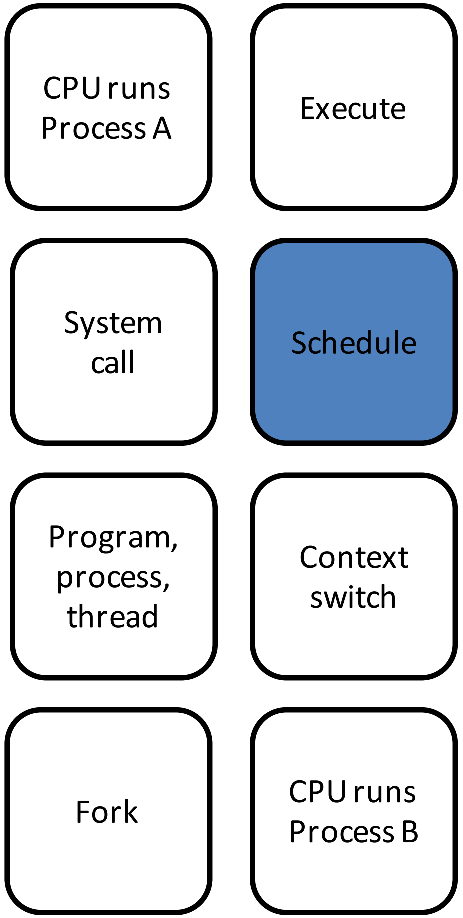
# Operating System Design and Implementation

*Process Management – Part II*

Shiao-Li Tsao

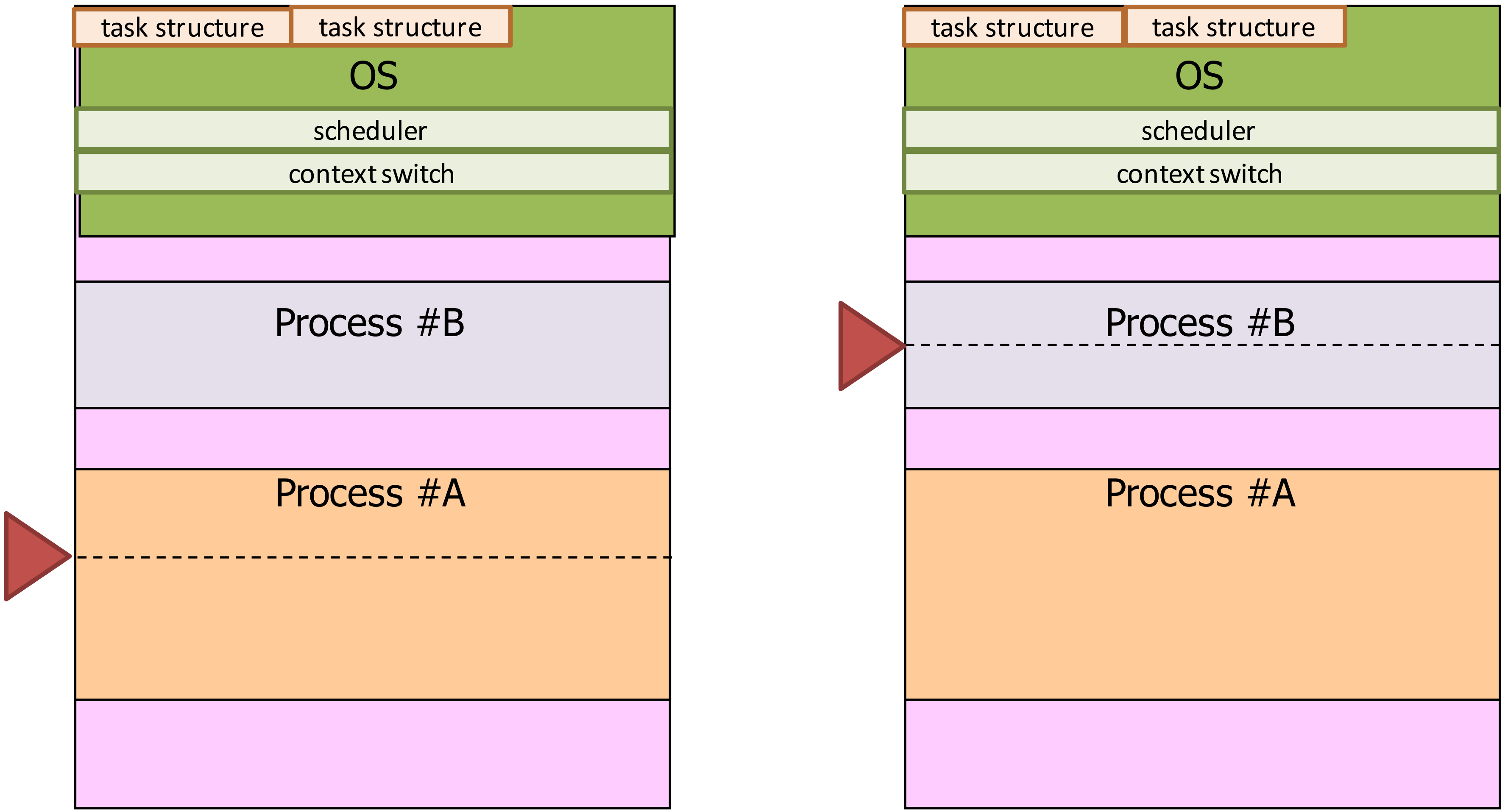
| | |
|---|---|
| CPU runs Process A | Execute |
| System call | Schedule |
| Program, process, thread | Context switch |
| Fork | CPU runs Process B |


CPU runs Process A
Execute
System call
Schedule
Program, process, thread
Context switch
Fork
CPU runs Process B

# Process schedule and context switching in Linux

- Scheduling
  - Find the next suitable process to run
- Context switch
  - Store the context of the current process, restore the context of the next process

# Scheduler in Details

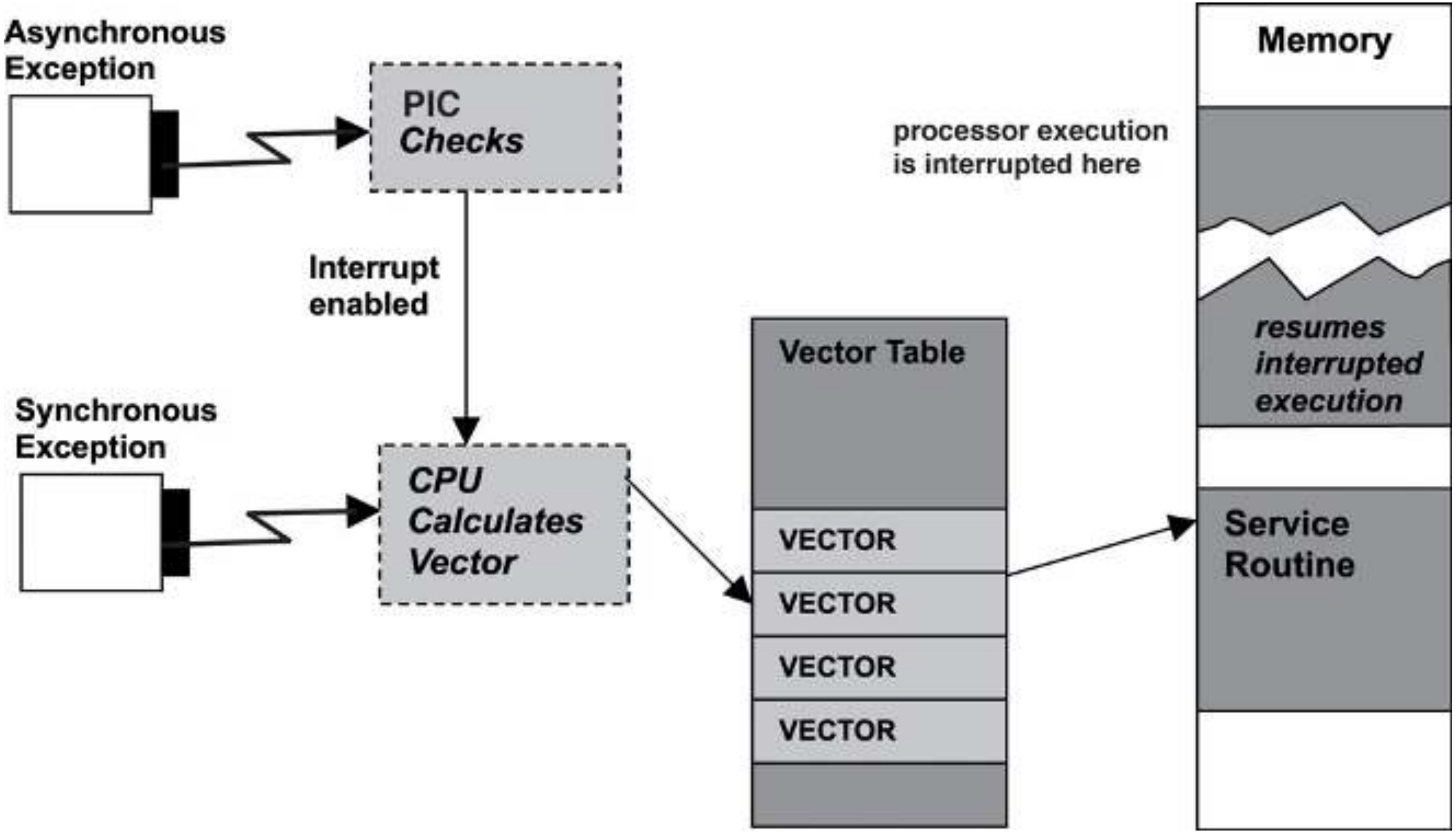


# Process schedule and context switching in Linux

- When is the scheduler be invoked
  - Direct invocation vs. Lazy invocation

  - When returning to user-space from a system call
  - When returning to user-space from an interrupt handler
  - When an interrupt handler exits, before returning to kernel-space
  - If a task in the kernel explicitly calls schedule()
  - If a task in the kernel blocks (which results in a call to schedule())

# Interrupt Basics



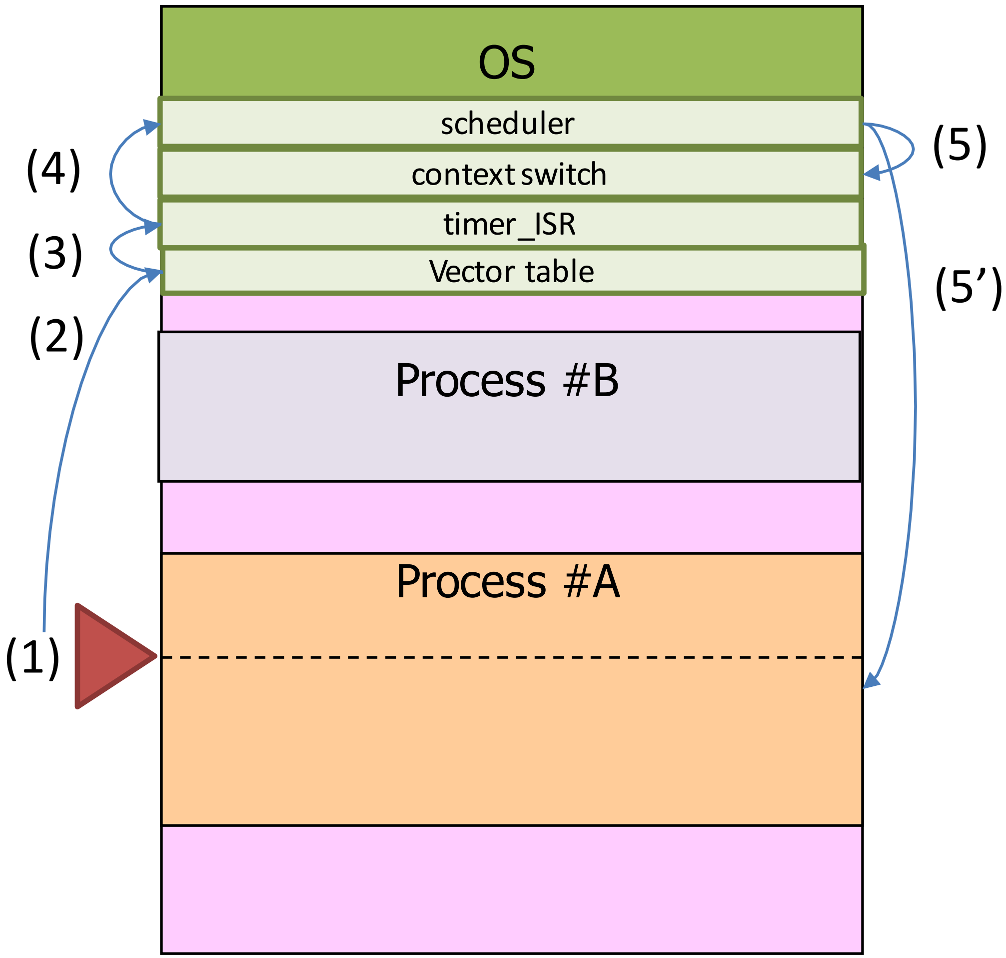

*Source: Qing Li "real-time concepts for embedded systems"*

# X86 Interrupts

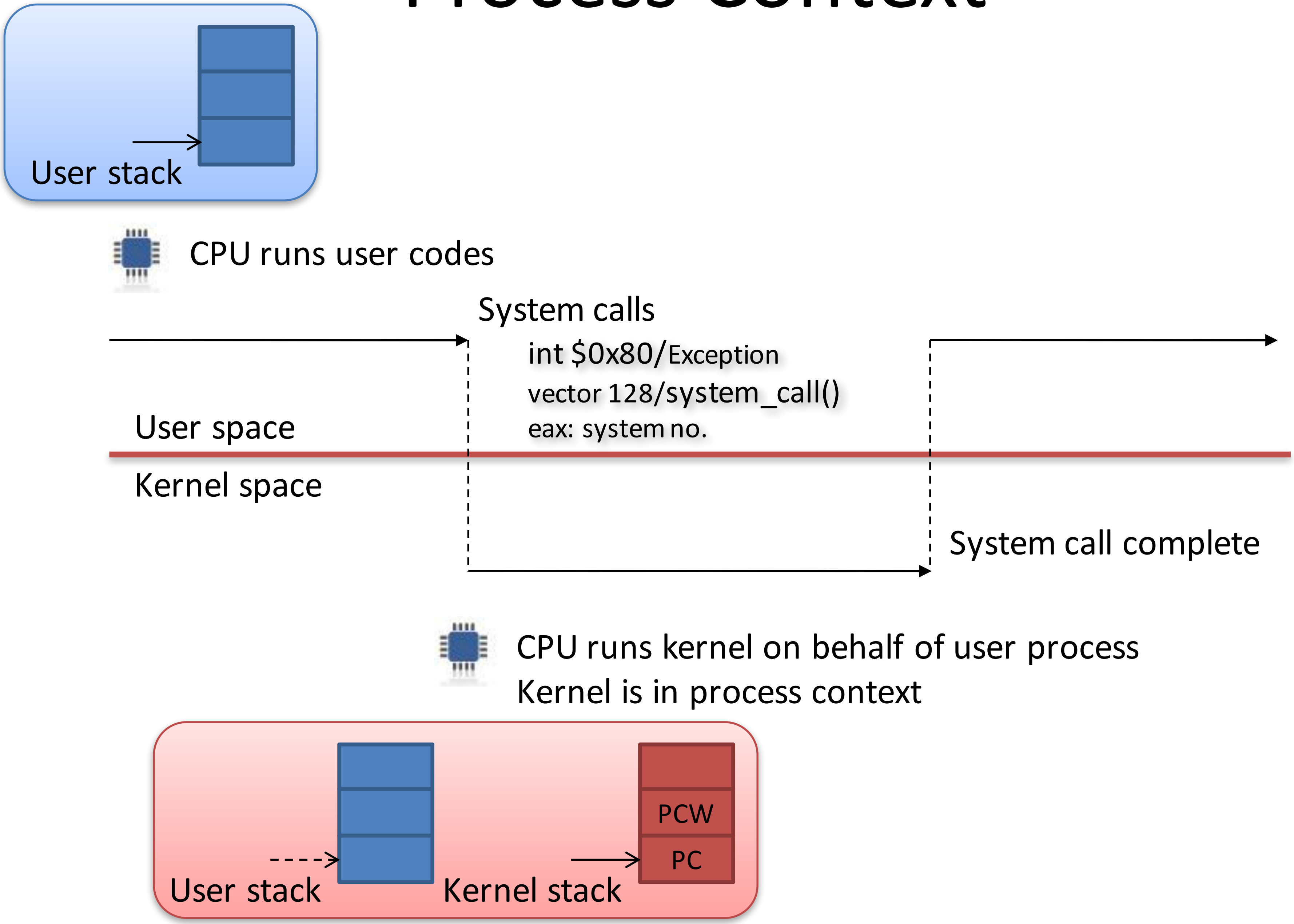
| IRQ | Standard Function | Bus Slot | Card Type | Recommended Use |
|---|---|---|---|---|
| 0 | System Timer | No | - | - |
| 1 | Keyboard Controller | No | - | - |
| 2 | 2nd IRQ Controller Cascade | No | - | - |
| 8 | Real-Time Clock | No | - | - |
| 9 | Avail. (as IRQ2 or IRQ9) | Yes | 8/16-bit | Network Card |
| 10 | Available | Yes | 16-bit | USB |
| 11 | Available | Yes | 16-bit | SCSI Host Adapter |
| 12 | Mouse Port/Available | Yes | 16-bit | Mouse Port |
| 13 | Math Coprocessor | No | — | — |
| 14 | Primary IDE | Yes | 16-bit | Primary IDE (hard disks) |
| 15 | Secondary IDE | Yes | 16-bit | 2nd IDE (CD-ROM/Tape) |
| 3 | Serial 2 (COM2:) | Yes | 8/16-bit | COM2:/Internal Modem |
| 4 | Serial 1 (COM1:) | Yes | 8/16-bit | COM1: |
| 5 | Sound/Parallel 2 (LPT2:) | Yes | 8/16-bit | Sound Card |
| 6 | Floppy Controller | Yes | 8/16-bit | Floppy Controller |
| 7 | Parallel 1 (LPT1:) | Yes | 8/16-bit | LPT1: |

| Vector range | Use |
|---|---|
| 0–19 (0x0–0x13) | Nonmaskable interrupts and exceptions |
| 20–31 (0x14–0x1f) | Intel-reserved |
| 32–127 (0x20–0x7f) | External interrupts (IRQs) |
| 128 (0x80) | Programmed exception for system calls |
| 129–238 (0x81–0xee) | External interrupts (IRQs) |

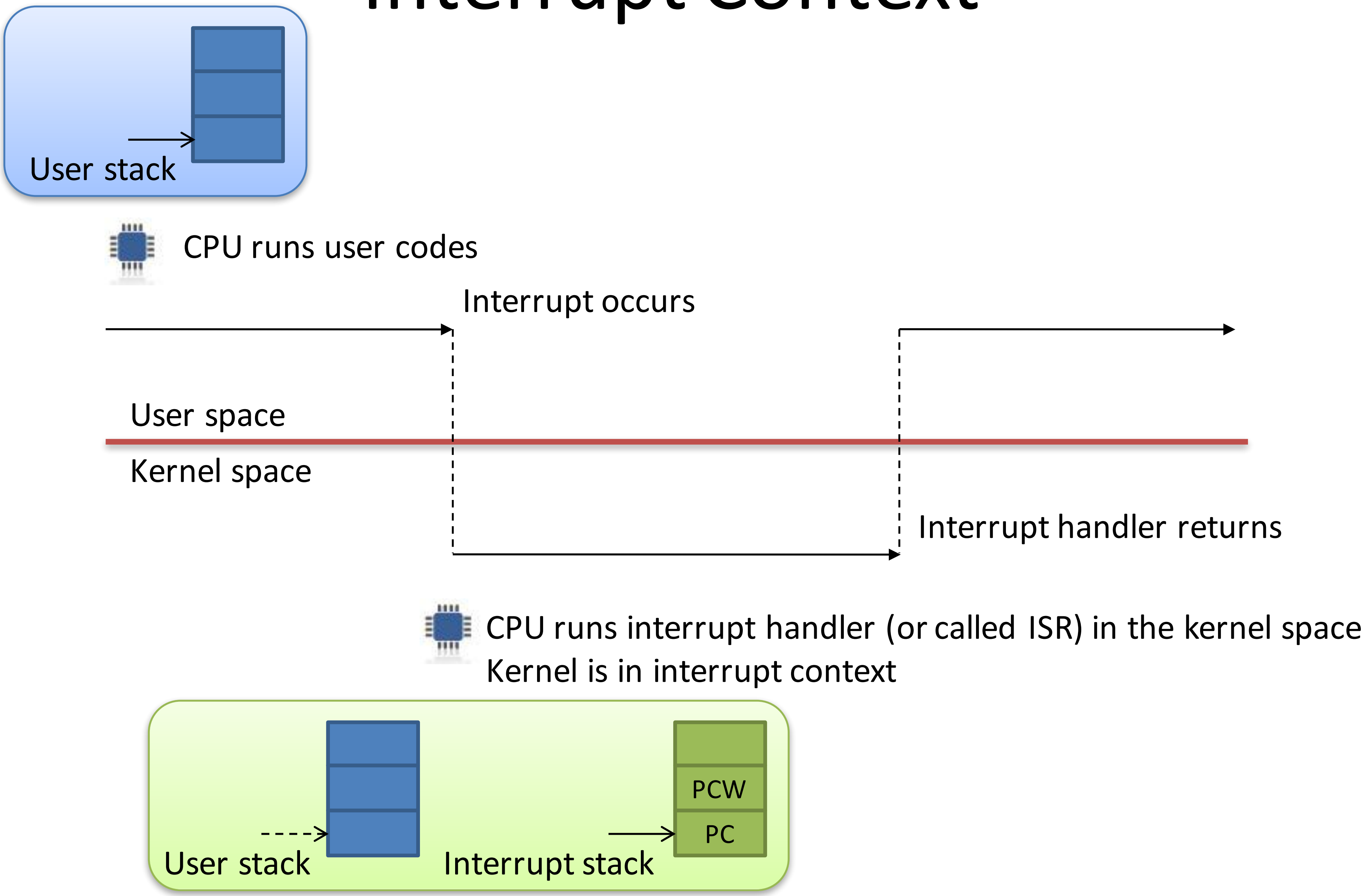
# Time Interrupt Basics



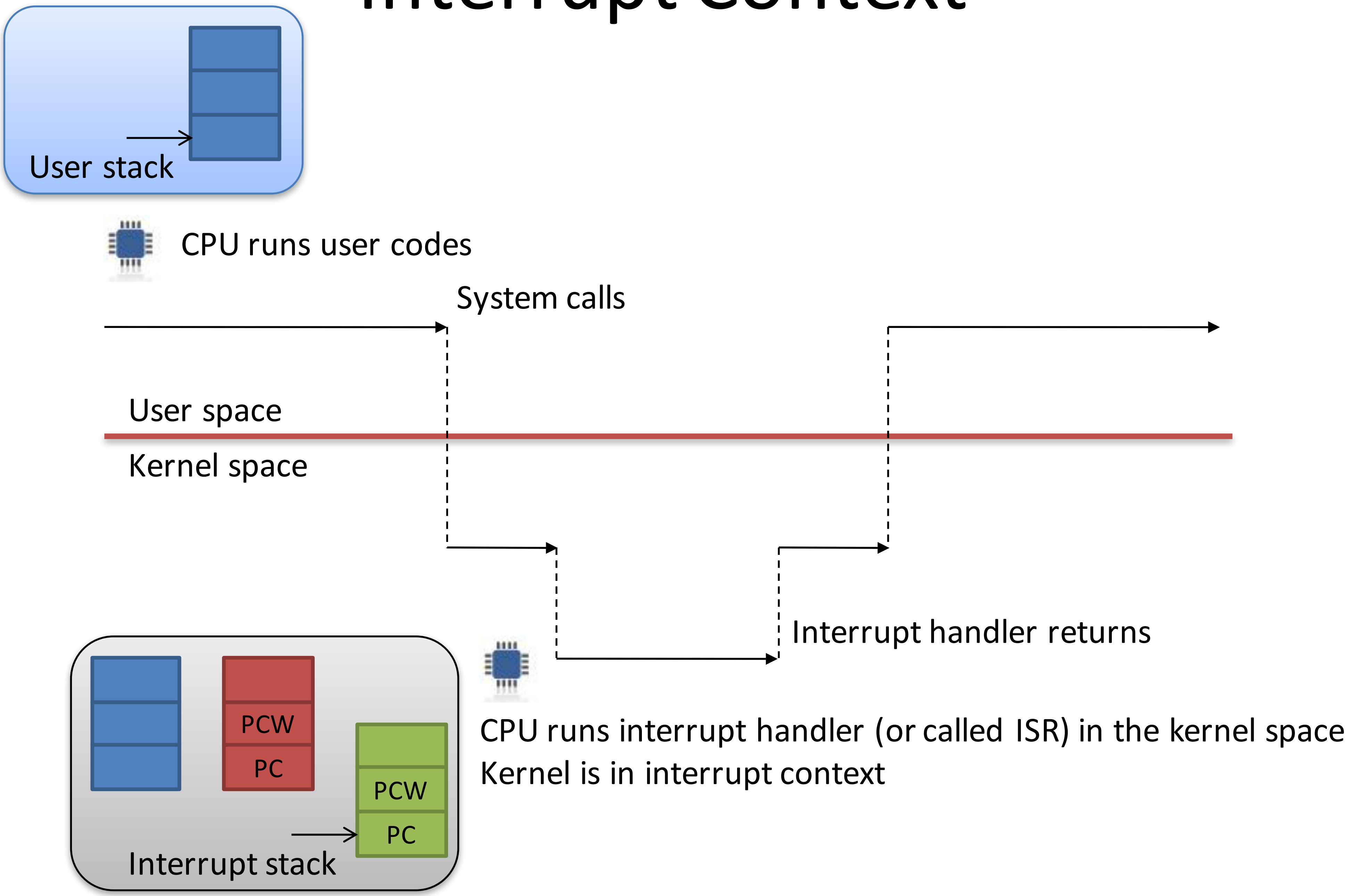
# Process Context

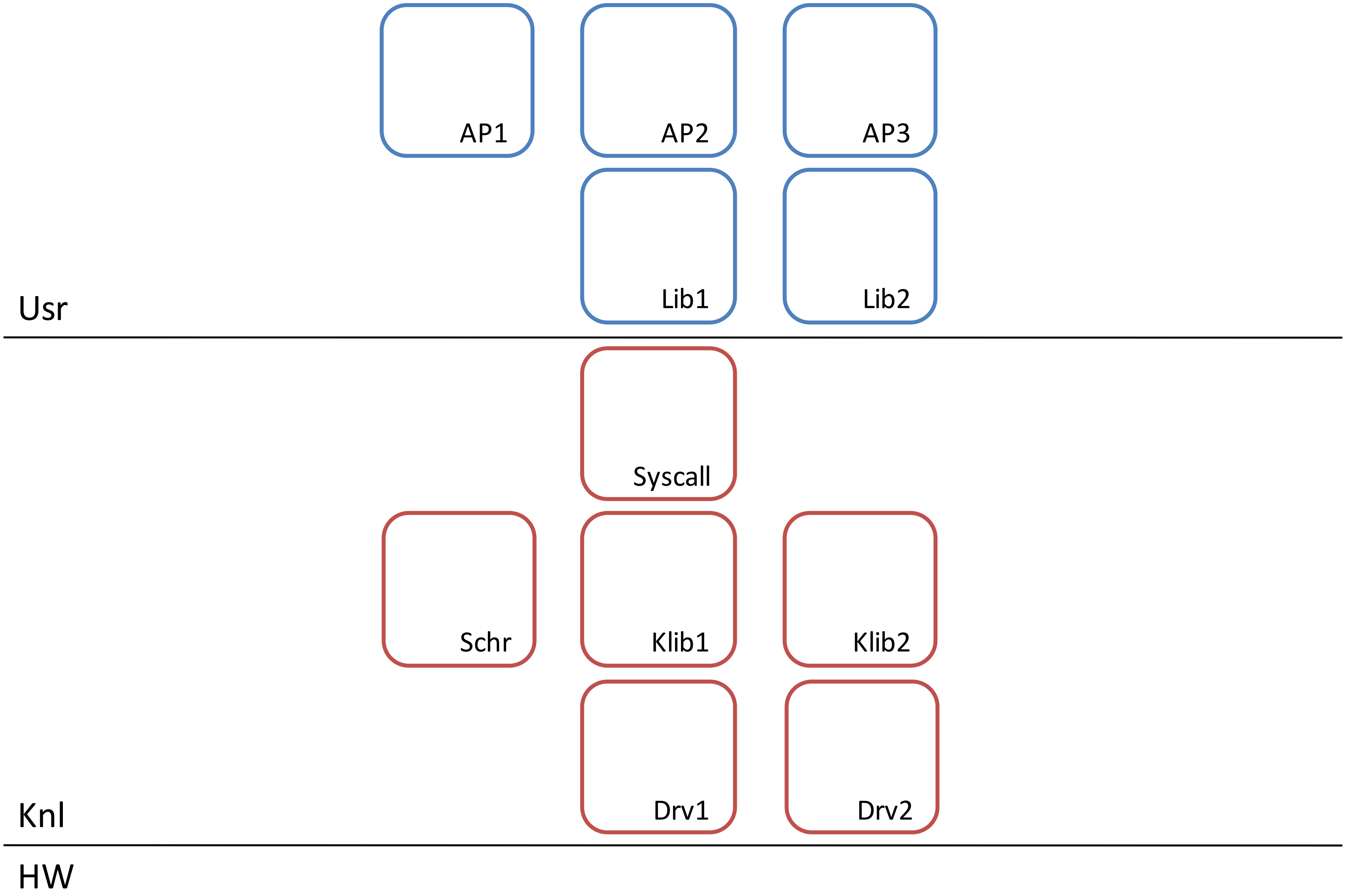


# Interrupt Context

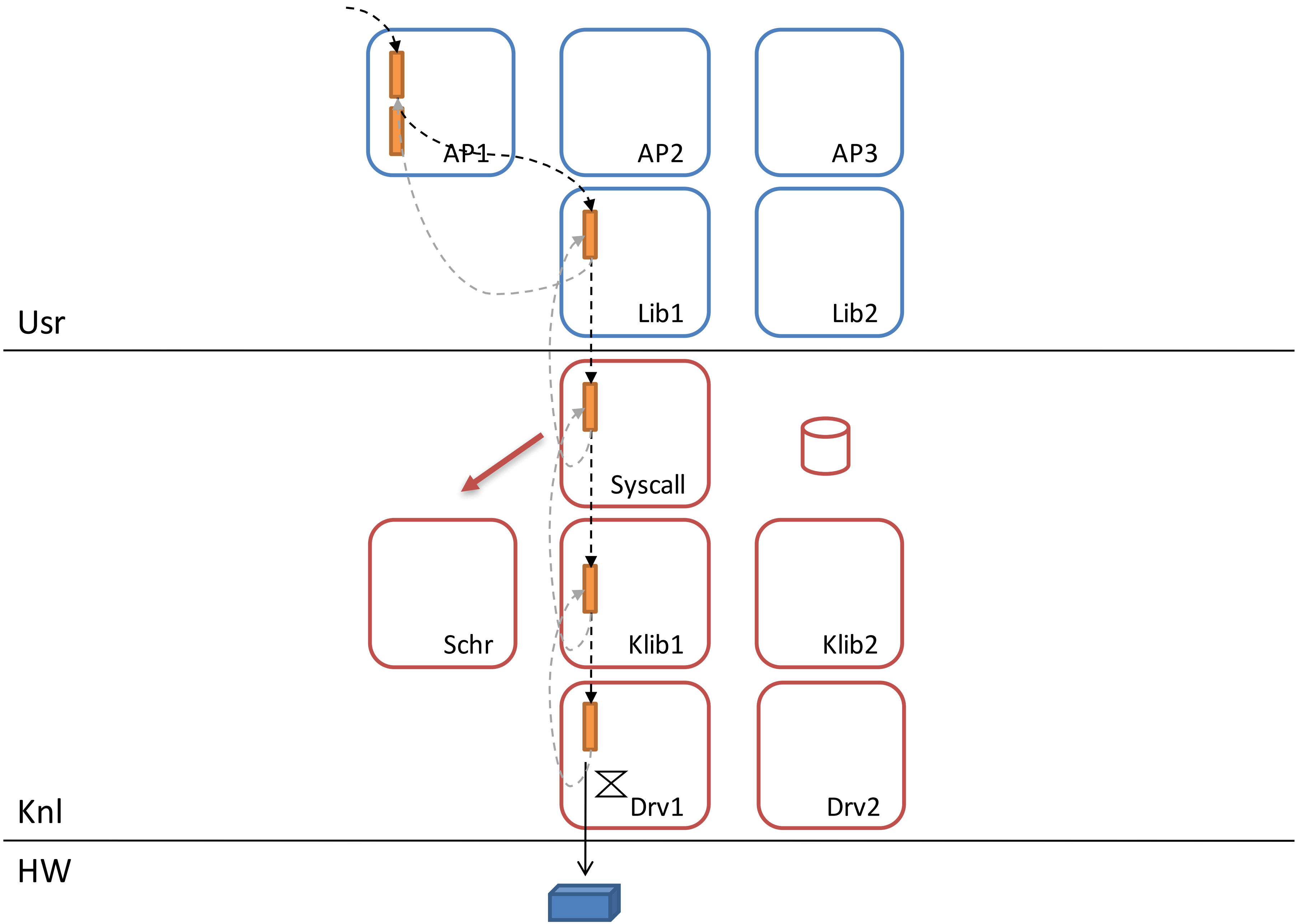


# Interrupt Context

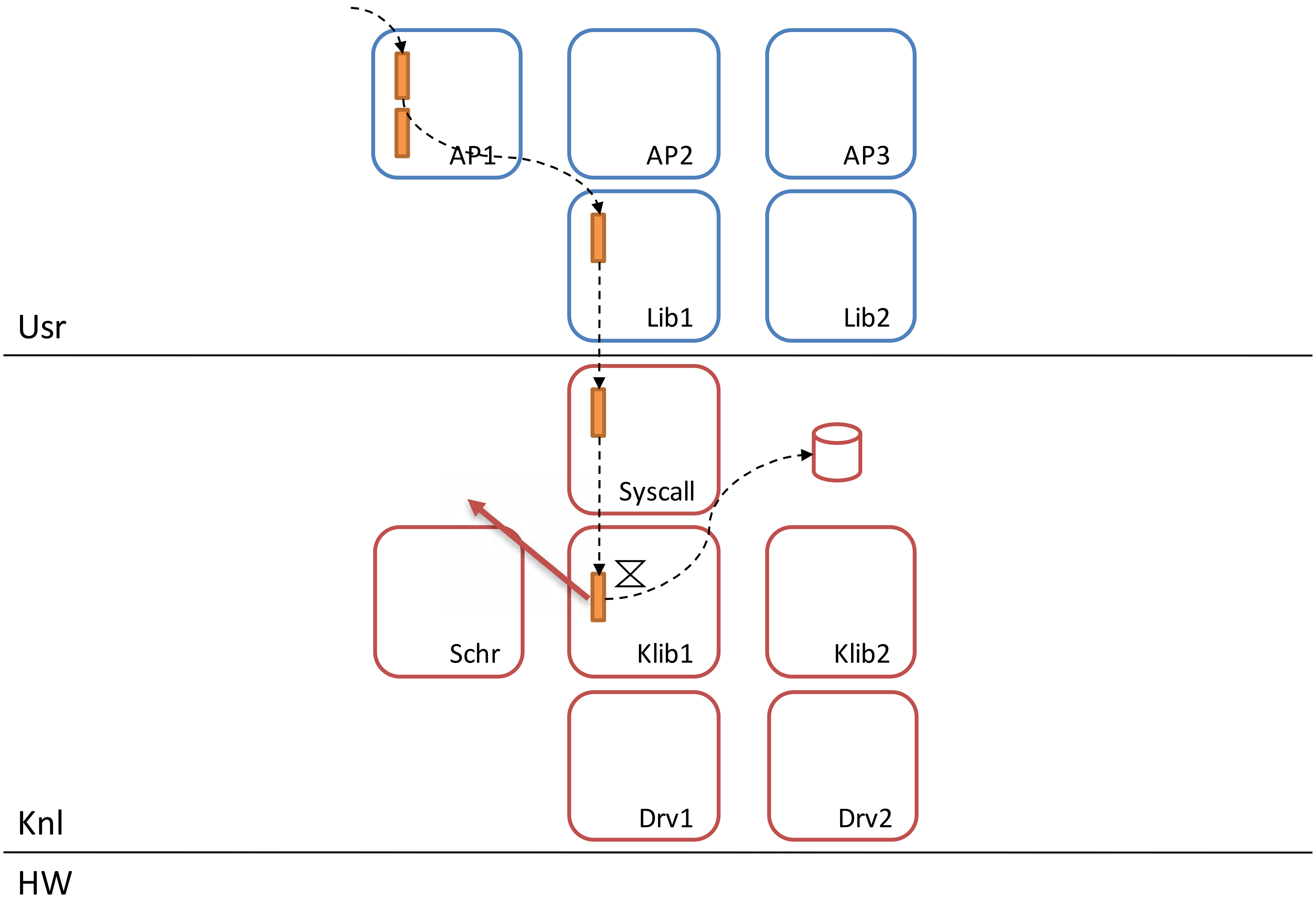



AP1
AP2
AP3
Lib1
Lib2
Usr
Syscall
Schr
Klib1
Klib2
Drv1
Drv2
Knl
HW

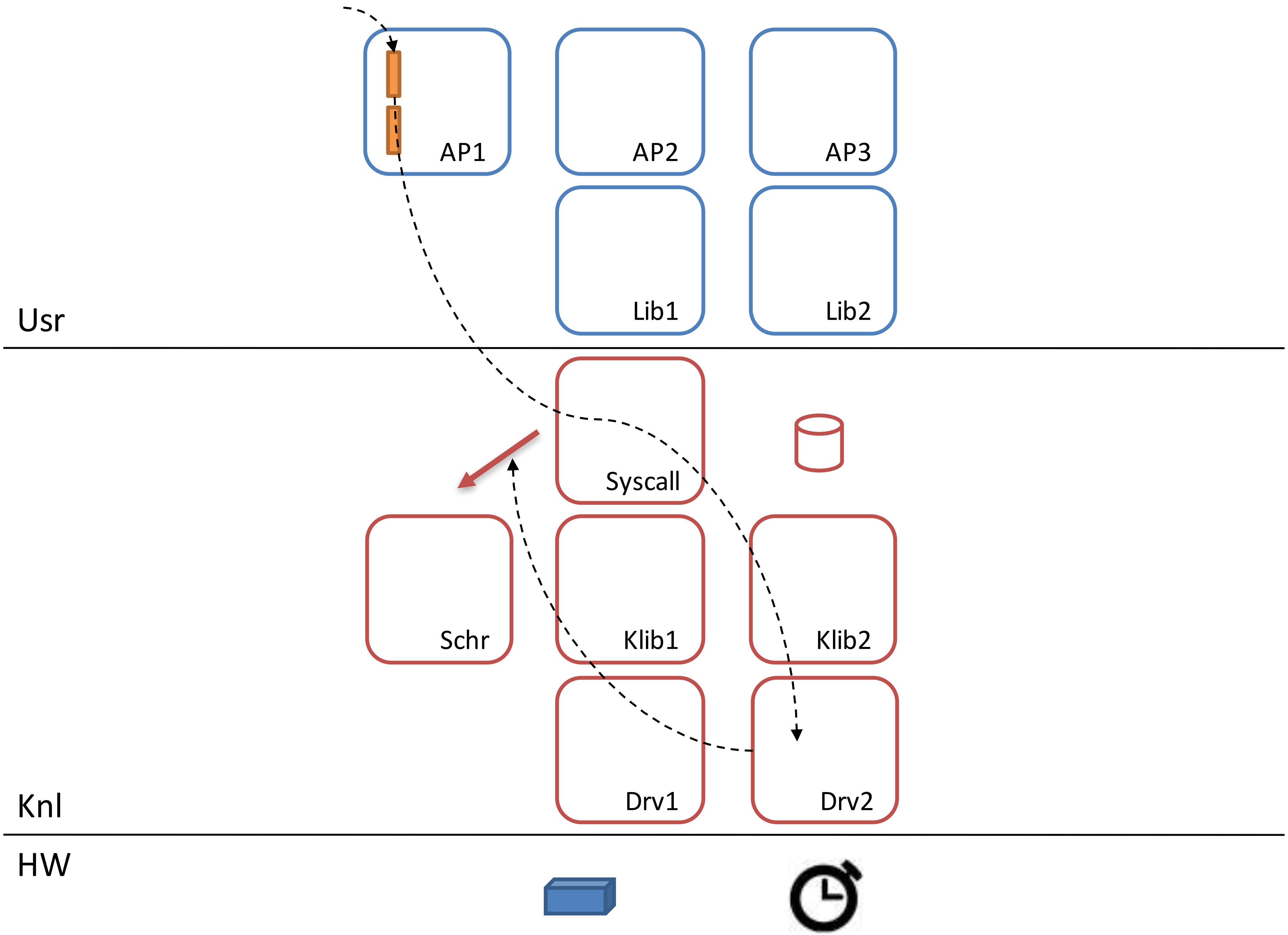
# When returning to user-space from a system call



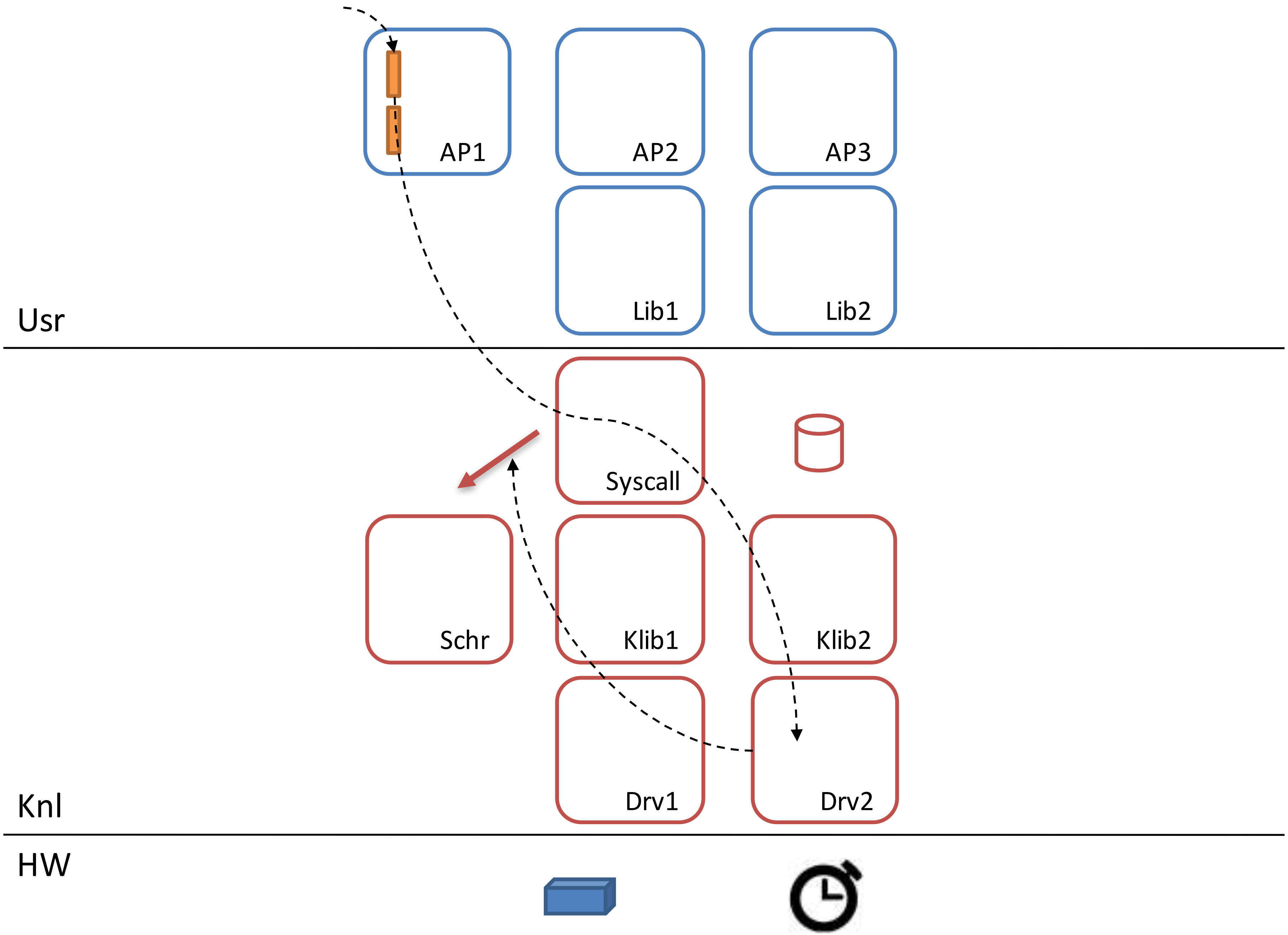
# If a task in the kernel blocks (which results in a call to schedule())



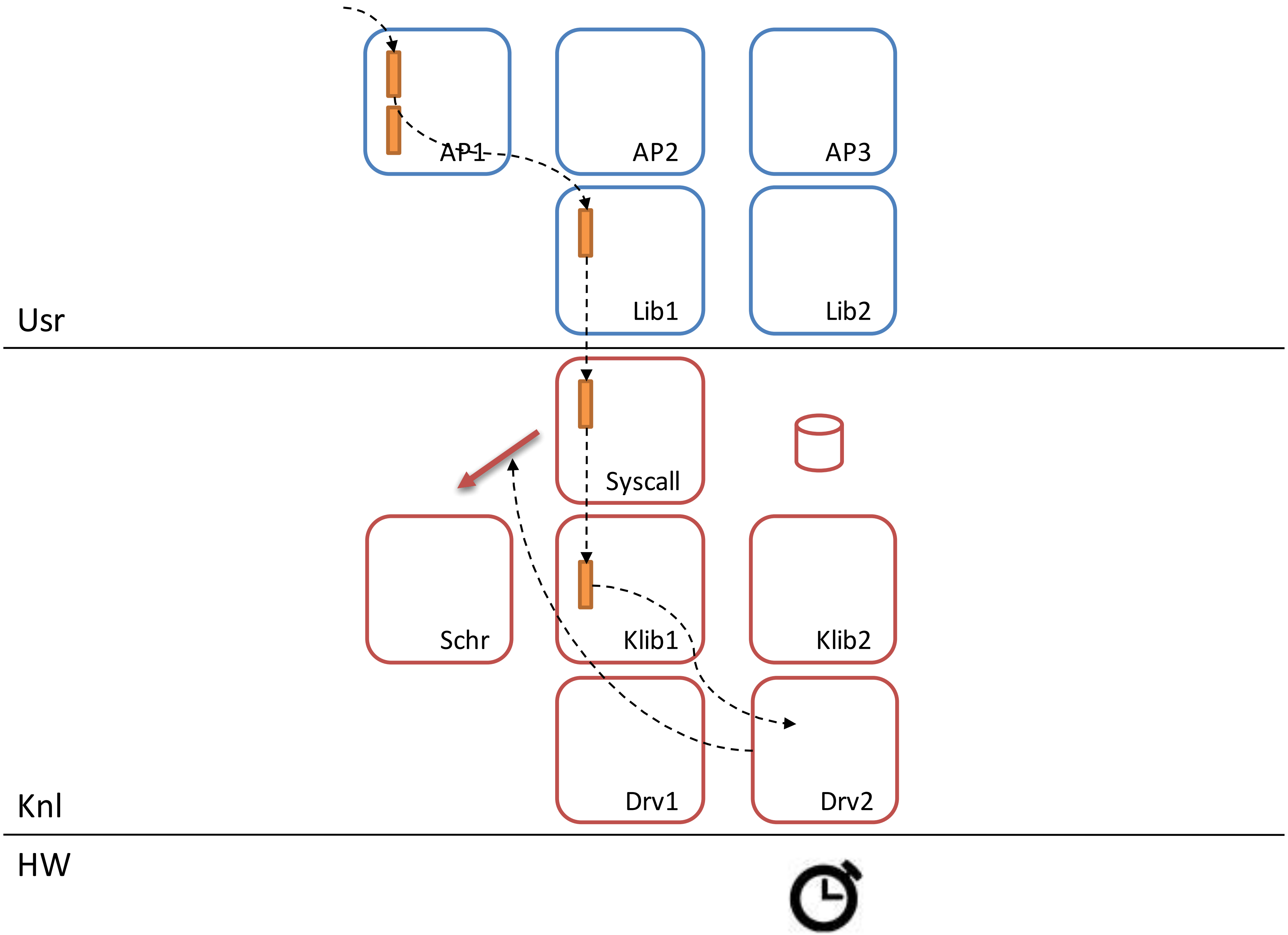
# When returning to user-space from an interrupt handler



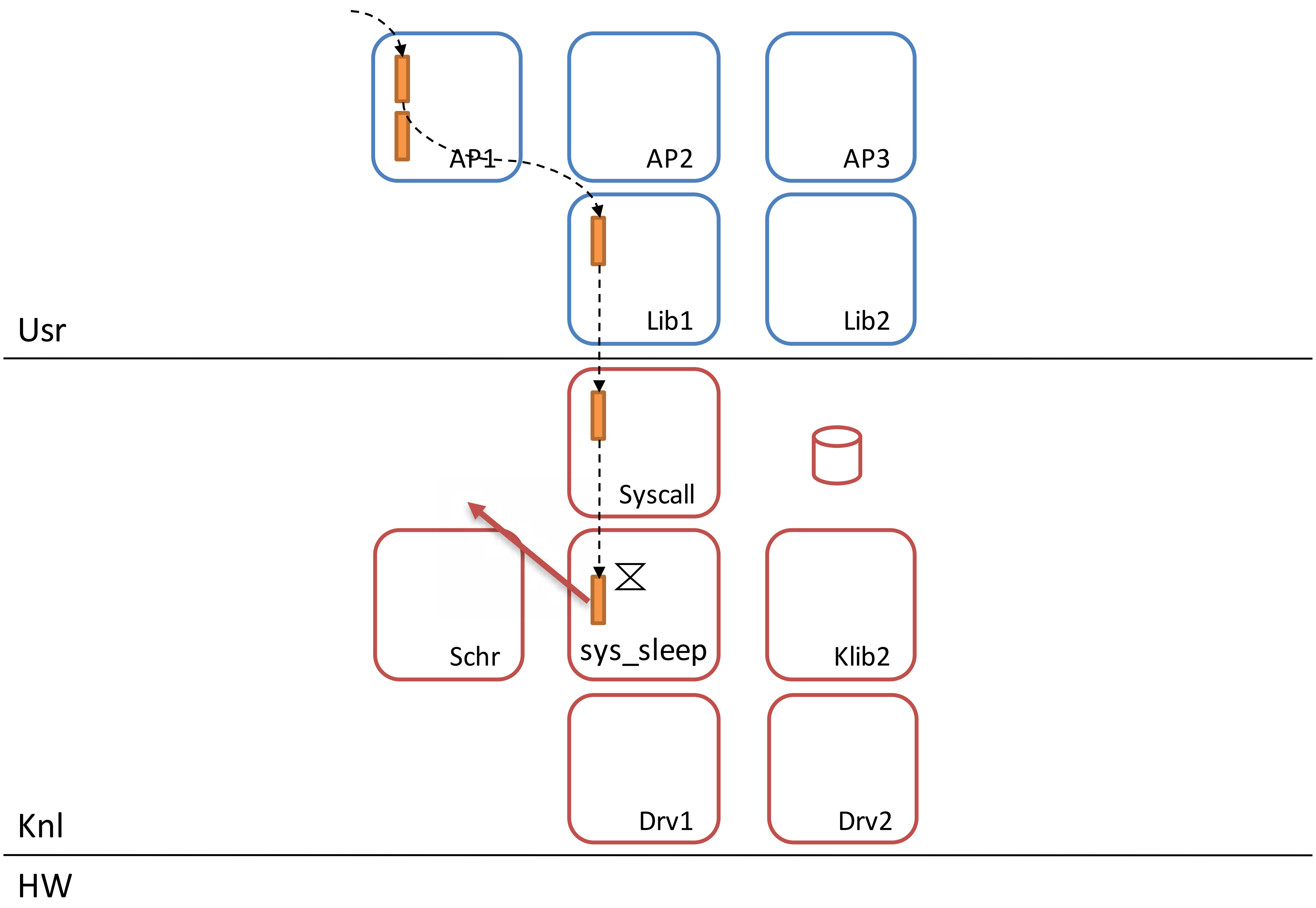
# When returning to user-space from an interrupt handler



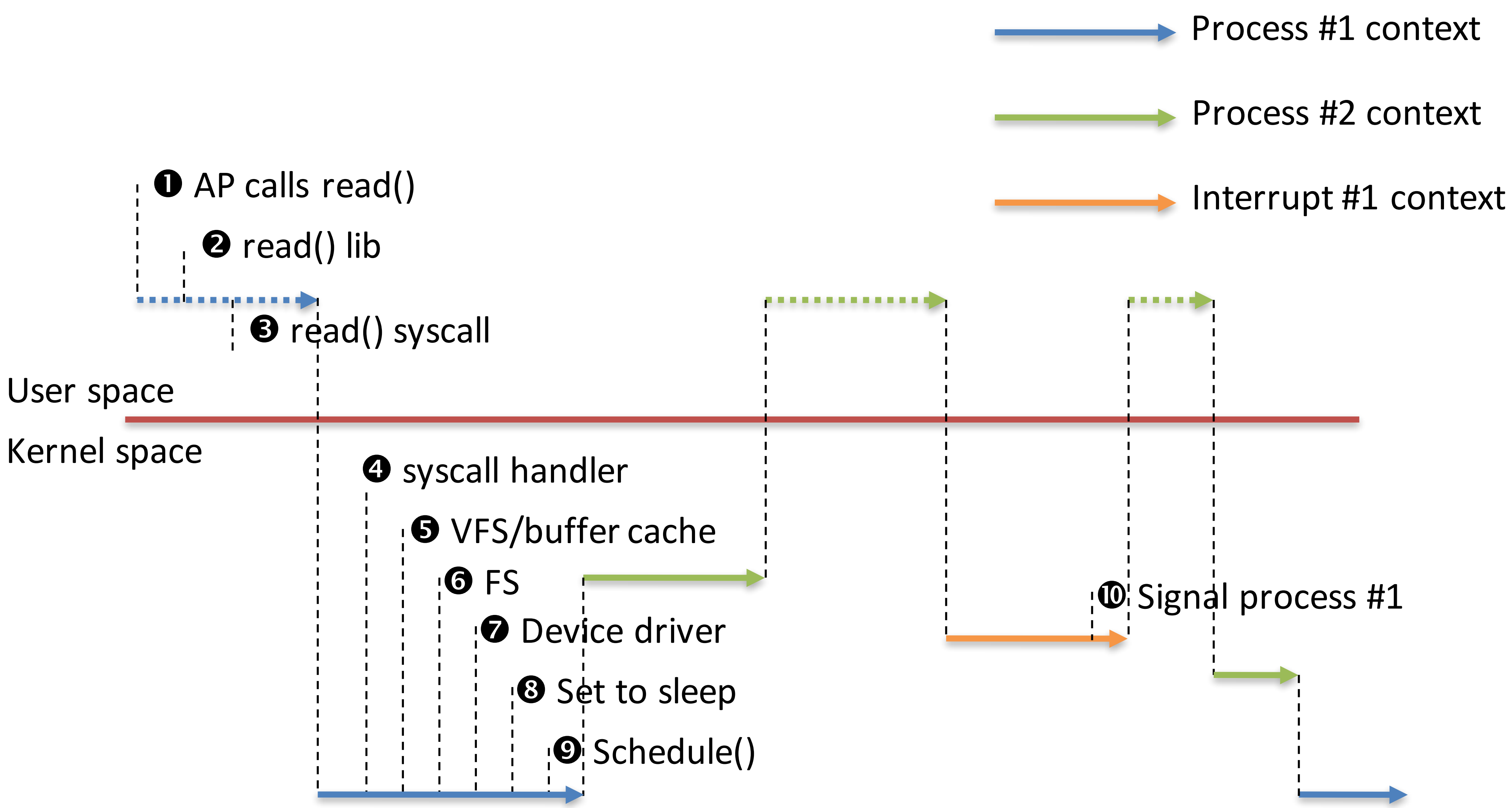
# When an interrupt handler exits, before returning to kernel-space



# If a task in the kernel explicitly calls schedule()

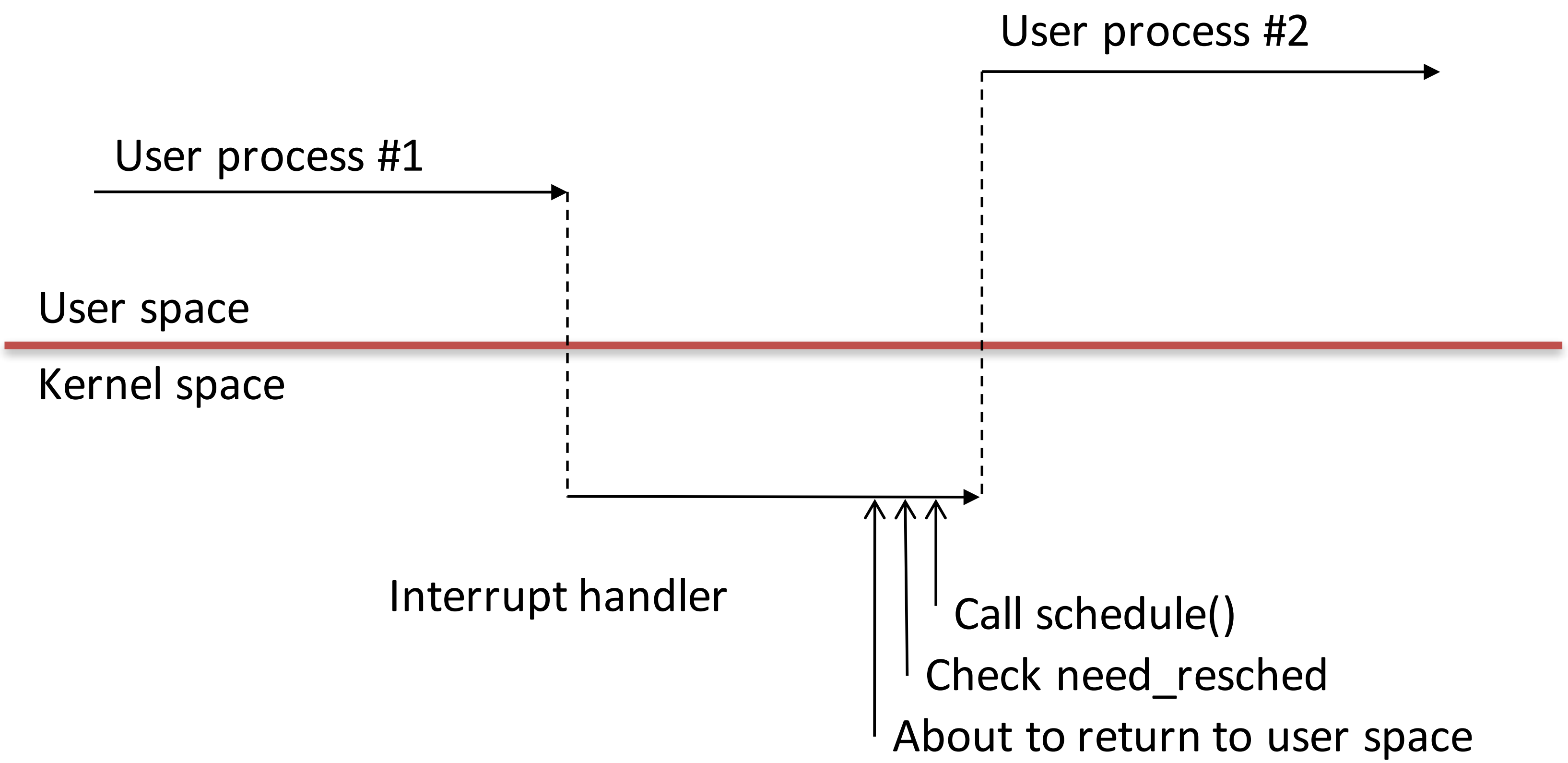


# Process context + interrupt context



# User preemption

- User preemption occurs when the kernel is in a safe state and about to return to user-space



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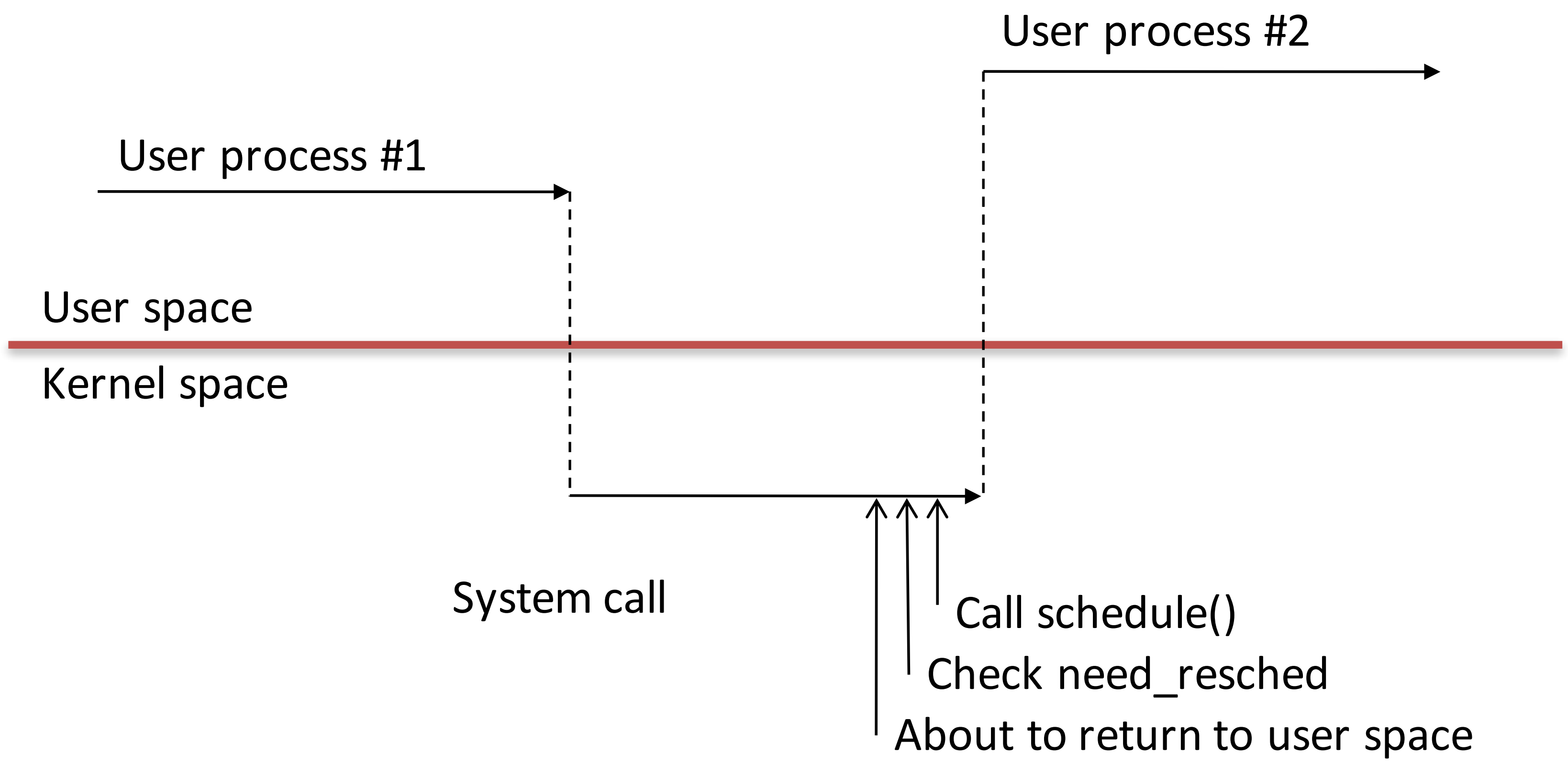
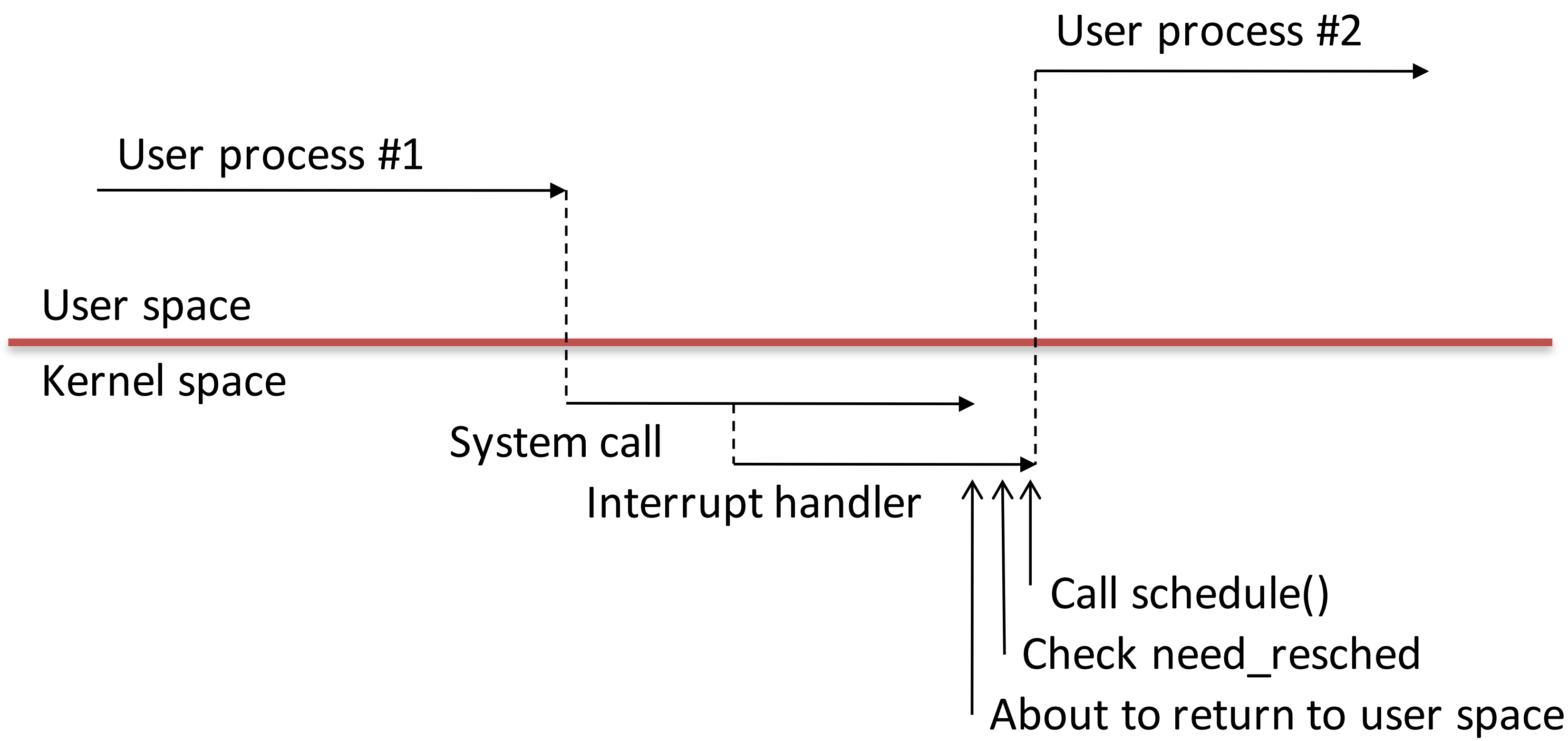


# Kernel preemption

- Linux kernel is possible to preempt a task at any point, so long as the kernel does not hold a lock



# Preemptive Kernel

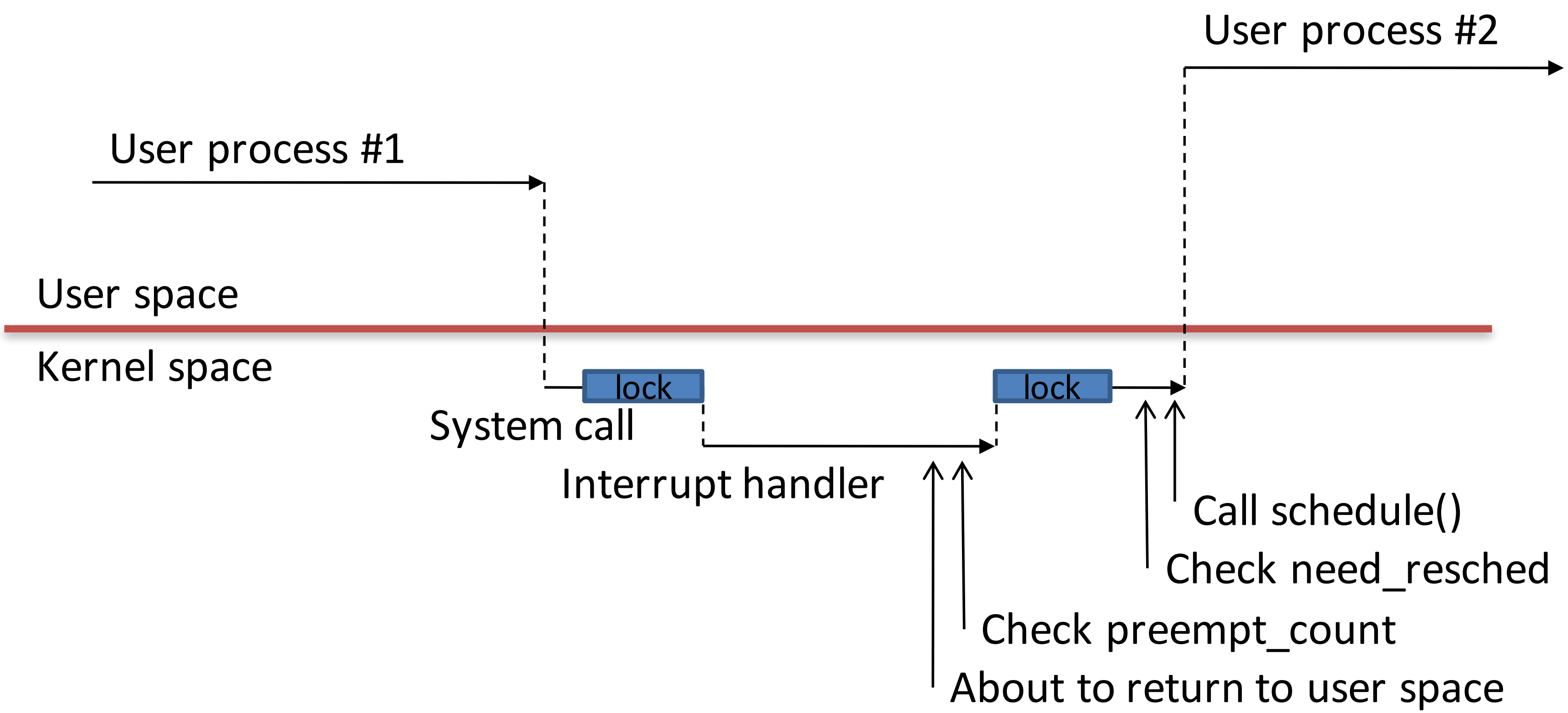
- Non-preemptive kernel supports user preemption
- Preemptive kernel supports kernel/user preemption

- Kernel can be interrupted ≠ kernel is preemptive
  - Non-preemptive kernel, interrupt returns to interrupted process
  - Preemptive kernel, interrupt returns to any schedulable process

# Preemptive Kernel

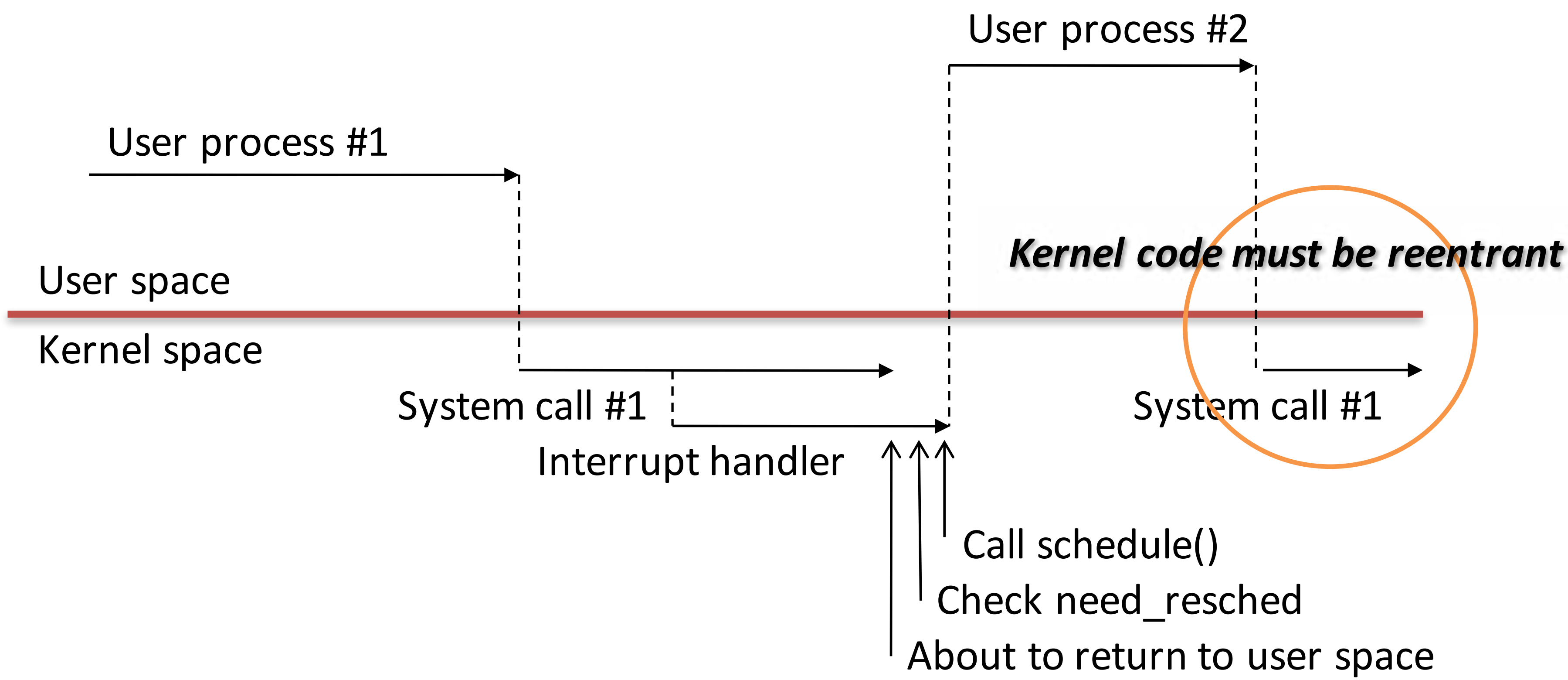
- 2.4 is a non-preemptive kernel
- 2.6 is a preemptive kernel
- 2.6 could disable CONFIG_PREEMPT

# Preemptive Kernel

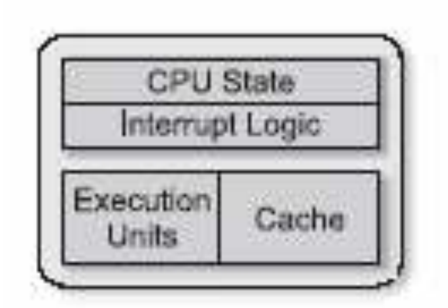


# Preemptive Kernel

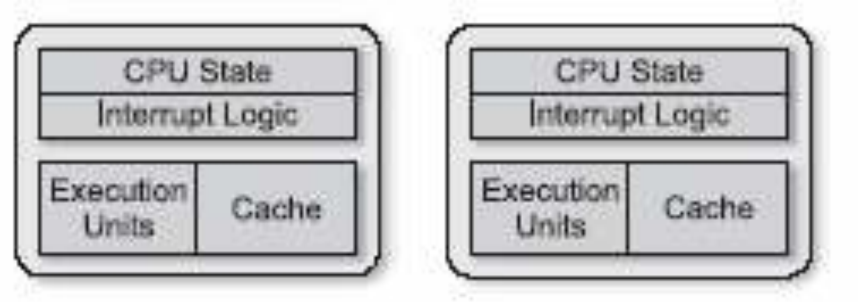
- How difficult to implement a preemptive kernel?



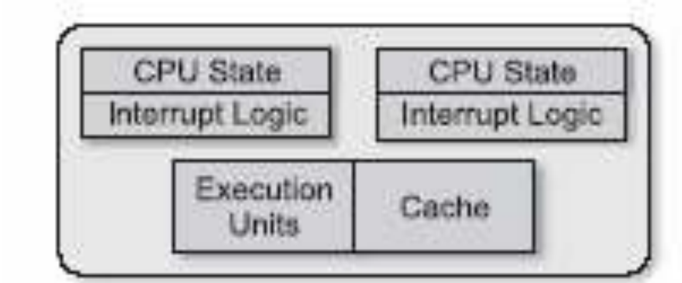
# Single Core vs. Multi-core



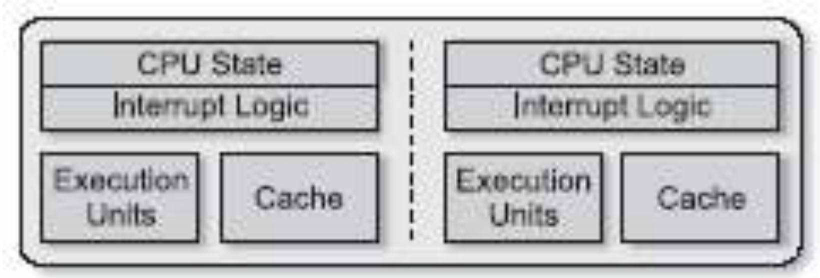

Single processor/single core



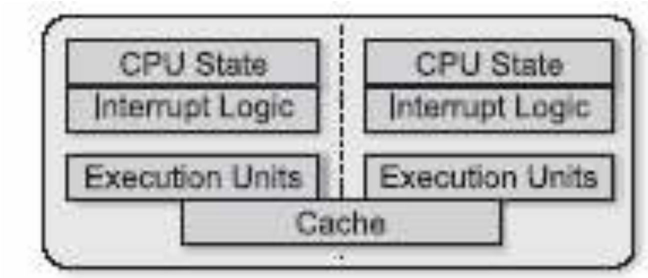

Multiple processor/single core



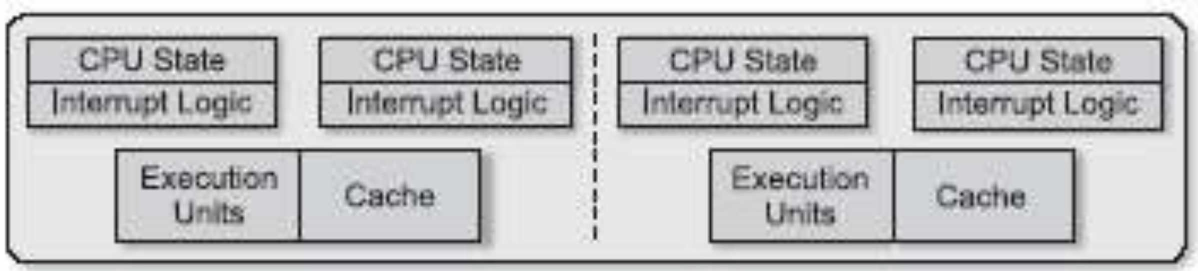

Single processor/single core/hyper threading




Single processor/multi core/separated cache

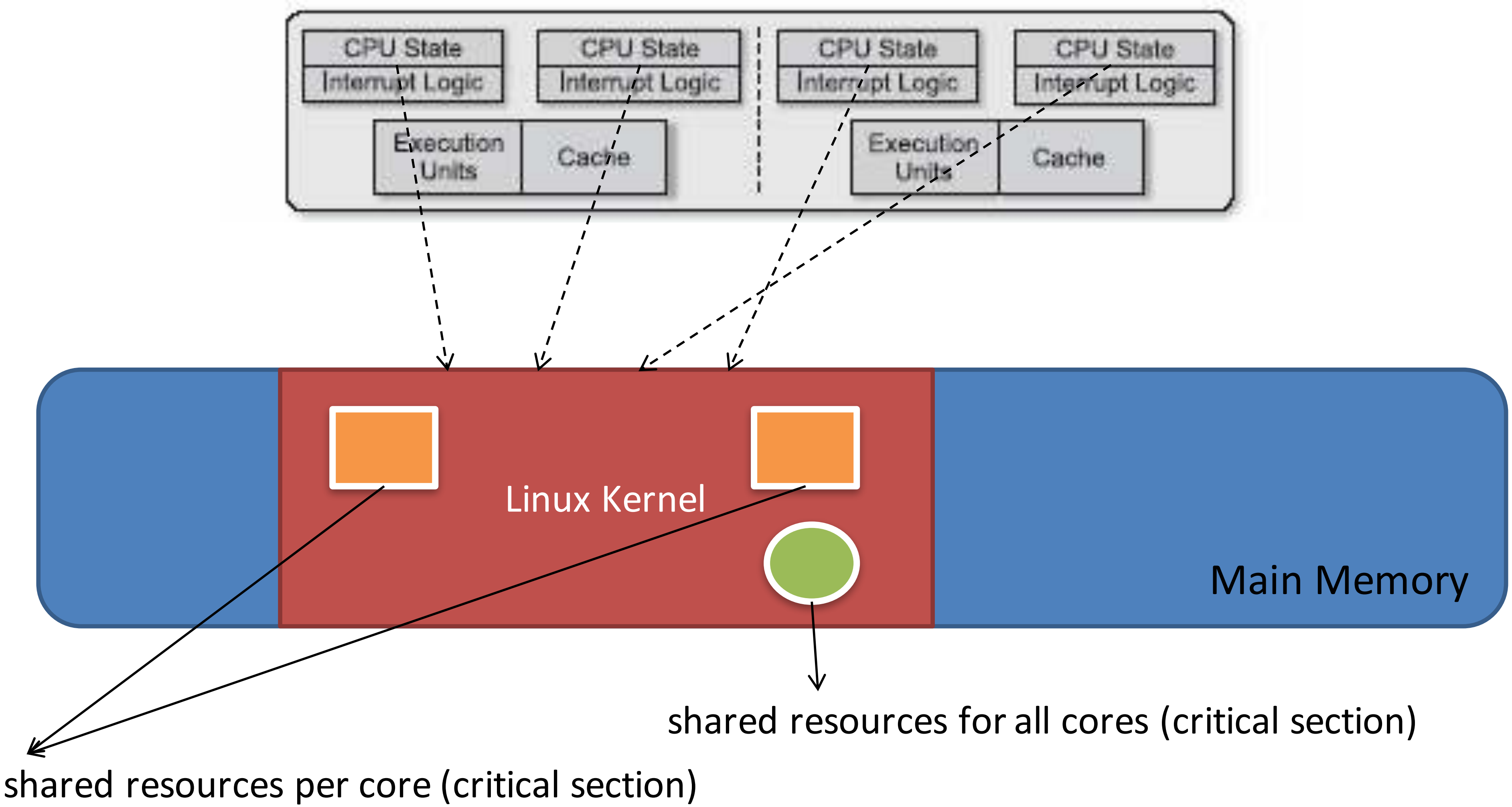



Single processor/multi core/shared cache




Single processor/multi core/hyper threading

# Single Core vs. Multi-core

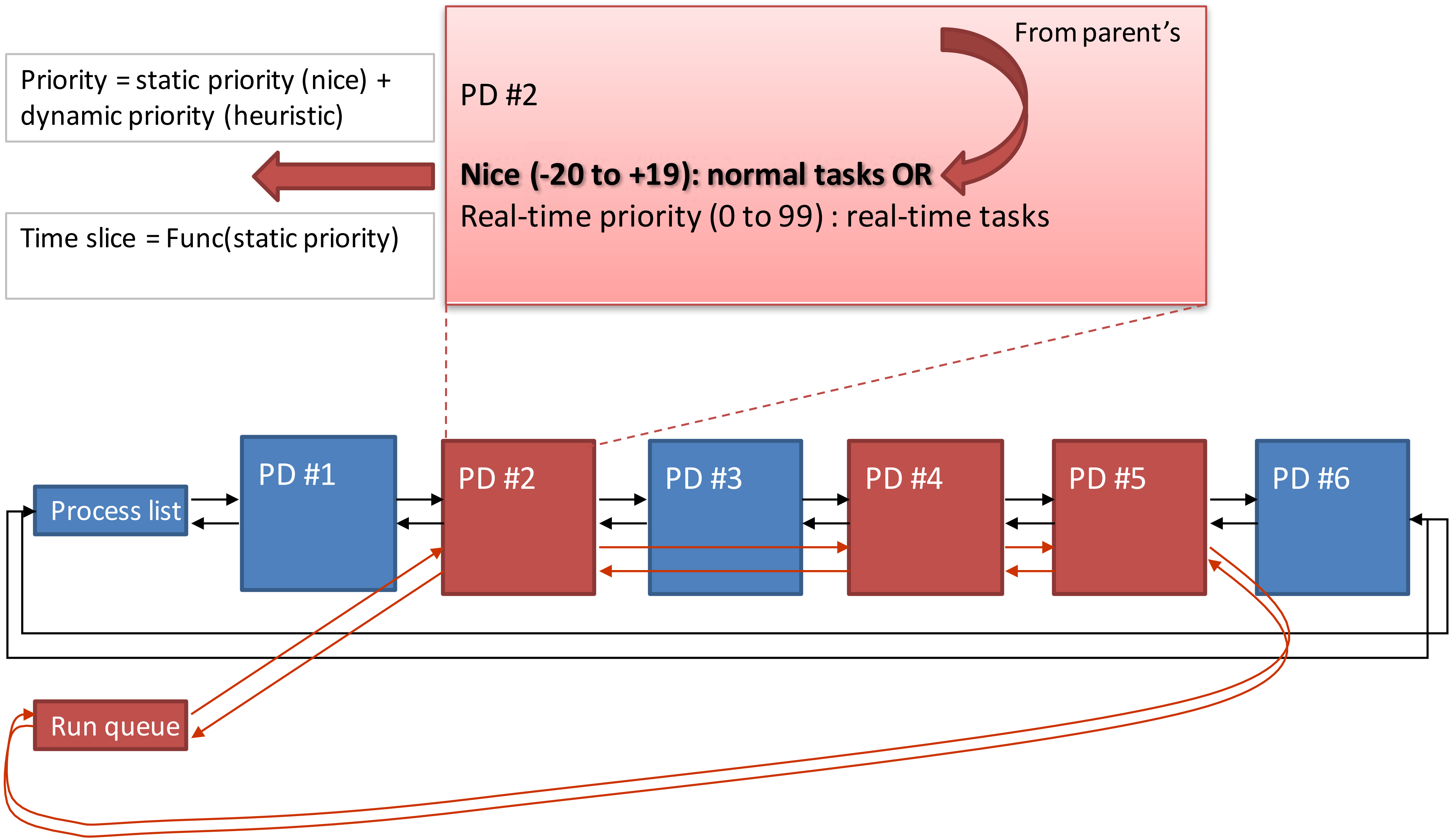


# Schedule Algorithms

- Think about yourself (your homework schedule)
  - Given that you have a lot of homework to do, each with a deadline
  - Profs. continue assigning new homework

  - What is the next homework to do? (next task to schedule)
  - Why should we stop a homework? (time to schedule)
  - How long can we concentrate on a homework? (scheduling period)
  - How long do we spend to determine the next homework? (scheduling algorithm overhead)
  - How much effort do we spend to switch homework? (context switch overhead)
  - What is the importance of a homework? (priority of a job)
  - How long does a homework need? (job length)

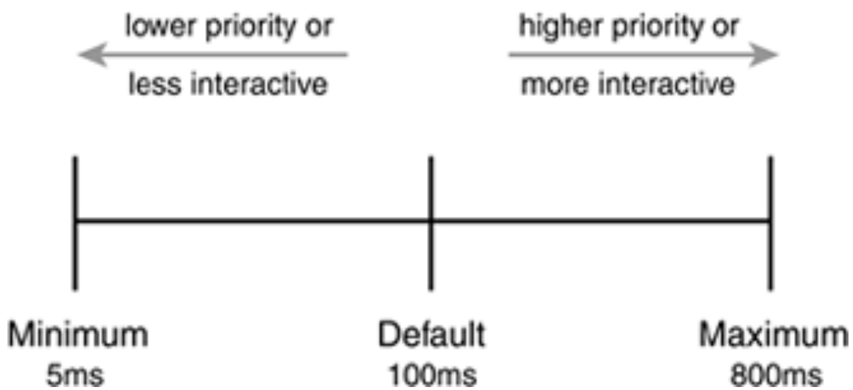
# How Linux Scheduler Works



# Timeslice

- Timeslice function

| Type of Task | Nice Value | Timeslice Duration |
|---|---|---|
| Initially created | parent's | half of parent's |
| Minimum Priority | +19 | 5ms (MIN_TIMESLICE) |
| Default Priority | 0 | 100ms (DEF_TIMESLICE) |
| Maximum Priority | -20 | 800ms (MAX_TIMESLICE) |

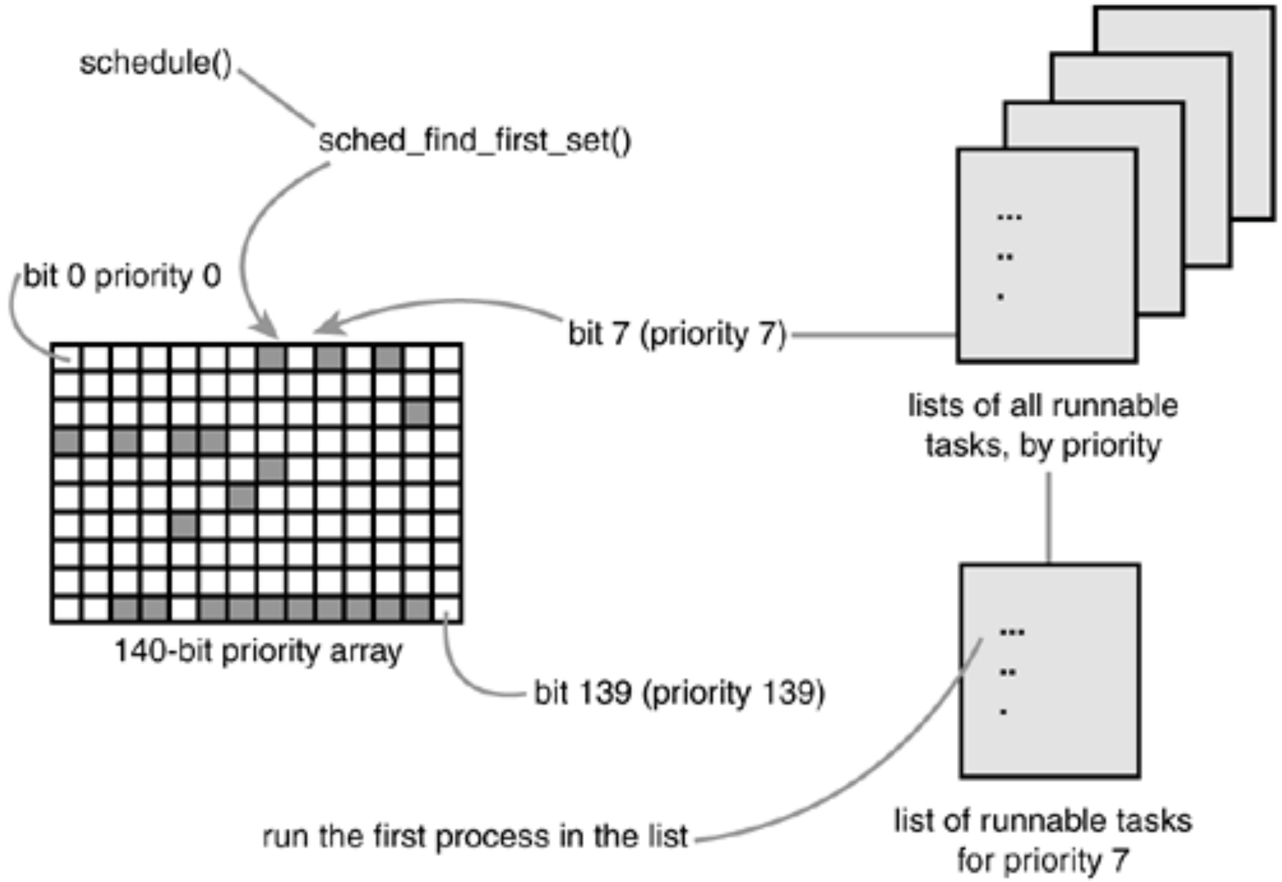



$$\begin{array}{c}\textit{base time quantum}\\ \text{(in milliseconds)}\end{array} = \begin{cases} (140 - \textit{static priority}) \times 20 & \text{if } \textit{static priority} < 120 \\ (140 - \textit{static priority}) \times 5 & \text{if } \textit{static priority} \geq 120 \end{cases} \quad (1)$$

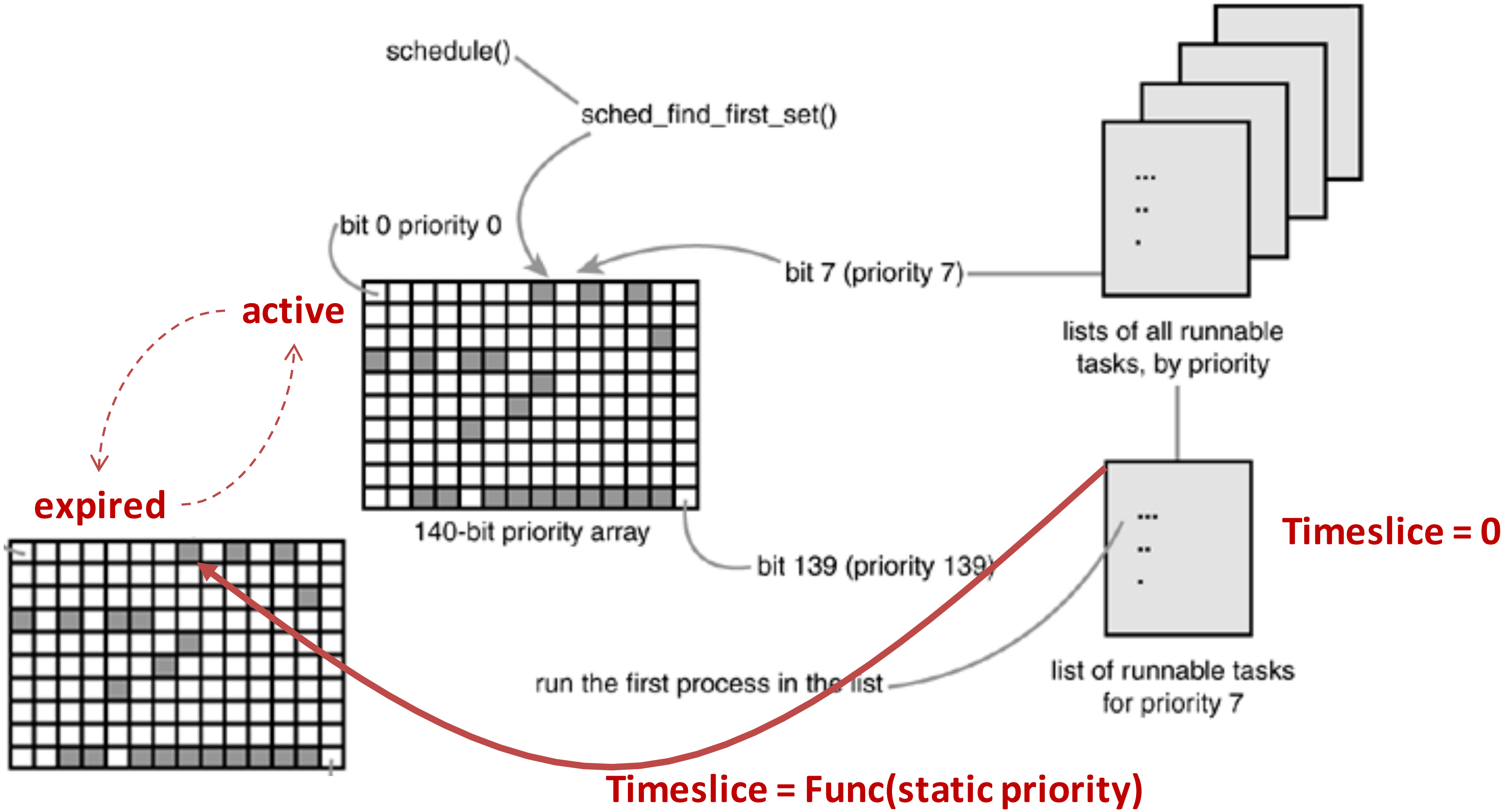
# Process schedule and context switching in Linux

- Priority-based scheduler
- Dynamic priority-based scheduling
  - Dynamic priority
    - Normal process
      - nice value: -20 to +19 (larger nice values imply you are being nice to others)
  - Static priority
    - Real-time process
      - 0 to 99
  - Total priority: 140

# Linux O(1) cheduler



# Recalculating timeslice



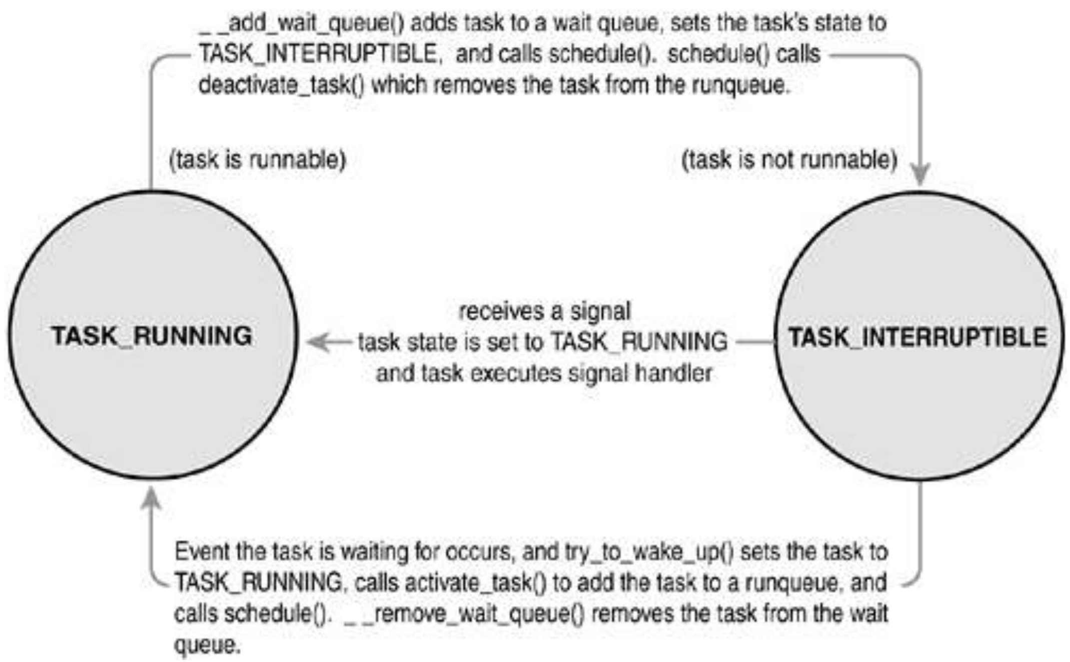
# Calculating Priority

- static_prio = nice
- Prio = nice – bonus + 5

  dynamic priority = max (100, min ( static priority - bonus + 5, 139))

- Heuristic
  - sleep_avg: (0 to MAX_SLEEP_AVG(10ms))
  - sleep_avg+=sleep (becomes runnable)
  - Sleep_avg-=run (every time tick when task runs)

# Sleeping and waking up

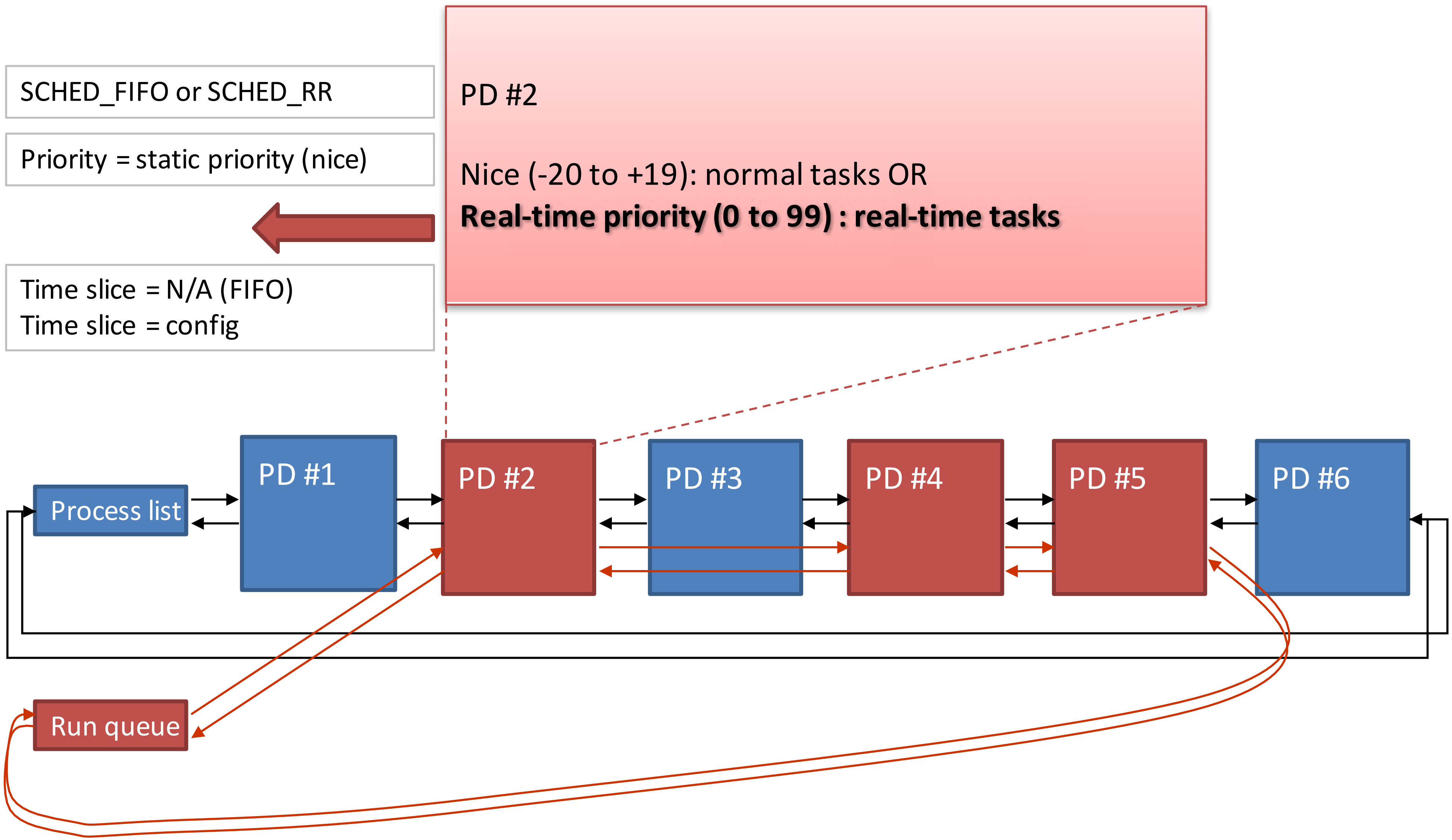


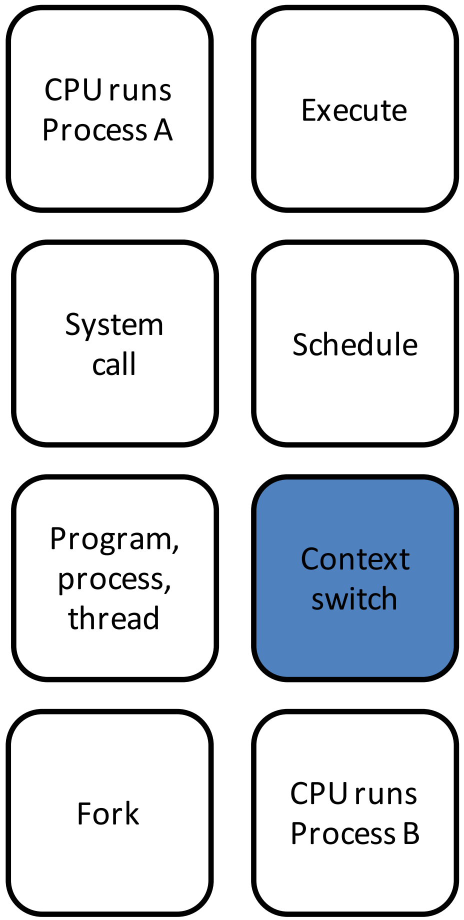

```
add_wait_queue(q, &wait);
while (!condition) {     /* condition is the event that we are waiting for */
        set_current_state(TASK_INTERRUPTIBLE); /* or TASK_UNINTERRUPTIBLE */
        if (signal_pending(current))
                /* handle signal */
        schedule();
}
set_current_state(TASK_RUNNING);
remove_wait_queue(q, &wait);
```

# System calls related to scheduling

| System call | Description |
|---|---|
| nice( ) | Change the static priority of a conventional process |
| getpriority( ) | Get the maximum static priority of a group of conventional processes |
| setpriority( ) | Set the static priority of a group of conventional processes |
| sched_getscheduler( ) | Get the scheduling policy of a process |
| sched_setscheduler( ) | Set the scheduling policy and the real-time priority of a process |
| sched_getparam( ) | Get the real-time priority of a process |
| sched_setparam( ) | Set the real-time priority of a process |
| sched_yield( ) | Relinquish the processor voluntarily without blocking |
| sched_get_ priority_min( ) | Get the minimum real-time priority value for a policy |
| sched_get_ priority_max( ) | Get the maximum real-time priority value for a policy |
| sched_rr_get_interval( ) | Get the time quantum value for the Round Robin policy |
| sched_setaffinity( ) | Set the CPU affinity mask of a process |
| sched_getaffinity( ) | Get the CPU affinity mask of a process |

# How Linux Scheduler Works

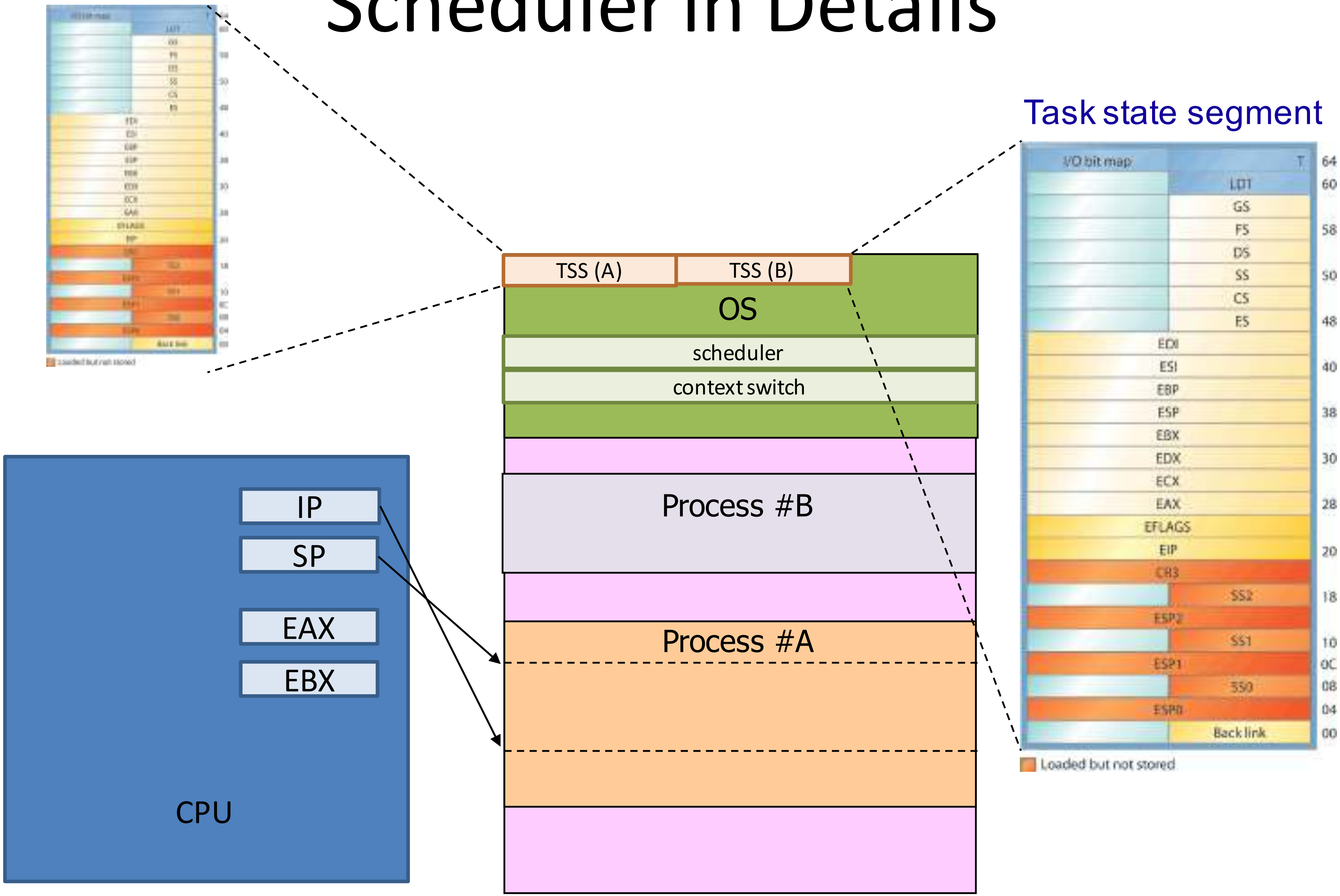



CPU runs Process A
Execute
System call
Schedule
Program, process, thread
Context switch
Fork
CPU runs Process B

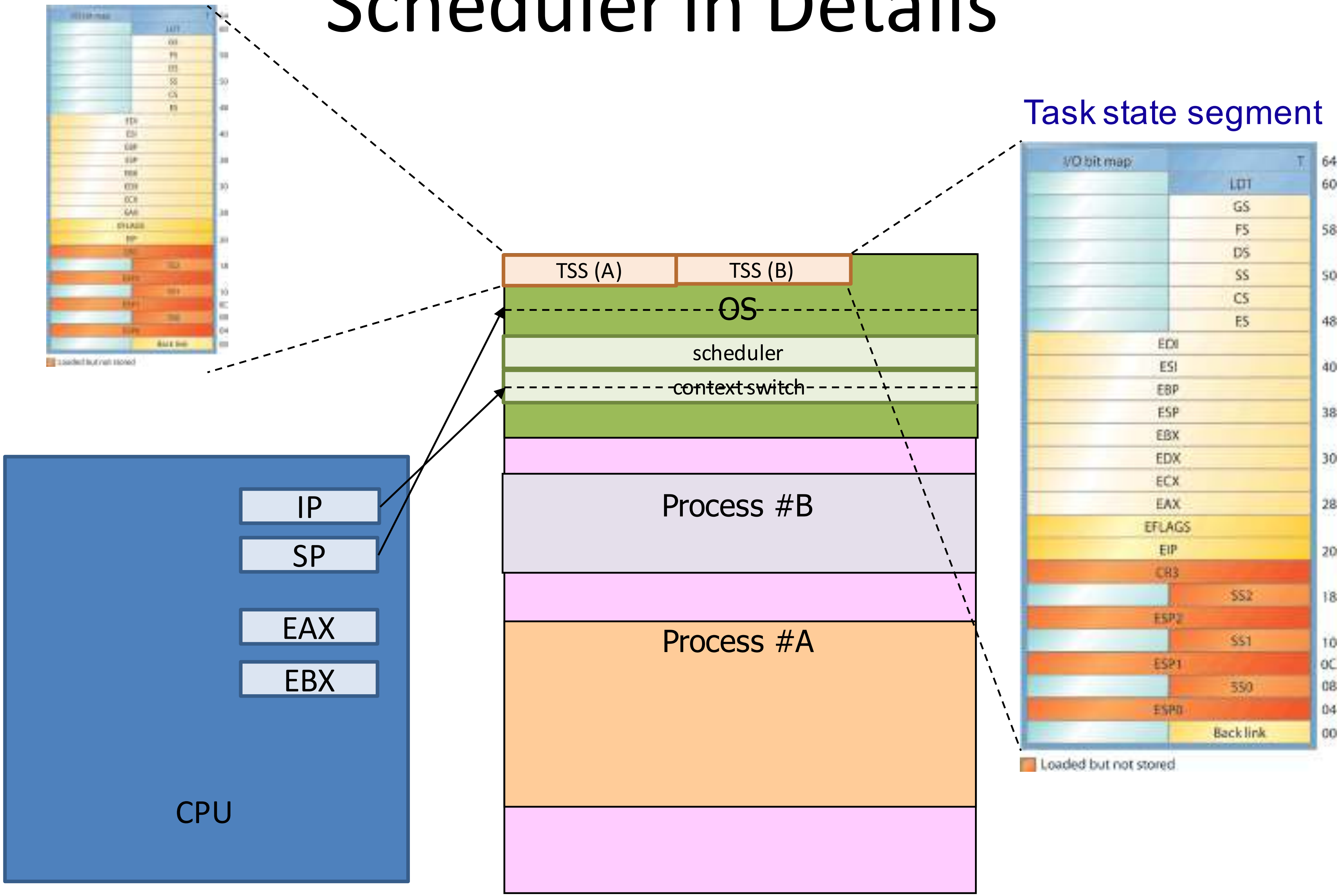
# Process schedule and context switching in Linux

- Context switch
  - Hardware context switch
    - Task State Segment Descriptor (Old Linux)
  - Step by step context switch
    - Better control and optimize
- Context switch
  - switch_mm()
    - Switch virtual memory mapping
  - switch_to()
    - Switch processor state
- Process switching occurs only in kernel mode
- The contents of all registers used by a process in User Mode have already been saved

# Scheduler in Details



# Scheduler in Details



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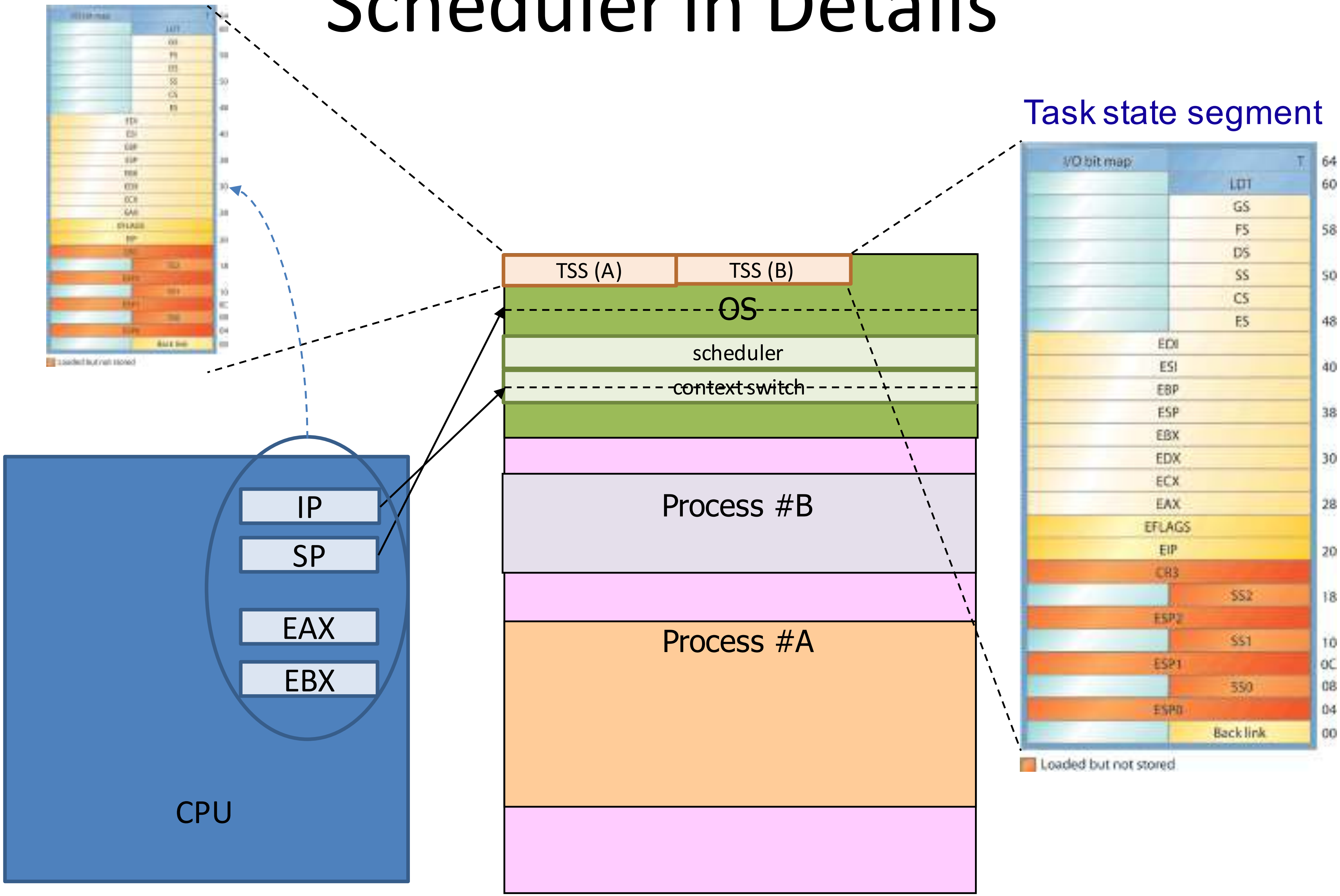

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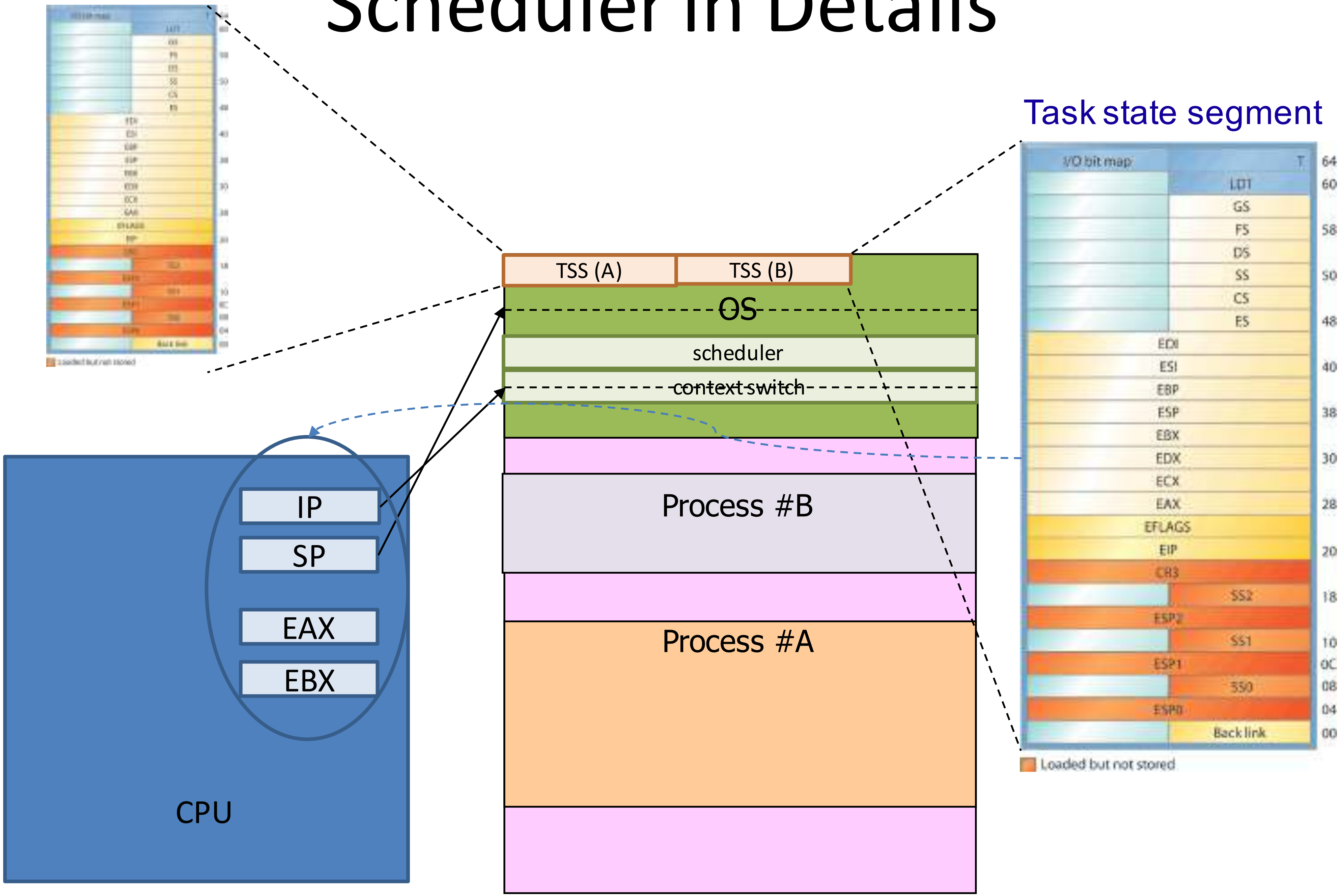

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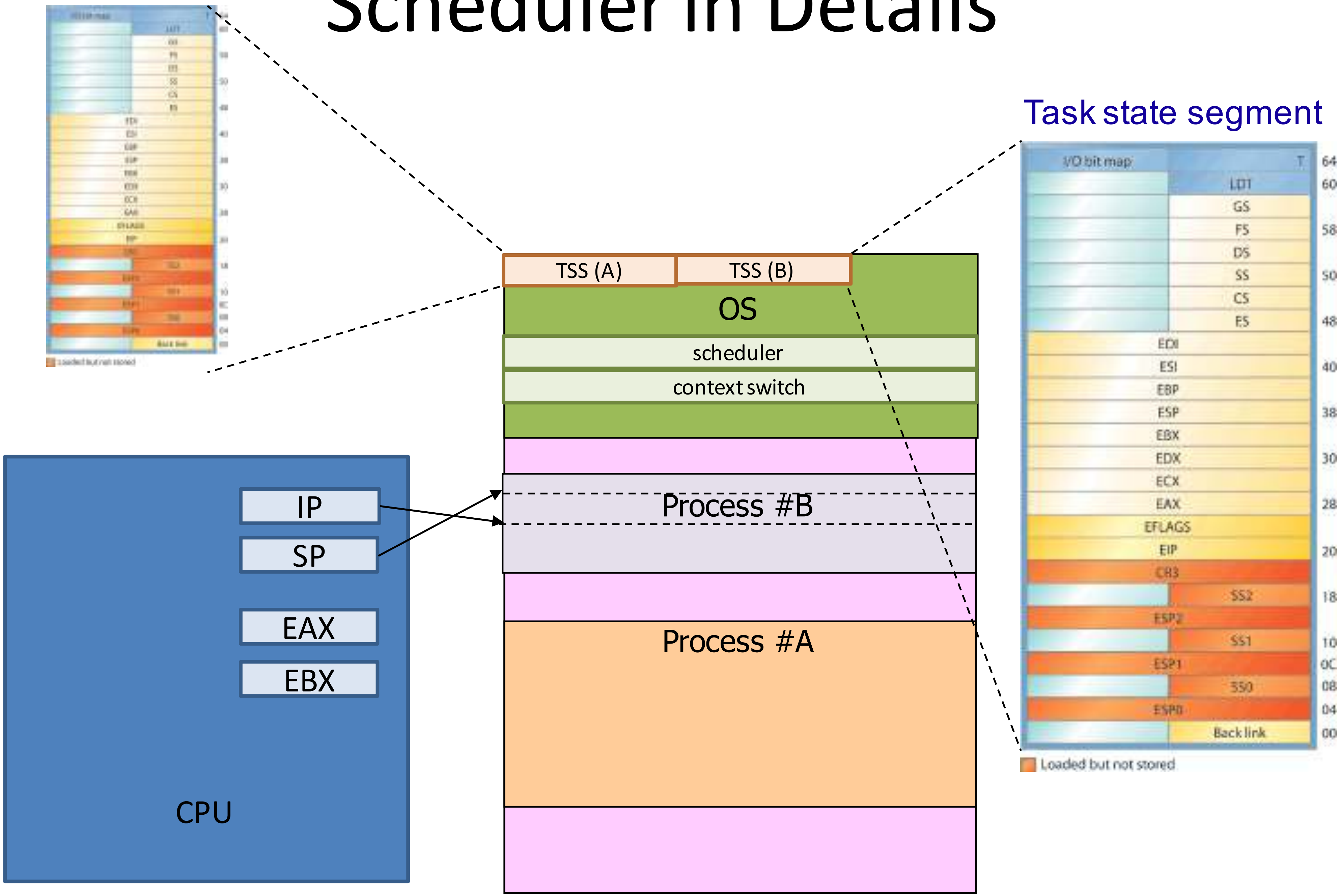
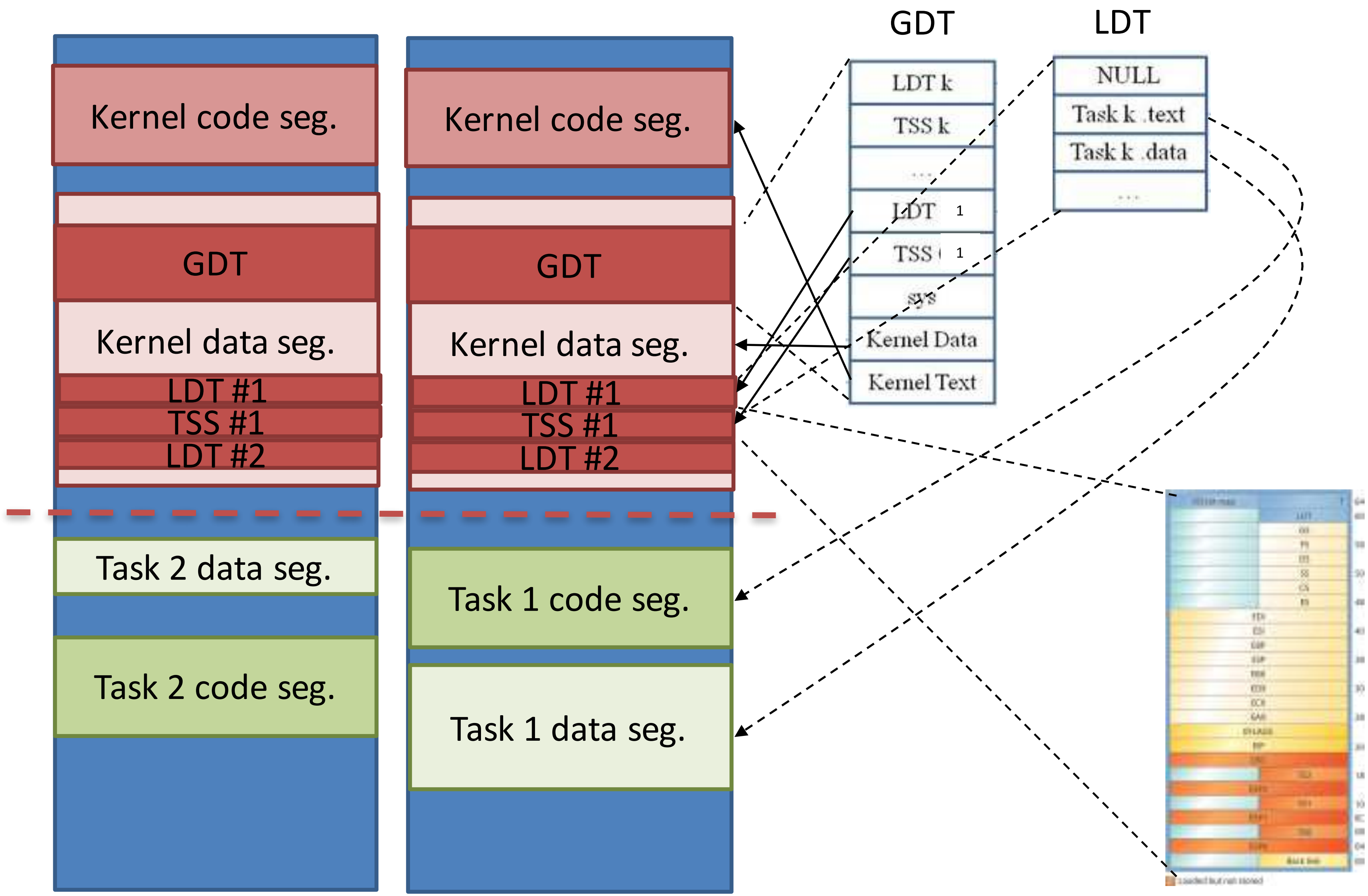
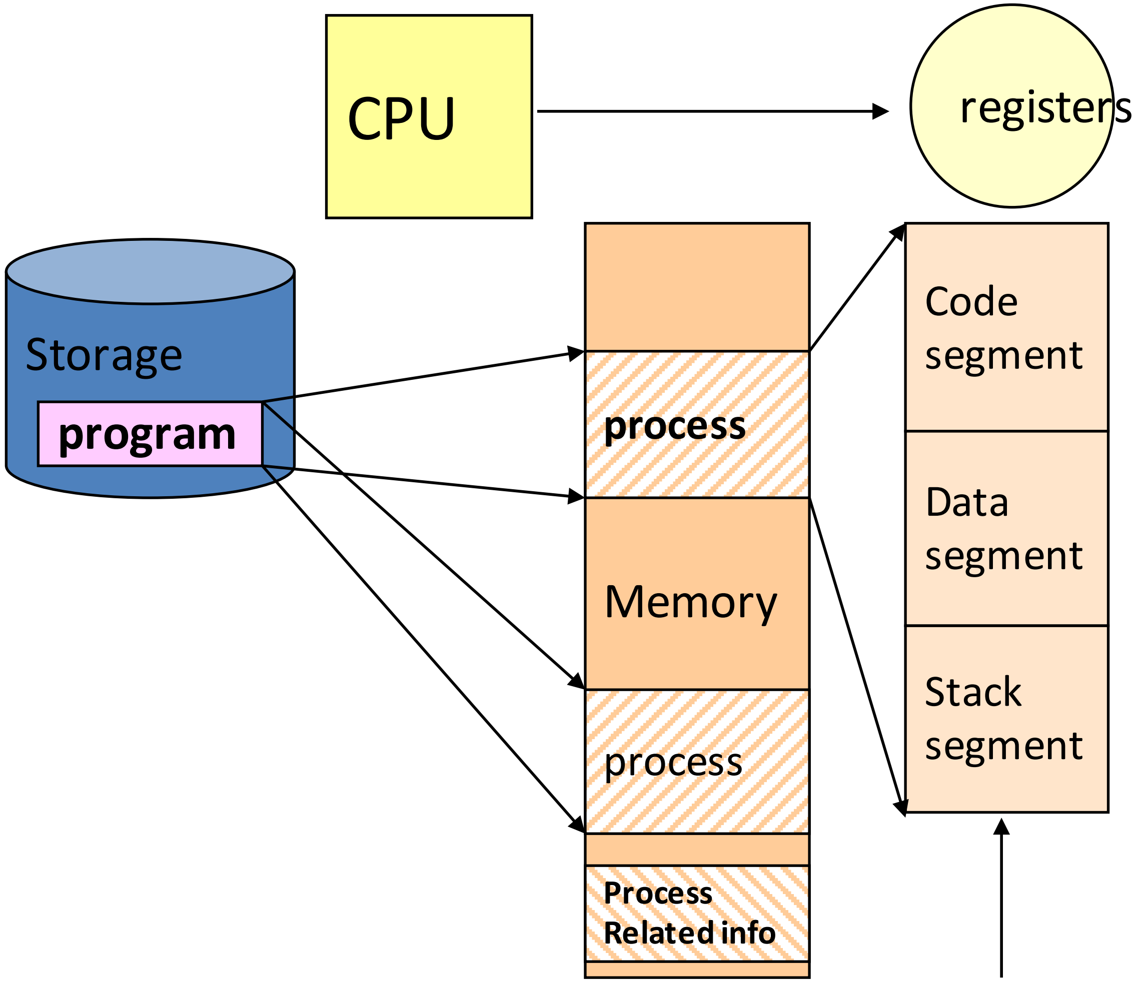


# How x86 helps in Context Switch



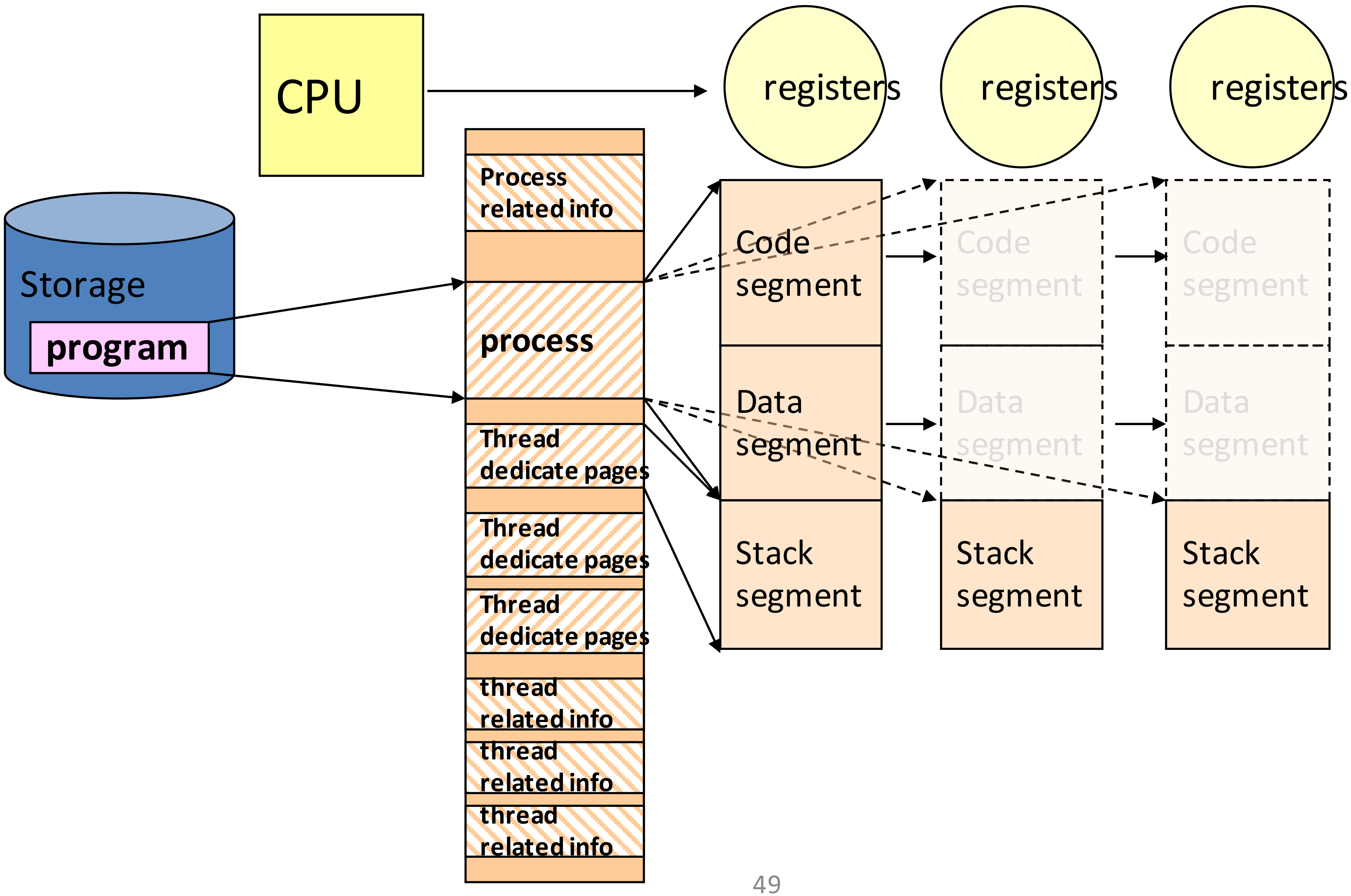
# Process related terms




*Is that good enough ?*
*If not, why ?*

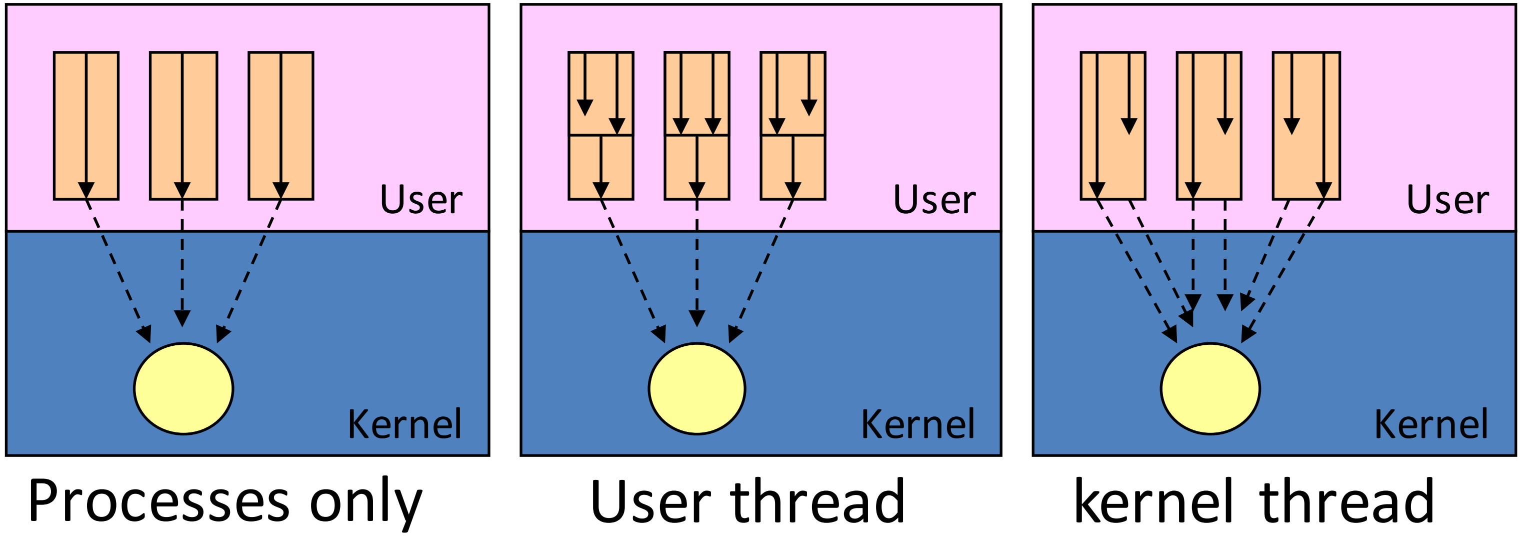
Physical memory might be discontinuous

# Process related terms (Cont.)



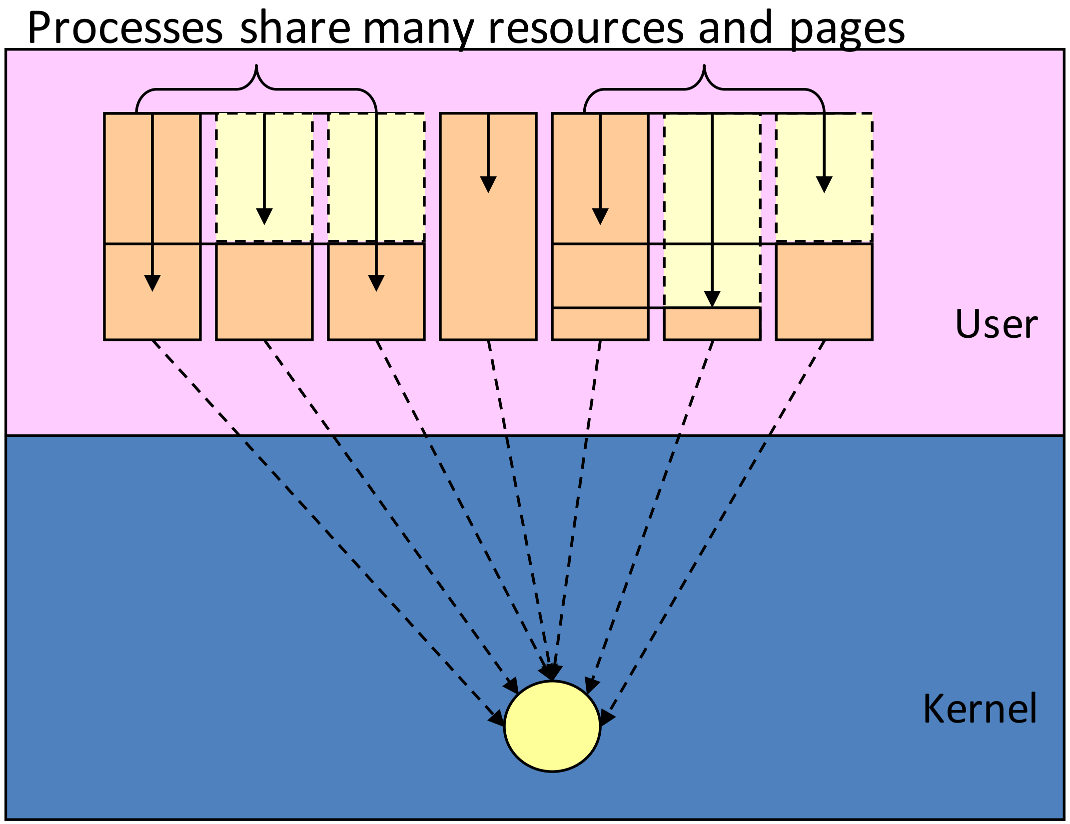
# Process related terms (Cont.)

- Depending on OS designs



# Process related terms (Cont.)

- Linux lightweight process

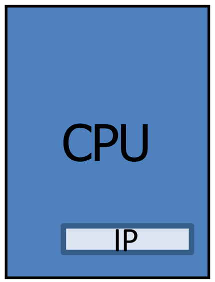


# Discussion on 3/22

```
#include<stdio.h>
void main()
{
        int x= 38;
        printf("Address of x = %p\n", &x);
}
```

```
/a.out
Address of x = 0x00010000
```

Cache, TLB,
virtual address,
logical address,
physical
address, ...




0x00010000???