Process Scheduling

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Introduction

- An important aspect of multiprogramming is scheduling. The resources that are scheduled are IO and processors.
- The goal is to achieve
    - High processor utilization
    - High throughput
        - number of processes completed per unit time
    - Low response time
        - time elapse from the submission of a request to the beginning of the response

Concepts

- **Preemptive algorithm:** A **preemptive** scheduling algorithm picks a process and lets it run for a maximum of some fixed time. If it is still running at the end of the time interval, it is suspended and the scheduler picks another process to run (if one is available).
- **Non preemptive Algorithm:** A **non preemptive** scheduling algorithm picks a process to run and then just lets it run until it blocks (either on I/O or waiting for another process) or voluntarily releases the CPU. Even if it runs for many hours, it will not be forcibly suspended.

Categories of Scheduling Algorithms

- Different environments need different scheduling algorithms
  - **Batch**
    - Still in wide use in business world
    - Non-preemptive algorithms reduces process switches
  - **Interactive**
    - Preemptive is necessary
  - **Real time**
    - Processes run quickly and block

Scheduling Algorithm Goals

All systems

Fair ness - giving each process a fair share of the CPU

Policy enforcement - seeing that stated policy is carried out

Balance - keeping all parts of the system busy

Batch systems

Throughput - maximize jobs per hour

Turnaround time - minimize time between submission and termination

CPU utilization - keep the CPU busy all the time

Interactive systems

Response time - respond to requests quickly

Proportionality - meet users' expectations

Real-time systems

Meeting deadlines - avoid losing data

Predictability - avoid quality degradation in multimedia systems

Scheduling Criteria

- **CPU utilization** – keep the CPU as busy as possible
- **Throughput** – number of completed jobs per time unit
- **Completion Time**: Time taken for the execution to complete, starting from arrival time.
- **Turn Around Time**: Time taken to complete after arrival. In simple words, it is the difference between the Completion time and the Arrival time.

Turn Around Time = Completion Time - Arrival Time

- **Waiting Time**: Total time the process has to wait before it's execution begins. It is the difference between the Turn Around time and the Burst time of the process.

Waiting Time = Turn around time - Burst Time

- **Response Ratio** = (Waiting Time + Burst time) / Burst time

Scheduling in Batch Systems

- First-come first-served
- Shortest job first
- Shortest Remaining Time Next

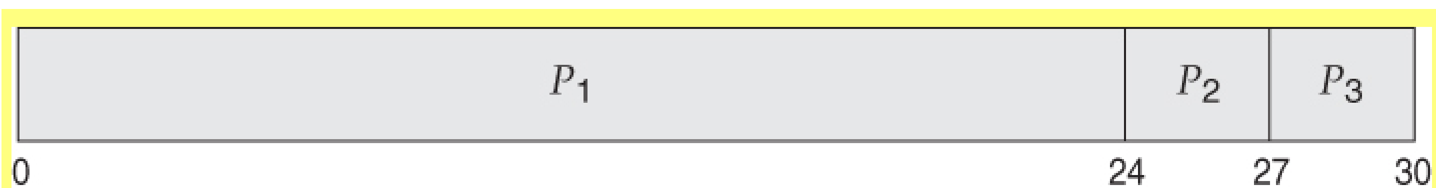
First-Come First-Serve(FCFS) Scheduling

- Runnable process added to the end of ready queue
- Non-preemptive
- FCFS is very simple - Just a FIFO queue, like customers waiting in line at the bank or the post office or at a copying machine.
- Unfortunately, however, FCFS can yield some very long average wait times, particularly if the first process to get there takes a long time.

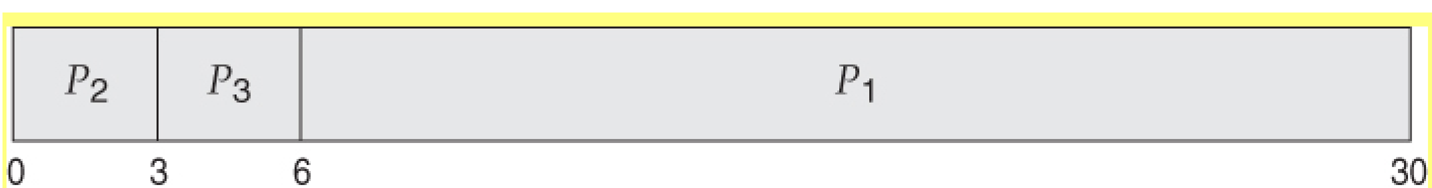
Example :1

Process	CPU Burst Time
P1	24
P2	3
P3	3

- In the first Gantt chart below, process P1 arrives first. Waiting time for *P1* = 0; *P2* = 24; *P3* = 27
- The average waiting time for the three processes is (0 + 24 + 27) / 3 = 17 ms.



- Suppose that the processes arrive in the order *P2* , *P3* , *P1* ,Waiting time for *P1* = 6*; P2* = 0*; P3 = 3*,In the second Gantt chart below, the same three processes have an average wait time of (0 + 3 + 6) / 3 = 3 ms.



Example :2

Process Id	Arrival time	Burst time
P1	0	2
P2	3	1
P3	5	6

Gantt Chart: Here, black box represents the idle time of CPU.

Gantt Chart

Turn Around time = Exit time/Completion time – Arrival time

Waiting time = Turn Around time – Burst time/Execution time

Process Id	**Exit time**	**Turn Around time**	**Waiting time**
P1	2	2 – 0 = 2	2 – 2 = 0
P2	4	4 – 3 = 1	1 – 1 = 0
P3	11	11- 5 = 6	6 – 6 = 0

Now,

Average Turn Around time = (2 + 1 + 6) / 3 = 9 / 3 = 3 unit

Average waiting time = (0 + 0 + 0) / 3 = 0 / 3 = 0 unit

Shortest-Job-First Scheduling (SJF)

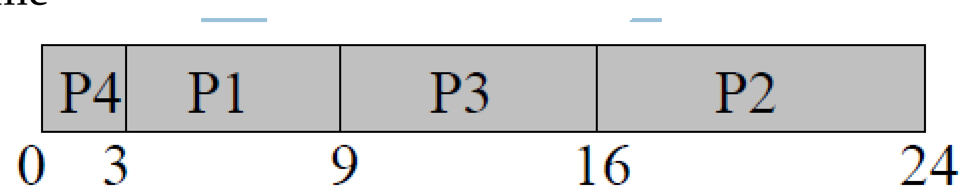
- **Shortest Job First (SJF)** is an algorithm in which the process having the smallest execution time is chosen for the next execution.
- It is a scheduling policy that selects for execution the waiting **process** with **Shortest job next (SJN), also known as shortest job first (SJF) or shortest process next (SPN),** the smallest execution time.

Non-Preemptive SJF

- Shortest next CPU burst first
- The shortest process is execution first.

Example :1

Process	CPU burst time
P1	6
P2	8
P3	7
P4	3



Average waiting time= (0+3+9+16)/4 = 7

Example : 2

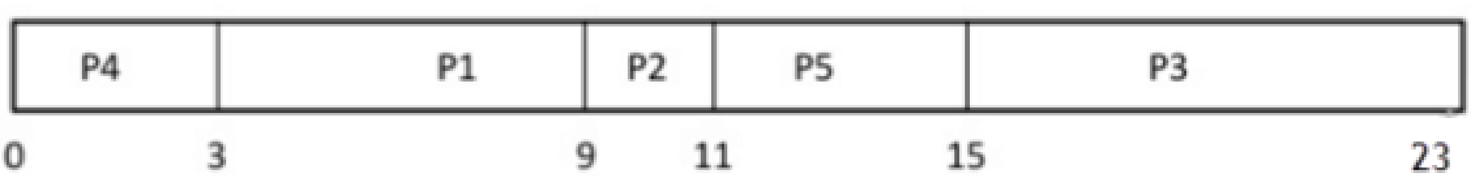
Process	Burst time/Execution time	Arrival time
P1	6	2
P2	2	5
P3	8	1
P4	3	0
P5	4	4

- ✓ **Completion time:** p1=9,p2=11,p3=23,p4=3, p5=15
- ✓ **Turn Around Time = (Completion Time - Arrival Time)**
- P1=9-2=7,p2=11-5=6,p3=23-1=22,p4=3-0=3,p5=15-4=11

Average Turn around time =7+6+22+3+11/5=49/5

- ✓ **Waiting Time = (Turn around time - Burst Time)**
- P4= 3-3=0 P1= 7-6=1 P2= 6-2=4 P5= 11-4=7 P3= 22-8=14

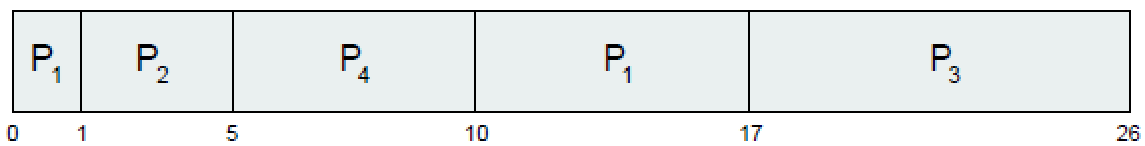
Average Waiting Time= 0+1+4+7+14/5 = 26/5 = 5.2



Shortest remaining time next

- A **preemptive** version of shortest job first is **shortest remaining time next**.
- A process with shortest burst time begins execution.
- If a process with even a shorter burst time arrives, the current process is removed or preempted from execution, and the shorter job is allocated CPU cycle.

Example :1



Process	CPU Burst Time	Arrival Time
P1	8	0
P2	4	1
P3	9	2
P4	5	3

Average Waiting Time = ((10-1) +(1-1) + (17-2) +(5-3))/4 = 26/4= 6.5 ms

Scheduling in Interactive Systems

- Round-Robin Scheduling
- Priority Scheduling
- Multiple Queues
- Shortest Process Next
- Guaranteed Scheduling
- Fair-Share Scheduling
- Lottery Scheduling

Round-Robin Scheduling

- One of the Most widely used, oldest, fairest, and easiest algorithms is **round robin**.
- Round robin is a preemptive algorithm
- The CPU is shifted to the next process after fixed interval time, which is called time quantum/time slice.
- Process runs until it blocks or time quantum exceeded
- If the process has blocked or finished before the quantum has elapsed, the CPU switching is done when the process blocks, of course.

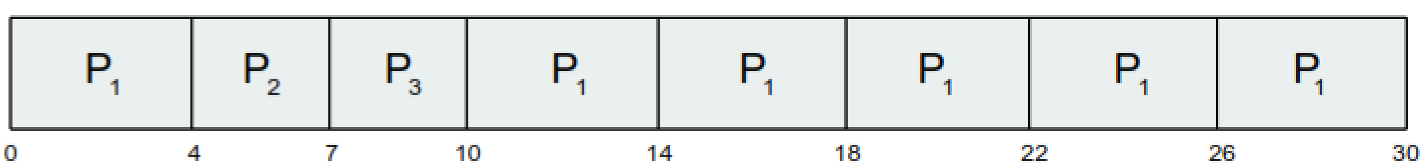
Example :1

Process	Burst time
P1	24
P2	3
P3	3

Time Slice=4.

Ready Queue: P1,P2,P3,P1

The Gantt chart assuming all processes arrive at time 0 is:



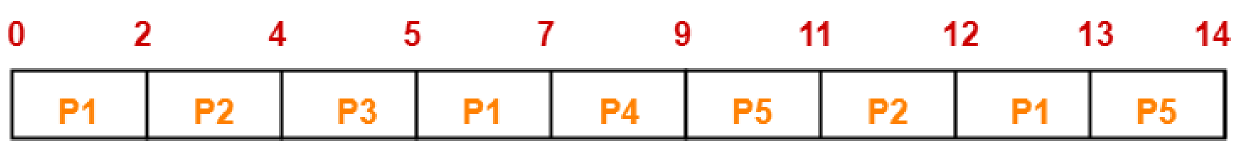
Average Waiting Time={(10-4)+(4-0)+(7-0)}/3=17/3=5.66 ms.

Example :2

If the CPU scheduling policy is Round Robin with time quantum = 2 unit, calculate the average waiting time and average turn around time.

Process	Arrival time	Burst time
P1	0	5
P2	1	3
P3	2	1
P4	3	2
P5	4	3

Ready Queue: P1, P2,P3,P1, P4, P5,P2, P1,P5



Gantt Chart

Process	Turn Around time	Waiting time
P1	13 – 0 = 13	13 – 5 = 8
P2	12 – 1 = 11	11 – 3 = 8
P3	5 – 2 = 3	3 – 1 = 2
P4	9 – 3 = 6	6 – 2 = 4
P5	14 – 4 = 10	10 – 3 = 7

Now,

Average Turn Around time = (13 + 11 + 3 + 6 + 10) / 5 = 43 / 5 = 8.6 unit

Average waiting time = (8 + 8 + 2 + 4 + 7) / 5 = 29 / 5 = 5.8 unit

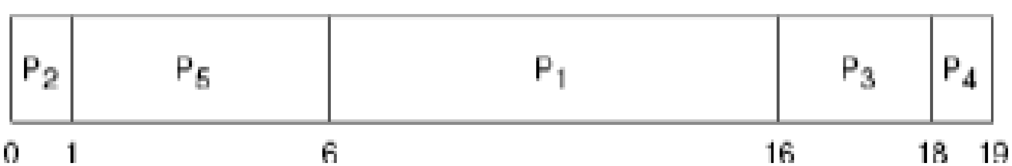
Priority Scheduling

- Jobs are run based on their priority, Always run the job with the highest priority
- Priorities can be **externally defined** (e.g., by user) or based on some **process-specific metrics** (e.g., their expected CPU burst)
- Can be preemptive
- Can be no preemptive
- Priorities can be **static** (i.e. they don’t change) or **dynamic** (they may change during execution)
- Problem =**Starvation** – low priority processes may never execute
- Solution = **Aging** – as time progresses increase the priority of the process

Example :1 If the CPU scheduling policy is priority non-preemptive, calculate the average waiting time and average turn around time. (lower number represents higher priority)

Process	Burst Time (ms)	Priority
P1	10	3
P2	1	1
P3	2	4
P4	1	5
P5	5	2

- Priority scheduling Gantt Chart assuming all arrive at time 0



Turn Around time = Exit time/completion time – Arrival time

Waiting time = Turn Around time – Burst time/Execution time

Average waiting time = (0+1+6+16+18)/5 = 8.2 msec

Example: 2

PROCESS	ARRIVAL TIME	BURST TIME	PRIORITY
P1	0	8	3
P2	1	1	1
P3	2	3	2
P4	3	2	3
P5	4	6	4

Priority Non-preemptive scheduling :

P1	P2	P3	P4	P5

0 8 9 12 14 20

Average waiting time (AWT)= ((0-0) + (8-1) + (9-2) + (12-3) + (14-4)) / 5 = 33 / 5 = 6.6

Average turnaround time (TAT)= ((8-0) + (9-1) + (12-2) + (14-3) + (20-4)) / 5= 53 / 5 = 10.6

Priority Preemptive scheduling :

P1	P2	P3	P1	P4	P5

0 1 2 5 12 14 20

Average waiting time (AWT)= ((5-1) + (1-1) + (2-2) + (12-3) + (14-4)) / 5 =

23/5 = 4.6

Average turnaround time (TAT)= ((12-0) + (2-1) + (5-2) + (14-3) + (20-4))

/ 5 = 43 / 5 = 8.5

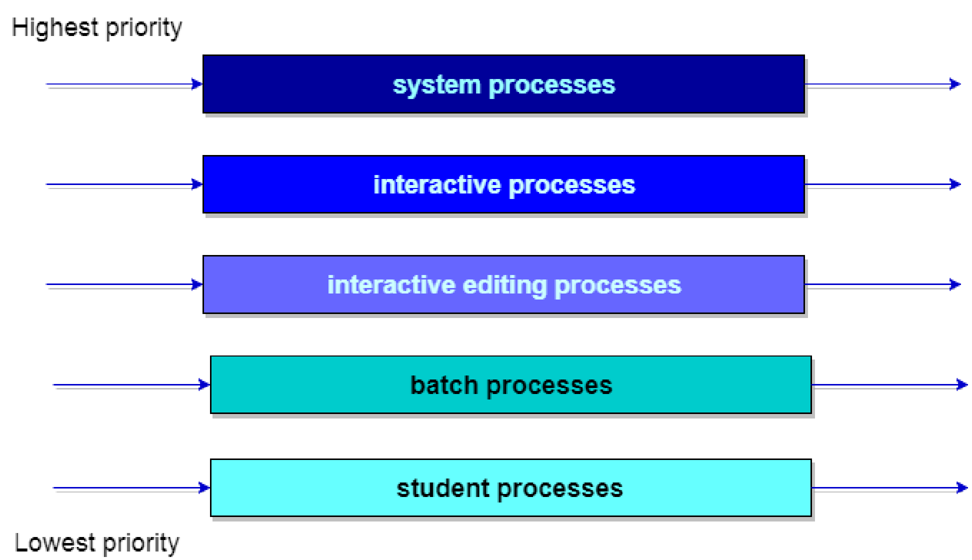
Multi-level queue

- A multi-level queue scheduling algorithm partitions the ready queue into several separate queues.
- The processes are permanently assigned to one queue, generally based on some property of the process, such as memory size, process priority, or process type

For Example:

- Separate queues might be used for foreground and background processes.
- The foreground queue might be scheduled by Round Robin algorithm, while the background queue is scheduled by an FCFS algorithm.

- Let us consider an example of a multilevel queue-scheduling algorithm with five queues:
  - System Processes
  - Interactive Processes
  - Interactive Editing Processes
  - Batch Processes
  - Student Processes



Example 1: Consider below table of four processes under Multilevel queue scheduling. Queue number denotes the queue of the process. Priority of queue 1 is greater than queue 2. queue 1 uses Round Robin (Time Quantum = 2) and queue 2 uses FCFS.

Process	Burst time	Arrival time	Queue number
P1	4	0	1
P2	3	0	1
P3	8	0	2
P4	5	10	1

Solution: **Gantt chart** of the problem

P1	P2	P1	P2	P3	P4	P3

0 2 4 6 7 10 15 20

Example 2: Consider below table of four processes under Multilevel queue scheduling. Queue number denotes the queue of the process. Queue1 is having higher priority and queue1 is using the FCFS approach and queue2 is using the round-robin approach(time quantum = 2ms).

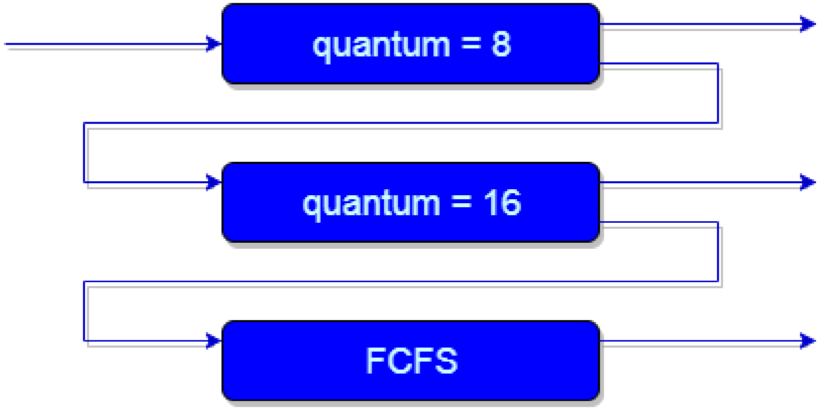
Process	Arrival time	Burst time	Queue
P1	0 ms	5 ms	1
P2	0 ms	3 ms	2
P3	0 ms	8 ms	2
P4	0 ms	6 ms	1

Gantt Chart

P1	P4	P2	P3	P2	P3
0 5	5 11	11 13	13 15	15 16	16 22

Multilevel Feedback Queue

- Multilevel feedback queue scheduling, allows a process to move between queues.
- The idea is to separate processes with different CPU-burst characteristics.
- 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 be moved to a higher-priority queue.



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

Guaranteed Scheduling

- Make real promises to the users about performance.
- If there are n users logged in while you are working, you will receive about 1 /n of the CPU power.
- Similarly, on a single-user system with n processes running, all things being equal, each one should get 1 /n of the CPU cycles.
- To make good on this promise, the system must keep track of how much CPU each process has had since its creation.
- CPU Time entitled= (Time Since Creation)/n
- Then compute the ratio of Actual CPU time consumed to the CPU time entitled.

- A ratio of 0.5 means that a process has only had half of what it should have had, and a ratio of 2.0 means that a process has had twice as much as it was entitled to.
- The algorithm is then to run the process with the lowest ratio until its ratio has moved above its closest competitor.

Fair-Share Scheduling

- Users are assigned some fraction of the CPU
  - Scheduler takes into account who owns a process before scheduling it
- E.g., two users each with 50% CPU share
  - User 1 has 4 processes: A, B, C, D
  - User 2 has 2 processes: E, F
- If round-robin scheduling is used, a possible scheduling sequence that meets all the constraints is this one:

A E B E C E D E A E B E C E D E ...

- On the other hand, if user 1 is entitled to twice as much CPU time as user 2, we might get

A B E C D E A B E C D E ...

Numerous other possibilities exist, of course, and can be exploited, depending on what the notion of fairness is.

Lottery Scheduling [Waldspurger and Weihl 1994]

- Jobs receive lottery tickets for various resources
  - E.g., CPU time
- At each scheduling decision, one ticket is chosen at random and the job holding that ticket wins
- If there are 100 tickets outstanding, and one process holds 20 of them, it will have a 20% chance of winning each lottery. In the long run, it will get about 20% of the CPU.
- Lottery scheduling can be used to solve problems that are difficult to handle with other methods.
- One example is a video server in which several processes are feeding video streams to their clients, but at different frame rates.
- Suppose that the processes need frames at 10, 20, and 25 frames/sec. By allocating these processes 10, 20, and 25 tickets, respectively, they will automatically divide the CPU in approximately the correct proportion, that is, 10 : 20 : 25.

Scheduling in Real-Time Systems

- A **real-time scheduling System** is composed of the **scheduler**, clock and the processing hardware elements.
- In a **real-time system**, a process or task has Schedulability ; tasks are accepted by a **real-time system** and completed as specified by the task deadline depending on the characteristic of the **scheduling** algorithm.
- Real-time systems are generally categorized as **hard real time**, meaning there are absolute deadlines that must be met—or else!— and **soft real time**, meaning that missing an occasional deadline is undesirable, but nevertheless tolerable.
- The events that a real-time system may have to respond to can be further categorized as **periodic** (meaning they occur at regular intervals) or **aperiodic** (meaning they occur unpredictably).

- For example, if there are *m* periodic events and event *i* occurs with period *Pi* and requires *Ci* sec of CPU time to handle each event, then the load can be handled only if A real-time system that meets this criterion is said to be **schedulable**.

$$\sum_{i=1}^{m} \frac{C_i}{P_i} \leq 1$$

- A process that fails to meet this test cannot be scheduled because the total amount of CPU time the processes want collectively is more than the CPU can deliver.