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Operating Systems

Lecture 6 CPU Scheduling

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Catalog Description

- Basic Concepts
- Scheduling Criteria
- Scheduling Algorithms
- Algorithm Evaluation

Chapter Objectives

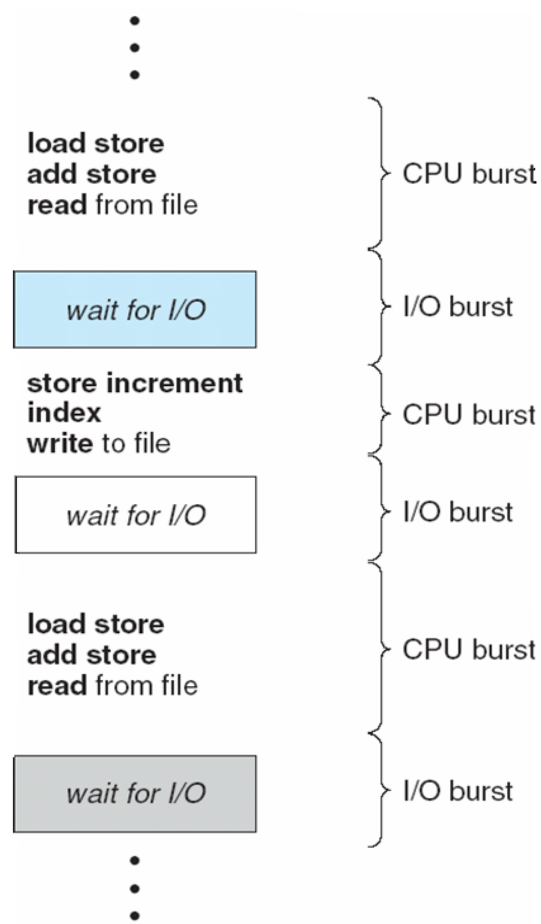
- To introduce CPU scheduling, which is the basis for multiprogrammed operating systems
- To describe various CPU-scheduling algorithms
- To discuss evaluation crieria for selecting a CPU-scheduling algorithm for a particular system.

Basic Concepts

- Scheduling is a fundamental OS function.
  - Almost all computer resources are scheduled before use.
  - CPU scheduling is the basis of multiprogrammed OSes.
- Objective of multiprogramming
  - Maximum CPU utilization

Basic Concepts

- CPU-I/O Burst Cycle
  - A property of process : 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
  - Begin and end with a CPU burst
  - Process execution = n (CPU execution + I/O wait) + CPU execution

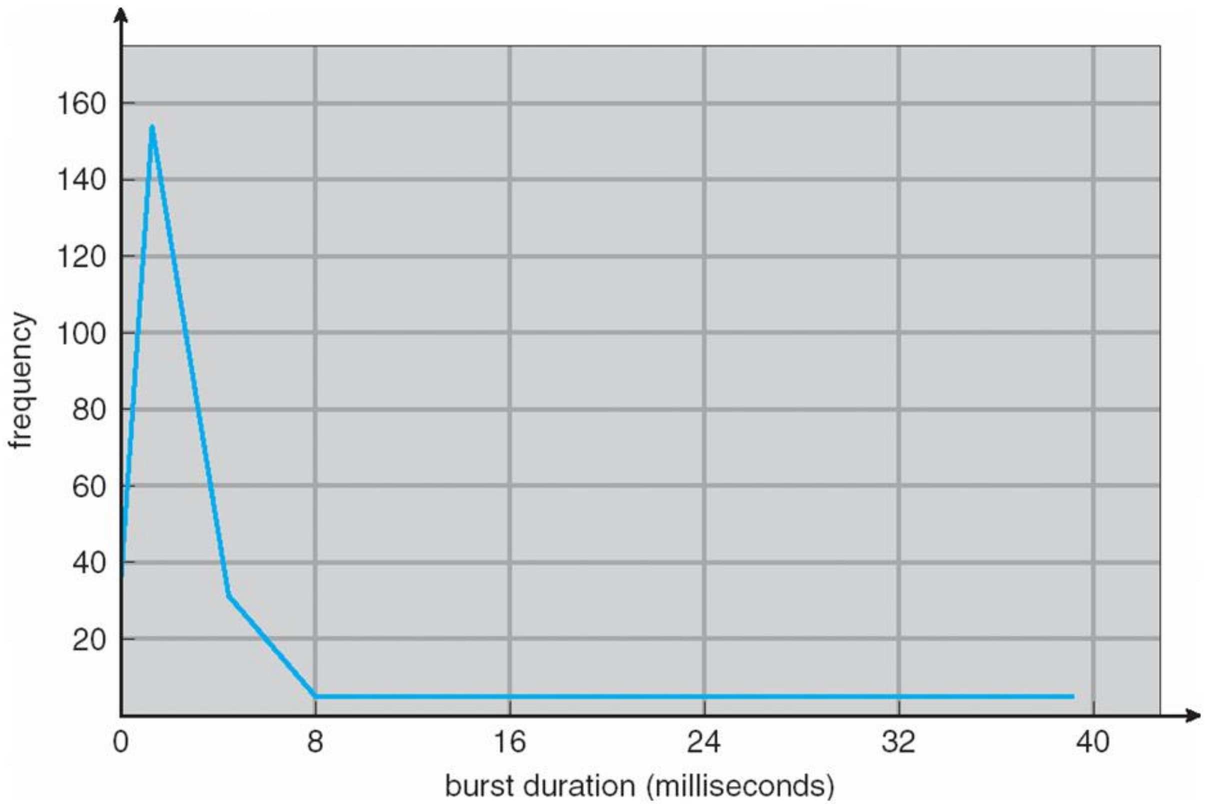


Basic Concepts

- CPU-I/O Burst Cycle
  - CPU burst distribution
    - ✓ CPU burst curve – exponential or hyper exponential
    - ✓ CPU-bound program
    - ✓ I/O-bound program

Basic Concepts

- Histogram of CPU-burst Times



Basic Concepts

- CPU Scheduler(Short-term Scheduler)
  - selects a process from the processes in memory that are ready to execute and allocates the CPU to that process
  - CPU scheduling decisions may take place when a process:
    - ✓ Switches from running to waiting state
    - ✓ Switches from running to ready state
    - ✓ Switches from waiting to ready state
    - ✓ Terminates
  - Scheduling under 1 and 4 is nonpreemptive
  - All other scheduling is preemptive

Basic Concepts

- Dispatcher
  - Dispatcher module 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 – the time it takes for the dispatcher to stop one process and start another running
    - ✓ SHOULD be as fast as possible

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Scheduling Criteria

- CPU utilization (CPU 利用率)
  - keep the CPU as busy as possible
- Throughput (吞吐率)
- Turnaround time (周转时间)
- Waiting time (等待时间)
- Response time (响应时间)

Scheduling Criteria

- Throughput
  - the number of processes that are completed per time unit
    - ✓ different from one process set to another process set
    - ✓ for long processes: may be 1 process per hour
    - ✓ for short transactions: may be 10 processes per second

Scheduling Criteria

- Turnaround time
  - the amount of time to execute a particular process
    - ✓ from the time of submission of a process to the time of completion
    - ✓ = the sum of the periods spent waiting to get into memory, waiting in the ready queue, executing on the CPU, and doing I/O.

Scheduling Criteria

- Waiting time
  - the amount of time a process has been waiting in the ready queue
  - = the sum of the periods spent 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 the time it takes to output the response
    - ✓ for time-sharing environment

Scheduling Algorithm Optimization Criteria

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

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Scheduling Algorithms

- FCFS(先来先服务) Scheduling
- SJF(短作业优先) Scheduling
- Priority Scheduling（优先级）
- Round Robin(时间片轮转) Scheduling
- Multilevel Queue（多级队列）Scheduling
- Multilevel Feedback Queue（多级反馈队列） Scheduling

Scheduling Algorithms

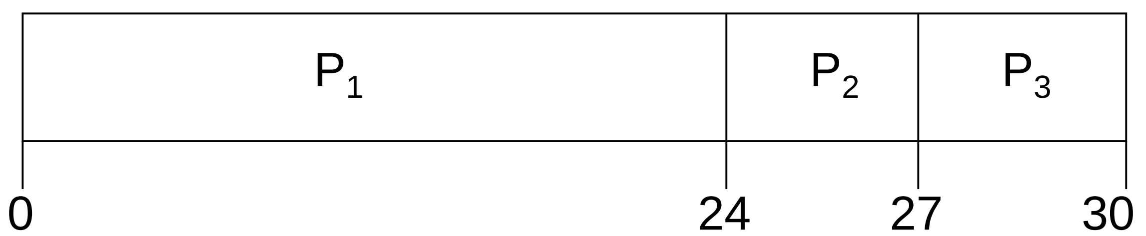
- FCFS(先来先服务) Scheduling
  - Nonpreemptive(非抢占)
  - Implementation
    - ✓ Normal Queue: FIFO Queue
    - ✓ Ordered by request time
    - ✓ Linked list
    - ✓ Insert: linked to the tail of the queue
    - ✓ Scheduling: removed from the head of the queue

Scheduling Algorithms

- Suppose that the processes arrive in the order: P1 , P2 , P3

Process	Burst Time(ms)
P_1	24
P_2	3
P_3	3

- The Gantt Chart for the schedule is:



- Waiting time for P1 = 0; P2 = 24; P3 = 27
- Average waiting time: (0 + 24 + 27)/3 = 17

Scheduling Algorithms

- Suppose that the processes arrive in the order: P2, P3, P1
- The Gantt Chart for the schedule is:

- Waiting time for P1 = 6; P2 = 0; P3 = 3
- Average waiting time: (6 + 0 + 3)/3 = 3
- Much better than previous case

Scheduling Algorithms

- Convoy effect（护航效应；护卫效应）
  - all the other processes wait for the one big process to get off the CPU
  - ＝short process behind long process
- Example situation:
  - one CPU-bound process
  - many I/O-bound processes

Scheduling Algorithms

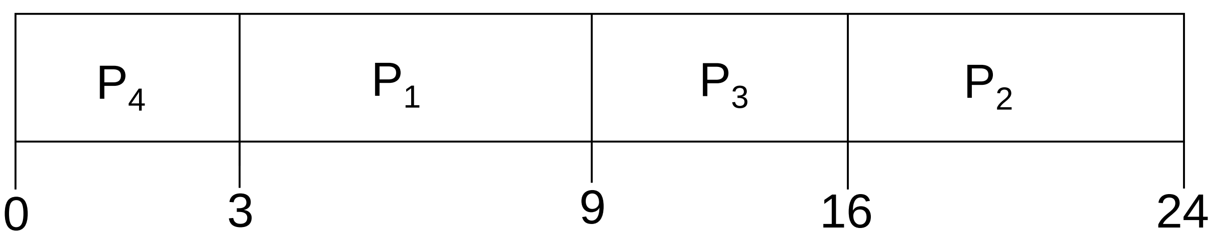
- Shortest-Job-First (SJF) Scheduling
  - Associate with each process the length of its next CPU burst.
  - Schedule the process with the shortest next CPU burst.

Scheduling Algorithms

- SJF scheduling example

Process	Burst Time(ms)
P1	6
P2	8
P3	7
P4	3

- The Gantt chart for the schedule is:



- Waiting time for P1= 3; P2 = 16; P3 = 9; P4 = 0
- Average waiting time: (3 + 16 + 9 + 0)/4 = 7
- If FCFS, average waiting time: (0 + 6 + 14 + 21)/4 = 10.25

Scheduling Algorithms

- Shortest-Job-First (SJF) Scheduling
  - Two schemes:
    - ✓ nonpreemptive

      －once the CPU is given to the process, it cannot be preempted until it completes its CPU burst
    - ✓ preemptive

      － if a new process arrives with CPU burst length less than the remaining time of current executing process, preempt. This scheme is known as the Shortest-Remaining-Time-First (SRTF)
  - SJF is optimal(最优的)

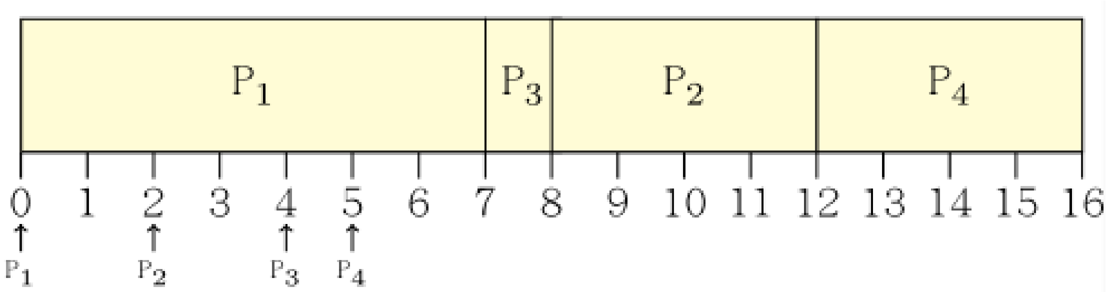
    － gives the minimum average waiting time(最小平均等待时间) for a given set of processes
    - ✓ The difficulty is knowing the length of the next CPU request

Scheduling Algorithms

- Example of Non-Preemptive SJF

Process	Arrival Time	Burst Time(ms)
P1	0.0	7
P2	2.0	4
P3	4.0	1
P4	5.0	4

- The Gantt chart for SJF (non-preemptive)



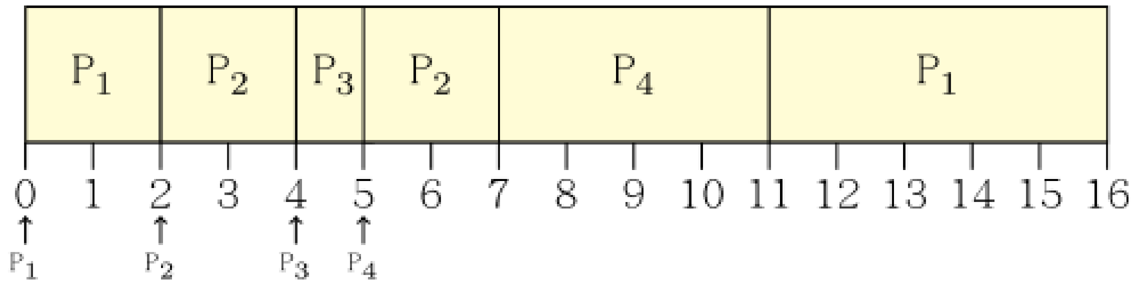
- Average waiting time: (0 + 6 + 3 + 7)/4 = 4

Scheduling Algorithms

- Example of Preemptive SJF

Process	Arrival Time	Burst Time
P1	0.0	7
P2	2.0	4
P3	4.0	1
P4	5.0	4

- The Gantt chart for SJF (preemptive)



- Average waiting time: ((11−2)+(5−4)+0+(7−5))/4=3

Scheduling Algorithms

- Determining Length of Next CPU Burst
  - can only estimate the length
  - can be done by using the length of previous CPU bursts, using exponential averaging(指数平均)
    - ✓ t_n = actual length of n^{th} CPU burst
    - ✓ τ_{n+1} = predicted value for the next CPU burst
    - ✓ α , $0 =< \alpha <= 1$
    - ✓ Define: $\tau_{n+1} = \alpha\ t_n + (1-\alpha)\ \tau_n$

Scheduling Algorithms

Examples of Exponential Averaging

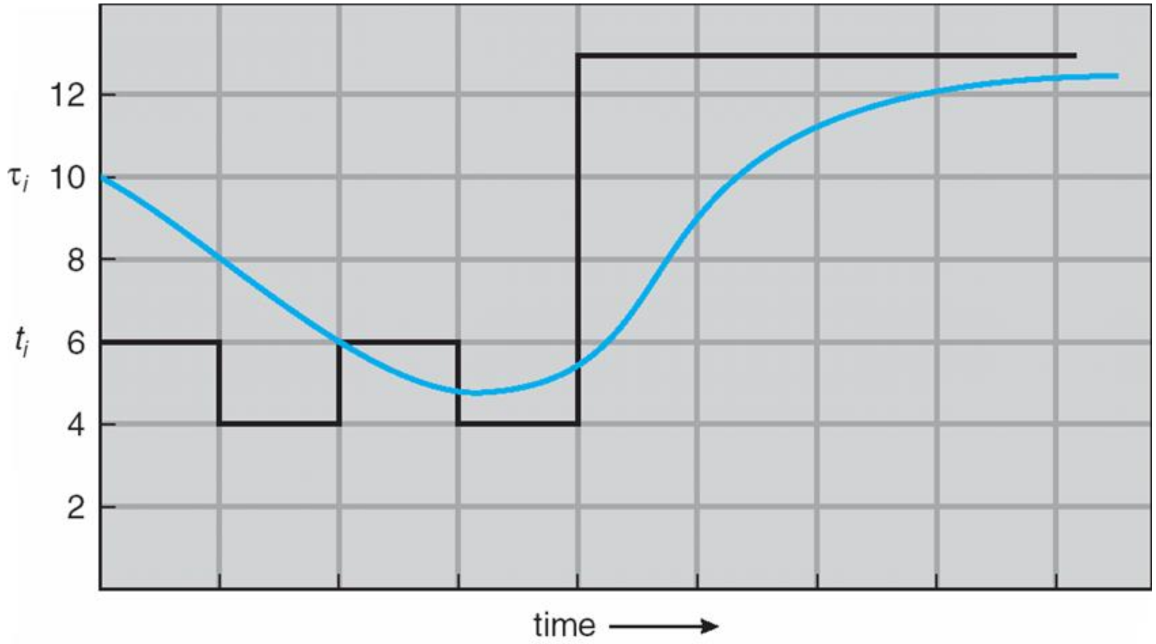
- α =0
  - $\tau_{n+1} = \tau_n$
  - Recent history does not count
- α =1
  - $\tau_{n+1} = \alpha\, t_n$
  - Only the actual last CPU burst counts
- If we expand the formula, we get:

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

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

Scheduling Algorithms

- Prediction of the Length of the Next CPU Burst
- **Example**: α **=1/2**, τ_0 **=10**



CPU burst (t_i)		6	4	6	4	13	13	13	…
"guess" (τ_i)	10	8	6	6	5	9	11	12	…

Scheduling Algorithms

- Priority Scheduling
  - A priority number(优先数) is associated with each process
  - The CPU is allocated to the process with the highest priority
  - Priority scheduling can be:
    - ✓ Preemptive VS. Nonpreemptive
  - SJF is a special case of general priority scheduling where priority is the (predicted) next CPU burst time
  - Problem – Starvation – low priority processes may never execute
  - Solution – Aging – as time progresses, the priority of the process can be increased

Scheduling Algorithms

- Example of Non-Preemptive Priority Scheduling

Process	Burst Time(ms)	Priority
P1	10.0	3
P2	1.0	1
P3	2.0	4
P4	1.0	5
P5	5.0	2

- The Gantt chart for Non-Preemptive Priority

P2	P5	P1	P3	P4

0 1 6 16 18 19

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

Scheduling Algorithms

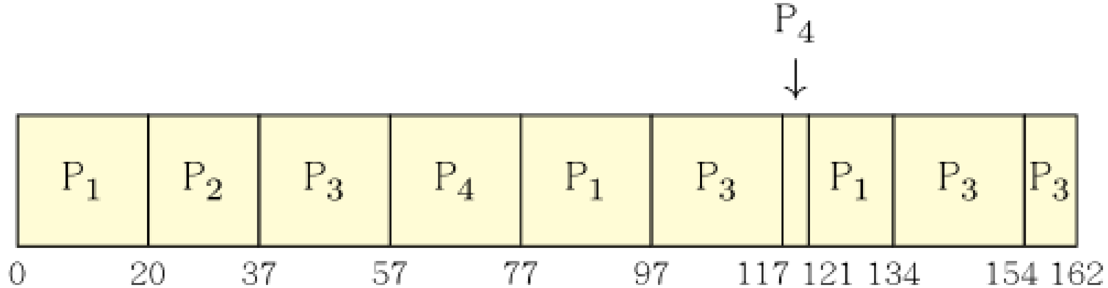
- Round Robin (时间片轮转，RR) Scheduling
  - Each process gets a small unit of CPU time (time quantum), usually 10-100 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue.
  - If there are n processes in the ready queue and the time quantum is q, then 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 - FCFS
    - ✓ q small - q must be large with respect to context switch, otherwise overhead is too high

Scheduling Algorithms

- Example of RR with Time Quantum = 20

Process	Burst Time
P1	53
P2	17
P3	68
P4	24

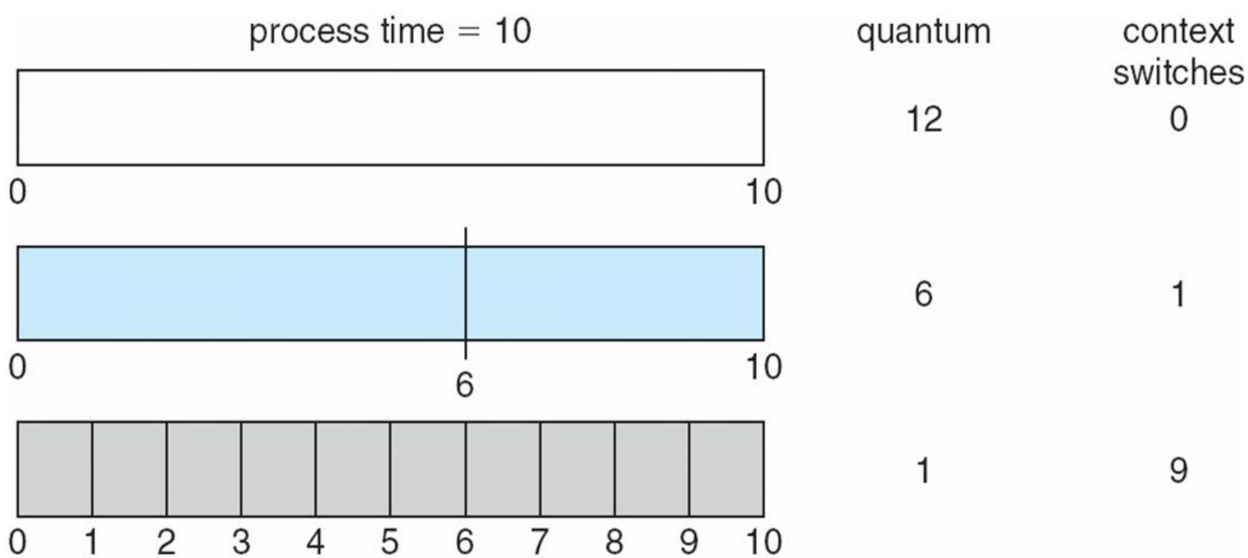
- The Gantt chart is:



- Typically, higher average turnaround time than SJF, but better response

Scheduling Algorithms

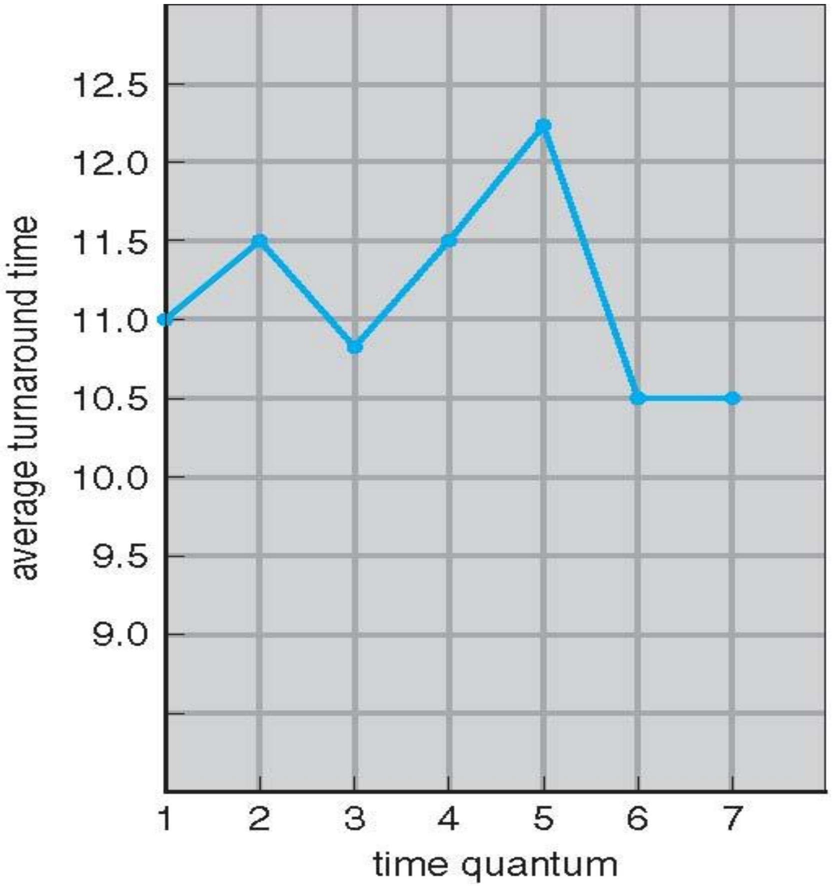
- Time Quantum and Context Switch Time
  - The effect of context switching on the performance of RR scheduling



  - typically the context-switch time is a small fraction of the time quantum
    - ✓ usually:time quantum:10 ~100ms & context switch time:10μs

Scheduling Algorithms

- Turnaround Time Varies With the Time Quantum



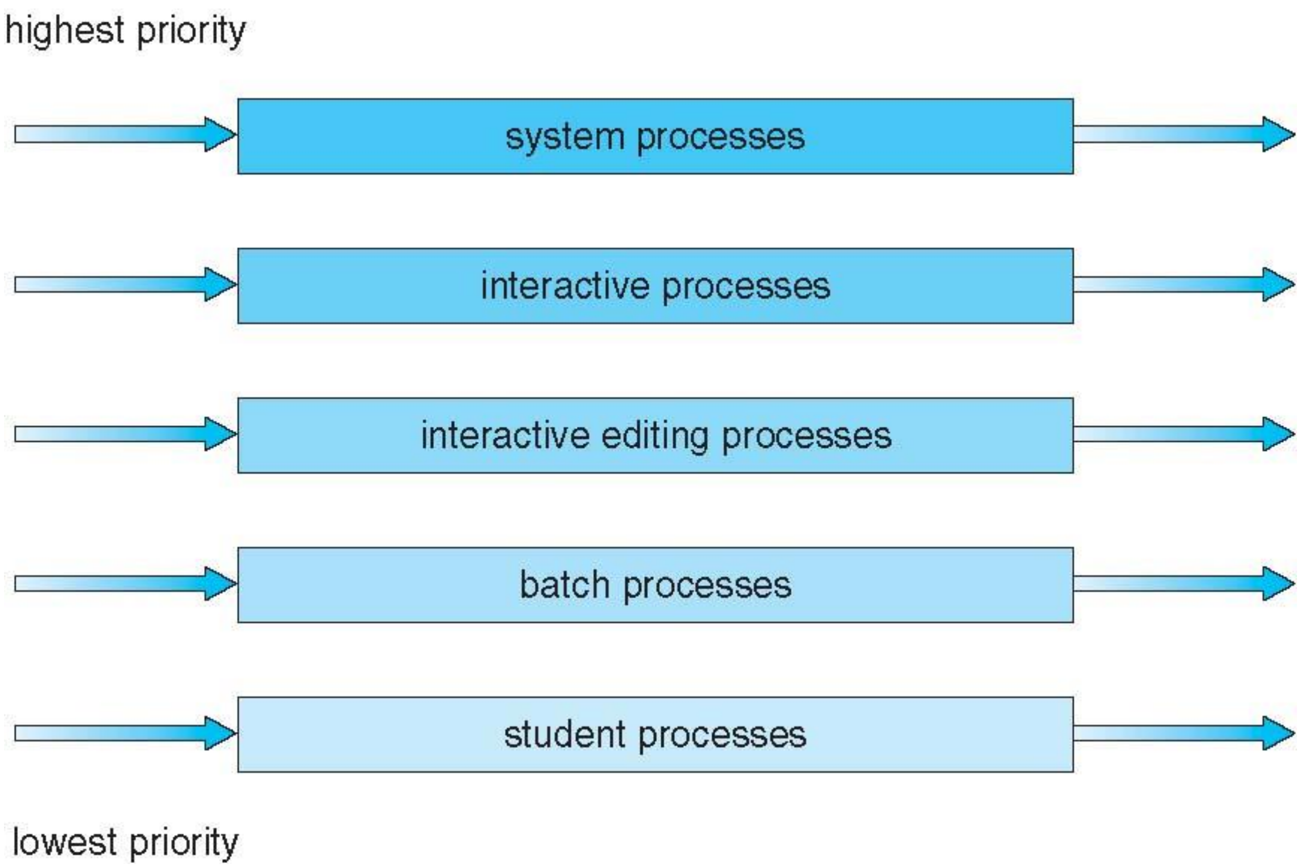
process	time
P_1	6
P_2	3
P_3	1
P_4	7

Scheduling Algorithms

- Multilevel Queue（多级队列）
  - Ready queue is partitioned into separate queues:
    foreground (interactive)
    background (batch)
  - Each queue has its own scheduling algorithm
    - ✓ foreground – RR
    - ✓ background – FCFS
  - Scheduling must be done between the queues
    - ✓ Fixed priority scheduling;
      – Example: serve all from foreground then from background).
      – Possibility of starvation.
    - ✓ Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its processes; i.e.,
      – 80% to foreground in RR
      – 20% to background in FCFS

Scheduling Algorithms

Multilevel Queue Scheduling



Scheduling Algorithms

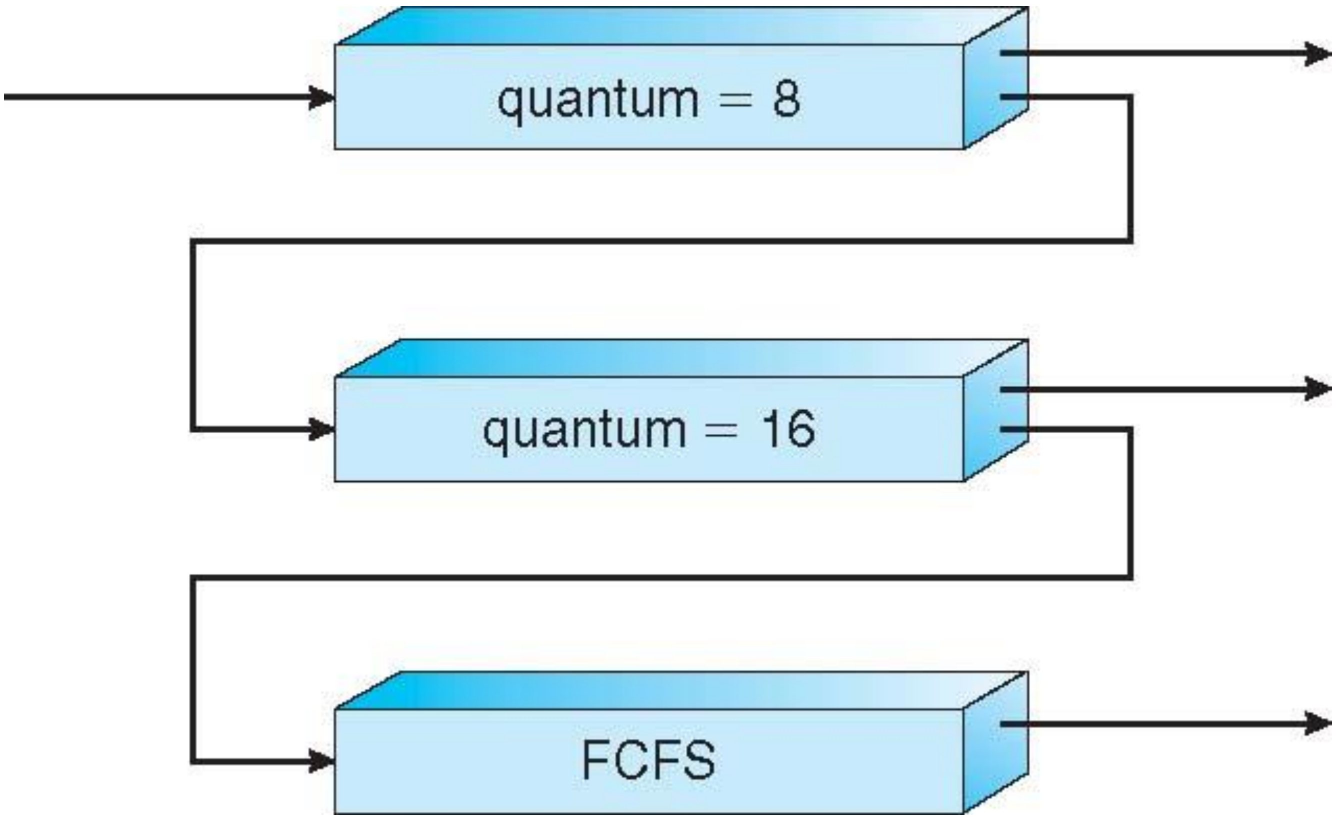
- Multilevel Feedback Queue（多级反馈队列）Scheduling
  - A process can move between the various queues; aging can be implemented in this way
  - Multilevel-feedback-queue(多级反馈队列) scheduler defined by the following parameters
    - ✓ number of queues
    - ✓ scheduling algorithms for each queue
    - ✓ method 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

Scheduling Algorithms

- Example of Multilevel Feedback Queue
  - Three queues:
    - ✓ Q0 – RR with time quantum 8 milliseconds
    - ✓ Q1 – RR time quantum 16 milliseconds
    - ✓ Q2 – FCFS
  - Scheduling
    - ✓ A new job enters queue Q0 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 Q1.
    - ✓ At Q1 job is again served FCFS and receives 16 additional milliseconds. If it still does not complete, it is preempted and moved to queue Q2.

Scheduling Algorithms

- Example of Multilevel Feedback Queue



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Algorithm Evaluation

- Algorithm Evaluation
  - How do we select a CPU scheduling algorithm for a particular system?
    - ✓ firstly, which criteria? What is the relative importance of these measures
    - ✓ then, evaluate the algorithms
      - -Deterministic Modeling(确定性建模)
      - -Queueing Models(排队模型)
      - -Simulations(模拟)
      - -Implementation Scheduling

Algorithm Evaluation

- Deterministic Modeling(确定性建模)
  - Analytic evaluation(分析评估法): One major class of evaluation methods
    - ✓ uses the given algorithm and the system workload to produce a formula or number that evaluates the performance of the algorithm for that workload.
  - Deterministic modeling(确定性建模) – takes a particular predetermined workload and defines the performance of each algorithm for that workload

Algorithm Evaluation

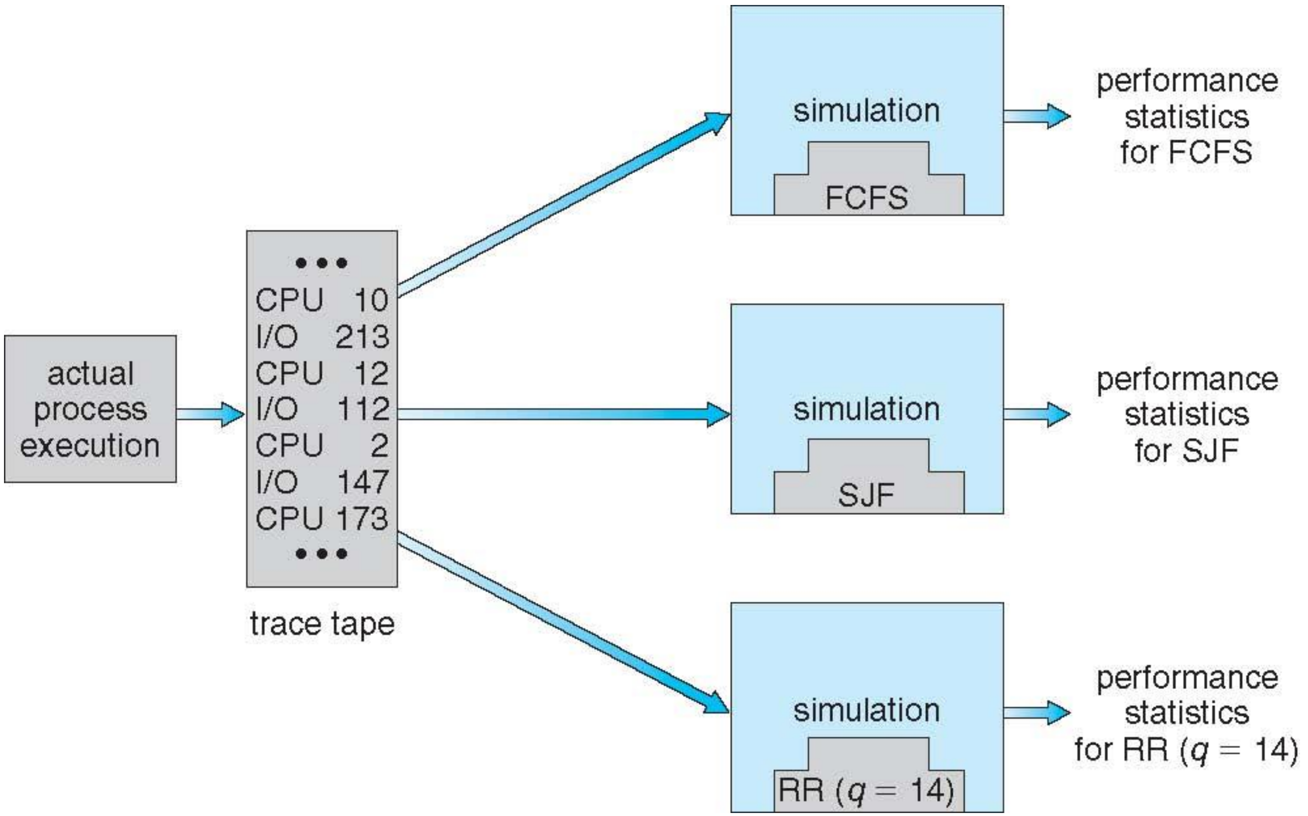
- Queuing Models(排队模型)
  - Usually, two distributions can be measured and then approximated or simply estimated
    - ✓ the distribution of CPU and I/O bursts
    - ✓ the arrival-time distribution
  - Queueing-network analysis(排队网络分析)
    - ✓ Computer System: a network of servers, each server has a queue of waiting processes
      - – CPU: ready queue;
      - – I/O: device queues (≡waiting queue)
    - ✓ Given arriving rates and service rates ⇒utilization,
      average queue length, average wait time, ...

Algorithm Evaluation

- Simulations(模拟)
  - Running simulations involves programming a model of the computer system.
    - ✓ Software data structures represent the major components
      - a clock
      - the system state is modified to reflect the activities of the devices, the processes and the scheduler.
    - ✓ finally, the statistics are gathered
  - How to generate the data to drive the simulation?
    - ✓ distribution-driven simulation
      - random-number generator, according to probability distributions, to generate processes, CPU burst times, arrivals, departures, ...
      - the distributions can be defined mathematically(uniform, exponential, Poisson) or empirically
      - may be inaccurate

Algorithm Evaluation

- Evaluation of CPU schedulers by Simulation
  - trace tapes(跟踪磁带)



Algorithm Evaluation

- Implementation
  - This approach puts the actual algorithm in the real system for evaluation under real operating conditions
  - the main difficulty: high cost

End of Chapter 6