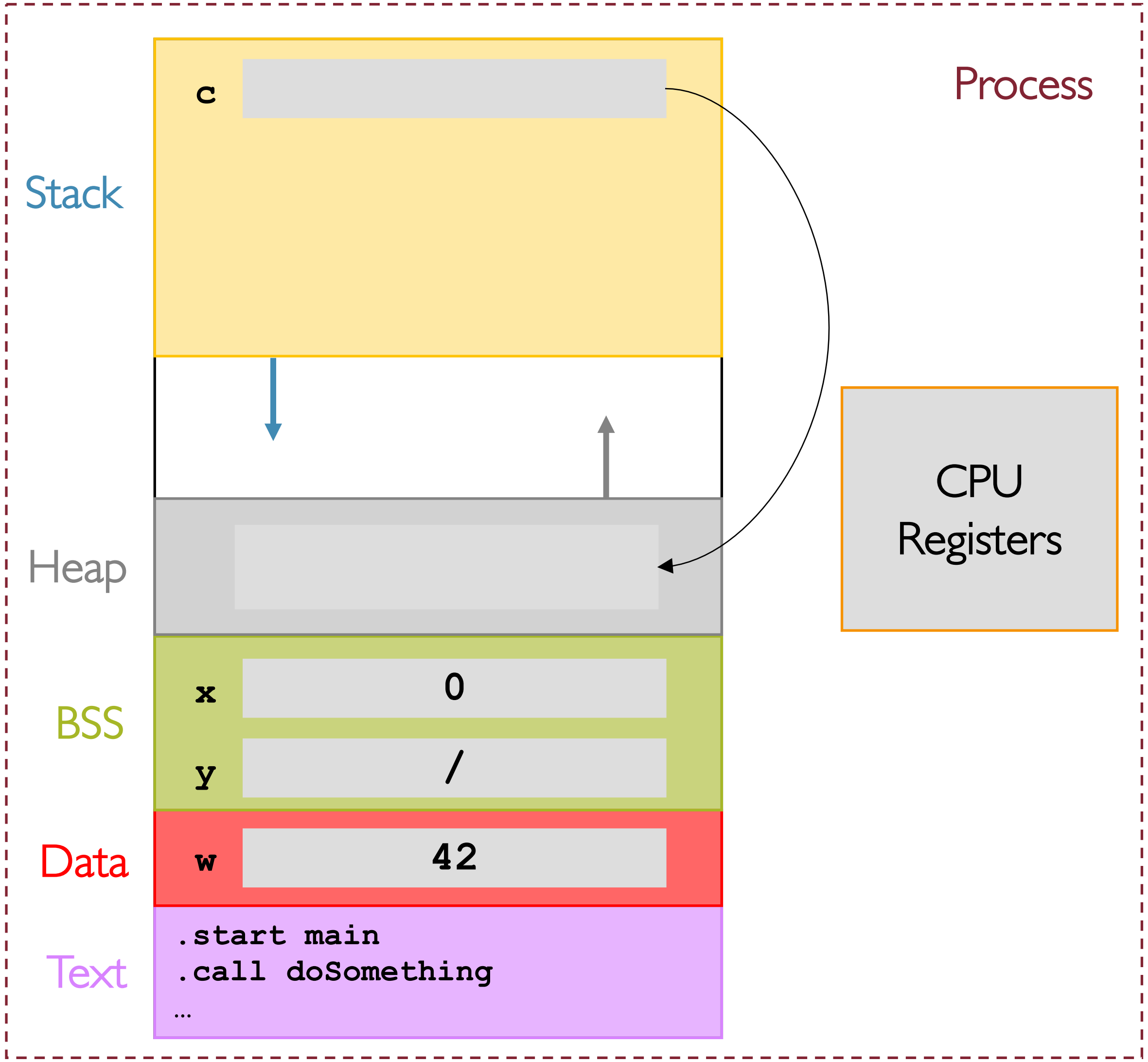
Program vs. Process: Example

Program

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

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

int main() {
    char* c = malloc(128);
    int k = 12;
    doSomething(k);
    …
}
```



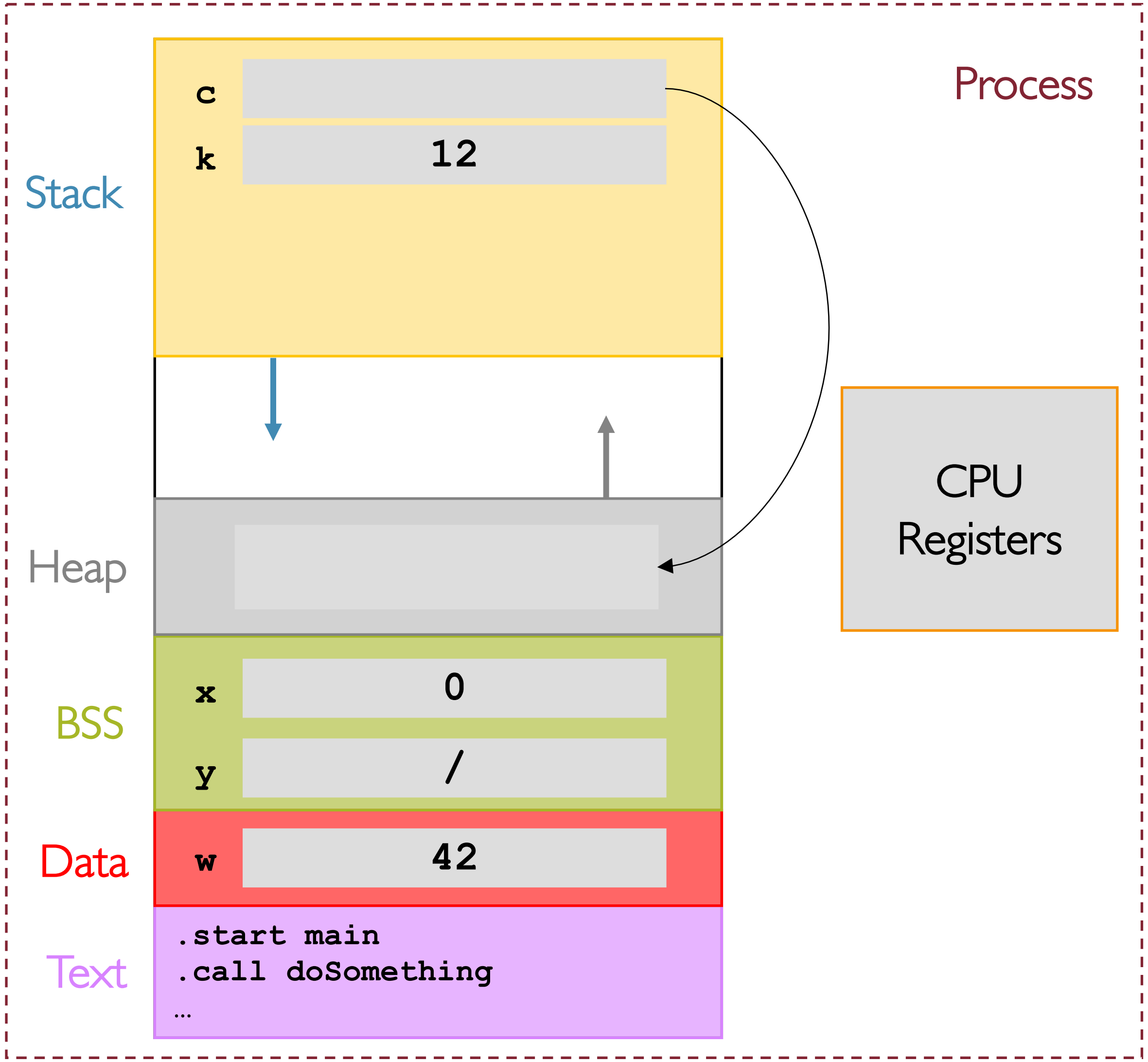
Program vs. Process: Example

Program

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

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

int main() {
    char* c = malloc(128);
    int k = 12;
    doSomething(k);
    …
}
```



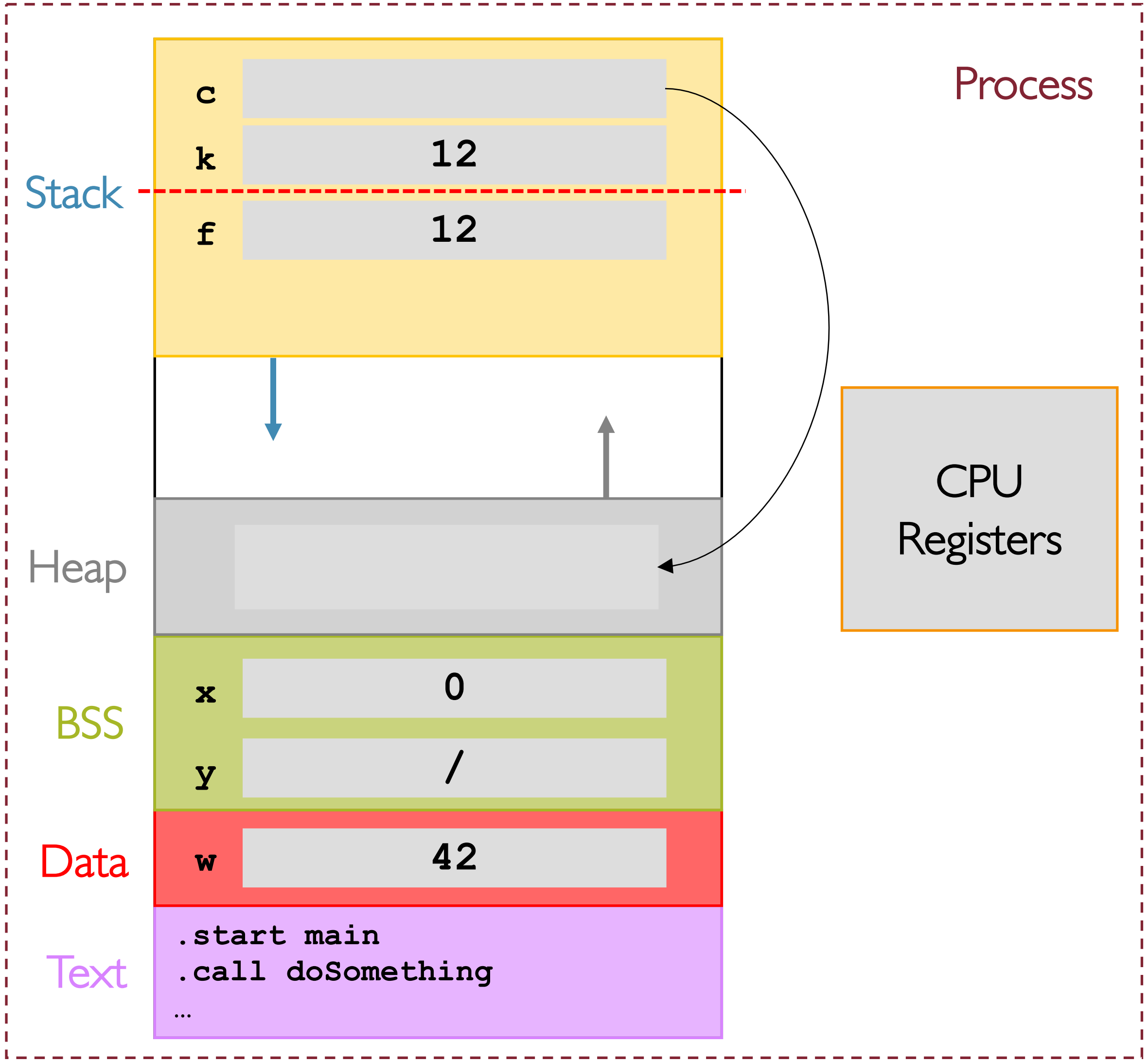
Program vs. Process: Example

Program

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

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

int main() {
    char* c = malloc(128);
    int k = 12;
    doSomething(k);
    …
}
```



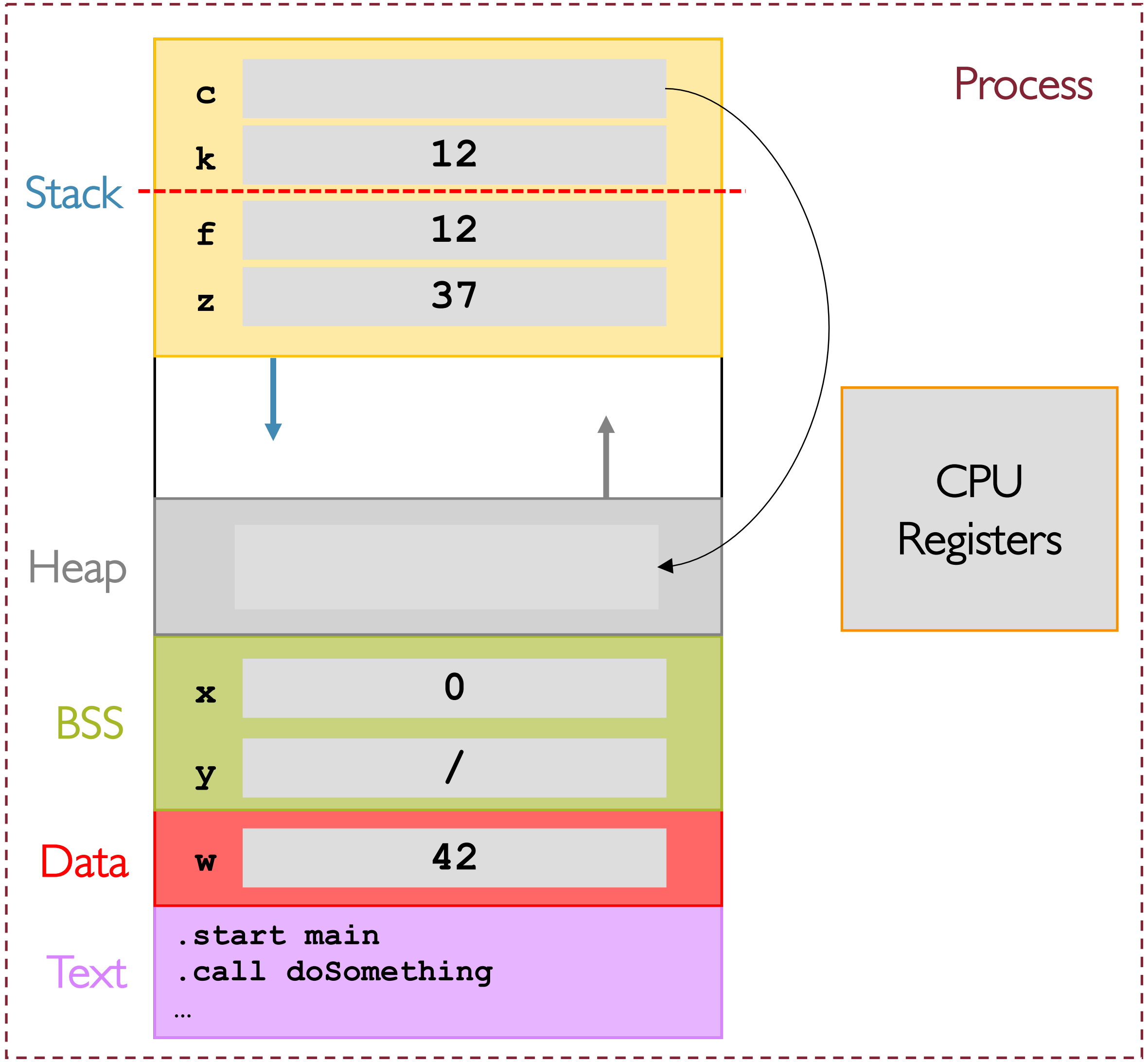
Program vs. Process: Example

Program

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

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

int main() {
    char* c = malloc(128);
    int k = 12;
    doSomething(k);
    …
}
```



Stack

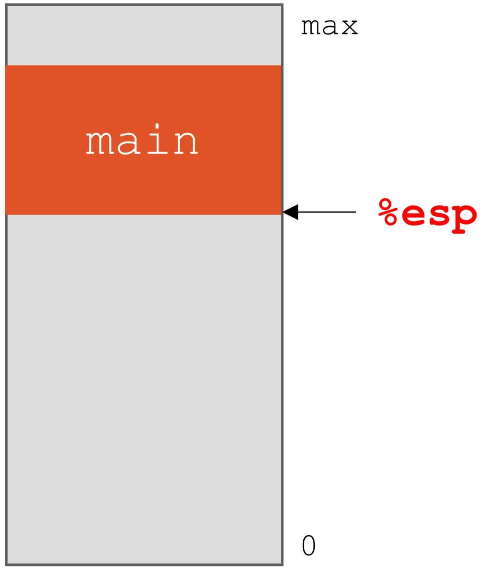
- 2 operations are defined on a stack:
  - **`push`** → used to place items onto the stack
  - **`pop`** → user to remove items from the stack
- A dedicated register (e.g., **`esp`**) whose content is the address in main memory of the top of the stack (**`%esp`** stands for its content)
- Stack memory 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

```
int main() {
    …
    foo(x, y);

void foo(a,b) {
        …
}
        …
}
```

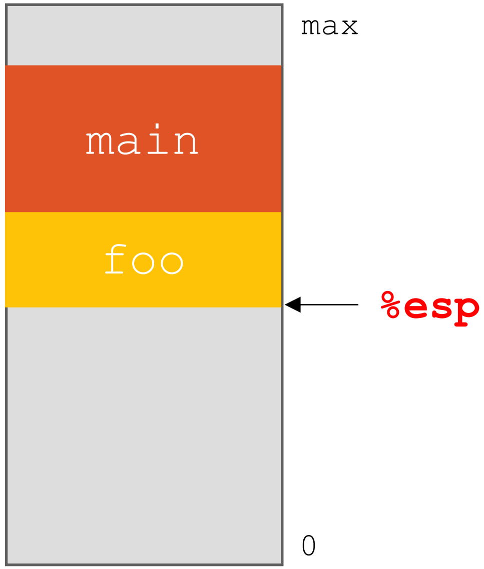


Function Call: Stack Frame

- 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

```
int main() {
        …
        foo(x, y);

void foo(a,b) {
        …
}
        …
}
```



Function Call: Stack Frame

- The stack frame for each function is divided into 3 parts:
  - function parameters + return address
  - back-pointer to the previous stack frame
  - local variables
- The first one is set by the caller
- The second and the third ones are set by the callee

Stack Frame: Function Parameters + Return

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

Stack Frame: Function Parameters + Return

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

The caller converts to

```
push c
push b
push a
call foo
```

Stack Frame: Function Parameters + Return

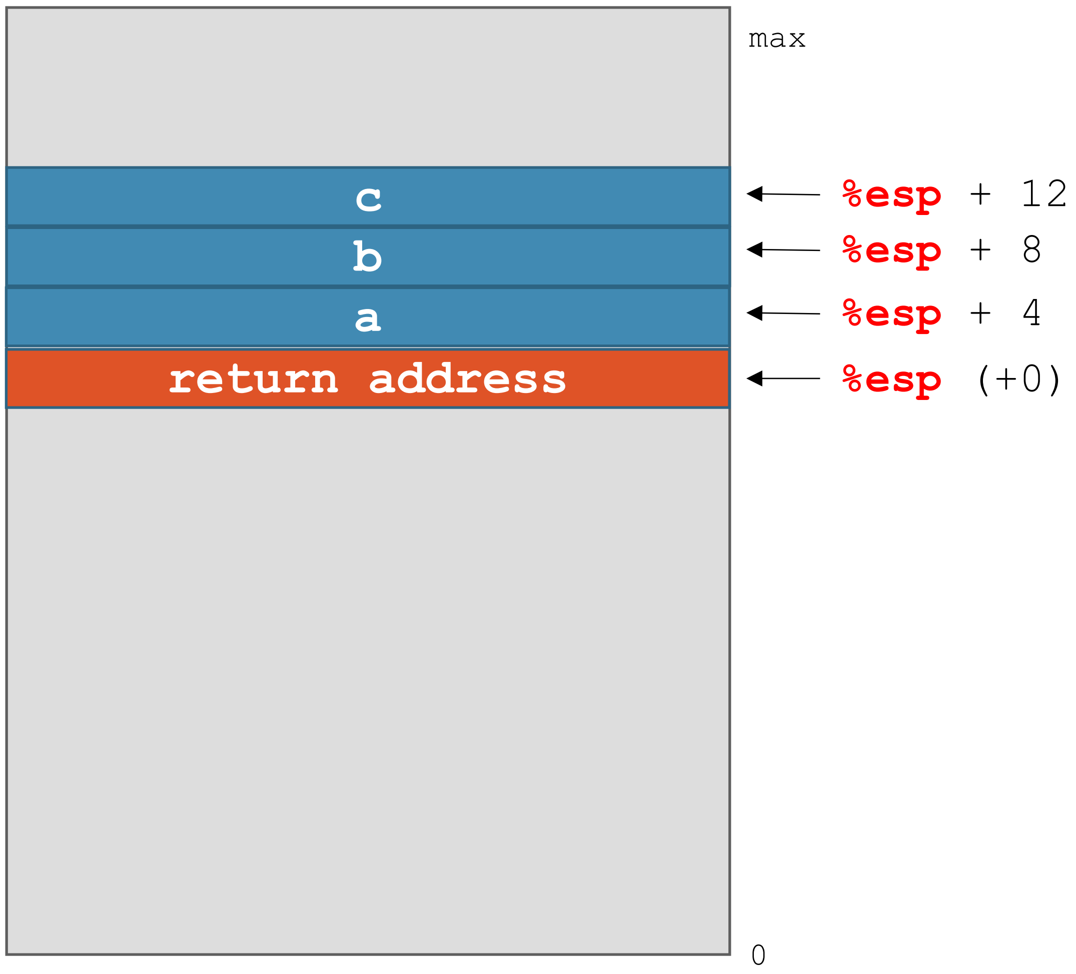
```
foo (a, b, c);
```

The caller converts to

```
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: Function Parameters + Return

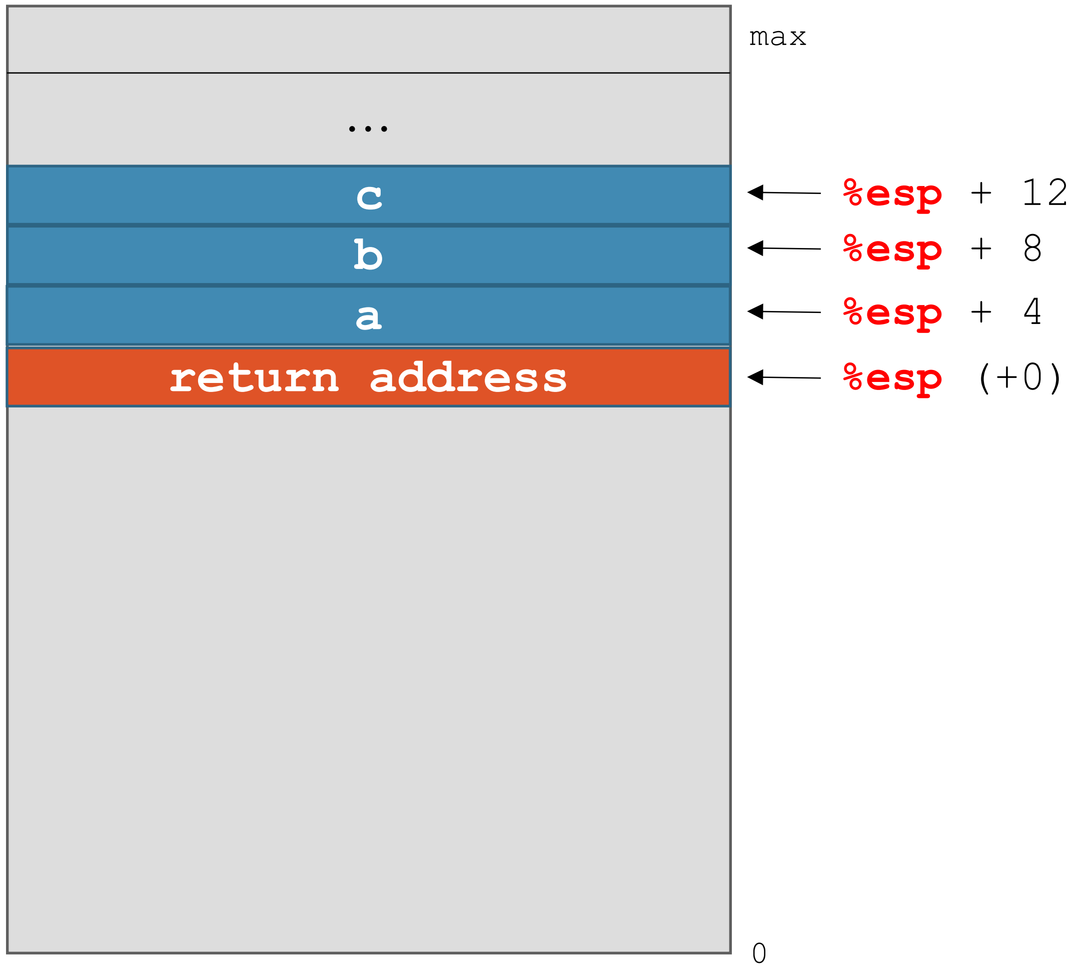


Stack Frame: Function Parameters + Return

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



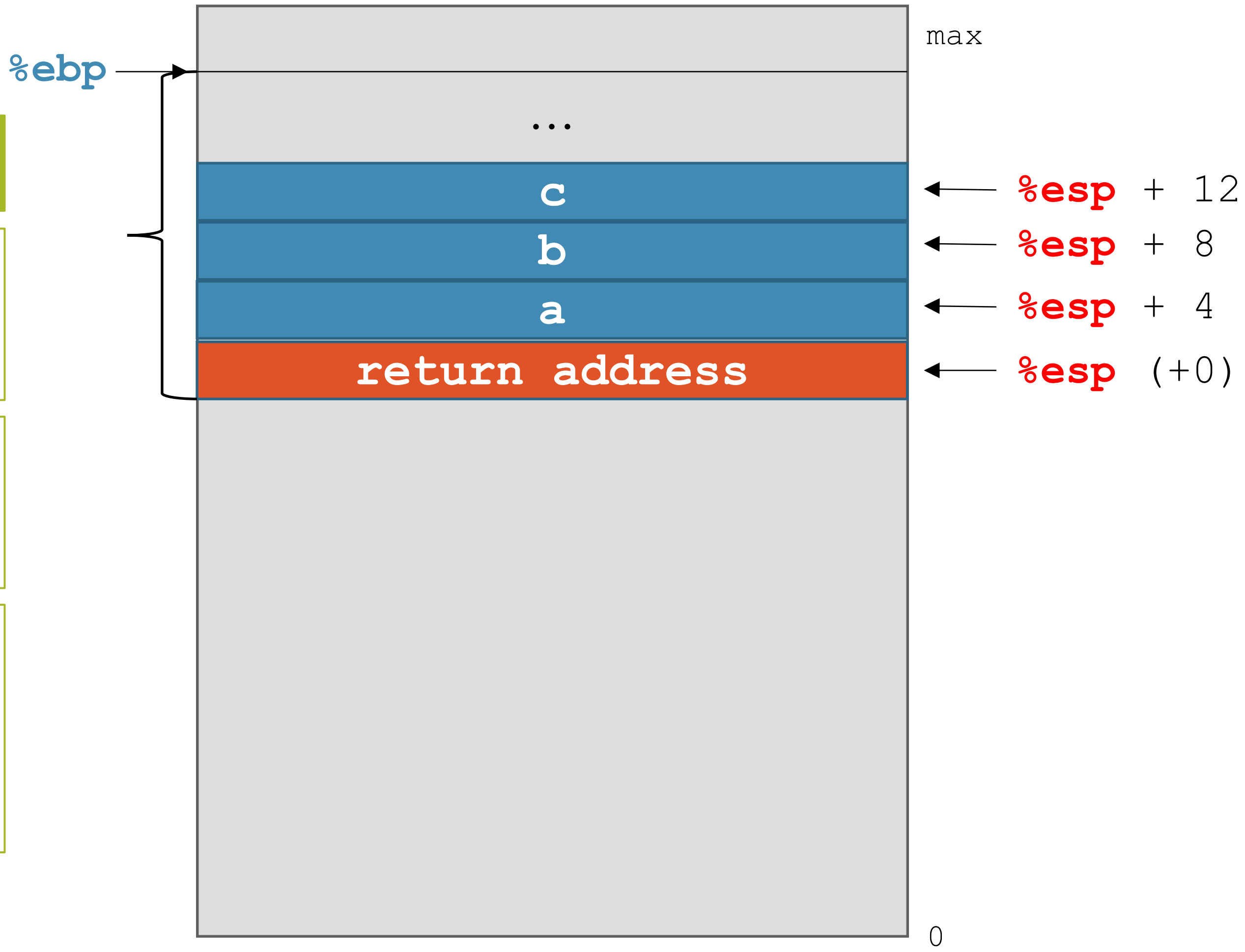
Stack Frame: Function Parameters + Return

Solution

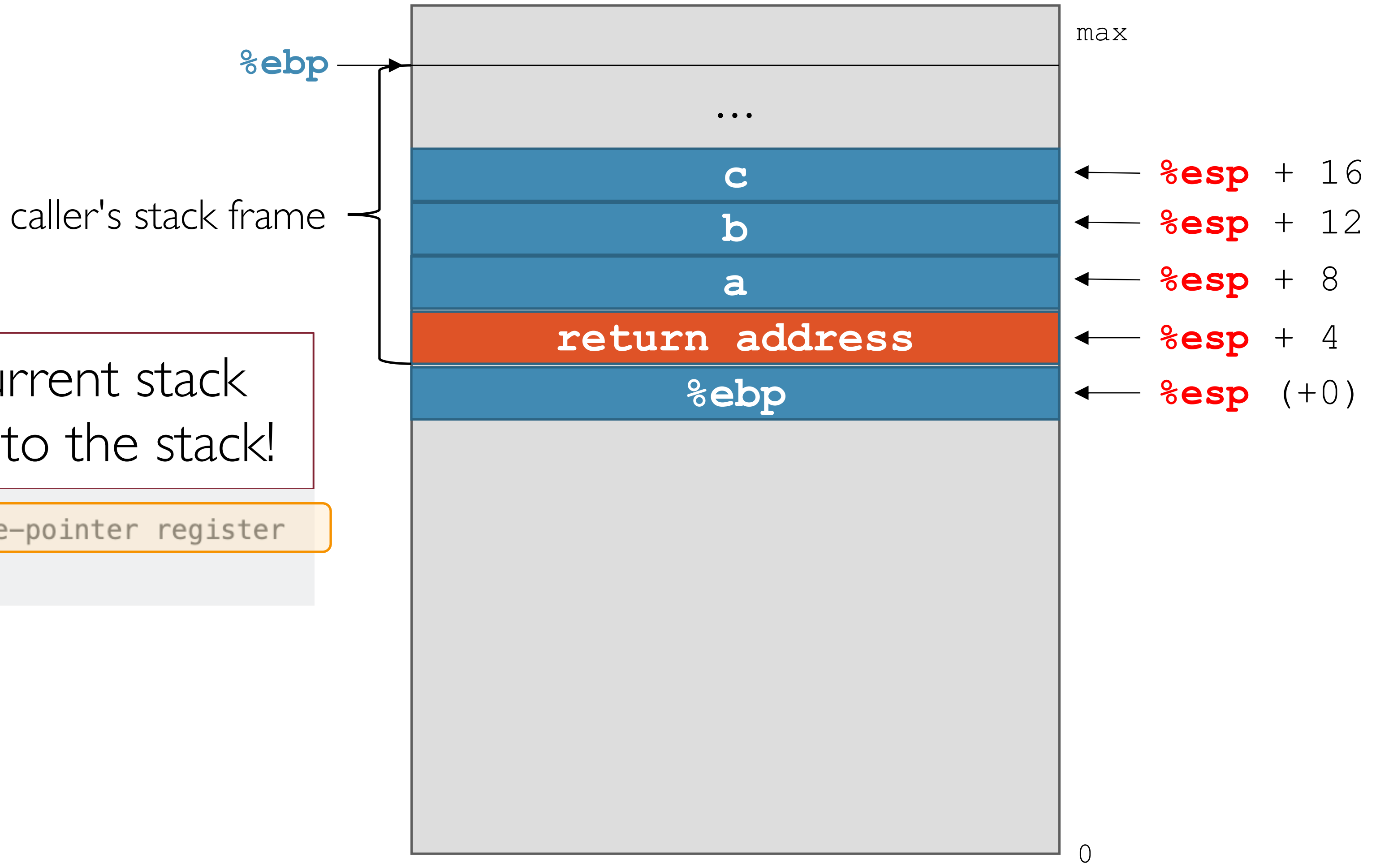
Instead of using a single pointer to the top of the stack (**esp**)

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



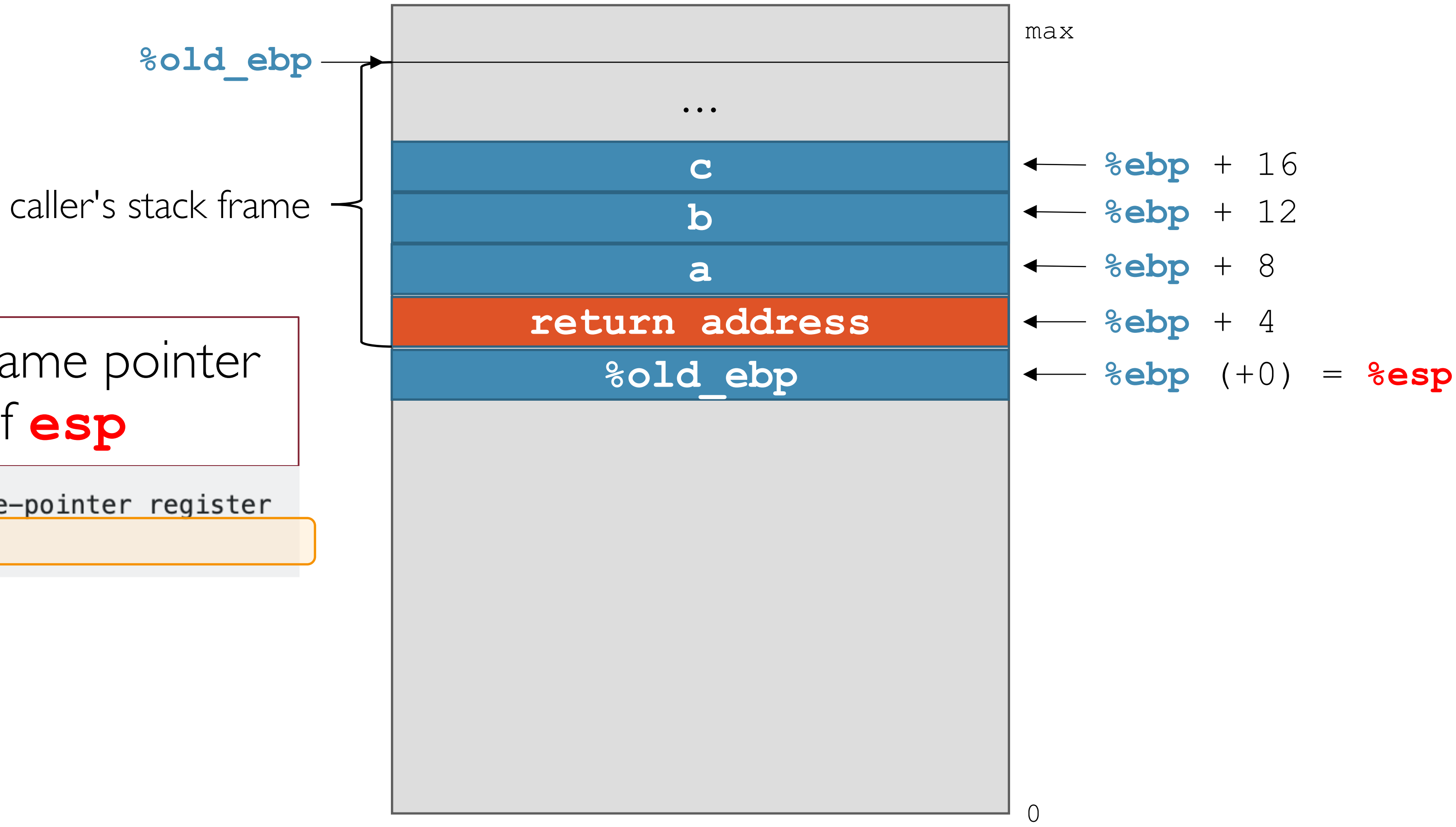
The callee first saves the current stack frame base pointer (%ebp) to the stack!

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

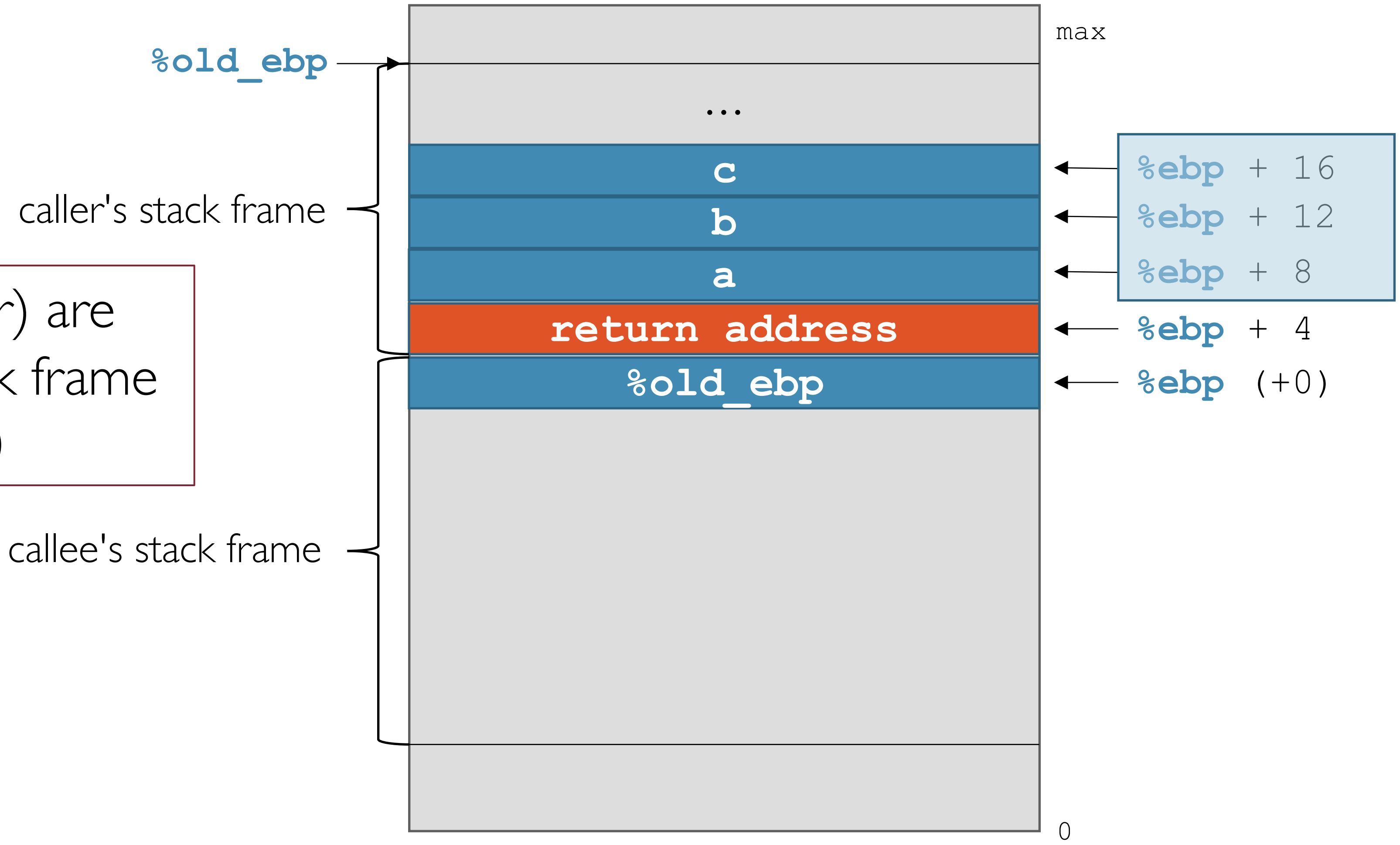
Stack Frame: Saving the Base Frame Pointer

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

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

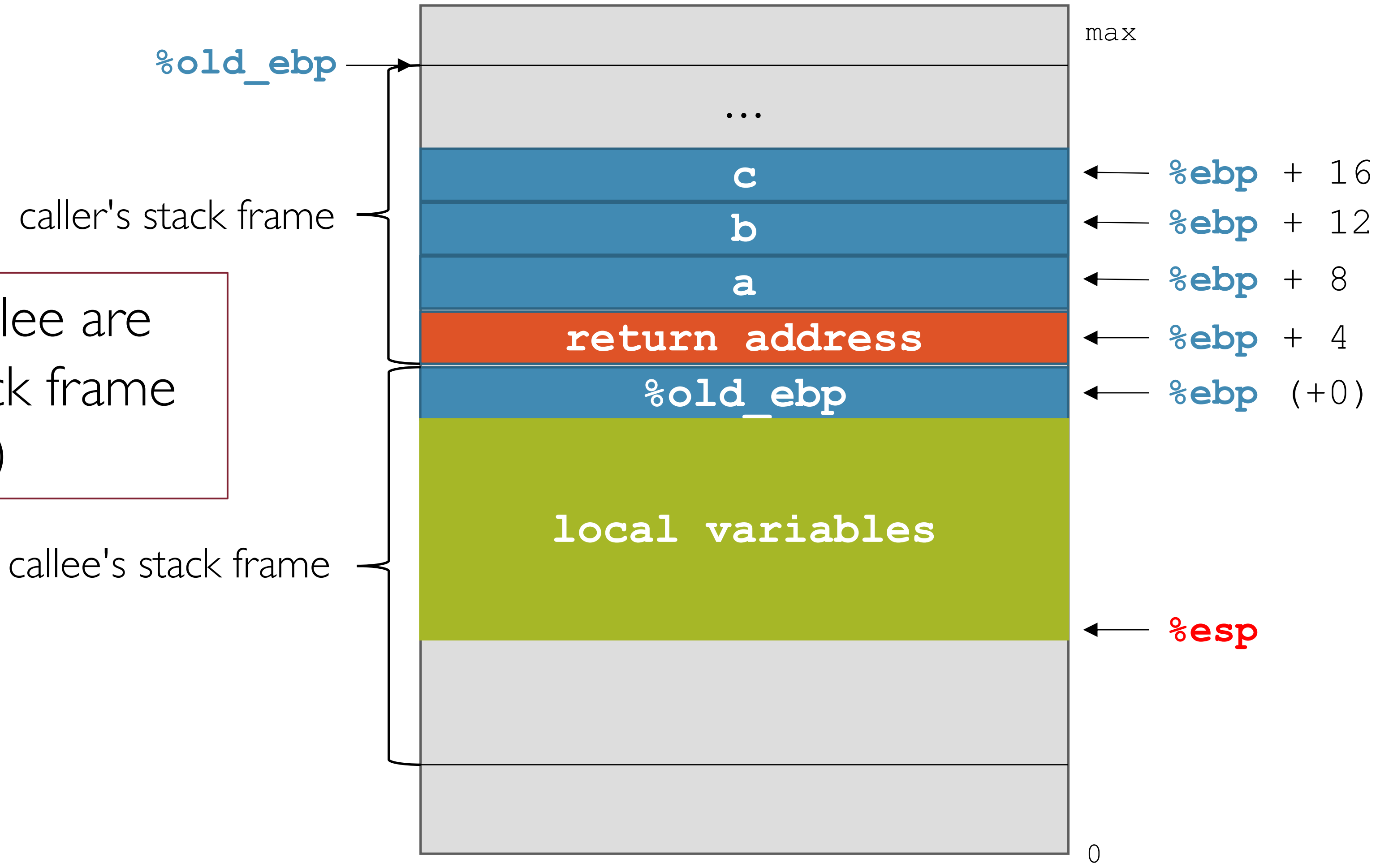


Parameters: Offset from the Base Frame Pointer



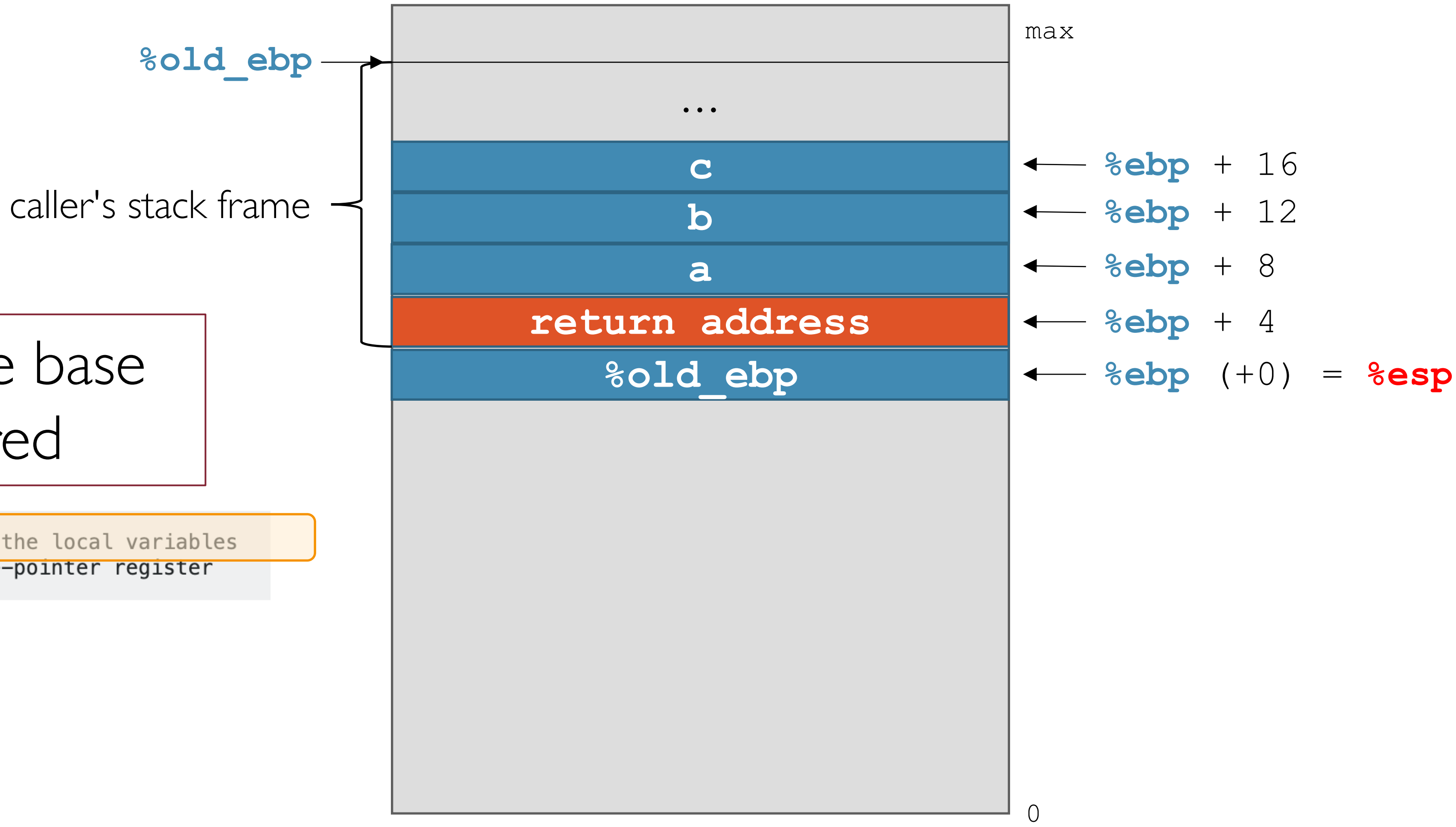
Parameters (of the caller) are accessed through the stack frame base pointer (**ebp**)

Local Variables: Offset from Stack Pointer



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

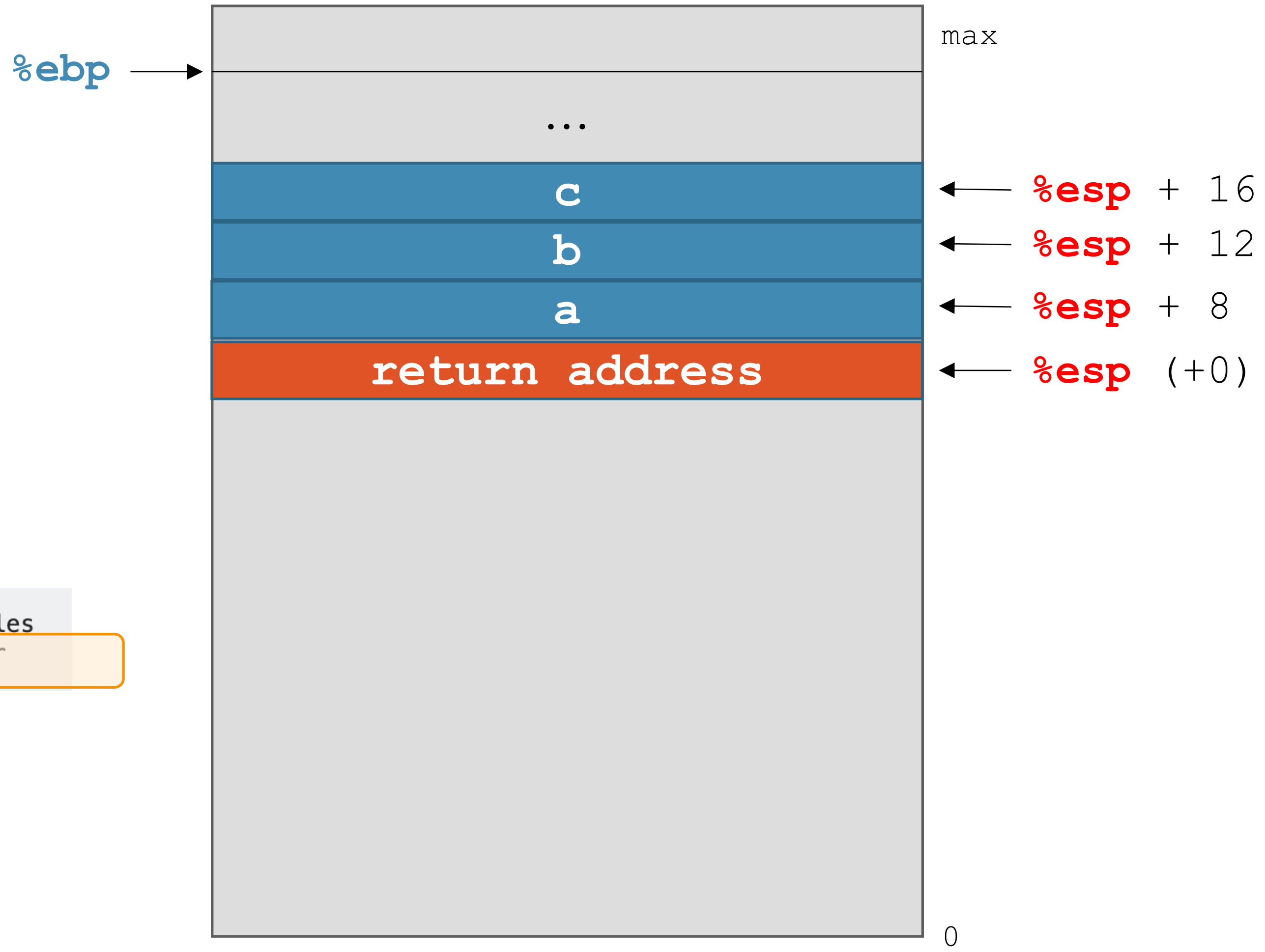
Stack Frame: Cleanup and Return



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
```

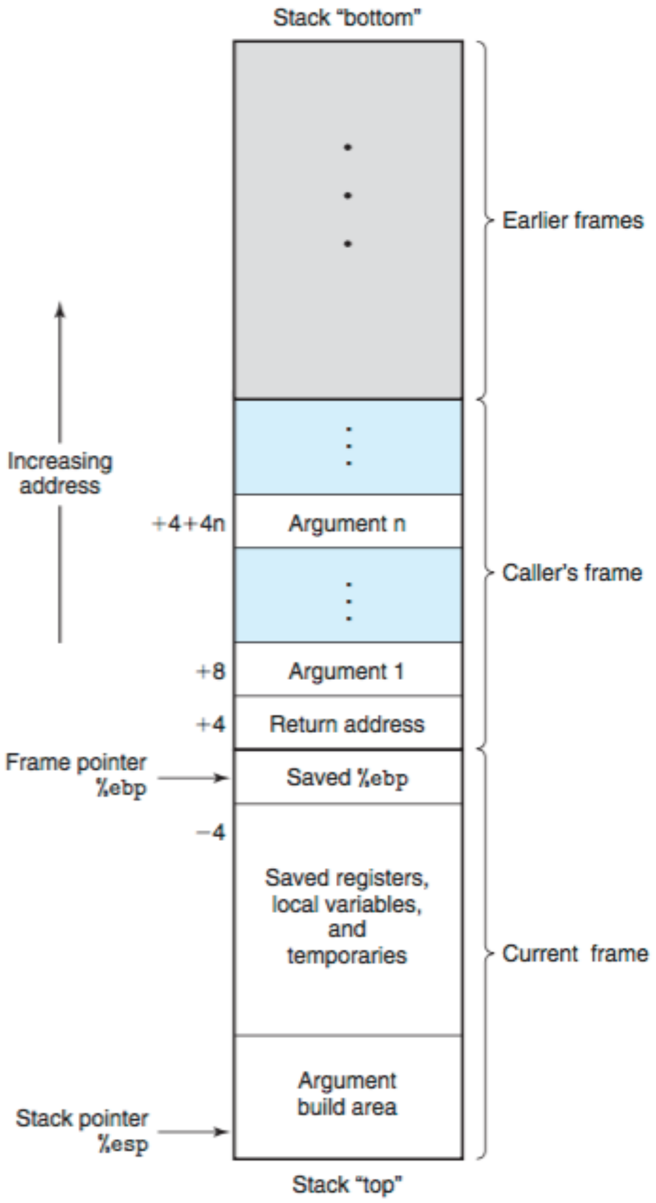
Stack Frame: Cleanup and Return



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



Process Execution State

- At each time a process can be in one of the following 5 states:

Process Execution State

- At each time a process can be in one of the following 5 states:
  - New → The OS has set up the process state

Process Execution State

- At each time a process can be in one of the following 5 states:
  - New → The OS has set up the process state
  - Ready → The process is ready to be executed yet waiting to be scheduled on to the CPU

Process Execution State

- At each time a process can be in one of the following 5 states:
  - New → The OS has set up the process state
  - Ready → The process is ready to be executed yet waiting to be scheduled on to the CPU
  - Running → The process is actually executing instructions on the CPU

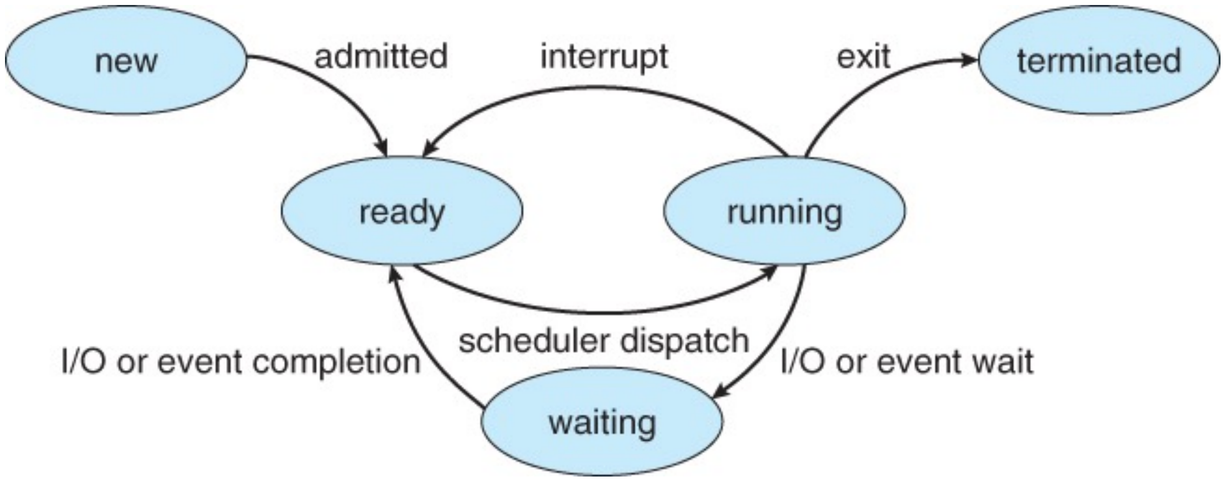
Process Execution State

- At each time a process can be in one of the following 5 states:
  - New → The OS has set up the process state
  - Ready → The process is ready to be executed yet waiting to be scheduled on to the CPU
  - Running → The process is actually executing instructions on the CPU
  - Waiting → The process is suspended waiting for a resource to be available or an event to complete/occur (e.g., keyboard input, disk access, timer, etc.)

Process Execution State

- At each time a process can be in one of the following 5 states:
  - New → The OS has set up the process state
  - Ready → The process is ready to be executed yet waiting to be scheduled on to the CPU
  - Running → The process is actually executing instructions on the CPU
  - Waiting → The process is suspended waiting for a resource to be available or an event to complete/occur (e.g., keyboard input, disk access, timer, etc.)
  - 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!");
    …
}
```

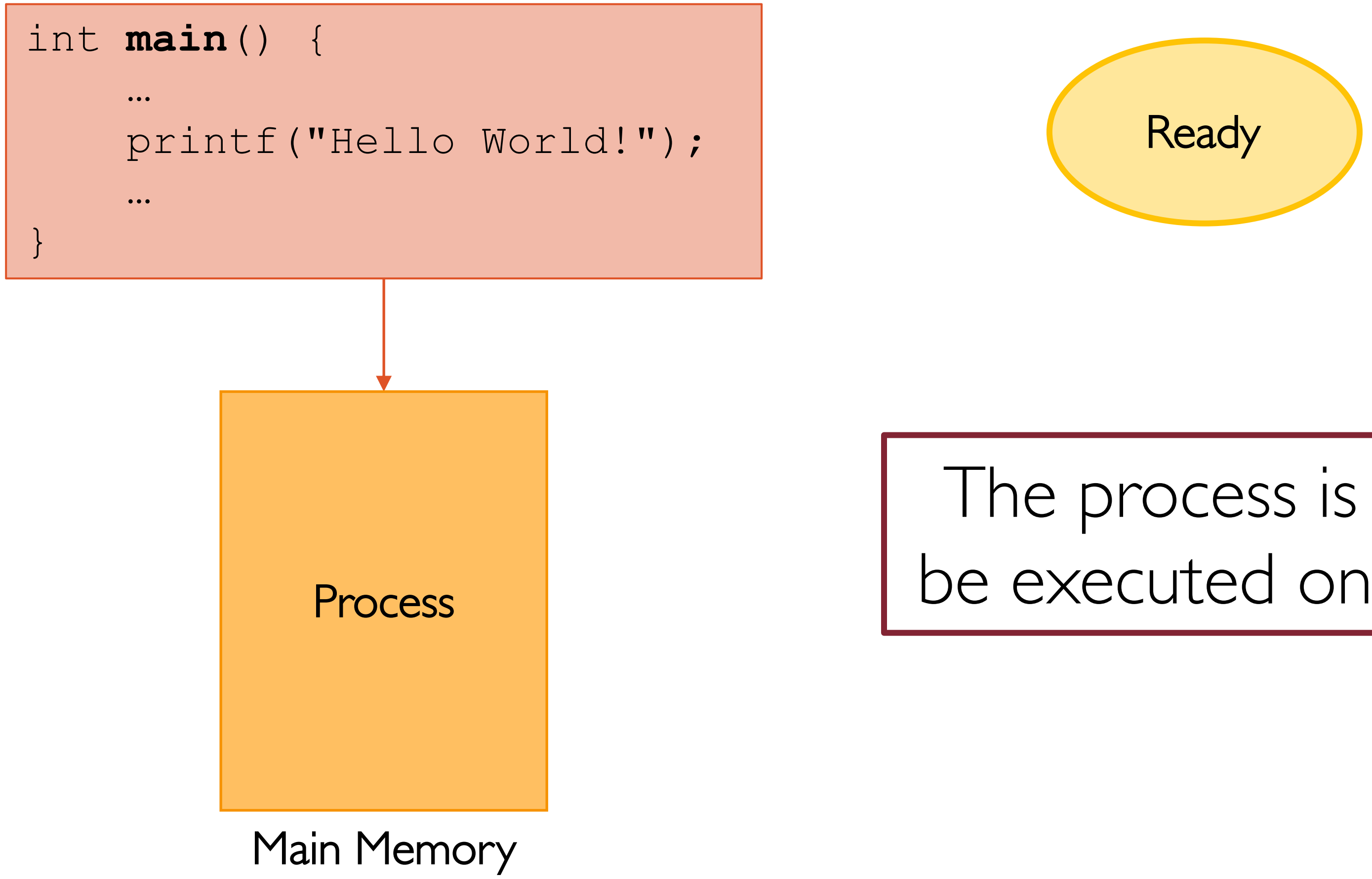
New

Process

Main Memory

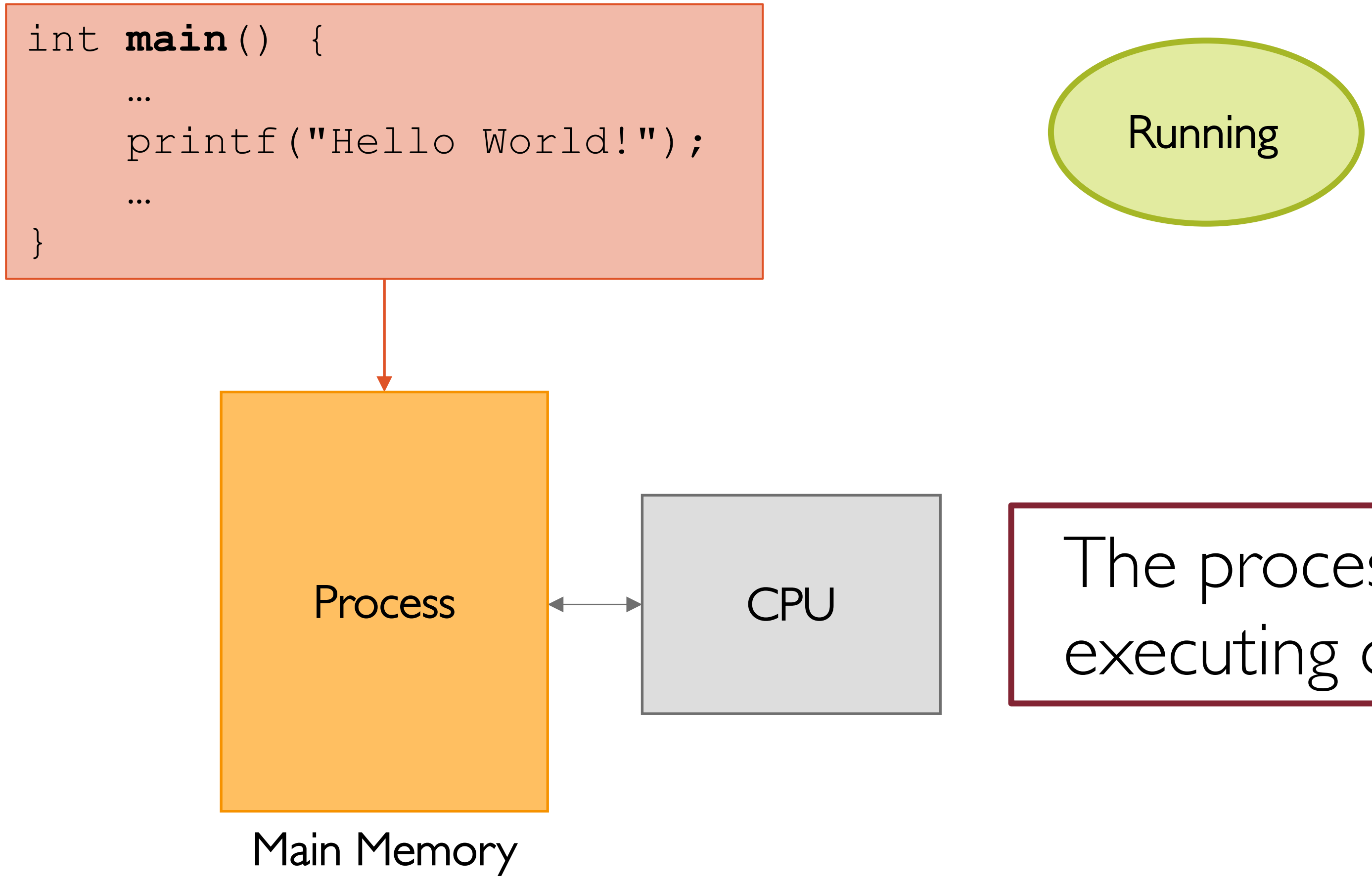
The process has been successfully set up

Process Execution State: Example



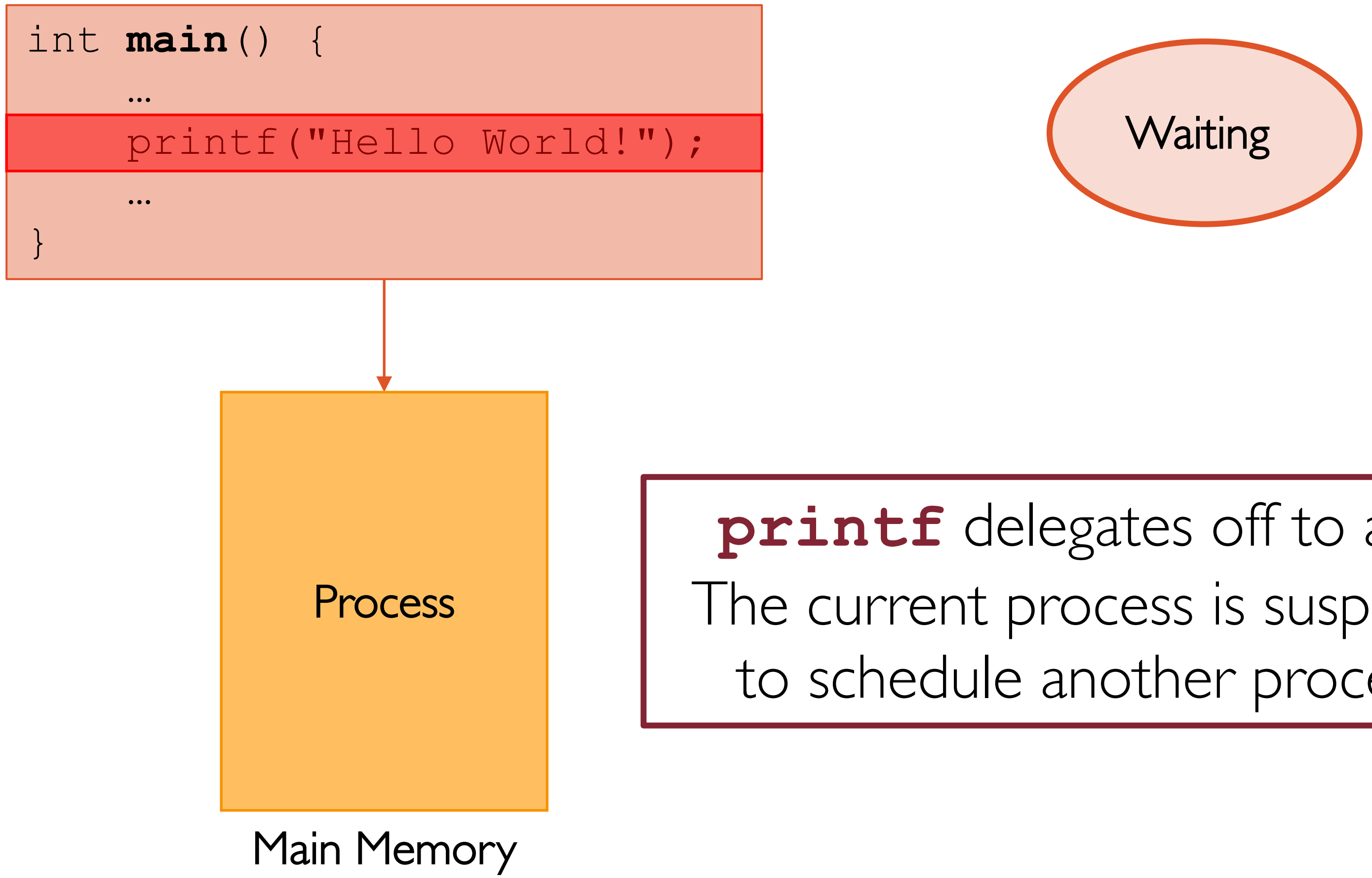
The process is ready to be executed on the CPU

Process Execution State: Example



The process is actually executing on the CPU

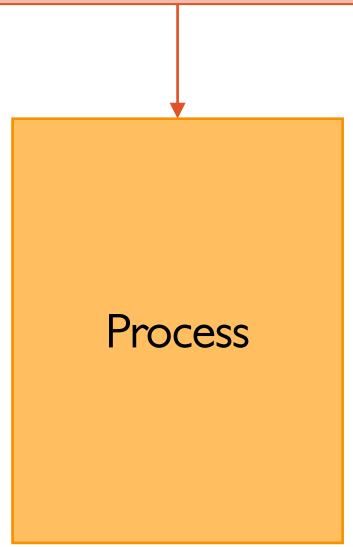
Process Execution State: Example



`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!");
    …
}
```

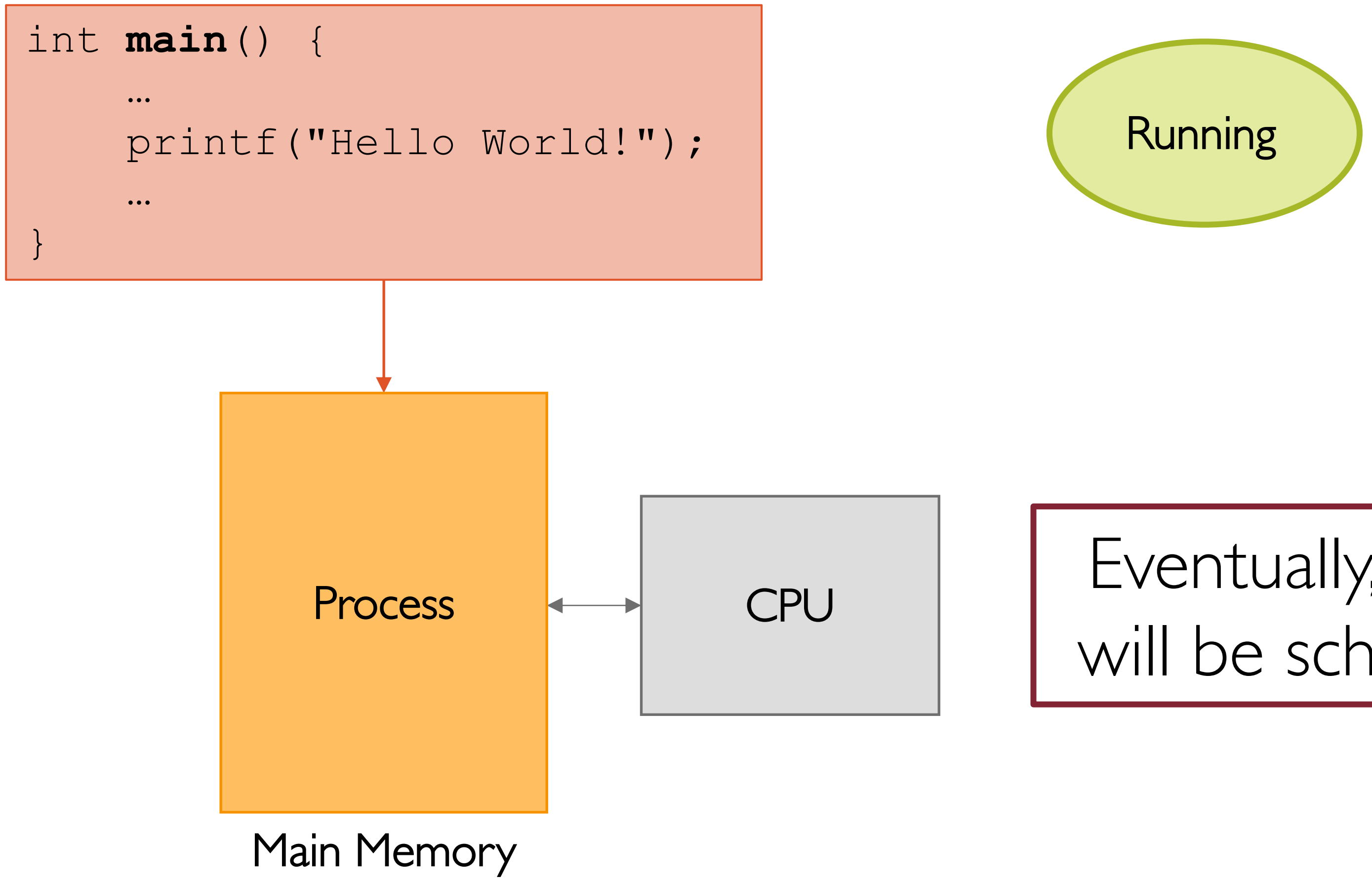


Main Memory

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)

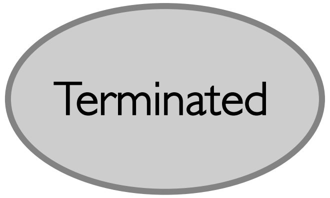
Process Execution State: Example



Eventually, the process will be scheduled again

Process Execution State: Example

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



Finally, the process terminates

Blocking vs. Non-Blocking Calls (Again)

- Most system calls (e.g., I/O ones) are blocking

Blocking vs. Non-Blocking Calls (Again)

- Most system calls (e.g., I/O ones) are blocking
  - the caller process (user space) can't do anything until the system call returns

Blocking vs. Non-Blocking Calls (Again)

- Most system calls (e.g., I/O ones) are blocking
  - the caller process (user space) can't do anything until the system call returns
  - the OS (kernel space):
    - sets the current process to a waiting state (i.e., waiting for the system call to return)
    - schedules a different ready process to avoid the CPU being idle

Blocking vs. Non-Blocking Calls (Again)

- Most system calls (e.g., I/O ones) are blocking
  - the caller process (user space) can't do anything until the system call returns
  - the OS (kernel space):
    - sets the current process to a waiting state (i.e., waiting for the system call to return)
    - schedules a different ready process to avoid the CPU being idle
  - once the system call returns the previously blocked process is ready to be scheduled for execution again

Blocking vs. Non-Blocking Calls (Again)

- Most system calls (e.g., I/O ones) are blocking
  - the caller process (user space) can't do anything until the system call returns
  - the OS (kernel space):
    - sets the current process to a waiting state (i.e., waiting for the system call to return)
    - schedules a different ready process to avoid the CPU being idle
  - once the system call returns the previously blocked process is ready to be scheduled for execution again
- 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

Process Control Block (PCB)

- At least, the PCB contains the following:

Process Control Block (PCB)

- At least, the PCB contains the following:
  - Process state → ready, waiting, running, etc.

Process Control Block (PCB)

- At least, the PCB contains the following:
  - Process state → ready, waiting, running, etc.
  - Process number (i.e., unique identifier)

Process Control Block (PCB)

- At least, the PCB contains the following:
  - Process state → ready, waiting, running, etc.
  - Process number (i.e., unique identifier)
  - Program Counter (PC) + Stack Pointer (SP) + general purpose registers

Process Control Block (PCB)

- At least, the PCB contains the following:
  - Process state → ready, waiting, running, etc.
  - Process number (i.e., unique identifier)
  - Program Counter (PC) + Stack Pointer (SP) + general purpose registers
  - CPU scheduling information → priority and pointers to state queues

Process Control Block (PCB)

- At least, the PCB contains the following:
  - Process state → ready, waiting, running, etc.
  - 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

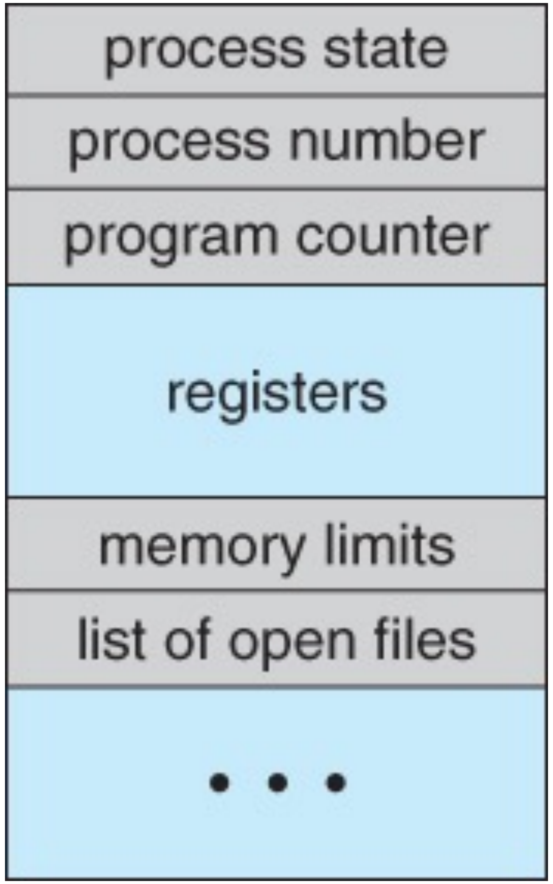
Process Control Block (PCB)

- At least, the PCB contains the following:
  - Process state → ready, waiting, running, etc.
  - 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

Process Control Block (PCB)

- At least, the PCB contains the following:
  - Process state → ready, waiting, running, etc.
  - 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)



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