CPU SCHEDULING

Scheduling Objectives

- Enforcement of fairness
  - in allocating resources to processes
- Enforcement of priorities
- Make best use of available system resources
- Give preference to processes holding key resources.
- Give preference to processes exhibiting good behavior.
- Degrade gracefully under heavy loads.

Outline

- Scheduling Objectives
- Levels of Scheduling
- Scheduling Criteria
- Scheduling Algorithms
  - FCFS, Shortest Job First, Priority, Round Robin
- Multiple Processor Scheduling
- Real-time Scheduling
- Algorithm Evaluation

Basic Concepts

- Maximum CPU utilization obtained with multiprogramming.
- CPU-I/O Burst Cycle
  - Process execution consists of a cycle of CPU execution and I/O wait.

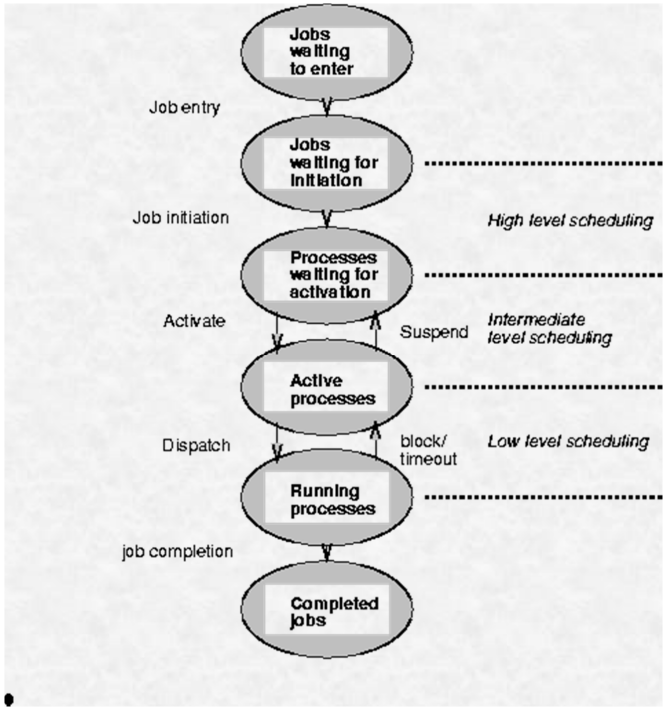
Levels of Scheduling

- High Level Scheduling or Job Scheduling
  - Selects jobs allowed to compete for CPU and other system resources.
- Intermediate Level Scheduling or Medium Term Scheduling
  - Selects which jobs to temporarily suspend/resume to smooth fluctuations in system load.
- Low Level (CPU) Scheduling or Dispatching
  - Selects the ready process that will be assigned the CPU.
  - Ready Queue contains PCBs of processes.

CPU Scheduler

- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them.
  - Non-preemptive Scheduling
    - Once CPU has been allocated to a process, the process keeps the CPU until
      - Process exits OR
      - Process switches to waiting state
  - Preemptive Scheduling
    - Process can be interrupted and must release the CPU.
      - Need to coordinate access to shared data

Levels of Scheduling(cont.)



Scheduling Criteria

- CPU Utilization
  - Keep the CPU and other resources as busy as possible
- Throughput
  - Number of processes that complete their execution per time unit.
- Turnaround time
  - amount of time to execute a particular process from its entry time.

Scheduling Criteria (cont.)

- Waiting time
  - amount of time a process has been waiting in the ready queue.
- Response Time (in a time-sharing environment)
  - amount of time it takes from when a request was submitted until the first response is produced, NOT output.

First Come First Serve (FCFS) Scheduling

- Policy: Process that requests the CPU *FIRST* is allocated the CPU *FIRST.*
  - FCFS is a non-preemptive algorithm.
- Implementation - using FIFO queues
  - incoming process is added to the tail of the queue.
  - Process selected for execution is taken from head of queue.
- Performance metric - Average waiting time in queue.
- Gantt Charts are used to visualize schedules.

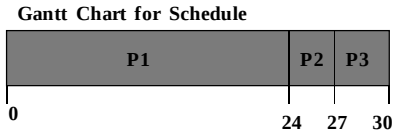
Optimization Criteria

- Max CPU Utilization
- Max Throughput
- Min Turnaround time
- Min Waiting time
- Min response time

First-Come, First-Served(FCFS) Scheduling

- Example

Process	Burst Time
P1	24
P2	3
P3	3



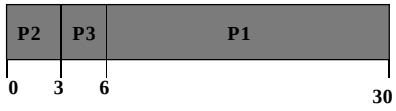
- Suppose the arrival order for the processes is
  - P1, P2, P3
- Waiting time
  - P1 = 0;
  - P2 = 24;
  - P3 = 27;
- Average waiting time
  - (0+24+27)/3 = 17

FCFS Scheduling (cont.)

- Example

Process	Burst Time
P1	24
P2	3
P3	3

Gantt Chart for Schedule



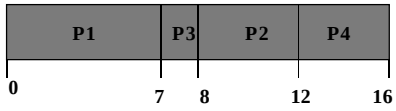
- Suppose the arrival order for the processes is
  - P2, P3, P1
- Waiting time
  - P1 = 6; P2 = 0; P3 = 3;
- Average waiting time
  - (6+0+3)/3 = 3 , better..
- *Convoy Effect*:
  - short process behind long process, e.g. 1 CPU bound process, many I/O bound processes.

Non-Preemptive SJF Scheduling

- Example

Process	Arrival Time	Burst Time
P1	0	7
P2	2	4
P3	4	1
P4	5	4

Gantt Chart for Schedule



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

Shortest-Job-First(SJF) Scheduling

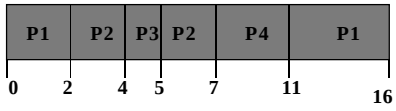
- Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time.
- Two Schemes:
  - Scheme 1: Non-preemptive
    - Once CPU is given to the process it cannot be preempted until it completes its CPU burst.
  - Scheme 2: Preemptive
    - If a new CPU process arrives with CPU burst length less than remaining time of current executing process, preempt. Also called Shortest-Remaining-Time-First (SRTF).
  - SJF is optimal - gives minimum average waiting time for a given set of processes.

Preemptive SJF Scheduling

- Example

Process	Arrival Time	Burst Time
P1	0	7
P2	2	4
P3	4	1
P4	5	4

Gantt Chart for Schedule



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

Priority Scheduling

- A priority value (integer) is associated with each process. Can be based on
  - Cost to user
  - Importance to user
  - Aging
  - %CPU time used in last X hours.
- CPU is allocated to process with the highest priority.
  - Preemptive
  - Nonpreemptive

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.
- *n* processes, time quantum = *q*
  - Each process gets 1/*n* CPU time in chunks of at most *q* time units at a time.
  - No process waits more than (*n*-1)*q* time units.
  - Performance
    - » Time slice *q* too large - FIFO behavior
    - » Time slice *q* too small - Overhead of context switch is too expensive.
    - » Heuristic - 70-80% of jobs block within timeslice

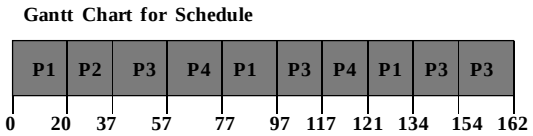
Priority Scheduling (cont.)

- SJN is a priority scheme where the 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.

Round Robin Example

- Time Quantum = 20

Process	Burst Time
P1	53
P2	17
P3	68
P4	24



Multiple-Processor Scheduling

- CPU scheduling becomes more complex when multiple CPUs are available.
  - Have one ready queue accessed by each CPU.
    - Self scheduled - each CPU dispatches a job from ready Q
    - Master-Slave - one CPU schedules the other CPUs
- Homogeneous processors within multiprocessor.
  - Permits Load Sharing
- Asymmetric multiprocessing
  - only 1 CPU runs kernel, others run user programs
  - alleviates need for data sharing

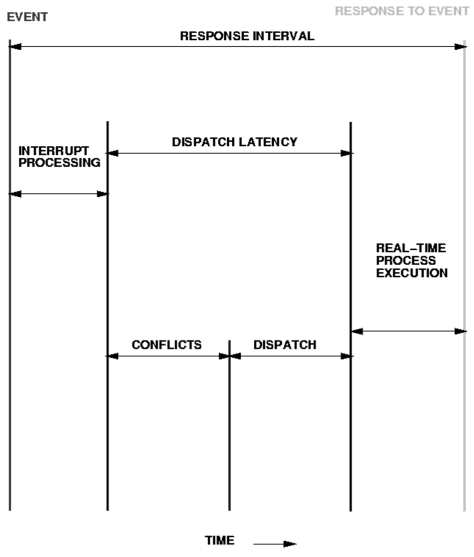
Issues in Real-time Scheduling

- Dispatch Latency
  - Problem - Need to keep dispatch latency small, OS may enforce process to wait for system call or I/O to complete.
  - Solution - Make system calls preemptible, determine safe criteria such that kernel can be interrupted.
- Priority Inversion and Inheritance
  - Problem: Priority Inversion
    - » Higher Priority Process needs kernel resource currently being used by another lower priority process..higher priority process must wait.
  - Solution: Priority Inheritance
    - » Low priority process now inherits high priority until it has completed use of the resource in question.

Real-Time Scheduling

- Hard Real-time Computing -
  - required to complete a critical task within a guaranteed amount of time.
- Soft Real-time Computing -
  - requires that critical processes receive priority over less fortunate ones.
- Types of real-time Schedulers
  - Periodic Schedulers - Fixed Arrival Rate
  - Demand-Driven Schedulers - Variable Arrival Rate
  - Deadline Schedulers - Priority determined by deadline
  - .....

Real-time Scheduling - Dispatch Latency



Algorithm Evaluation

- Deterministic Modeling
  - Takes a particular predetermined workload and defines the performance of each algorithm for that workload. Too specific, requires exact knowledge to be useful.
- Queuing Models and Queuing Theory
  - Use distributions of CPU and I/O bursts. Knowing arrival and service rates - can compute utilization, average queue length, average wait time etc...
  - Little's formula - $n = \lambda \times W$ where n is the average queue length, λ is the avg. arrival rate and W is the avg. waiting time in queue.
- Other techniques: Simulations, Implementation