Georgia Tech Computer Science

CS2200
Systems and Networks
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Lecture 13: Processor Scheduling

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Lecture slides adapted from Bill Leahy and Charles Lively of Georgia Tech

Roadmap

Starting Chapter 6

- Process as an abstraction
- Scheduler
- Process, job, thread, task
- States of process
- Process control block (PCB)
- Types of scheduler
- Algorithms
- Metrics & Evaluation

What is an operating system?

- An operating system is a special program that manages access of user programs to hardware resources
- The OS provides a number of abstractions, e.g.
  - Multiple processes (how can one physical processor run multiple programs at the same time?)
  - Memory permissions to protect other processes and the OS
  - Shared access to I/O devices, e.g. networks, file systems
  - Resource sharing (processors, memory, I/O, …)
  - Additional operations (read, write, exit, get more memory, change permissions, …) implemented through traps

Levels of Abstraction

Application (Algorithms expressed in High Level Language)
System Software (Compiler, OS, etc.)
Computer Architecture (ISA)
Machine Organization (Datapath and Control)
Sequential and Combinational Logic Elements
Logic Gates
Transistors
Solid-State Physics (Electrons and Holes)

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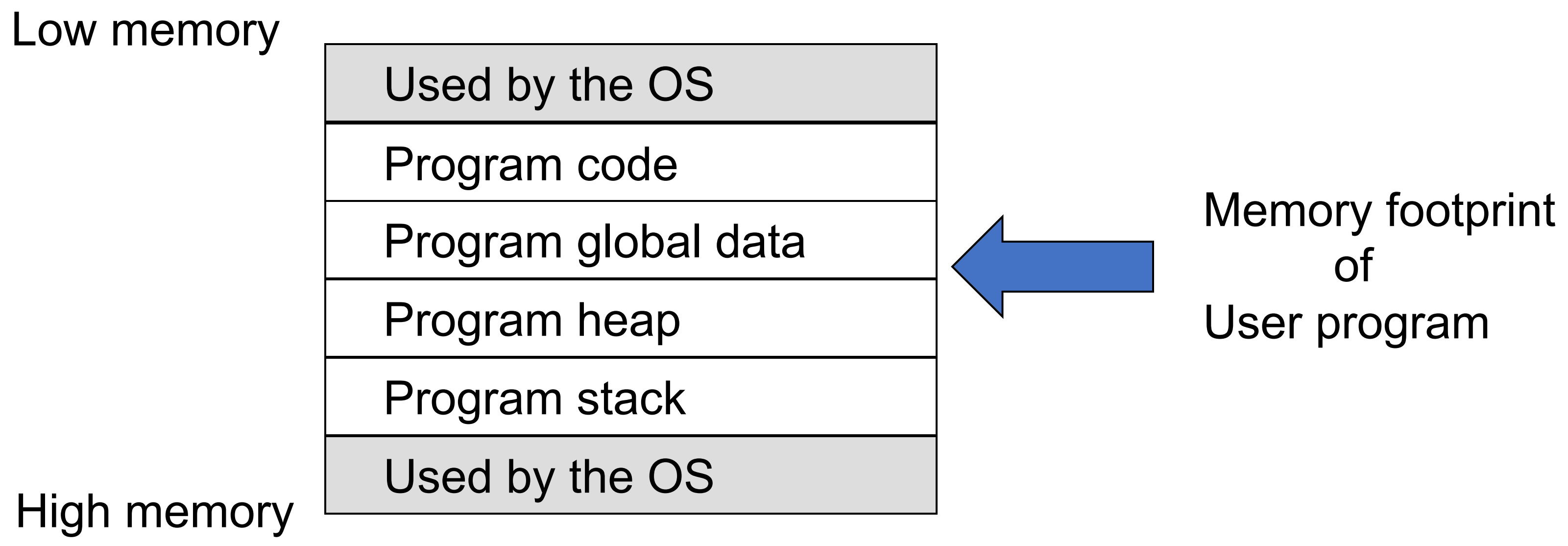
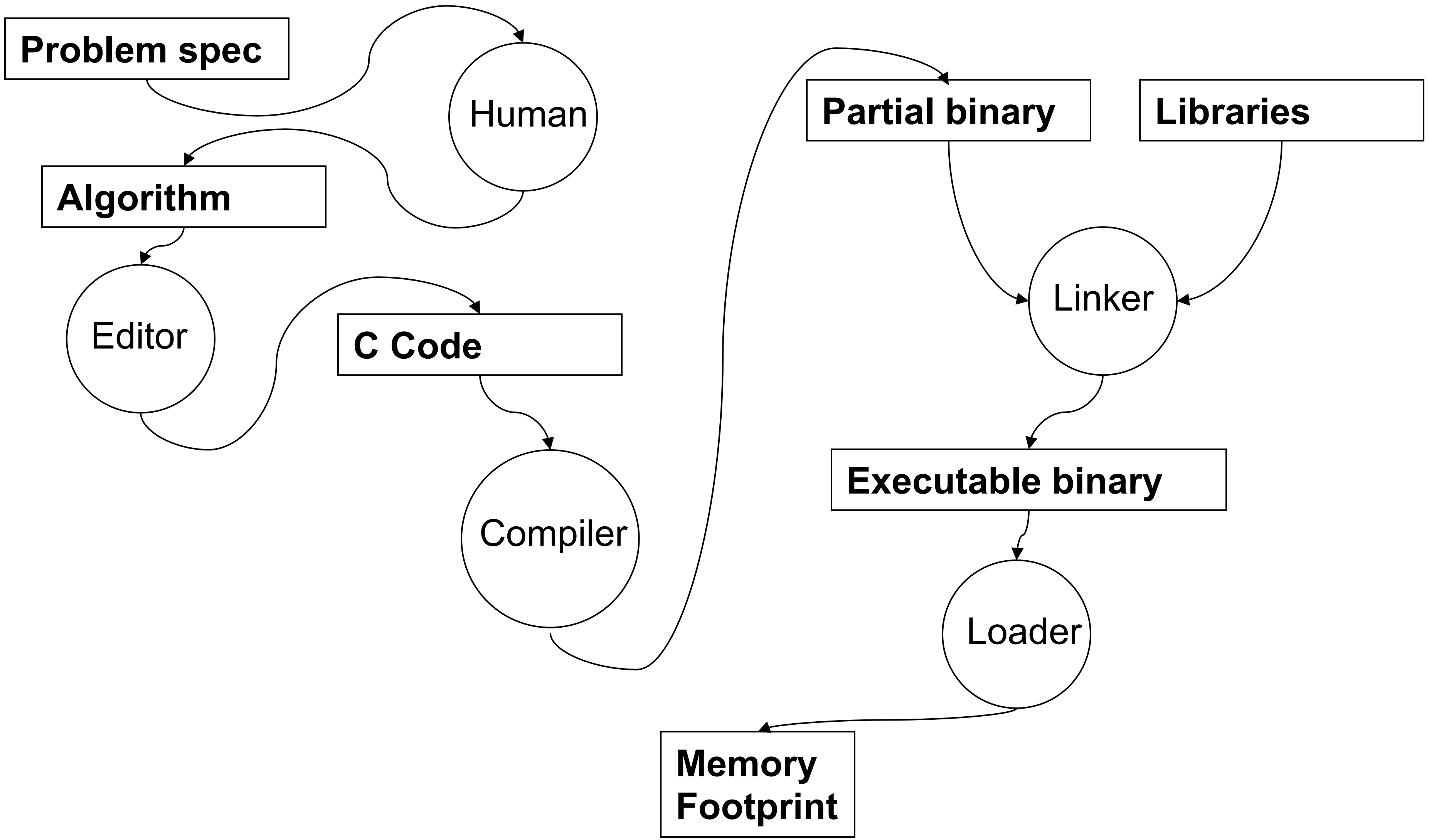
A program in memory

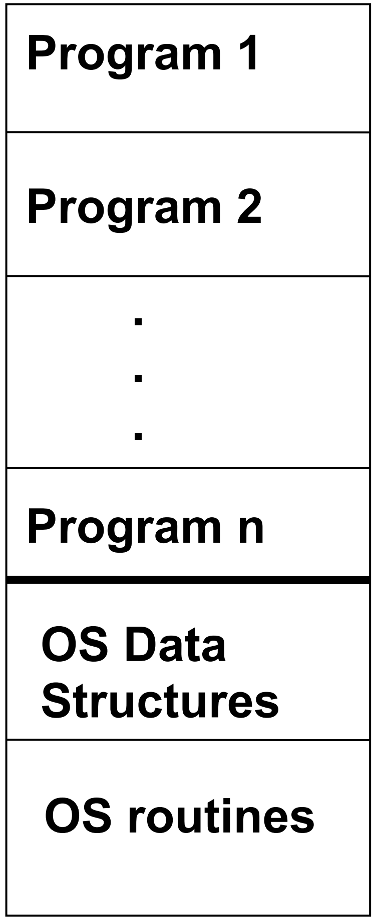


How do we create a program?



Incoming

More Than One Program in Memory?



- What's the difference between a process and a program?
- A process is a program AND all of the state that represents its execution, e.g.
  - Registers
  - Memory
  - PC
  - Stack
- So far we've been talking about computers that have one single process with the state maintained in hardware
- Interrupts were our first clue that it doesn't have to be this way

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Process differs from program in that

1% A. There is no difference

28% B. A process is a machine language representation of a program

60% C. A process is a program in execution

4% D. A process is a program that executes correctly

7% E. A process is a special kind of program that is part of the operating system

0% F. No clue

Concepts

- Multitasking
  - Shortest Job First
  - Priority
  - Round Robin
  - Preemption
  - First Come First Served

Concepts

- Multitasking
  - Shortest Job First
  - Priority
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In the context of your life

Your To Do List:
- Laundry
- Prepare food and eat
- Call Mom
- Prepare for tests

You:

How do you timeshare yourself?!

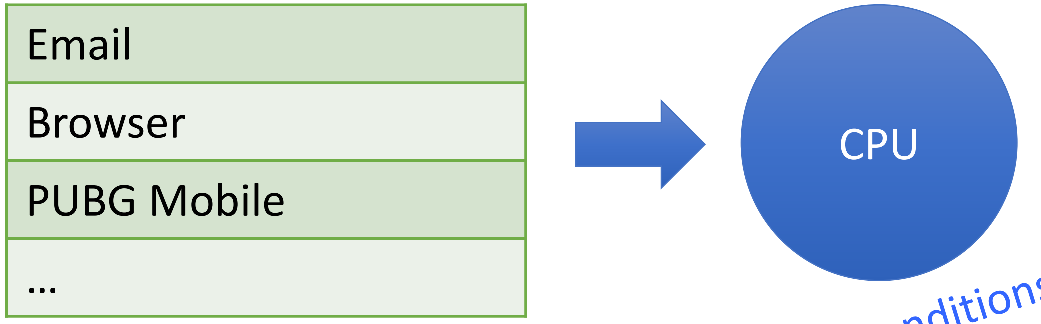
Laundry ----------------------

Prep & Eat ----------

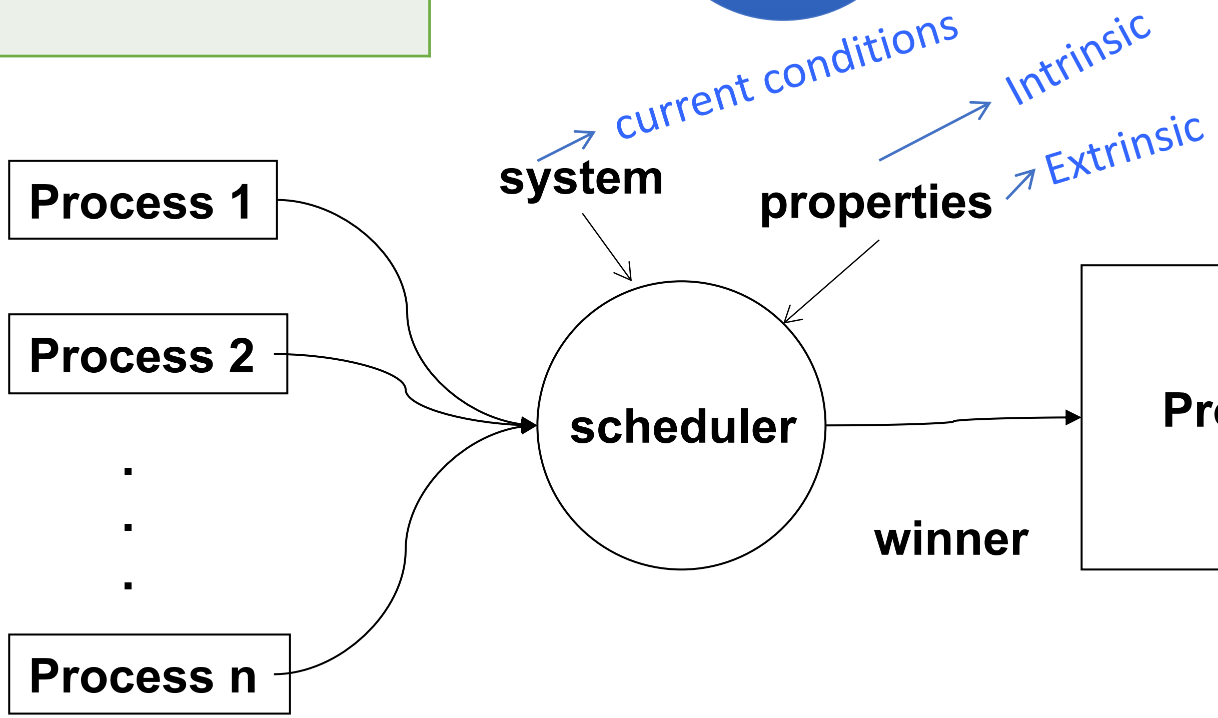
Call Mom --------

Test Prep ----------

Multitasking in the computer world



How do we timeshare a processor?



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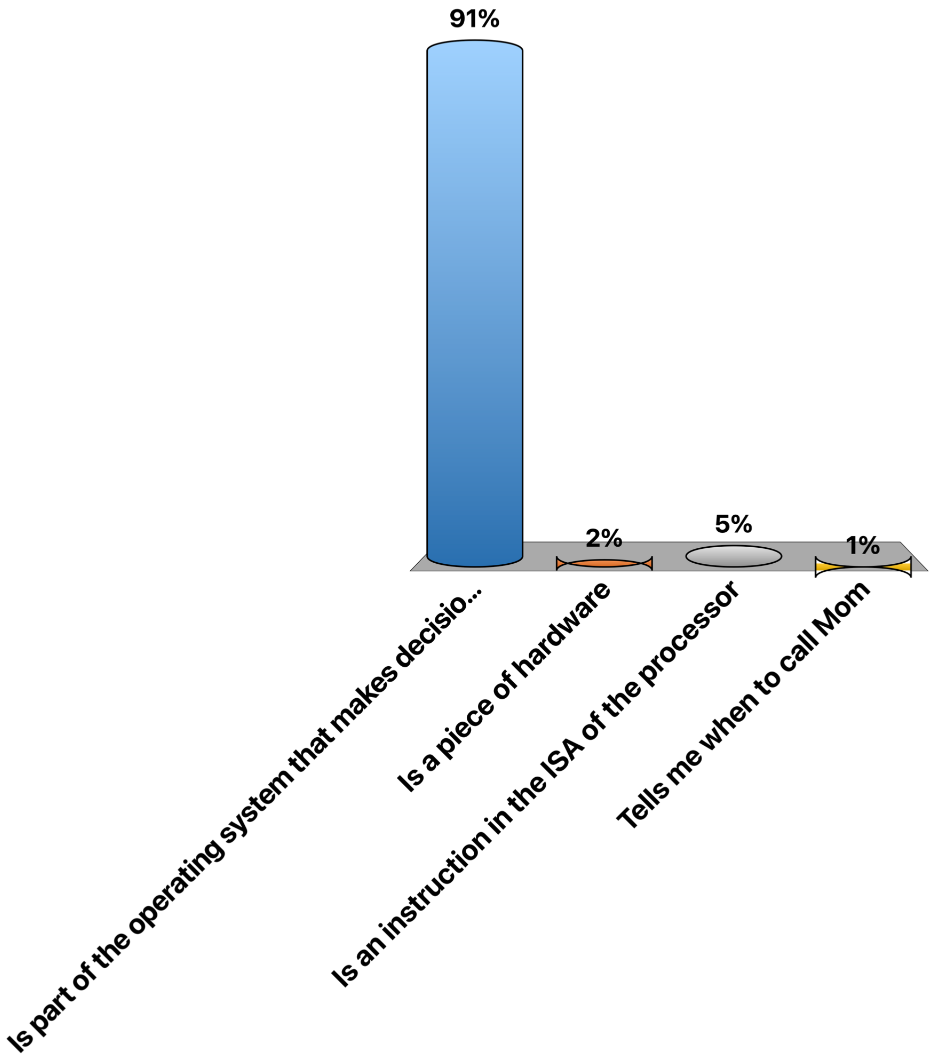
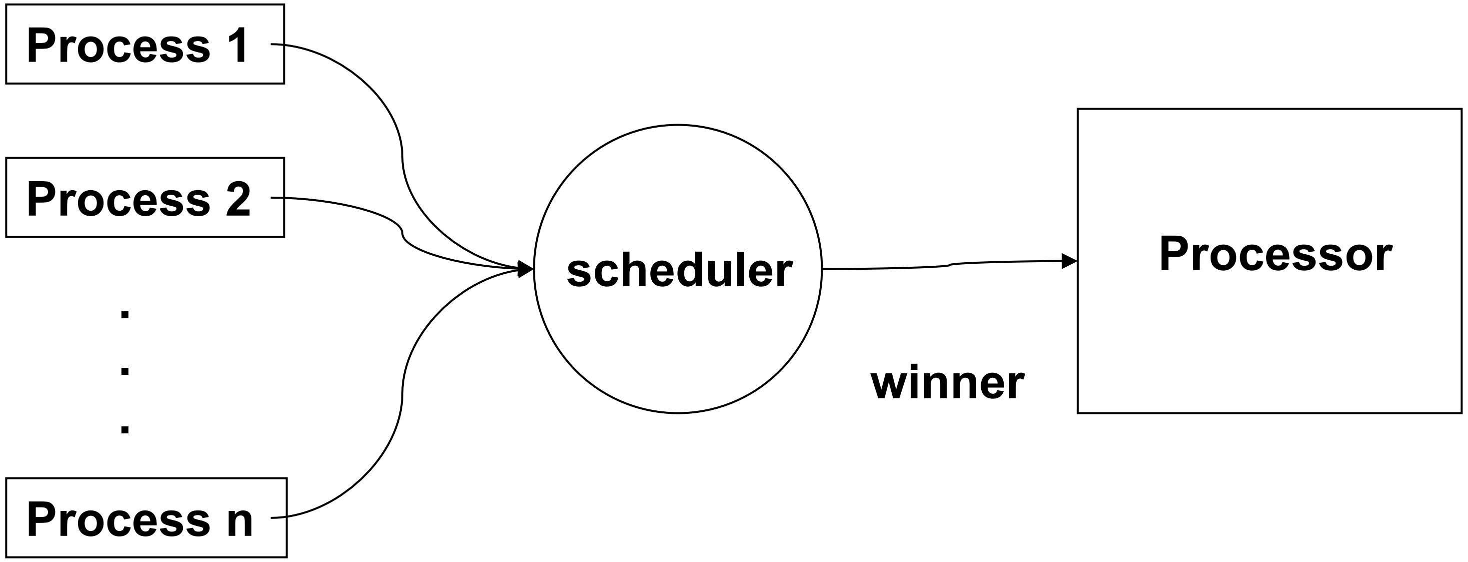
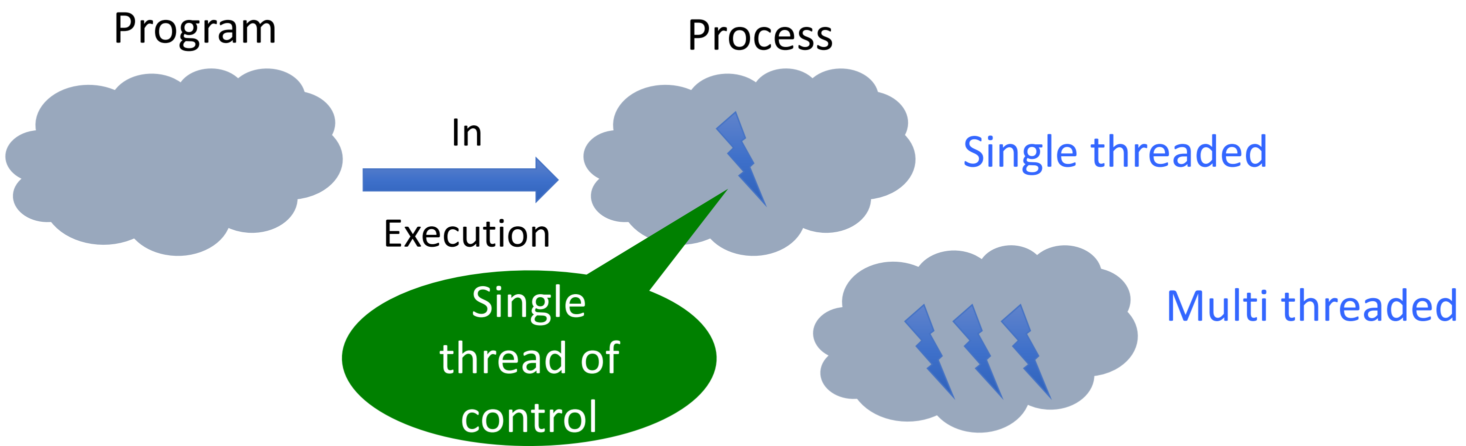
A scheduler

A. Is part of the operating system that makes decisions to allocate the processor resources to processes
B. Is a piece of hardware
C. Is an instruction in the ISA of the processor
D. Tells me when to call Mom



Quick aside: Threads

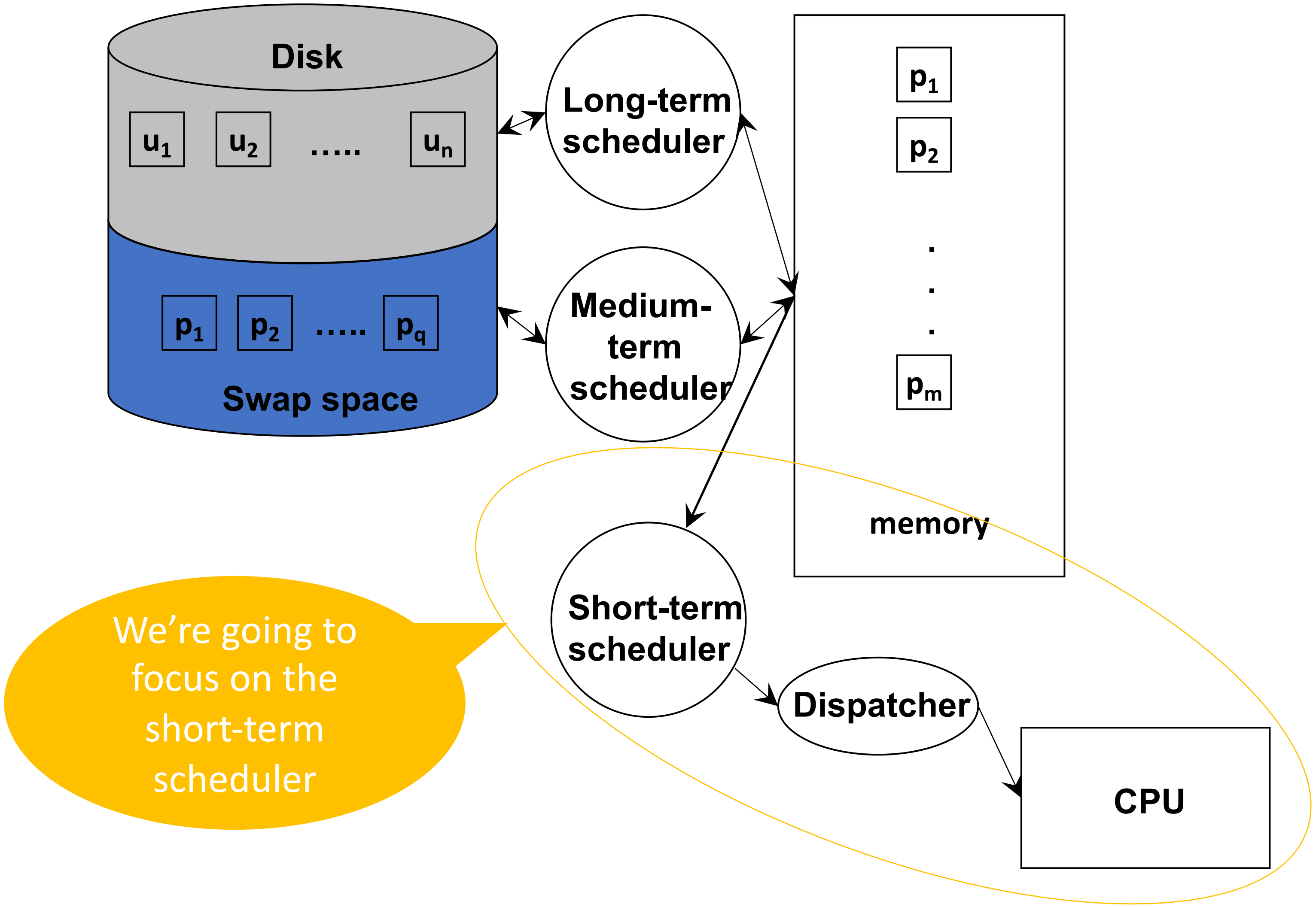




Terminology

Name	Usual Connotation	Use in this chapter
Job	Unit of scheduling	Synonymous with process
Process	Program in execution; unit of scheduling	Synonymous with job
Thread	Unit of scheduling and/or execution; contained within a process	Not used in the scheduling algorithms described in this chapter
Task	Unit of work; unit of scheduling	Not used in the scheduling algorithms described in this chapter, except in describing the scheduling algorithm of Linux

Schedulers



Disk
u_1
u_2
.....
u_n
p_1
p_2
.....
p_q
Swap space
Long-term scheduler
Medium-term scheduler
p_1
p_2
p_m
memory
Short-term scheduler
Dispatcher
CPU
We're going to focus on the short-term scheduler

Terminology

Name	Environment	Role
Loader	In every OS	Load user program from disk into memory
Long term scheduler	Batch oriented OS	Control the job mix in memory to balance use of system resources (CPU, memory, I/O)
Medium term scheduler	Every modern OS (time-shared, interactive)	Balance the mix of processes in memory to avoid thrashing
Short term scheduler	Every modern OS (time-shared, interactive)	Schedule the memory resident processes on the CPU
Dispatcher	In every OS	Populate the CPU registers with the state of the process selected for running by the short-term scheduler

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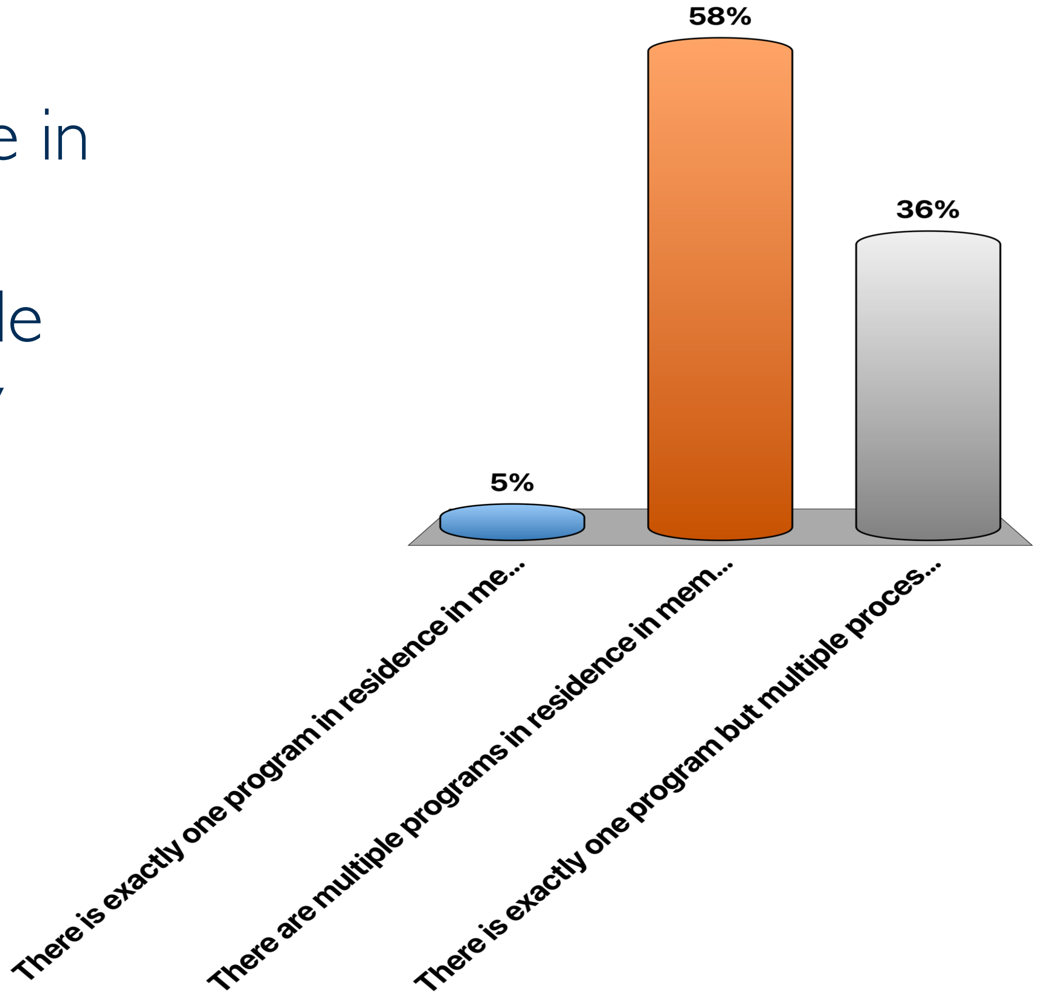
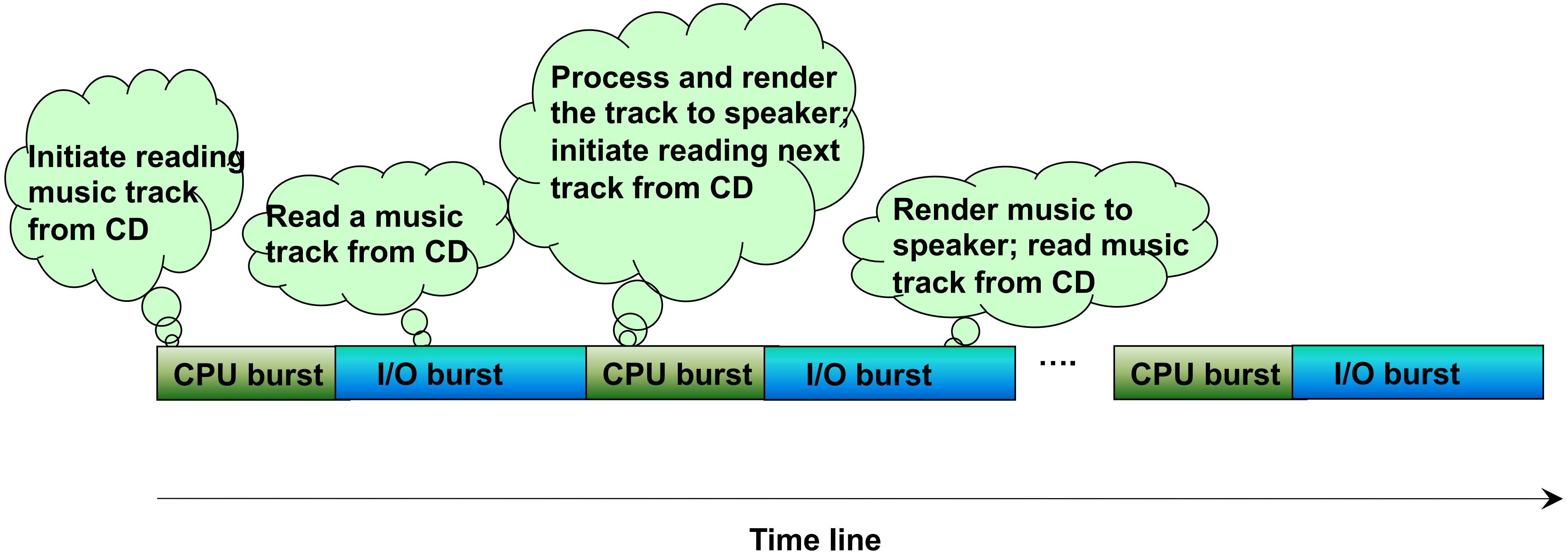
In most modern-day operating systems

A. There is exactly one program in residence in memory at any point in time
B. There are multiple programs in residence in memory at any point in time
C. There is exactly one program but multiple processes in residence in memory at any point in time



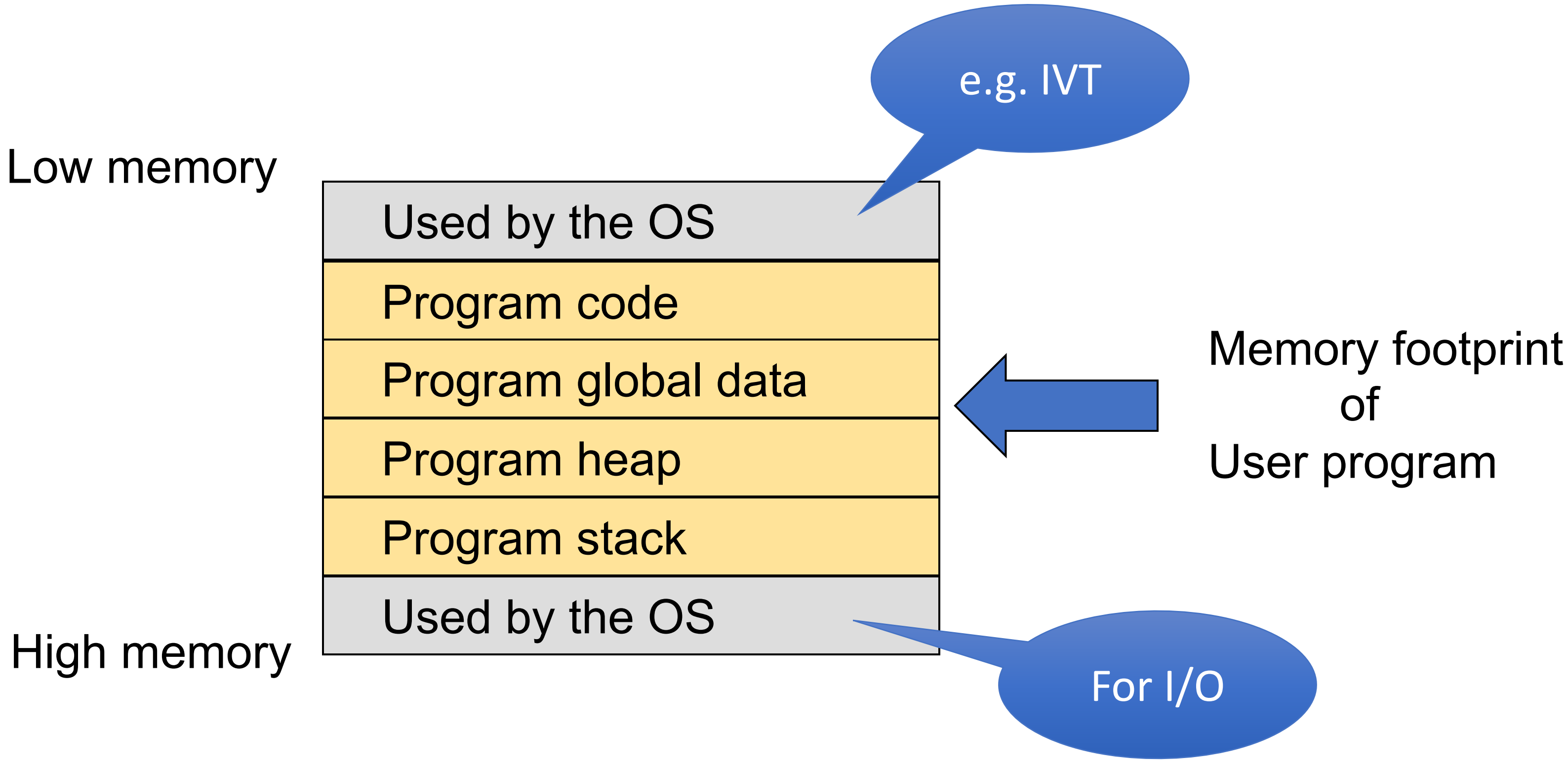
What's the process doing?



Program property:

CPU to I/O ratio

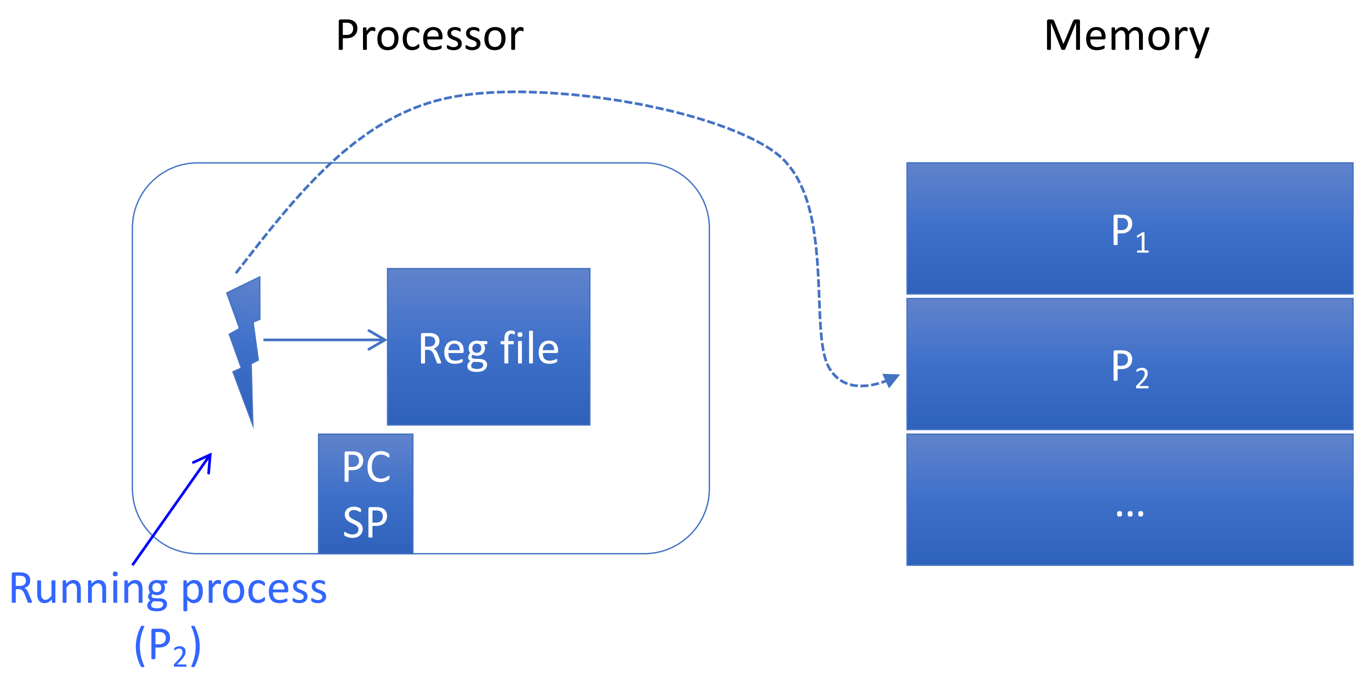
Recall the memory footprint of a program



Process state

Process$_2$ is running. The program is in memory. Where is its state?

Where will its state be when some other process is running?



PCB – Process Control Block

We need a data structure to represent a process' state

```
enum  state_type {new, ready, running,
                    waiting, halted};
typedef struct control_block_type {
   enum state_type state;
   address PC;
   int reg_file[NUMREGS];
   struct control_block *next_pcb;
   int priority;
   address memory_footprint;
   ….
   ….
} control_block;
```

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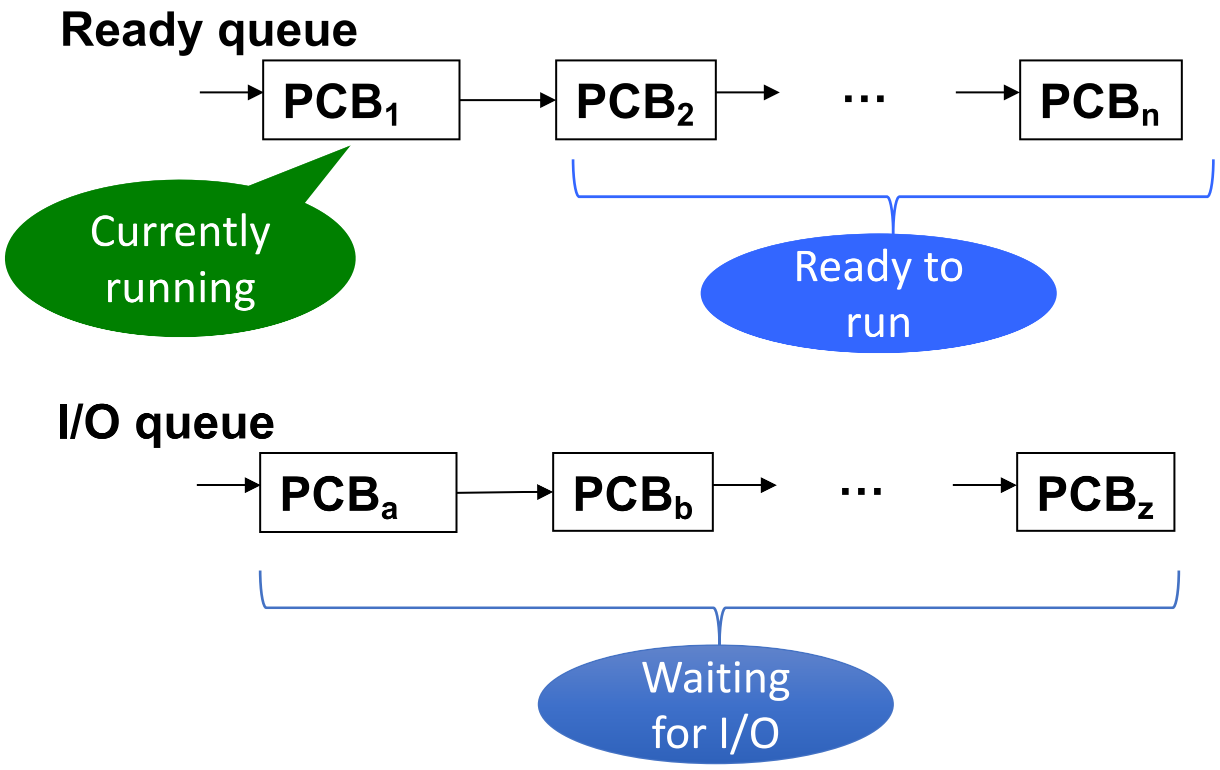
One of these is NOT part of the PCB

- 19% A. General purpose registers that are visible to the instruction set
- 9% B. Program counter and the register that represents the stack pointer
- 10% C. Information about the process' memory footprint
- 54% D. Internal registers in the datapath of the processor (FBUF, DBUF, etc.)
- 9% E. Priority information

PCB – Process Control Block

```
enum  state_type {new, ready, running,
                  waiting, halted};
typedef struct control_block_type {
   enum state_type state;
   address PC; // where to resume                    volatile
   int reg_file[NUMREGS]; // reg contents            state
   struct control_block *next_pcb;
   int priority; // extrinsic attribute
   address memory_footprint; // memory occupancy
   ….
   ….
} control_block;
```

Data structures used by scheduler



Steps in scheduling

- Grab the attention of the processor
- Save the state of the current process
- Select a new process to run
- Dispatch the selected process

- Preemptive vs. non-preemptive

External interrupt (e.g. timer)

System call (trap), I/O request, process exit

Steps in scheduling

- Grab the attention of the processor
- Save the state of the current process
- Select a new process to run
- Dispatch the selected process

- Dump the "state" (PC, registers) into PCB of currently running process

Steps in scheduling

- Grab the attention of the processor
- Save the state of the current process
- Select a new process to run
- Dispatch the selected process

- This is the short-term scheduling algorithm's result → select a PCB to "dispatch"

Steps in scheduling

- Grab the attention of the processor
- Save the state of the current process
- Select a new process to run
- Dispatch the selected process

- What is "dispatch"?
  ➔ load "state" of the selected PCB into processor registers (PC, reg file)

Steps in scheduling

This whole process is called a "context switch"

- Grab the attention of the processor
- Save the state of the current process
- Select a new process to run
- Dispatch the selected process

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A preemptive scheduling algorithm requires

0% A. A trap instruction

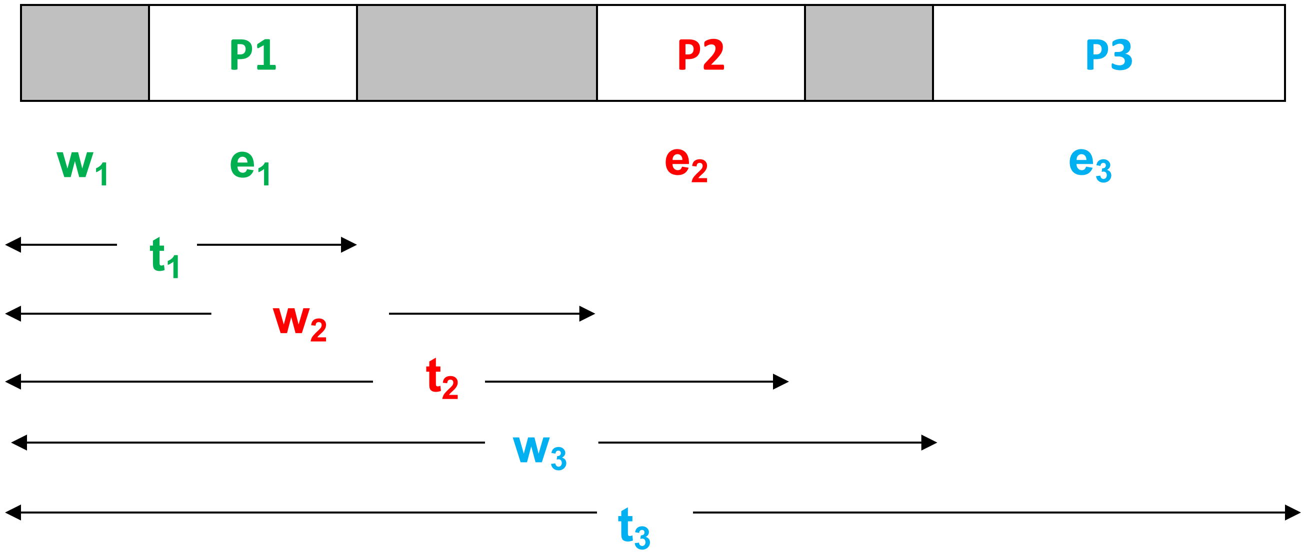
0% B. An external interrupt

0% C. The currently running process to terminate

0% D. The currently running process to make an I/O request

Name	Description
CPU burst	Continuous CPU activity by a process before requiring an I/O operation
I/O burst	Activity initiated by the CPU on an I/O device
PCB	Process context block that holds the state of a process (i.e., program in execution)
Ready queue	Queue of PCBs that represent the set of memory resident processes that are ready to run on the CPU
I/O queue	Queue of PCBs that represent the set of memory resident processes that are waiting for some I/O operation either to be initiated or completed
Non-Preemptive algorithm	Algorithm that allows the currently scheduled process on the CPU to voluntarily relinquish the processor (either by terminating or making an I/O system call)
Preemptive algorithm	Algorithm that forcibly takes the processor away from the currently scheduled process in response to an external event (e.g. I/O completion interrupt, timer interrupt)
Thrashing	A phenomenon wherein the dynamic memory usage of the processes currently in the ready queue exceed the total memory capacity of the system

Metrics

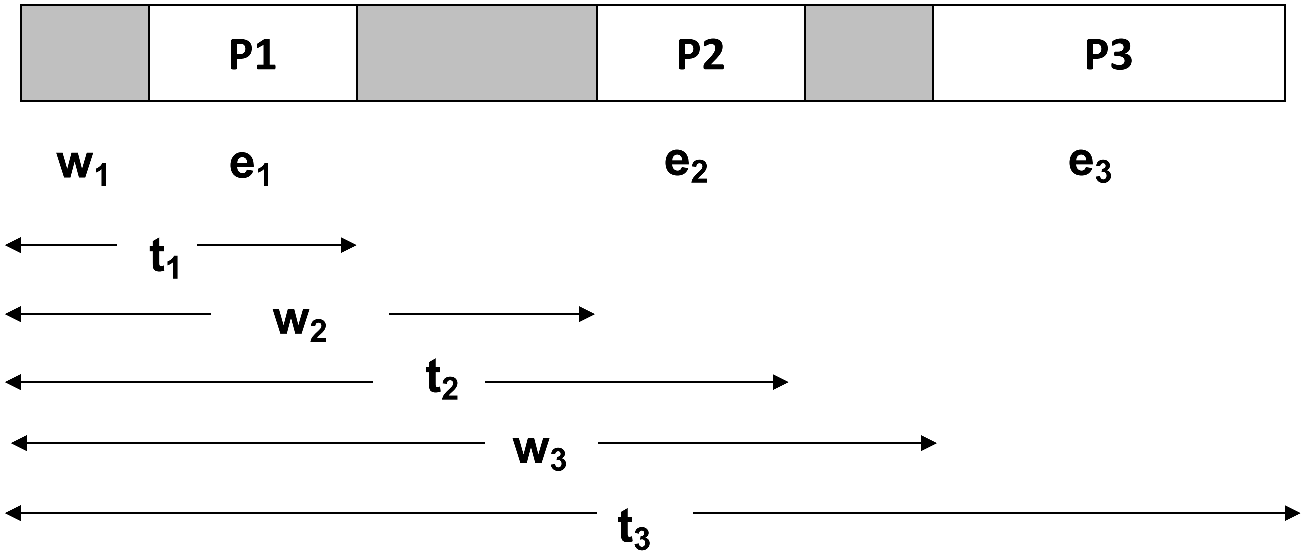


For process P_i

- w_i = wait time
- e_i = execution time
- t_i = elapsed time
  (turnaround time)

Throughput?
Avg. Turnaround Time?
Avg. Wait Time?
Response time?

Metrics



For process P_i

- w_i = wait time
- e_i = execution time
- t_i = elapsed time (turnaround time)

System Centric

Throughput? $3 / t_3$ jobs/sec

Avg. Turnaround Time? $(t_1+t_2+t_3)/3$ sec

Avg. Wait Time? $(w_1+w_2+w_3)/3$ sec

User Centric

Response time? $R_{P1}=t_1$, $R_{P2}=t_2$, $R_{P3}=t_3$

Name	Notation	Units	Description
CPU Utilization	**-**	**%**	**Percentage of time the CPU is busy**
Throughput	**n/T**	**Jobs/s**	**System-centric metric quantifying the number of jobs *n* executed in time interval *T***
Avg. Turnaround time (t_{avg})	**$(t_1+t_2+\ldots+t_n)/n$**	**Secs**	**System-centric metric quantifying the average time it takes for a job to complete**
Avg. Waiting time (w_{avg})	**$(w_1+w_2+\ldots+w_n)/n$**	**Secs**	**System-centric metric quantifying the average waiting time that a job experiences**
Response time	**t_i**	**Secs**	**User-centric metric quantifying the turnaround time for a specific job *I***
Variance in Response time	**$E[(t_i - t_{avg})^2]$**	**$Secs^2$**	**User-centric metric that quantifies the statistical variance of the actual response time (t_i) experienced by a process (P_i) from the expected value (t_{avg})**
Starvation	**-**	**-**	**User-centric qualitative metric that signifies denial of service to a particular process or a set of processes due to some intrinsic property of the scheduler**
Convoy effect	**-**	**-**	**User-centric qualitative metric that results in a detrimental effect to some set of processes due to some intrinsic property of the scheduler [This often appears as a "convoy" of short jobs waiting for the completion of a long job; non-preemptive FCFS is the convoy effect's native habitat.]**

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The most user-centric metric of a scheduler is…

0% A. Throughput

0% B. Average waiting time

0% C. Average turnaround time

0% D. CPU utilization

0% E. Response time

0% F. None of the above

Non-preemptive scheduling algorithms

- FCFS
- SJF

Intrinsic property

- Priority → Extrinsic property
- Resource requirements:

	P1	P2	P3
CPU	**10**	**1**	**2**
I/O	**10**	**2**	**3**

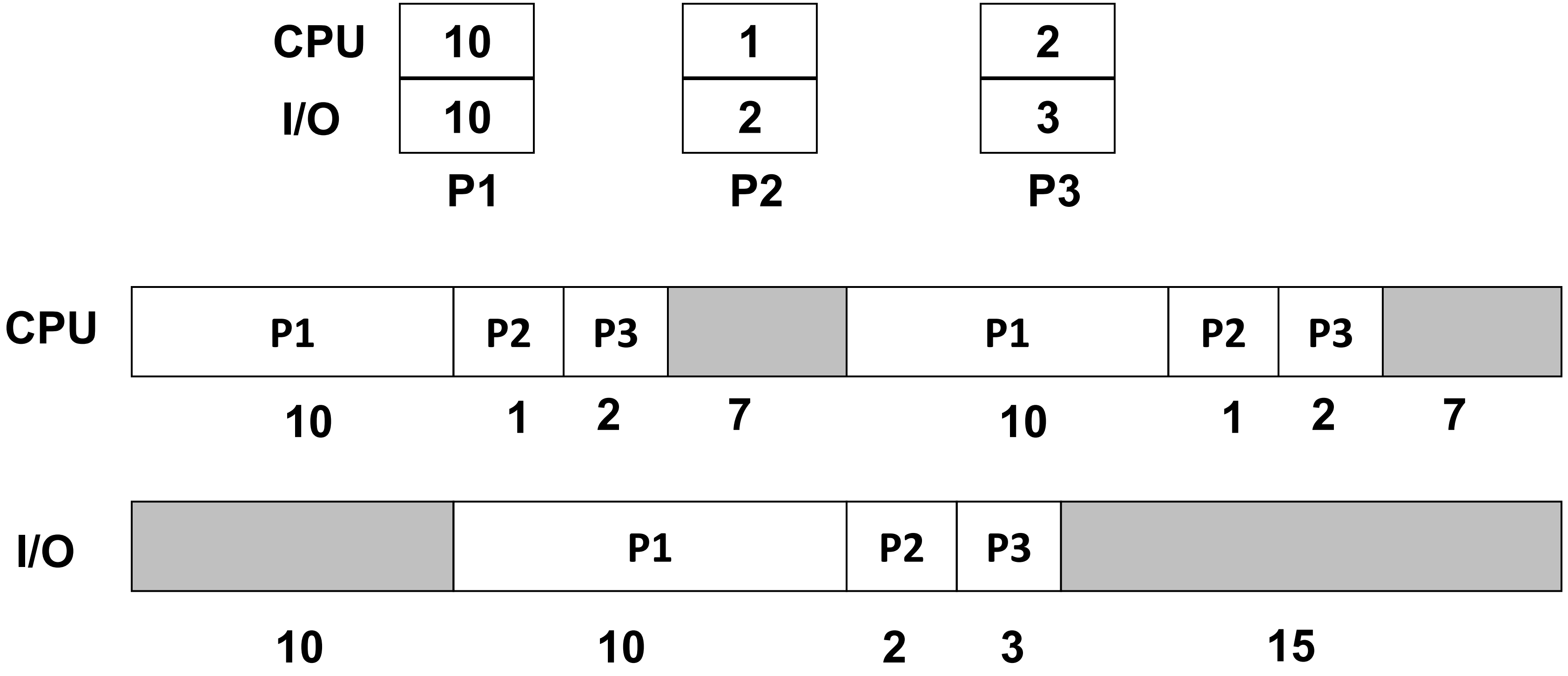
Burst times

- Arrival order
  - P1, P2, P3 in order at nearly the same time

Assume each process goes through following steps

1. CPU burst
2. I/O Burst
3. CPU Burst
4. Done

FCFS

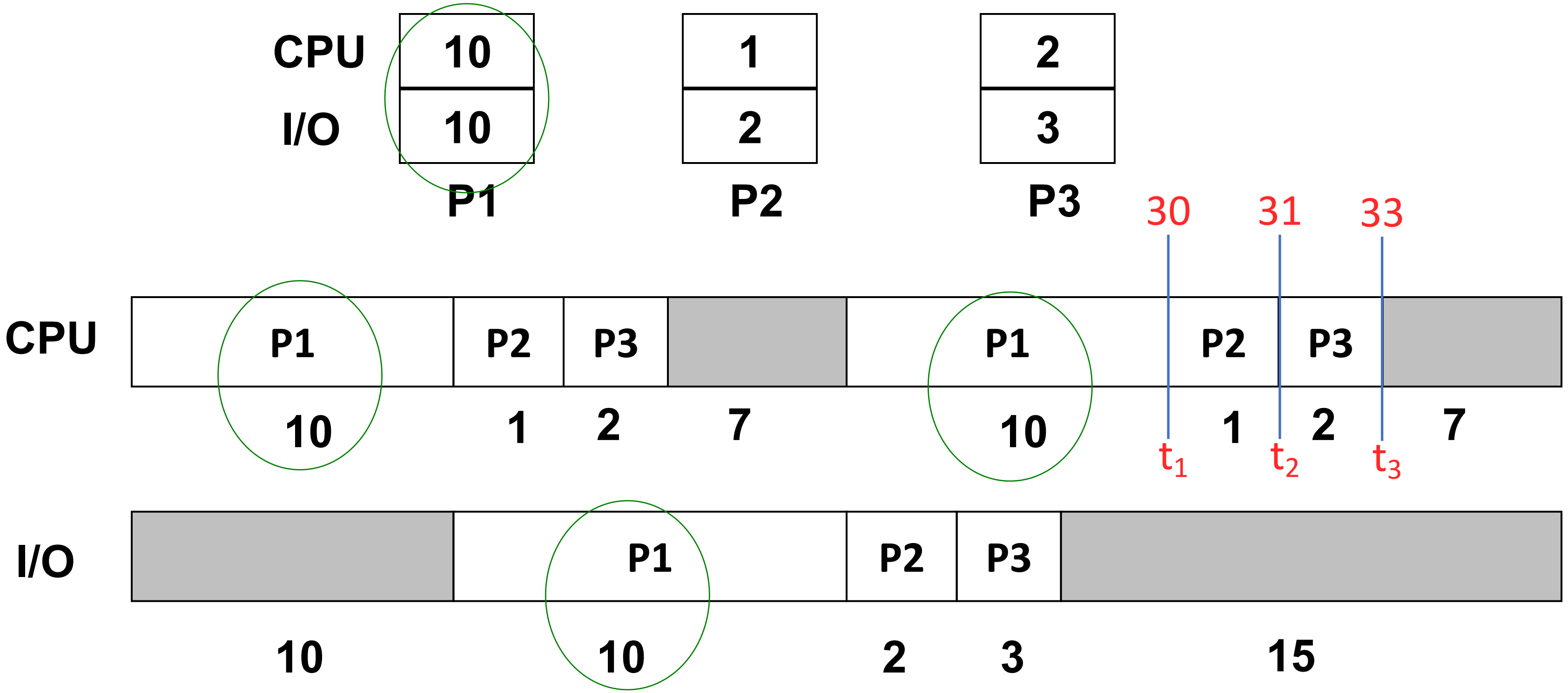


$t_i = w_i + e_i$

What are the waiting times?

FCFS

Process behavior: CPU → I/O → CPU → done



$w_{P1} = t_1 - e_1$

$w_{P2} = t_2 - e_2$

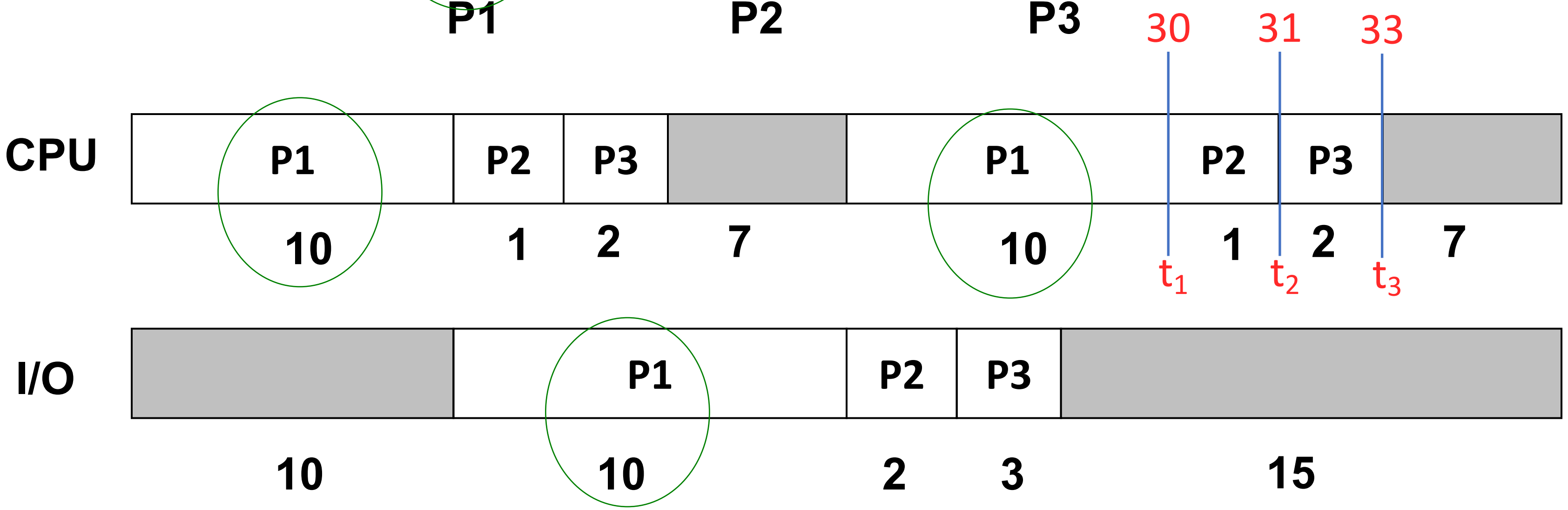
$w_{P3} = t_3 - e_3$

$e_1 = ?$

FCFS

Process behavior: CPU → I/O → CPU → done

	P1	P2	P3
CPU	10	1	2
I/O	10	2	3



$w_{P1} = t_1 - e_1$

$w_{P2} = t_2 - e_2$

$w_{P3} = t_3 - e_3$

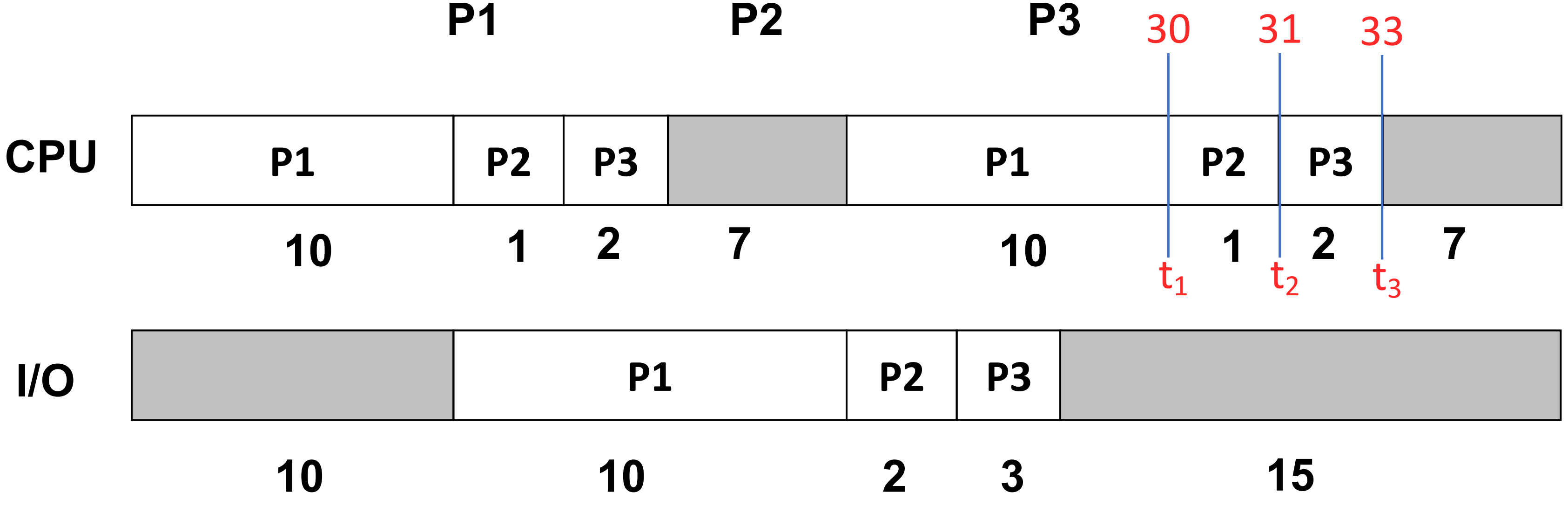
$e_1 = 10+10+10$, $t_1 = 30$

$W_{P1} = 30 - 30 = 0$

Individual Activity!

You do the same thing for P2 and P3 (compute w_{P2} and w_{P3})

	P1	P2	P3
CPU	10	1	2
I/O	10	2	3



$w_{P1} = 0$ $w_{P2} = t_2 - e_2$ $w_{P3} = t_3 - e_3$

$W_{P1} = 30 - 30 = 0$

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What is the wait time for P2?

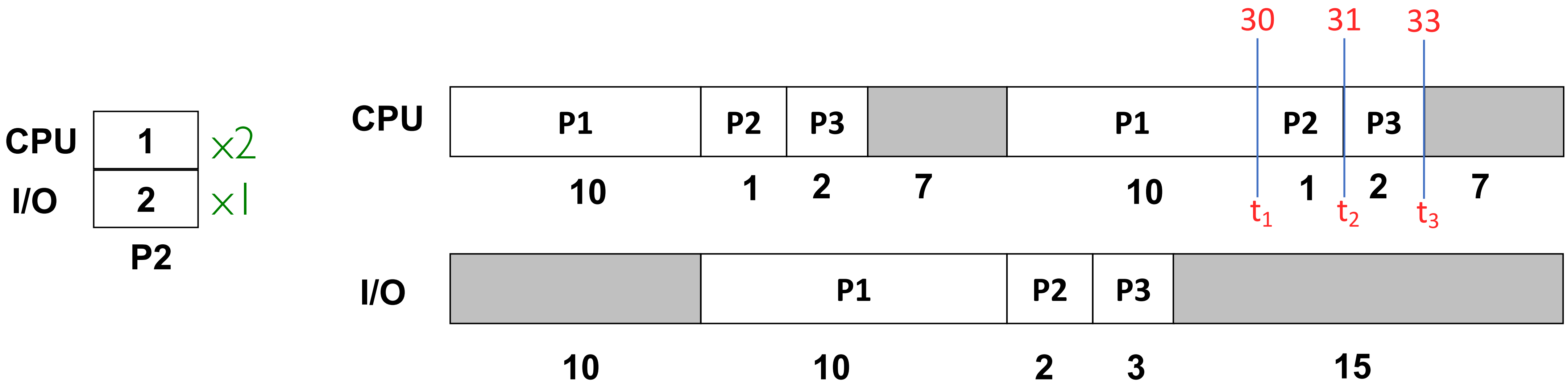
0% A. Didn't understand how to work it out

0% B. 0

0% C. 26

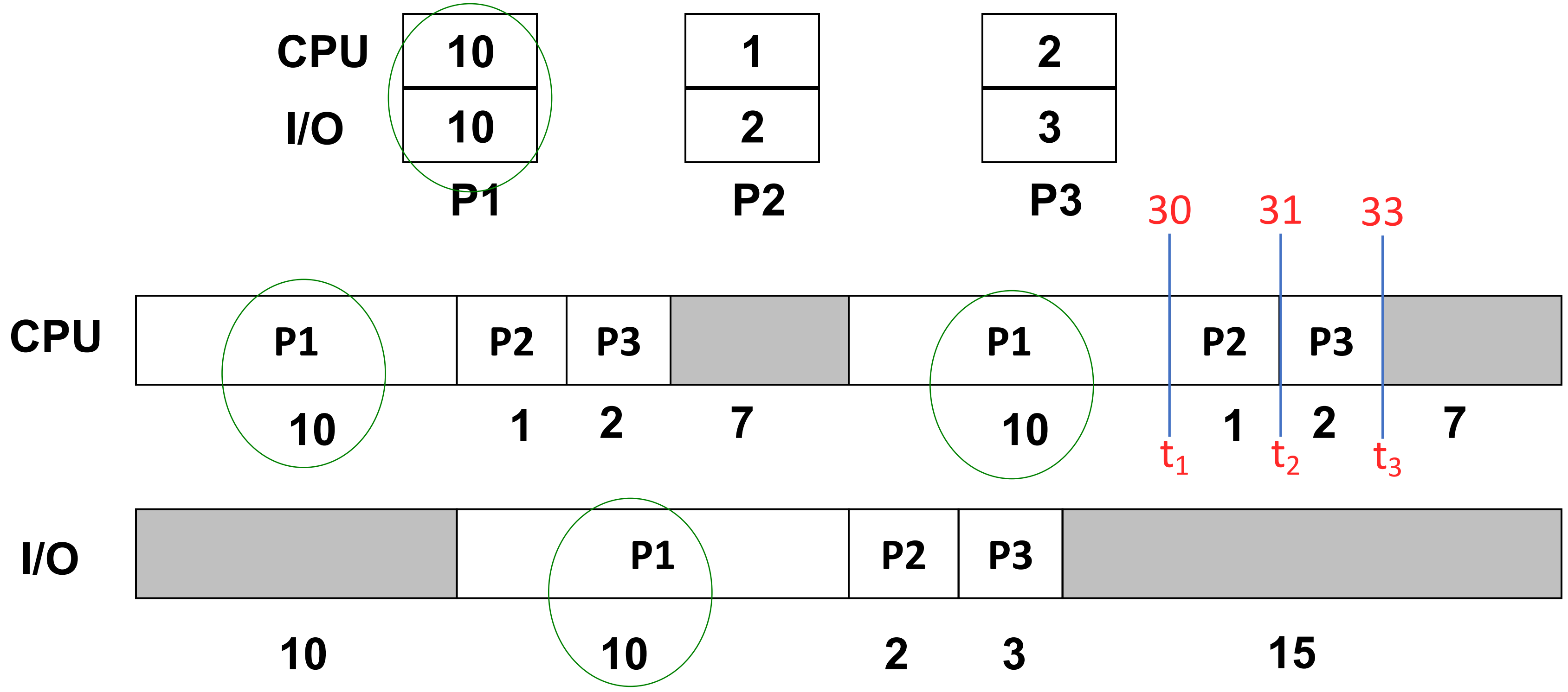
0% D. 27

0% E. Forgot how to subtract



FCFS

Process behavior: CPU → I/O → CPU → done



$w_{P1} = t_1 - e_1$ $w_{P2} = t_2 - e_2$ $w_{P3} = t_3 - e_3$

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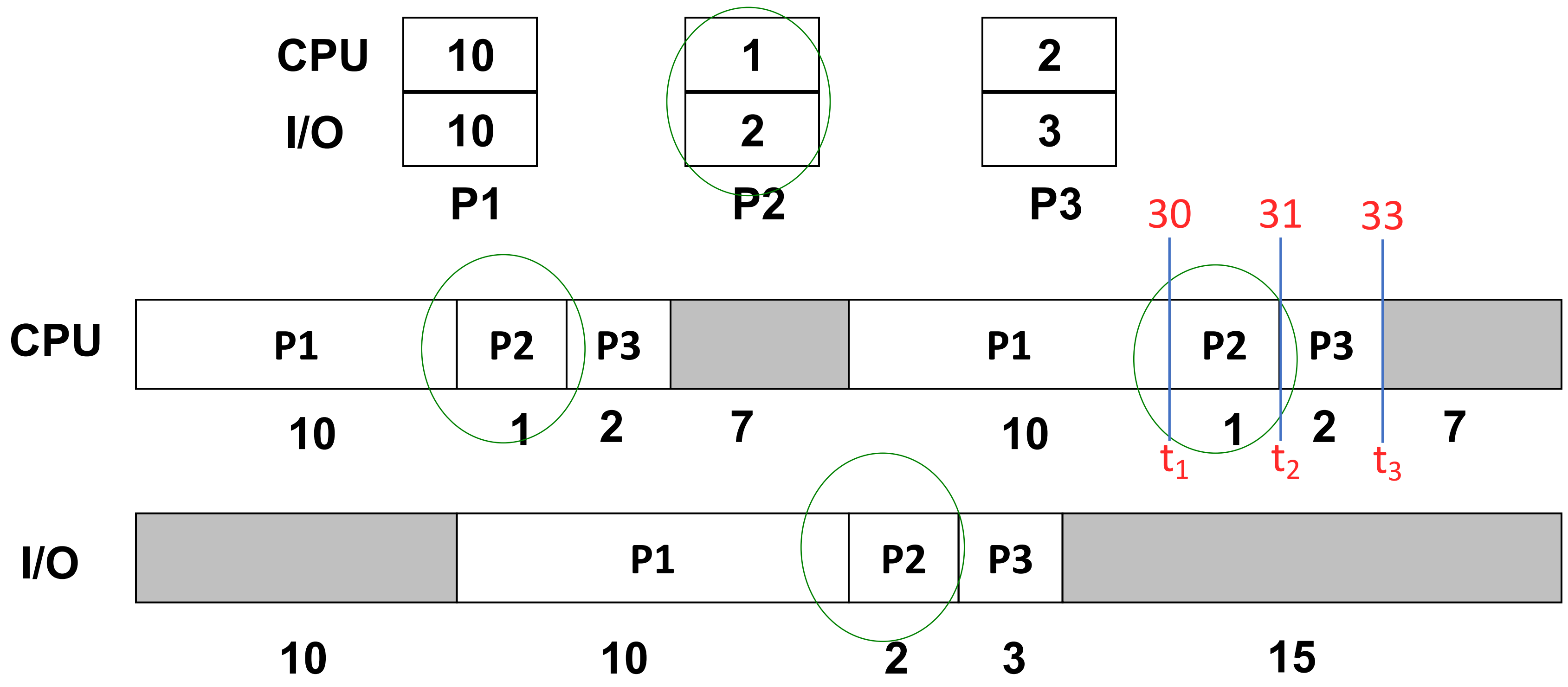
$w_{P1} = 30 - 30 = 0$

FCFS

Process behavior: CPU → I/O → CPU → done



$w_{P1} = t_1 - e_1$

$w_{P2} = t_2 - e_2$

$w_{P3} = t_3 - e_3$

$e_1 = 10+10+10$, $t_1 = 30$

$w_{P1} = 30 - 30 = 0$

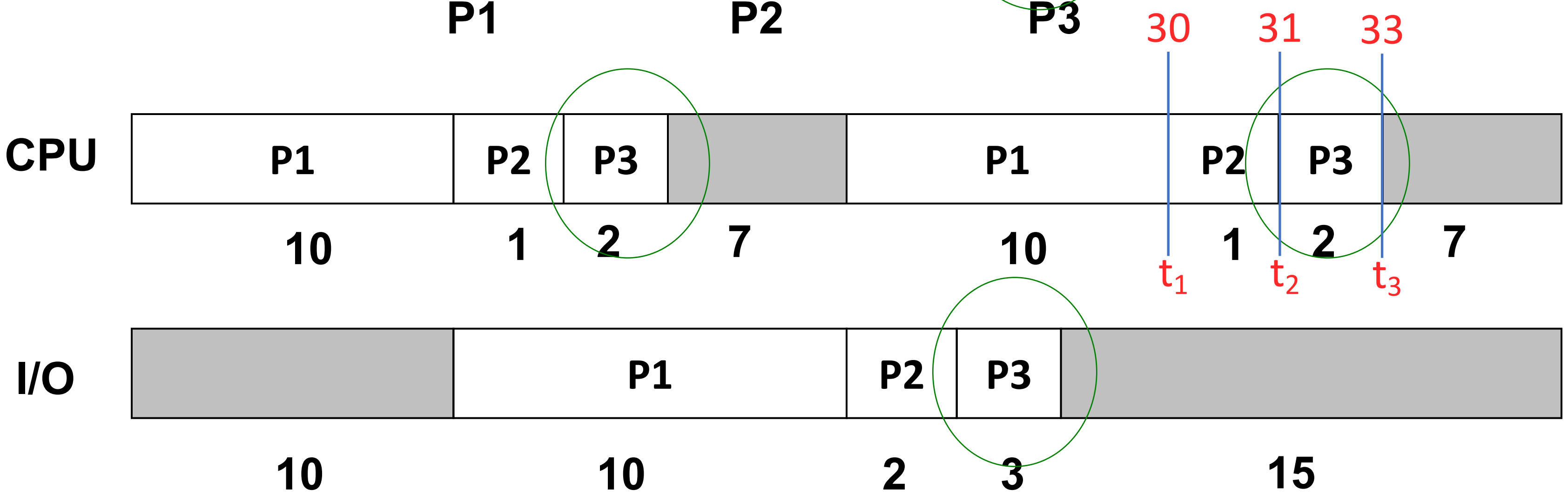
$e_2=1+2+1$, $t_2=31$

$w_{P2} = 31 - 4 = 27$

FCFS

Process behavior: CPU → I/O → CPU → done

	P1	P2	P3
CPU	10	1	2
I/O	10	2	3



$w_{P1} = t_1 - e_1$

$e_1 = 10+10+10$, $t_1 = 30$

$w_{P1} = 30 - 30 = 0$

$w_{P2} = t_2 - e_2$

$e_2=1+2+1$, $t_2=31$

$w_{P2} = 31 - 4 = 27$

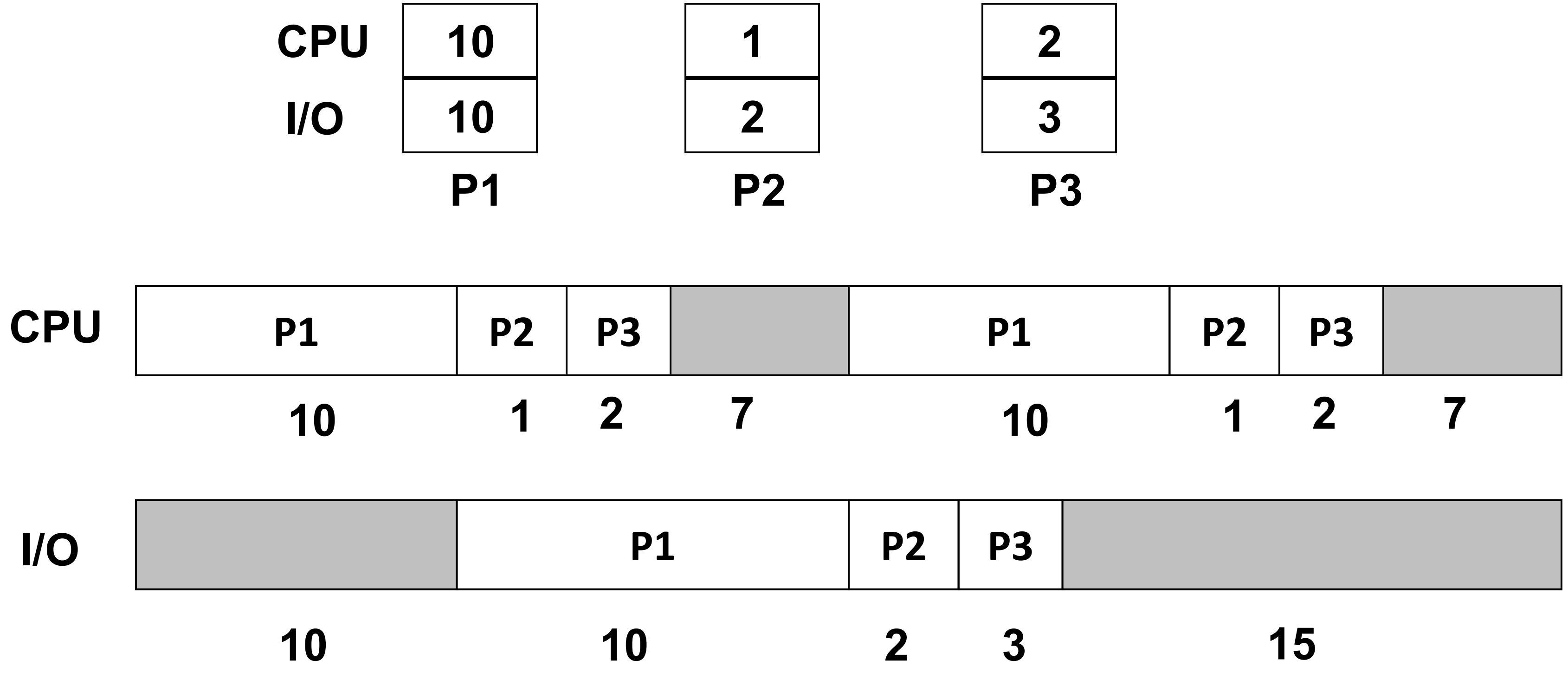
$w_{P3} = t_3 - e_3$

$e_3=2+3+2$, $t_3=33$

$w_{P3} = 33 - 7 = 26$

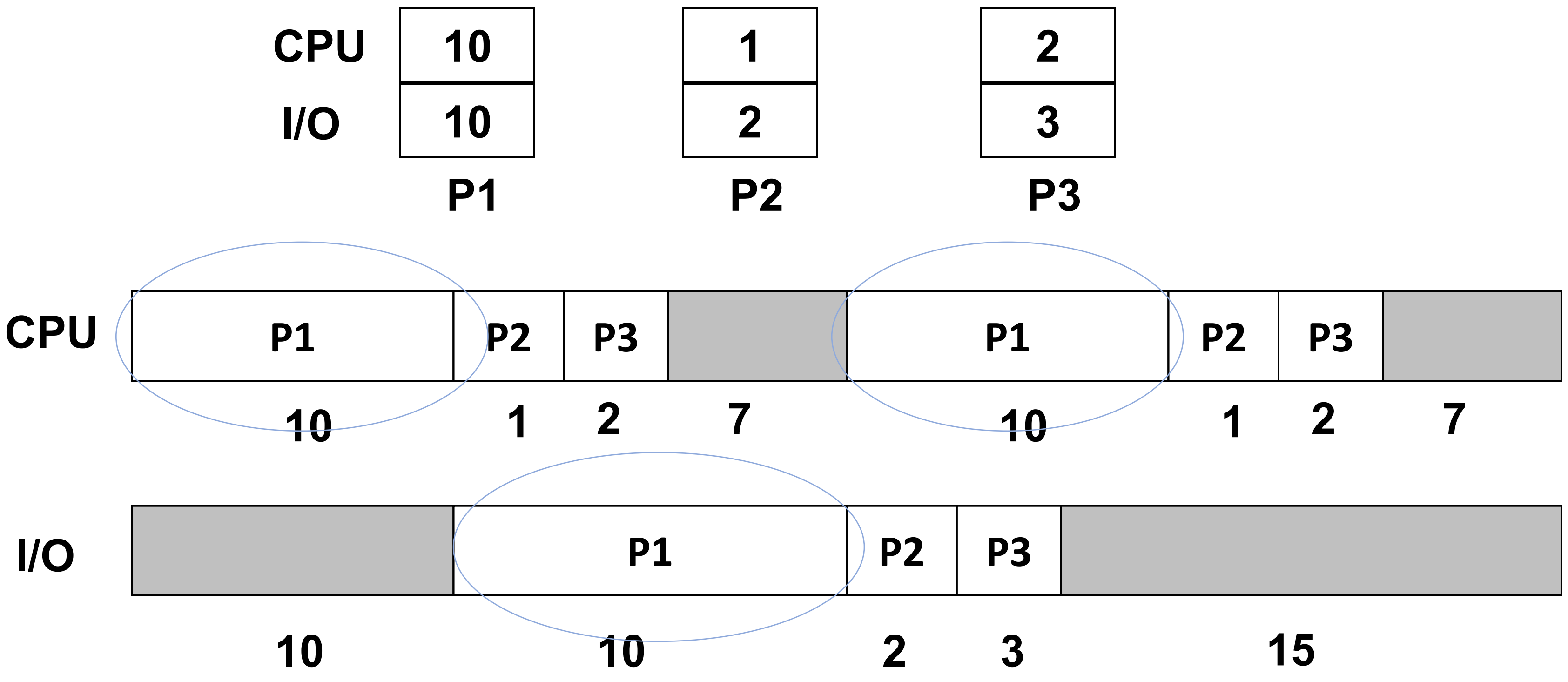
FCFS

$w_{P1} = 0$ $w_{P2} = 27$ $w_{P3} = 26$



- High average waiting times

FCFS



- High average waiting times – in this case (0+26+27=)53 / 3
- High average turnaround times – in this case (30+31+33=)94 / 3
- Convoy effect