Operating Systems Concepts

CPU Scheduling

CS 4375, Fall 2025

Instructor: MD Armanuzzaman (***Arman***)
marmanuzzaman@utep.edu

September 24, 2025

Summery

- Assembly programming
- Privileged CPU features
  - Registers and instructions
- xv6 system call
  - How does the whole cycle of system calls work?
  - Go over code snippets

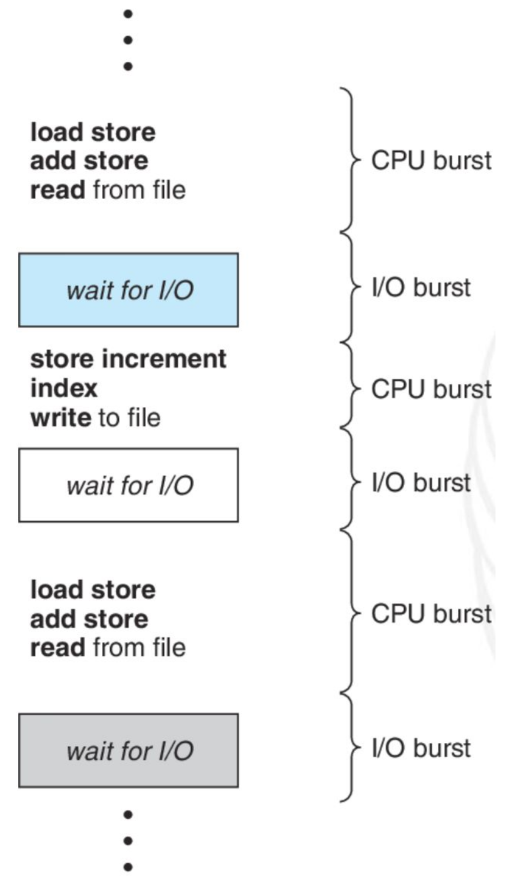
Agenda

- CPU Scheduling:
  - Basic concepts
  - Scheduling Criteria & Metrics
  - Different Scheduling Algorithms
    - FCFS
    - SJF
    - Priority
    - RR
  - Preemptive vs Non-preemptive Scheduling
  - Gantt Charts & Performance Comparison

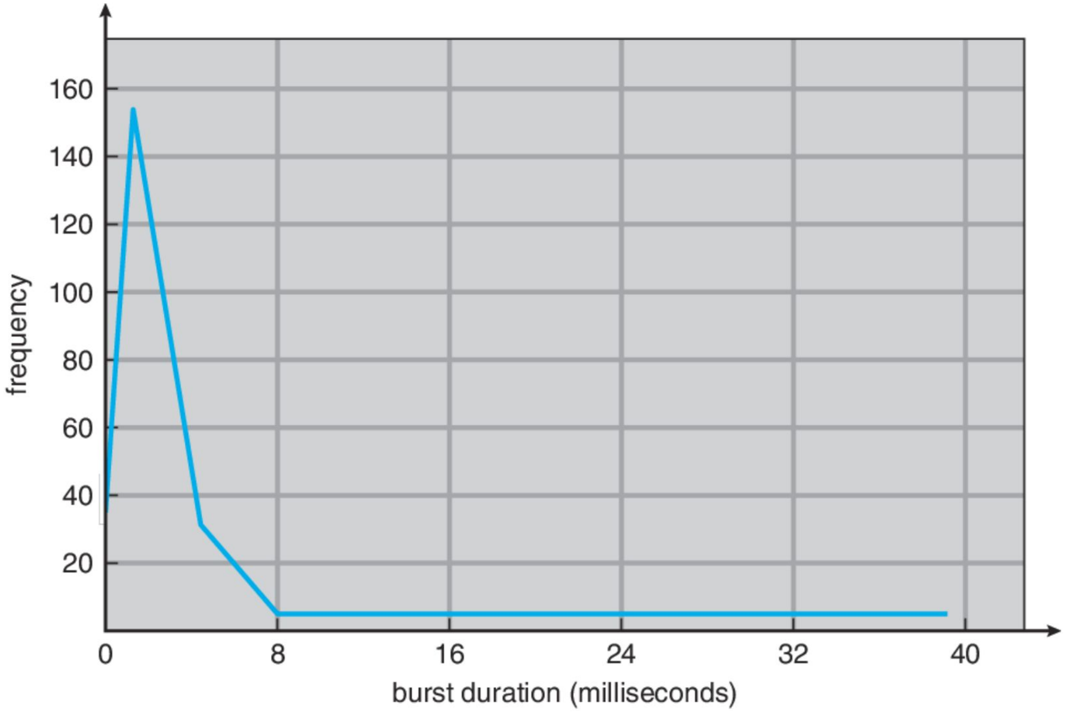
Basic Concepts

- Multiprogramming is needed for efficient CPU utilization
- CPU Scheduling: deciding when to execute which processes
- 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

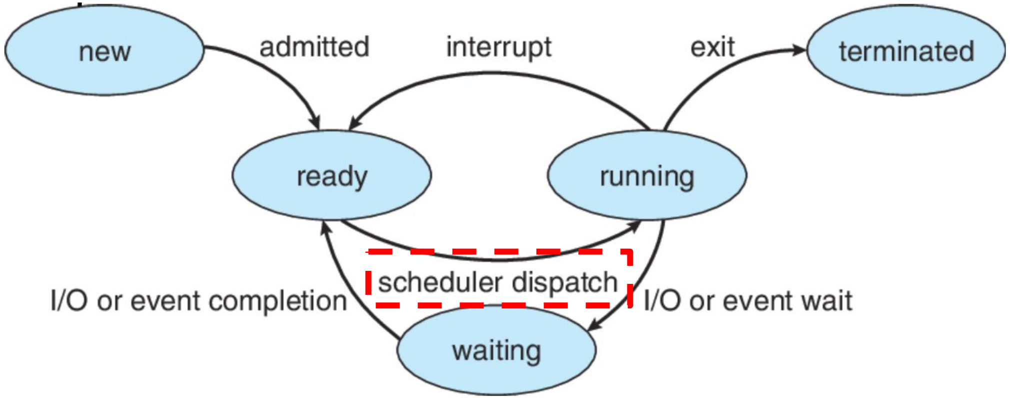


Histogram of CPU-burst Durations



Process State

- A process changes its state during execution:
    - **New**: The process is being created
    - **Ready**: The process is waiting to be assigned to a processor
    - **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 $\Longrightarrow$ short-term scheduler
- CPU scheduling decisions may take place when a process:

1.	A new process arrives	*preemptive*
2.	Switches from running to ready state	*preemptive*
3.	Switches from waiting to ready	*preemptive*
4.	Switches from running to waiting state	*non-preemptive/cooperative*
5.	Terminates	*non-preemptive/cooperative*

CPU Scheduler

- Scheduling under 4 (wait) and 5 (termination) is *non-preemptive/cooperative*
    - Once a process gets the CPU, keeps it until termination/switching to waiting state/release of the CPU
- All other schedulings are *preemptive*
    - Most OSs use this
    - e.g. time quota expires
    - Cost associated with access to shared data

Dispatcher

- Dispatcher module gives control of the CPU to the process selected by the short-term scheduler.
- It's function involves:
  - Switching context
  - Switching to user mode
  - Jumping to the proper location in the user program to resume that program
- Dispatch latency: Time it takes for the dispatcher to stop one process and start another one.

Scheduling Criteria

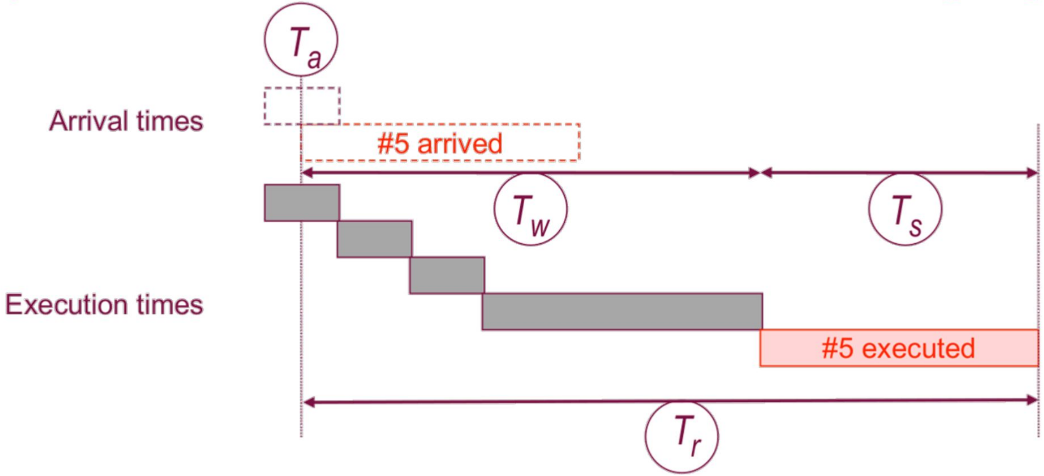
- CPU Utilization: Keep the CPU as busy as possible — **Maximize**
- Throughput: # of processes that complete their execution per time unit — **Maximize**
- Response Time: Amount of time it takes from when a request was submitted until the first response (not output) is produced (for time-sharing environment) — **Minimize**
- Waiting Time: Total amount of time a process has been waiting in the ready queue — **Minimize**
- Turnaround Time: Amount of time passed to finish execution of a particular process i.e. execution(service) time + waiting time — **Minimize**

Optimization Criteria

- Maximize CPU Utilization
- Maximize Throughput
- Minimize Response Time
- Minimize Waiting Time
- Minimize Turnaround Time

Scheduling Metrics

- T_a - **Arrival time:** Time the process became “READY” [again]
- T_w - **Waiting time:** Time spent waiting for the CPU
- T_s - **Service time:** Time spent executing in the CPU
- T_r - **Turnaround time:** Time spent waiting and executing = $T_w + T_s$

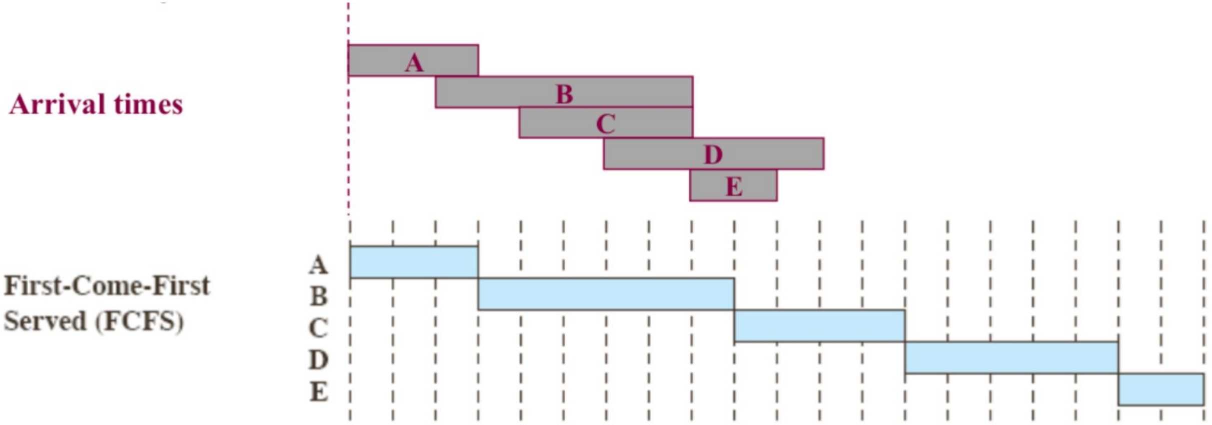


$T_r / T_s = 2.5$

Scheduling: First-Come, First-Served (FCFS)

- Processes are assigned the CPU in the order they request it
- When the running process blocks, the first "READY" process is selected
- When a process gets "READY", it is put at the end of the queue

FCFS Scheduling Policy



FCFS		A	B	C	D	E	Mean
	Finish Time	3	9	13	18	20	
	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

Scheduling: FCFS Example

- Suppose that the processes arrive in the order: P_1, P_2, P_3

Process	Burst Time
P_1	24
P_2	3
P_3	3

- The Gantt chart for the schedule is:

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

Scheduling: FCFS 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

Scheduling: FCFS 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

Scheduling: FCFS Example

Convoy effect: short process behind long process

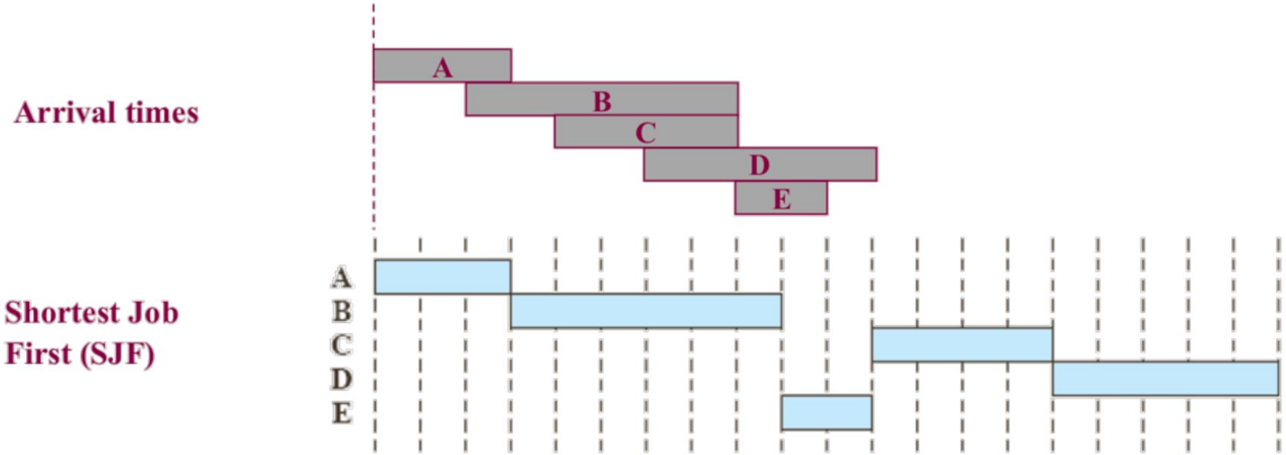
Scheduling: Shortest-Job-First (SJF)

- 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 scheme is known as the **Shortest-Remaining-Time-First (SRTF)**
- Assumes the run times are known in advance!
- SJF(SRTF) is optimal – gives minimum average waiting time for a given set of processes

Scheduling: Non-Preemptive SJF

- Among several equally important "READY" jobs (or CPU bursts), the scheduler picks the one that will finish the earliest

SJF Scheduling Policy

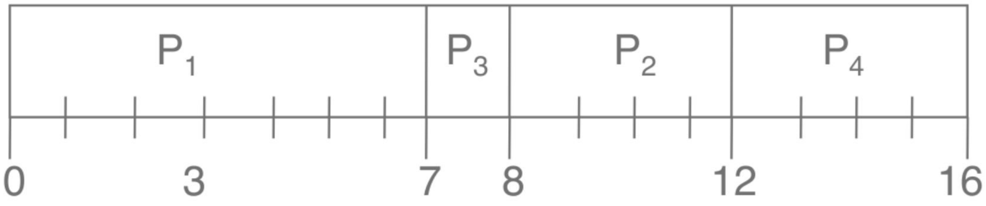


SJF	Finish Time	A 3	B 9	C 15	D 20	E 11	Mean
	Turnaround Time (T_r)	3	7	11	14	3	7.60
	T_r/T_s	1.00	1.17	2.75	2.80	1.50	1.84

Scheduling: Non-Preemptive SJF Example

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

- The Gantt chart for the schedule is:

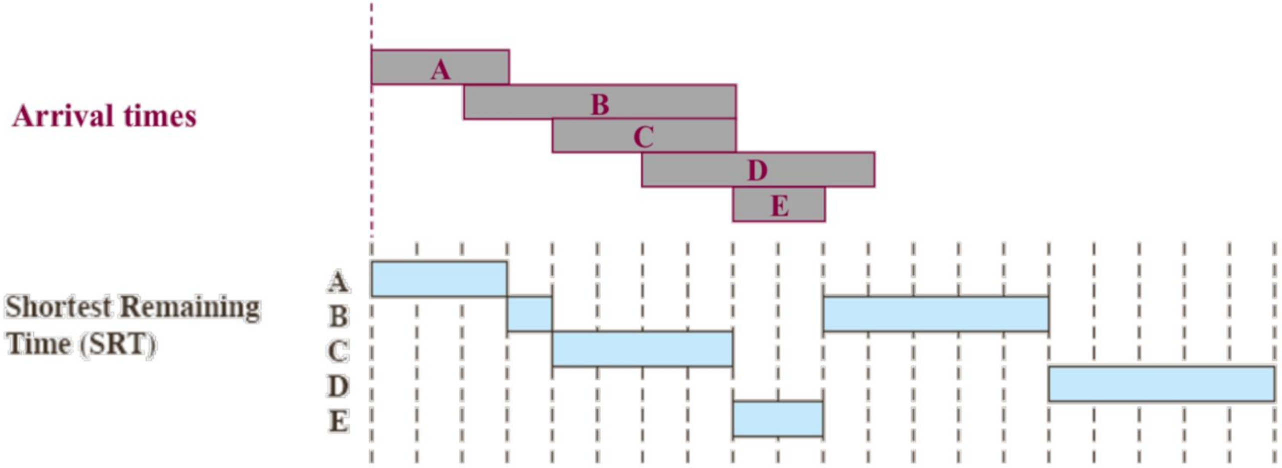


- Average waiting time: (0 + 6 + 3 + 7) / 4 = 4

Scheduling: Preemptive SJF

- Choose the process whose remaining run time is shortest.
- Allows new short jobs to get good service

SRT Scheduling Policy

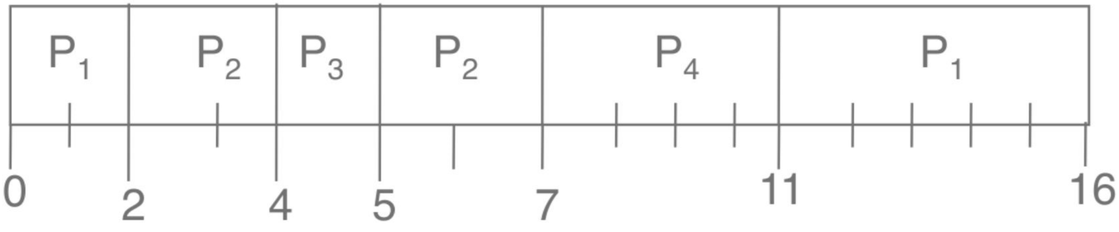


SRT		A	B	C	D	E	Mean
	Finish Time	3	15	8	20	10	
	Turnaround Time (T_r)	3	13	4	14	2	7.20
	T_r/T_s	1.00	2.17	1.00	2.80	1.00	1.59

Scheduling: Preemptive SJF Example

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

- The Gantt chart for the schedule is:



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

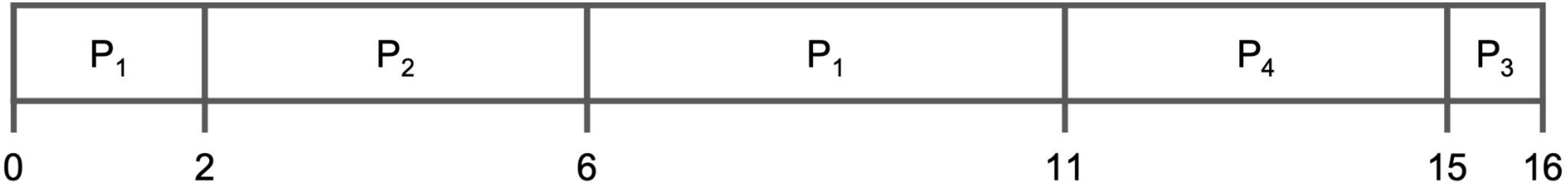
Scheduling: Priority

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority (smallest/largest number)
- 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 higher priority, preempt
- 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

Scheduling: Priority Example

Process	Arrival Time	Burst Time	Priority
P_1	0	7	2
P_2	2	4	1
P_3	4	1	4
P_4	5	4	3

- Non-preemptive:
  - $P_1 \to P_2 \to P_4 \to P_3$
- Preemptive:



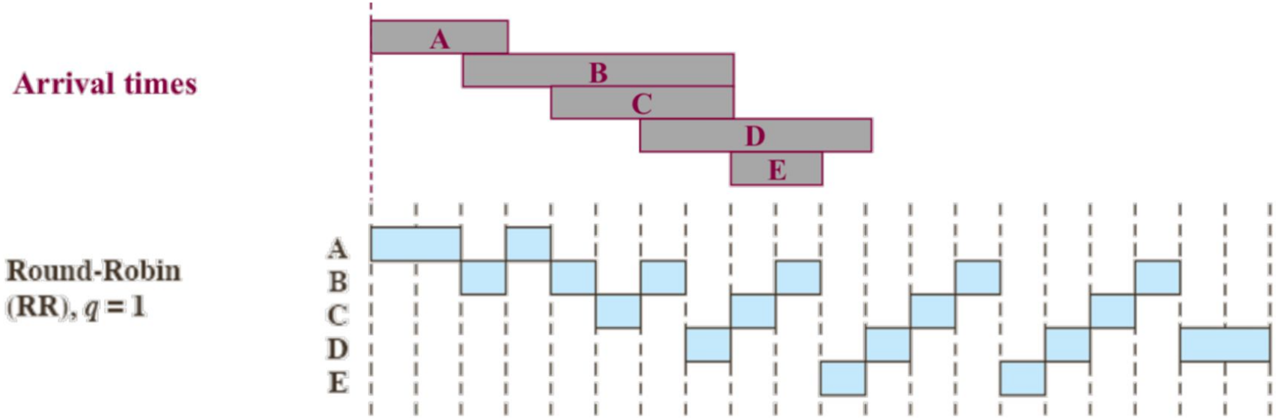
Scheduling: Round-Robin (RR)

- Each process gets a small unit of CPU time (i.e. *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:
  - Large ***q*** → FCFS
  - Small ***q*** → **q** must be large enough with respect to context switch time, otherwise over head would be too high

Scheduling: Round-Robin (RR)

- Preemptive FCFS, based on a timeout interval, the time quantum (**TIME_SLICE**)
- The running process is interrupted by the clock and put last in a FIFO "READY" queue

RR (q = 1) Scheduling Policy

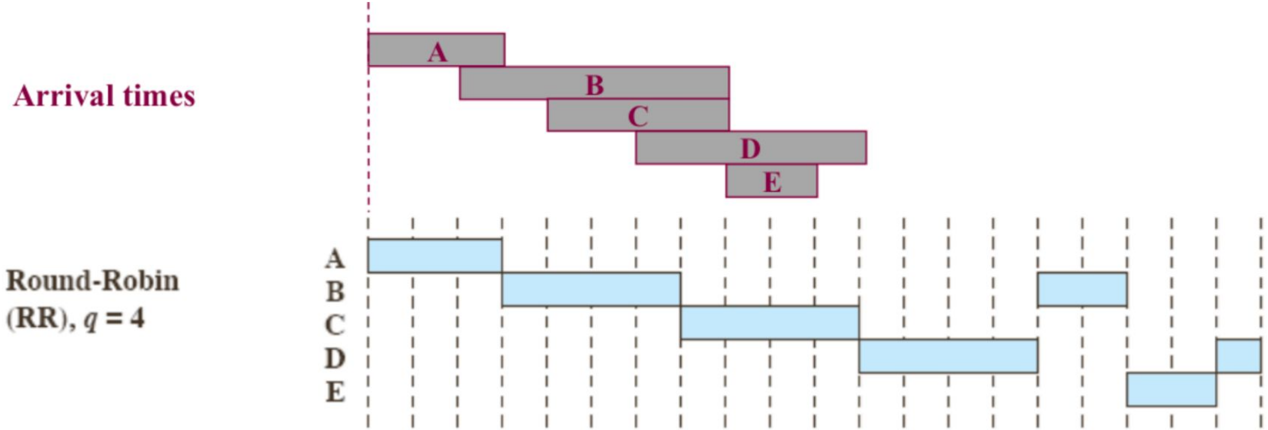


RR $q = 1$							
	Finish Time	A 4	B 18	C 17	D 20	E 15	Mean
	Turnaround Time (T_r)	4	16	13	14	7	10.80
	T_r/T_s	1.33	2.67	3.25	2.80	3.50	2.71

Scheduling: Round-Robin (RR)

- A crucial parameter is the quantum **q** (~10-100ms)
  - **q** should be large compared to context switch latency (~10μs)
  - **q** should be less than the longest CPU burst, or RR **degenerates** to FCFS

RR (q = 4) Scheduling Policy



RR $q = 4$	A	B	C	D	E	Mean
Finish Time	3	17	11	20	19	
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

Scheduling: RR Example

- Consider **q** = 20

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

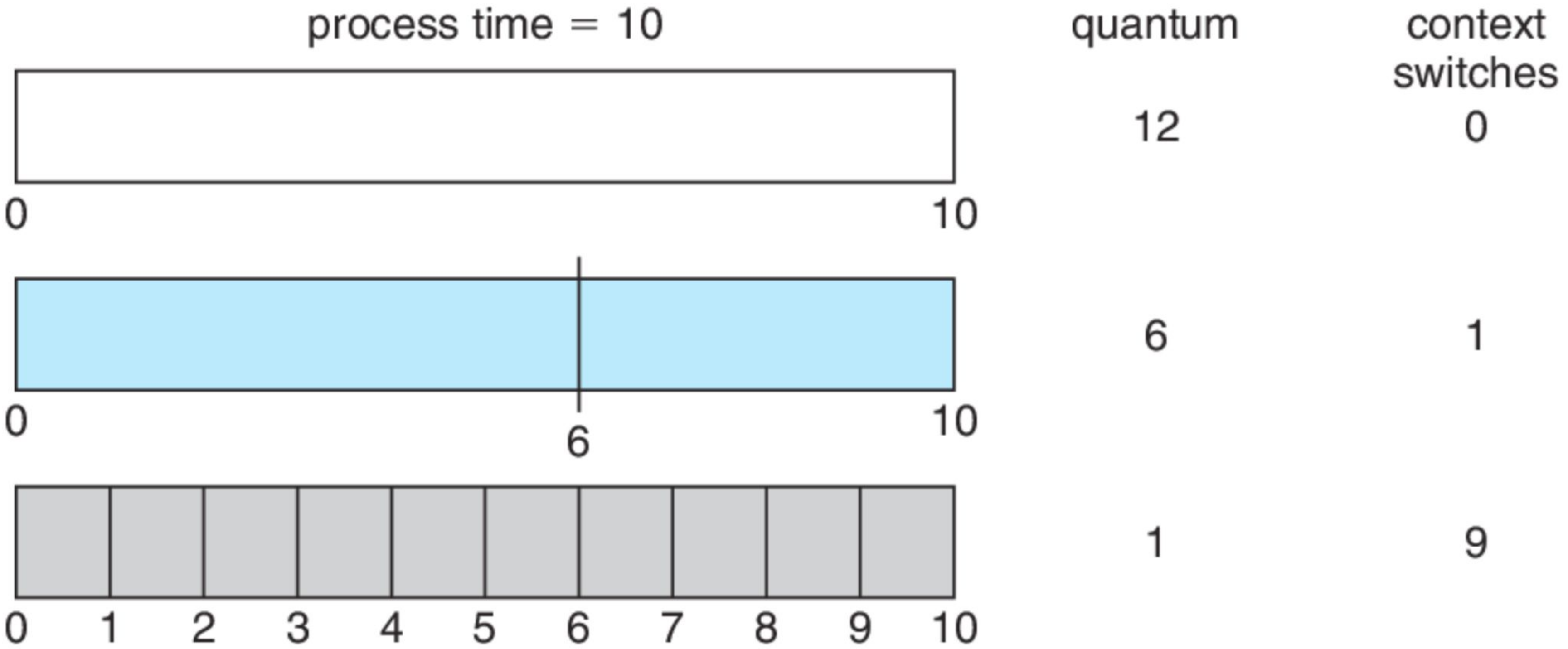
- The Gantt chart for the schedule is:

P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_1	P_3	P_3

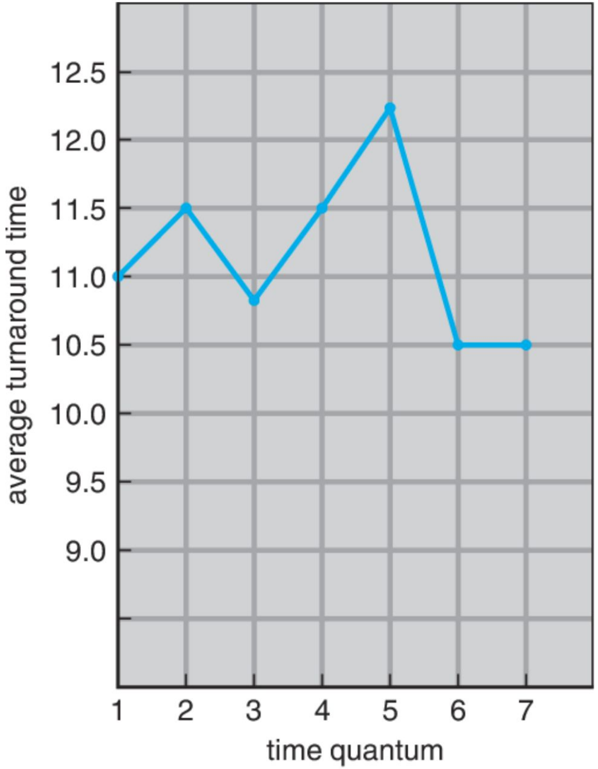
0 20 37 57 77 97 117 121 134 154 162

- 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

Exercise

- Consider a system using round-robin scheduling with a fixed quantum q. Every context switch takes s milliseconds. Any given process runs for an average of t milliseconds before it blocks or terminates (burst time)
- Determine the fraction of CPU time that will be wasted because of context switches for each of the following cases (Your answer should be in terms of q, s, and t)

  a. $t \leq q$

  b. $t \gg q$ (t is much greater than q)

  c. $q \rightarrow 0$

$$\frac{\textit{Context switching time}}{\textit{Context switching time + useful CPU burst}}$$

Exercise

- Consider a system using round-robin scheduling with a fixed quantum q. Every context switch takes s milliseconds. Any given process runs for an average of t milliseconds before it blocks or terminates (burst time)
- Determine the fraction of CPU time that will be wasted because of context switches for each of the following cases (Your answer should be in terms of q, s, and t)

    a. $t \leq q$ — $s / (t + s)$
    b. $t \gg q$ (t is much greater than q) — $s / (q + s)$
    c. $q \rightarrow 0$ — 100%

Comparison: FCFS

- PROS:
  - It is a fair algorithm
    - Schedule in the order that they arrive
- CONS:
  - Average response time can be lousy
    - Small requests wait behind big ones (convoy effect)
  - May lead to poor utilization of other resources
    - FCFS may result in poor overlap of CPU and I/O activity
      - E.g., a CPU-intensive job prevents an I/O intensive job from doing a small bit of computation, thus preventing it from going back and keep the I/O subsystem busy

Comparison: SJF

- PROS:
  - Provably optimal with respect to average waiting time
    - Prevents convoy effect
- CONS:
  - Can cause starvation of long jobs
  - Requires advanced knowledge of CPU burst times
    - This is not easy to predict!

Comparison: Priority

- PROS:
  - Guarantees early completion of high priority jobs
- CONS:
  - Can cause starvation of low priority jobs
  - How to decide/assign priority value?

Comparison: Round-Robin

- PROS:
    - Great for timesharing
        - No starvation
    - Does not require prior knowledge of CPU burst times
    - Generally reduces average response time
- CONS:
    - What if all jobs are almost the same length
        - Increases the turnaround time
    - How to set the “best” time quantum?
        - If too small, it increases context-switch overhead
        - If too large, response time degrades

Exercise

Process	Arrival Time	Burst Time	Priority
P_1	9	3	5
P_2	6	4	4
P_3	8	5	3
P_4	7	9	2
P_5	5	7	1

- Consider Shortest-Remaining-Time-First (SRTF) scheduling policy is used.
  a. Draw the Gantt chart
  b. Find the response time, waiting time, and turnaround time for each process.

Exercise

Process	Arrival Time	Burst Time	Priority
P_1	0	20	3
P_2	5	15	1
P_3	10	10	2
P_4	15	5	4

- Draw Gantt charts, find average turnaround time, waiting time, response time for each processor, for each of FCFS, SJF (non-preemptive), SRTF (preemptive), RR (**q=4**), Priority (preemptive and non-preemptive)

Announcement

- Quiz 2 (Released on Blackboard)
  - Due at 11.59 PM tomorrow
  - 30 minutes, single attempt, 15 MCQs
- Homework 2
  - Due on Wednesday october 1st, 11.59 PM