CS 423
Operating System Design: The Kernel Abstraction

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* Thanks for Prof. Adam Bates for the slides.

Overview

Process concept

- A process is the OS abstraction for executing a program with limited privileges

Dual-mode operation: user vs. kernel

- Kernel-mode: execute with complete privileges
- User-mode: execute with fewer privileges

Safe control transfer

- How do we switch from one mode to the other?

Process Abstraction

Process: an instance of a program that runs with limited rights on the machine

- Thread: a sequence of instructions within a process
  - Potentially many threads per process (for now, assume 1:1)
- Address space: set of rights of a process
  - Memory that the process can access
  - Other permissions the process has (e.g., which system calls it can make, what files it can access)

Thought Experiment

How can we permit a process to execute with only limited privileges?

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How can we implement execution with limited privilege?

- Execute each program instruction in a simulator
- If the instruction is permitted, do the instruction
- Otherwise, stop the process
- Basic model in Javascript and other interpreted languages

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Ok… but how do we go faster?

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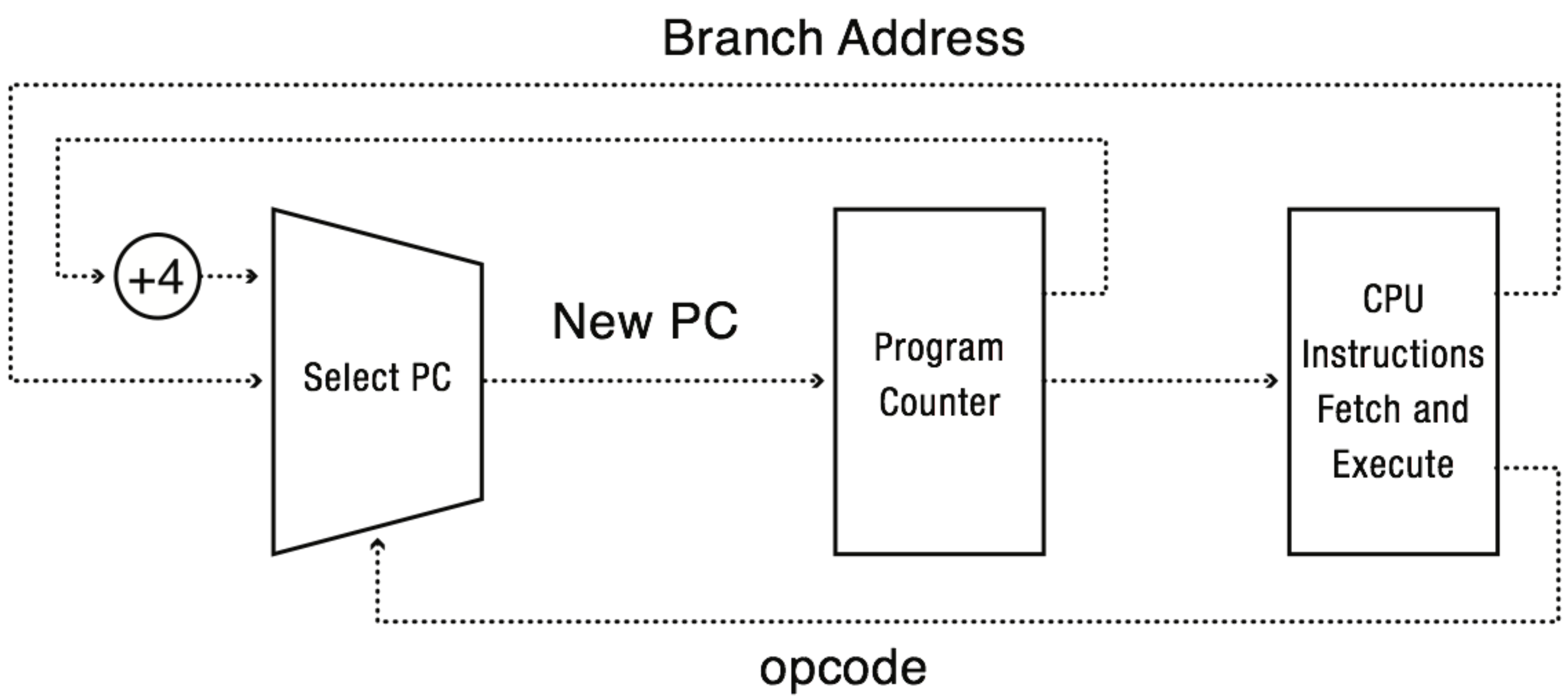
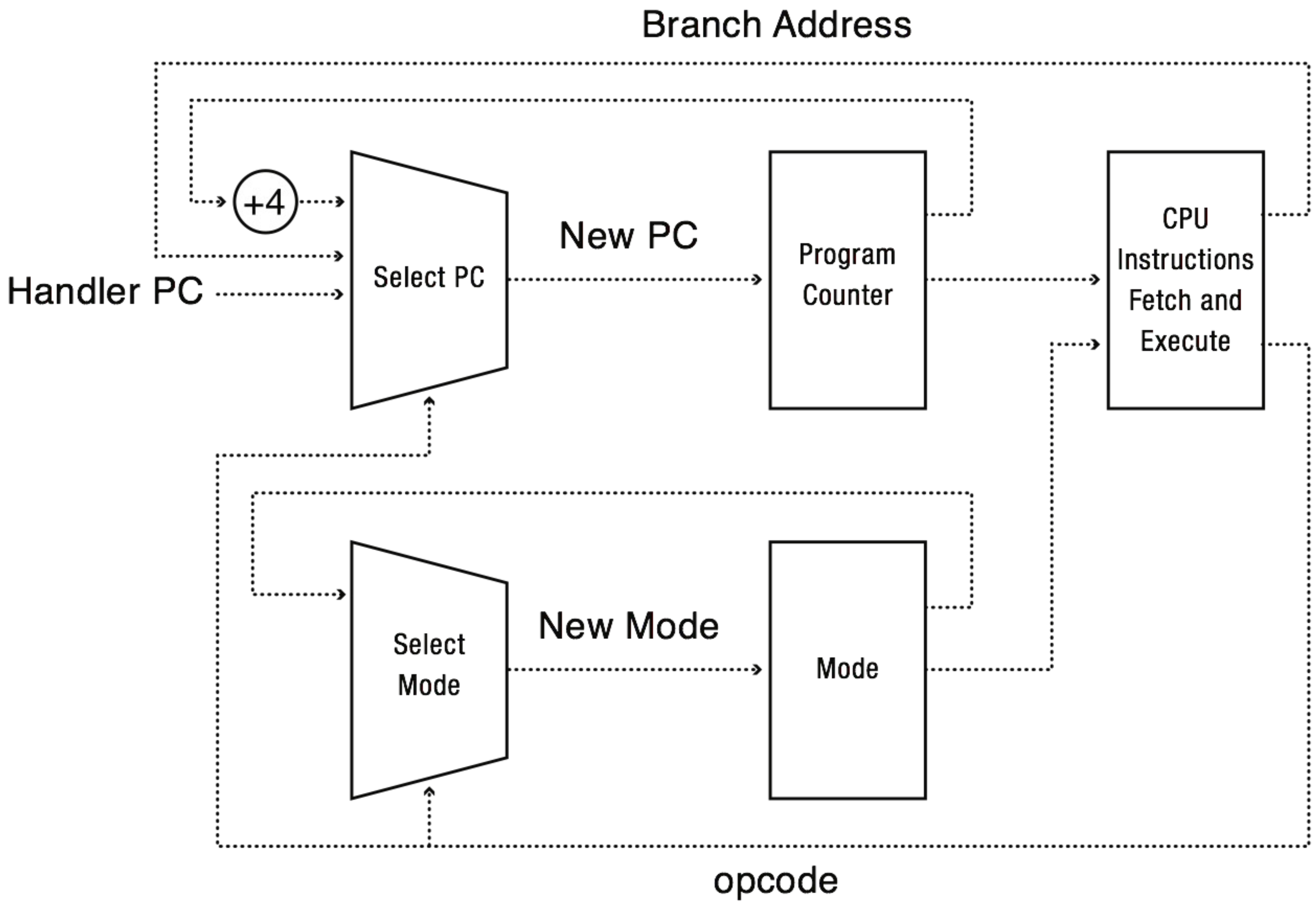
Ok… but how do we go faster?

- Run the unprivileged code directly on the CPU!

A Model of a CPU



A CPU with Dual-Mode Operation



HW Support for Dual-Mode

Privileged instructions
- Available to kernel
- Not available to user code

Limits on memory accesses
- To prevent user code from overwriting the kernel

Timer
- To regain control from a user program in a loop

Safe way to switch from user mode to kernel mode, and vice versa

Privileged Instructions

Examples?

What should happen if a user program attempts to execute a privileged instruction?

User->Kernel Switches

How/when do we switch from user to kernel mode?

1. Interrupts
   - Triggered by timer and I/O devices
2. Exceptions
   - Triggered by unexpected program behavior
   - Or malicious behavior!
3. System calls (aka protected procedure call)
   - Request by program for kernel to do some operation on its behalf
   - Only limited # of very carefully coded entry points

Question

How does the OS know when a process is in an infinite loop?

Hardware Timer

Hardware device that periodically interrupts the processor

- Returns control to the kernel handler
- Interrupt frequency set by the kernel
  Not by user code!
- Interrupts can be temporarily deferred
  Not by user code! Interrupt deferral crucial for implementing mutual exclusion

Kernel->User Switches

How/when do we switch from kernel to user mode?

1. New process/new thread start
   - Jump to first instruction in program/thread
2. Return from interrupt, exception, system call
   - Resume suspended execution (return to PC)
3. Process/thread context switch
   - Resume some other process (return to PC)
4. User-level upcall (UNIX signal)
   - Asynchronous notification to user program

CPU State

What is the CPU's behavior defined by at any given moment?

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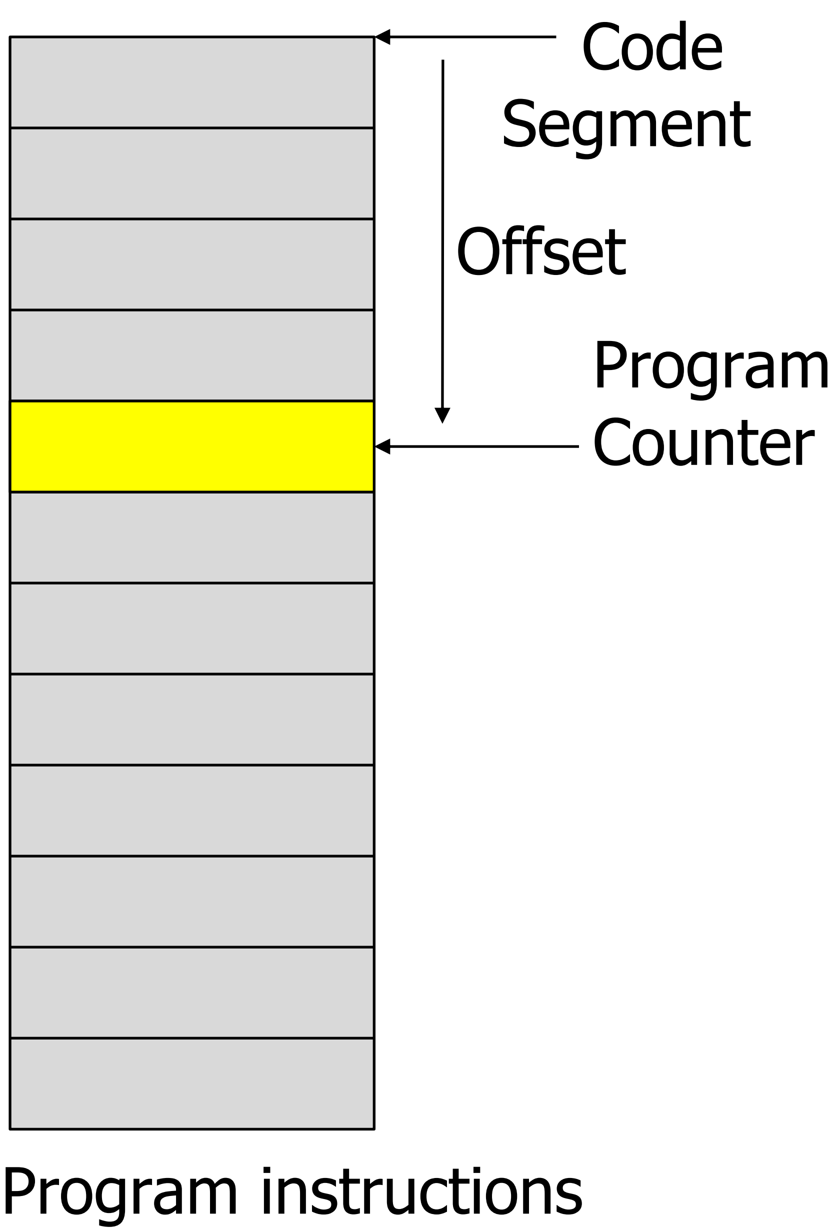

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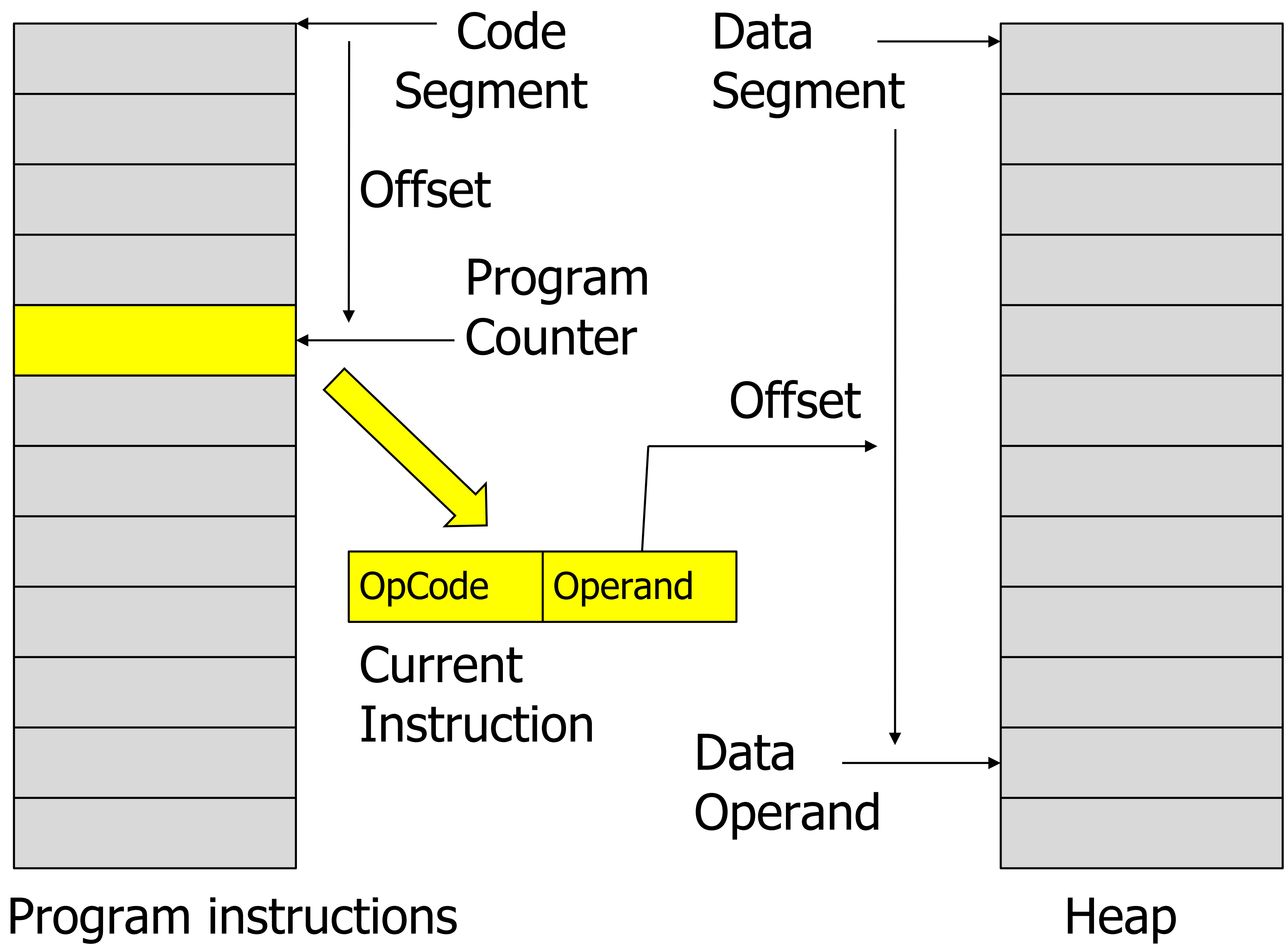

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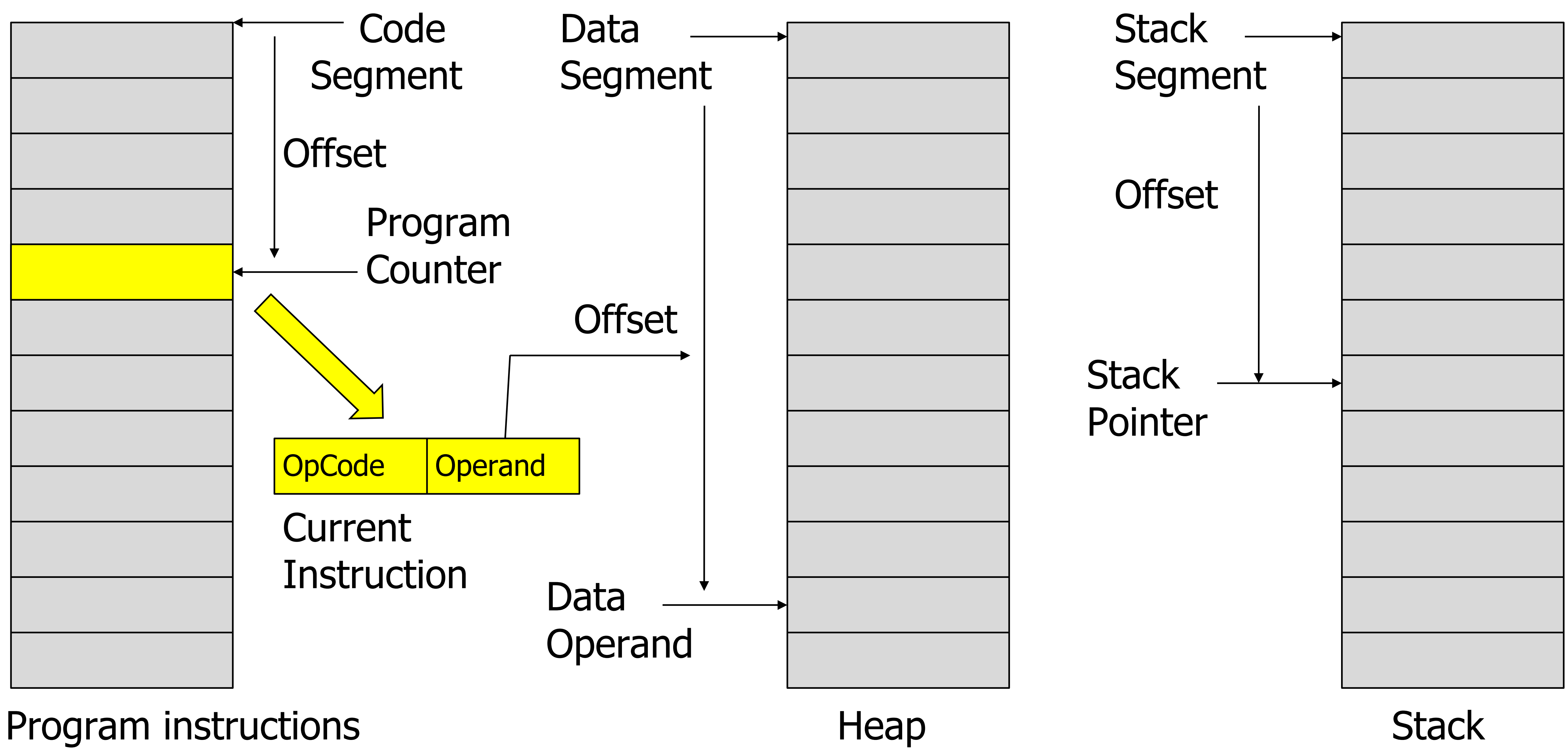

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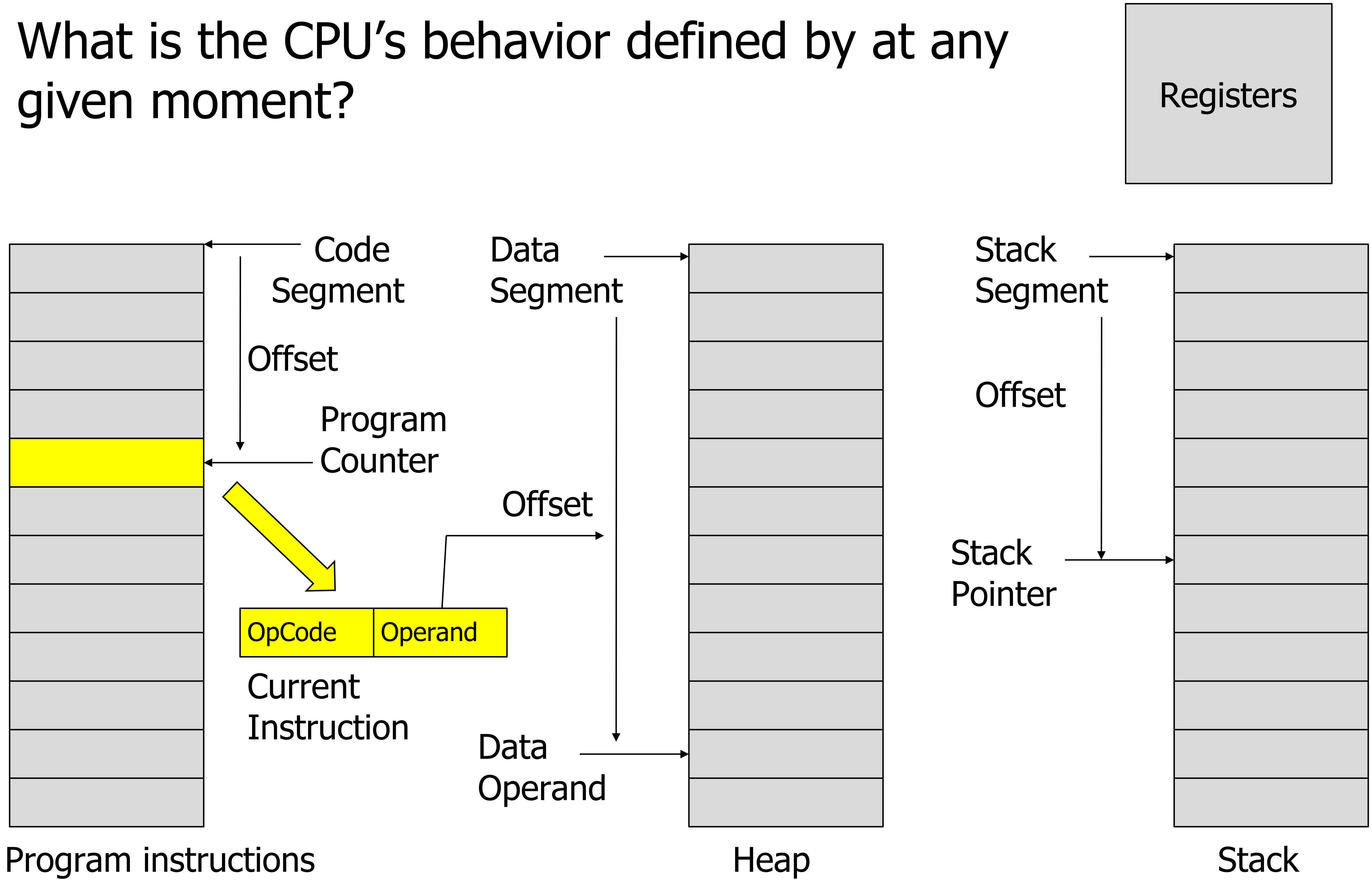
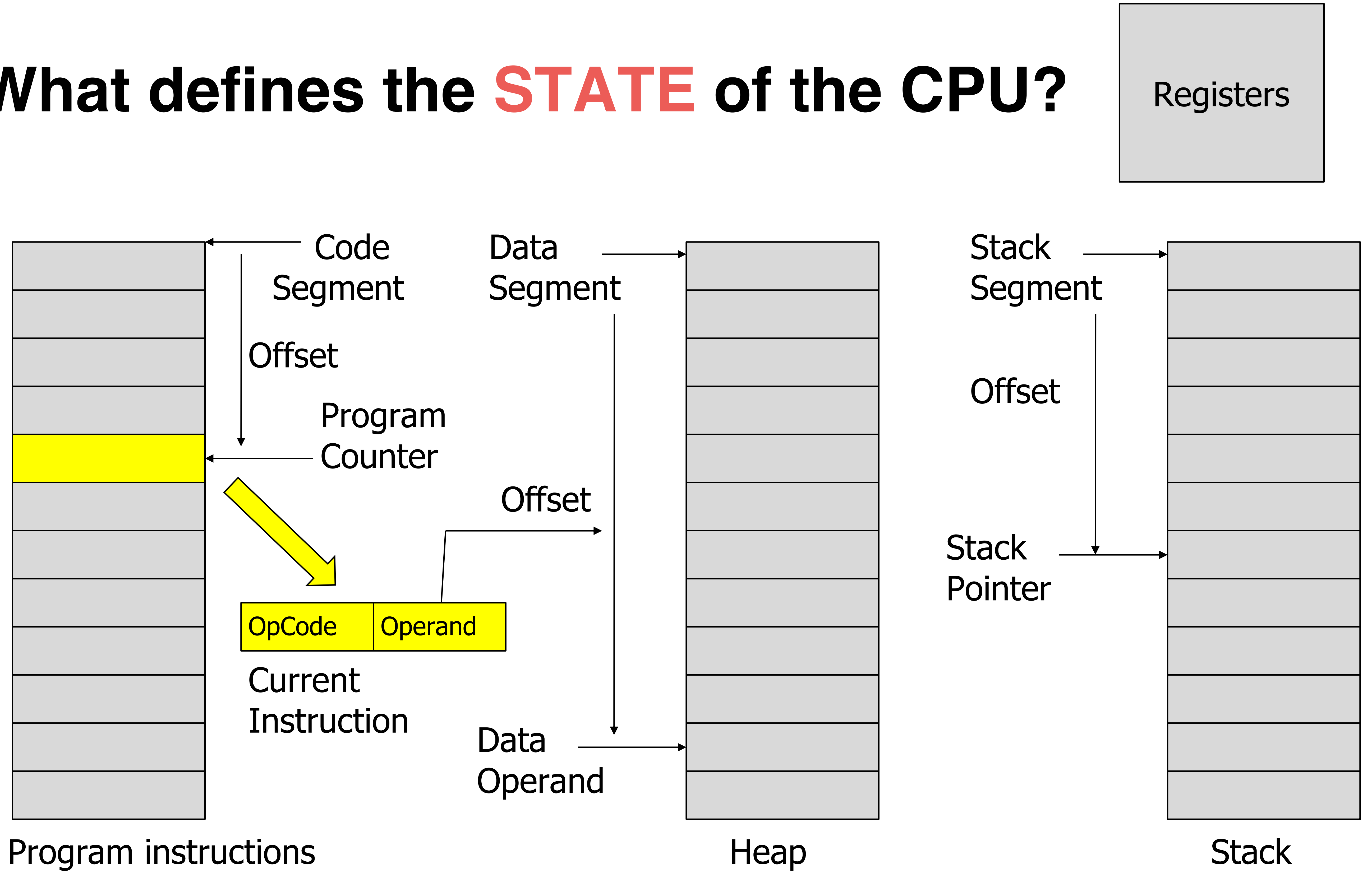


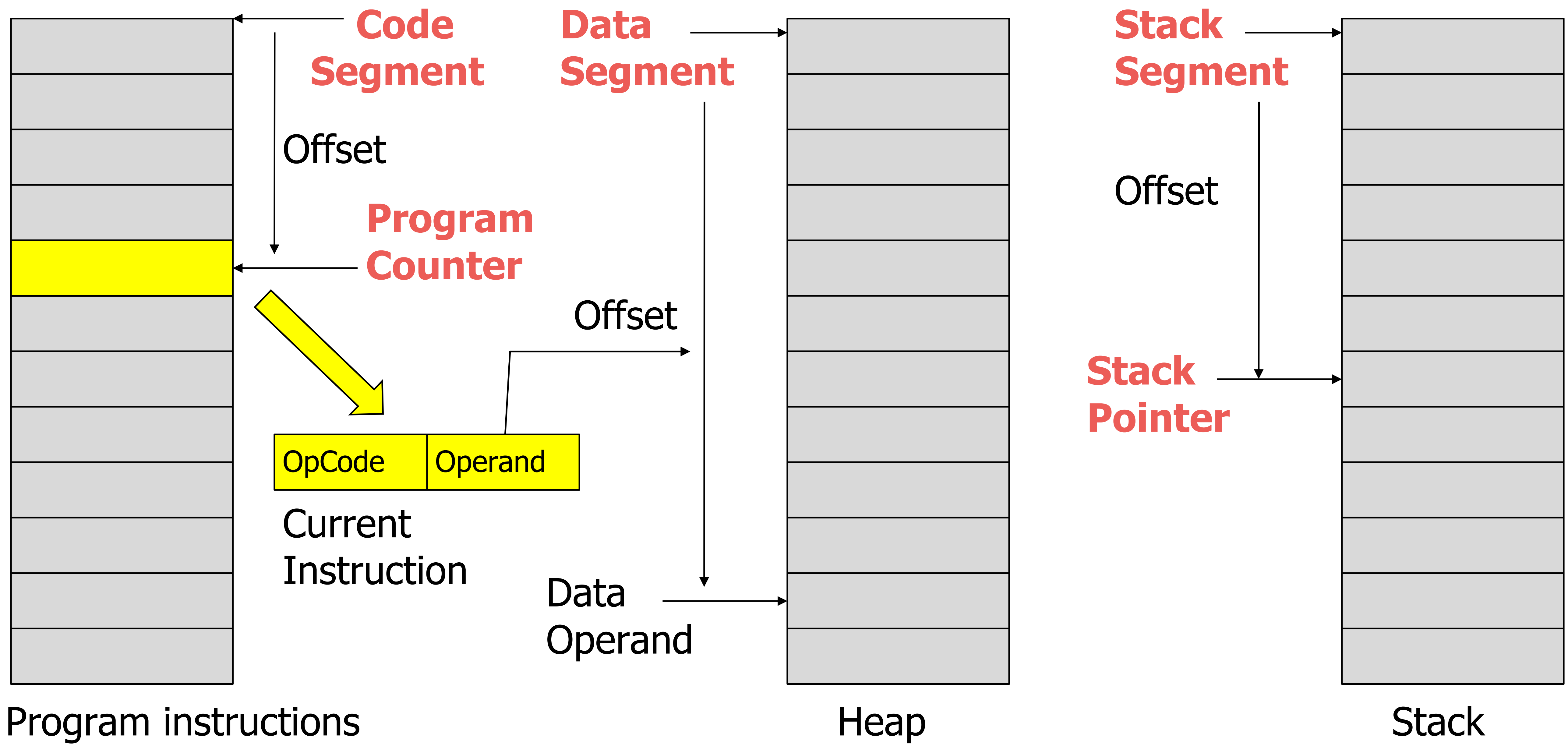
CPU State

What defines the STATE of the CPU?

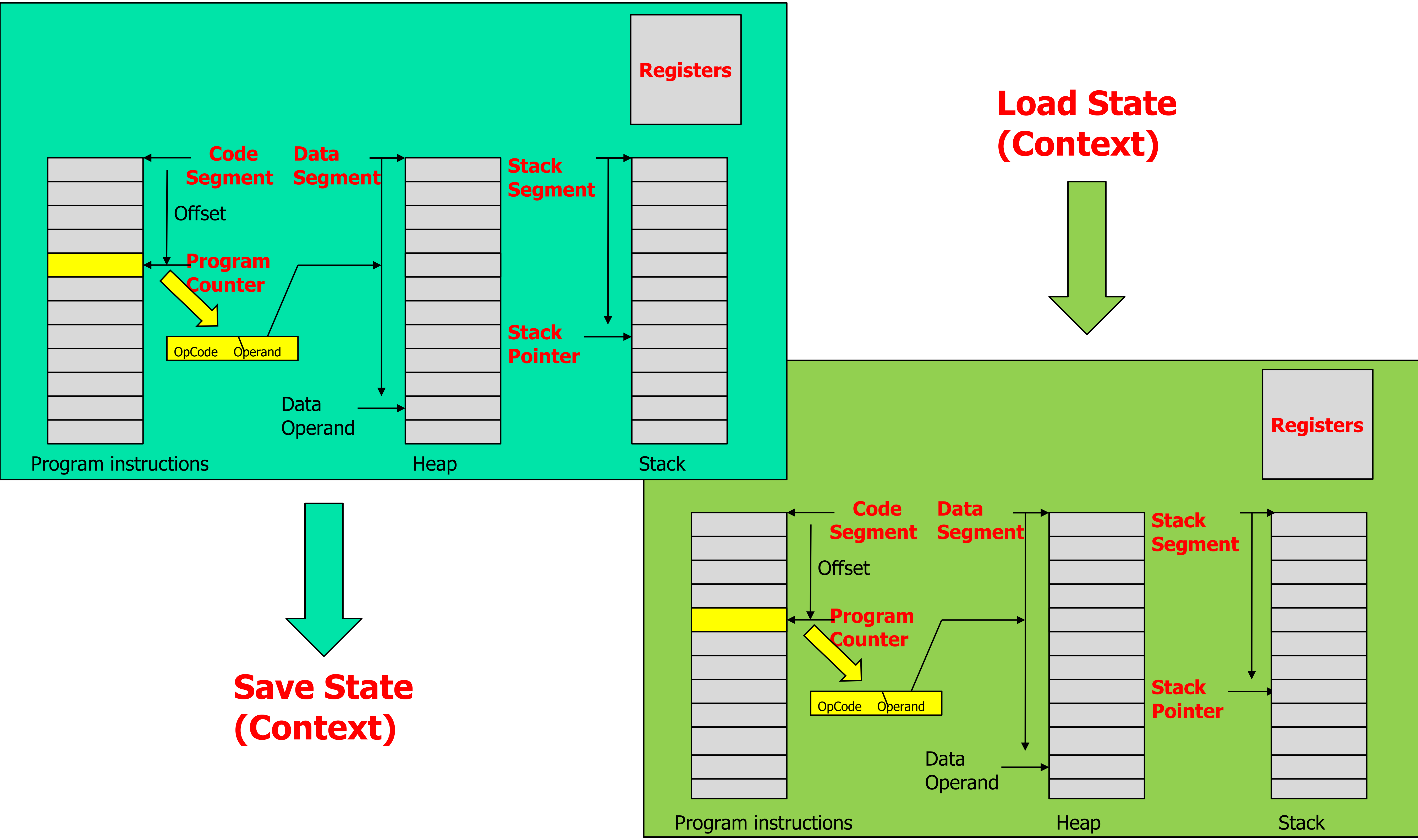


What's a 'real' CPU?

What's the STATE of a real CPU?

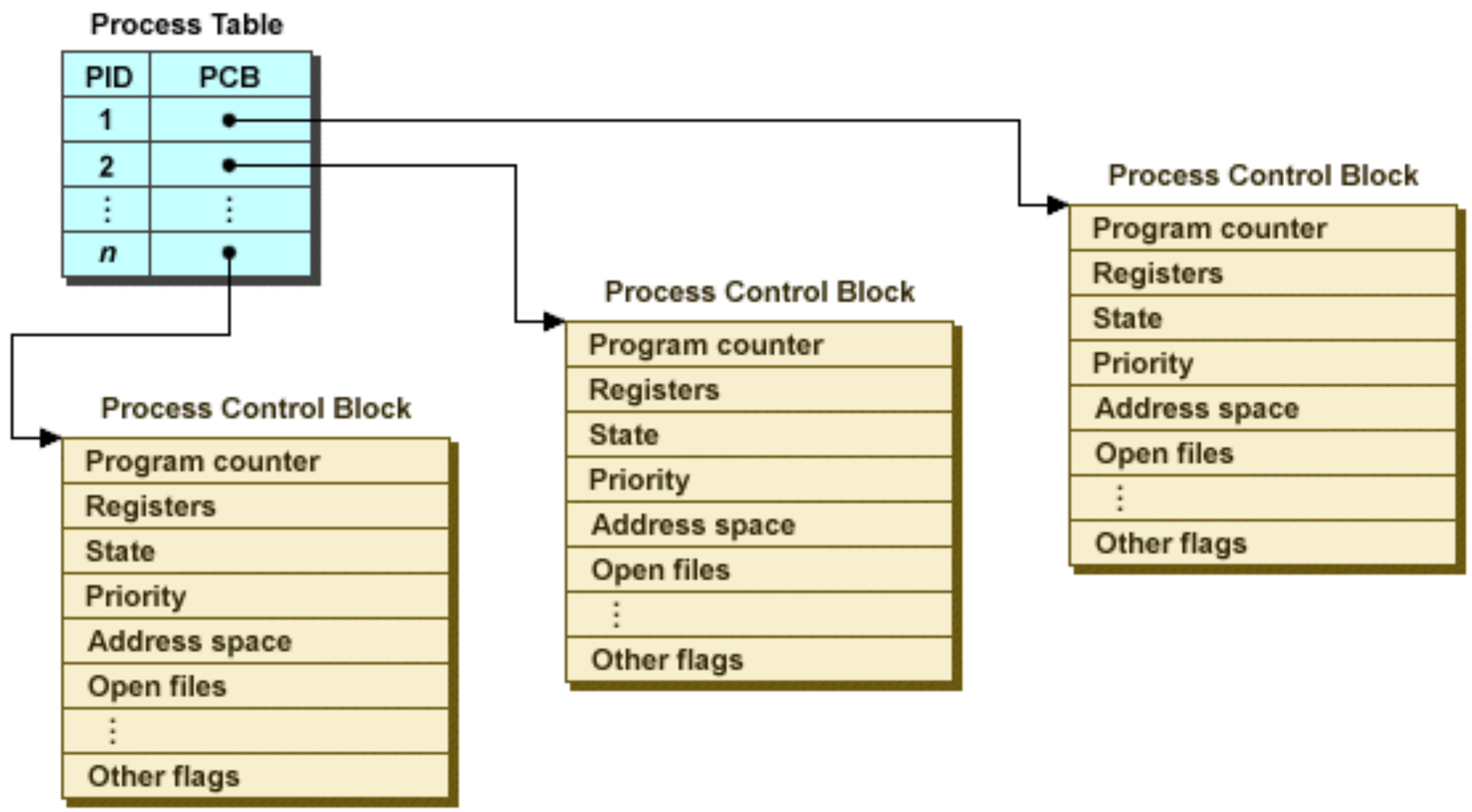


The Context Switch

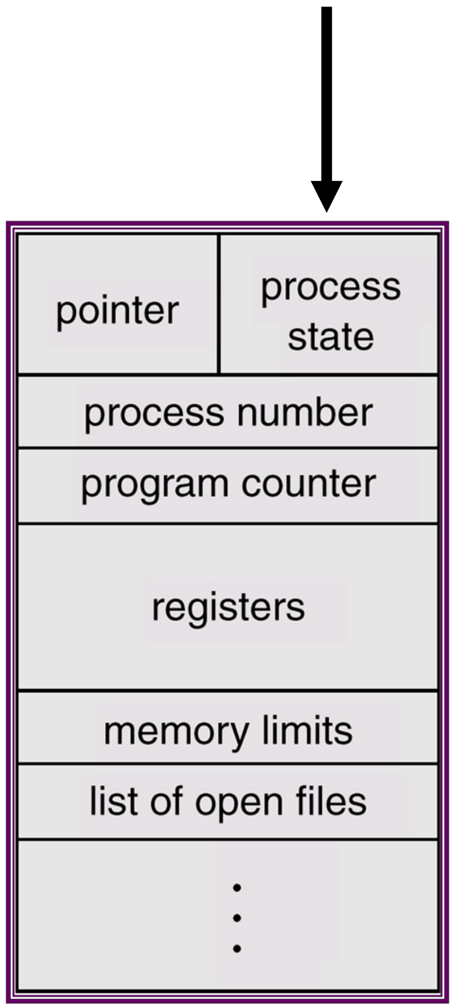


Process Control Block

The state for processes that are not running on the CPU are maintained in the Process Control Block (PCB) data structure

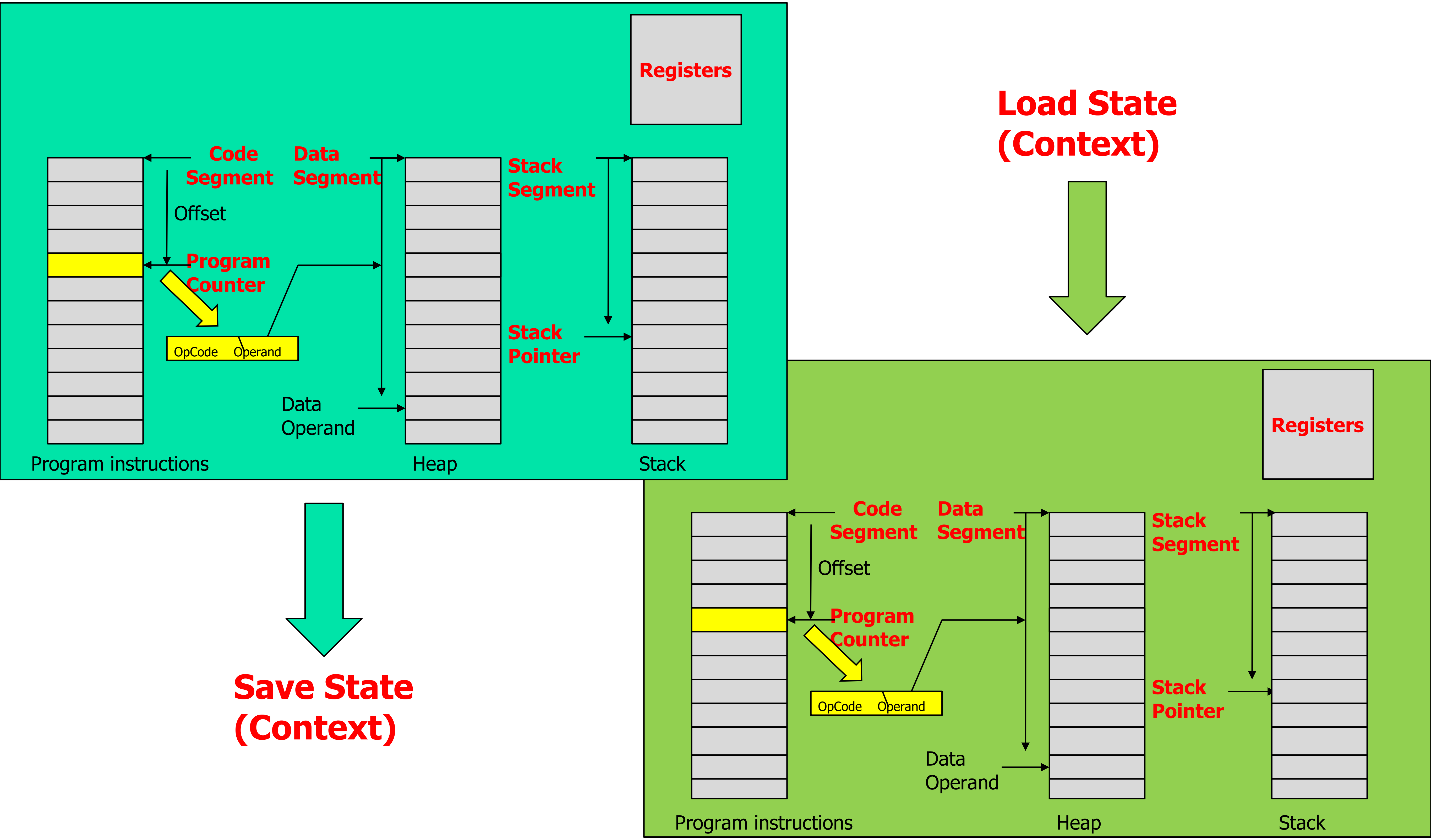


Updated during context switch



An alternate PCB diagram

The Context Switch



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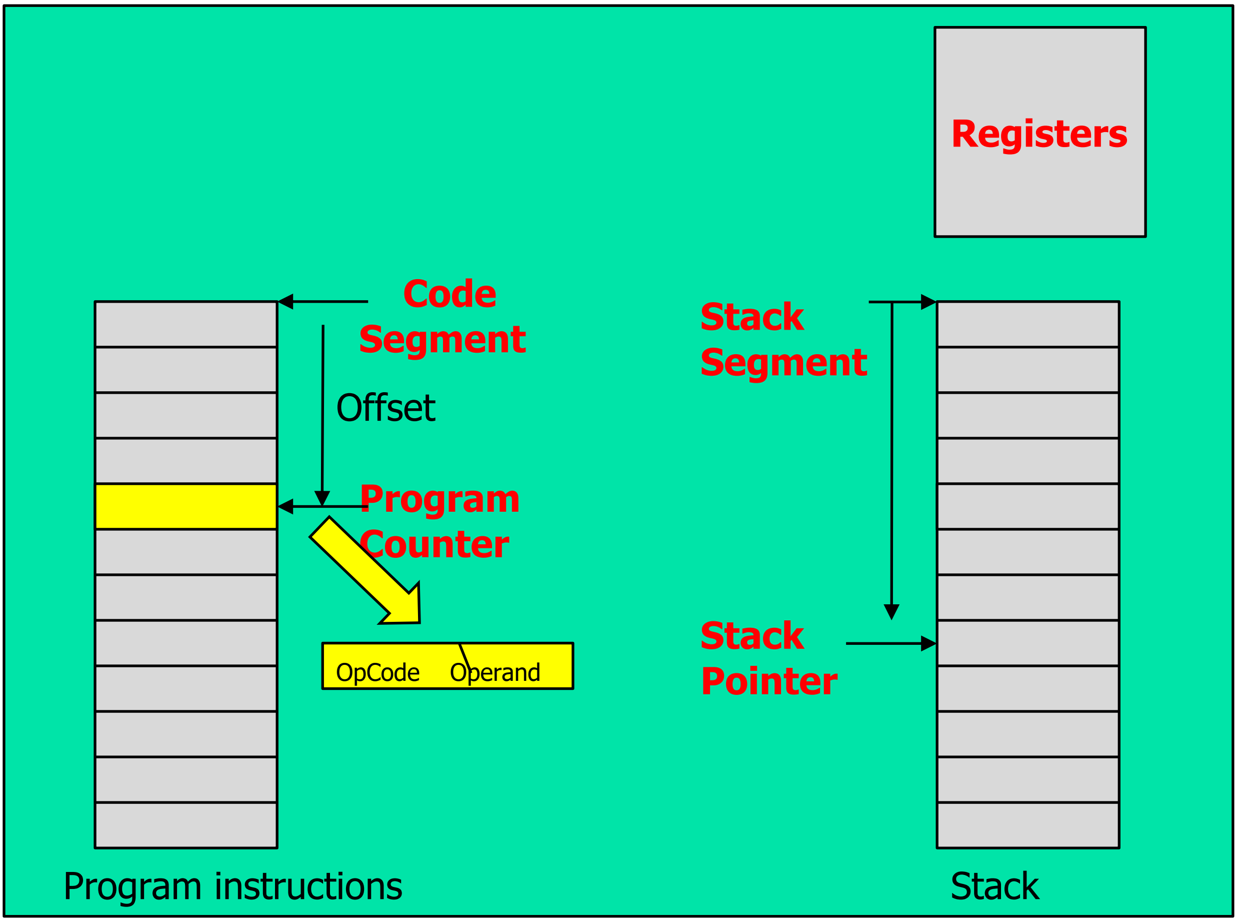
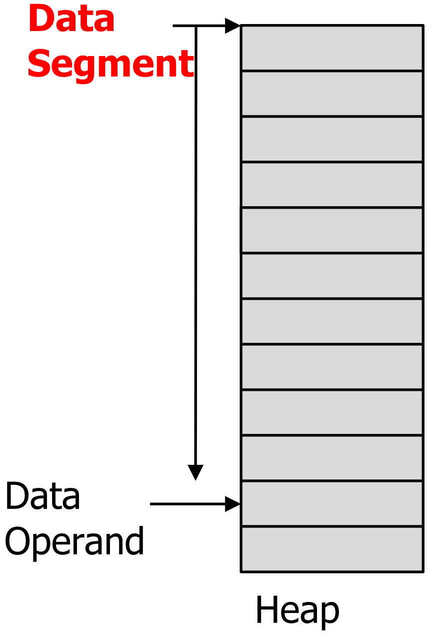
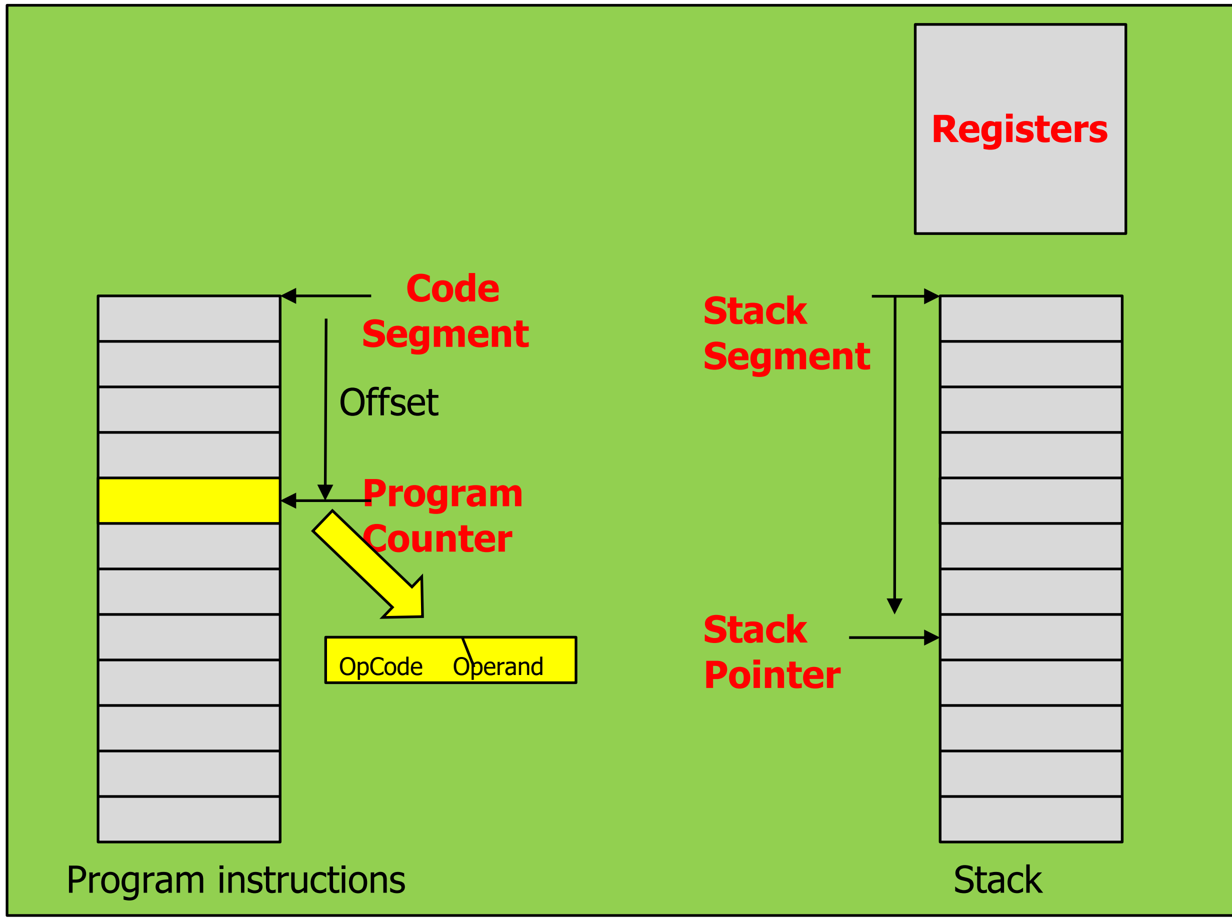




Note: In **thread** context switches, heap is not switched!

Load State (Context)



Save State (Context)

The Context Switch

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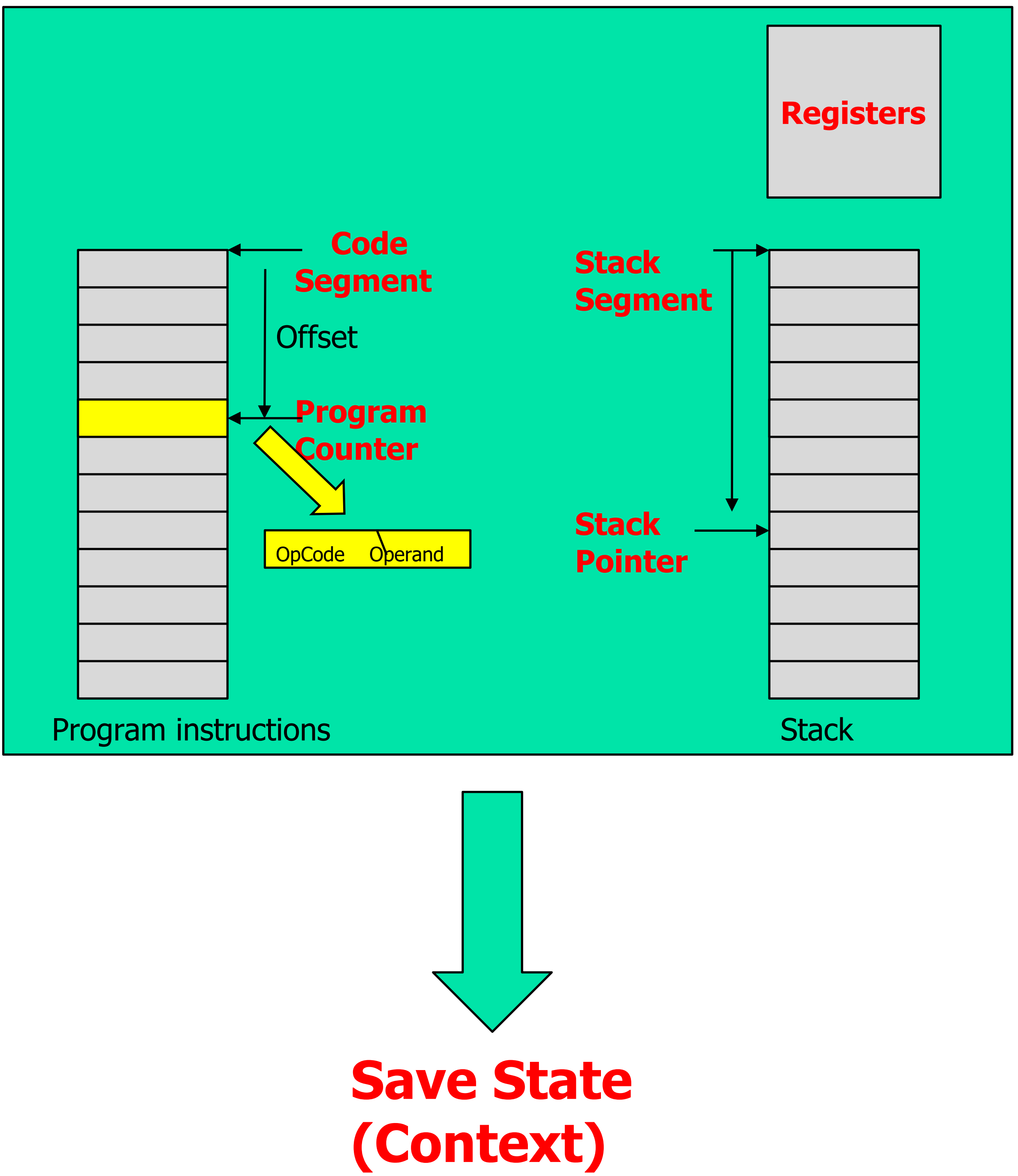

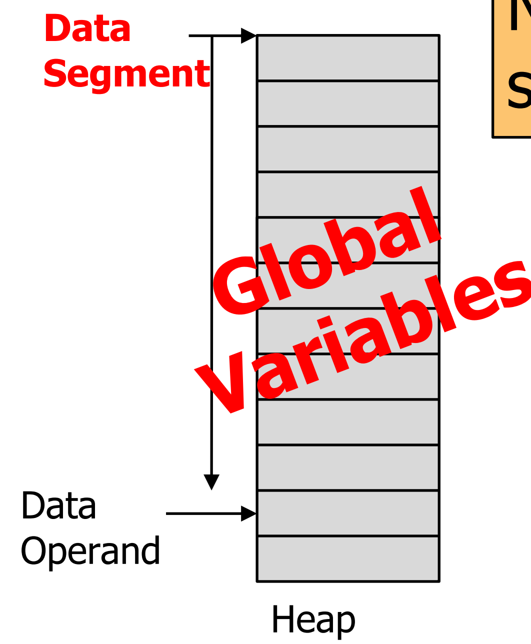

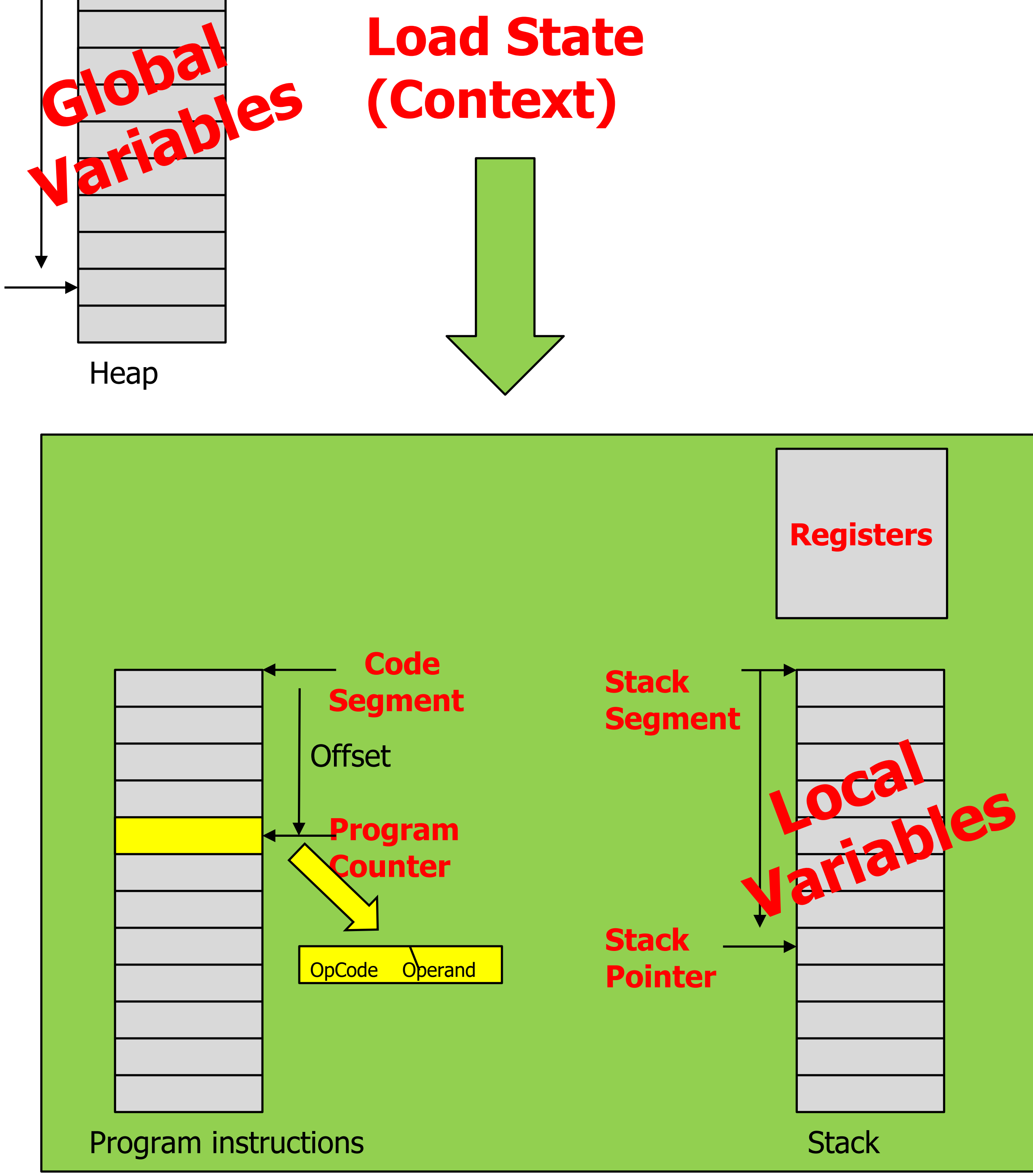

Thread Context Switch

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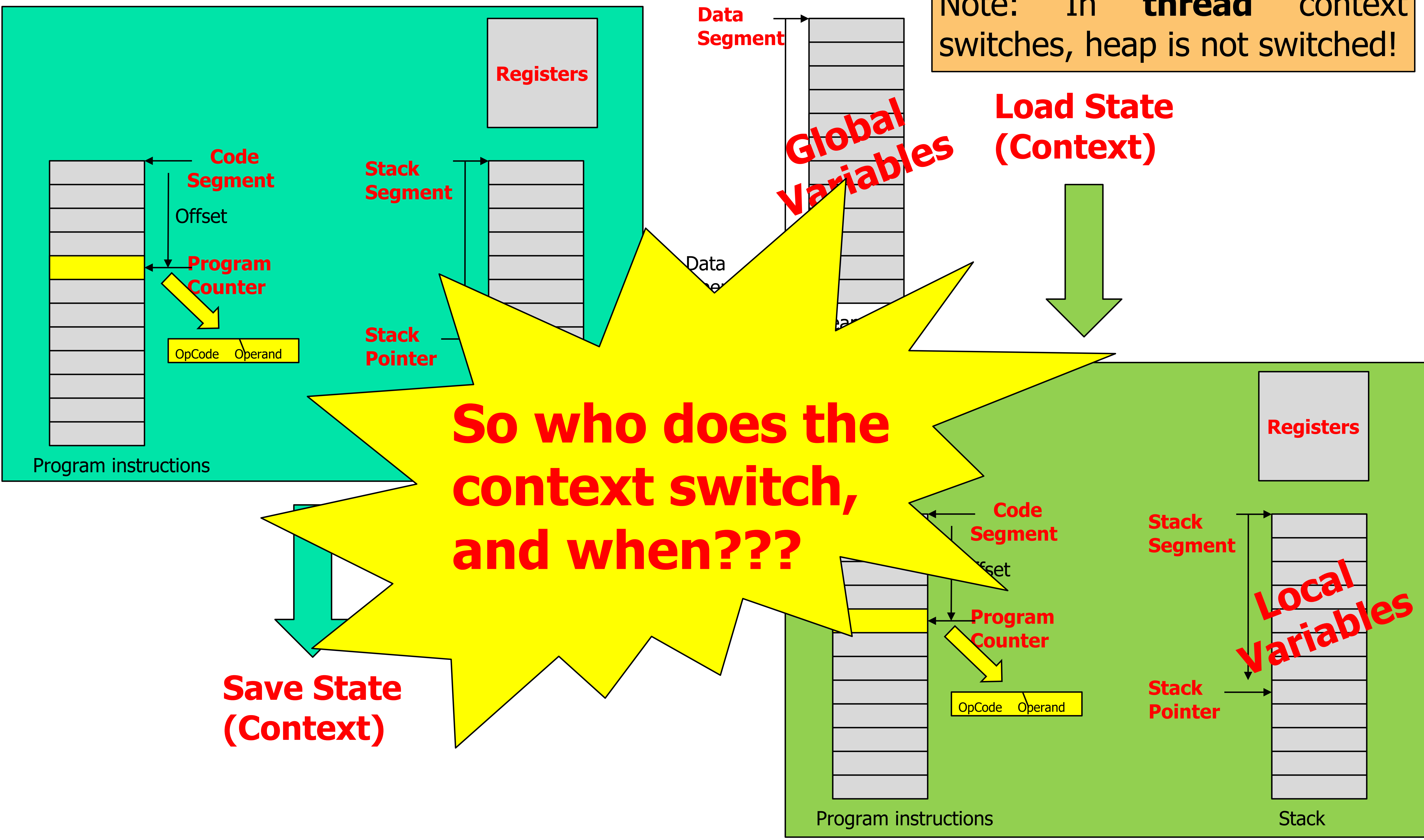

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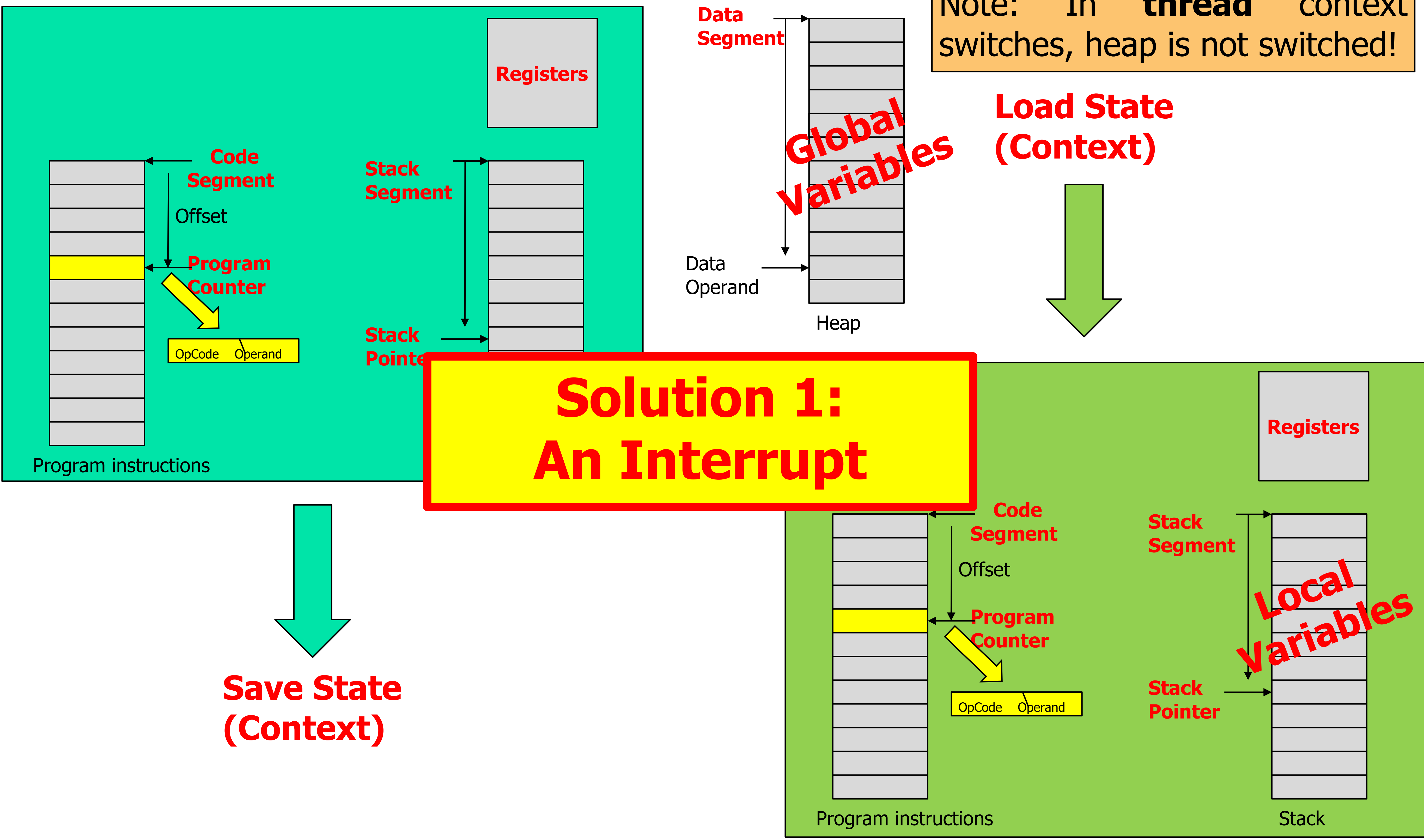
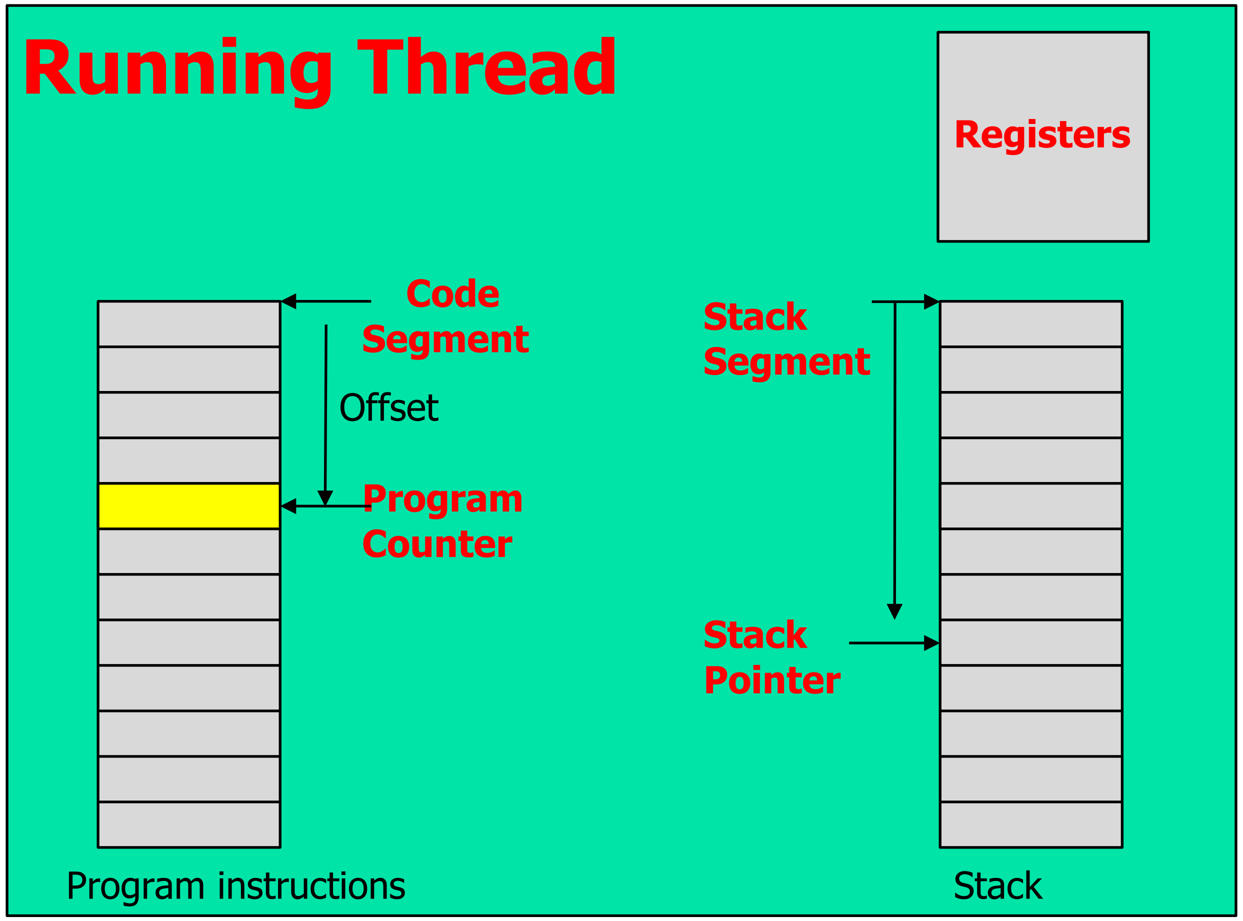
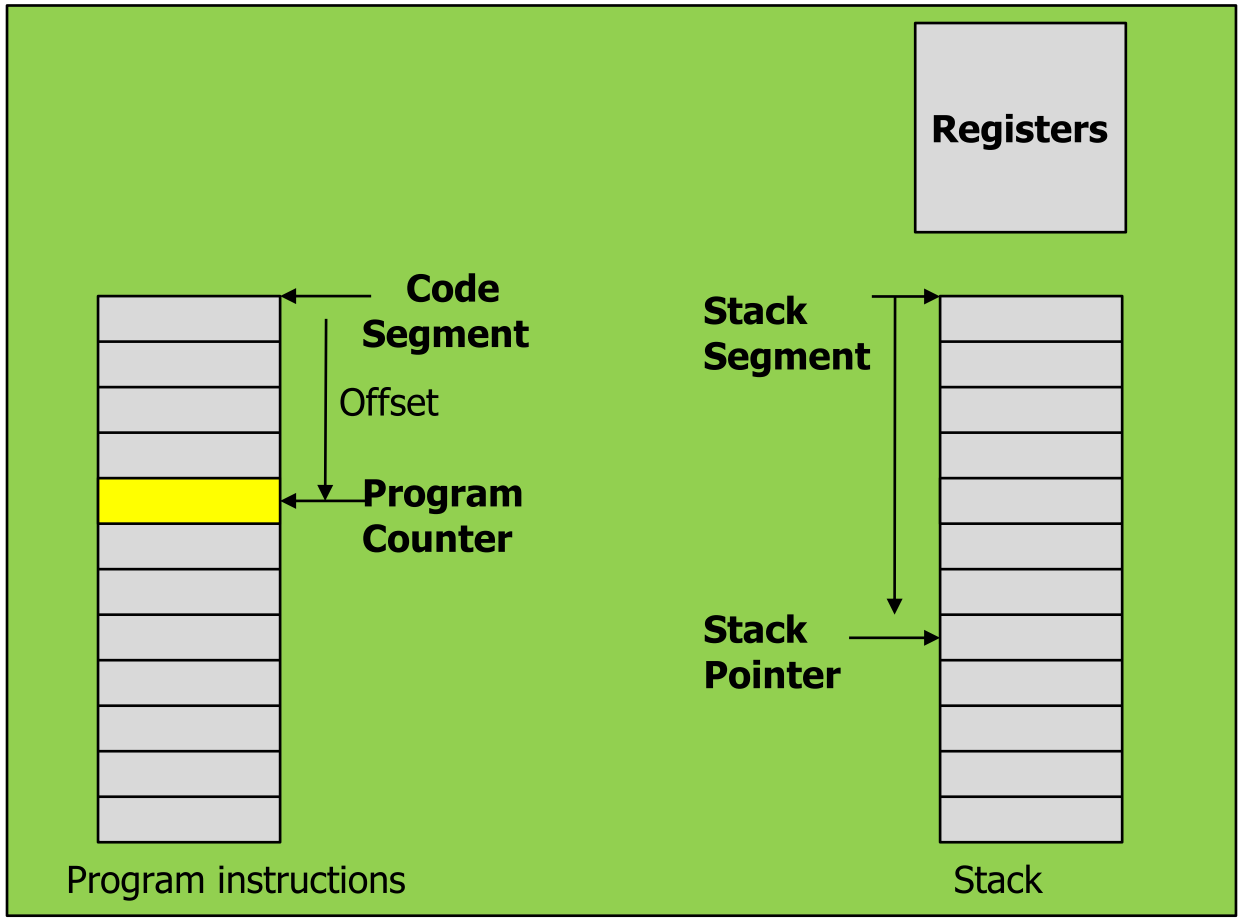


CTX Switch: Interrupt





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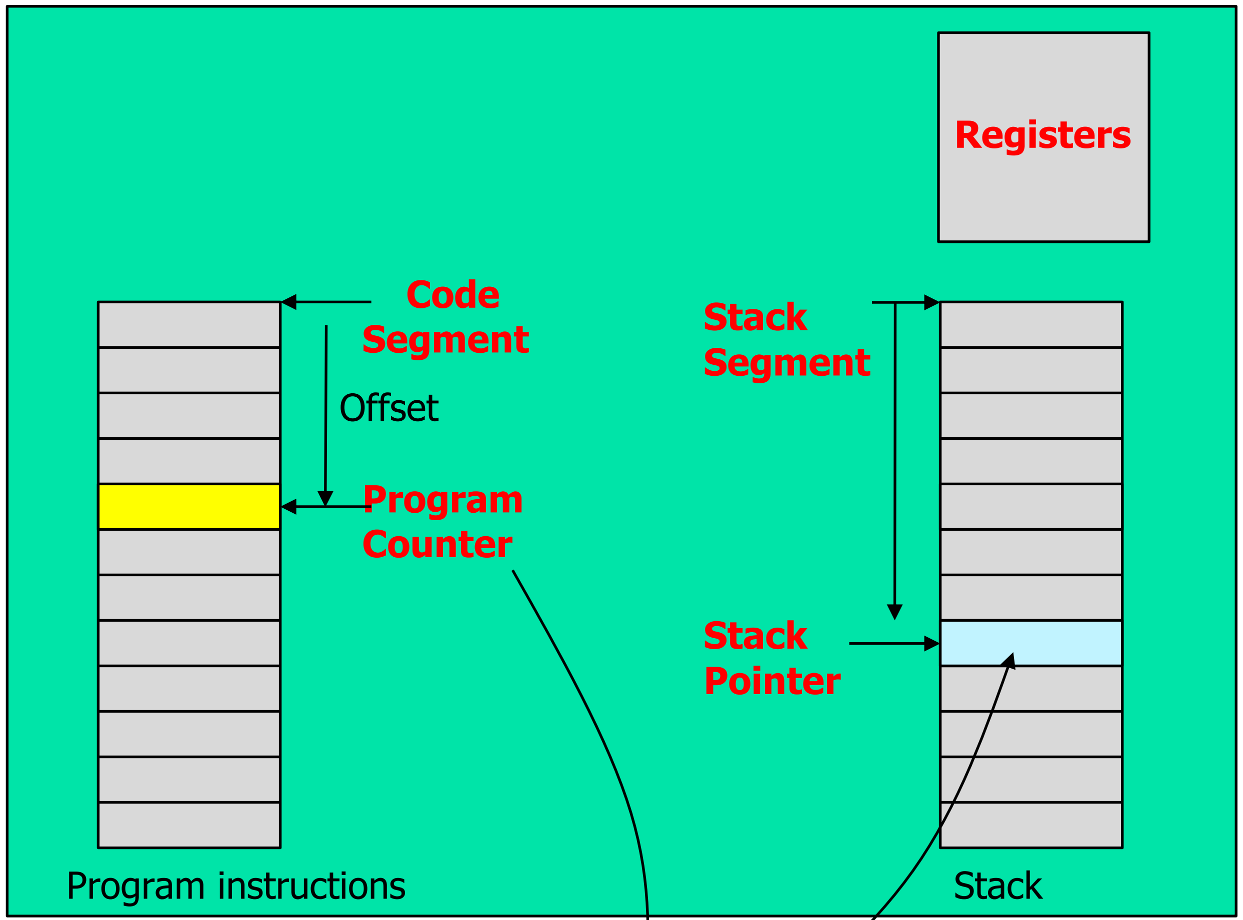
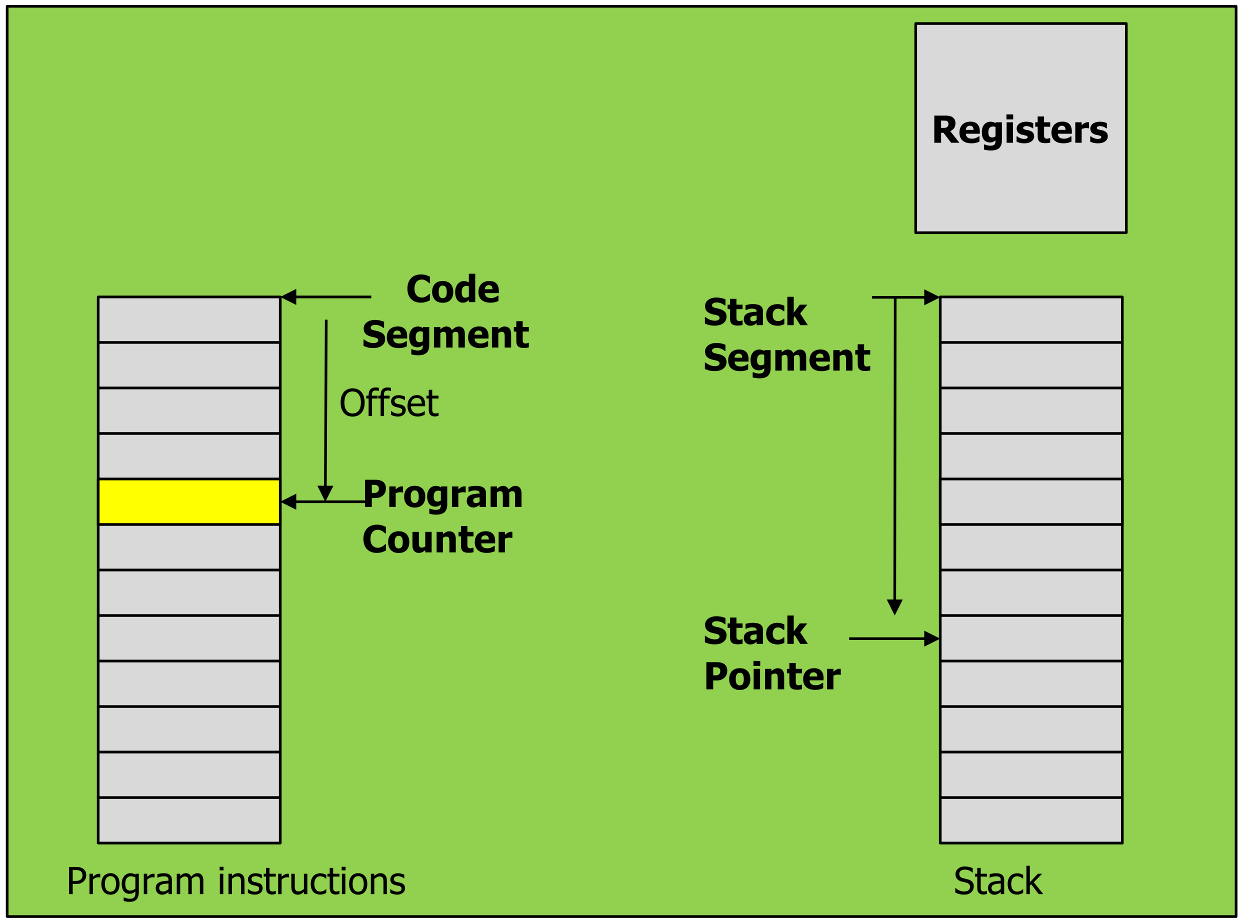
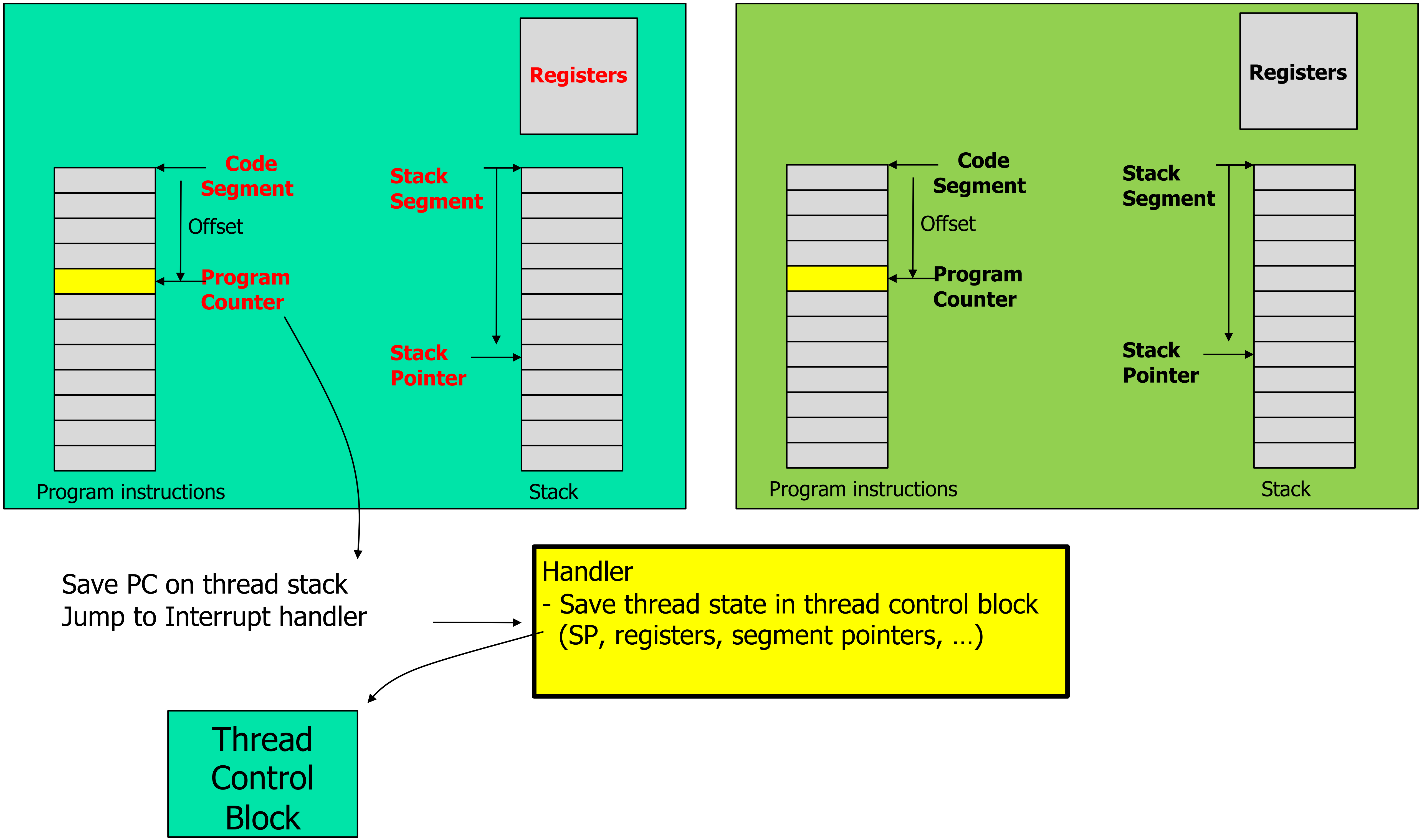




Interrupt

Save PC on thread stack
Jump to Interrupt handler

CTX Switch: Interrupt



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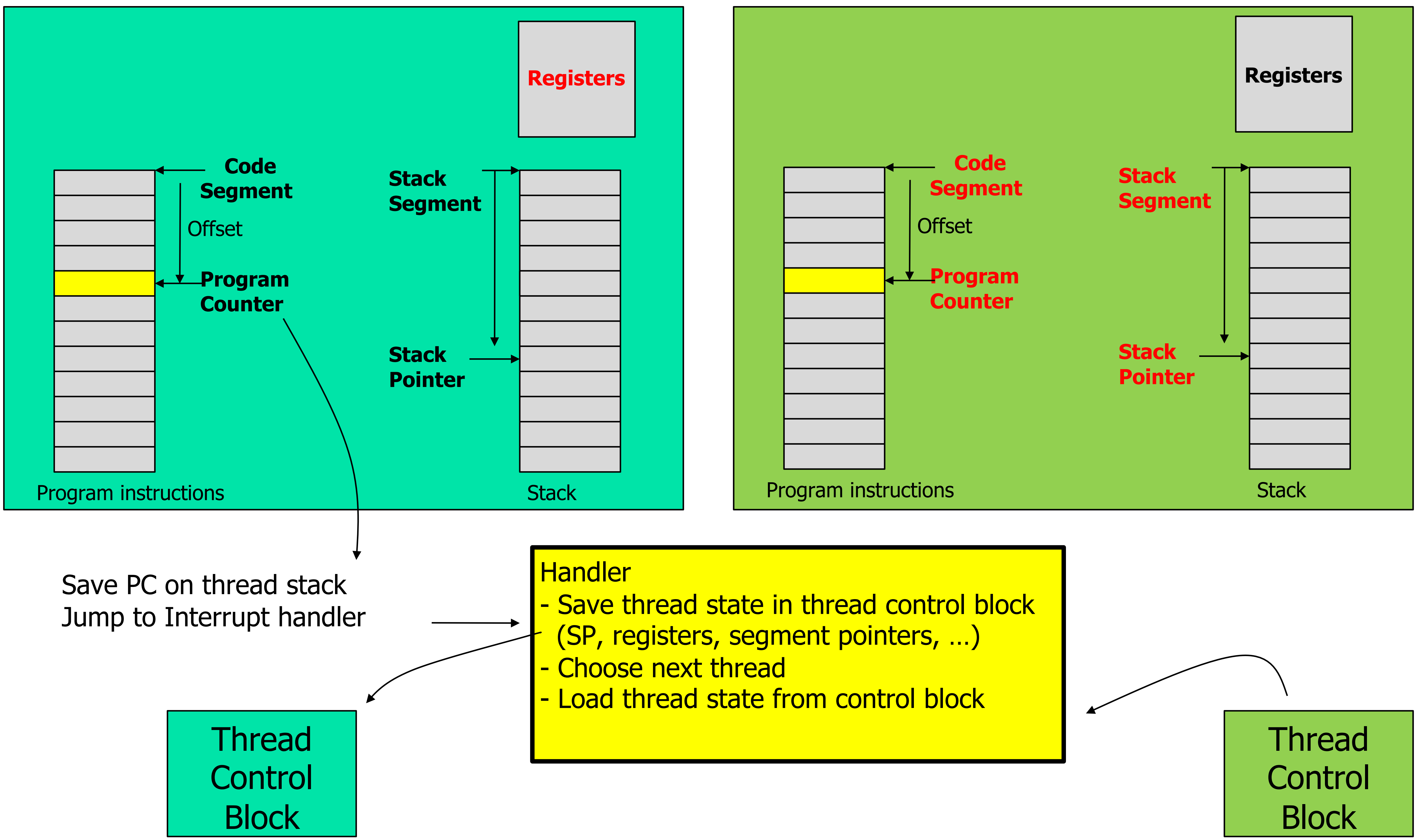

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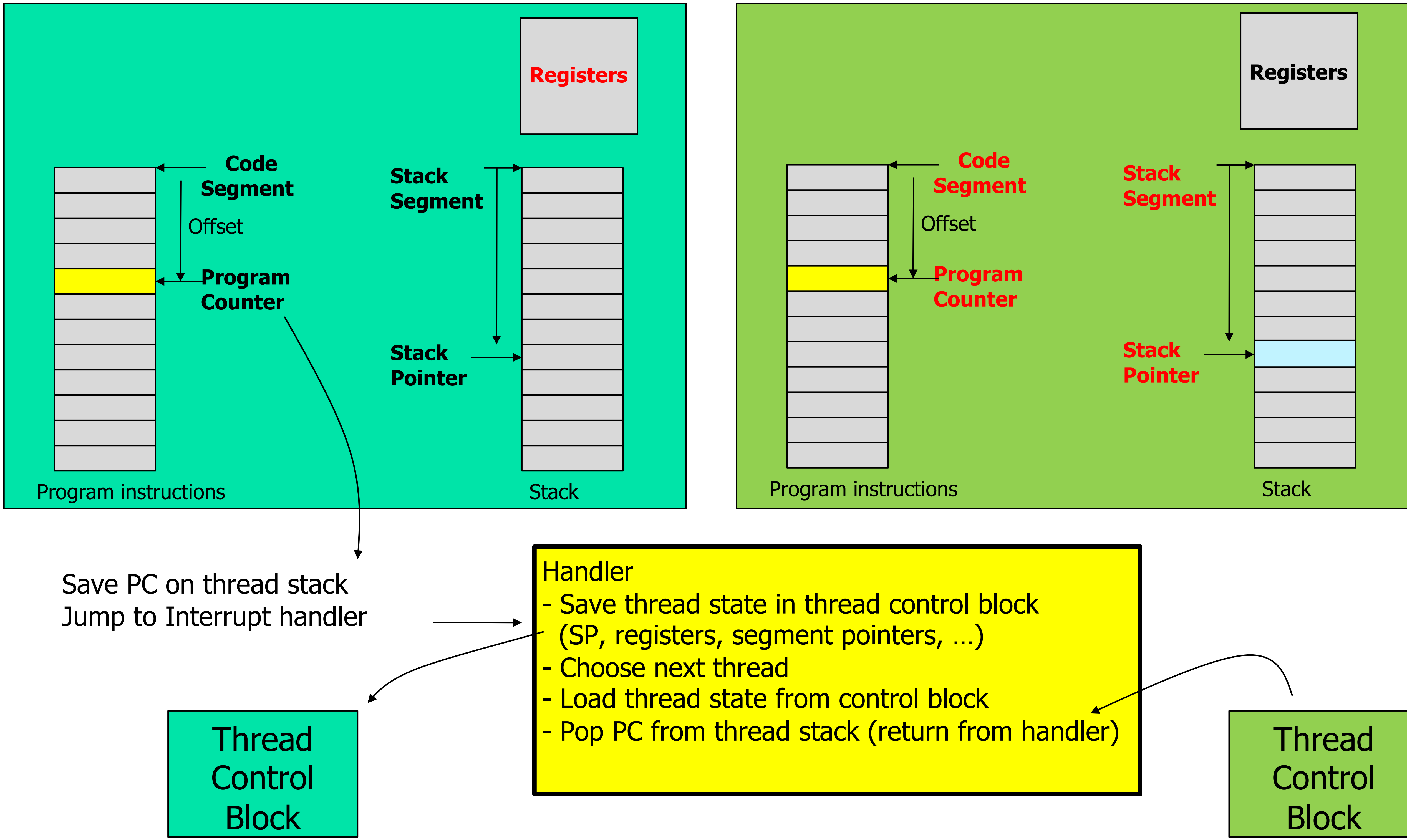

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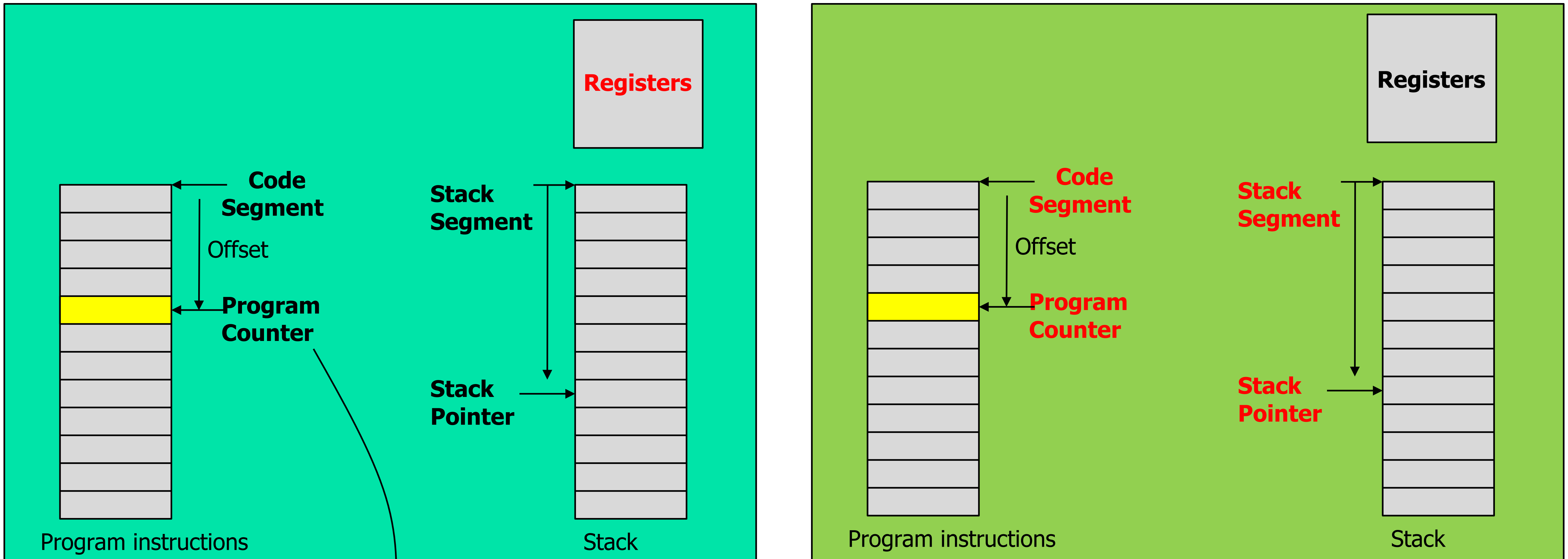


Save PC on thread stack
Jump to Interrupt handler

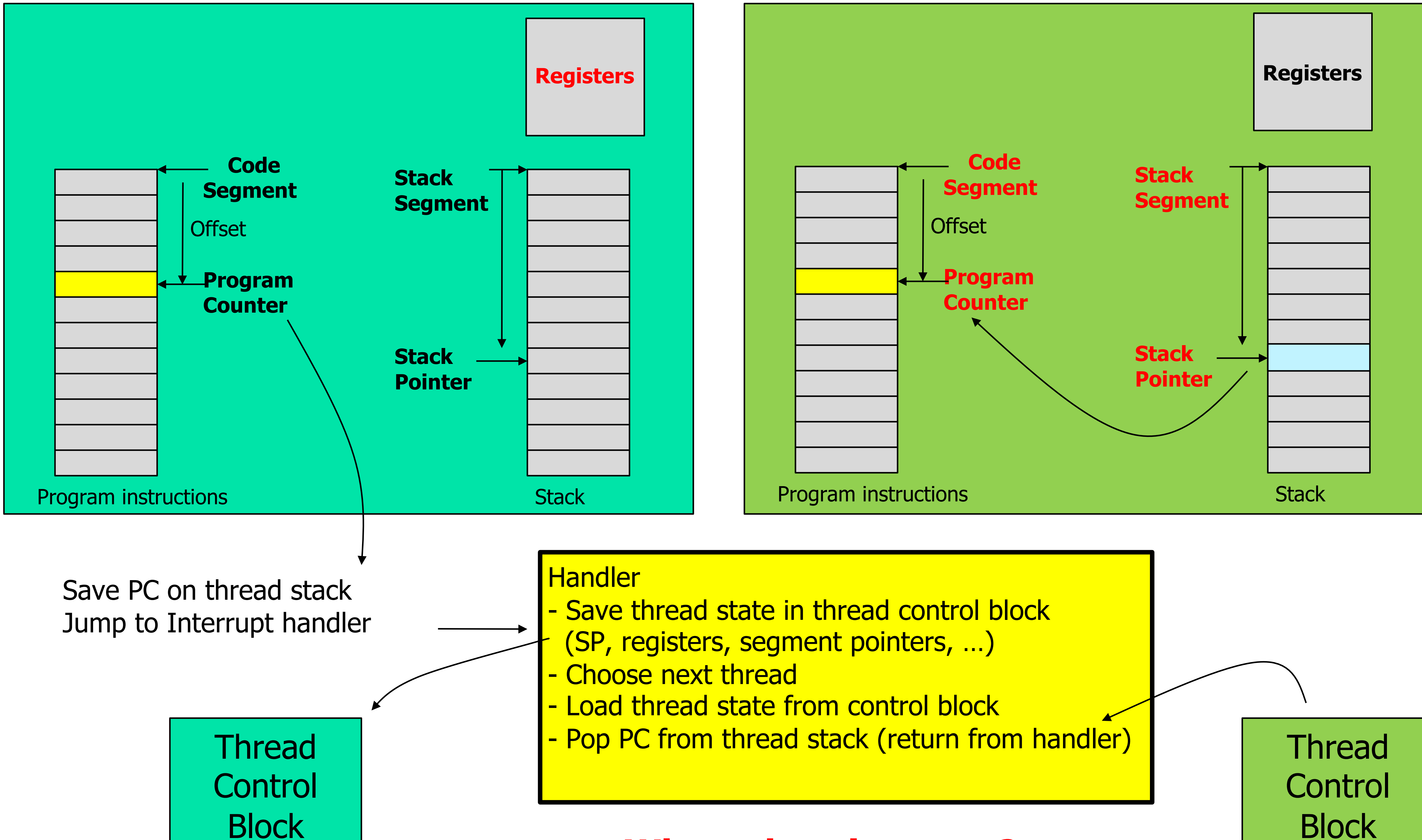
Handler
- Save thread state in thread control block
  (SP, registers, segment pointers, …)
- Choose next thread
- Load thread state from control block
- Pop PC from thread stack (return from handler)

Thread Control Block

Thread Control Block

Where does it return?

CTX Switch: Interrupt



Where does it return?

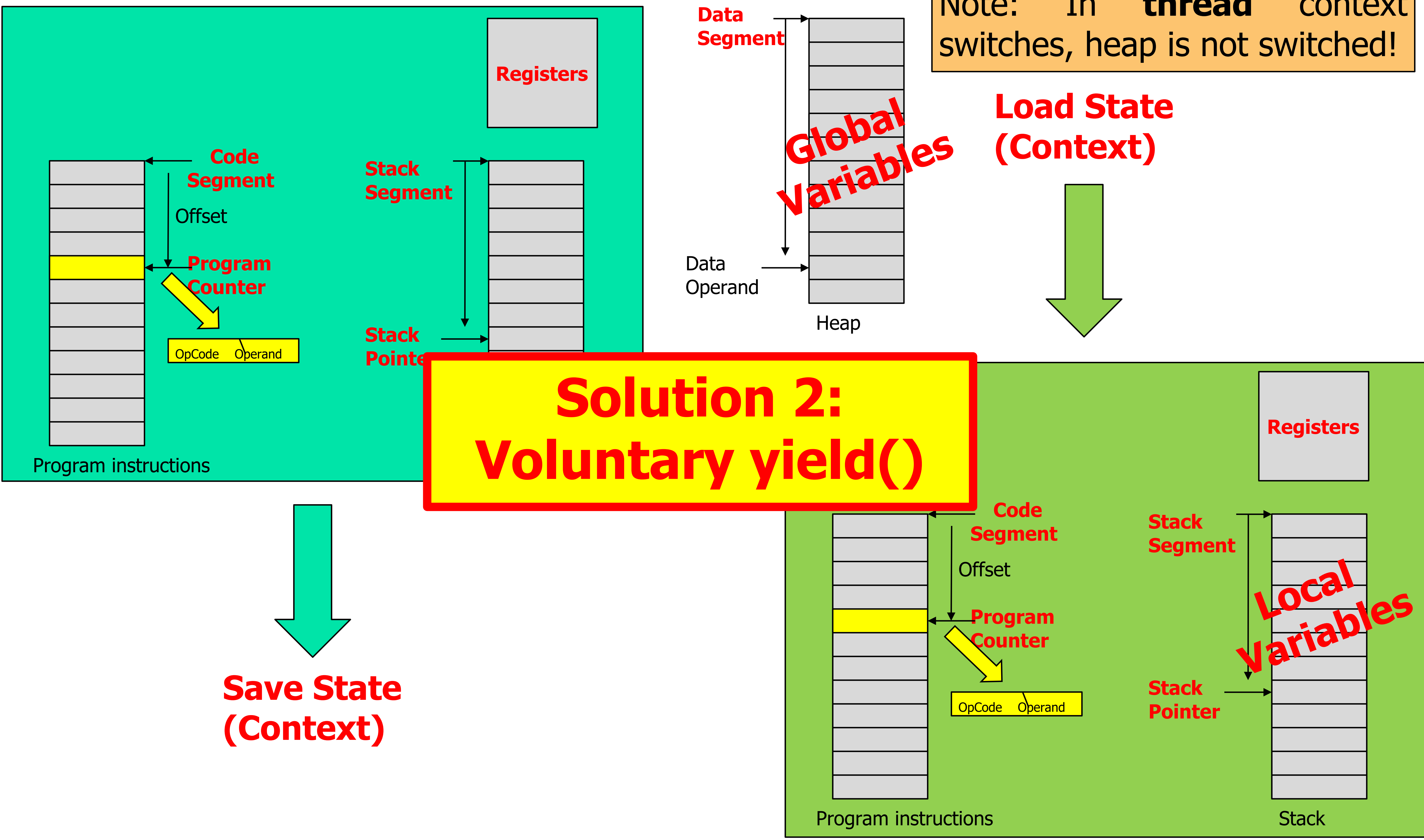
CTX Switch: Interrupt

What are some examples of context switches due to interrupts?

- **Clock Interrupt:** Task exceeds its time slice
- **I/O Interrupt**: Waiting processes may be preempted
- **Memory Fault:** CPU attempts to access a virtual memory address that is not in main memory. OS may resume execution of another process while retrieving the block, then moves process to ready state.

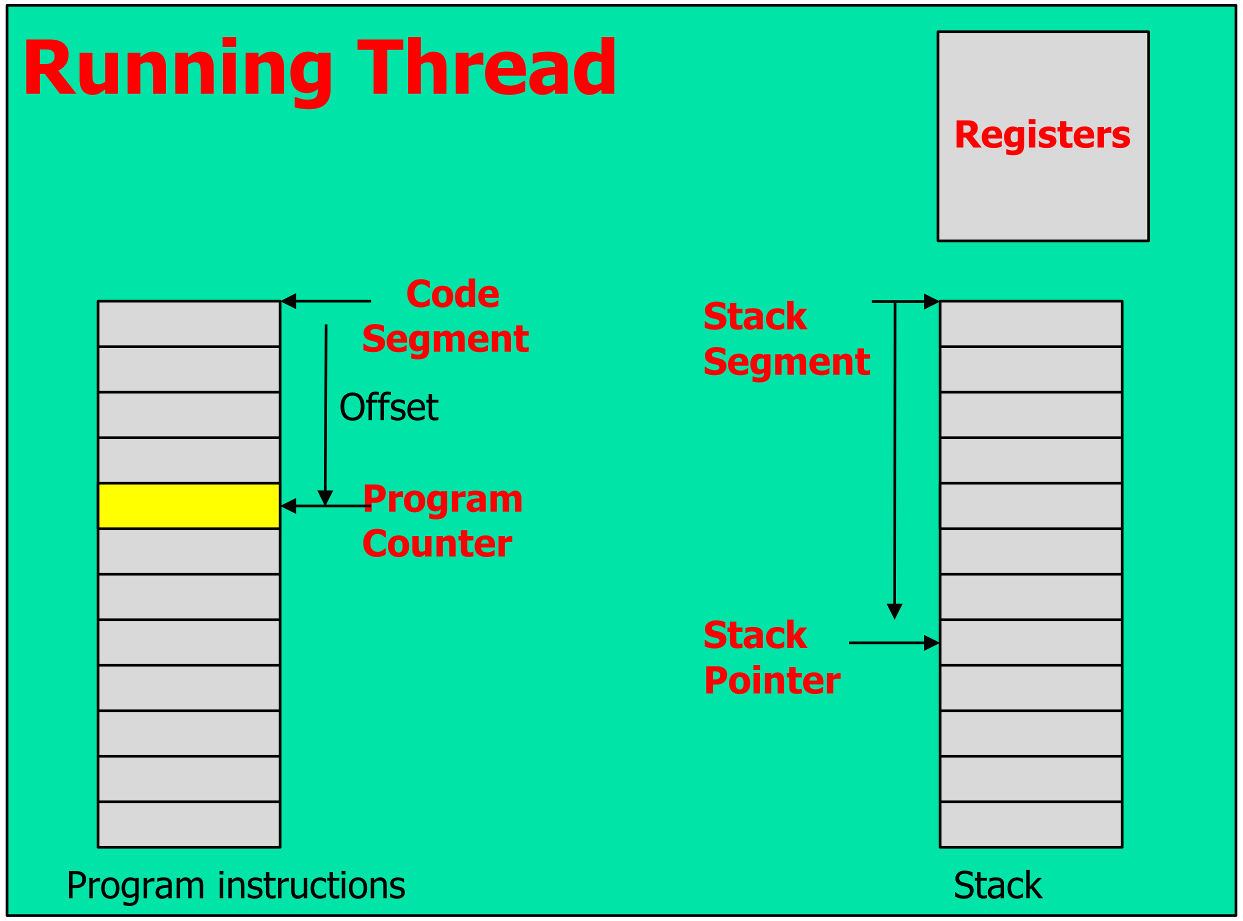
Thread Context Switch

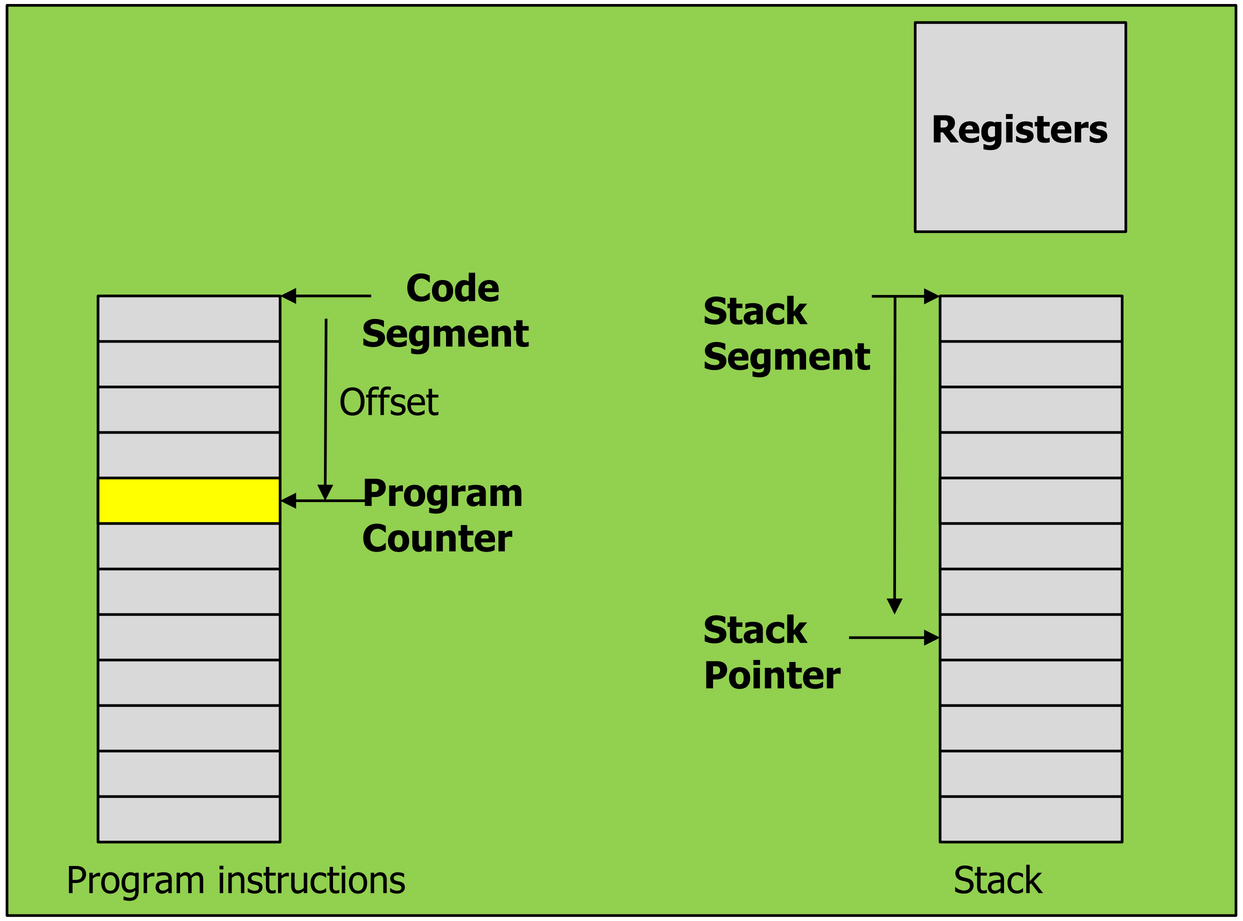
Note: In **thread** context switches, heap is not switched!



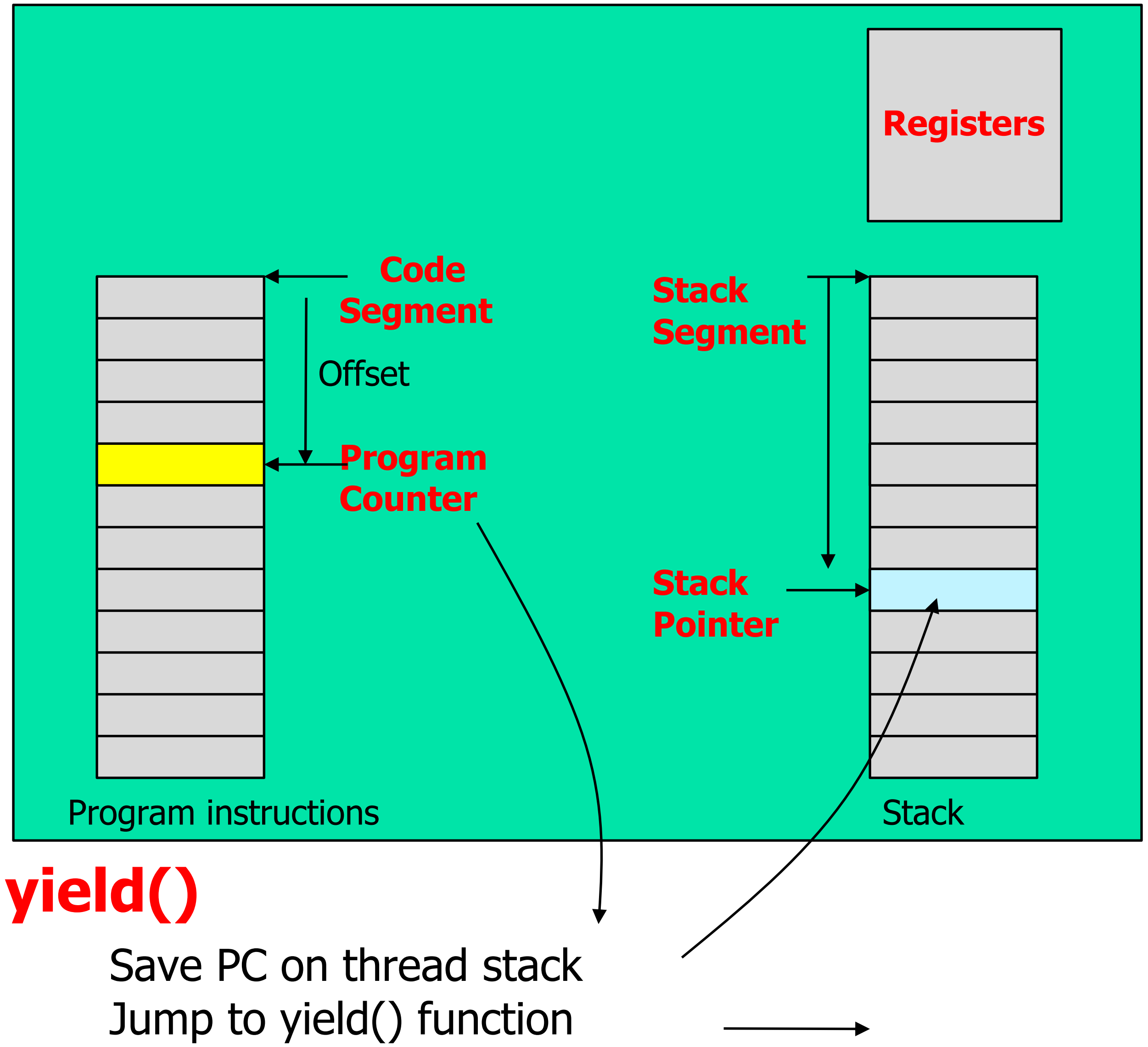
Solution 2: Voluntary yield()

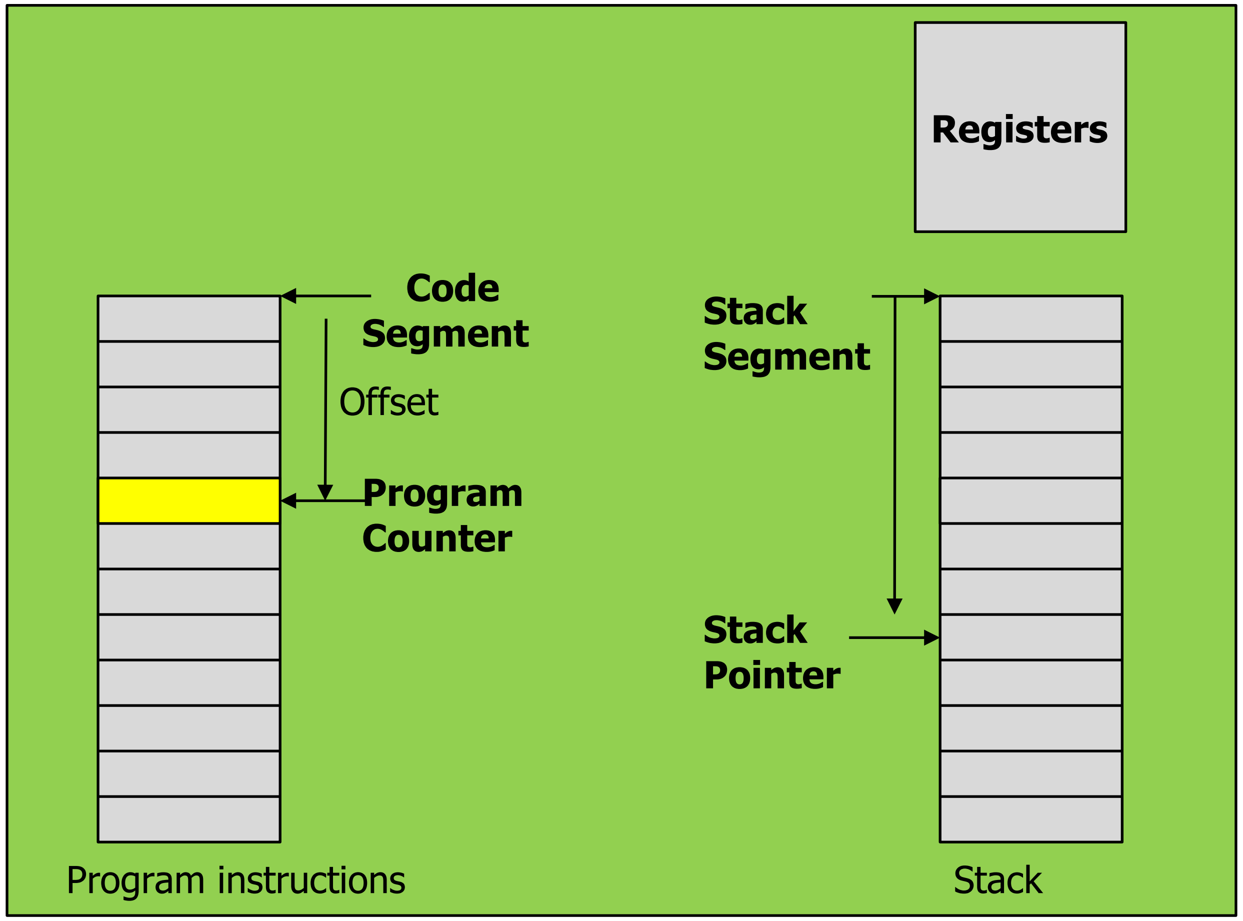
CTX Switch: Yield





CTX Switch: Yield

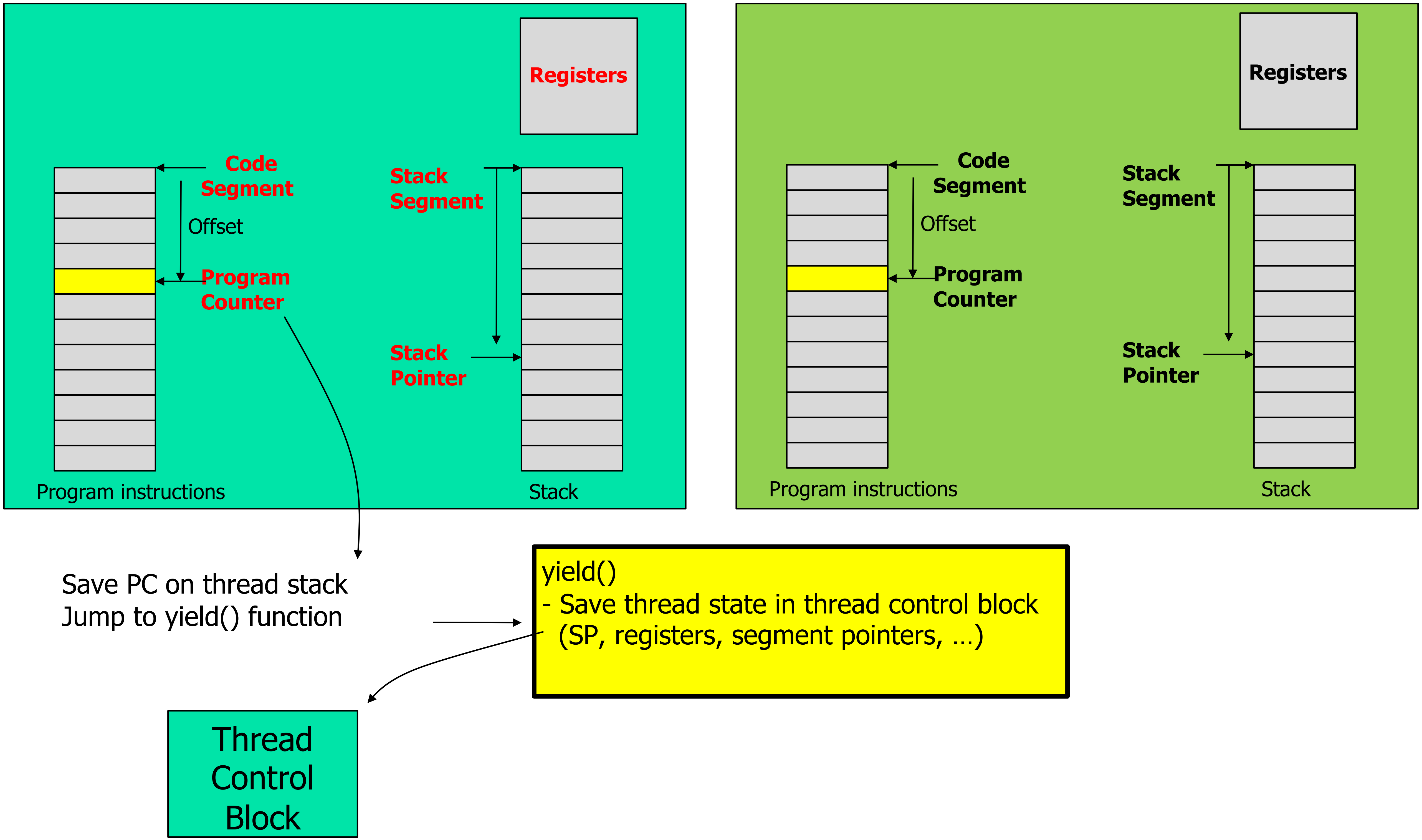




yield()

Save PC on thread stack
Jump to yield() function

CTX Switch: Yield



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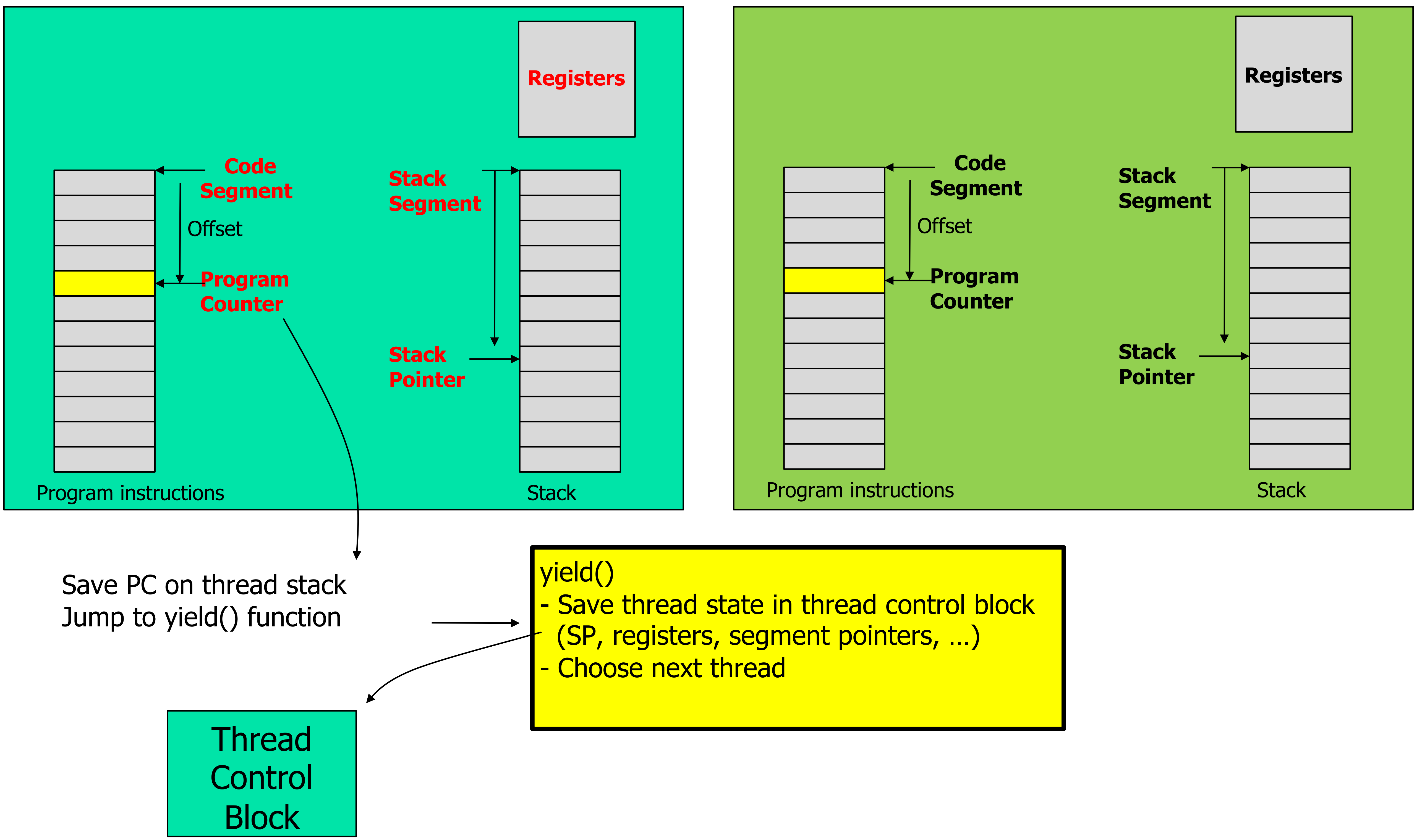

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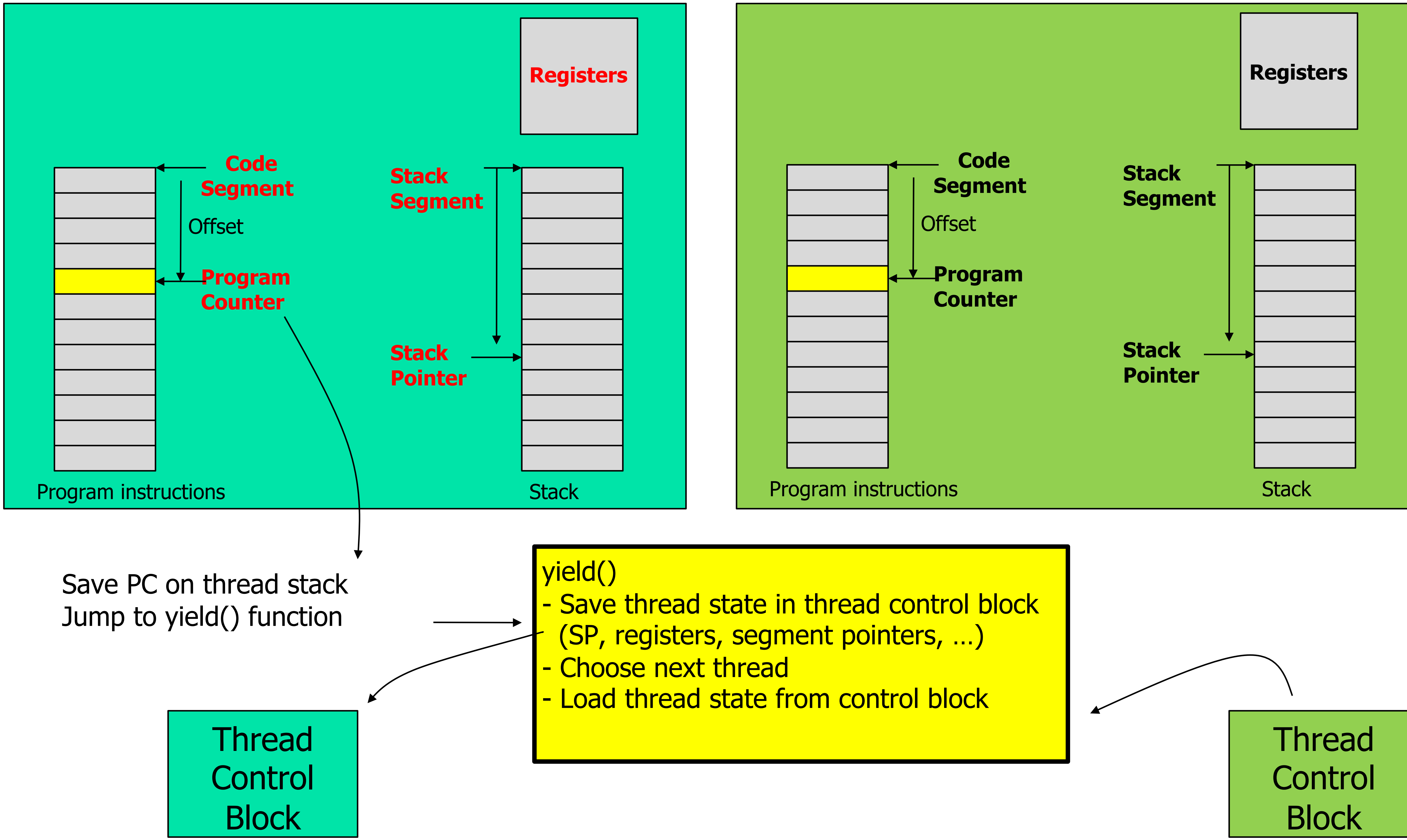

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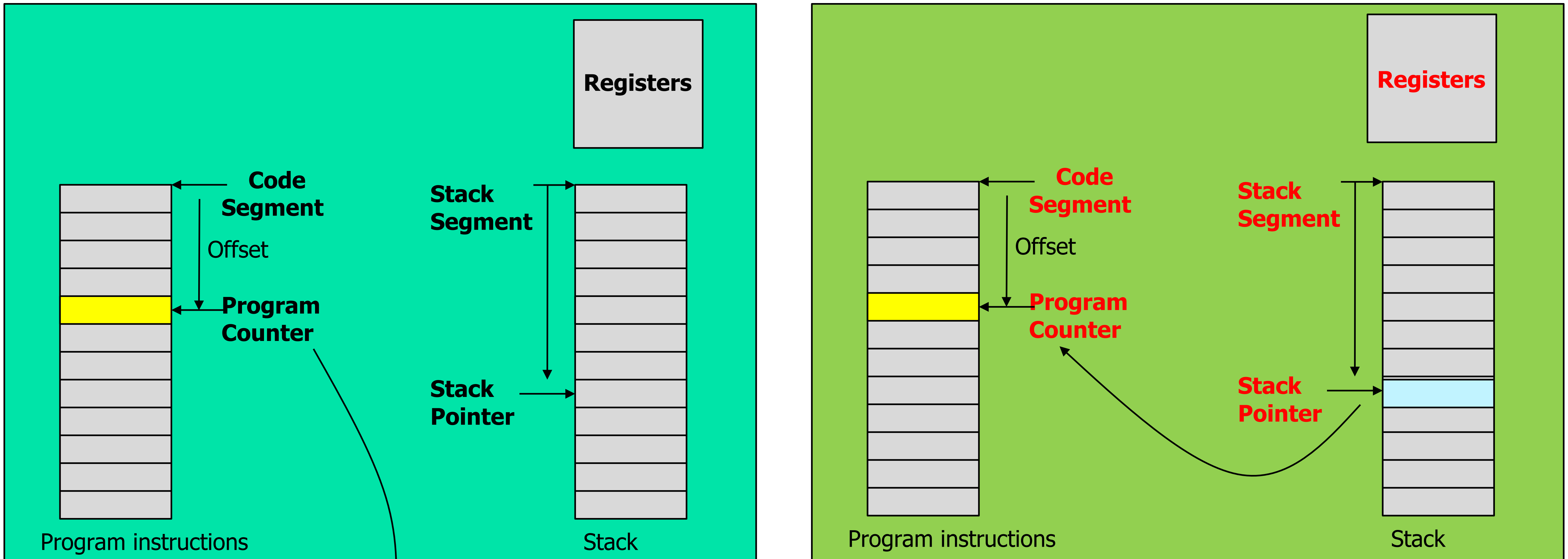

Save PC on thread stack
Jump to yield() function

yield()
- Save thread state in thread control block
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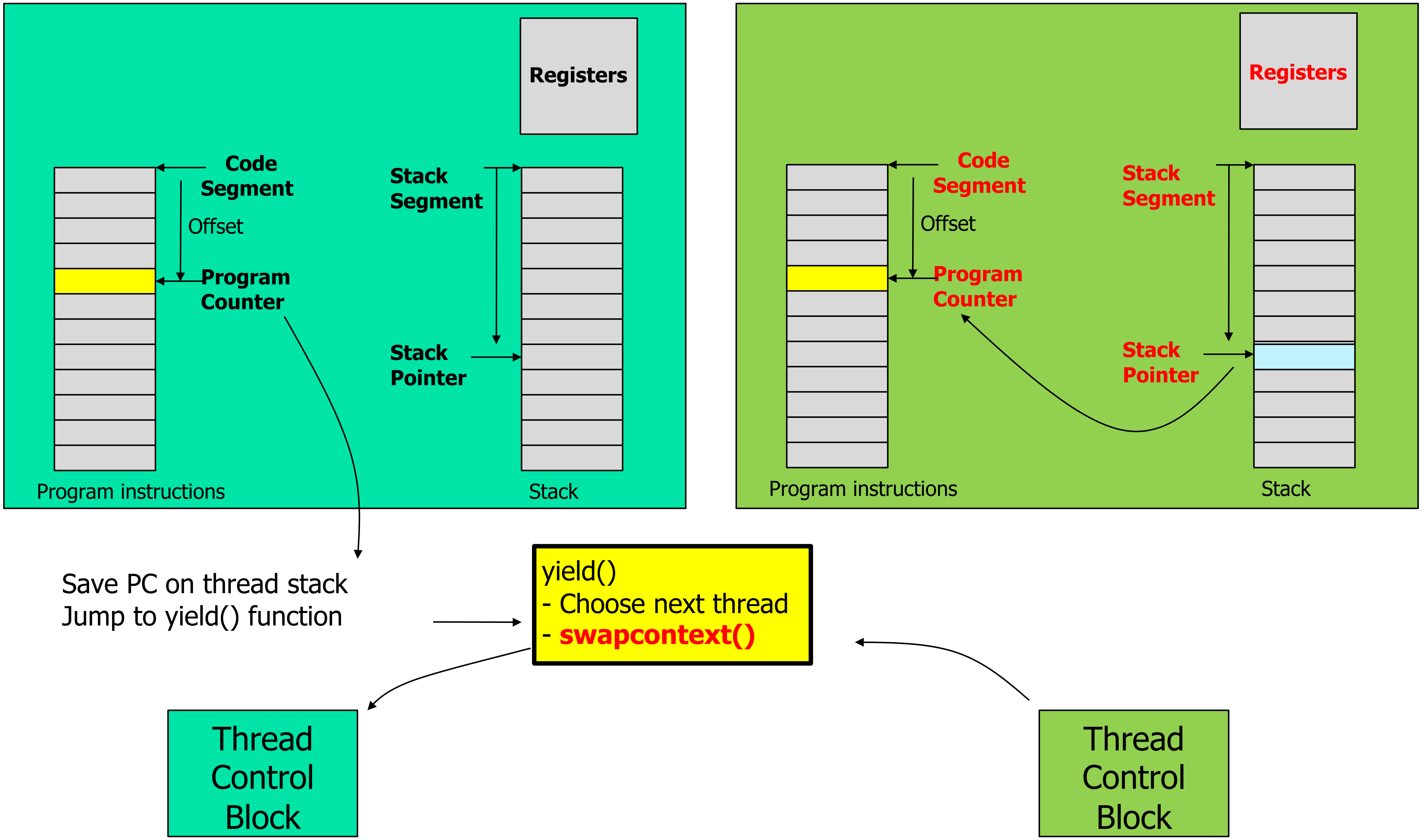
- Pop PC from thread stack (return from handler)

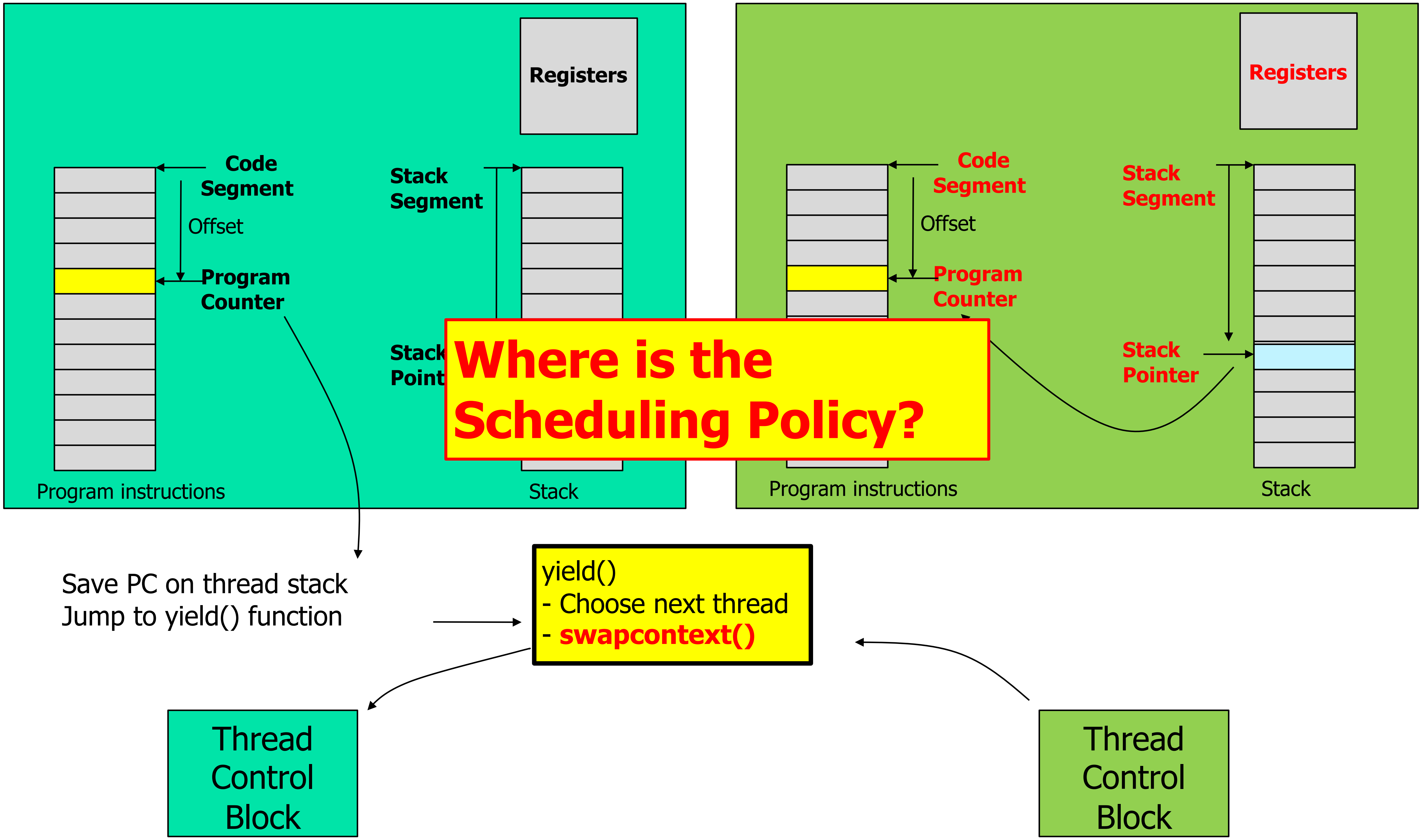
Thread Control Block

Thread Control Block

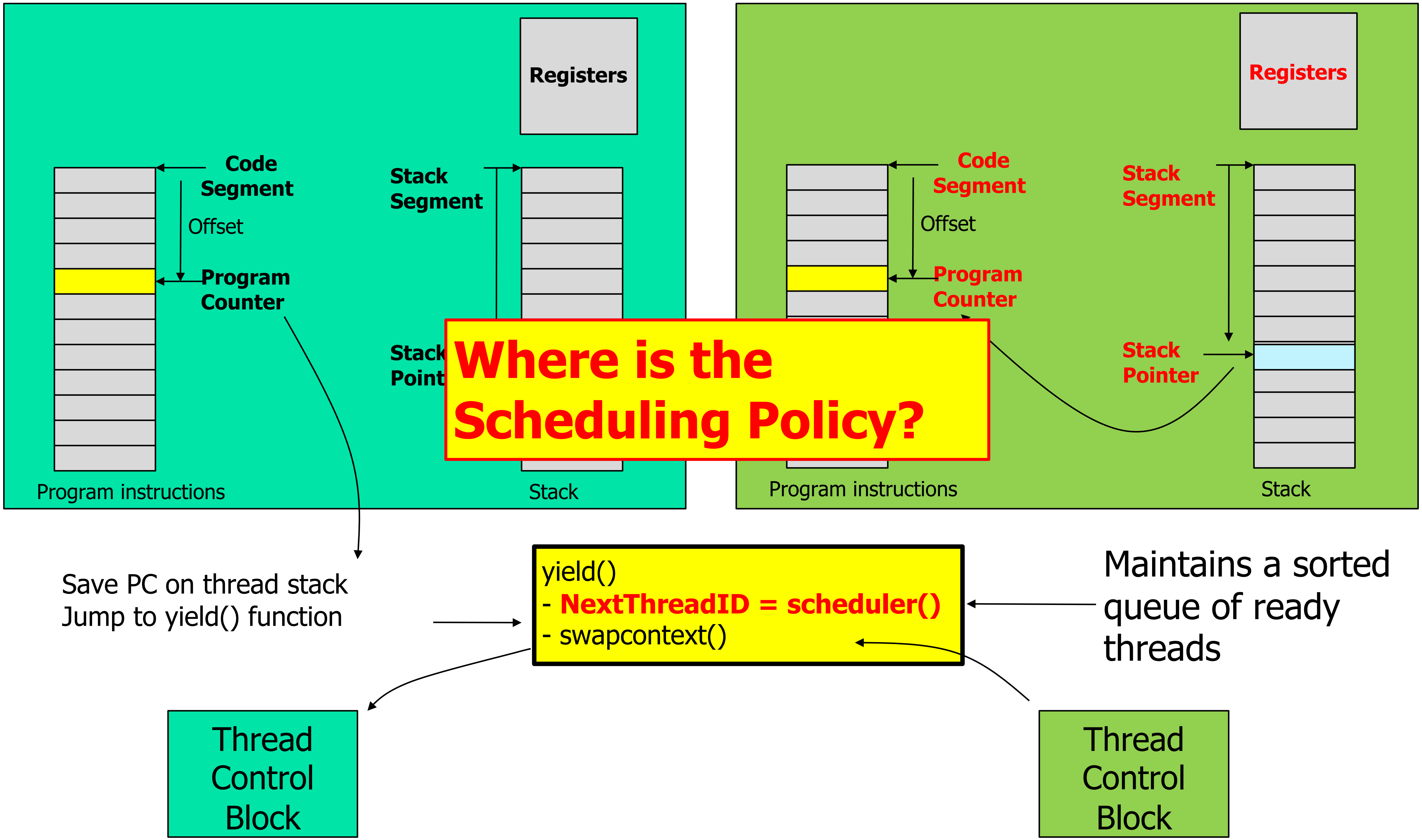
CTX Switch: Yield



Scheduler


Registers
Code Segment
Offset
Program Counter
Stack Segment
Stack Pointer
Program instructions
Stack
Registers
Code Segment
Offset
Program Counter
Stack Segment
Stack Pointer
Program instructions
Stack
Where is the Scheduling Policy?
Save PC on thread stack
Jump to yield() function
yield()
- Choose next thread
- swapcontext()
Thread Control Block
Thread Control Block

Scheduler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Where is the Scheduling Policy?
Save PC on thread stack
Jump to yield() function
yield()
- NextThreadID = scheduler()
- swapcontext()
Maintains a sorted queue of ready threads
Thread Control Block
Thread Control Block