CPU Scheduling

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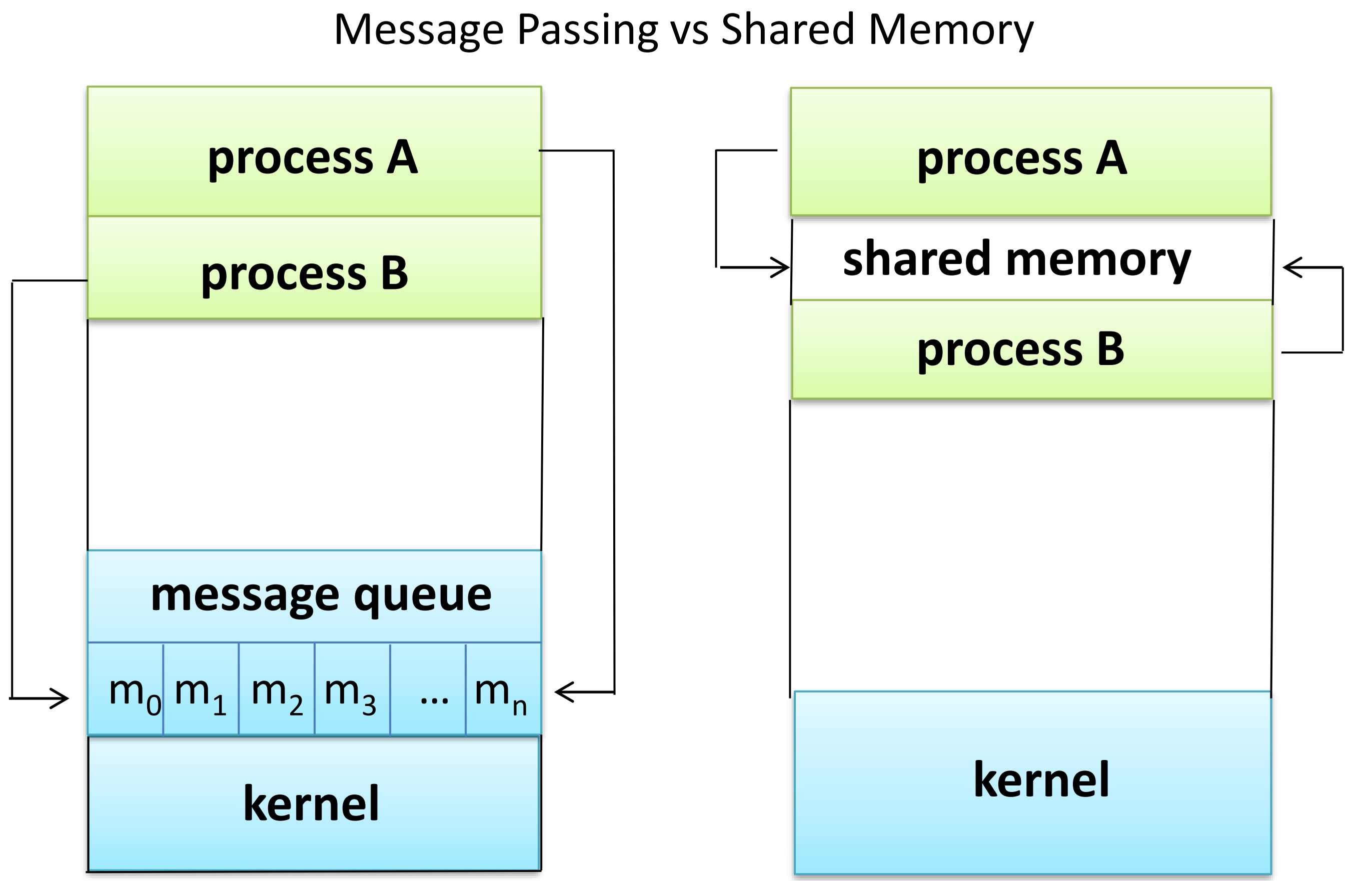
Lecture 6

COMP304 - Operating Systems (OS)

Inter-process Communication (IPC)

- *An independent* process cannot affect or be affected by the execution of another process.
- *Cooperating* processes can affect or be affected by the execution of another processes
- Cooperating processes need **inter-process communication**
- Two models of IPC
  - **Shared memory**
  - **Message passing**

Two Models of Communication



- Message passing requires the message of A to be copied to a buffer and copied to process B's memory – thus it is slower but safer

Scheduling

- One of the main tasks of an OS is to schedule processes to execute.

- Long-term scheduler (or job scheduler) – selects which processes should be brought into the ready queue.
- Short-term scheduler (or CPU scheduler) – selects which process should be executed next and allocates CPU to that process.

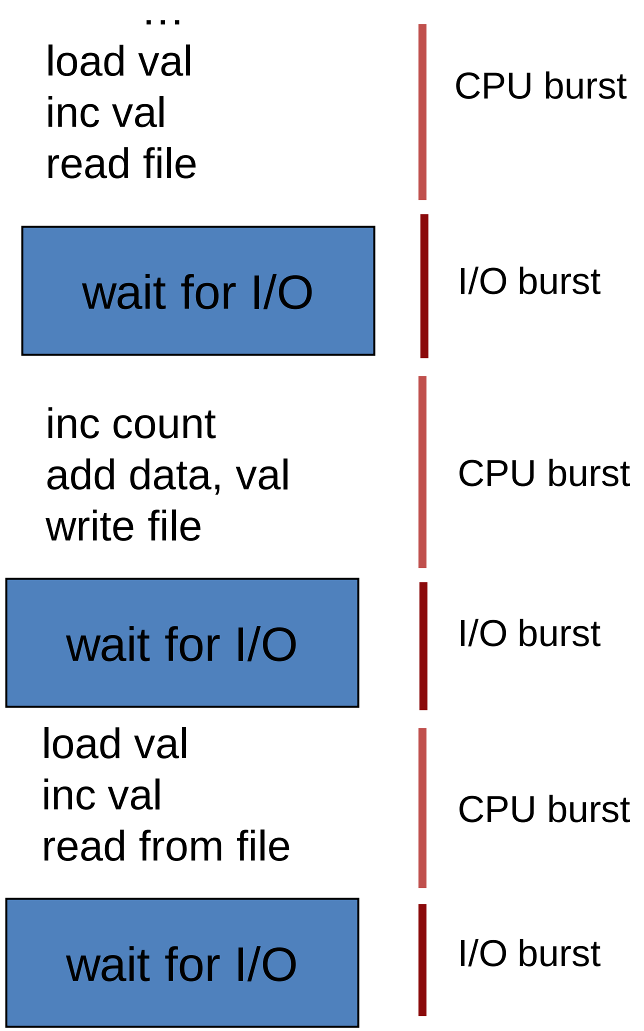
Schedulers

- Short-term scheduler is invoked very frequently (milliseconds)
  - $\Rightarrow$ must be fast.
- Long-term scheduler is invoked very infrequently (seconds, minutes)
  - $\Rightarrow$ can be slow.
- The long-term scheduler controls the ***degree of multiprogramming***.

CPU-I/O Burst Cycle

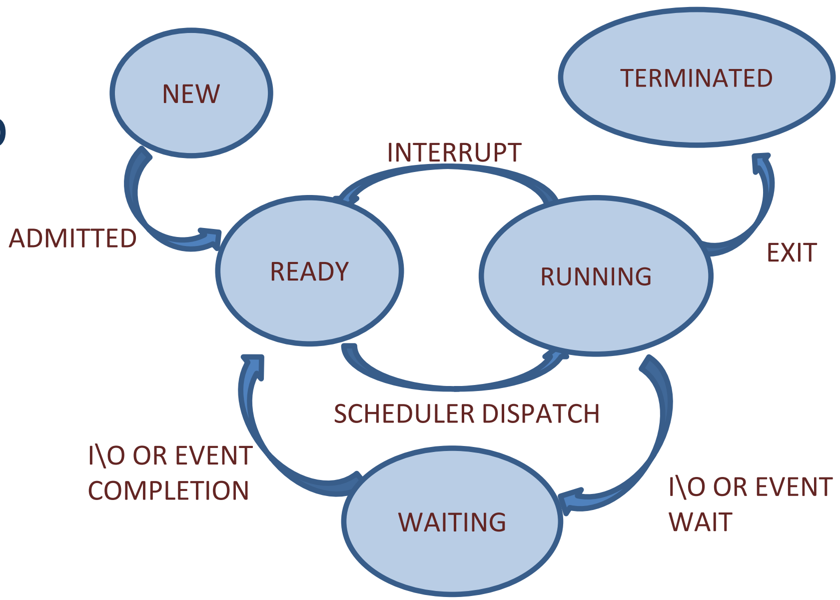
- CPU–I/O Burst Cycle – Process execution consists of a *cycle* of CPU execution and I/O wait

- Processes can be described as either:
  - *I/O-bound process* – spends more time doing I/O than computations; many, short CPU bursts.
  - *CPU-bound process* – spends more time doing computations; few, very long CPU bursts.



CPU Scheduler

- Selects among the processes in memory that are ready to execute, and allocates the CPU to one of them.
- CPU scheduling decisions may take place when a process:
  1. Switches from running to waiting state.
  2. Switches from running to ready state.
  3. Switches from waiting to ready.
  4. Terminates.



(Non)-preemptive

- Non-preemptive
  - Process voluntarily releases CPU
- Preemptive
  - OS kicks the process out from the CPU

- 1 and 4 non-preemptive
- 2 and 3 are preemptive

Scheduling Criteria

- CPU utilization – keep the CPU as busy as possible
- Throughput – # of processes that completes their execution per time unit
- Turnaround time – amount of time to execute a particular process (time between entry and exit)
- 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

- Let $P = \{p_i \mid 0 \leq i < n\}$ = set of processes
- Let $S(p_i) \in$ {running, ready, waiting}
- Let $t(p_i)$ = Time process needs to be in running state (the service time, CPU burst)
- Let $T_{TRnd}(p_i)$ = Time from p_i first enters ready to last exits system (turnaround time)
- Batch Throughput rate = inverse of avg T_{TRnd}
- Let $R(p_i)$ = Time p_i is in ready state before first transition to running (or response time) (different than "waiting time")

Optimization Criteria

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

It is important to minimize the variance in response time than minimize the average response time – provides fairness

Dispatcher

- Dispatcher module is part of the OS that gives control of the CPU to the process selected by the short-term scheduler; this involves:
  - switching context
  - switching to user mode
  - jumping to the proper location in the user program to restart that program
- *Dispatch latency* – time it takes for the dispatcher to stop one process and start another running.

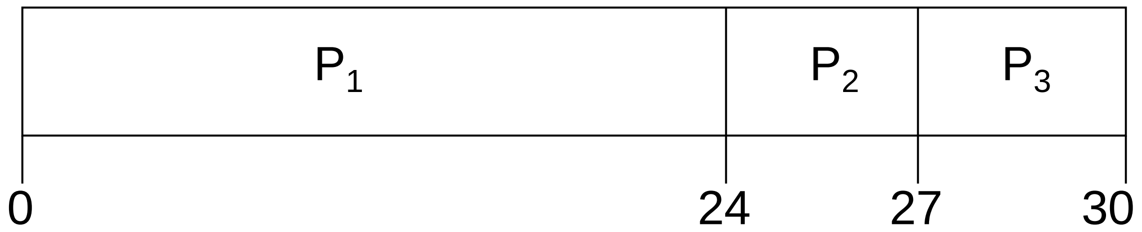
Scheduling Algorithms

If you were the OS, how would you decide who should run next?

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:



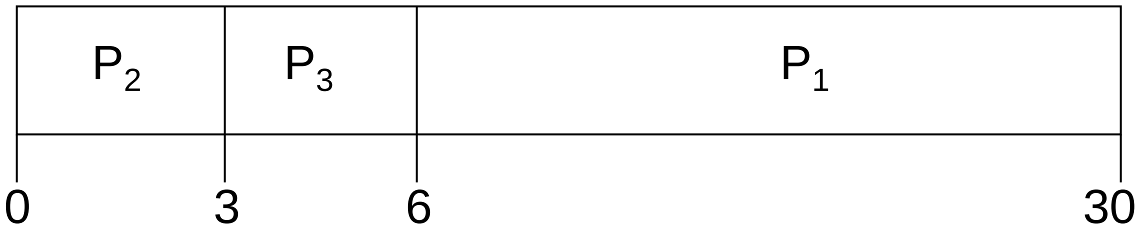
- Waiting times for: $P_1 = 0$; $P_2 = 24$; $P_3 = 27$
- Average waiting time: $(0 + 24 + 27)/3 = 17$

FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order

$$P_2 , P_3 , P_1$$

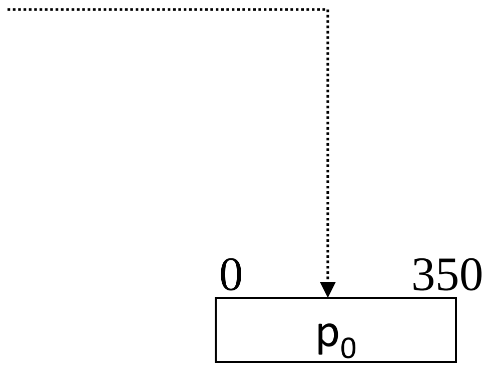
- The Gantt chart for the schedule is:



- 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 a long process

FCFS Scheduling (Cont.)

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

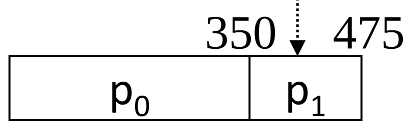


$T_{TRnd}(p_0) = \tau(p_0) = 350$

$R(p_0) = 0$

FCFS Scheduling (Cont.)

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



$T_{TRnd}(p_0) = \tau(p_0) = 350$

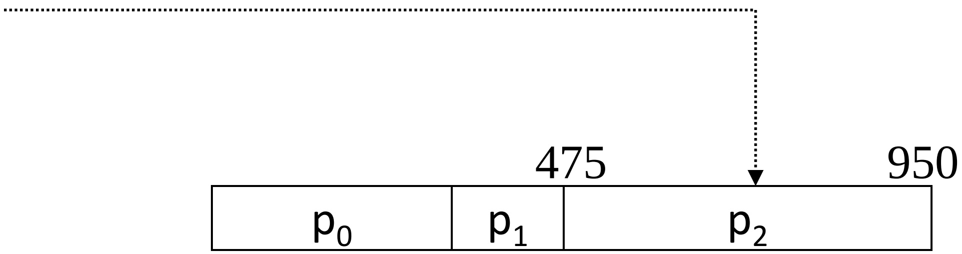
$T_{TRnd}(p_1) = (\tau(p_1) + T_{TRnd}(p_0)) = 125+350 = 475$

$R(p_0) = 0$

$R(p_1) = T_{TRnd}(p_0) = 350$

FCFS Scheduling (Cont.)

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



$T_{TRnd}(p_0) = \tau(p_0) = 350$

$T_{TRnd}(p_1) = (\tau(p_1) + T_{TRnd}(p_0)) = 125+350 = 475$

$T_{TRnd}(p_2) = (\tau(p_2) + T_{TRnd}(p_1)) = 475+475 = 950$

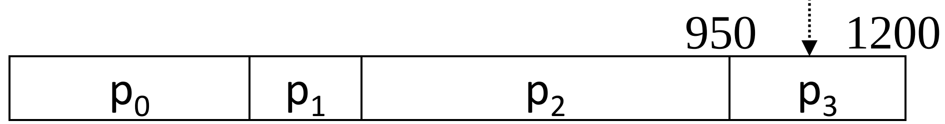
$R(p_0) = 0$

$R(p_1) = T_{TRnd}(p_0) = 350$

$R(p_2) = T_{TRnd}(p_1) = 475$

FCFS Scheduling (Cont.)

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



$T_{TRnd}(p_0) = \tau(p_0) = 350$

$T_{TRnd}(p_1) = (\tau(p_1) + T_{TRnd}(p_0)) = 125+350 = 475$

$T_{TRnd}(p_2) = (\tau(p_2) + T_{TRnd}(p_1)) = 475+475 = 950$

$T_{TRnd}(p_3) = (\tau(p_3) + T_{TRnd}(p_2)) = 250+950 = 1200$

$R(p_0) = 0$

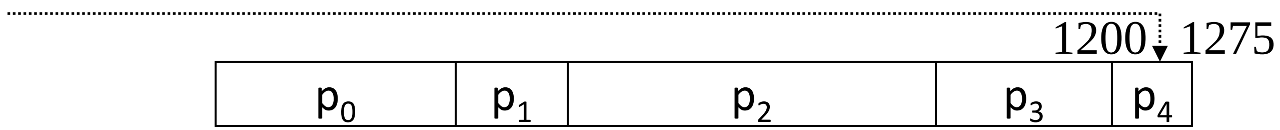
$R(p_1) = T_{TRnd}(p_0) = 350$

$R(p_2) = T_{TRnd}(p_1) = 475$

$R(p_3) = T_{TRnd}(p_2) = 950$

FCFS Scheduling (Cont.)

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



$T_{TRnd}(p_0) = \tau(p_0) = 350$

$T_{TRnd}(p_1) = (\tau(p_1) + T_{TRnd}(p_0)) = 125+350 = 475$

$T_{TRnd}(p_2) = (\tau(p_2) + T_{TRnd}(p_1)) = 475+475 = 950$

$T_{TRnd}(p_3) = (\tau(p_3) + T_{TRnd}(p_2)) = 250+950 = 1200$

$T_{TRnd}(p_4) = (\tau(p_4) + T_{TRnd}(p_3)) = 75+1200 = 1275$

$R(p_0) = 0$

$R(p_1) = T_{TRnd}(p_0) = 350$

$R(p_2) = T_{TRnd}(p_1) = 475$

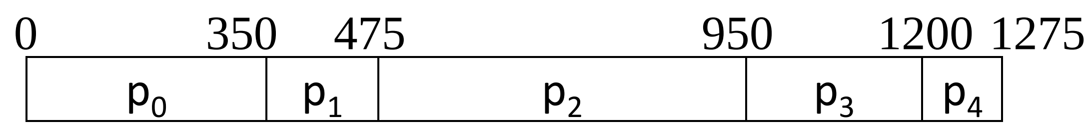
$R(p_3) = T_{TRnd}(p_2) = 950$

$R(p_4) = T_{TRnd}(p_3) = 1200$

FCFS Scheduling- Average Wait Time

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

- <u>Easy to implement</u>
- Not a great performer
- Non-preemptive



$T_{TRnd}(p_0) = \tau(p_0) = 350$

$T_{TRnd}(p_1) = (\tau(p_1) + T_{TRnd}(p_0)) = 125+350 = 475$

$T_{TRnd}(p_2) = (\tau(p_2) + T_{TRnd}(p_1)) = 475+475 = 950$

$T_{TRnd}(p_3) = (\tau(p_3) + T_{TRnd}(p_2)) = 250+950 = 1200$

$T_{TRnd}(p_4) = (\tau(p_4) + T_{TRnd}(p_3)) = 75+1200 = 1275$

$R(p_0) = 0$

$R(p_1) = T_{TRnd}(p_0) = 350$

$R(p_2) = T_{TRnd}(p_1) = 475$

$R(p_3) = T_{TRnd}(p_2) = 950$

$R(p_4) = T_{TRnd}(p_3) = 1200$

Average response (wait) time $R_{avg} = (0+350+475+950+1200)/5 = 2974/5 = 595$

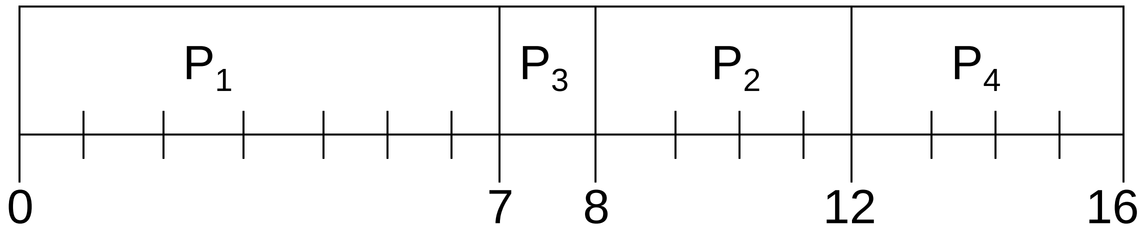
2. Shortest Job First (SJF) Scheduling

- 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)

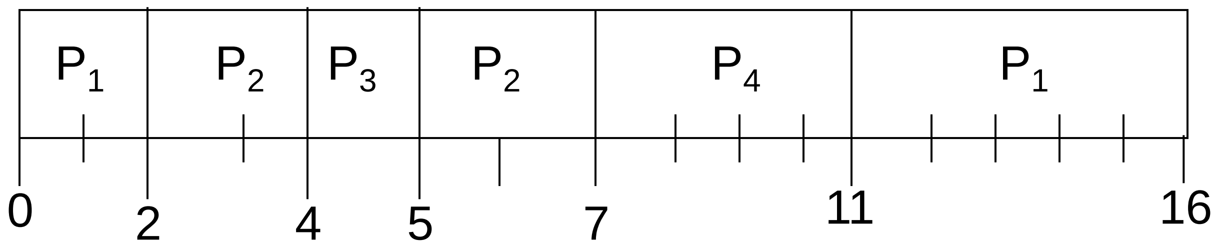


- Average waiting time ?
  $= (0 + 6 + 3 + 7)/4 = 4$

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

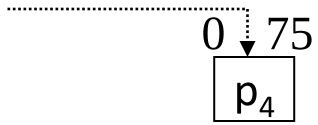
- SJF (preemptive)



- Average waiting time ?
  = (9 + 1 + 0 +2)/4 = 3

Example of SJF

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

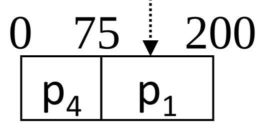


$T_{TRnd}(p_4) = \tau(p_4) = 75$

$R(p_4) = 0$

Example of SJF

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



$T_{TRnd}(p_1) = \tau(p_1)+\tau(p_4) = 125+75 = 200$

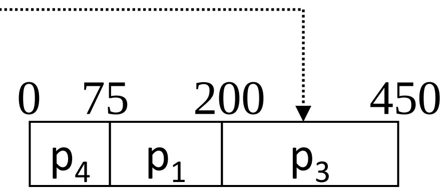
$R(p_1) = 75$

$T_{TRnd}(p_4) = \tau(p_4) = 75$

$R(p_4) = 0$

Example of SJF

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



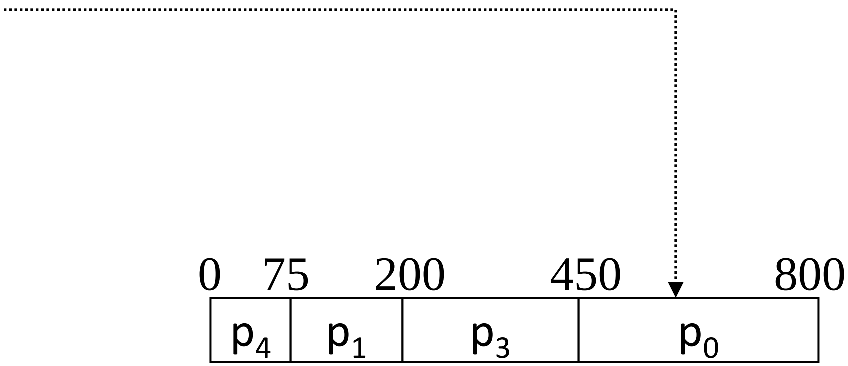
$T_{TRnd}(p_1) = \tau(p_1)+\tau(p_4) = 125+75 = 200$ $\qquad R(p_1) = 75$

$T_{TRnd}(p_3) = \tau(p_3)+\tau(p_1)+\tau(p_4) = 250+125+75 = 450$ $\qquad R(p_3) = 200$

$T_{TRnd}(p_4) = \tau(p_4) = 75$ $\qquad R(p_4) = 0$

Example of SJF

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



$T_{TRnd}(p_0) = \tau(p_0)+\tau(p_3)+\tau(p_1)+\tau(p_4) = 350+250+125+75 = 800$ $\quad R(p_0) = 450$

$T_{TRnd}(p_1) = \tau(p_1)+\tau(p_4) = 125+75 = 200$ $\quad R(p_1) = 75$

$T_{TRnd}(p_3) = \tau(p_3)+\tau(p_1)+\tau(p_4) = 250+125+75 = 450$ $\quad R(p_3) = 200$

$T_{TRnd}(p_4) = \tau(p_4) = 75$ $\quad R(p_4) = 0$

Example of SJF

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

0	75	200	450	800	1275
p_4	p_1	p_3	p_0	p_2	

$T_{TRnd}(p_0) = \tau(p_0)+\tau(p_3)+\tau(p_1)+\tau(p_4) = 350+250+125+75 = 800$ $\quad R(p_0) = 450$

$T_{TRnd}(p_1) = \tau(p_1)+\tau(p_4) = 125+75 = 200$ $\quad R(p_1) = 75$

$T_{TRnd}(p_2) = \tau(p_2)+\tau(p_0)+\tau(p_3)+\tau(p_1)+\tau(p_4) = 475+350+250+125+75 = 1275$ $\quad R(p_2) = 800$

$T_{TRnd}(p_3) = \tau(p_3)+\tau(p_1)+\tau(p_4) = 250+125+75 = 450$ $\quad R(p_3) = 200$

$T_{TRnd}(p_4) = \tau(p_4) = 75$ $\quad R(p_4) = 0$

Example of SJF

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

- Minimizes waiting time – Why?
- May starve large jobs

0	75	200	450	800	1275
p_4	p_1	p_3	p_0	p_2	

$T_{TRnd}(p_0) = \tau(p_0)+\tau(p_3)+\tau(p_1)+\tau(p_4) = 350+250+125+75 = 800$ $\quad R(p_0) = 450$

$T_{TRnd}(p_1) = \tau(p_1)+\tau(p_4) = 125+75 = 200$ $\quad R(p_1) = 75$

$T_{TRnd}(p_2) = \tau(p_2)+\tau(p_0)+\tau(p_3)+\tau(p_1)+\tau(p_4) = 475+350+250+125+75 = 1275$ $\quad R(p_2) = 800$

$T_{TRnd}(p_3) = \tau(p_3)+\tau(p_1)+\tau(p_4) = 250+125+75 = 450$ $\quad R(p_3) = 200$

$T_{TRnd}(p_4) = \tau(p_4) = 75$ $\quad R(p_4) = 0$

Average response (wait) time $R_{avg} = (450+75+800+200+0)/5 = 1525/5 = 305$

Shortest Job First

- The SJF is provably optimal
- It gives the minimum average waiting time for a given set of processes
- Moving a short process before a long one decreases the waiting time of the short process more than it increases the waiting time of the long process

- What is the difficulty of using the shortest job first scheduler?

Determining the Length of the Next CPU Burst

- Can only estimate the length.
- Can be done by using the length of previous CPU bursts, using **exponential averaging**.

1. $t_n =$ actual length of n^{th} CPU burst
2. $\tau_{n+1} =$ predicted value for the next CPU burst
3. $\alpha, 0 \leq \alpha \leq 1$
4. Define :

$$\tau_{n+1} = \alpha \, t_n + (1-\alpha)\tau_n$$

Examples of Exponential Averaging

- $\alpha = 0$
  - $\tau_{n+1} = \tau_n$
  - Recent information does not count.
- $\alpha = 1$
  - $\tau_{n+1} = t_n$
  - Only the actual last CPU burst counts.
- If we expand the formula, we get:

$$\begin{aligned}\tau_{n+1} = \alpha\, t_n &+ (1 - \alpha)\, \alpha\, t_{n-1} + \ldots \\ &+ (1 - \alpha)^j\, \alpha\, t_{n-j} + \ldots \\ &+ (1 - \alpha)^{n+1}\, \tau_0\end{aligned}$$

- Since both α and $(1 - \alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor.

Question

_____ is the number of processes that are completed per time unit.

A) CPU utilization

B) Response time

C) Turnaround time

D) Throughput

Question

- The strategy of making processes that are logically runnable to be temporarily suspended is called :

  a) Non preemptive scheduling
  b) Preemptive scheduling
  c) Shortest job first
  d) First come First served

Answer is b)

Reading

- Read Chapter 5
- 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

Puzzle

- A group of people wants to get through a tunnel.
  - A can make it in 1 minute,
  - B can in 2 minutes,
  - C can in 4 and
  - D can in 5 minutes.
- Unfortunately, not more than two persons can go through the narrow tunnel at one time, moving at the speed of the slower one.
- They have a single torch to show their way in dark
- What is the minimum time for all to make it to the other side of the tunnel?