Processor Scheduling

Background

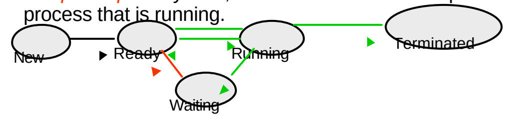
- The previous lecture introduced the basics of concurrency
  - Processes and threads
  - Definition, representation, management
- We now understand how a programmer can spawn concurrent computations
- The OS now needs to partition one of the central resources, the CPU, between these concurrent tasks

Scheduling

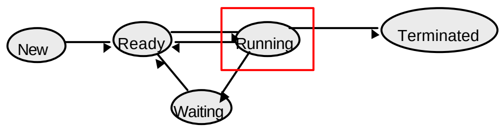
- The *scheduler* is the manager of the CPU resource
- It makes allocation decisions – it chooses to run certain processes over others from the ready queue
  - Zero threads: just loop in the idle loop
  - One thread: just execute that thread
  - More than one thread: now the scheduler has to make a resource allocation decision
- The *scheduling algorithm* determines how jobs are scheduled

Scheduling

- Threads alternate between performing I/O and performing computation
- In general, the scheduler runs:
  - when a process switches from running to waiting
  - when a process is created or terminated
  - when an interrupt occurs
- In a *non-preemptive* system, the scheduler waits for a running process to explicitly block, terminate or yield
- In a *preemptive* system, the scheduler can interrupt a process that is running.



Process States



Processes are I/O-bound when they spend most of their time in the waiting state
Processes are CPU-bound when they spend their time in the ready and running states

Time spent in each entry into the running state is called a CPU burst

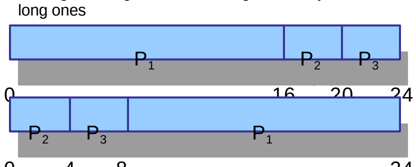
Scheduling Evaluation Metrics

- There are many possible quantitative criteria for evaluating a scheduling algorithm:
  - CPU utilization: percentage of time the CPU is not idle
  - Throughput: completed processes per time unit
  - Turnaround time: submission to completion
  - Waiting time: time spent on the ready queue
  - Response time: response latency
  - Predictability: variance in any of these measures

- The right metric depends on the context

Scheduling Algorithms FCFS

- **First-come First-served (FCFS) (FIFO)**
  - Jobs are scheduled in order of arrival
  - Non-preemptive
- **Problem:**
  - Average waiting time can be large if small jobs wait behind long ones



  - May lead to poor overlap of I/O and CPU and convoy effects

Scheduling Algorithms LIFO

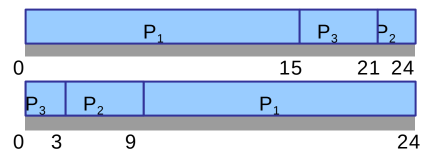
- **Last-In First-out (LIFO)**
  - Newly arrived jobs are placed at the head of the ready queue
  - Improves response time for newly created threads
- **Problem:**
  - May lead to starvation – early processes may never get the CPU

Problem

- You work as a short-order cook
  - A short order cook has to cook food for customers as they come in and specify which dish they want
  - Each dish takes a different amount of time to prepare
- You want to minimize the average amount of time the customers wait for their food
- What strategy would you use ?
  - Note: most restaurants use FCFS.

Scheduling Algorithms SJF

- **Shortest Job First (SJF)**
  - Choose the job with the shortest next CPU burst
  - Provably optimal for minimizing average waiting time



- **Problem:**
  - Impossible to know the length of the next CPU burst

Shortest Job First Prediction

- Approximate the duration of the next CPU-burst from the durations of the previous bursts
  - The past can be a good predictor of the future
- No need to remember entire past history
- Use exponential average:
  - t_n duration of the n^{th} CPU burst
  - $?_{n+1}$ predicted duration of the $(n+1)^{st}$ CPU burst
  - $?_{n+1} = ?\ t_n + (1- ?)\ ?_n$
  - where 0 ? ? ? 1
  - ? determines the weight placed on past behavior

Scheduling Algorithms SRTF

- SJF can be either preemptive or non-preemptive
  - The distinction occurs when a new, short job arrives while the currently process has a long time left to execute
- Preemptive SJF is called *shortest remaining time first*

Priority Scheduling

- **Priority Scheduling**
  - Choose next job based on priority
  - For SJF, priority = expected CPU burst
  - Can be either preemptive or non-preemptive
- **Problem:**
  - Starvation: jobs can wait indefinitely
- **Solution to starvation**
  - Age processes: increase priority as a function of waiting time

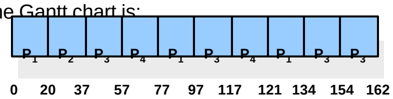
Round Robin

- **Round Robin (RR)**
  - Often used for timesharing
  - Ready queue is treated as a circular queue (FIFO)
  - Each process is given a time slice called a *quantum*
  - It is run for the quantum or until it blocks
  - RR allocates the CPU uniformly (fairly) across all participants. If average queue length is n, each participant gets 1/n
  - As the time quantum grows, RR becomes FCFS
  - Smaller quanta are generally desireable, because they improve response time
- **Problem:**
  - Context switch overhead of frequent context switch

RR with Time Quantum = 20

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

- The Gantt chart is:

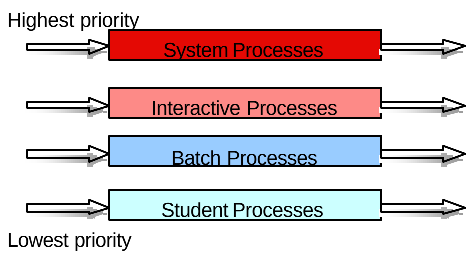


- Typically, higher average turnaround than SJF, but better response time.

Scheduling Algorithms

- **Multi-level Queue Scheduling**
- **Implement multiple ready queues based on job "type"**
  - interactive processes
  - CPU-bound processes
  - batch jobs
  - system processes
  - student programs
- **Different queues may be scheduled using different algorithms**
- **Intra-queue CPU allocation can be either strict or proportional**
- **Problem: Classifying jobs into queues is difficult**
  - A process may have CPU-bound phases as well as interactive ones

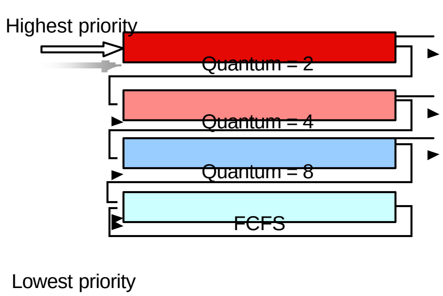
Multilevel Queue Scheduling



Scheduling Algorithms

- **Multi-level Feedback Queues**
- **Implement multiple ready queues**
  - Different queues may be scheduled using different algorithms
  - Just like multilevel queue scheduling, but assignments are not static
- **Jobs move from queue to queue based on feedback**
  - Feedback = The behavior of the job, e.g. does it require the full quantum for computation, or does it perform frequent I/O ?
- **Very general algorithm**
- **Need to select parameters for:**
  - Number of queues
  - Scheduling algorithm within each queue
  - When to upgrade and downgrade a job

Multilevel Feedback Queue Scheduling



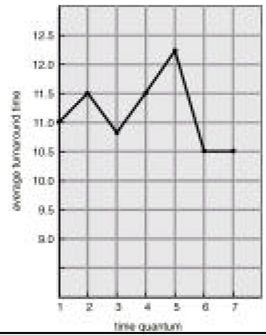
Real-time Scheduling

- Real-time processes have timing constraints
  - Expressed as deadlines or rate requirements
- Common RT scheduling policies
  - Rate monotonic
    - Simple, just one scalar priority related to the periodicity of the job
    - Priority = 1/rate
    - Static
  - Earliest deadline first (EDF)
    - Dynamic but more complex
    - Priority = deadline
- Both schemes require admission control to provide guarantees

Scheduling on a Multiprocessor

- Two alternatives based on the total number of queues:
  - Each processor has its own separate queue
  - All processors share a common ready-queue, and autonomously pick threads to execute from this common queue whenever they are idle (work stealing)
- Scheduling locally on any single processor is mostly the same as scheduling on a uniprocessor
- Issues:
  - Want to keep threads local to a processor (processor affinity)
  - Want to keep related threads together (gang-scheduling)

Turnaround Time Varies With The Time Quantum



process	time
P_1	6
P_2	3
P_3	1
P_4	7