# CS 471 Operating Systems

Yue Cheng

George Mason University

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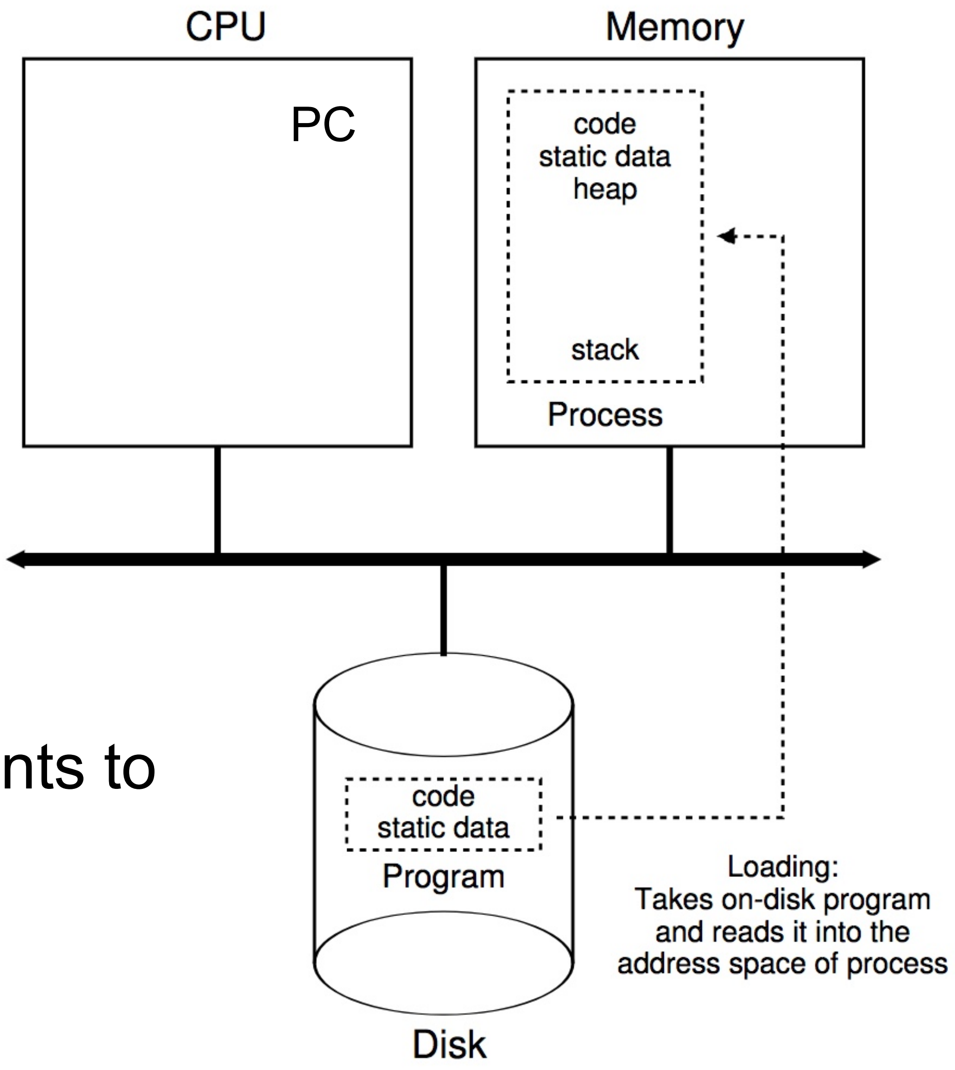
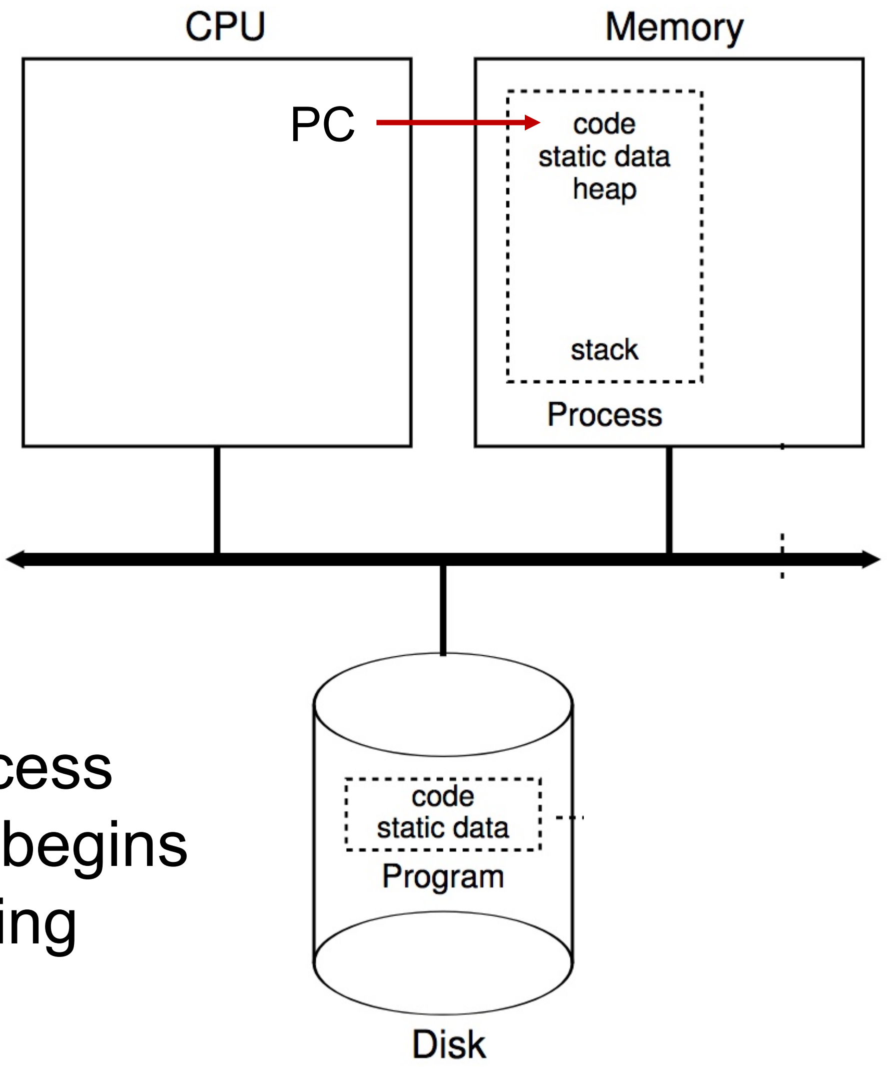
## Process Creation



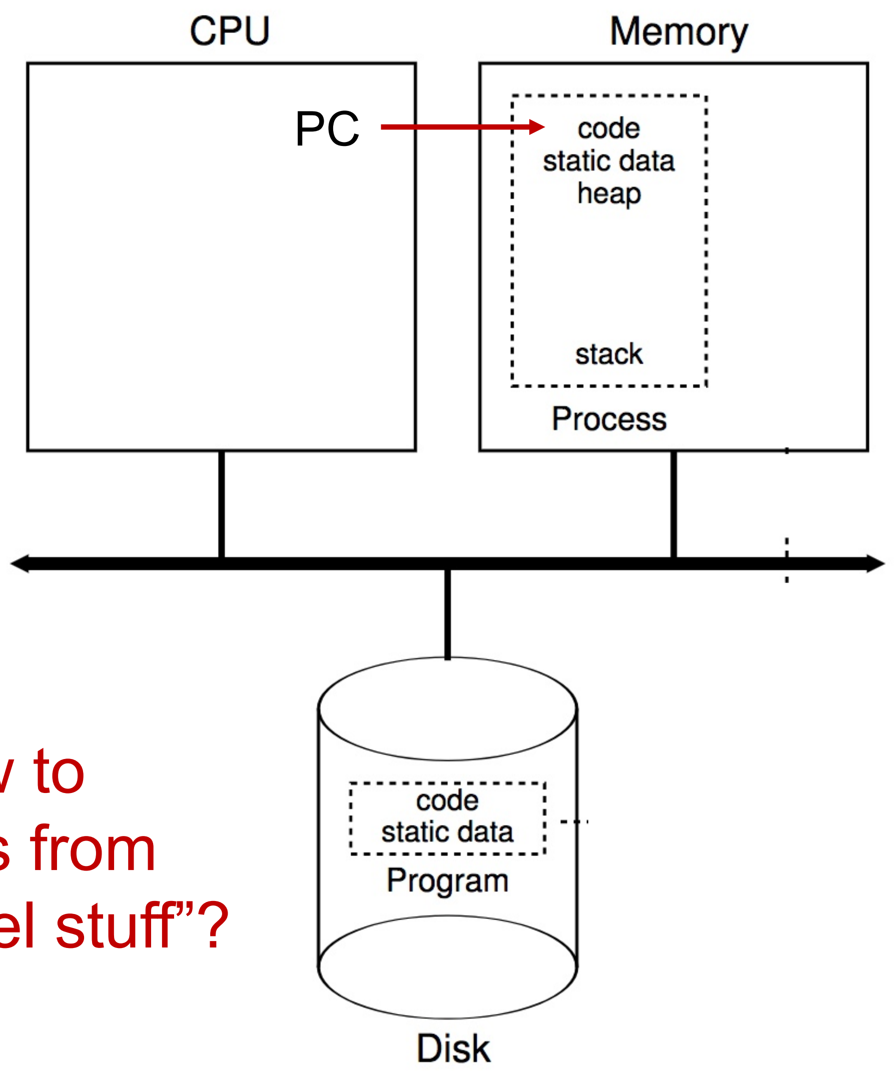
Before, PC points to kernel code

# Process Creation



Now, after process creation, CPU begins directly executing process code

# Process Creation



**Challenge**: how to prevent process from doing “OS kernel stuff”?

# Limited Direct Execution (LDE)

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- Low-level mechanism that implements the user-kernel space separation

- Usually let processes run with no OS involvement
- Limit what processes can do
- Offer privileged operations through well-defined channels with help of OS

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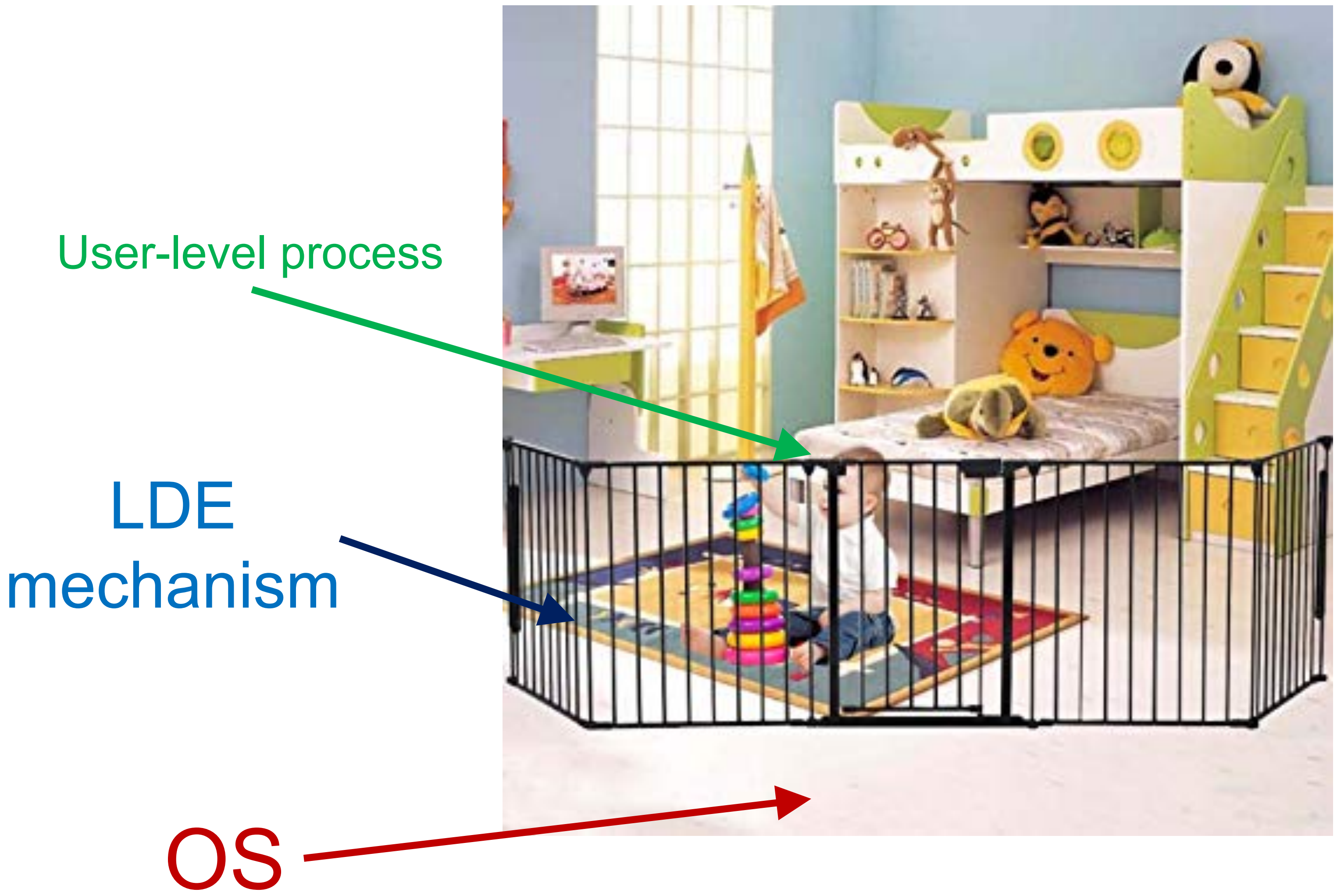

## What to limit?

- General memory access
- Disk I/O
- Certain x86 instructions

## How to limit?

- Need hardware support
- Add additional execution mode to CPU

- User mode: restricted, limited capabilities
- Kernel mode: privileged, not restricted

- **Processes** start in user mode
- **OS** starts in kernel mode

# LDE: Remaining Challenges

1. What if process wants to do something privileged?
2. How can OS switch processes (or do anything) if it’s not running?

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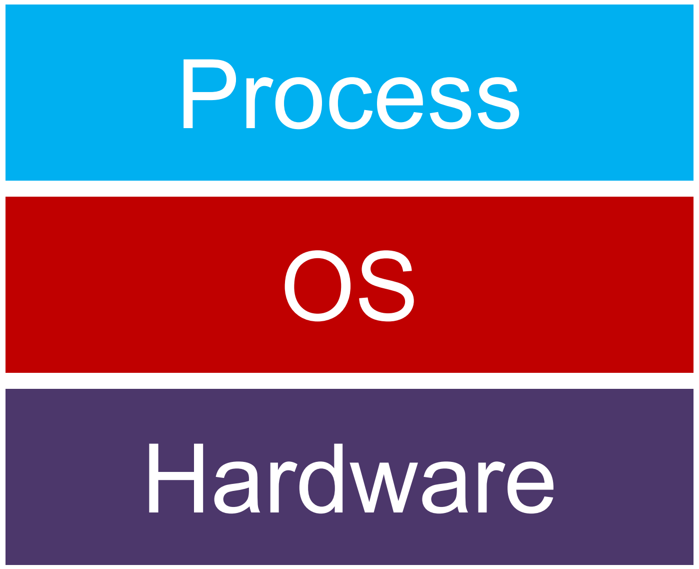
## Taking Turns



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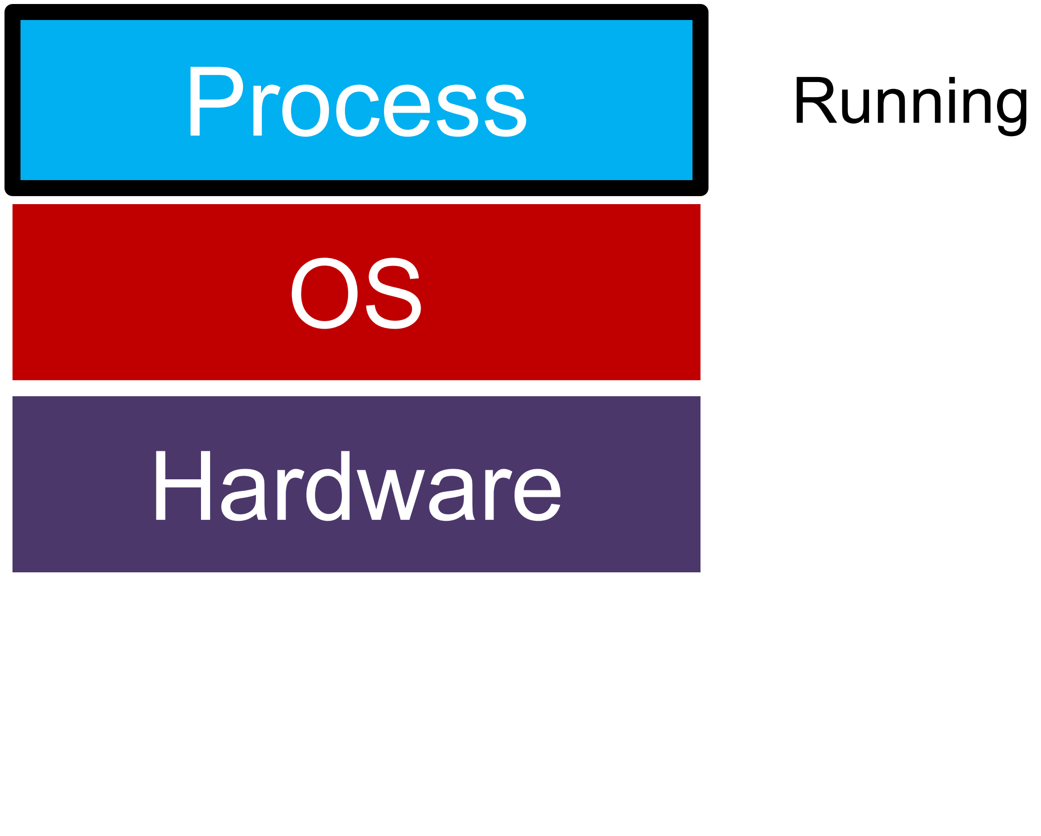

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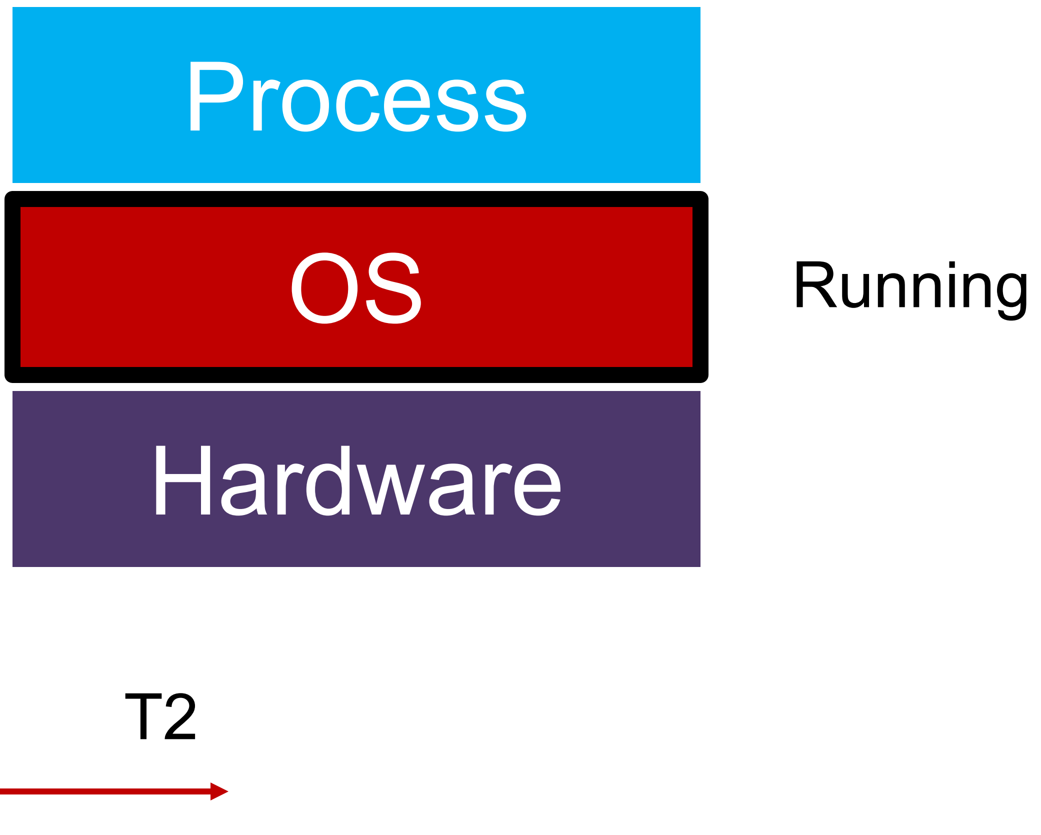

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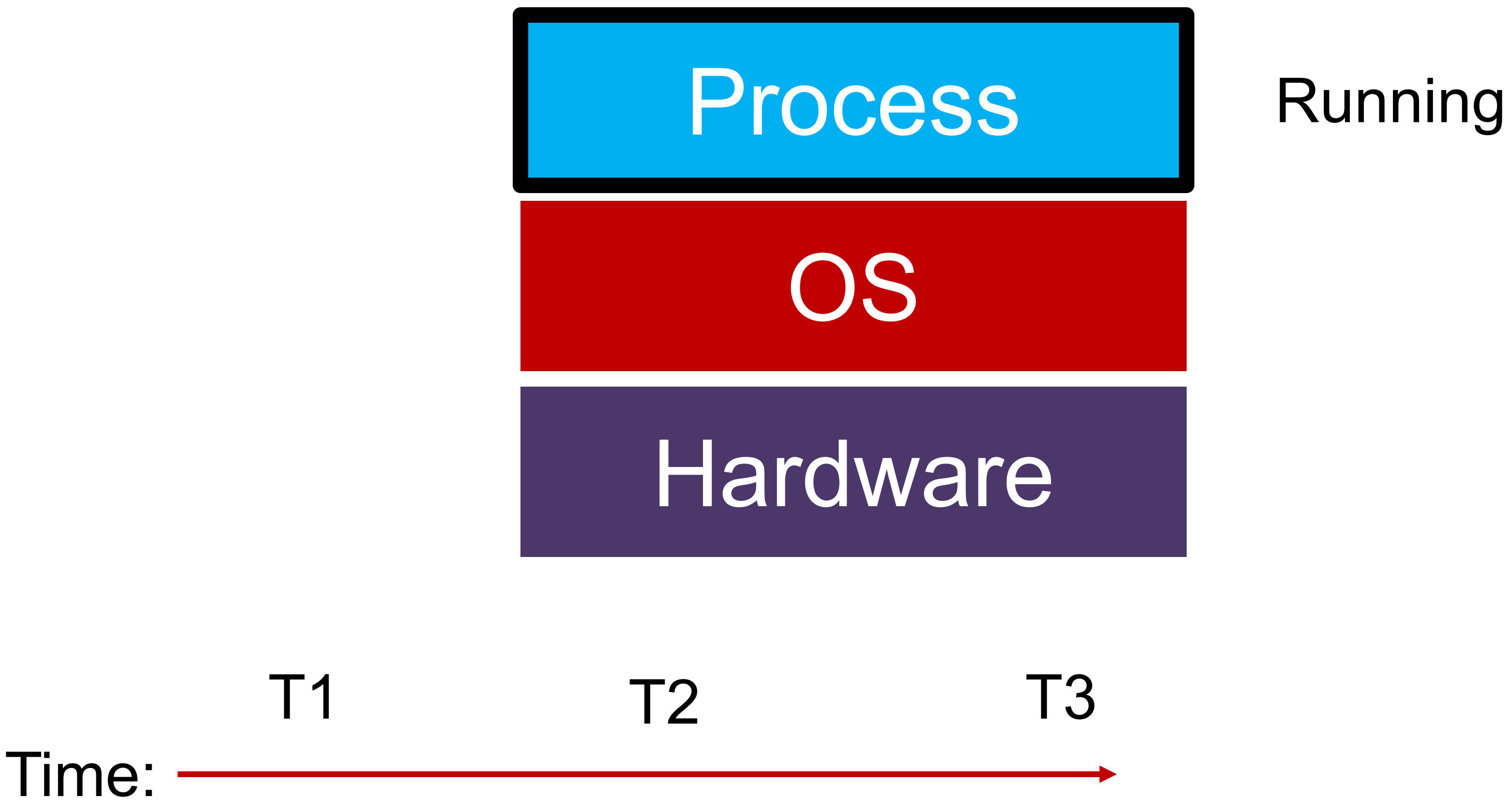

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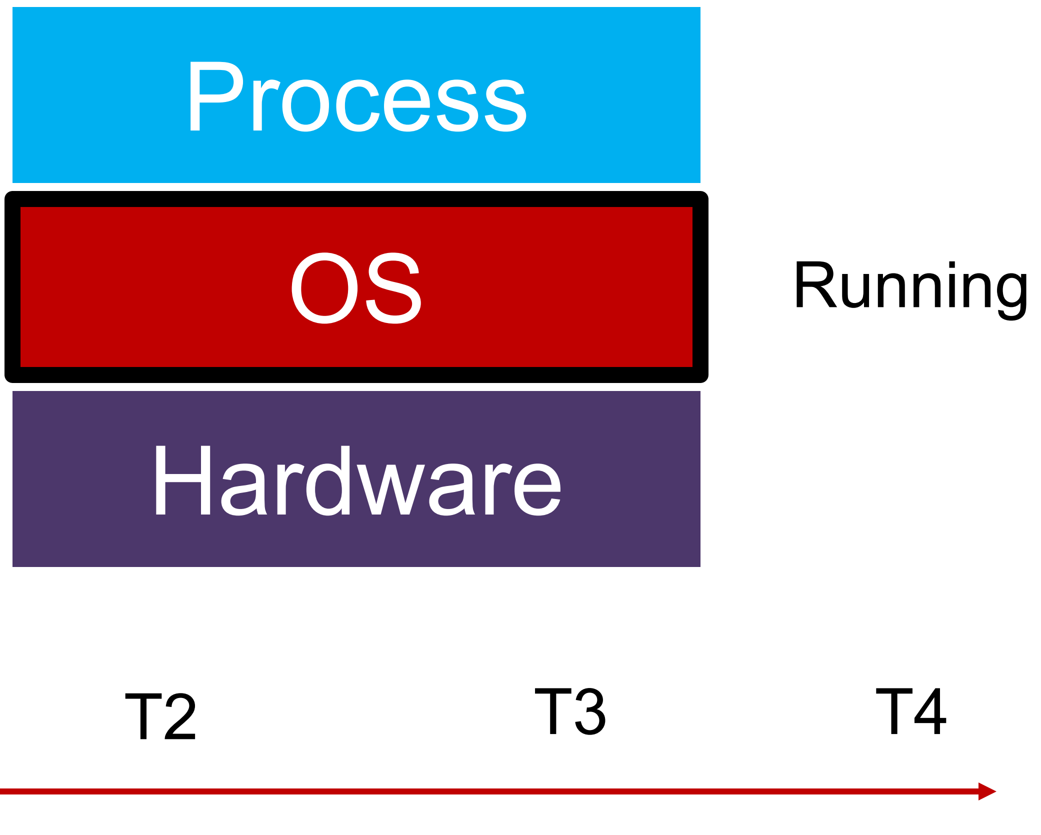
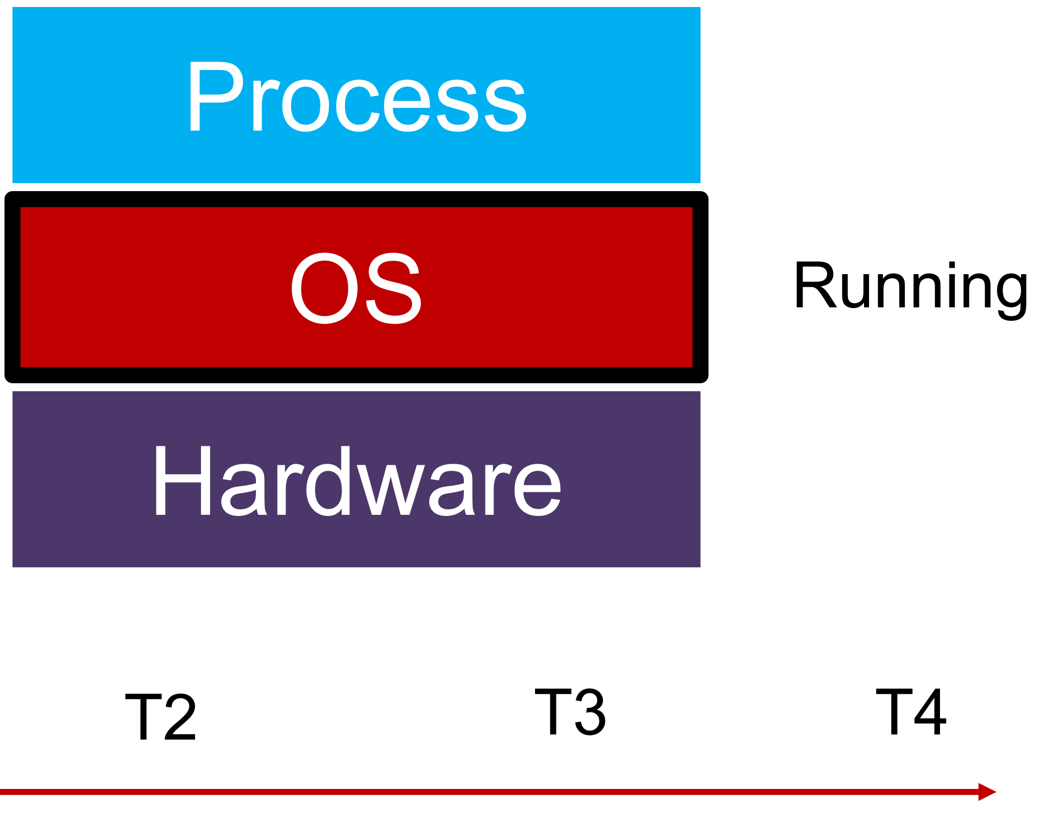


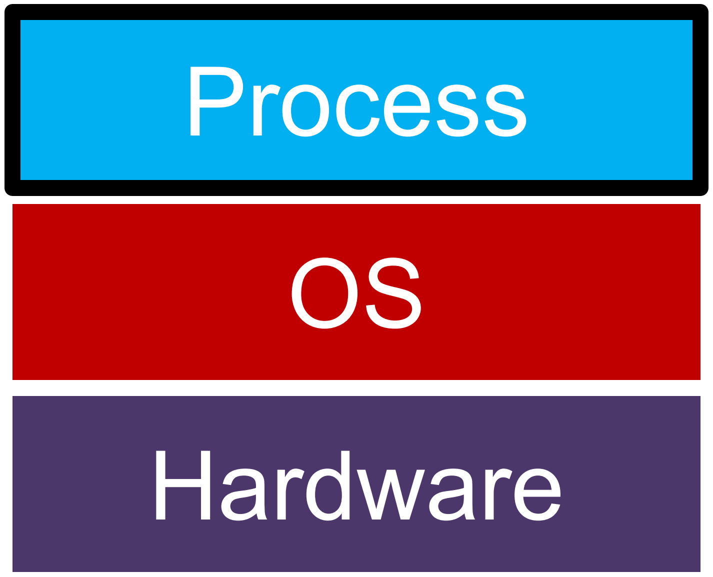
# Taking Turns

**Question**: when/how do we switch to OS?

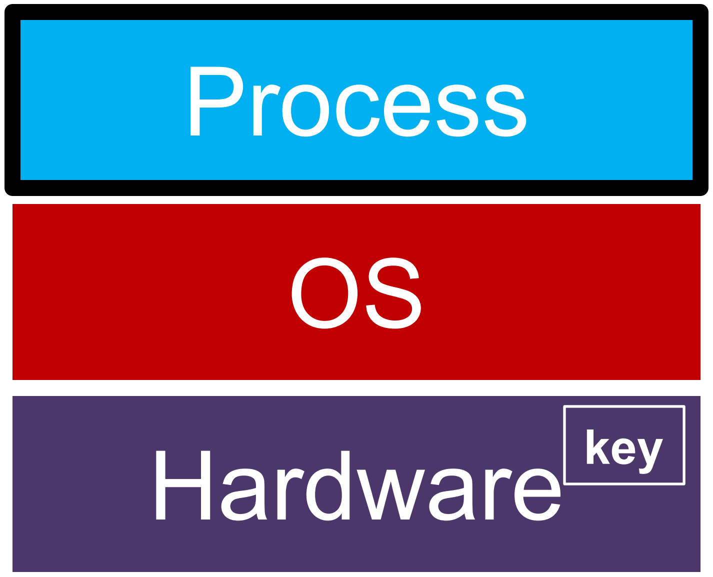


## Exceptions

# Interrupt



## Interrupt



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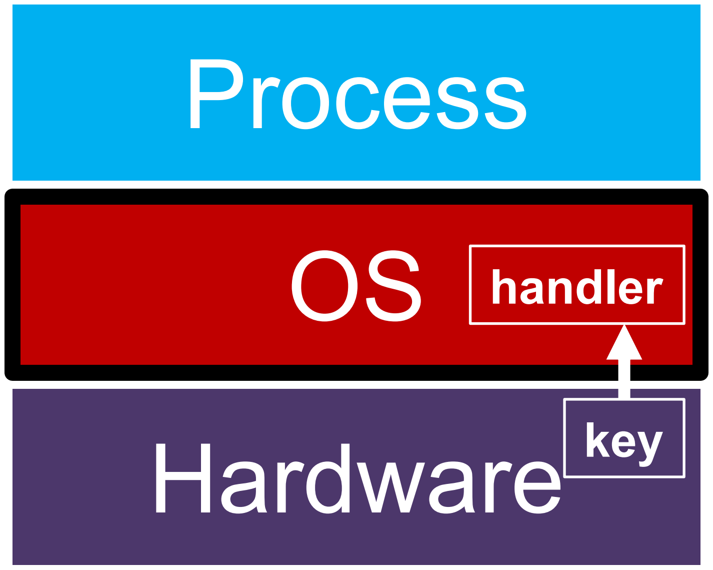
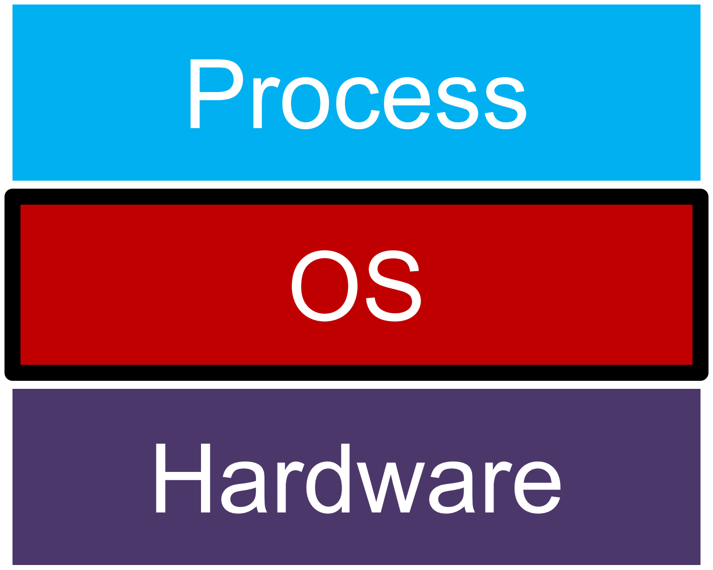
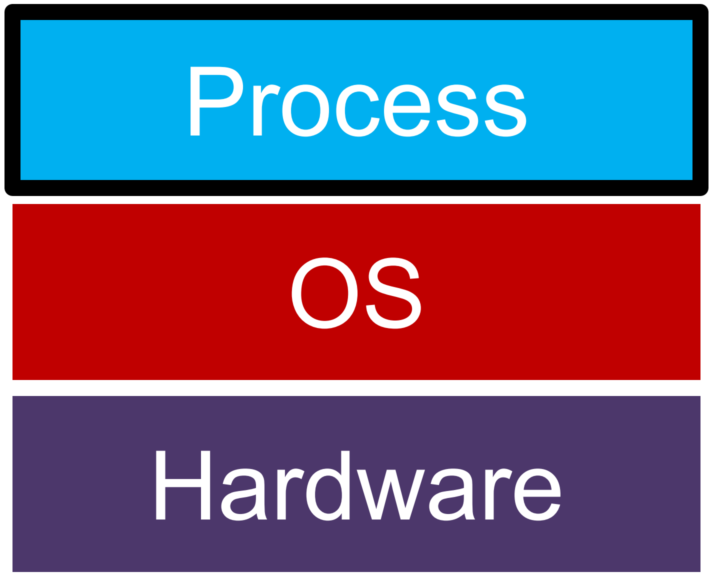


Hardware interrupt

## Interrupt



# System Call



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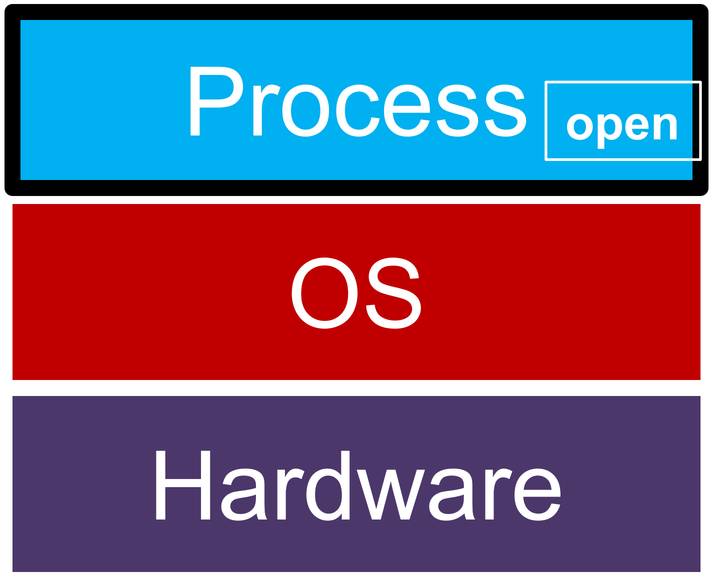

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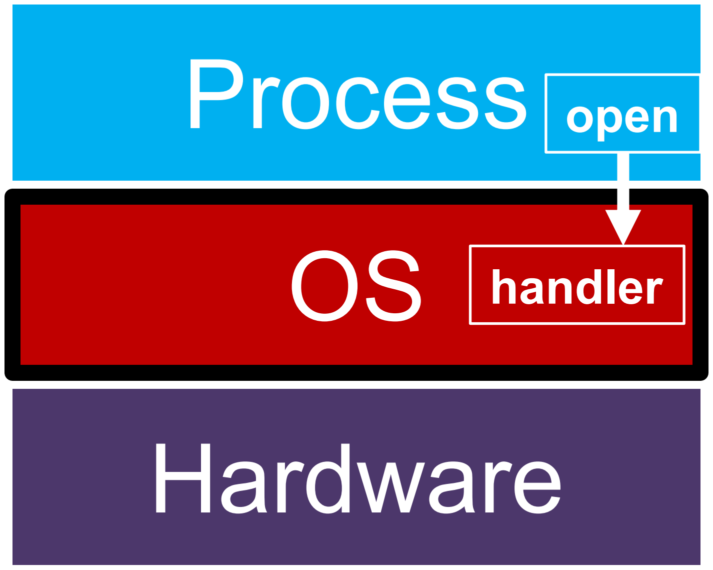
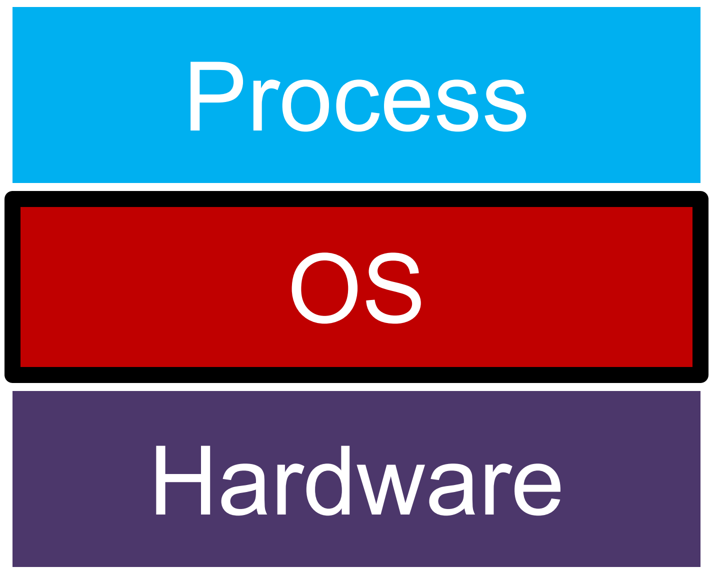


System call "trap"

## System Call

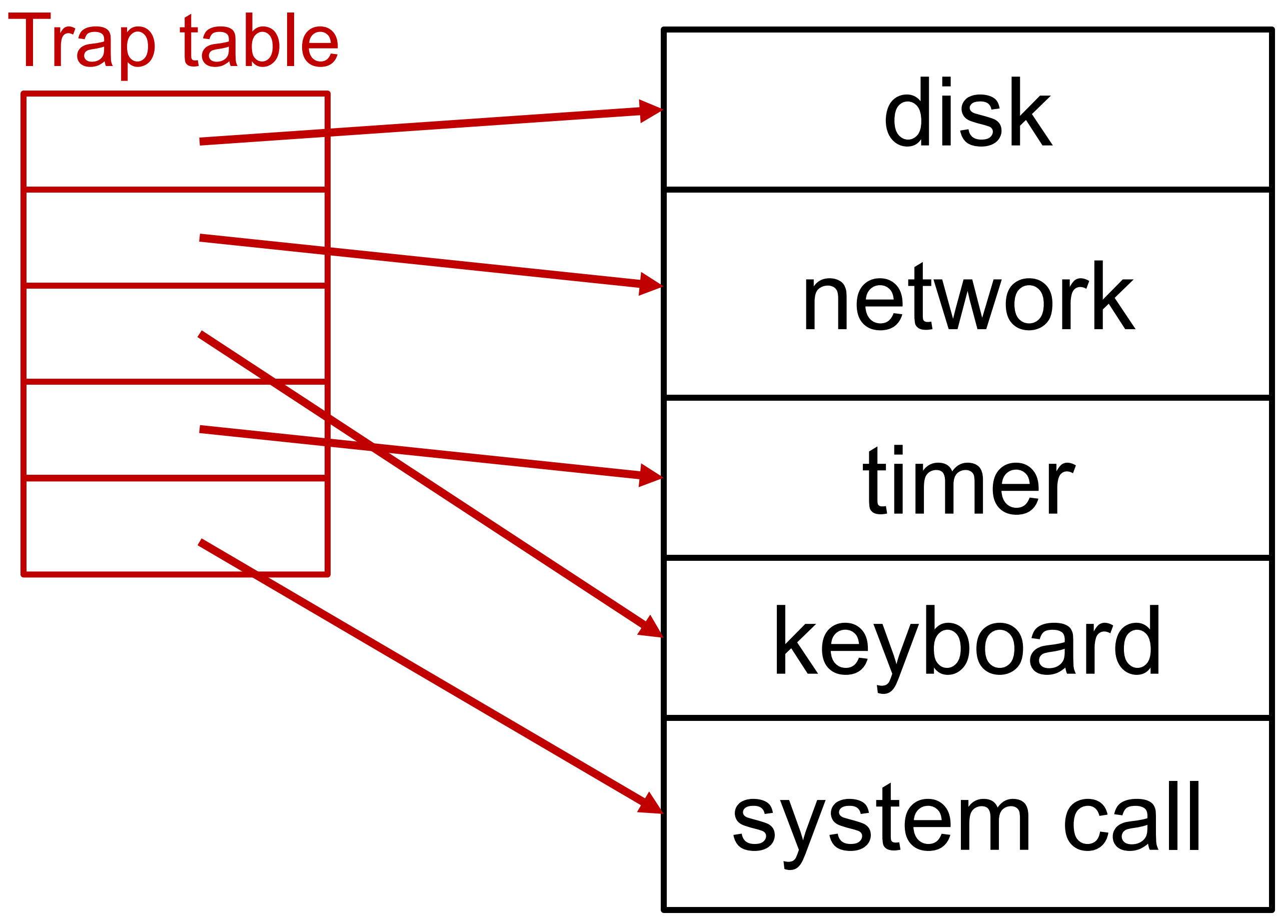


## Exception Handling

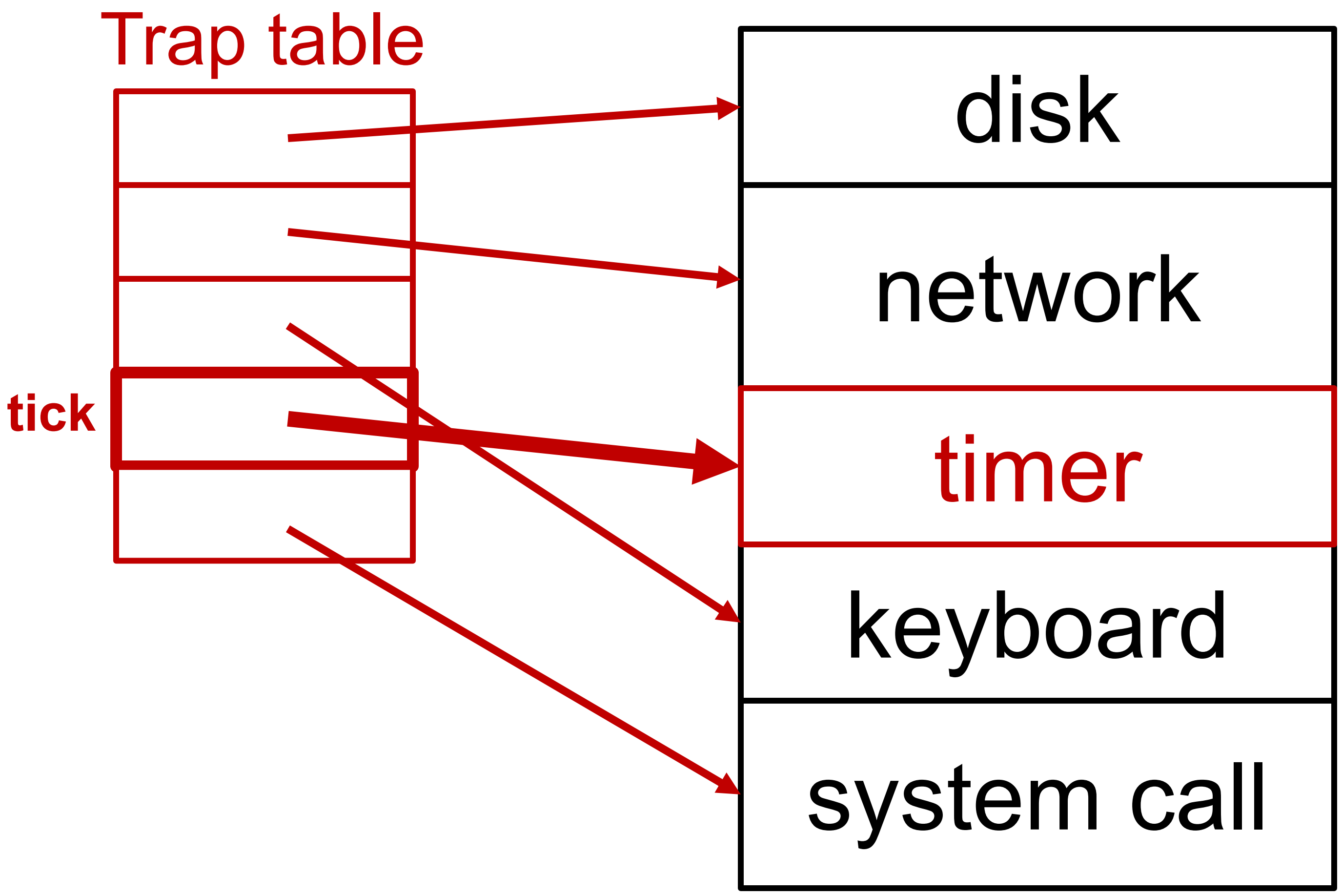
## Exception Handling: Implementation

- Goal: Processes and hardware should be able to call functions in the OS

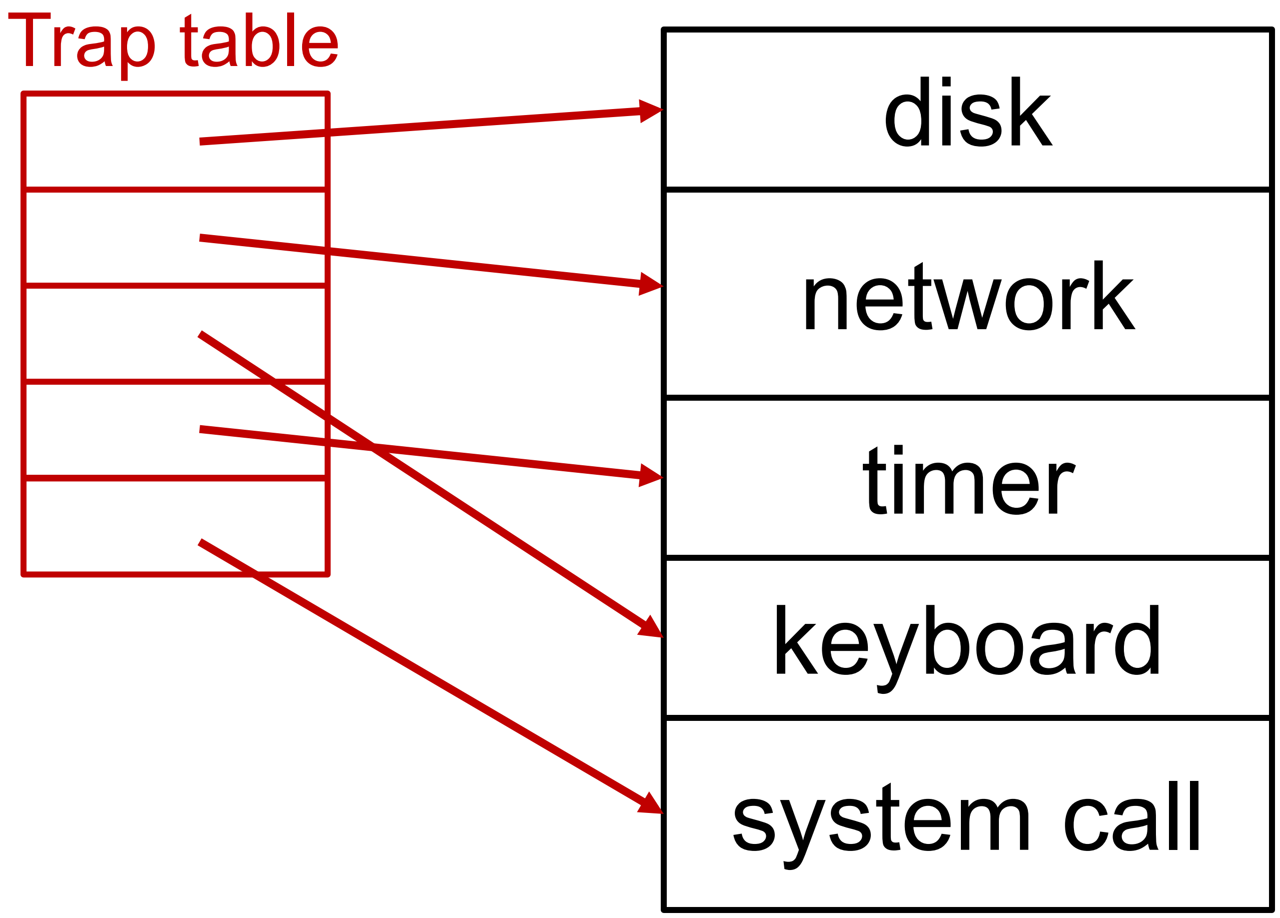
- Corresponding OS functions should be:
  - At well-known locations
  - Safe from processes



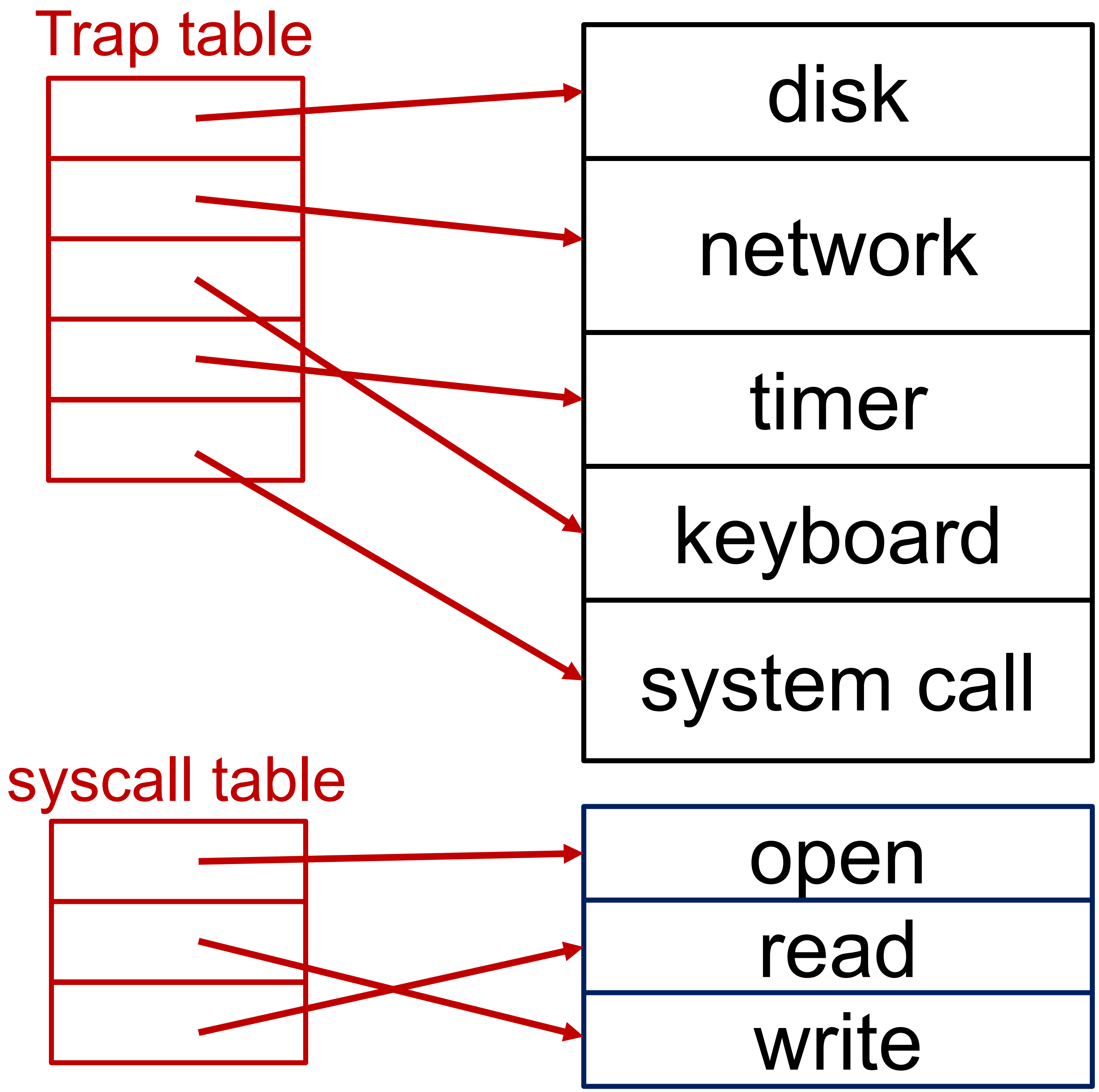
Use array of function pointers to locate OS functions
(**Hardware knows where this is**)



Use array of function pointers to locate OS functions
(Hardware knows this through **`lidt`** instruction)



How to handle variable number of system calls?


Trap table
disk
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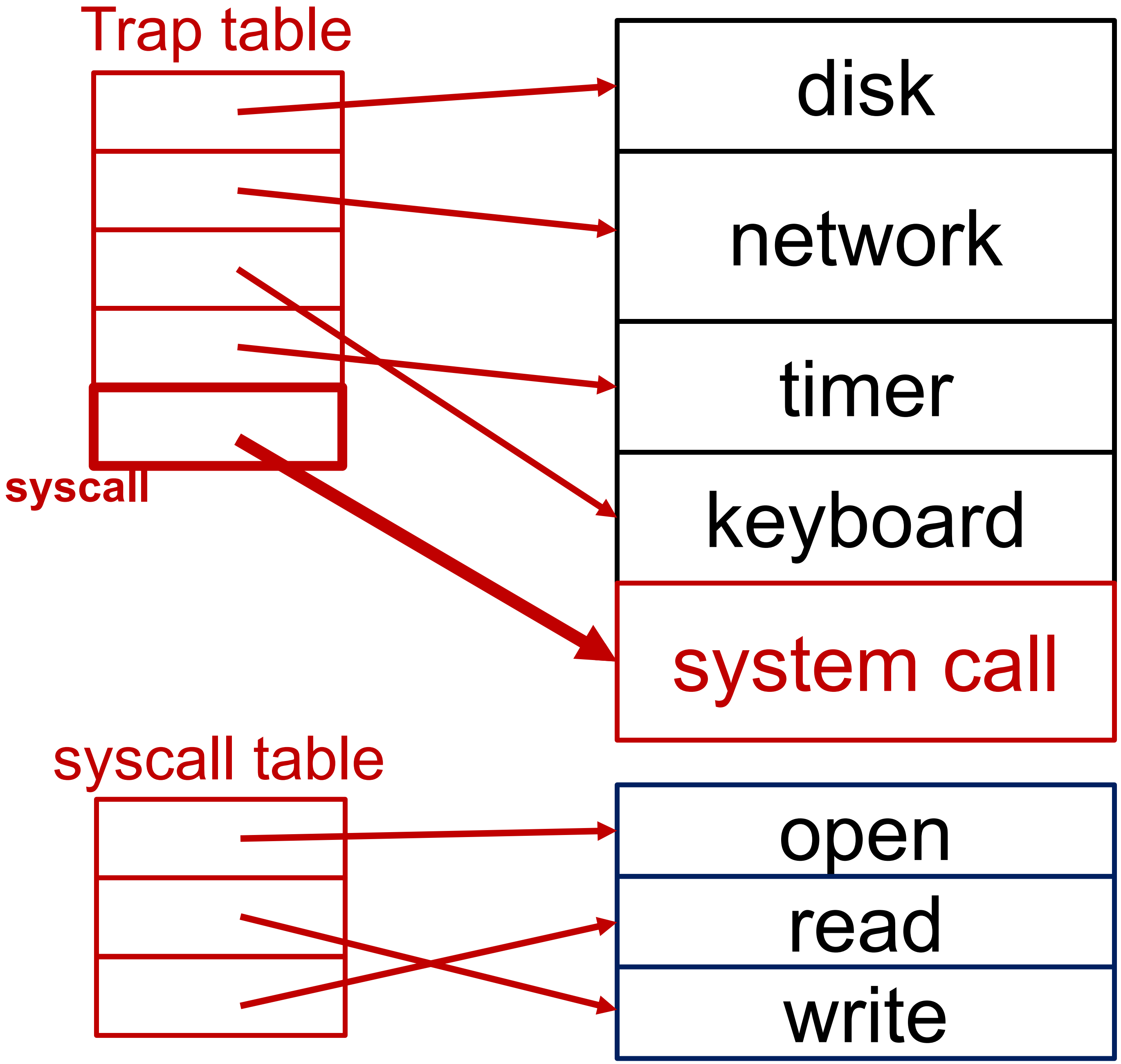
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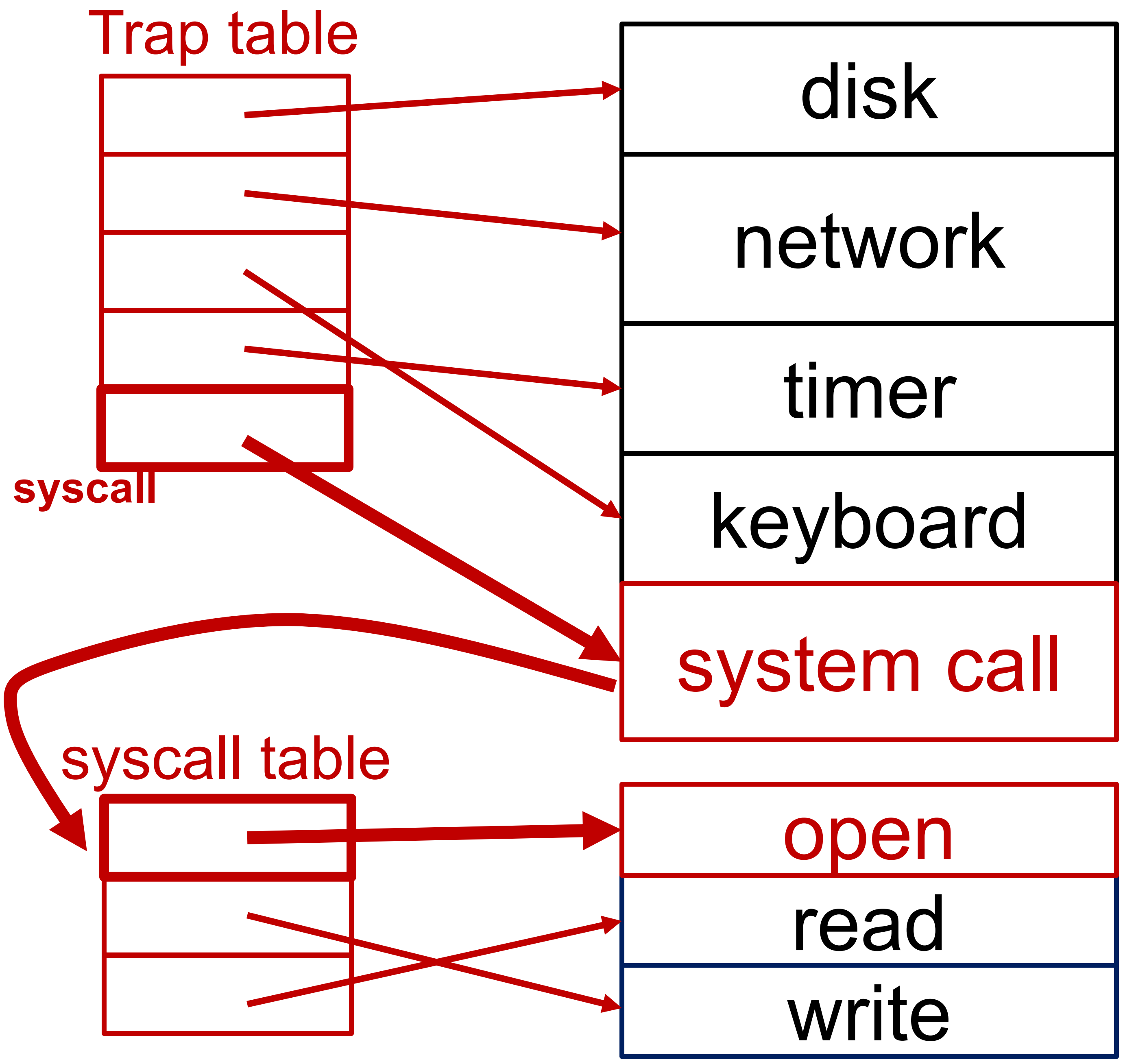
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## Safe Transfers

- Only certain kernel functions should be callable
- Privileges should escalate at the moment of the call
  - Read/write disk
  - Kill processes
  - Access all memory
  - …

## LDE: Remaining Challenges

1. ~~What if process wants to do something privileged?~~
2. **How can OS switch processes (or do anything) if it's not running?**

## Sharing (virtualizing) the CPU

## How does OS share…

- CPU?
- Memory?
- Disk?

## How does OS share…

- CPU? (a: **time sharing**)
- Memory? (a: space sharing)
- Disk? (a: space sharing)

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**Today**

- Memory? (a: space sharing)

- Disk? (a: space sharing)

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**Today**

- Memory? (a: space sharing)
- Disk? (a: space sharing)

**Goal:** processes should **not** know they are sharing **(each process will get its own virtual CPU)**

## What to do with processes that are not running?

- A: Store context in OS struct

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- Context:
  - CPU registers
  - Open file descriptors
  - State (sleeping, running, etc.)

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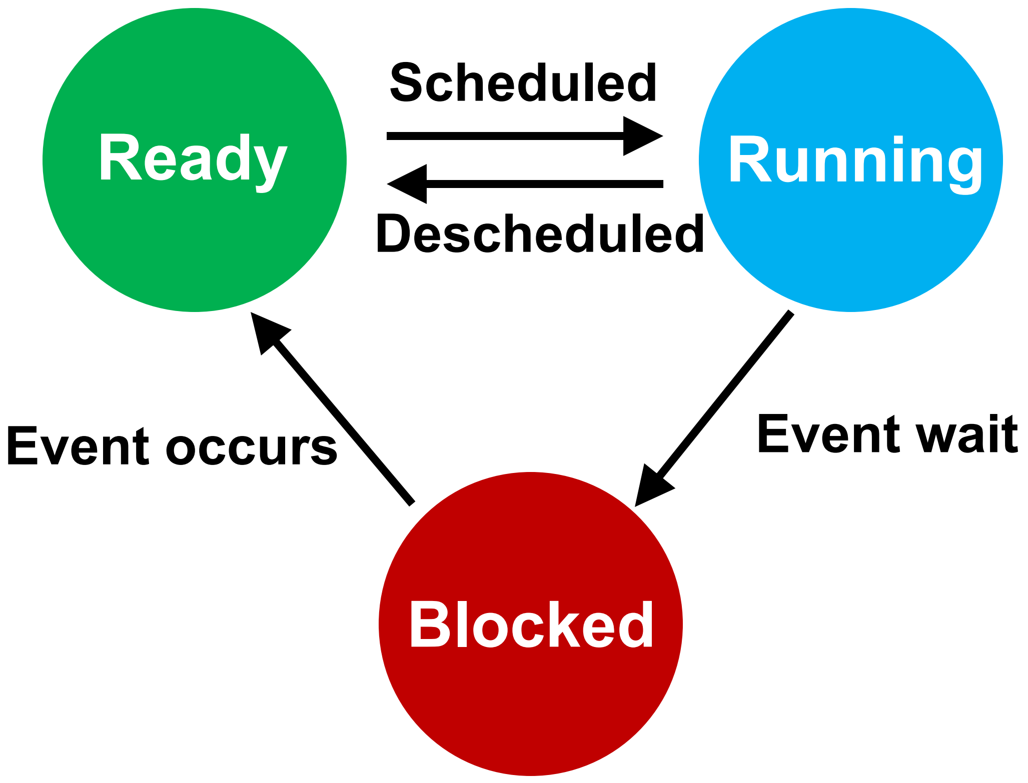
# Process State Transitions



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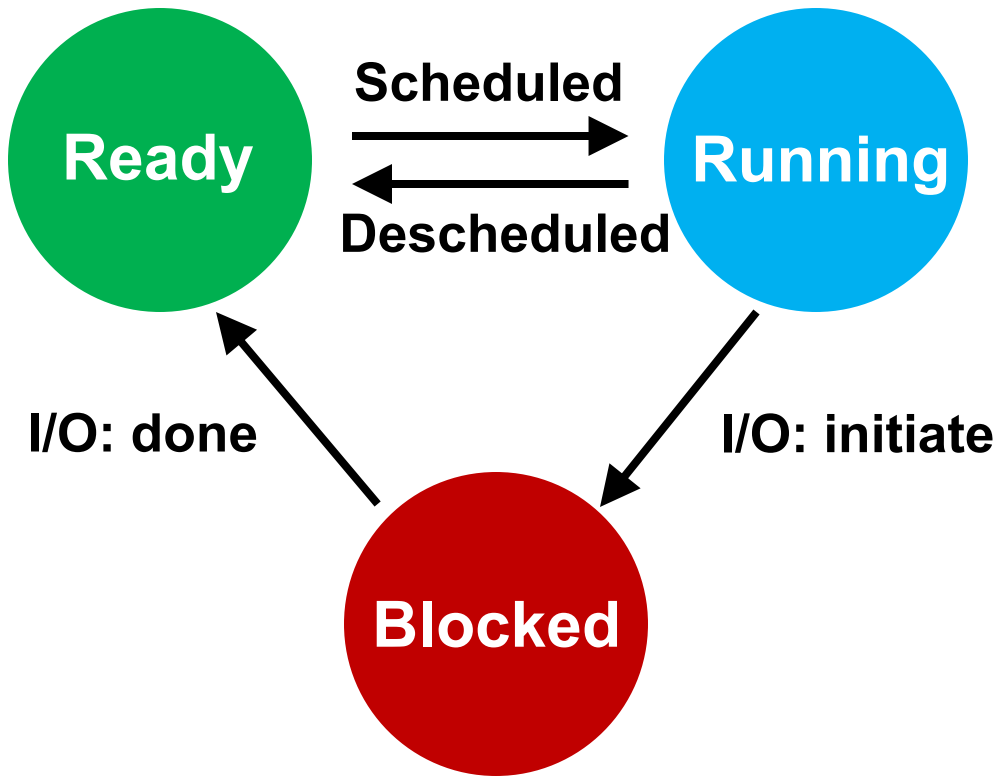

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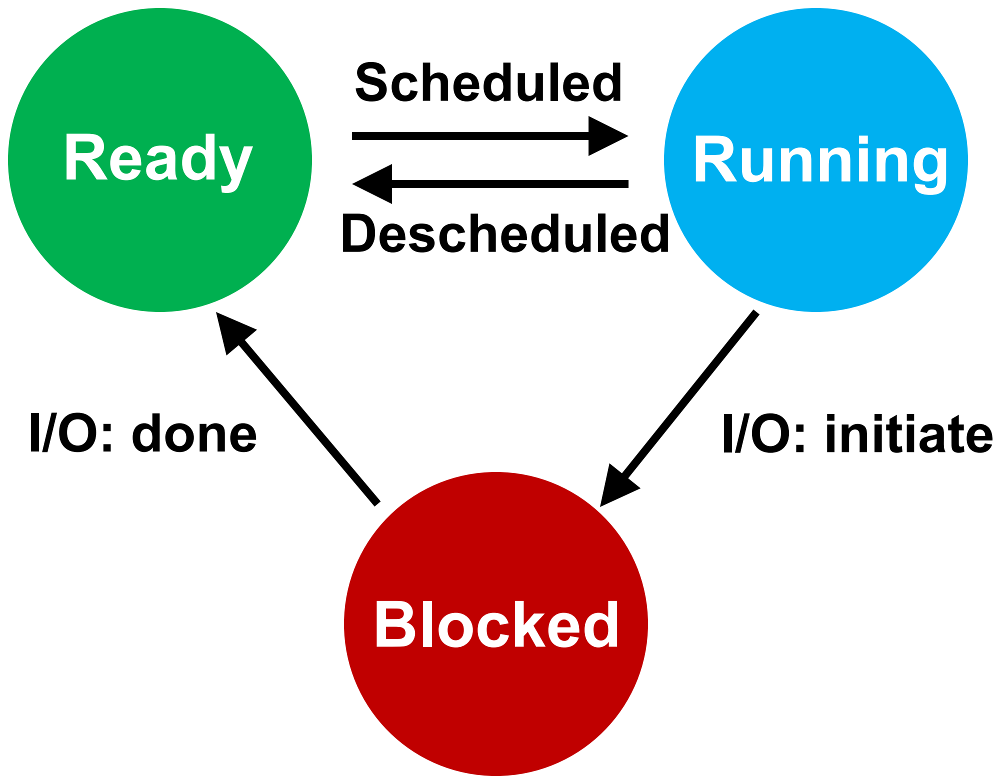
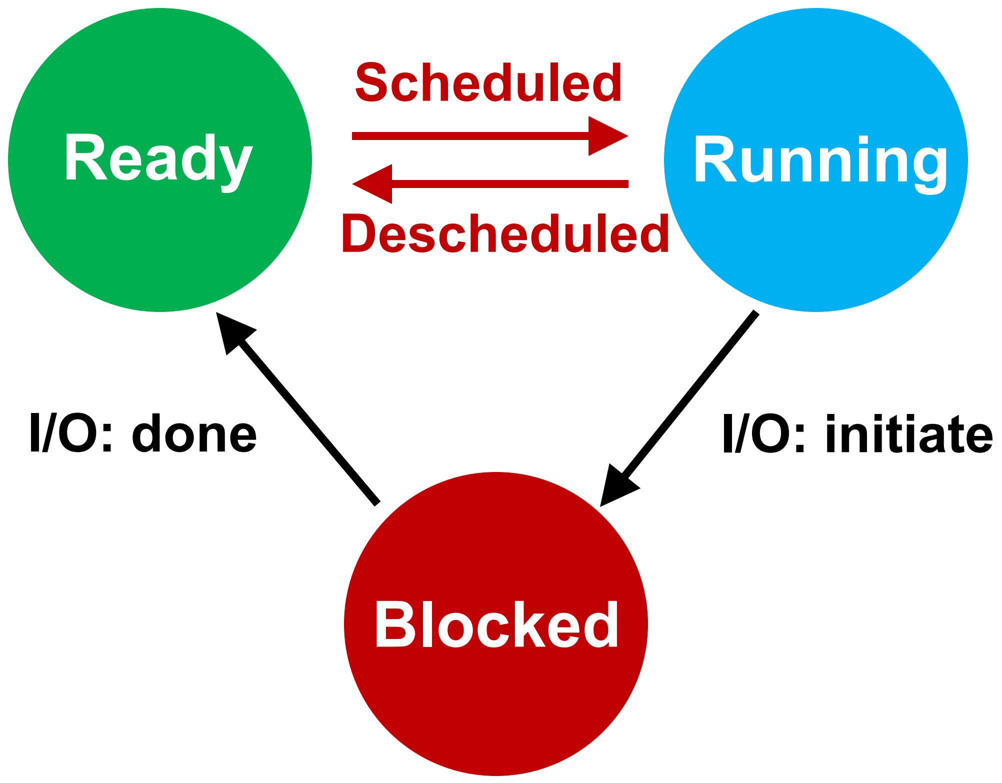


View process state with “`ps xa`”

# How to transition? (mechanism) When to transition? (policy)



# Context Switch

- Problem: When to switch process contexts?
- Direct execution => OS can’t run while process runs

- Can OS do anything while it’s not running?
- A: it can’t

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- Solution: Switch on **interrupts**
  - But what interrupt?

# Cooperative Approach

- Switch contexts for syscall interrupt
  - Special `yield()` system call

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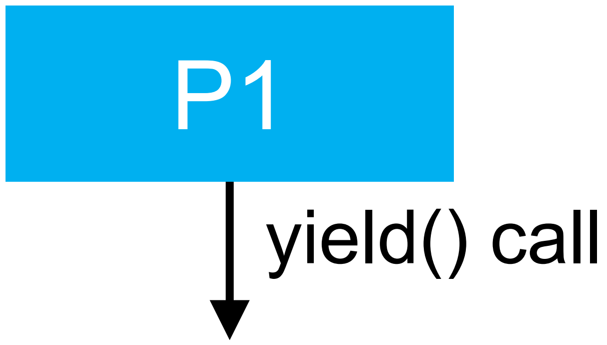

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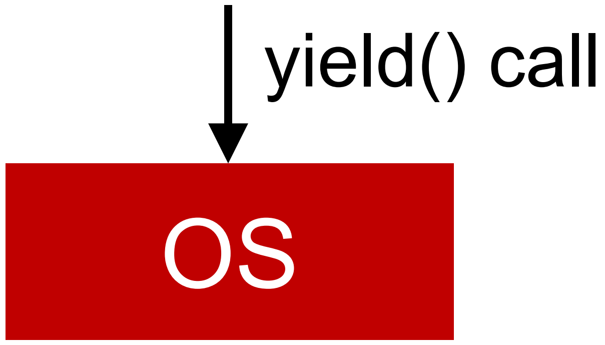

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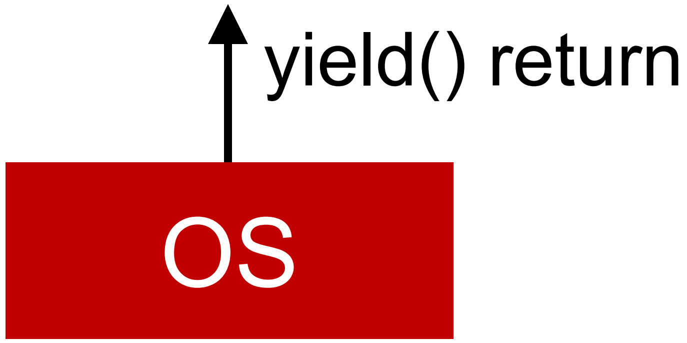

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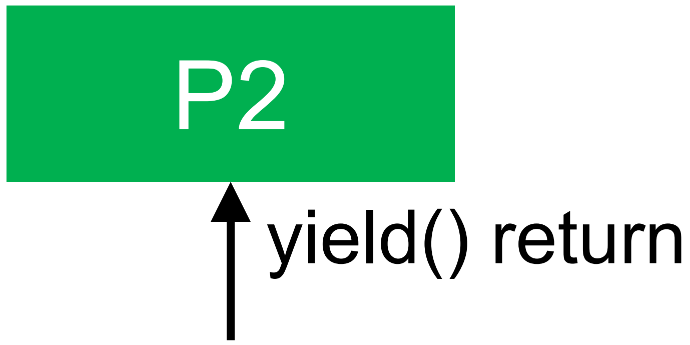

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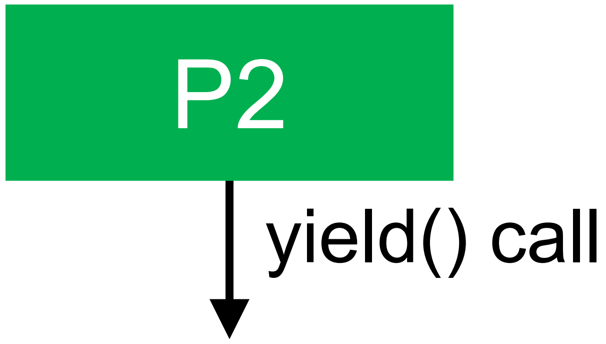

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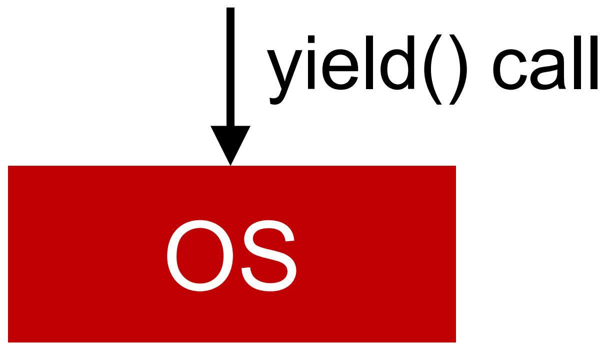

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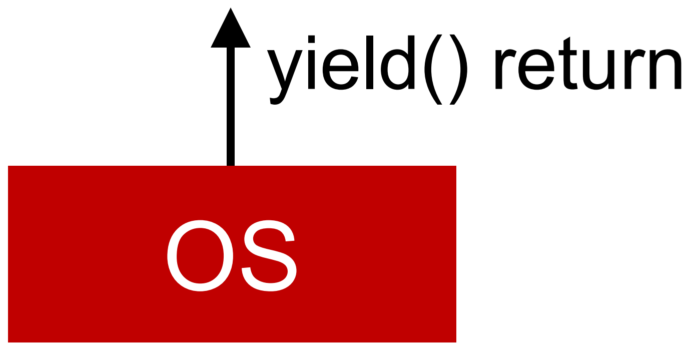

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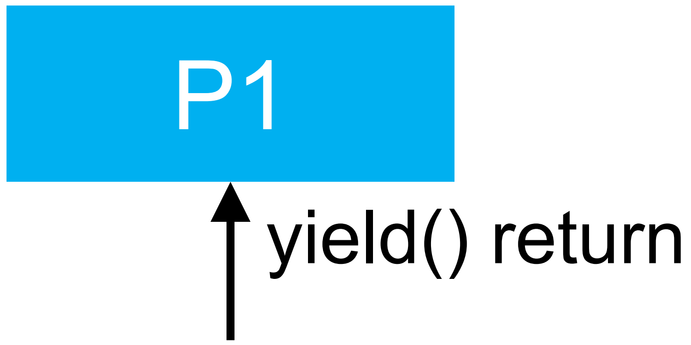

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**Critiques?**

# Cooperative Approach

- Switch contexts for syscall interrupt
  - Special `yield()` system call
- Cooperative approach is a **passive** approach

**Critiques?**

**What if P1 never calls yield()?**

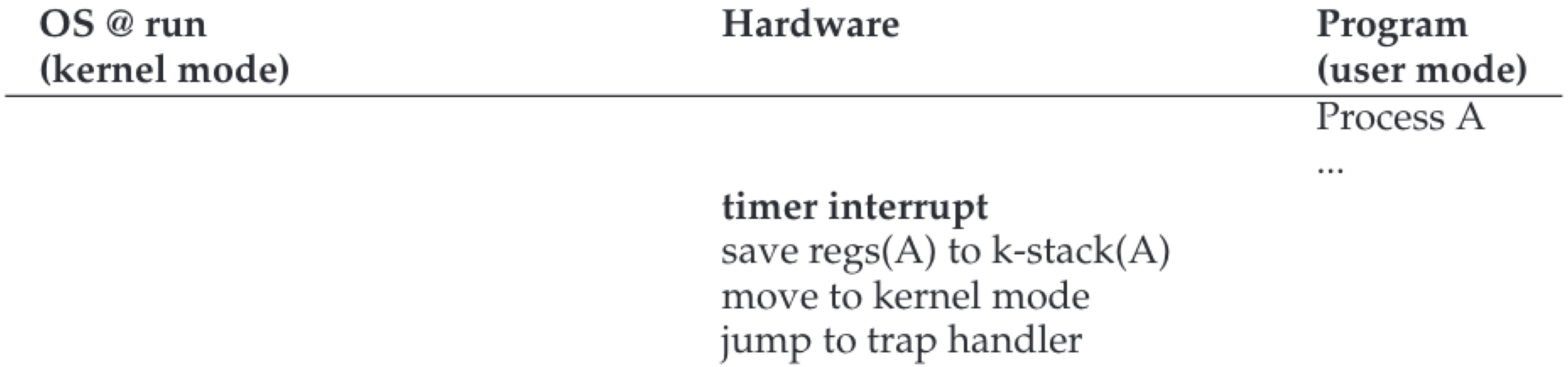
# Non-Cooperative Approach

- Switch contexts on timer (hardware) interrupt
- Set up before running any processes
- Hardware does not let processes prevent this
  - Hardware/OS enforces process preemption

# Non-Cooperative Approach

| **OS @ run (kernel mode)** | **Hardware** | **Program (user mode)** |
|---|---|---|
| | | Process A |
| | | ... |

# Non-Cooperative Approach



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| | save regs(A) to k-stack(A) | |
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| | **timer interrupt**<br>save regs(A) to k-stack(A)<br>move to kernel mode<br>jump to trap handler | |
| Handle the trap<br>Call `switch()` routine<br>save regs(A) to proc-struct(A)<br>restore regs(B) from proc-struct(B)<br>switch to k-stack(B)<br>**return-from-trap (into B)** | | |

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| **return-from-trap (into B)** | | |
| | restore regs(B) from k-stack(B) | |
| | move to user mode | |
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| | | Process B |
| | | ... |

# Preemptive Approach

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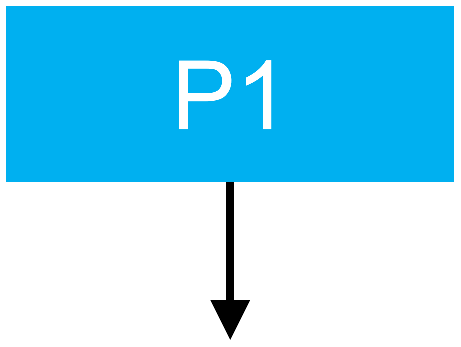

tick

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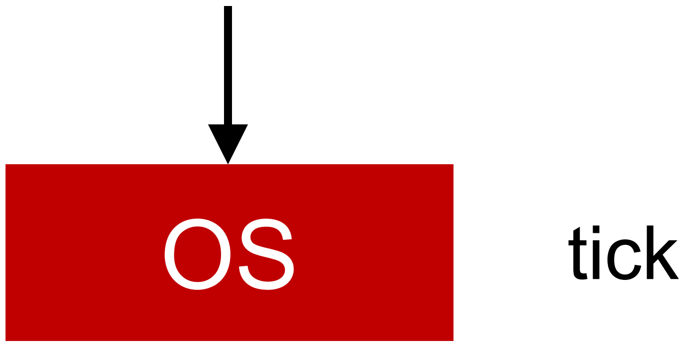

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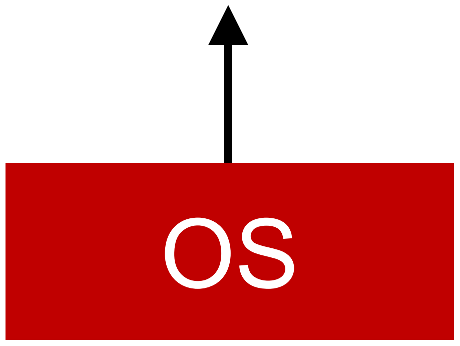

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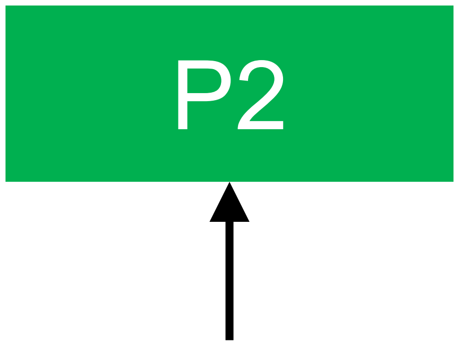

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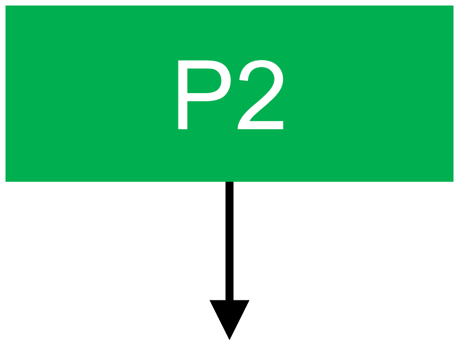

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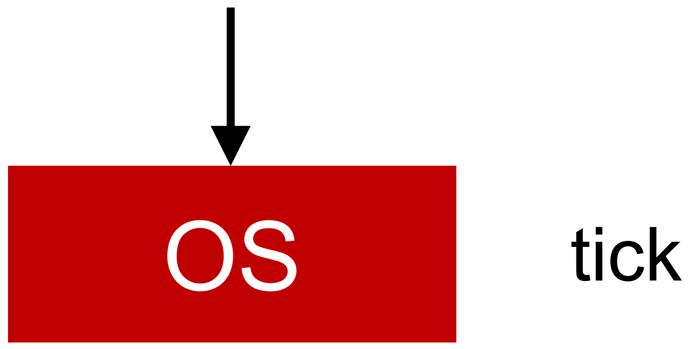

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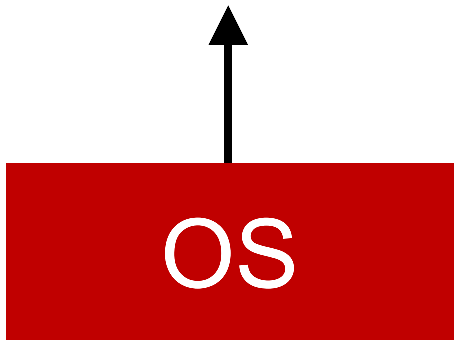

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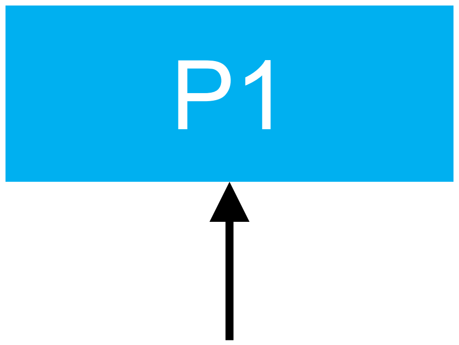

## Preemptive Approach

## Summary

- Smooth context switching makes each process think it has its own CPU (virtualization!)
- Limited direct execution makes processes fast
- Hardware provides a lot of OS support
  - Limited direct execution
  - Timer interrupt
  - Automatic register saving