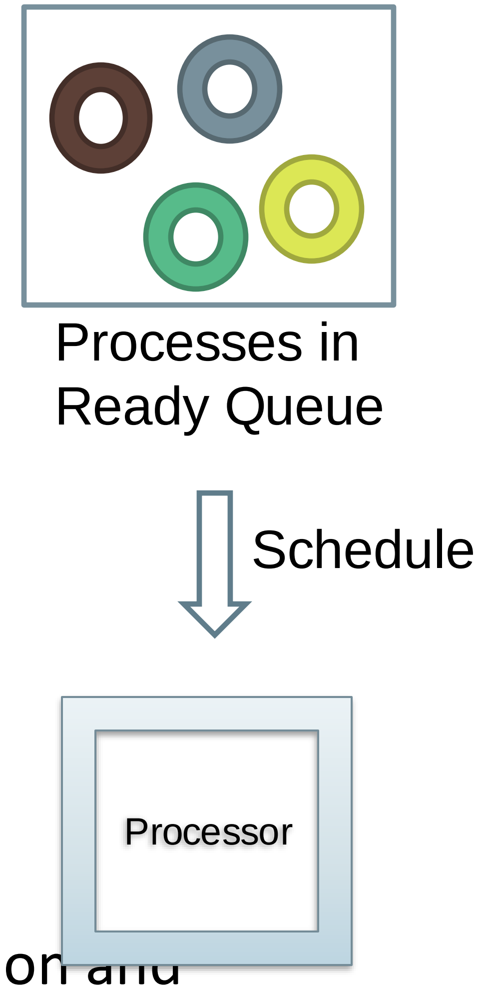
OPERATING SYSTEMS

CPU Scheduling

Basic Concepts

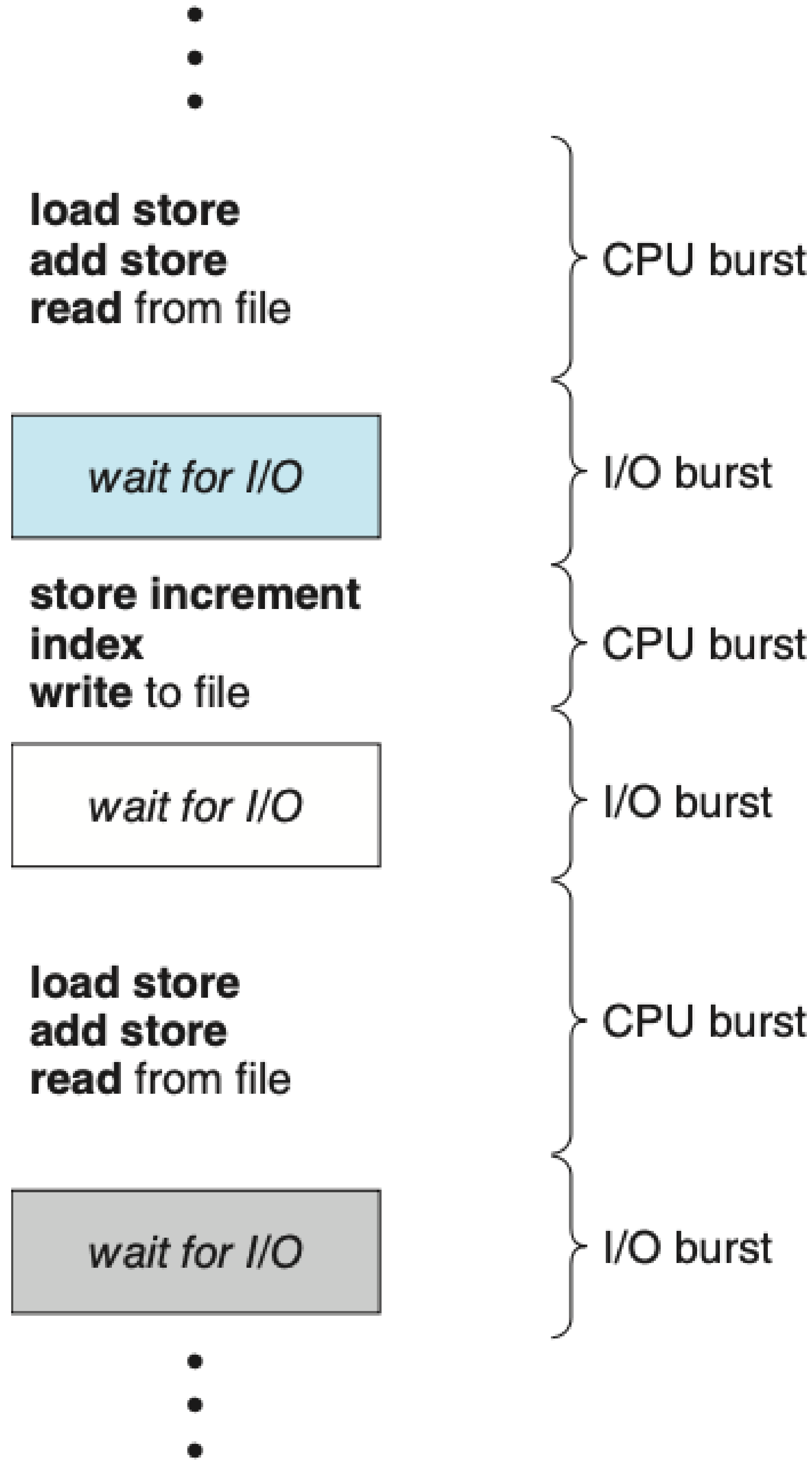
- Maximum CPU utilization obtained with multiprogramming

- Continuous Cycle :
    - one process has to wait (I/O)
    - Operating system takes the CPU away
    - Give CPU to another process
    - This pattern continues



- CPU–I/O Burst Cycle : Process execution consists of a *cycle* of CPU execution and I/O wait

Basic Conce



load store
add store
read from file
CPU burst
wait for I/O
I/O burst
store increment
index
write to file
CPU burst
wait for I/O
I/O burst
load store
add store
read from file
CPU burst
wait for I/O
I/O burst

CPU Scheduler

- **Selects from among the processes in ready queue, and allocates the CPU to one of them**
  - FIFO queue
  - Priority queue
  - Tree
  - Unordered linked-list
- **CPU scheduling decisions may take place when a process:**
  1. Switches from running to waiting state (I/O request)
  2. Switches from running to ready state (e.g. when interrupt occurs)
  3. Switches from waiting to ready (e.g. at completion of I/O)
  4. Terminates
- Scheduling under 1 and 4 is ***nonpreemptive***
- All other scheduling is ***preemptive***
  - Consider access to shared data
  - Consider preemption while in kernel mode
  - Consider interrupts occurring during crucial OS activities

Scheduling Criteria

- **CPU utilization** – keep the CPU as busy as possible

- **Throughput** – # of processes that complete their execution per time unit

- **Turnaround time**
  – amount of time to execute a particular process
  -- the interval from the time of submission of a process to the time of the completion.
  -- sum of the periods spent waiting to get into memory, waiting in the ready queue, executing on the CPU, doing I/O

- **Waiting time** – amount of time a process has been waiting in the ready queue

- **Response time** – amount of time it takes from when a request was submitted until the first response is produced, not output (for time-sharing environment)

Scheduling Algorithm Optimization Criteria

- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

OPERATING SYSTEMS

CPU Scheduling Algorithms

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First Come First Serve (FCFS)

First-Come, First-Served (FCFS) Scheduling

Process	Arrival Time	Burst Time
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

The Gantt Chart for the schedule is:

P_1	P_2	P_3	P_4

0 8 12 21 26

Ready Queue

0	$P_1(8)$		
1	$P_2(4)$		
2	$P_2(4)$	$P_3(9)$	
3	$P_2(4)$	$P_3(9)$	$P_4(5)$
8	$P_3(9)$	$P_4(5)$	
12	$P_4(5)$		
21	**Empty**		
26	**Empty**		

First-Come, First-Served (FCFS) Scheduling

Process	Arrival Time	Burst Time
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

The Gantt Chart for the schedule is:

P_1	P_2	P_3	P_4

0 8 12 21 26

Average Waiting Time (AWT):

(0 + (8 – 1) + (12 – 2) + (21 – 3)) / 4 = 8.75

Turnaround Time:

P_1 = 8, P_2 = (12 - 1) = 11, P_3 = 21 – 2 = 19, P_4 = 26 – 3 = 23

OPERATING SYSTEMS

CPU Scheduling Algorithms

-

Shortest Job First (SJF)

Shortest-Job-First (SJF) Scheduling

- Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time
- Two schemes:
    - **Non-preemptive** – once CPU given to the process it cannot be preempted until completes its CPU burst
    - **preemptive** – if a new process arrives with CPU burst length less than remaining time of current executing process, preempt. This scheme is known as the Shortest-Remaining-Time-First (SRTF)
- SJF is optimal – gives minimum average waiting time for a given set of processes

Example of Shortest-remaining-time-first

Process	Arrival Time	Burst Time
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

Gantt Chart:

P_1	P_2	P_4	P_1	P_3

0 1 5 10 17 26

<u>Ready Queue</u>

0	$P_1(8)$
1	$P_1(7)$
2	$P_1(7)$, $P_3(9)$
3	$P_1(7)$, $P_3(9)$, $P_4(5)$
5	$P_1(7)$, $P_3(9)$
10	$P_3(9)$
17	Empty
26	Empty

Example of Shortest-remaining-time-first

Process	Arrival Time	Burst Time
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

Gantt Chart:

P_1	P_2	P_4	P_1	P_3

0 1 5 10 17 26

Average Waiting Time (AWT):

((10 – 9) + (1-1) + (17 - 2) +(5 - 3)) / 4 = 6.5

Turnaround Time:

P_1 = 17, P_2 = (5 - 1) = 4, P_3 = 26 – 2 = 24, P_4 = 10 – 3 = 7

OPERATING SYSTEMS

CPU Scheduling Algorithms

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Priority Scheduling

Priority Scheduling

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority (smallest integer ≡ highest priority)
  - Preemptive
  - Nonpreemptive
- SJF is priority scheduling where priority is the inverse of predicted next CPU burst time
- Priority can be defined either internally or externally.
  - Factors for internal priority assignment:
    - Time limit, memory requirements, the number or open files etc.
  - Factors for external priority assignment:
    - Importance of the process, the type and amount of funds being paid for computer use, department sponsoring works etc.

Example of Priority Scheduling (Preemptive)

Process	Arrival Time	Burst Time	Priority
P_1	0	8	3
P_2	1	4	1
P_3	2	9	4
P_4	3	5	5

Priority scheduling Gantt Chart

P_1	P_2	P_1	P_3	P_4

0 1 5 12 21 26

- Problem ≡ **Starvation** – low priority processes may never execute
- Solution ≡ **Aging** – as time progresses increase the priority of the process

Ready Queue

0	$P_1(8)$		
1	$P_1(7)$		
2	$P_1(7)$	$P_3(9)$	
3	$P_1(7)$	$P_3(9)$	$P_4(5)$
5	$P_3(9)$	$P_4(5)$	
12	$P_4(5)$		
21	Empty		
26	Empty		

OPERATING SYSTEMS

CPU Scheduling Algorithms

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Round Robin (RR)

Round Robin (RR)

- Each process gets a small unit of CPU time (**time quantum** q), usually 10-100 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue.
- If there are *n* processes in the ready queue and the time quantum is *q*, then each process gets 1/*n* of the CPU time in chunks of at most *q* time units at once. No process waits more than $(n-1)q$ time units.
- Timer interrupts every quantum to schedule next process
- Performance
  - *q* large ⇒ FIFO
  - *q* small ⇒ *q* must be large with respect to context switch, otherwise overhead is too high

Example of RR with Time Quantum = 4

Process	Arrival Time	Burst Time
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

The Gantt chart is:

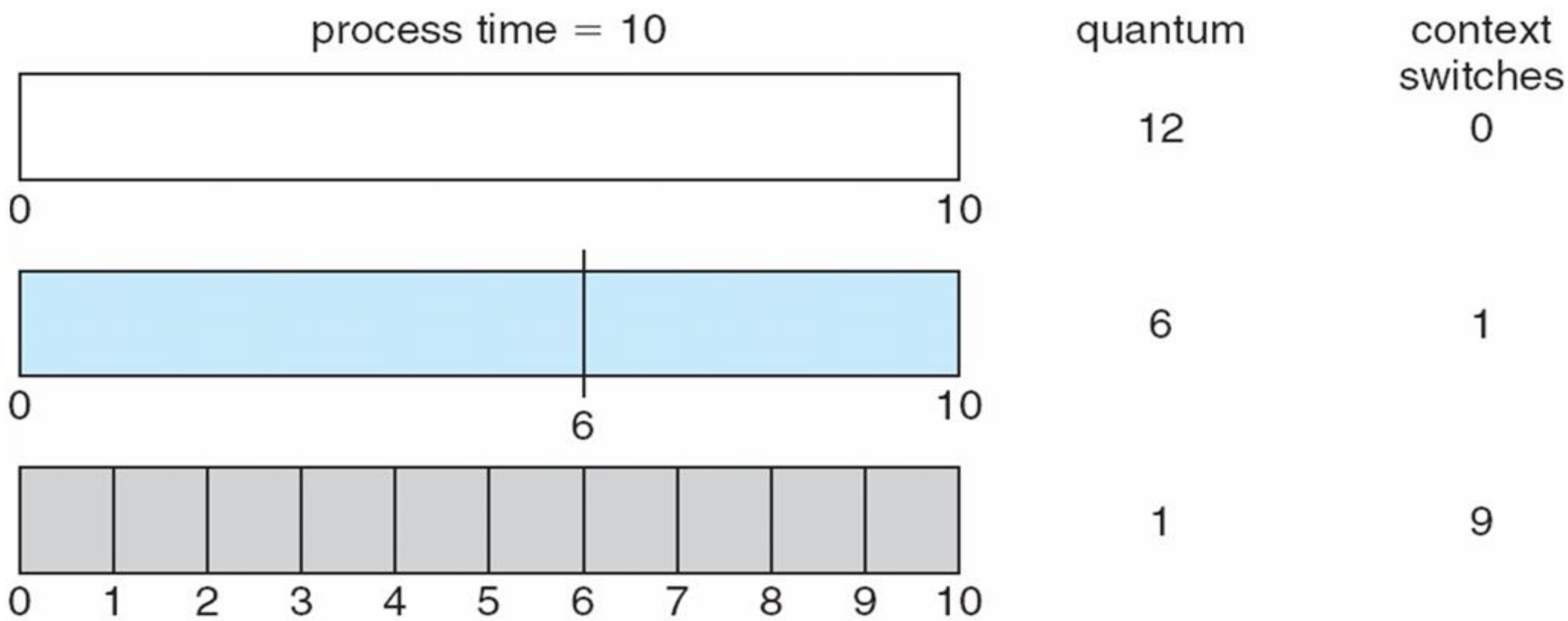
P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_3

0 4 8 12 16 20 24 25 26

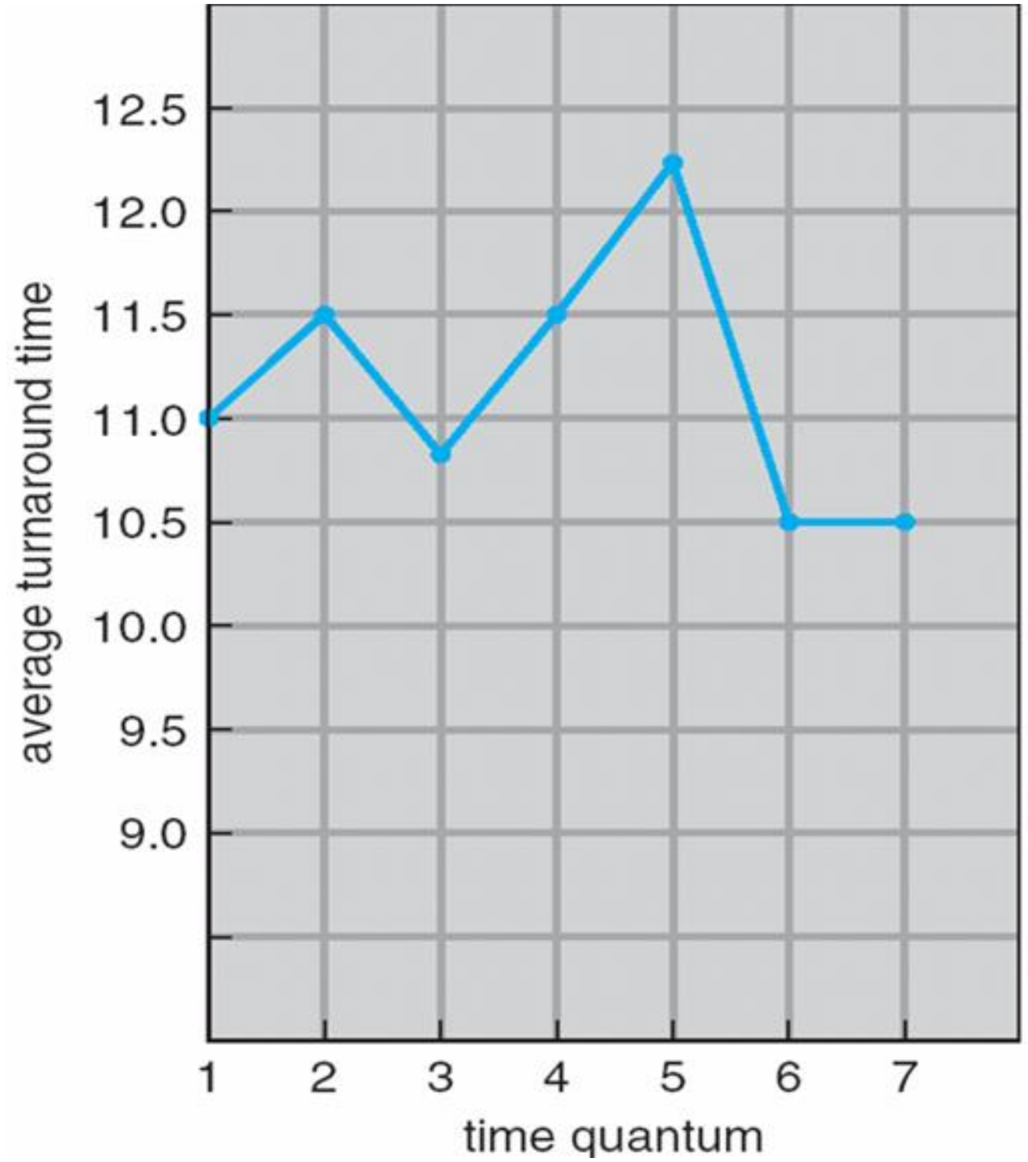
Ready Queue:

0	$P_1(8)$
1	$P_2(4)$
2	$P_2(4)$, $P_3(9)$
3	$P_2(4)$, $P_3(9)$, $P_4(5)$
4	$P_3(9)$, $P_4(5)$, $P_1(4)$
8	$P_4(4)$, $P_1(4)$
12	$P_1(4)$, $P_3(5)$
16	$P_3(5)$, $P_4(1)$
20	$P_4(1)$
24	$P_3(1)$
25	Empty
26	Empty

Time Quantum and Context Switch Time



Turnaround Time Varies With The Time Quantum



process	time
P_1	6
P_2	3
P_3	1
P_4	7

80% of CPU bursts should be shorter than quantum

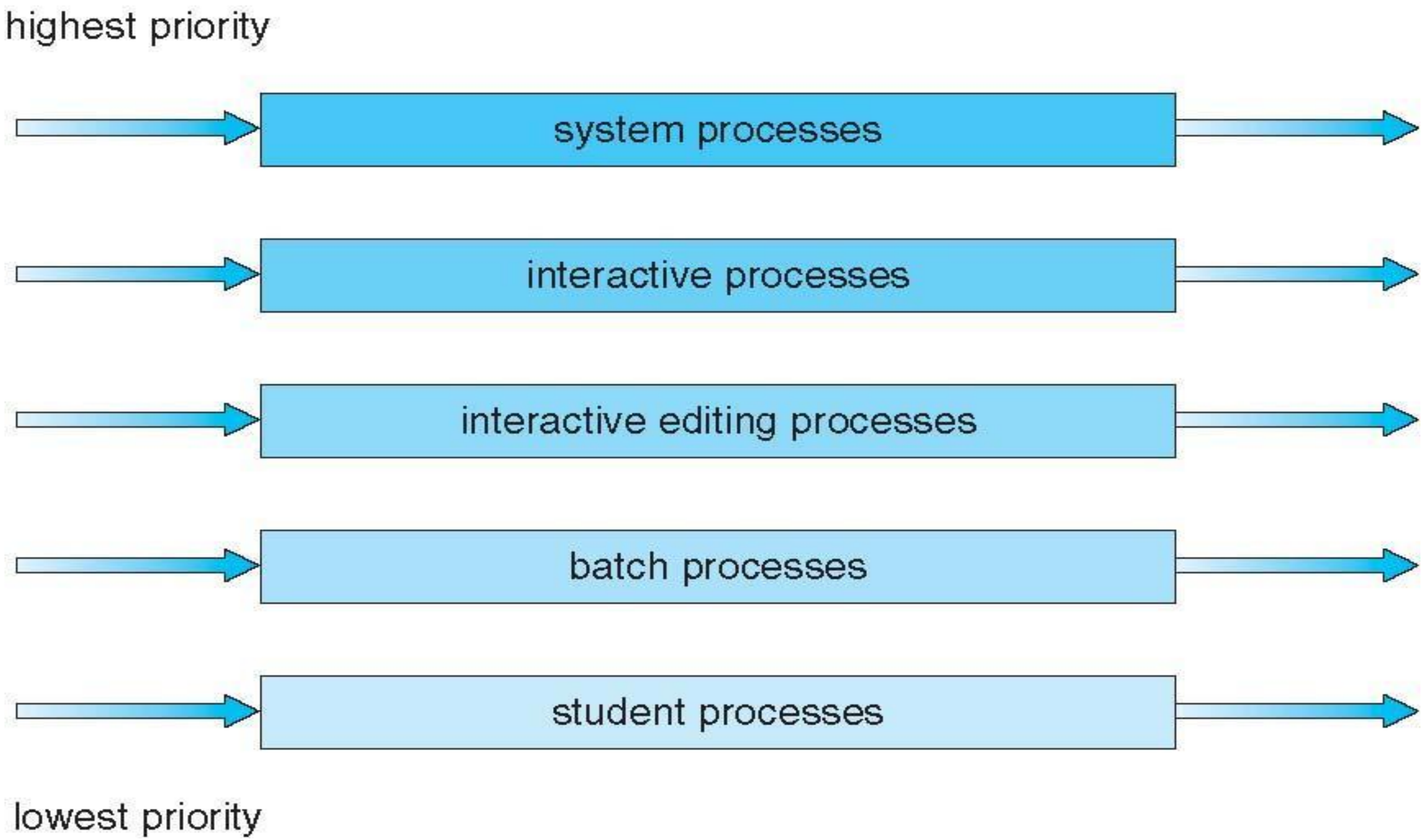
OPERATING SYSTEMS

CPU Scheduling - Multilevel Queue, Multilevel Feedback Queue

Multilevel Queue

- Another class of scheduling algorithm needs- in which processes are classified into different groups, e.g.:
  - foreground (interactive) processes
  - background (batch) processes
- They have different response time requirements-so different scheduling needs.
- Foreground processes may have priority over background processes.
- A multilevel queue-scheduling algorithm partitions the ready queue into several separate queues-we can see it in the figure of next slide:-
- Each queue has its own scheduling algorithm:
  - Foreground queue scheduled by – RR algorithm
  - Background queue scheduled by – FCFS algorithm
- Scheduling must be done between the queues:
  - Fixed priority preemptive scheduling; (i.e., serve all from foreground then from background). Possibility of starvation.
  - Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; i.e., foreground queue can be given 80% of the CPU time for RR-scheduling among its processes, while 20% to background in FCFS manner.

Multilevel Queue Scheduling



Multilevel Feedback Queue scheduling

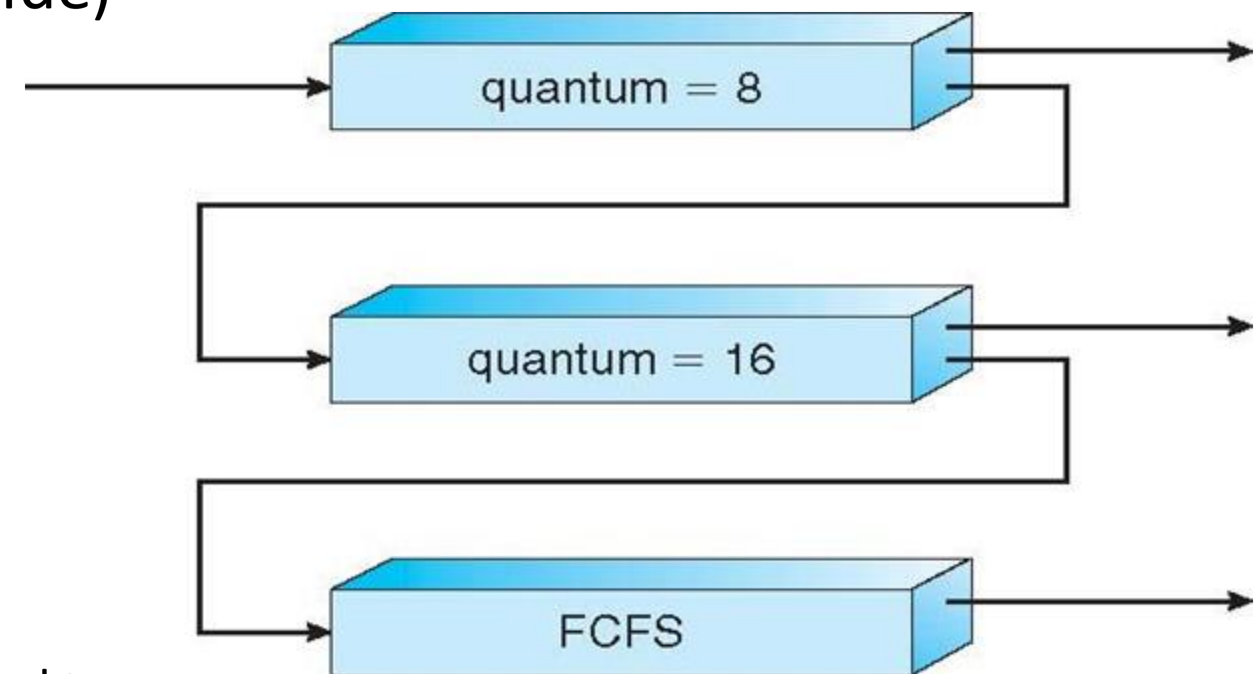
- Multilevel Feedback Queue scheduling, allows a process to move between queues.
- If a process uses too much CPU time, it will be moved to a lower priority queue.
- Similarly, a process that waits too long in a lower-priority queue may me moved to a higher-priority queue.

- Multilevel-feedback-queue scheduler defined by the following parameters:
  - number of queues
  - scheduling algorithms for each queue
  - method used to determine when to upgrade a process
  - method used to determine when to demote a process
  - method used to determine which queue a process will enter when that process needs service

Example of Multilevel Feedback Queue

- Three queues: (can see the figure in next slide)
  - Q_0 – RR with time quantum 8 milliseconds
  - Q_1 – RR time quantum 16 milliseconds
  - Q_2 – FCFS

- Scheduling
  - A new job enters queue Q_0 which is served for RR
    - When it gains CPU, job receives 8 milliseconds
    - If it does not finish in 8 milliseconds, job is moved to queue Q_1
  - At Q_1 job is again served RR and receives 16 additional milliseconds
    - If it still does not complete, it is preempted and moved to queue Q_2



Example of Multilevel Feedback Queue

Problem 1:

Processes	Burst Time
P1	12
P2	8
P3	18

Queue 0 (Priority 0): Round-robin (quantum=2)

Time			
0:	P1 (12)	P2 (8)	P3 (18)
2:	P2 (8)	P3 (18)	
4:	P3 (18)		
4:	Empty		

Queue 1 (Priority 1): Round-robin (quantum=4)

Time		
0:	Empty	
2:	P1 (10)	
4:	P1 (10)	P2 (6)
6:	P2 (6)	P3 (16)
10:	P3 (16)	
14:	Empty	

Queue 2 (Priority 2): Round-robin (quantum=8)

Time		
0:	Empty	
10:	P1 (6)	
14:	P1 (6)	P2 (2)
18:	P2 (2)	P3 (12)
24:	P3 (12)	
34:	P3 (4)	
38:	Empty	

Gantt Chart:

	0–2	2–4	4–6	6–10	10–14	14–18	18–24	24–26	26–34	34–38
CPU:	P1	P2	P3	P1	P2	P3	P1	P2	P3	P3

Example of Multilevel Feedback Queue

Problem 1:

Processes	Burst Time
P1	12
P2	8
P3	18

Gantt Chart:

CPU:

P1	P2	P3	P1	P2	P3	P1	P2	P3	P3

0 2 4 6 10 14 18 24 26 34 38

Waiting Time:

P1=(0-0)+(6-2)+(18-10)=12

P2=(2-0)+(10-4)+(24-14)=18

P3=(4-0)+(14-6)+(26-18)+(34-34)=20

Avg=(12+18+20)/3=16.67

Response Time:

P1=(0-0)=0

P2=(2-0)=2

P3=(4-0)=4

Avg=(0+2+4)/3=2

Turnaround Time:

P1=(24-0)=24

P2=(26-0)=26

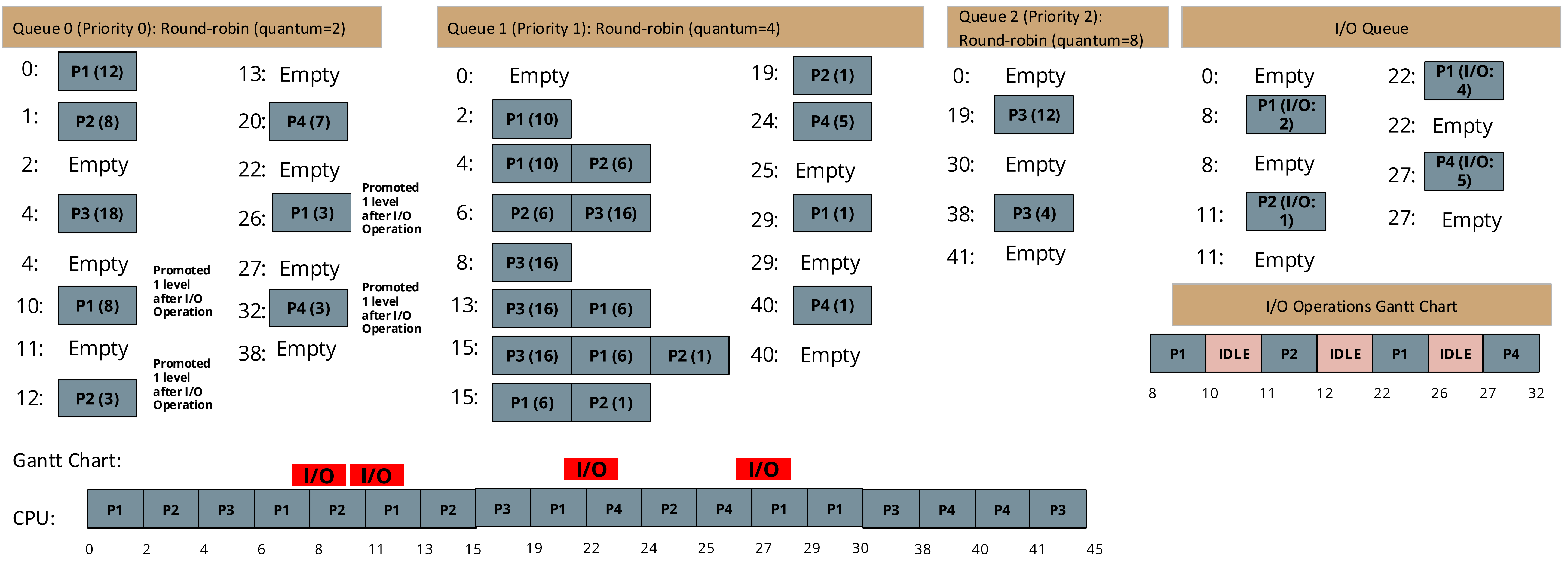
P3=(38-0)=38

Avg=(24+26+38)/3=29.33

Example of Multilevel Feedback Queue

Problem 2:

Processes	Burst Time	Arrival Time	I/O Time
P1	**12**	**0**	**6** [2s I/O operation after total 4s of CPU allocation & 4s I/O operation after total 9s of CPU allocation]
P2	**8**	**1**	**1** [1s I/O operation after total 5s of CPU allocation]
P3	**18**	**4**	**N/A**
P4	**7**	**20**	**5** [5s I/O operation after total 4s of CPU allocation]



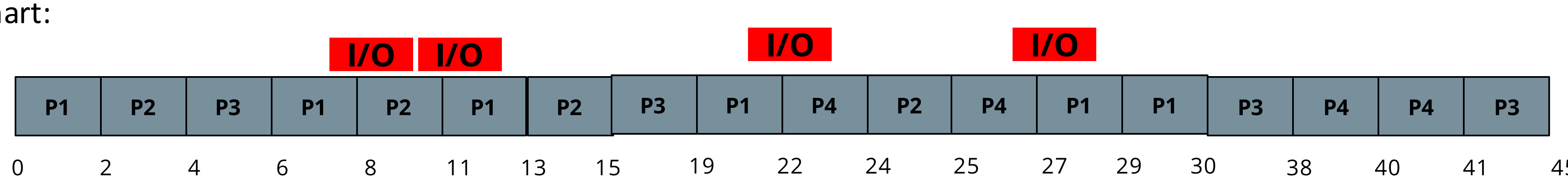
Example of Multilevel Feedback Queue

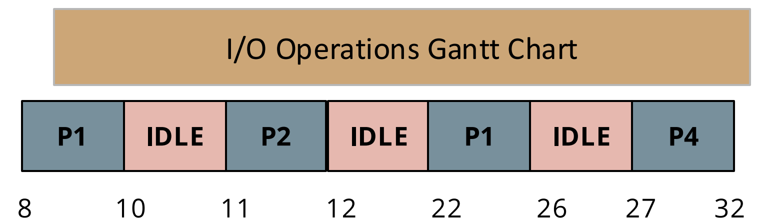
Problem 2:

Processes	Burst Time	Arrival Time	I/O Time
P1	12	0	6 [2s I/O operation after total 4s of CPU allocation & 4s I/O operation after total 9s of CPU allocation]
P2	8	1	1 [1s I/O operation after total 5s of CPU allocation]
P3	18	4	N/A
P4	7	20	5 [5s I/O operation after total 4s of CPU allocation]

Gantt Chart:

CPU:





Waiting Time:

11- 8 – (10 - 8)

P1=(0-0)+(6-2)+(11-10)+(19-13)+(27-26)+(29-29)
=12

27 – 22 – (26 - 22)

P2=(2-1)+(8-4)+(13-12)+(24-15)=15

P3=(4-4)+(15-6)+(30-19)+(41-38)=23

P4=(22-20)+(25-24)+(38-32)+(40-40)=9

Avg=(12+15+23+9)/4=14.75

Response Time:

P1=(0-0)=0

P2=(2-1)=1

P3=(4-4)=0

P4=(22-20)=2

Avg=(0+1+0+2)/4=0.75

Turnaround Time:

P1=(30-0)=30

P2=(25-1)=24

P3=(45-4)=41

P4=(41-20)=21

Avg=(30+24+41+21)/4=29