**Tutorial 3: Scheduling Algorithm**

NOTE:

1. For algorithm that have both pre-emptive and non-pre-emptive, if the question did not mention any method, by default it is referring to the non-pre-emptive method.
2. If the question did not give the arrival time, assume that all the processes start with 0.

Exercises for scheduling algorithms:

1. First come first serve (FCFS) – non pre-emptive
2. Average waiting time (AWT= )

Average turnaround time(ATAT=)

|  |  |  |
| --- | --- | --- |
| Process | Arrival time | Burst time |
| P1 | 4 | 5 |
| P2 | 6 | 4 |
| P3 | 0 | 3 |
| P4 | 6 | 2 |
| P5 | 5 | 4 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| P3 |  | P1 | P5 | P2 | P4 |
| 0 3 |  |  |  |  |  |
|  |  | 4 9 |  |  |  |
|  |  |  | 13 |  |  |
|  |  |  |  | 17 |  |
|  |  |  |  |  | 19 |

|  |  |  |
| --- | --- | --- |
|  | TAT | WT |
| P1 | 9 – 4 = 5 | 5 - 5 = 0 |
| P2 | 17 - 6 = 11 | 11 - 4 = 7 |
| P3 | 3 – 0 = 3 | 3 - 3 = 0 |
| P4 | 19 - 6 = 13 | 13 – 2 = 11 |
| P5 | 13 – 5 = 8 | 8 – 4 = 4 |

ATAT = (5+11+3+13+8) / 5 = 8

AWT = (7+11+4) / 5 = 4.4

1. (AWT= )

|  |  |
| --- | --- |
| Process | Burst time |
| P1 | 12 |
| P2 | 4 |
| P3 | 6 |
| P4 | 5 |

|  |  |  |  |
| --- | --- | --- | --- |
| P1 | P2 | P3 | P4 |
| 0 12 |  |  |  |
|  | 16 |  |  |
|  |  | 22 |  |
|  |  |  | 27 |

|  |  |  |
| --- | --- | --- |
|  | TAT | WT |
| P1 | 12 – 0 = 12 | 12 – 12 = 0 |
| P2 | 16 - 0 = 16 | 16 – 4 = 12 |
| P3 | 22 – 0 = 22 | 22 – 6 = 16 |
| P4 | 27 - 0 = 27 | 27 – 5 = 22 |

ATAT = (12+16+22+27) / 4 = 19.25

AWT = (12+16+22) / 4 = 12.5

1. Shortest Job First (SJF) – pre-emptive & non pre-emptive
2. Pre-empt – can also be called SRTF (AWT= )

|  |  |  |
| --- | --- | --- |
| Process | Arrival time | Burst time |
| P1 | 8 | 1 DONE |
| P2 | 5 | 1 DONE |
| P3 | 2 | 7-1 = 6 DONE |
| P4 | 4 | 3 -1 = 2 DONE |
| P5 | 2 | 8 DONE |
| P6 | 4 | 2 DONE |
| P7 | 3 | 5 – 1 = 4 DONE |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| P3 | P7 | P6 | P2 | P4 | P1 | P4 | P7 | P3 | P5 |
| 3 |  |  |  |  |  |  |  | 21 |  |
|  | 4 |  |  |  |  |  | 15 |  |  |
|  |  | 6 |  |  |  |  |  |  |  |
|  |  |  | 7 |  |  |  |  |  |  |
|  |  |  |  | 8 |  | 11 |  |  |  |
|  |  |  |  |  | 9 |  |  |  |  |
|  |  |  |  |  |  |  |  |  | 29 |

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 9– 8 = 1 | 1 – 1 = 0 |
| P2 | 7 – 5 = 2 | 2 – 1 = 1 |
| P3 | 21 – 2 = 19 | 19 - 7 = 12 |
| P4 | 11 – 4 = 7 | 7 – 3 = 4 |
| P5 | 29 – 2 = 27 | 27 – 8 = 19 |
| P6 | 6 – 4 = 2 | 2-2 = 0 |
| P7 | 15 – 3 = 12 | 12 – 5 = 7 |

ATAT = (1+2+19+7+27+2+12) / 7 = 10

AWT = (1+12+4+19+7) / 7 = 6.14

1. Pre-empt – can also be called SRTF (AWT= )

|  |  |  |
| --- | --- | --- |
| Process | Arrival time | Burst time |
| P1 | 2 | 1 DONE |
| P2 | 1 | 5 DONE |
| P3 | 4 | 1 DONE |
| P4 | 0 | 6-2 = 4 DONE |
| P5 | 2 | 3 – 1 = 2DONE |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| P4 | P1 | P5 | P3 | P5 | P4 | P2 |
| 2 |  |  |  |  | 11 |  |
|  | 3 |  |  |  |  |  |
|  |  | 4 |  | 7 |  |  |
|  |  |  | 5 |  |  |  |
|  |  |  |  |  |  | 16 |

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 3– 2 = 1 | 1 – 1 = 0 |
| P2 | 16 – 1 = 15 | 15 – 5 = 10 |
| P3 | 5 – 4 = 1 | 1 – 1 = 0 |
| P4 | 11 – 0 = 11 | 11 – 6 = 5 |
| P5 | 7 – 2 = 5 | 5 – 3 = 2 |

ATAT = (1+15+1+11+5) / 5 = 6.6

AWT = (10+5+2) / 5 = 3.4

1. Non-pre-emp (AWT= )

|  |  |  |
| --- | --- | --- |
| Process | Arrival time | Burst time |
| P1 | 2 | 1 |
| P2 | 1 | 5 |
| P3 | 4 | 1 |
| P4 | 0 | 6 |
| P5 | 2 | 3 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| P4 | P1 | P3 | P5 | P2 |
| 6 |  |  |  |  |
|  | 7 |  |  |  |
|  |  | 8 |  |  |
|  |  |  | 11 |  |
|  |  |  |  | 16 |

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 7– 2 = 5 | 5 – 1 = 4 |
| P2 | 16 – 1 = 15 | 15 – 5 = 10 |
| P3 | 8 – 4 = 4 | 4 – 1 = 3 |
| P4 | 6 – 0 = 6 | 6 – 6 = 0 |
| P5 | 11 – 2 = 9 | 9 – 3 = 6 |

ATAT = (5+15+4+6+9) / 5 = 7.8

AWT = (4+10+3+6) / 5 = 4.6

1. Non-pre-emp (AWT= )

|  |  |  |
| --- | --- | --- |
| Process | Arrival time | Burst time |
| P1 | 0 | 5DONE |
| P2 | 2 | 3 DONE |
| P3 | 4 | 2 DONE |
| P4 | 6 | 4 DONE |
| P5 | 7 | 1 DONE |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| P1 | P3 | P5 | P2 | P4 |
| 5 |  |  |  |  |
|  | 7 |  |  |  |
|  |  | 8 |  |  |
|  |  |  | 11 |  |
|  |  |  |  | 15 |

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 5– 0 = 5 | 5 – 5 = 0 |
| P2 | 11 – 2 = 9 | 9 – 3 = 6 |
| P3 | 7 – 4 = 3 | 3 - 2 = 1 |
| P4 | 15 – 6 = 9 | 9 - 4 = 5 |
| P5 | 8 – 7 = 1 | 1 – 1 = 0 |

ATAT = (5+9+3+9+1) / 5 = 5.4

AWT = (6+1+5) / 5 = 2.4

1. Round Robin (RR) – pre-emptive
2. Time Quantum=3 (AWT = )



|  |  |  |
| --- | --- | --- |
| Process | Arrival time | Burst time |
| P1 | 0 | 8 |
| P2 | 5 | 2 |
| P3 | 1 | 7 |
| P4 | 6 | 3 |
| P5 | 8 | 5 |

0 3 6 9 11 14 17 20 22 24 25

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| P1 | P3 | P1 | P2 | P4 | P5 | P3 | P1 | P5 | P3 |

**Correction**:

* SHOW CONTEXT TRACKING

0 3 6 9 11 14 17 20 22 23 25

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| P1 | P3 | P1 | P2 | P4 | P3 | P5 | P1 | P3 | P5 |

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 22 – 0 = 22 | 22 – 8 = 14 |
| P2 | 11 – 5 = 6 | 6 – 2 = 4 |
| P3 | 25 – 1 = 24  23 – 1 = 22 | 24 – 7 = 17  22 - 7 = 15 |
| P4 | 14 – 6 = 8 | 8 – 3 = 5 |
| P5 | 24 – 8 = 16  25 – 8 = 17 | 16 – 5 = 11  17 – 5 = 12 |

ATAT = (22+6+24+8+16) / 5 = 15.2

ATAT = (22+6+22+8+17) / 5 = 15

AWT = (14+4+17+5+11) / 5 = 10.2

AWT = 14+4+15+5+12 / 5 = 50 / 5 = 10

1. Time Quantum=6 (AWT= )

|  |  |  |
| --- | --- | --- |
| Process | Arrival time | Burst time |
| P1 | 0 | 15 |
| P2 | 4 | 3 |
| P3 | 3 | 9 |
| P4 | 2 | 6 |
| P5 | 1 | 12 |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| P1 | P5 | P4 | P3 | P2 | P1 | P5 | P3 | P1 |

0 6 12 18 24 27 33 39 42 45

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 45 – 0 = 45 | 45 – 15 = 30 |
| P2 | 27 – 4 = 23 | 23 – 3 = 20 |
| P3 | 42 – 3 = 39 | 39 – 9 = 30 |
| P4 | 18 – 2 = 16 | 16 – 6 = 10 |
| P5 | 39 – 1= 38 | 38 – 12 = 26 |

ATAT = (45+23+39+16+38) / 5 = 32.2

AWT = (30+20+30+10+26) / 5 = 23.2

1. Time Quantum=10 (AWT= )

0 10 20 27 37 42 45 55 65 72 75

|  |  |
| --- | --- |
| Process | Burst time |
| P1 | 13 |
| P2 | 27 |
| P3 | 7 |
| P4 | 23 |
| P5 | 5 |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| P1 | P2 | P3 | P4 | P5 | P1 | P2 | P4 | P2 | P4 |

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 45 | 45 – 13 = 32 |
| P2 | 72 | 72 – 27 = 45 |
| P3 | 27 | 27- 7 = 20 |
| P4 | 75 | 75 – 23 = 52 |
| P5 | 42 | 42 – 5 = 37 |

ATAT = (45+72+27+75+42) / 5 = 52.2

AWT = (32+45+20+52+37) / 5 = 37.2

7 Priority – pre-emptive & non pre-emptive

1. Non pre-emp (AWT= )

|  |  |  |
| --- | --- | --- |
| Process | Priority | Burst time |
| P1 | 2 | 11 |
| P2 | 0 | 20 |
| P3 | 3 | 2 |
| P4 | 1 | 10 |
| P5 | 4 | 16 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| P2 | P4 | P1 | P3 | P5 |

0 20 30 41 43 59

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 41 | 41 – 11 = 30 |
| P2 | 20 | 20 – 20 = 0 |
| P3 | 43 | 43 – 2 = 41 |
| P4 | 30 | 30 – 10 = 20 |
| P5 | 59 | 59 – 16 = 43 |

ATAT = (41+20+43+30+59) / 5 = 38.6

AWT = (30+41+20+43) / 5 = 26.8

1. Non pre-emp (AWT= )

|  |  |  |  |
| --- | --- | --- | --- |
| Process | Arrival time | Priority | Burst time |
| P1 | 0 | 3 | 8 d |
| P2 | 1 | 4 | 2 |
| P3 | 3 | 4 | 4 |
| P4 | 4 | 5 | 1 |
| P5 | 5 | 2 | 6d |
| P6 | 6 | 6 | 5 |
| P7 | 10 | 1 | 1 d |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| P1 | P5 | P7 | P2 | P3 | P4 | P6 |

0 8 14 15 17 21 22 27

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 8 – 0 = 8 | 8 – 8 = 0 |
| P2 | 17 – 1 = 16 | 16 – 2 = 14 |
| P3 | 21 – 3 = 18 | 18 – 4 = 14 |
| P4 | 22 – 4 = 18 | 18 – 1 = 17 |
| P5 | 14 – 5 = 9 | 9 – 6 = 3 |
| P6 | 27 – 6 = 21 | 21 – 5 = 16 |
| P7 | 15 – 10 = 5 | 5 – 1 = 4 |

ATAT = (8+16+18+18+9+21+5) / 7 = 13.57

AWT = (14+14+17+3+16+4) / 7 = 9.71

1. Pre-emp (AWT= )

0 5 10 11 12 15 17 21 22 27

|  |  |  |  |
| --- | --- | --- | --- |
| Process | Arrival time | Priority | Burst time |
| P1 | 0 | 3 | 8 |
| P2 | 1 | 4 | 2 |
| P3 | 3 | 4 | 4 |
| P4 | 4 | 5 | 1 |
| P5 | 5 | 2 | 6 |
| P6 | 6 | 6 | 5 |
| P7 | 10 | 1 | 1 |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| P1 | P5 | P7 | P5 | P1 | P2 | P3 | P4 | P6 |

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 15 – 0 = 15 | 15 – 8 = 7 |
| P2 | 17- 1 = 16 | 16 – 2 = 14 |
| P3 | 21 – 3 = 18 | 18 – 4 = 14 |
| P4 | 22 – 4 =18 | 18 – 1 = 17 |
| P5 | 12 – 5 = 7 | 7 – 6 = 1 |
| P6 | 27 – 6 = 21 | 21 – 5 = 16 |
| P7 | 11 – 10 = 1 | 1 – 1 = 0 |

ATAT = (15+16+18+18+7+21+1) / 7 = 13.71

AWT = (7+14+14+17+1+16) / 7 = 9.86

1. Pre-emp (AWT= )

|  |  |  |  |
| --- | --- | --- | --- |
| Process | Arrival time | Priority | Burst time |
| P1 | 0 | 3 | 8 – 3d |
| P2 | 1 | 5 | 2 |
| P3 | 3 | 1 | 3d |
| P4 | 4 | 4 | 4d |
| P5 | 6 | 2 | 1d |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| P1 | P3 | P5 | P1 | P4 | P2 |

0 3 6 7 12 16 18

|  |  |  |
| --- | --- | --- |
|  | TAT (CompleteT – ArrivalT) | WT (TAT – BurstT) |
| P1 | 12 – 0 = 12 | 12 – 8 = 4 |
| P2 | 18 – 1 = 17 | 17 – 2 = 15 |
| P3 | 6 – 3 = 3 | 3 – 3 = 0 |
| P4 | 16 – 4 = 12 | 12 – 4 = 8 |
| P5 | 7 – 6 = 1 | 1 – 1 = 0 |

ATAT = (12+17+3+12+1) / 5 = 9

AWT = (4+15+8) / 5 = 5.4

Summary of Scheduling Algorithms:

* FCFS: Not fair, and average waiting time is poor.
* Round Robin: Fair, but average waiting time is poor. If time quantum is small, there will be a lot of context switching.
* SJF: Not fair, but average waiting time is minimized assuming we can accurately predict the length of the next CPU burst. Starvation is possible.
* Priority : Not fair as it could lead to starvation where lower priority processes could not be executed. But can be countered using aging method.