Context Switch in TOS

Objectives

- Explain non-preemptive scheduling
- Explain step-by-step how a context switch works in TOS

Status Quo

- We can create new processes in TOS.
- New processes are added to the ready queue.
- The ready queue contains all runnable processes.
- BUT: so far, none of these new processes ever gets executed.
- What is missing: running those processes!
- What needs to be done: implement a function that switches the context, so that another process gets the chance to run.

Context switching in TOS

- First step: cooperative multi-tasking
  - Pre-emptive multi-tasking will come later
  - For now, a process voluntarily gives up the CPU by calling the function `resign()`
- Eventually control is passed back to the original caller because it is assumed that other processes also call `resign()`
- Therefore, from a process' perspective, `resign()` is not doing anything, except causing a delay before `resign()` returns

resign() example

- Assumption: there is only one process in the ready queue
- In this example, `resign()` simply does nothing, like a function call that immediately returns.
- `active_proc` is not changed

```
.
.
.
kprintf ("Location A\n");
resign();
kprintf ("Location B\n");
.
.
.
```

Output

```
Location A
Location B
```

resign() example

- Assumption: after the call to `create_process()`, there are two processes on the ready queue and `process_a` has a higher priority
- Call to `resign()` does a context switch to `process_a`, because it has the higher priority
- `active_proc` changes after resign

```
void process_a (PROCESS self, PARAM param)
{
  kprintf (“Location C\n”);
  assert (self == active_proc);
  while (1);
}

void kernel_main()
{
  init_process();
  init_dispatcher();
  create_process (process_a, 5, 0,
                  “Process A”);
  kprintf (“Location A\n”);
  resign();
  kprintf (“Location B\n”);
  while (1);
}
```

Output

```
Location A
Location C
```

resign() example

- Assumption: after the call to `create_process()`, there are two processes on the ready queue and `process_a` has a higher priority
- First call to `resign()` switches context to `process_a`
- `process_a` removes itself from the ready queue and then calls `resign()` again. This will do a context switch back to the first process.
- If `remove_ready_queue(self)` were not called, the program would print "Location D" instead of "Location B"

```
void process_a (PROCESS self, PARAM param)
{
  kprintf ("Location C\n");
  remove_ready_queue (self);
  resign();
  kprintf ("Location D\n");
  while (1);
}

void kernel_main()
{
  init_process();
  init_dispatcher();
  create_process (process_a, 5, 0
                  "Process A");
  kprintf ("Location A\n");
  resign();
  kprintf ("Location B\n");
  while (1);
}
```

Output

```
Location A
Location C
Location B
```

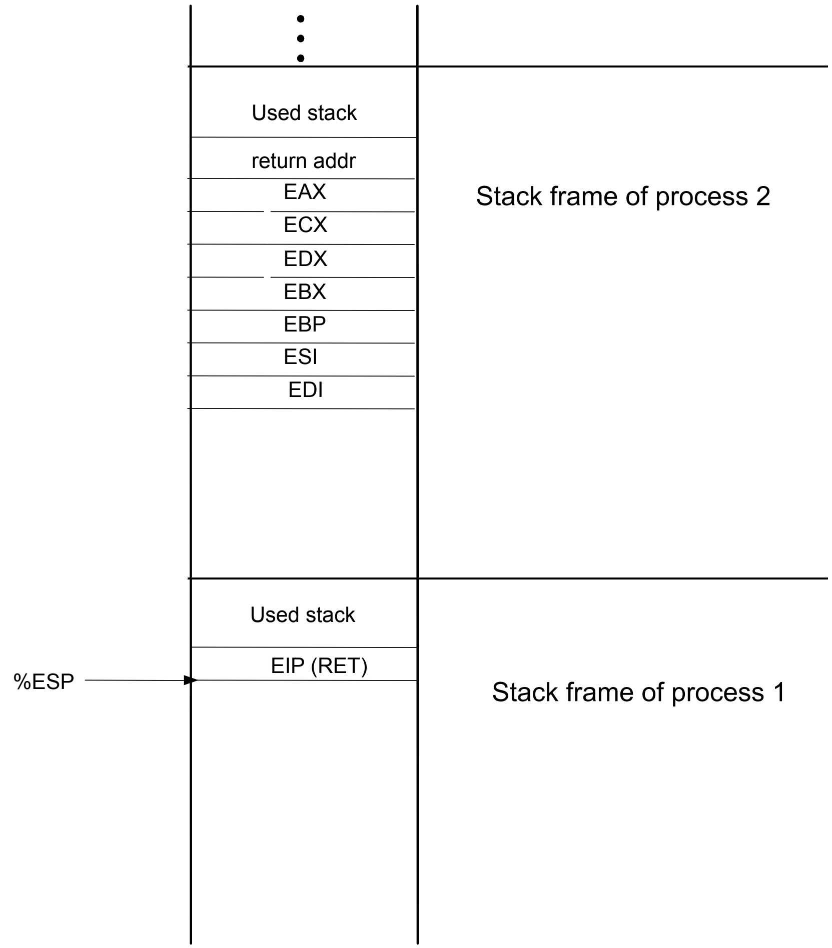
Understanding resign()

- `resign()` implements a context switch, i.e. it gives another process the chance to run.
- Conceptually, `resign()` is doing the following:
  - Save the context of the current process pointed to by `active_proc`
  - `active_proc = dispatcher()`
  - Restore the context
  - RET

But how does it work exactly?

Implementing resign()

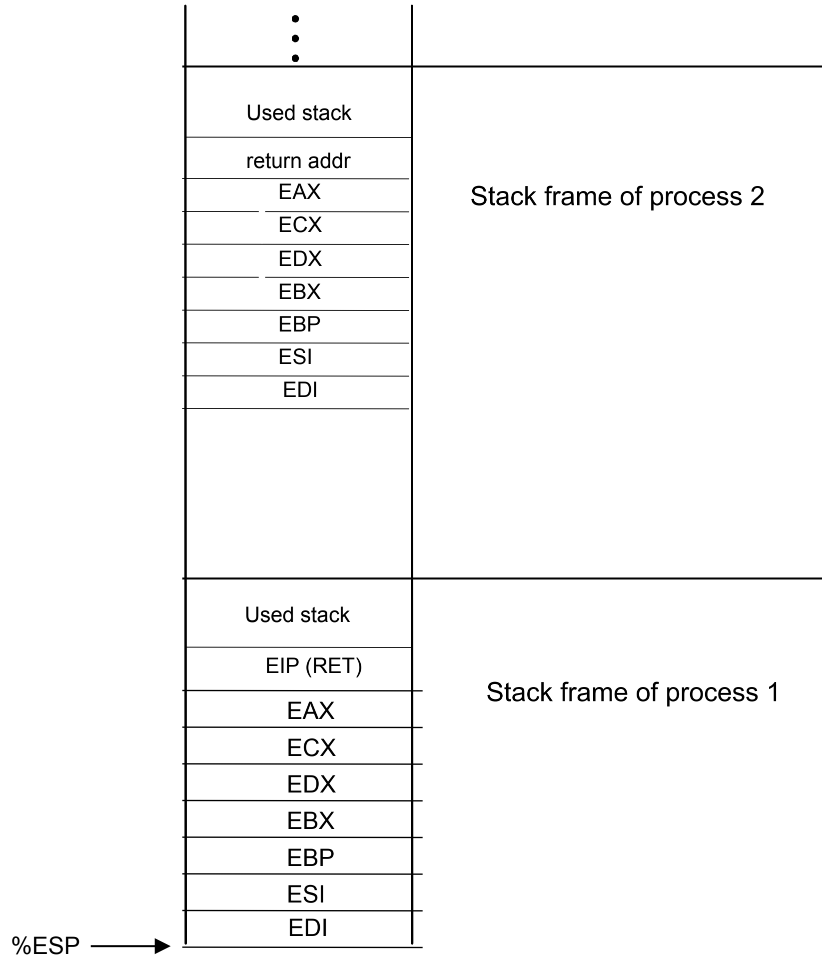
- Process 2 previously called `resign()`
- Process 1 calls `resign()`, the stacks are as shown
- The goal is to "suspend" process 1 within `resign()` and "resume" where process 2 left off in `resign()`
- First step: save the registers for process 1



Implementing resign()

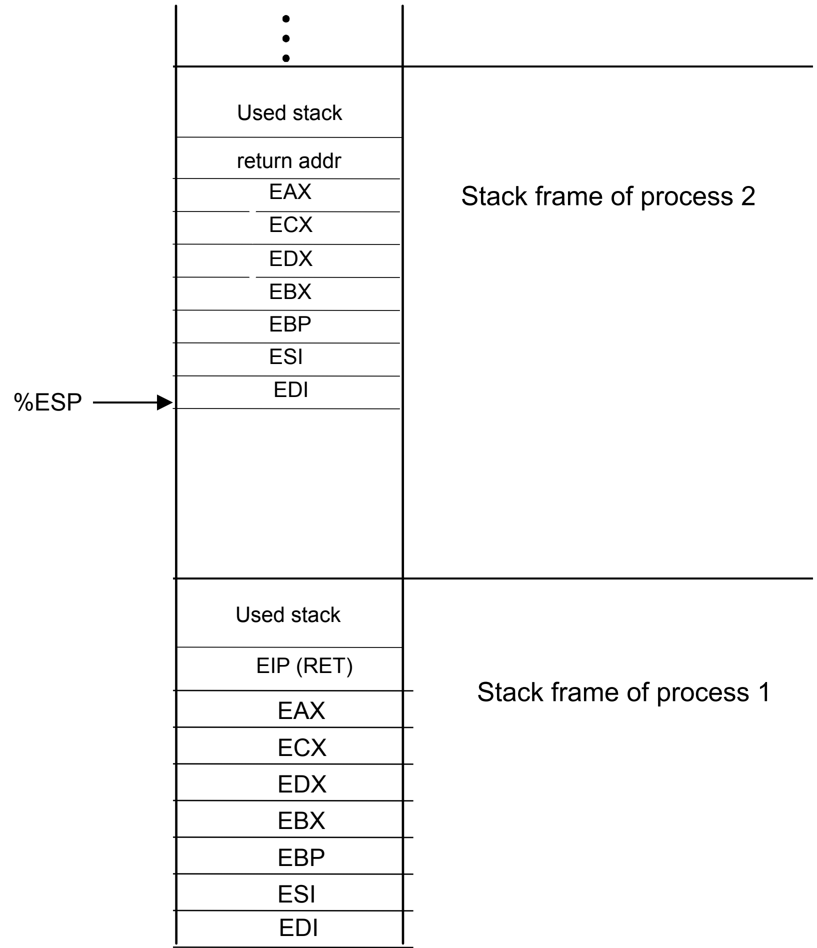
- State of process 1 is saved -- now we actually make the switch:

```
active_proc->esp = %ESP;
active_proc = dispatcher();
%ESP = active_proc->esp;
```



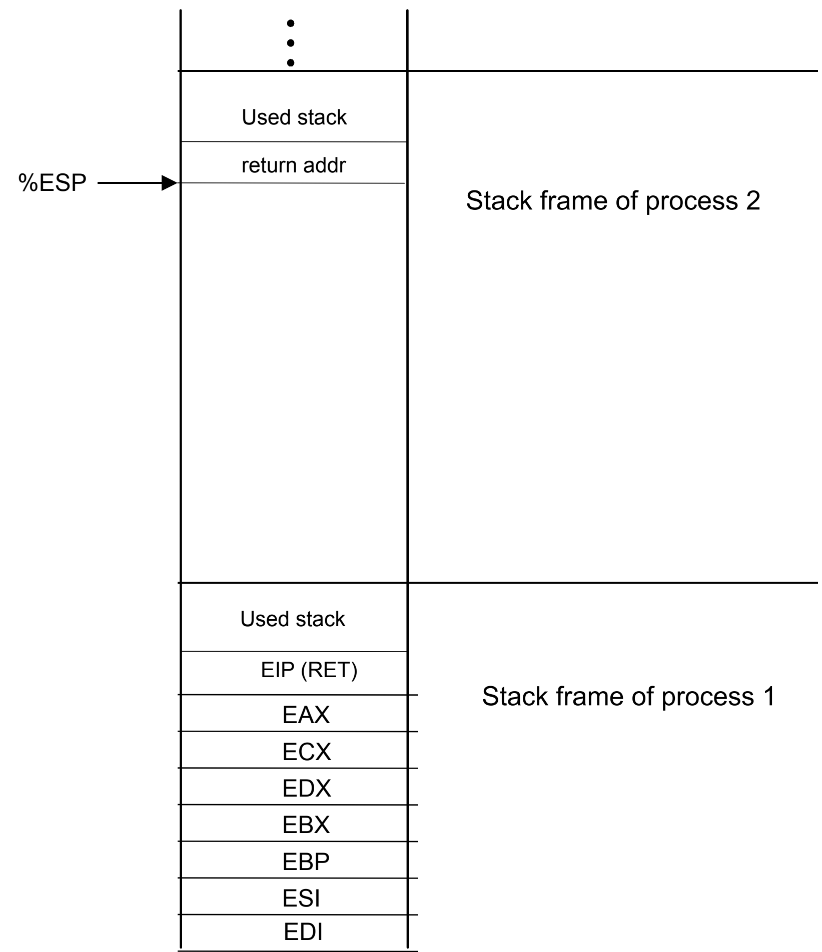
Implementing resign()

- Finally, we restore the state of process 2 by popping the saved register values from the stack
- Note, the registers were stored on the stack when process 2 entered `resign()`



Implementing resign()

- We' re done -- when we finish with the `ret` instruction, we jump back to where process 2 called `resign()`



Understanding resign()

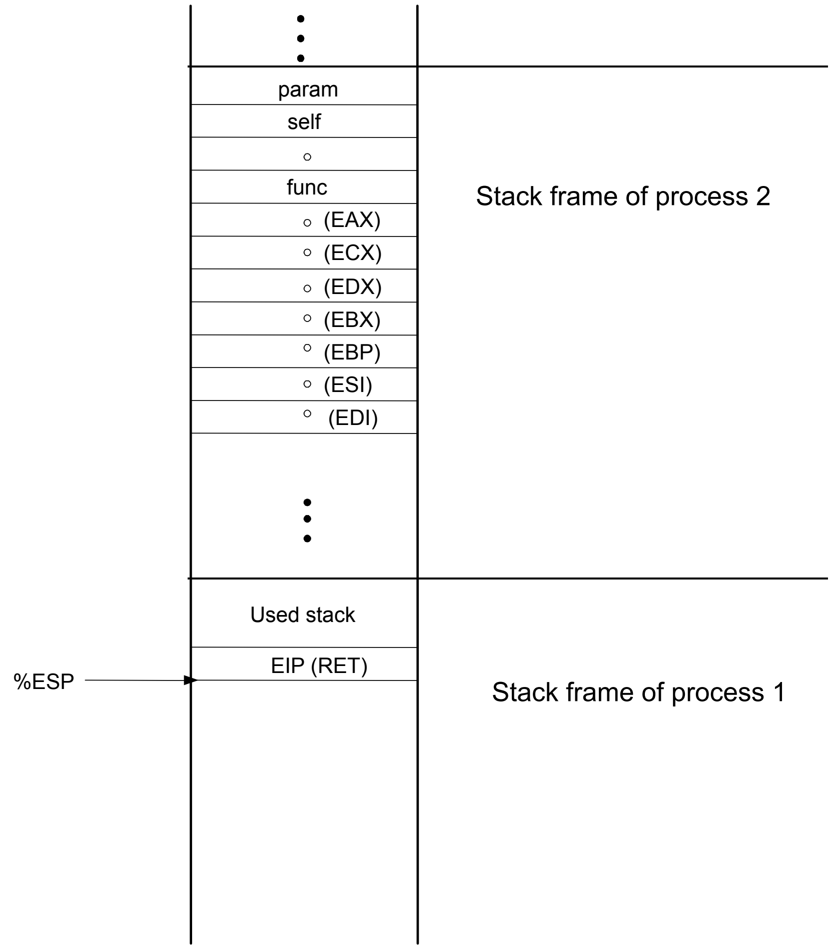
- It is especially important to note that the context pushed is not necessarily the same as the context popped
  - recall that `active_proc` and (hence) %ESP register changed in between push and pop context.
  - then we aren't looking at the same stack now!
  - but how can we be sure that the ESP register is pointing to *some* stack?

Understanding resign()

- We made the assumption that wherever `active_proc->esp` points to is where context of the current process is saved
- To satisfy this assumption, we always need to save the context of a process so that it can be popped at some time in the future
- We have already done this!
  - for a new process we setup the stack (see `create_process()`)
  - for process calling `resign()` we setup the stack (identical to the way we did it for `create_process()`) before call to `dispatch()`
  - now you should be able to connect the dots

Implementing resign()

- By creating the initial stack frame carefully in `create_process()`, we ensure that `resign()` can switch to a brand new process as well as one that previously called `resign()`
- Process 1 is active
- Process 2 was created with `create_process()` but has never run.



Understanding resign()

- And don't forget – because the context popped was different than the context pushed in the beginning of `resign()`, the return address also is different
- So `resign()` pushed one return address and popped another return address by clever ESP register manipulation
- What does this mean?
  `resign()` returns to some other address, not to the caller process
- tada! we have a context switch!

Notes on inline assembly

- As explained earlier, `resign()` does amongst others the following:

```
active_proc->esp = %ESP;
active_proc = dispatcher();
%ESP = active_proc->esp;
```

- The first and the third instruction require inline assembly, because the `%ESP` register is accessed.
- There is no C-instruction with which this could be achieved, that is why inline assembly is necessary.

Accessing the Stack Pointer

- This can be accomplished with the following instructions:

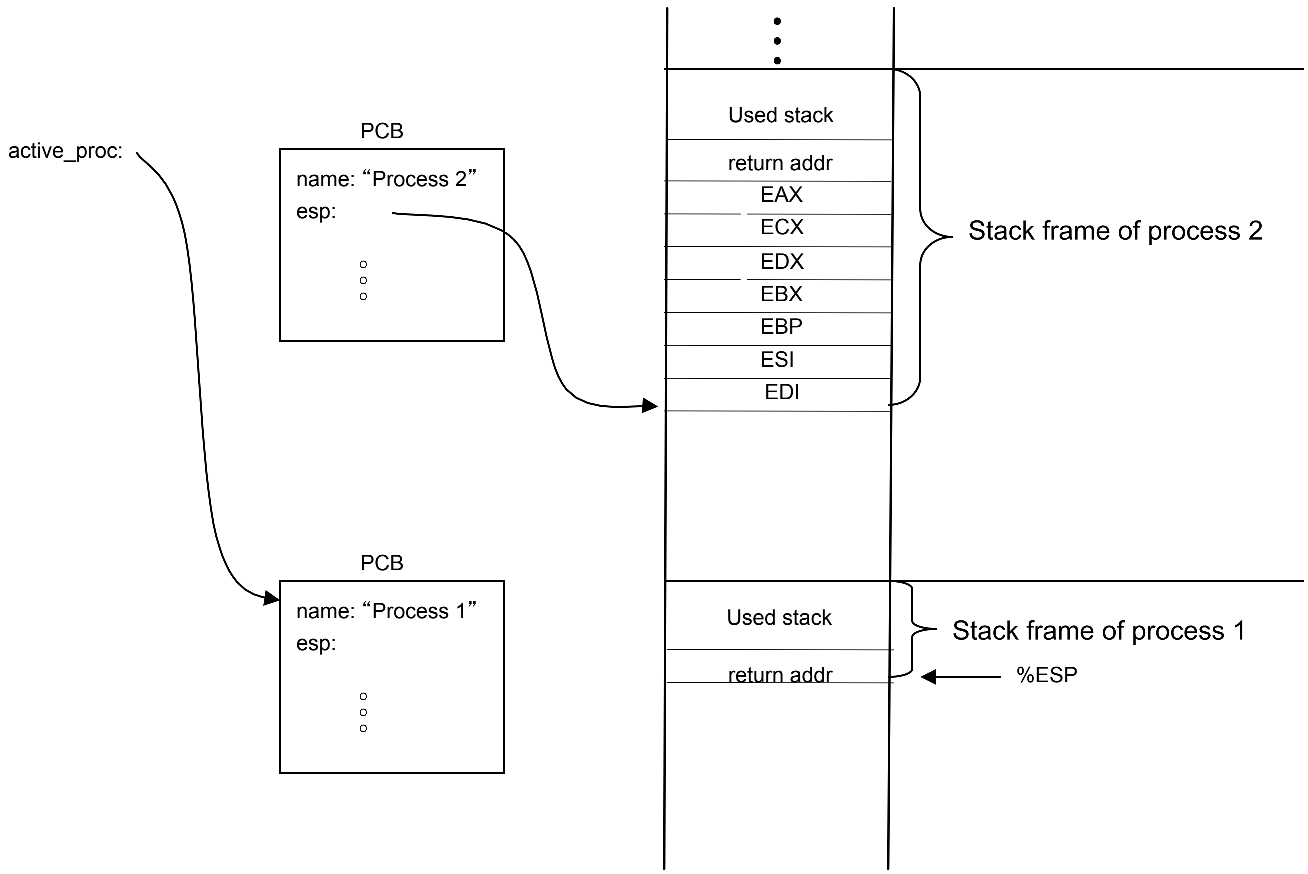
```
/* Save the stack pointer to the PCB */
asm ("movl %%esp,%0" : "=r" (active_proc->esp) : );
/* Select a new process to run */
active_proc = dispatcher();
/* Load the stack pointer from the PCB */
asm ("movl %0,%%esp" : : "r" (active_proc->esp));
```

- Notes:
  - The register name `%ESP` has to be prefixed with another `%`
  - The specifier "`=r`" means "an output parameter that should be placed in an x86 register"
  - The specifier "`r`" means "an input parameter that should be placed in an x86 register"

Example of resign()

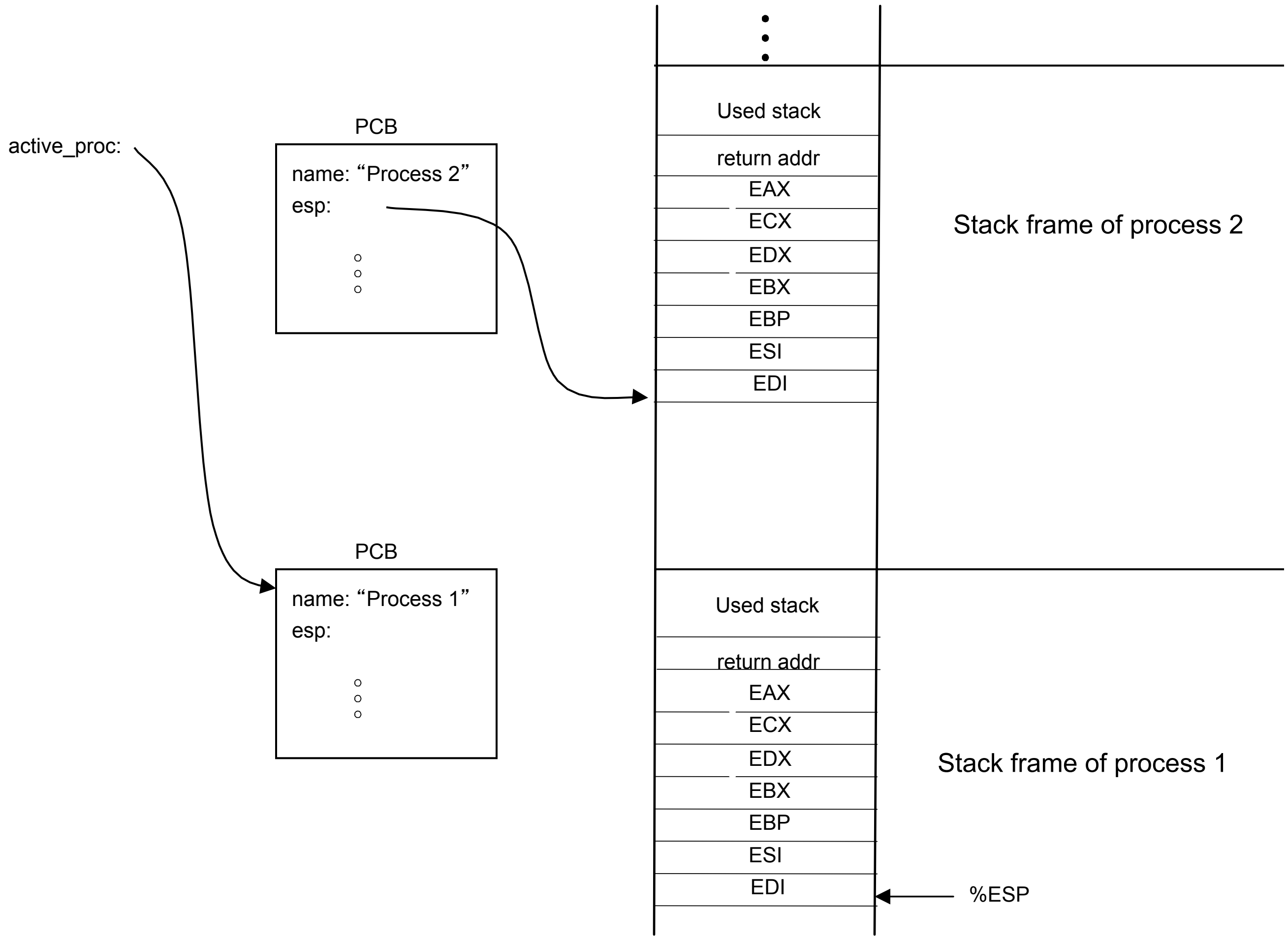
- Process 1 is active, it calls `resign()`
- Process 2 previously called `resign()`, it is ready to run but not currently running.
- Inside `resign()`, assume that `dispatcher()` returns process 2 so we must perform a switch from process 1 to process 2.

Example of resign()



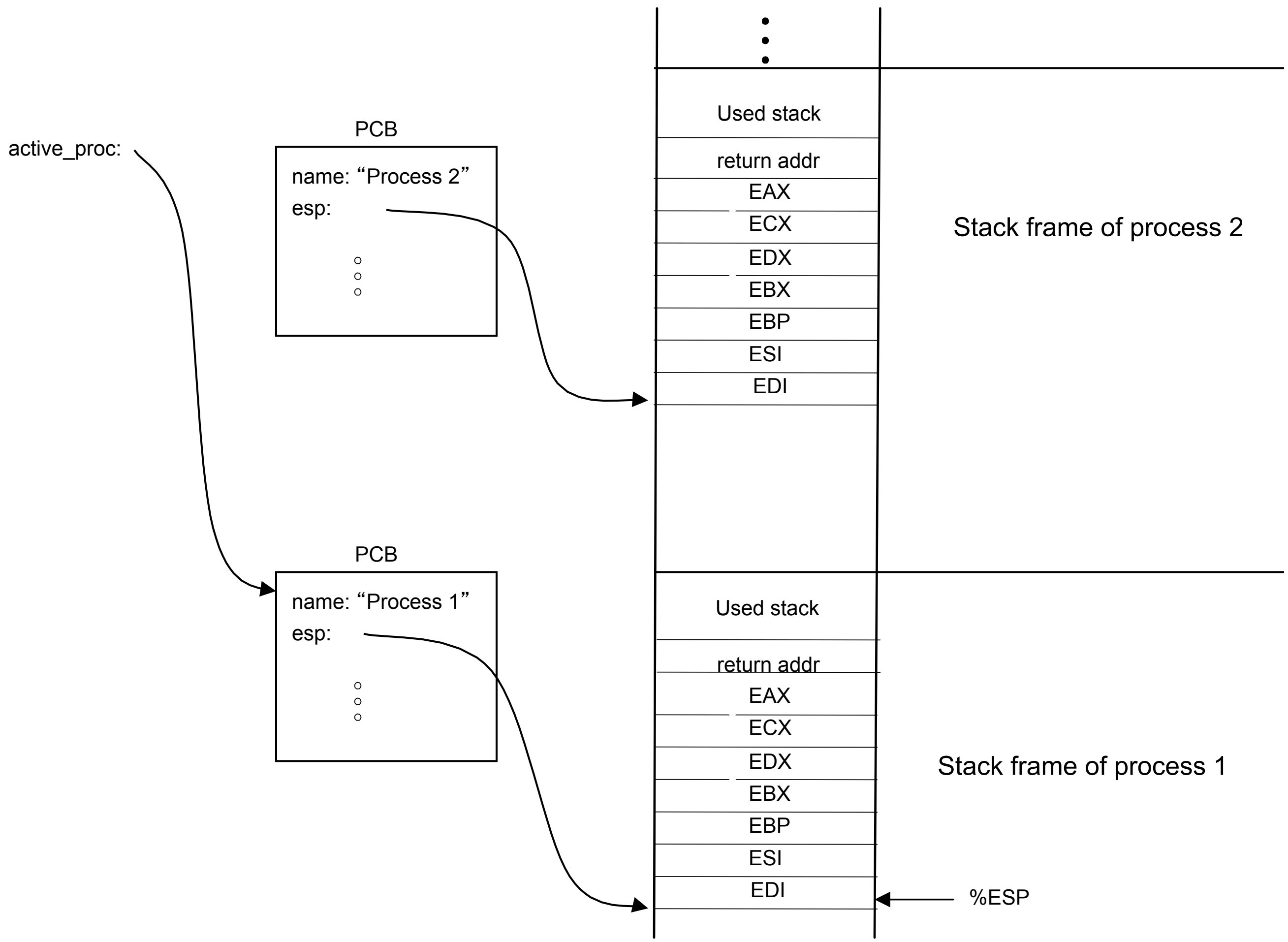
- First step: save the registers for process 1

Example of resign()



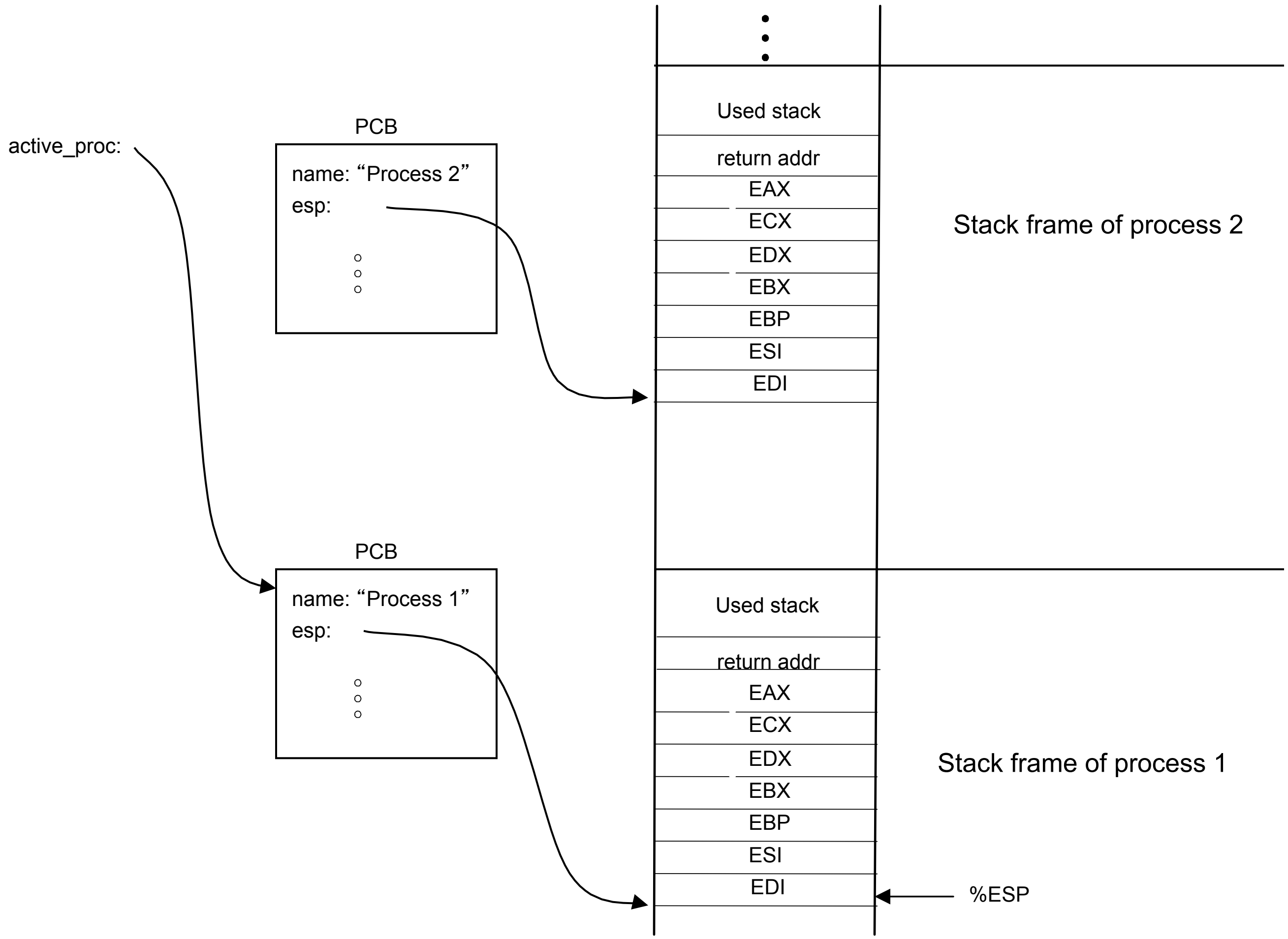
- First step: save the registers for process 1

Example of resign()



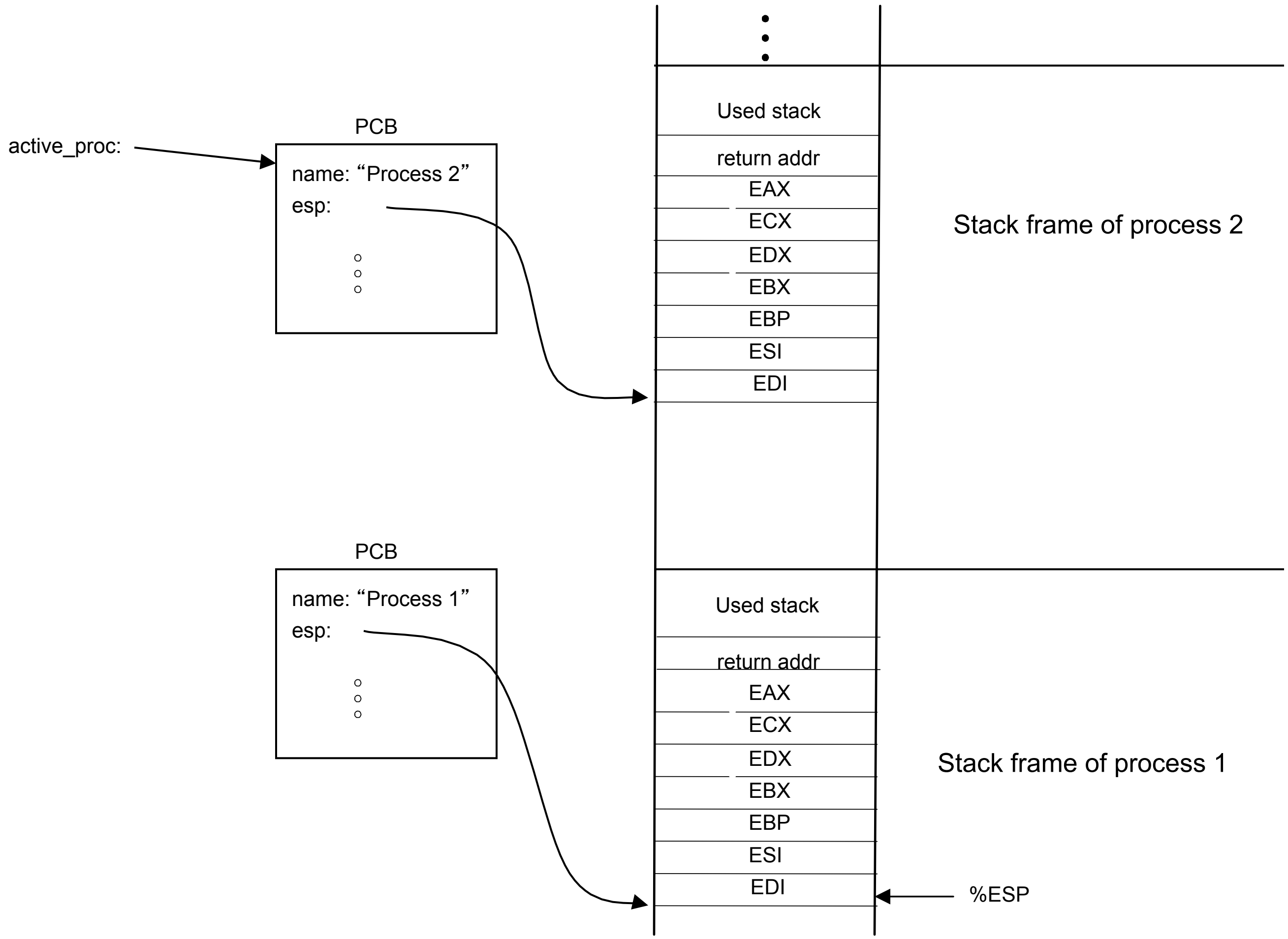
- Next step: save the stack pointer for process 1

Example of resign()



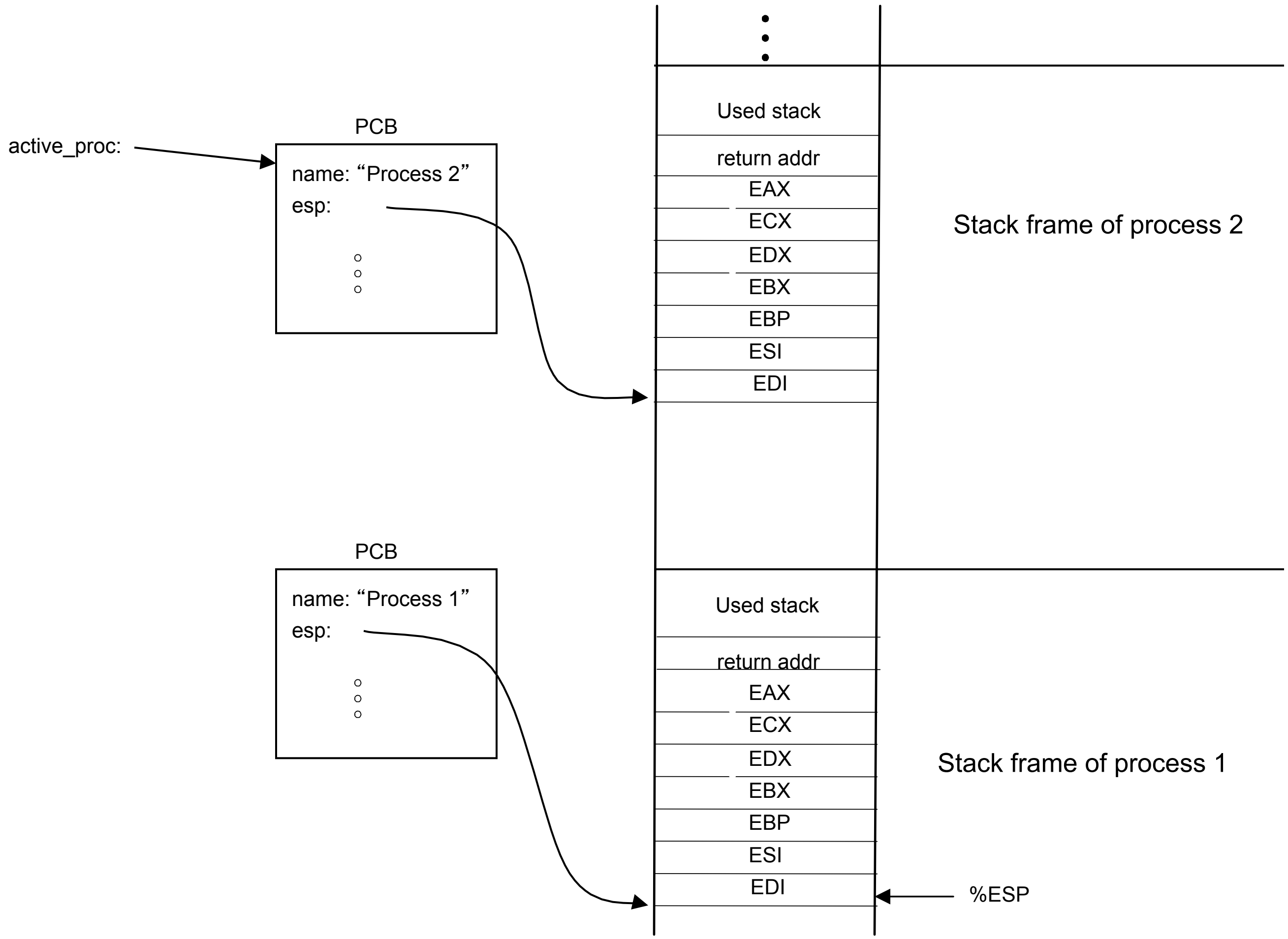
- Next step: choose new process- `dispatcher()`

Example of resign()



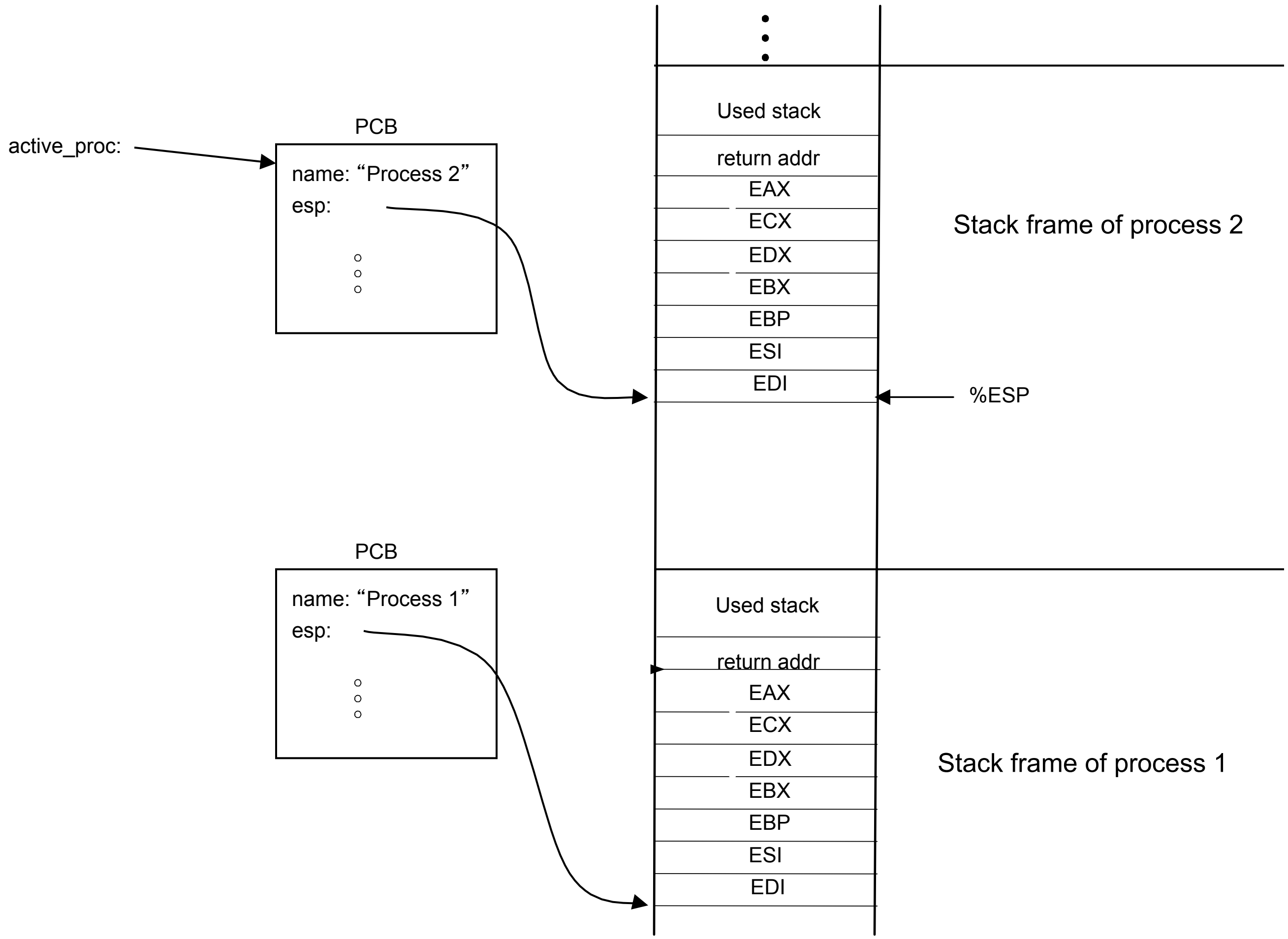
- Next step: choose new process- `dispatcher()`

Example of resign()



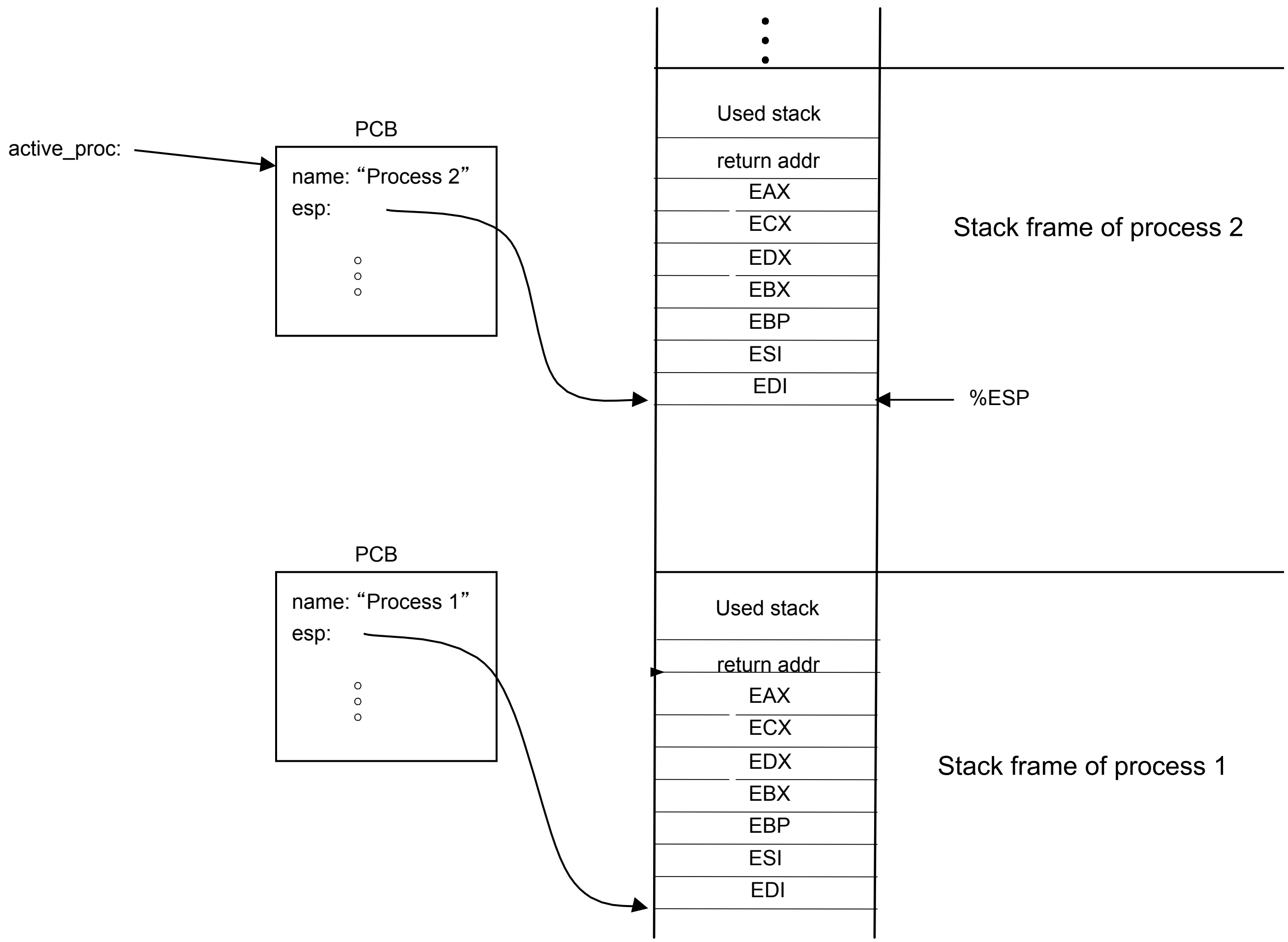
- Next step: restore the stack pointer for process 2

Example of resign()



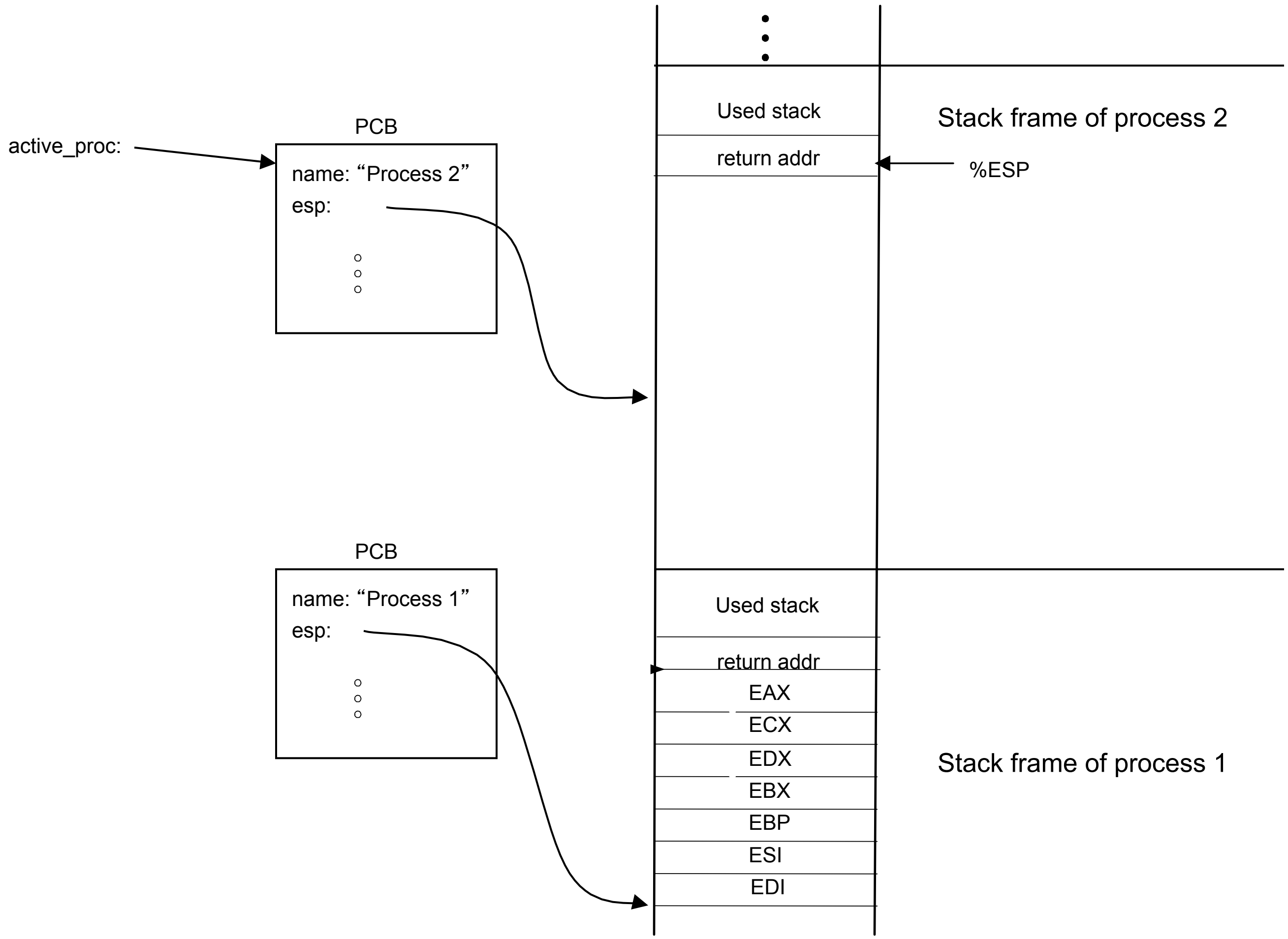
- Next step: restore the stack pointer for process 2

Example of resign()



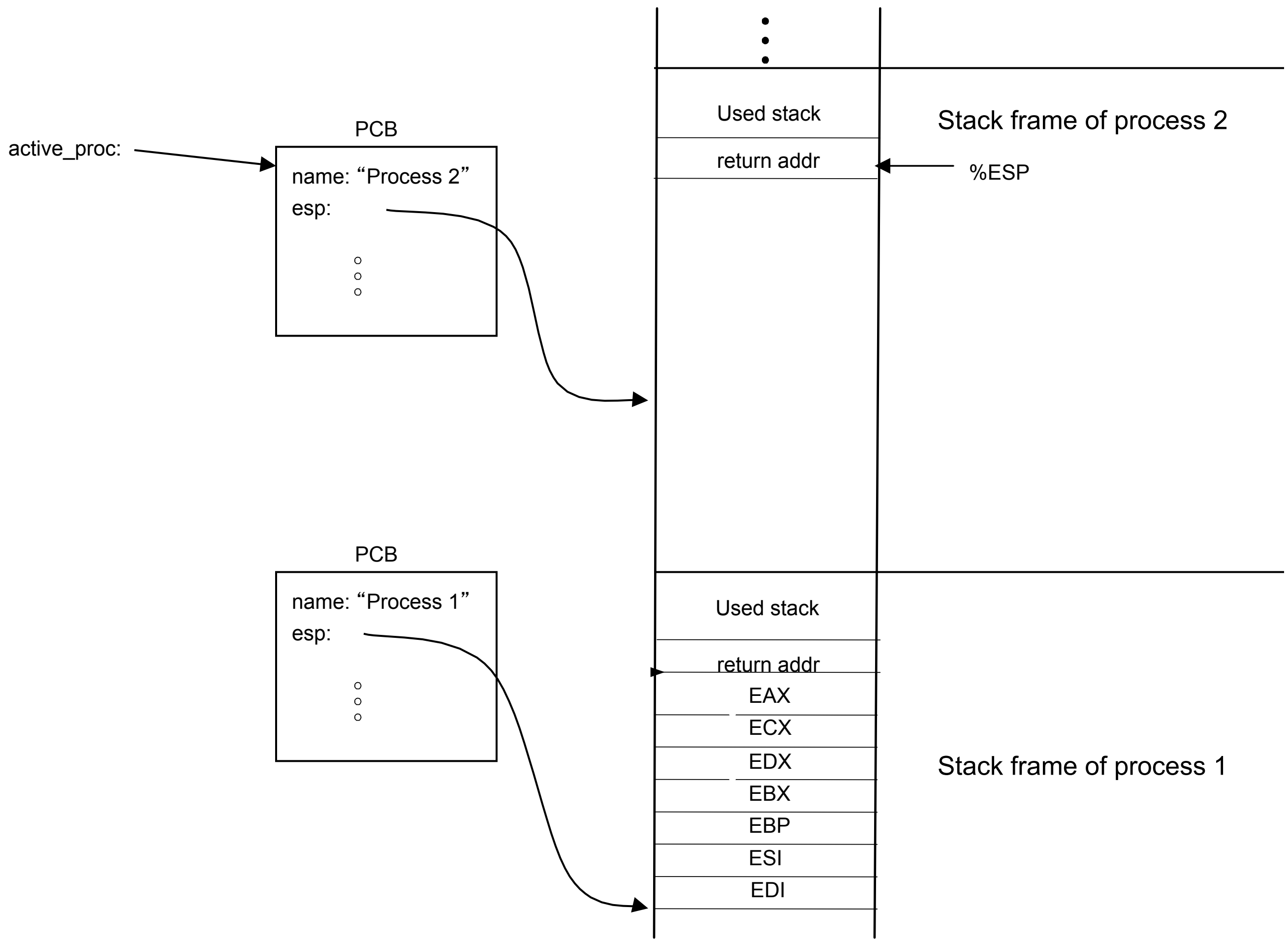
- Next step: restore the registers for process 2

Example of resign()



- Next step: restore the registers for process 2

Example of resign()



- Finished! We return from `resign()` and process 2 continues where it left off

Context Switch

- Context switch is implemented by one function:
  `void resign()`
- This function is located in the file `~/tos/kernel/dispatch.c`

Assignment 4

- Implement `resign()` (in `dispatch.c`)
- Test cases:
  - `test_dispatcher_1`
  - `test_dispatcher_2`
  - `test_dispatcher_3`
  - `test_dispatcher_4`
  - `test_dispatcher_5`
  - `test_dispatcher_6`
  - `test_dispatcher_7`
- Hint: the tests for assignment 4 may fail because of errors in assignment 3!

Assignment 4 Hints

- This project is relatively straightforward to code, but difficult to debug
- In general, using assert is a good thing but here it is dangerous:

```
active_proc = dispatcher();
assert(active_proc != NULL);
```

- Calling assert pushes arguments on the stack but we are trying to manually manage the stack!

Safe assertions in resign

- In this case, we can get work around the problem:

```
void check_active() {
    assert(active_proc != NULL);
}
…
active_proc = dispatcher();
check_active();
```

- Inside `resign()`, we call `check_active()` which has no arguments so no stack problems
- This approach is only necessary inside `resign()`

Inline Assembly

- For simple self-contained instructions:

  `asm("pushl %eax");`

- But sometimes we need to refer to a C expression inside the inline assembly:

  `asm("movl %esp, active_proc->esp");`

- Things get really messy here, just cut-and-paste from the next slide!

Inline Assembly

- The middle steps of `resign()`:

```
/* Save the stack pointer to the PCB */
asm ("movl %%esp,%0" : "=r" (active_proc->esp) : );

/* Select a new process to run */
active_proc = dispatcher();

/* Load the stack pointer from the PCB */
asm ("movl %0,%%esp" : : "r" (active_proc->esp));
```

- Notes the register name `%esp` has to be prefixed with another `%`

PacMan (1)

- Earlier you were told to create several ghost processes in `init_pacman()` via:

```
int i;
for (i = 0; i < num_ghosts; i++)
    create_process(ghost_proc, 3, 0, "Ghost");
```

- It was said although you create several ghost processes, you will not see them yet, because they will not yet get scheduled.
- After the for-loop, add a call to `resign()` as the next experiment.
- Because the ghost process has a higher priority than the boot process, you should see *one* ghost.
- Note: you will only see *one* ghost, even though you might have created several ghost processes (why?)

PacMan (2)

- The reason you will see only one ghost is because TOS only supports cooperative multitasking at this point.
- In order to see the other ghosts, each ghost needs to voluntarily relinquish control of the CPU by making a call to `resign()`.
- Earlier you were told to implement a function called `create_new_ghost()` according to the following pseudo code:

```
void create_new_ghost()
{
    GHOST ghost;
    init_ghost(&ghost);
    while (1) {
       remove ghost at old position (using remove_cursor())
       compute new position of ghost
       show ghost at new position (using show_cursor())
       do a delay
       resign()
   }
}
```

- Add a call to `resign()` in that function as indicated above. Now you should see several ghosts!

Concurrency

- Right now we only support cooperative multitasking. I.e., a TOS process needs to call `resign()` to initiate a context switch.
- Once TOS supports interrupts, we will be able to support pre-emptive multitasking. I.e., a context switch may happen between *any* two machine code instructions.
- Multiple tasks running simultaneously may inadvertently interfere with each other
- Example -- “Too Much Milk”

Too Much Milk

Person 1	Person 2	Time
Look in Fridge		
Go to Store		
	Look in Fridge	
	Go to Store	
	Return with Milk	
Return with Milk		

Synchronization

- Synchronization errors are difficult to find since they are not easily repeatable.
  - Bug only occurs with particular scheduling patterns
- Once a bug is found, how to fix it?
  - Identify “critical sections”
  - Only let one task enter a critical section at a time using a lock
  - Other synchronization techniques (semaphores, monitors) not covered in this course
  - Our solution: synchronization via message passing (discussed later)

Too Much Milk, fixed

Time

Acquire Lock

Look in Fridge

Go to Store

Return with Milk

Release Lock

Too Much Milk

Person 1	Person 2	Time
Acquire Lock		
Look in Fridge		
Go to Store		
	Acquire Lock	
	blocked	
Return with Milk		
Release Lock	Look in Fridge	

Synchronization

- Does the following code have a potential synchronization problem?

```
void increment(int* ip)
{
  *ip = *ip + 1;
}
```

Synchronization

- Does the following code have a potential synchronization problem?

```
increment:
  pushl %ebx
  movl 4(%esp), %eax
  movl (%eax), %ebx
  add 1, %ebx
  mov %ebx, (%eax)
  popl %ebx
  ret
```