CSE 421/521 - Operating Systems
Fall 2014

Lecture - V
CPU Scheduling - I

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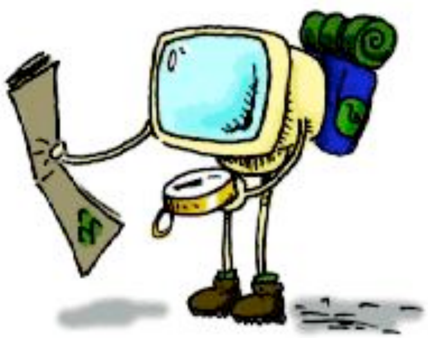
Roadmap

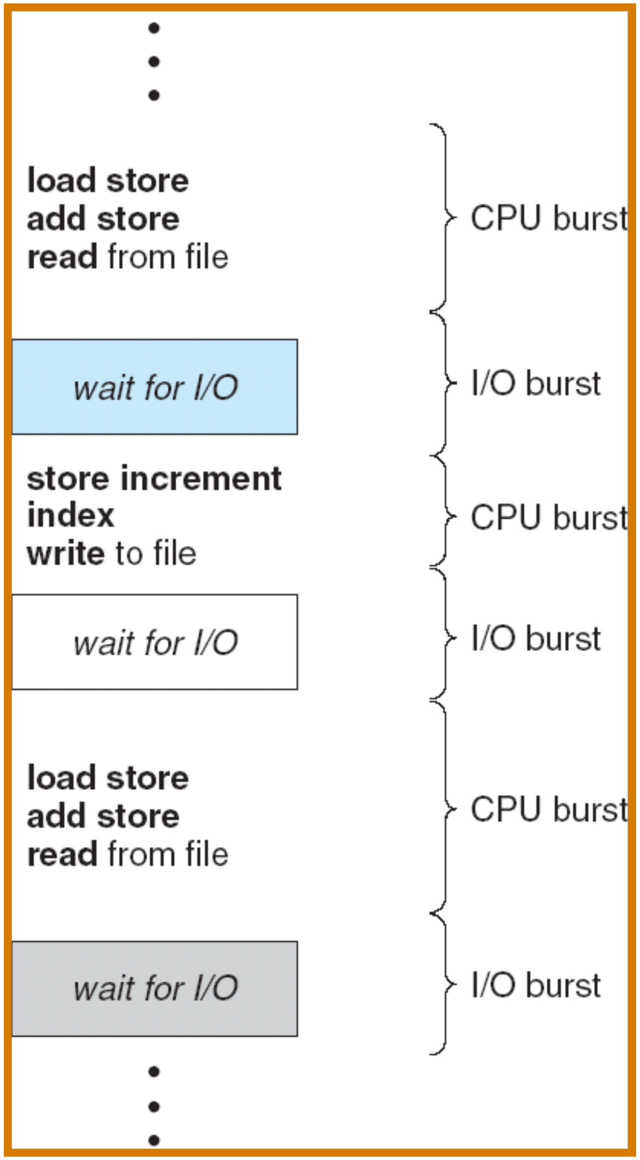
- CPU Scheduling
  - Basic Concepts
  - Scheduling Criteria & Metrics
  - Different Scheduling Algorithms
    - FCFS
    - SJF
    - Priority
    - RR
  - Preemptive vs Non-preemptive Scheduling
  - Gantt Charts & Performance Comparison
  - Multilevel Feedback Queues



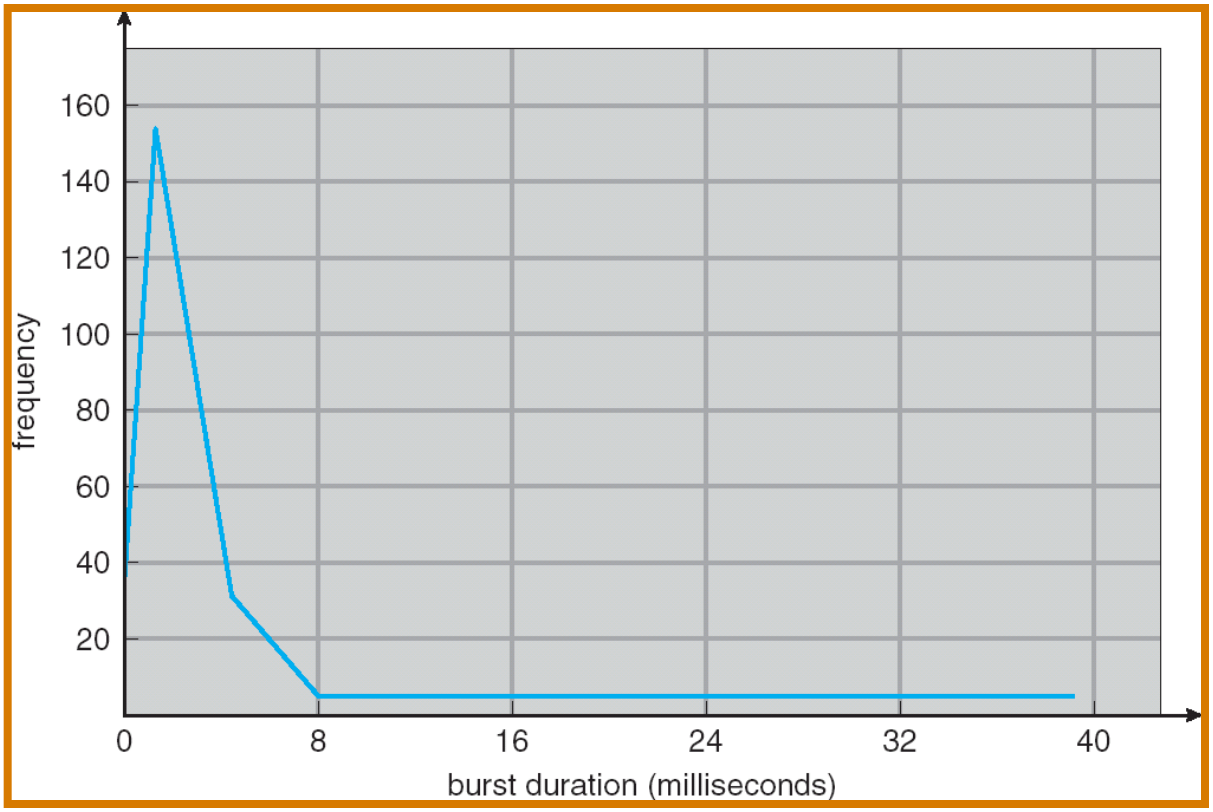
Basic Concepts

- Multiprogramming is needed for efficient CPU utilization
- CPU Scheduling: deciding which processes to execute when
- Process execution begins with a CPU burst, followed by an I/O burst
- CPU–I/O Burst Cycle – Process execution consists of a *cycle* of CPU execution and I/O wait

Alternating Sequence of CPU And I/O Bursts

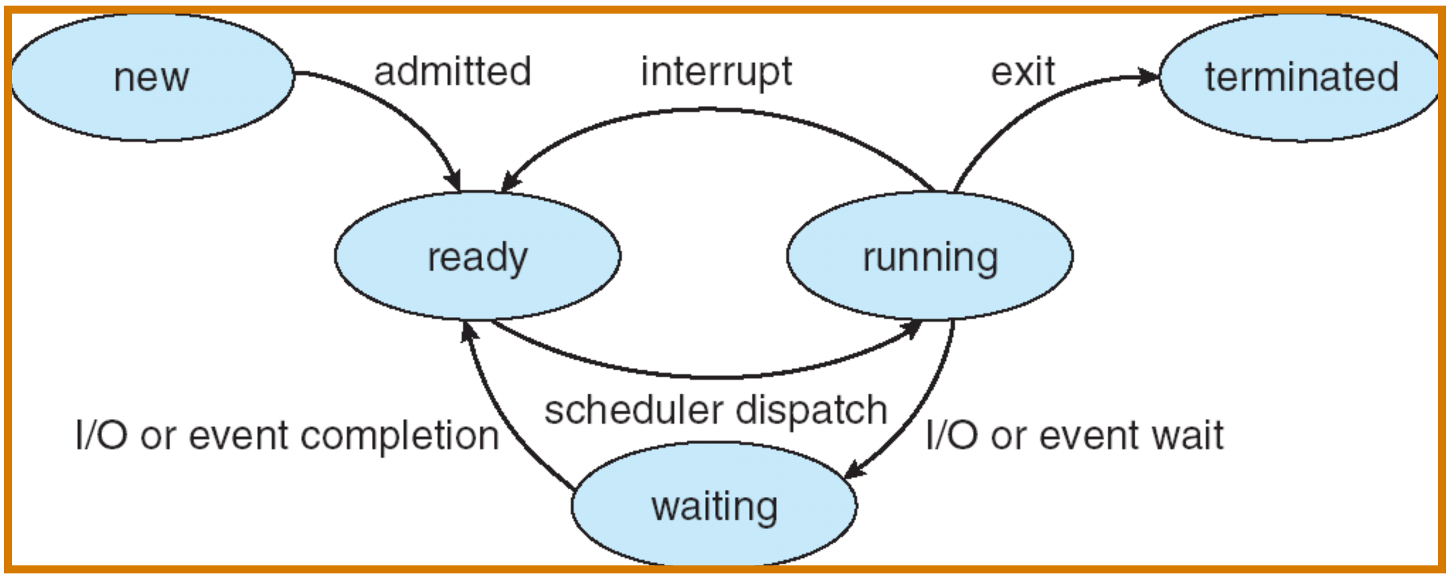


Histogram of CPU-burst Durations



Process State

- As a process executes, it changes *state*
  - **new**: The process is being created
  - **ready**: The process is waiting to be assigned to a process
  - **running**: Instructions are being executed
  - **waiting**: The process is waiting for some event to occur
  - **terminated**: The process has finished execution



CPU Scheduler

- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them
  - ➔ short-term scheduler
- 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
  5. A new process arrives
- Scheduling under 1 and 4 is *nonpreemptive/cooperative*
  - Once a process gets the CPU, keeps it until termination/switching to waiting state/release of the CPU
- All other scheduling is *preemptive*
  - Most OS use this
  - Cost associated with access to shared data
  - i.e. time quota expires

Dispatcher

- Dispatcher module gives control of the CPU to the process selected by the short-term scheduler;

  Its function 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 Criteria

- CPU utilization – keep the CPU as busy as possible --> maximize
- Throughput – # of processes that complete their execution per time unit -->maximize
- Turnaround time – amount of time passed to finish execution of a particular process --> minimize
  - i.e. execution time + waiting time
- Waiting time – total amount of time a process has been waiting in the ready queue -->minimize
- 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) -->minimize

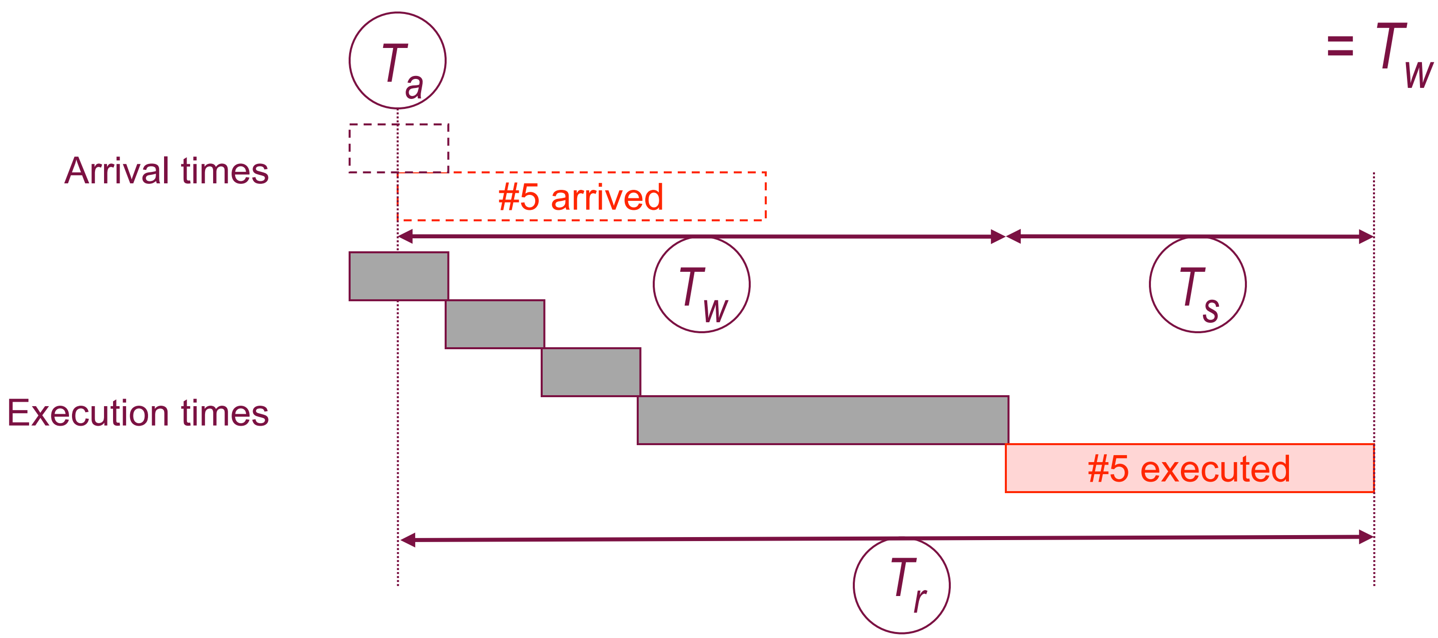
Optimization Criteria

- Maximize CPU utilization
- Maximize throughput
- Minimize turnaround time
- Minimize waiting time
- Minimize response time

Scheduling Metrics

- Scheduling metrics
  - arrival time T_a = time the process became "Ready" (again)
  - wait time T_w = time spent waiting for the CPU
  - service time T_s = time spent executing in the CPU
  - turnaround time T_r = total time spent waiting and executing

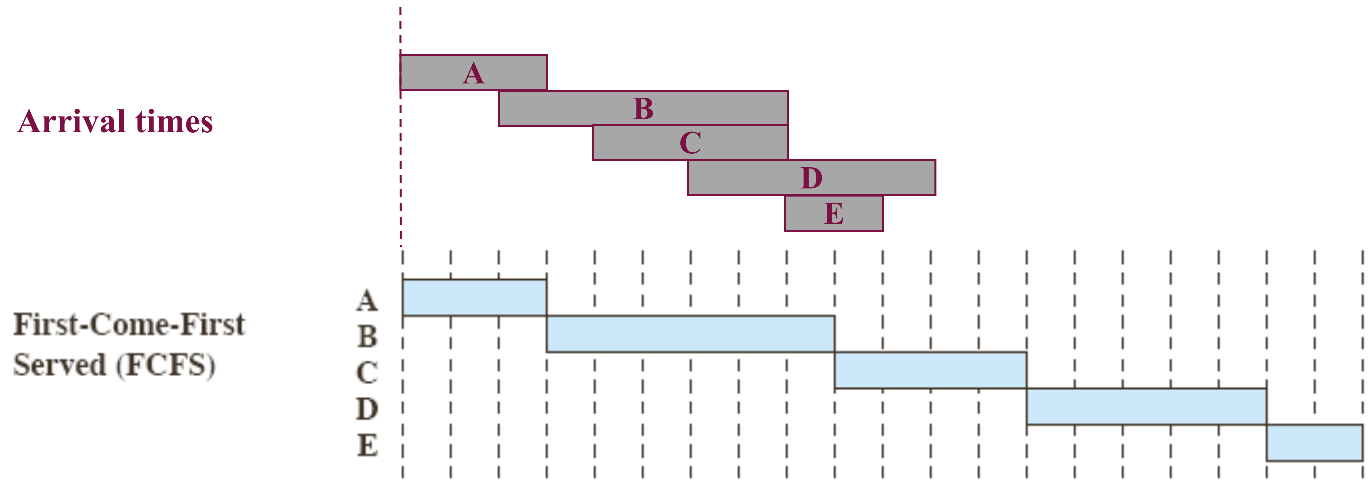
$$= T_w + T_s$$



$T_r / T_s = 2.5$

First-Come, First-Served (FCFS) Scheduling

- ✓ processes are assigned the CPU in the order they request it
- ✓ when the running process blocks, the first “Ready” is run next
- ✓ when a process gets “Ready”, it is put at the end of the queue



FCFS	Finish Time	**A** 3	**B** 9	**C** 13	**D** 18	**E** 20	**Mean**
	Turnaround Time (T_r)	3	7	9	12	12	8.60
	T_r/T_s	1.00	1.17	2.25	2.40	6.00	2.56

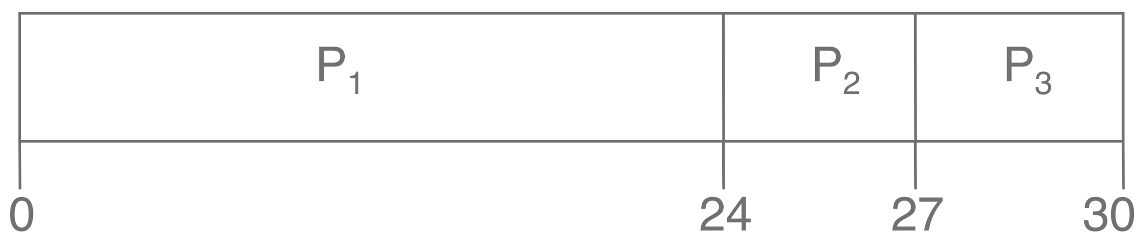
FCFS scheduling policy

Stallings, W. (2004) *Operating Systems: Internals and Design Principles (5th Edition).*

FCFS Scheduling - Example

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:



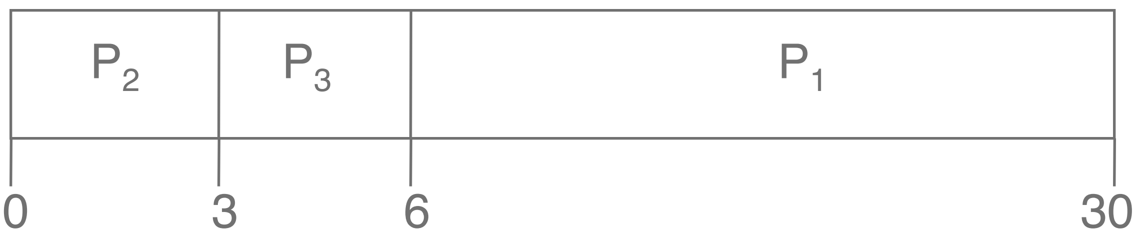
- Waiting time for P_1 = 0; P_2 = 24; P_3 = 27
- Average waiting time: (0 + 24 + 27)/3 = 17

FCFS Scheduling - Example

Suppose that the processes arrive in the order

$$P_2 , P_3 , P_1$$

- The Gantt chart for the schedule is:



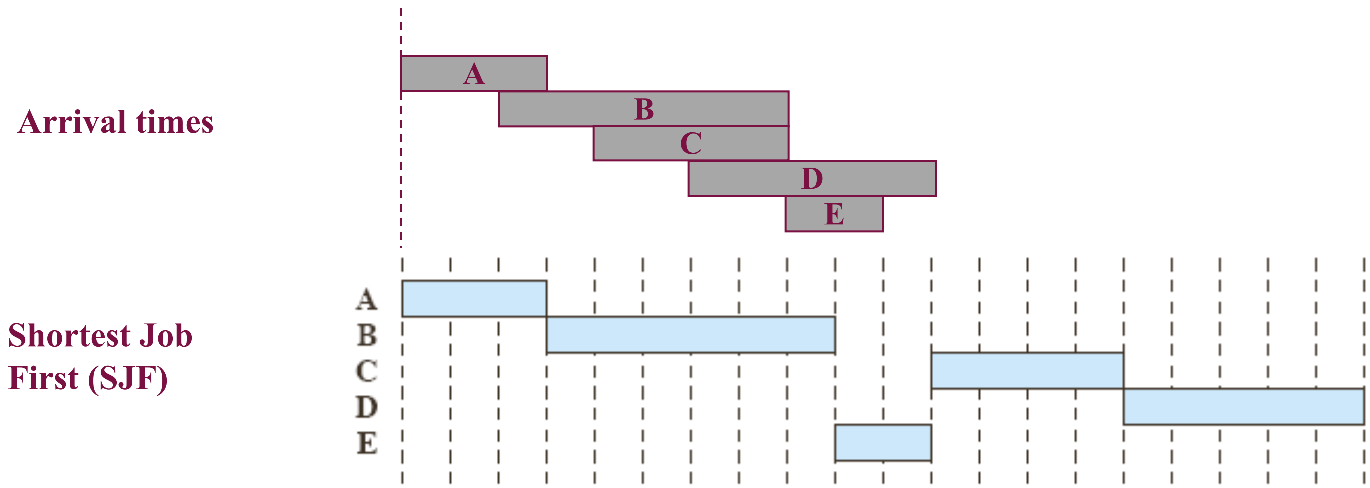
- Waiting time for $P_1 = 6$; $P_2 = 0$; $P_3 = 3$
- Average waiting time: (6 + 0 + 3)/3 = 3
- Much better than previous case
- *Convoy effect* short process behind long process

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

Non-Preemptive SJF

- nonpreemptive, assumes the run times are known in advance
- among several equally important “Ready” jobs (or CPU bursts), the scheduler picks the one that will finish the earliest



SJF	Finish Time	A 3	B 9	C 15	D 20	E 11	Mean
	Turnaround Time (T_r)	3	7	11	14	3	7.60
	T_r/T_s	1.00	1.17	2.75	2.80	1.50	1.84

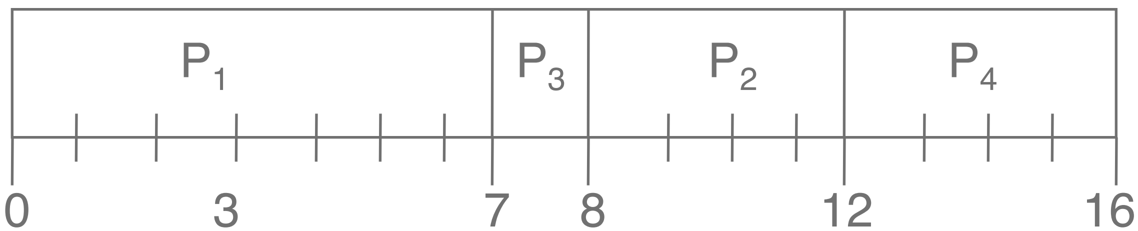
SJF scheduling policy

Stallings, W. (2004) Operating Systems: Internals and Design Principles (5th Edition).

Non-Preemptive SJF - Example

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

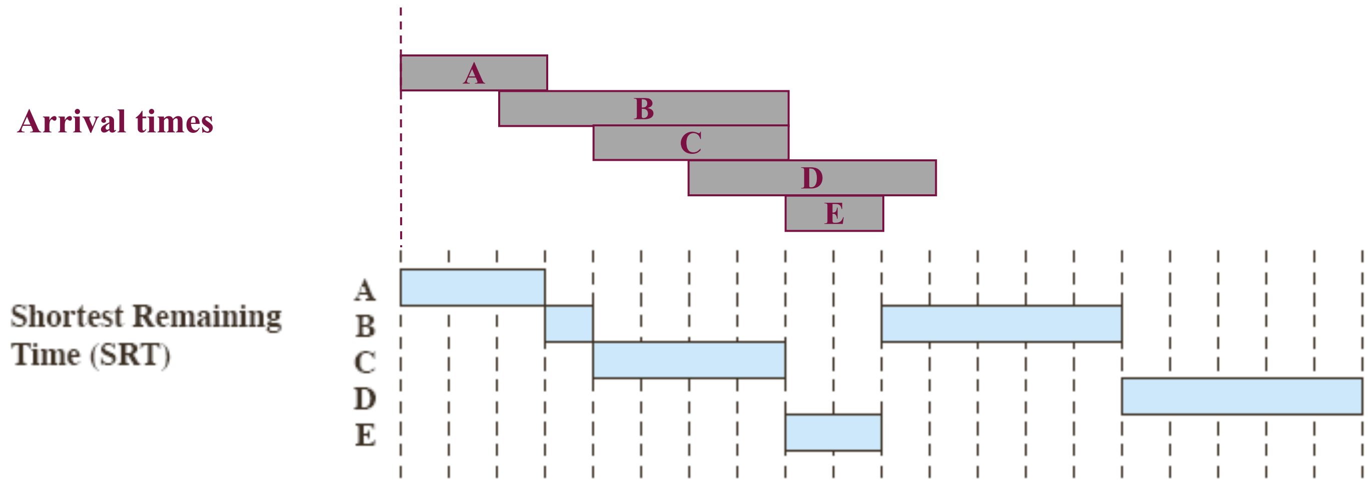
- SJF (non-preemptive) Gantt Chart



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

Preemptive SJF (SRT)

- <u>Shortest Remaining Time (SRT)</u>
  - ✓ <u>preemptive</u> version of SJF, also assumes known run time
  - ✓ choose the process whose <u>remaining</u> run time is shortest
  - ✓ allows new short jobs to get good service



SRT	Finish Time	**A** 3	**B** 15	**C** 8	**D** 20	**E** 10	**Mean**
	Turnaround Time (T_r)	3	13	4	14	2	7.20
	T_r/T_s	1.00	2.17	1.00	2.80	1.00	1.59

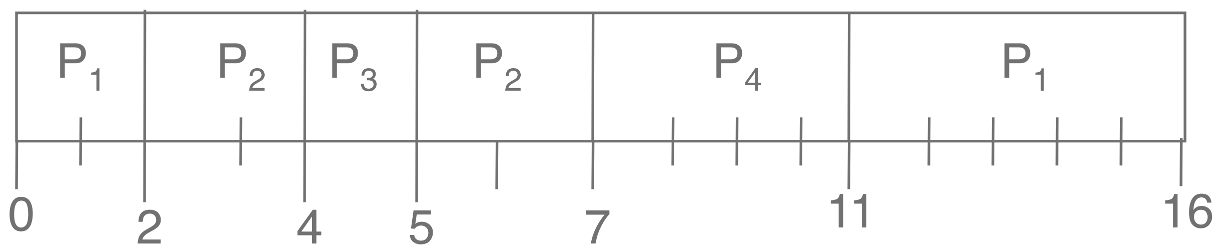
SRT scheduling policy

Stallings, W. (2004) *Operating Systems: Internals and Design Principles (5th Edition).*

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) Gantt Chart



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 a priority scheduling where priority is the predicted next CPU burst time
- Problem ≡ Starvation – low priority processes may never execute
- Solution ≡ Aging – as time progresses increase the priority of the process

Example of Priority

Process	Arrival Time	Burst Time	Priority
P_1	0.0	7	2
P_2	2.0	4	1
P_3	4.0	1	4
P_4	5.0	4	3

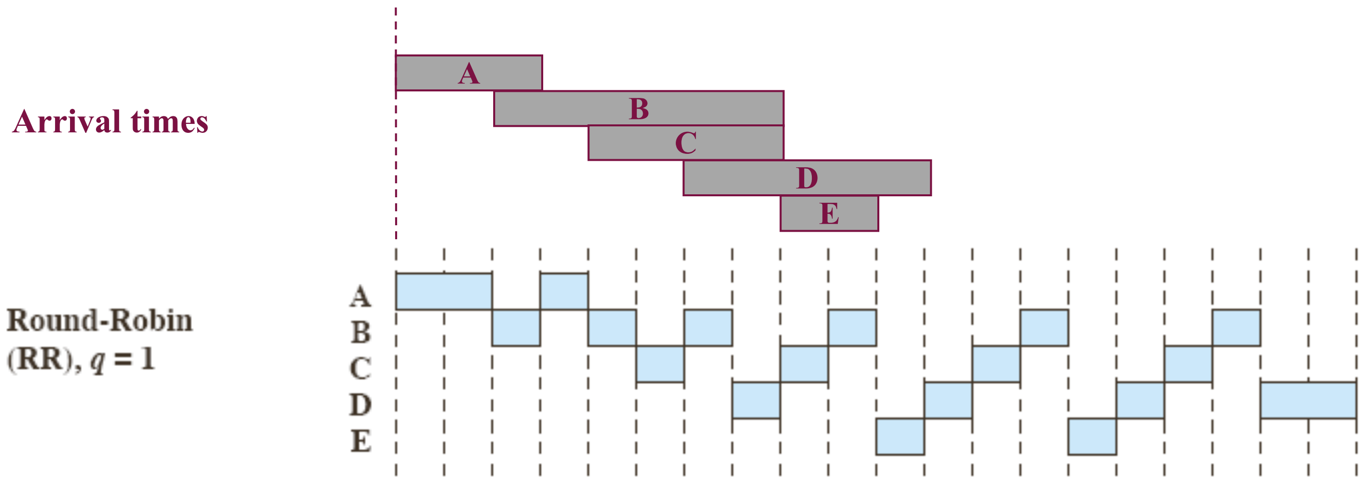
- Priority (non-preemptive)
  - P1 --> P2 --> P4 --> P3
- Priority (preemptive)
  - ??

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.
- Performance
  - q large $\Rightarrow$ FIFO
  - q small $\Rightarrow$ q must be large with respect to context switch, otherwise overhead is too high

Round Robin (RR)

- ✓ preemptive FCFS, based on a timeout interval, the **quantum** *q*
- ✓ the running process is interrupted by the clock and put last in a FIFO "Ready" queue; then, the first "Ready" process is run instead



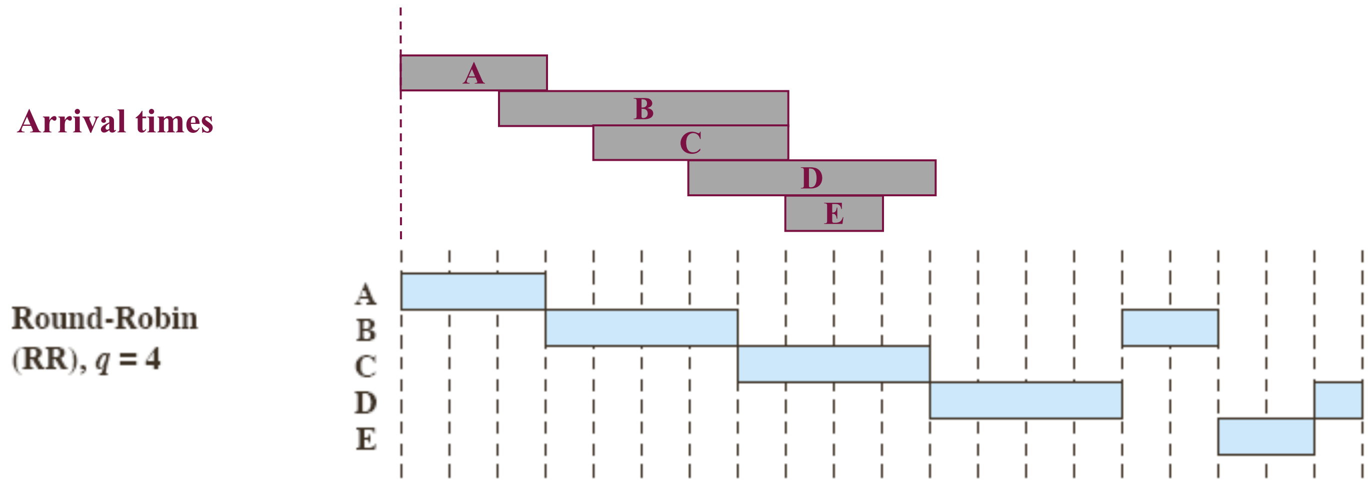
RR $q = 1$		A	B	C	D	E	Mean
	Finish Time	4	18	17	20	15	
	Turnaround Time (T_r)	4	16	13	14	7	10.80
	T_r/T_s	1.33	2.67	3.25	2.80	3.50	2.71

RR (*q* = 1) scheduling policy

Stallings, W. (2004) *Operating Systems: Internals and Design Principles (5th Edition).*

Round Robin (RR)

- a crucial parameter is the quantum *q* (generally ~10–100ms)
  - *q* should be big compared to context switch latency (~10μs)
  - *q* should be less than the longest CPU bursts, otherwise RR degenerates to FCFS



RR $q = 4$							
	Finish Time	**A** 3	**B** 17	**C** 11	**D** 20	**E** 19	**Mean**
	Turnaround Time (T_r)	3	15	7	14	11	10.00
	T_r/T_s	1.00	2.5	1.75	2.80	5.50	2.71

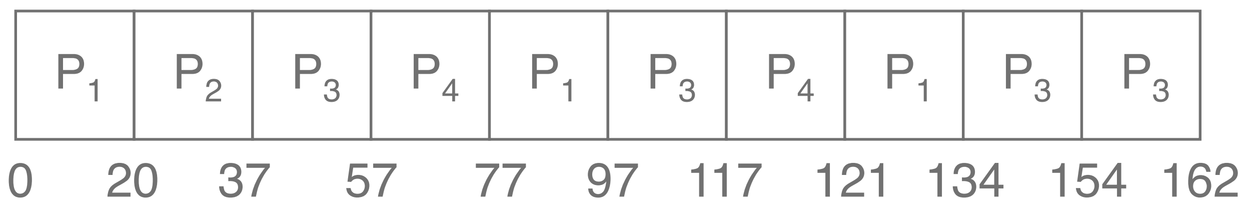
RR (*q* = 4) scheduling policy

Stallings, W. (2004) *Operating Systems: Internals and Design Principles (5th Edition).*

Example of RR with Time Quantum = 20

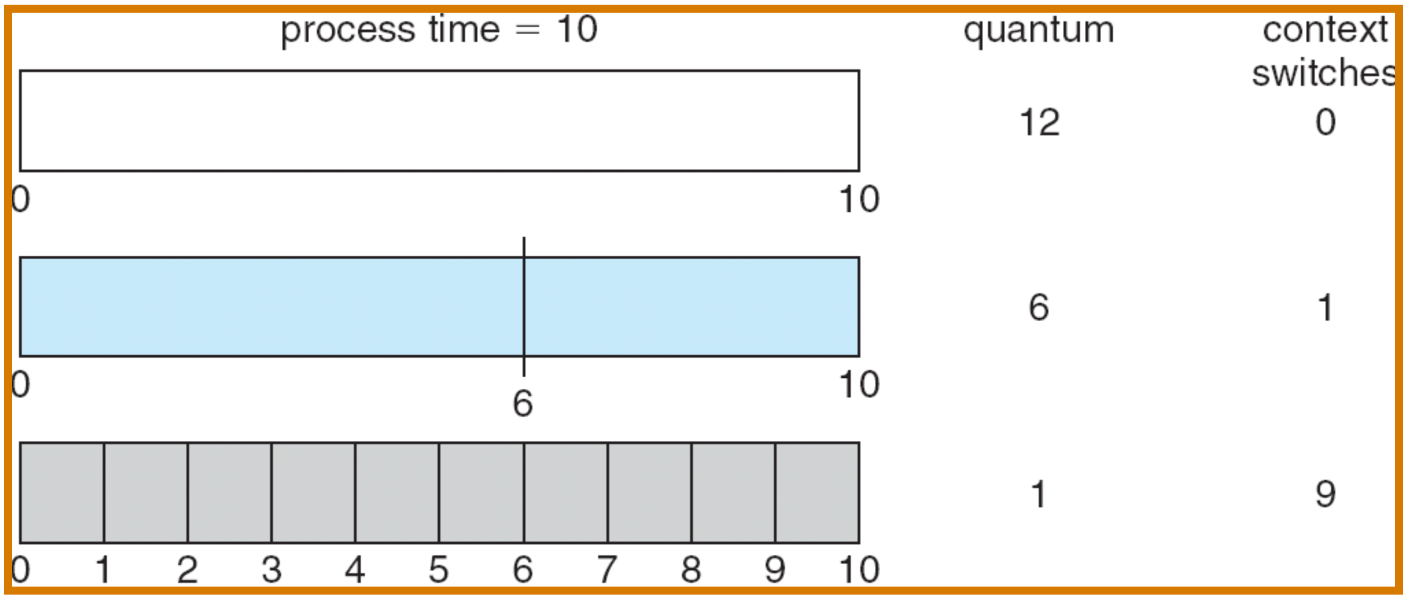
<u>Process</u>	<u>Burst Time</u>
P_1	53
P_2	17
P_3	68
P_4	24

- For q=20, the Gantt chart is:

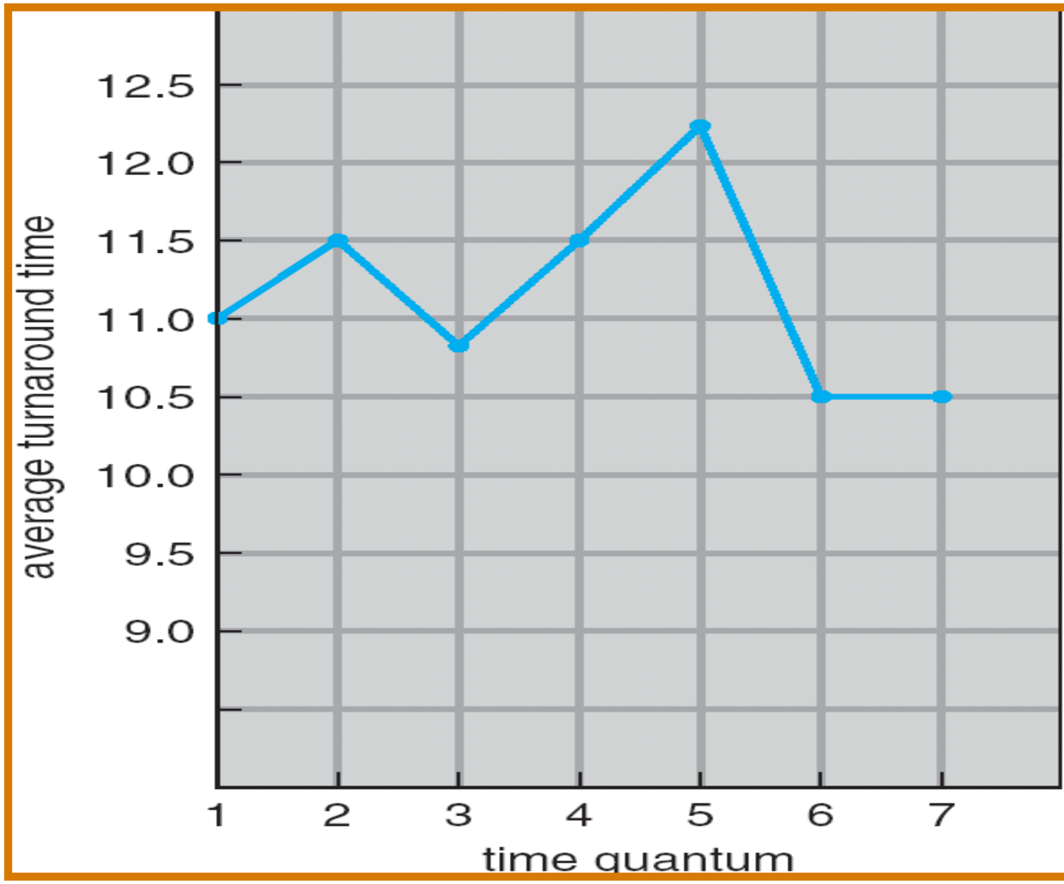


Typically, higher average turnaround than SJF,
but better *response*

Time Quantum and Context Switch Time



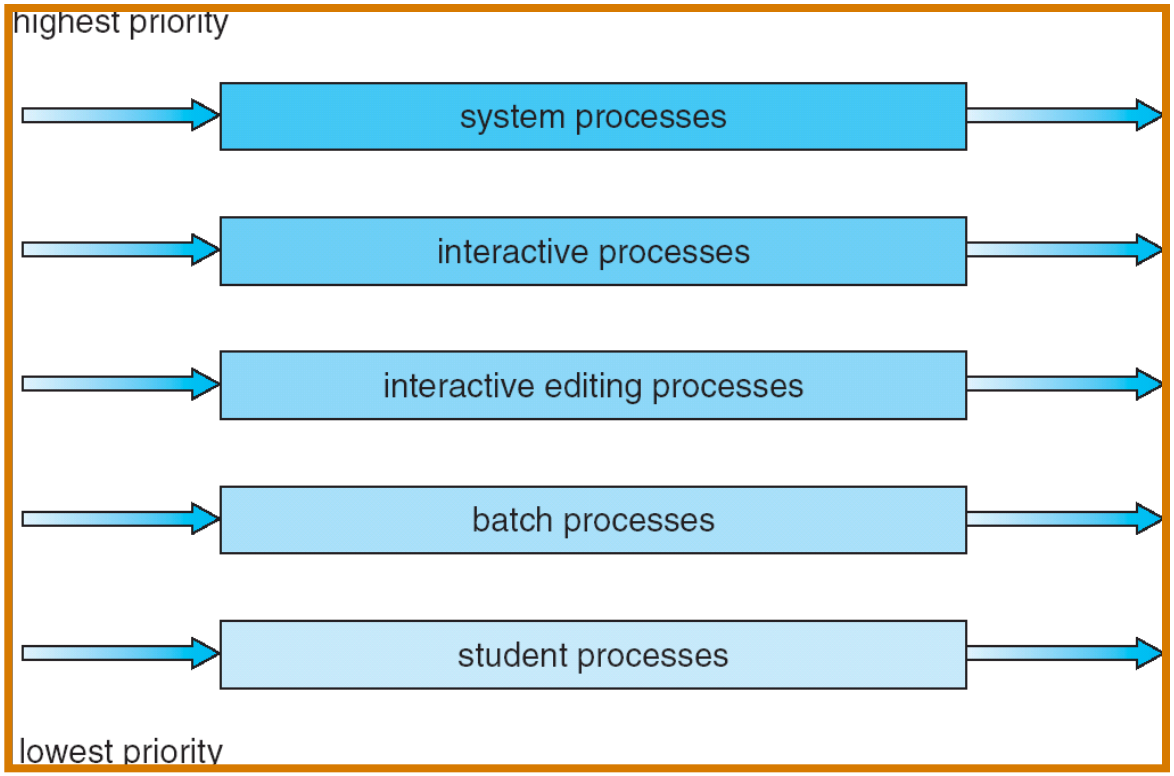
Turnaround Time Varies With The Time Quantum



process	time
P_1	6
P_2	3
P_3	1
P_4	7

Multilevel Queues

Multilevel Queue Scheduling



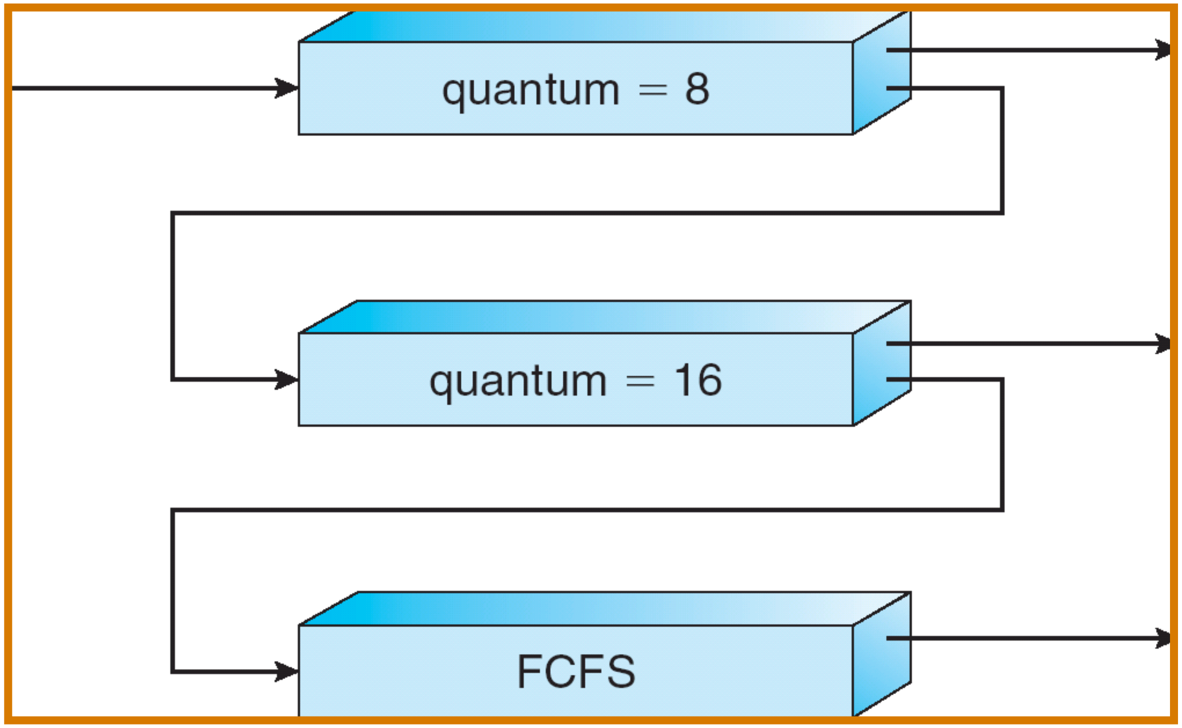
Multilevel Feedback Queue

- A process can move between the various 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

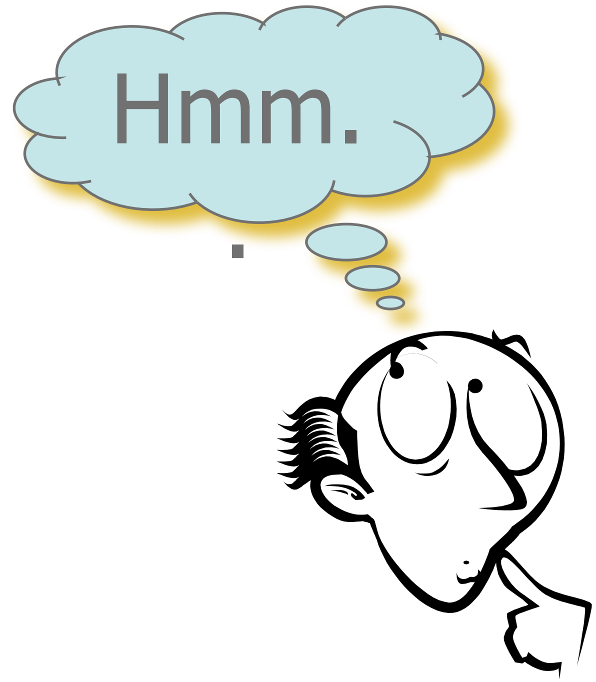
- Three queues:
  - Q_0 – RR with time quantum 8 milliseconds
  - Q_1 – RR time quantum 16 milliseconds
  - Q_2 – FCFS
- Scheduling
  - A new job enters queue Q_0 which is served FCFS. When it gains CPU, job receives 8 milliseconds. If it does not finish in 8 milliseconds, job is moved to queue Q_1.
  - 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.

Multilevel Feedback Queues



Summary

- CPU Scheduling
  - Basic Concepts
  - Scheduling Criteria & Metrics
  - Different Scheduling Algorithms
    - FCFS
    - SJF
    - Priority
    - RR
  - Multilevel Feedback Queues



- Next Lecture: Project-1 Discussion
- Reading Assignment: Chapter 5 from Silberschatz.

Acknowledgements

- “Operating Systems Concepts” book and supplementary material by A. Silberschatz, P. Galvin and G. Gagne
- “Operating Systems: Internals and Design Principles” book and supplementary material by W. Stallings
- “Modern Operating Systems” book and supplementary material by A. Tanenbaum
- R. Doursat and M. Yuksel from UNR