KOÇ UNIVERSITY

CPU Scheduling Algorithms

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Lecture 7

COMP304 - Operating Systems (OS)

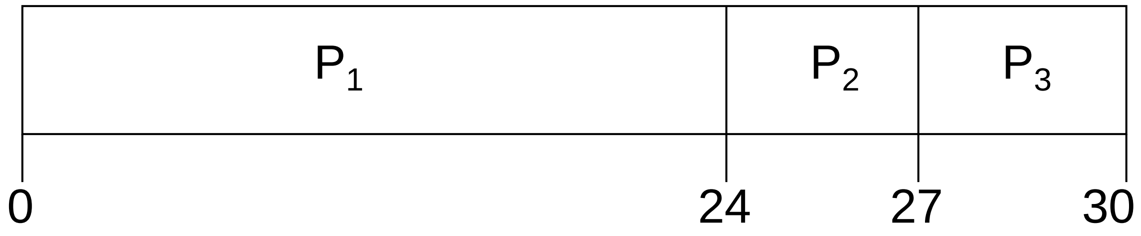
Terminology

- 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
- 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)

1. First-Come, First Served (FCFS)

Process	Burst Time
P_1	24
P_2	3
P_3	3

- Suppose that the processes arrive in the order: P_1 , P_2 , P_3
  The Gantt Chart for the schedule is:



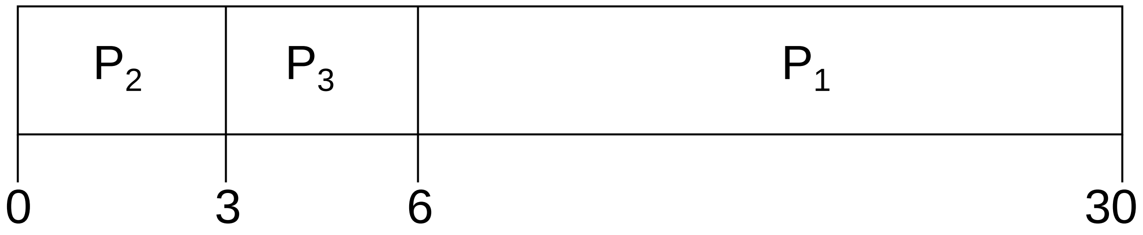
- Waiting times for: $P_1 = 0$; $P_2 = 24$; $P_3 = 27$
- Average waiting time: $(0 + 24 + 27)/3 = 17$

FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order

$$P_2 , P_3 , P_1$$

- The Gantt chart for the schedule is:



- Waiting time for $P_1 = 6$; $P_2 = 0$; $P_3 = 3$
- Average waiting time: $(6 + 0 + 3)/3 = 3$
- Much better than previous case.
- **Convoy effect:** short process behind long process

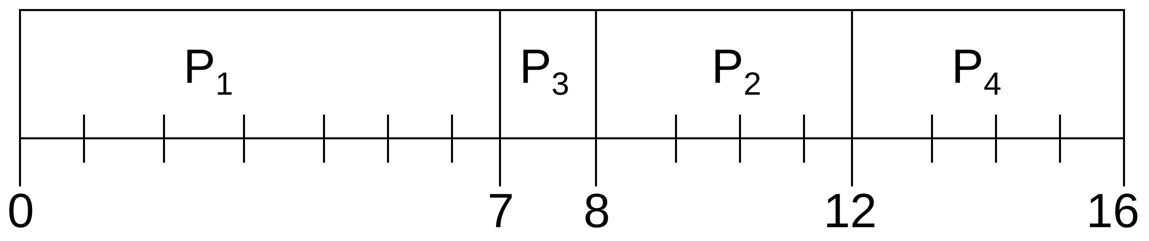
2. Shortest Job First (SJF) Scheduling

- 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 is known as the **Shortest-Remaining-Time-First (SRTF)**.
- SJF is **optimal** – gives minimum average waiting time for a given set of processes.

Non-preemptive (SJF) Scheduling

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

- SJF (non-preemptive)

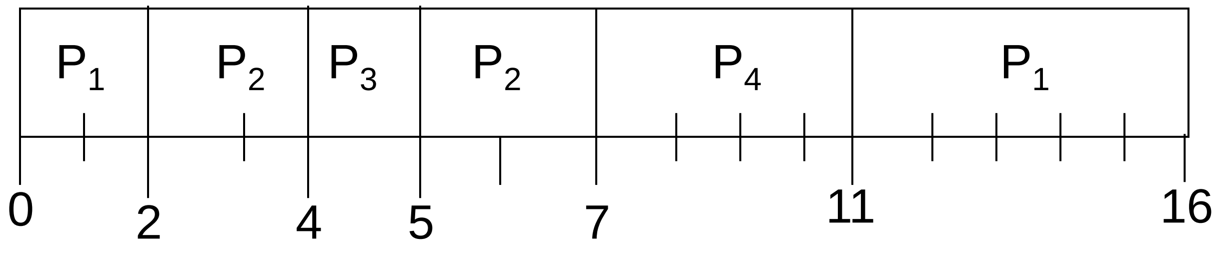


- Average waiting time ?
  = (0 + 6 + 3 + 7)/4 = 4

Example of Preemptive SJF

Process	Arrival Time	Burst Time
P_1	0.0	7
P_2	2.0	4
P_3	4.0	1
P_4	5.0	4

- SJF (preemptive)



- Average waiting time ?

$= (9 + 1 + 0 + 2)/4 = 3$

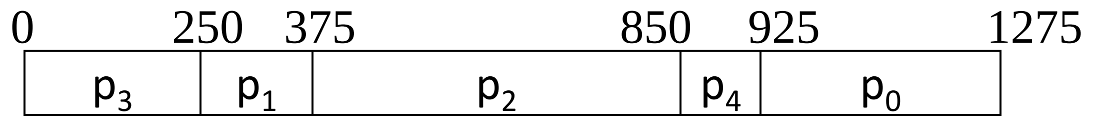
3. Priority Scheduling

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority (smallest integer $\equiv$ highest priority).
- Can be preemptive and nonpreemptive
- FCFS and SJF are special cases of priority scheduling
  - Why?
  - In FCFS priority is based on the arrival time
  - SJF is a priority scheduling where priority is the predicted next CPU burst time.

Priority Scheduling

Pid	$\tau(p_i)$	Priority
0	350	5
1	125	2
2	475	3
3	250	1
4	75	4

- Nonpreemptive example



$T_{TRnd}(p_0) = \tau(p_0)+\tau(p_4)+\tau(p_2)+\tau(p_1)\ )+\tau(p_3) = 350+75+475+125+250$
$= 1275$
$T_{TRnd}(p_1) = \tau(p_1)+\tau(p_3) = 125+250 = 375$
$T_{TRnd}(p_2) = \tau(p_2)+\tau(p_1)+\tau(p_3) = 475+125+250 = 850$
$T_{TRnd}(p_3) = \tau(p_3) = 250$
$T_{TRnd}(p_4) = \tau(p_4)+ \tau(p_2)+ \tau(p_1)+\tau(p_3) = 75+475+125+250 = 925$

$R(p_0) = 925$
$R(p_1) = 250$
$R(p_2) = 375$

$R(p_3) = 0$
$R(p_4) = 850$

Average response time $R_{avg} = (925+250+375+0+850)/5 = 2400/5 = 480$

Problem with Priority Scheduling

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

IBM 7094 operator's console

- Rumor has it that,
  - when they shut down the IBM 7094 at MIT in 1973, they found a low-priority process that had been submitted in 1967 and had not yet been run.

Priority

- What if a high-priority process needs to access the data that is currently being held by a low- priority process?

- The high-priority process is blocked by the low-priority process. This is priority inversion.
- This can be solved with priority-inheritance protocol.
  - The low priority process accessing the data inherits the high priority until it is done with the resource.
  - When the low-priority process finishes, its priority reverts back to the original.

4. Round Robin (RR)

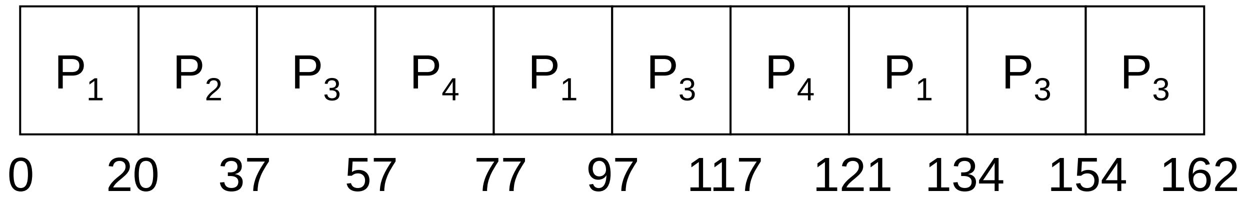
- Each process gets a small unit of CPU time (**time quantum**), usually 10-100 milliseconds.
- After this time has elapsed, the process is **preempted** and added to the end of the ready queue.

- 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.

Example of RR with Time Quantum = 20

<u>Process</u>	<u>Burst Time</u>
P_1	53
P_2	17
P_3	68
P_4	24

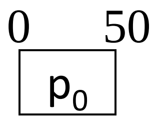
- The Gantt chart is:



- Typically, higher average turnaround than SJF, but **better response**.

Round Robin (Time Quantum=50)

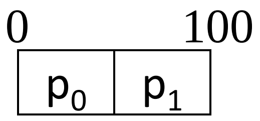
i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75



$R(p_0) = 0$

Round Robin (Time Quantum=50)

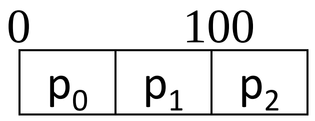
i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75



$R(p_0) = 0$
$R(p_1) = 50$

Round Robin (Time Quantum=50)

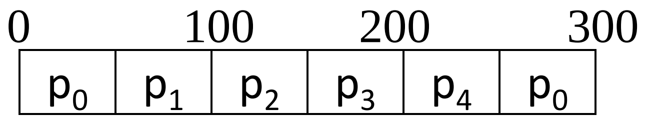
i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75



$R(p_0) = 0$
$R(p_1) = 50$
$R(p_2) = 100$

Round Robin (Time Quantum=50)

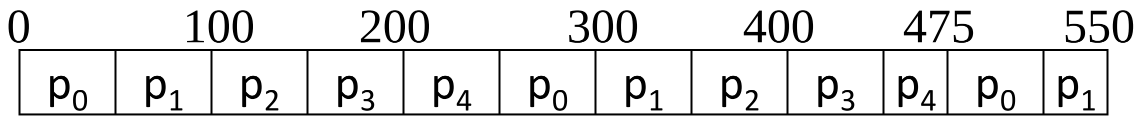
i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75



$R(p_0) = 0$
$R(p_1) = 50$
$R(p_2) = 100$
$R(p_3) = 150$
$R(p_4) = 200$

Round Robin (Time Quantum=50)

i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75



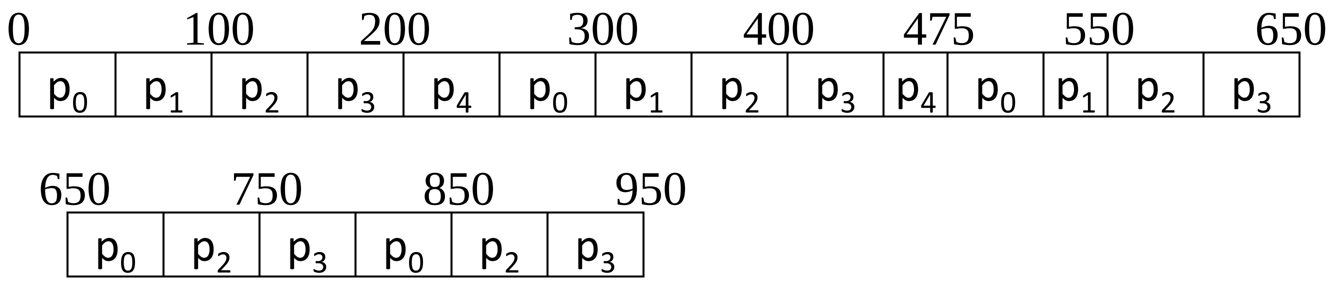
$T_{TRnd}(p_1) = 550$

$T_{TRnd}(p_4) = 475$

$R(p_0) = 0$
$R(p_1) = 50$
$R(p_2) = 100$
$R(p_3) = 150$
$R(p_4) = 200$

Round Robin (Time Quantum=50)

i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75


0
100
200
300
400
475
550
650
p_0 p_1 p_2 p_3 p_4 p_0 p_1 p_2 p_3 p_4 p_0 p_1 p_2 p_3
650
750
850
950
p_0 p_2 p_3 p_0 p_2 p_3

$T_{TRnd}(p_1) = 550$

$T_{TRnd}(p_3) = 950$

$T_{TRnd}(p_4) = 475$

$R(p_0) = 0$

$R(p_1) = 50$

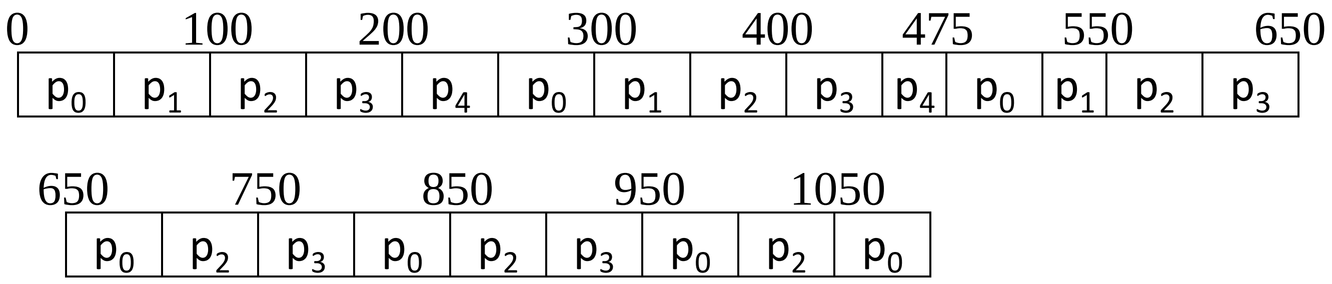
$R(p_2) = 100$

$R(p_3) = 150$

$R(p_4) = 200$

Round Robin (Time Quantum=50)

i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75



0
100
200
300
400
475
550
650
p_0 p_1 p_2 p_3 p_4 p_0 p_1 p_2 p_3 p_4 p_0 p_1 p_2 p_3
650
750
850
950
1050
p_0 p_2 p_3 p_0 p_2 p_3 p_0 p_2 p_0

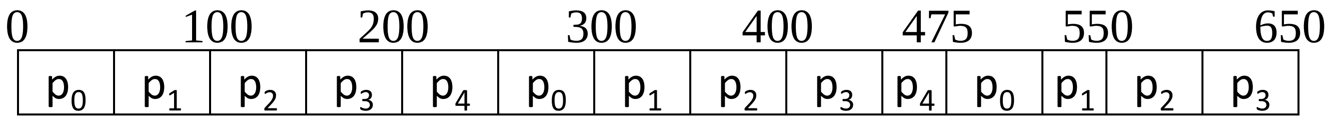
$T_{TRnd}(p_0) = 1100$
$T_{TRnd}(p_1) = 550$

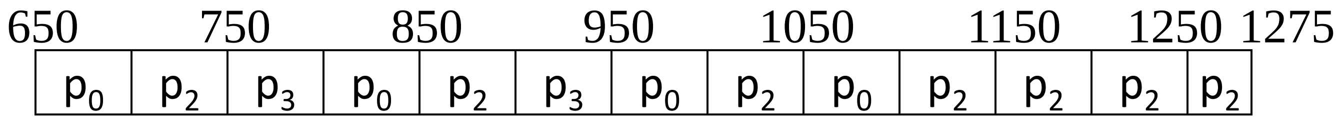
$T_{TRnd}(p_3) = 950$
$T_{TRnd}(p_4) = 475$

$R(p_0) = 0$
$R(p_1) = 50$
$R(p_2) = 100$
$R(p_3) = 150$
$R(p_4) = 200$

Round Robin (Time Quantum=50)

i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75





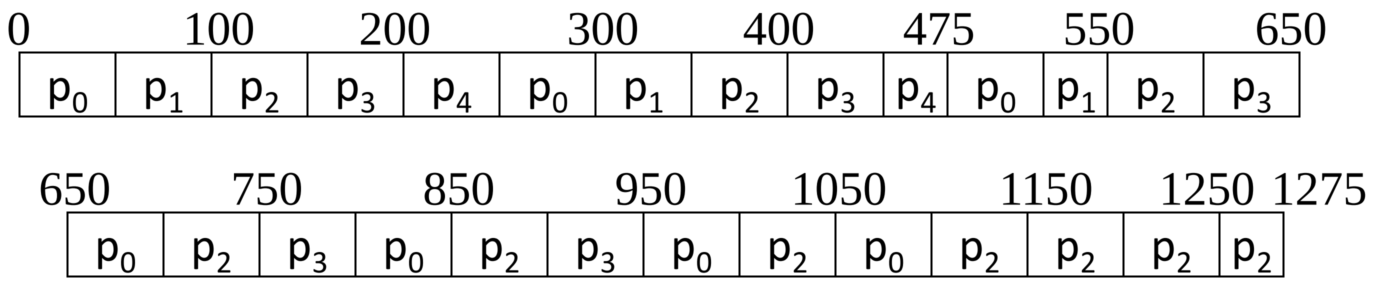
$T_{TRnd}(p_0) = 1100$
$T_{TRnd}(p_1) = 550$
$T_{TRnd}(p_2) = 1275$
$T_{TRnd}(p_3) = 950$
$T_{TRnd}(p_4) = 475$

$R(p_0) = 0$
$R(p_1) = 50$
$R(p_2) = 100$
$R(p_3) = 150$
$R(p_4) = 200$

Round Robin (Time Quantum=50)

- Equitable
- Most widely-used

i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75


0 100 200 300 400 475 550 650
p_0 p_1 p_2 p_3 p_4 p_0 p_1 p_2 p_3 p_4 p_0 p_1 p_2 p_3
650 750 850 950 1050 1150 1250 1275
p_0 p_2 p_3 p_0 p_2 p_3 p_0 p_2 p_0 p_2 p_2 p_2 p_2

$T_{TRnd}(p_0) = 1100$
$T_{TRnd}(p_1) = 550$
$T_{TRnd}(p_2) = 1275$
$T_{TRnd}(p_3) = 950$
$T_{TRnd}(p_4) = 475$

$R(p_0) = 0$
$R(p_1) = 50$
$R(p_2) = 100$
$R(p_3) = 150$
$R(p_4) = 200$

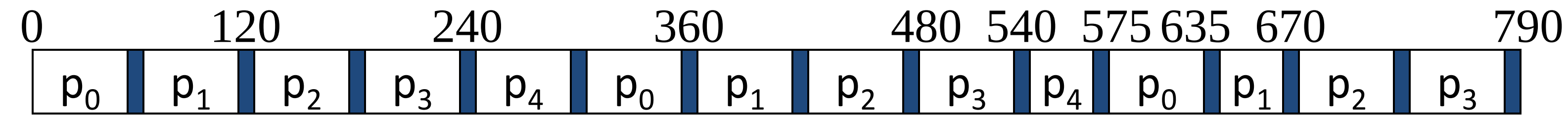
$T_{TRnd\text{—}avg} = (1100+550+1275+950+475)/5 = 4350/5 = 870$

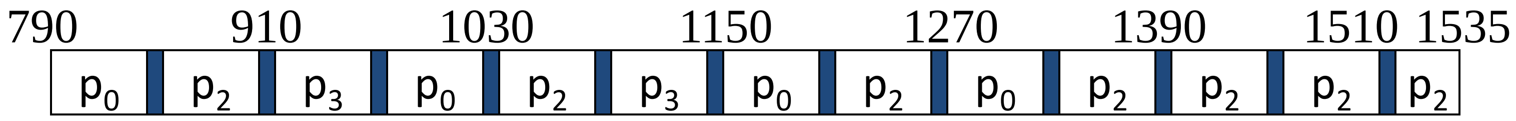
Average response (wait) time $R_{avg} = (0+50+100+150+200)/5 = 500/5 = 100$

RR (TQ=50, Overhead =10)

•Context Switch Overhead must be considered

i	$\tau(p_i)$
0	350
1	125
2	475
3	250
4	75



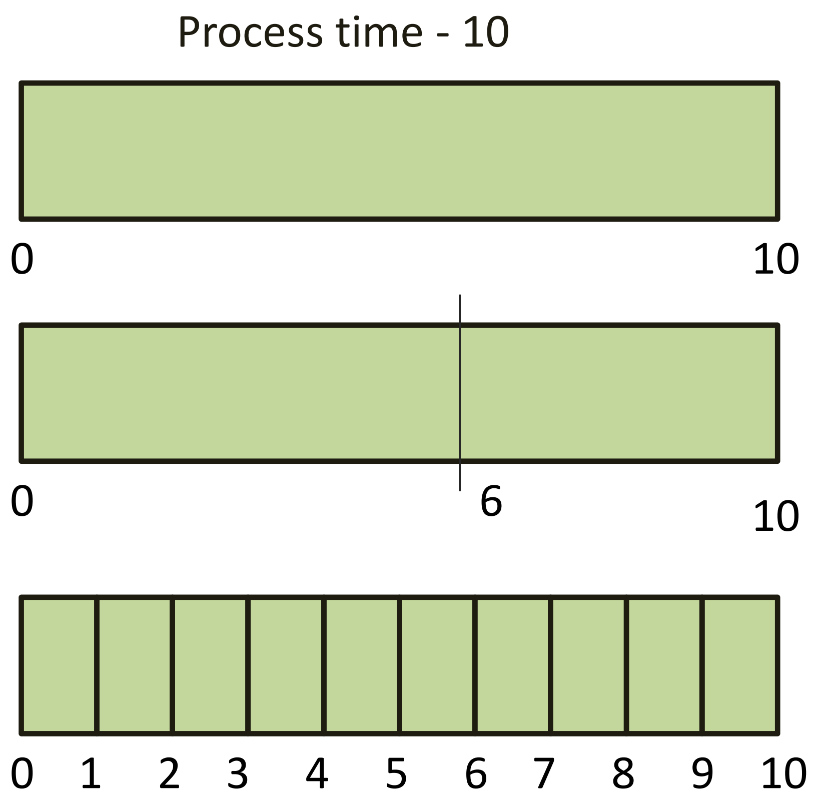


$T_{TRnd}(p_0) = 1320$	$R(p_0) = 0$
$T_{TRnd}(p_1) = 660$	$R(p_1) = 60$
$T_{TRnd}(p_2) = 1535$	$R(p_2) = 120$
$T_{TRnd}(p_3) = 1140$	$R(p_3) = 180$
$T_{TRnd}(p_4) = 565$	$R(p_4) = 240$

$T_{TRnd\text{—}avg} = (1320+660+1535+1140+565)/5 = 5220/5 = 1044$

Average response (wait) time $R_{avg} = (0+60+120+180+240)/5 = 600/5 = 120$

Time Quantum and Context Switch Time



quantum	Context switches
12	0
6	1
1	9

- *quantum* large ⇒ FIFO
- *quantum* small ⇒ *quantum* must be large enough with respect to context switch, otherwise overhead is too high.

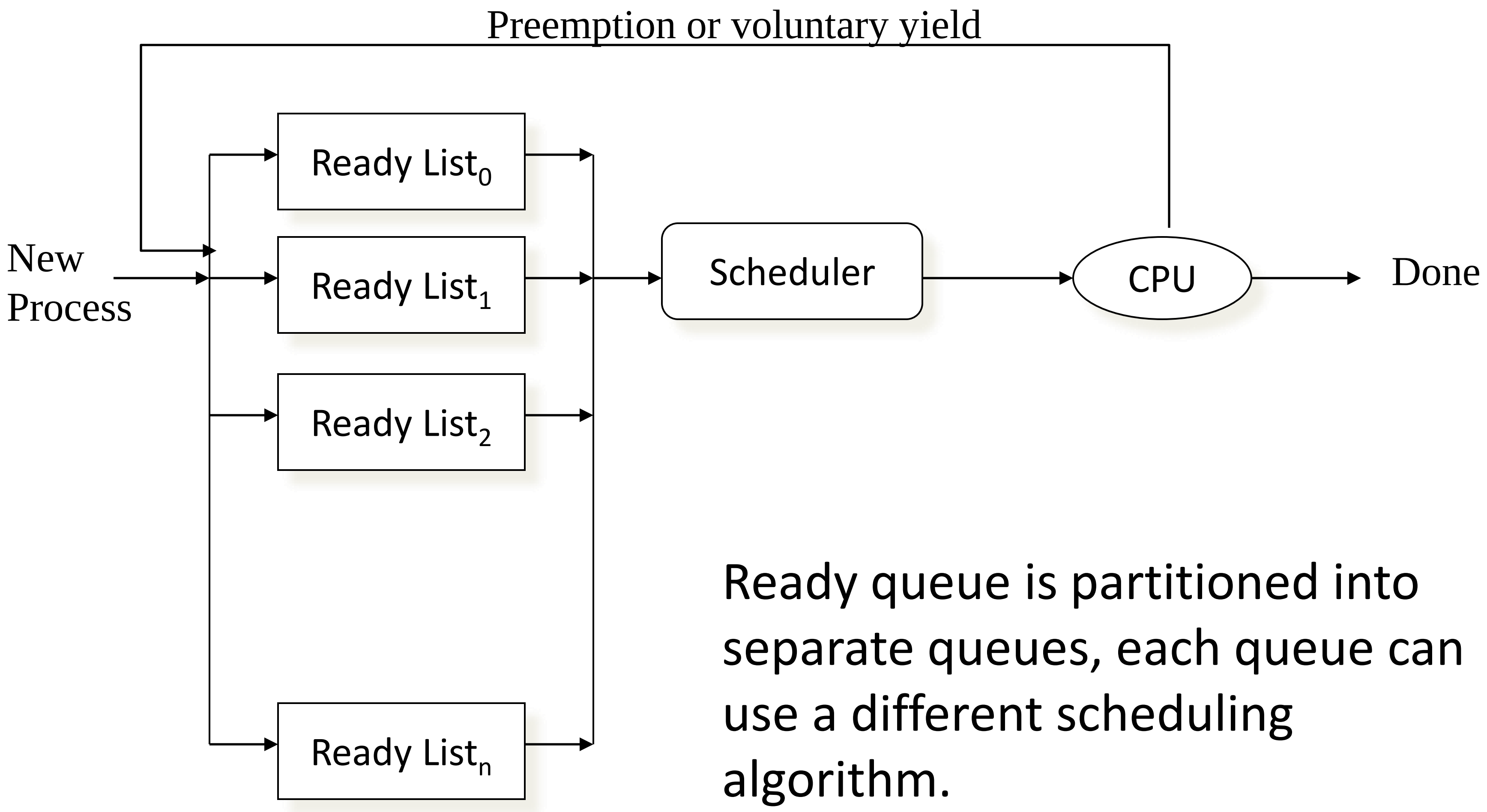
RR algorithm

- Consider a variant of the RR scheduling algorithm where the entries in the ready queue are pointers to the PCBs.
- What would be the effect of putting two pointers to the same process in the ready queue?
- How would you modify the basic RR algorithm to achieve the same effect without the duplicate pointers?

5. Multilevel Queue

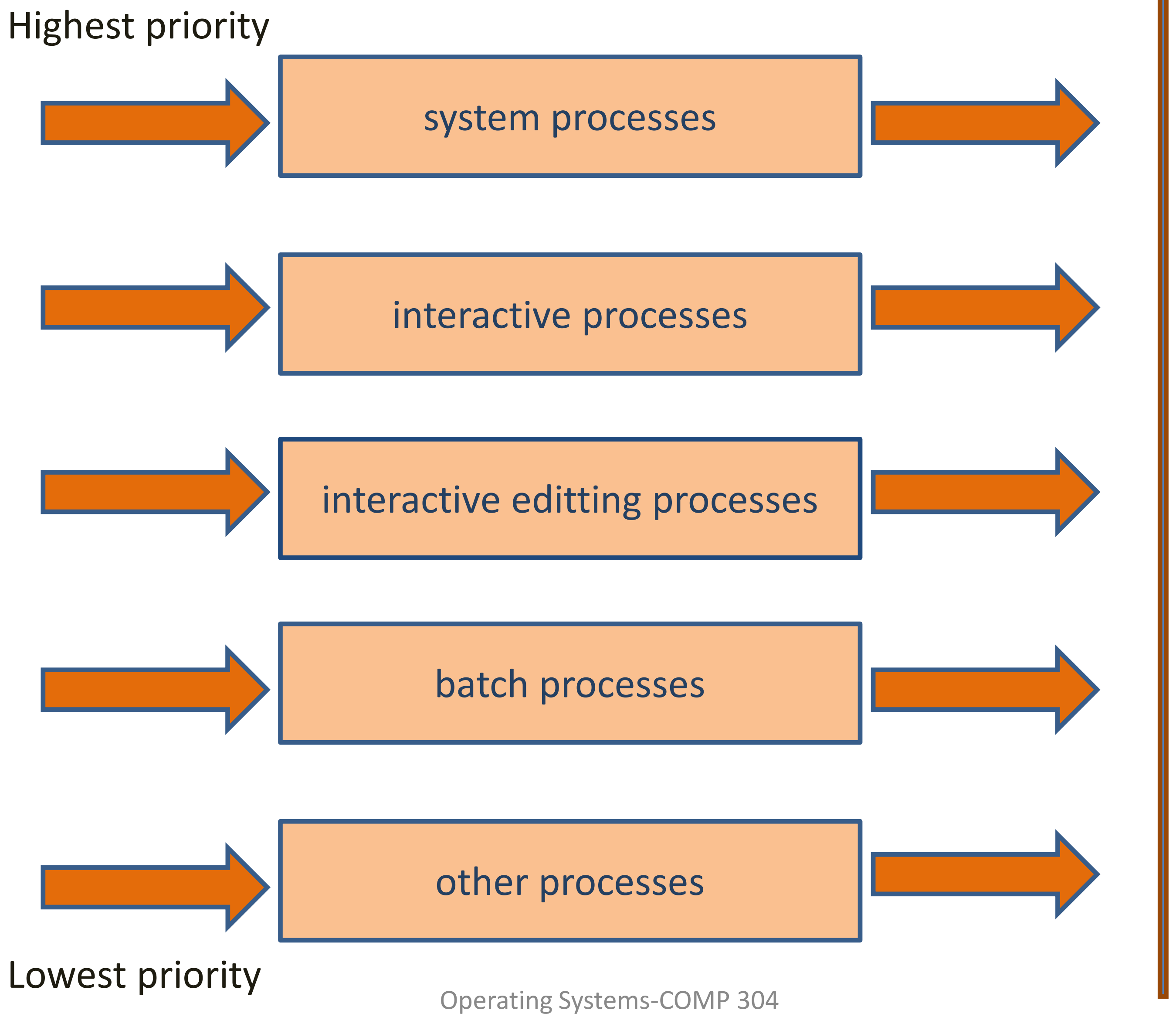
- Ready queue is partitioned into separate queues:
  foreground (interactive)
  background (batch)
- Each queue has its own scheduling algorithm,
  foreground – RR
  background – FCFS
- Scheduling must be done between the queues.
  - Fixed priority scheduling – (i.e., serve all from foreground then from background). Possibility of **starvation**.
  - Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; i.e., 80% to foreground in RR, 20% to background in FCFS

Multi-Level Queues



Ready queue is partitioned into separate queues, each queue can use a different scheduling algorithm.

Example- Multi-level Queue

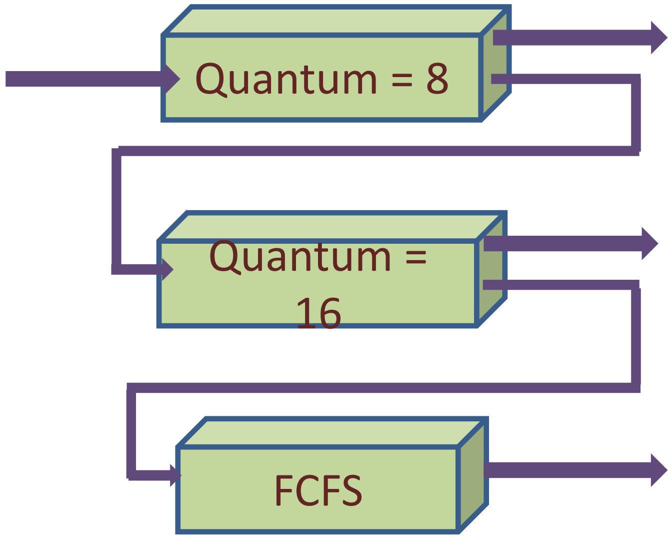


6. Multilevel Feedback Queue

- Multilevel queue with feedback scheduling is similar to multilevel queue; however, it allows processes to move between queues.
- **Aging** can be implemented this way.
- 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:
  - Q_0 – time quantum 8 milliseconds
  - Q_1 – time quantum 16 milliseconds
  - Q_2 – FCFS non-preemption
- Example Scheduling
  - A new job enters queue Q_0. 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 FCFS and receives 16 additional milliseconds.
  - If it still does not complete, it is preempted and moved to queue Q_2.



Multiple-Processor Scheduling

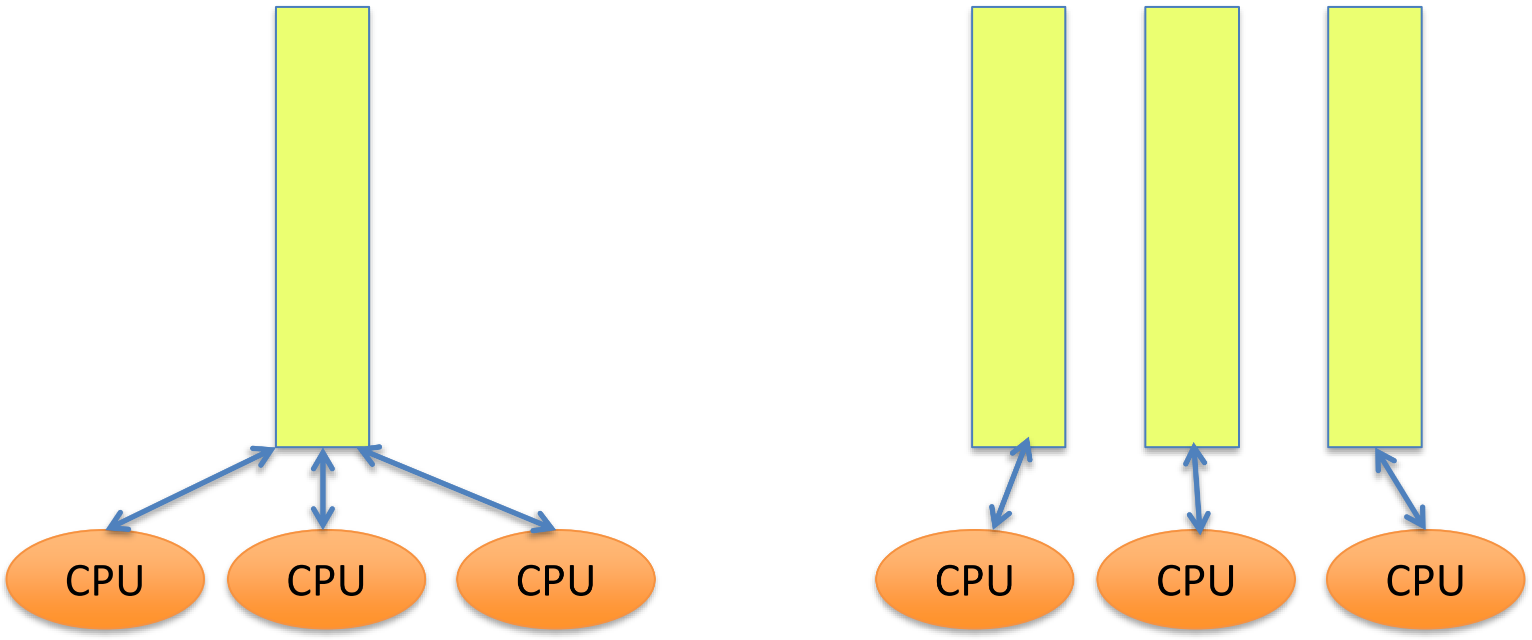
- CPU scheduling is more complex when multiple CPUs are available
  - **Asymmetric multiprocessing** – only one processor accesses the system data structures, alleviating the need for data sharing
  - **Symmetric multiprocessing (SMP)** – each processor is self-scheduling, all processes in common ready queue, or each has its own private queue of ready processes
- **Processor affinity** – process has affinity for processor on which it is currently running
  - **soft affinity** (can be changed at a later time)
  - **hard affinity** (process doesn't move to another processor)
  - Variations including **processor sets**

Global vs Per-Core Scheduler

- **Global Scheduler:** The global scheduler is responsible for making high-level decisions about which threads or processes are ready to run and assigning them to specific CPU cores. It considers factors like thread priorities, CPU affinity, and load balancing across the cores.

- **Per-Core Schedulers:** Each CPU core may have its own local scheduler, which handles the fine-grained decisions related to executing threads or processes on that core. These per-core schedulers typically work under the guidance of the global scheduler.

Multicore Scheduling



- In SMP, each CPU has its own private ready queue for the processes waiting to be run on that CPU

Process Migration

- OS needs to keep all CPUs loaded for efficiency
- **Load balancing** attempts to keep workload evenly distributed
- **Push migration** – periodically checks load on each processor, and if found any of them overloaded, pushes task from overloaded CPU to other CPUs
- **Pull migration** – idle processors pull waiting tasks from busy processor

Starvation

- Which of the following scheduling algorithms could result in starvation?
  - First-come, first serve
  - Shortest job first
  - Round robin
  - Priority

Scheduling in Linux

- How does Linux schedule processes?

Reading

- Read Chapter 5 (Textbook)
- Read Chapter 4 (Linux Kernel Development)

- Acknowledgments
  - Original slides are by **Didem Unat** which were adapted from
    - Öznur Özkasap (Koç University)
    - Operating System and Concepts (9th edition) Wiley