CPU Scheduling Goals

- CPU scheduler must decide:
  - How long a process executes
  - In which order processes will execute
- User-oriented scheduling policy goals:
  - Minimize **average response time** (time from request received until response starts) while maximizing **number of interactive users** receiving adequate response
  - Minimize **turnaround time** (time from process start until completion)
    - Execution time plus waiting time
  - Minimize **variance of average response time**
    - Predictability is important
    - Process should always run in (roughly) same amount of time regardless of the load on the system

CPU Scheduling Goals (cont.)

- System-oriented scheduling policy goals:
  - Maximize **throughput** (number of processes that complete in unit time)
  - Maximize **processor utilization** (percentage of time CPU is busy)
- Other (non-performance related) system-oriented scheduling policy goals:
  - *Fairness* — in the absence of guidance from the user or the OS, processes should be treated the same, and no process should suffer *starvation* (being infinitely denied service)
    - May have to be less fair in order to minimize average response time!
  - Balance resources — keep all resources of the system (CPU, memory, disk, I/O) busy
    - Favor processes that will underuse stressed resources

FCFS Evaluation

- Non-preemptive
- Response time — slow if there is a large variance in process execution times
  - If one long process is followed by many short processes, short processes have to wait a long time
  - If one CPU-bound process is followed many I/O-bound processes, there's a "convoy effect"
    - Low CPU and I/O device utilization
- Throughput — not emphasized
- Fairness —penalizes short processes and I/O bound processes
- Starvation — not possible
- Overhead — minimal

Preemptive vs. Non-Preemptive Scheduling

- *Non-preemptive* scheduling — scheduler executes only when:
  - Process is terminated
  - Process switches from running to blocked
- *Preemptive* scheduler — scheduler can execute at (almost) any time:
  - Executes at times above, also when:
    - Process is created
    - Blocked process becomes ready
    - A timer interrupt occurs
  - More overhead, but keeps long processes from monopolizing CPU
  - Must not preempt OS kernel while it's servicing a system call (e.g., reading a file) or otherwise in an inconsistent state
  - ✘ Can still leave data shared between user processes in an inconsistent state

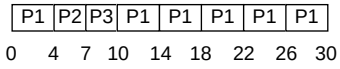
Round-Robin

- Policy:
  - Define a fixed *time slice* (also called a *time quantum*)
  - Choose process from head of ready queue
  - Run that process for at most one time slice, and if it hasn't completed by then, add it to the tail of the ready queue
  - If that process terminates or blocks before its time slice is up, choose another process from the head of the ready queue, and run that process for at most one time slice…
- Implement using:
  - Hardware timer that interrupts at periodic intervals
  - FIFO ready queue (add to tail, take from head)

Round-Robin Example

- Example 1:

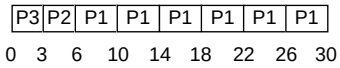
Process (Arrival Order)	P1	P2	P3
Burst Time	24	3	3
Arrival Time	0	0	0



average waiting time = (4 + 7 + (10–4)) / 3 = 5.66

- Example 2:

Process (Arrival Order)	P3	P2	P1
Burst Time	3	3	24
Arrival Time	0	0	0



average waiting time = (0 + 3 + 6) / 3 = 3

Round-Robin Evaluation

- Preemptive (at end of time slice)
- Response time — good for short processes
  - Long processes may have to wait $n*q$ time units for another time slice
    - n = number of other processes, q = length of time slice
- Throughput — depends on time slice
  - Too small — too many context switches
  - Too large — approximates FCFS
- Fairness — penalizes I/O-bound processes (may not use full time slice)
- Starvation — not possible
- Overhead — low

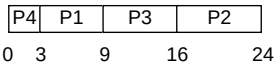
Shortest-Job-First (SJF)

- Other names:
  - Shortest-Process-Next (SPN)
- Policy:
  - Choose the process that has the smallest next CPU burst, and run that process non-preemptively (until termination or blocking)
  - In case of a tie, FCFS is used to break the tie
- Difficulty: determining length of next CPU burst
  - Approximation — predict length, based on past performance of the process, and on past predictions

SJF Example

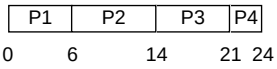
- SJF Example:

Process (Arrival Order)	P1	P2	P3	P4
Burst Time	6	8	7	3
Arrival Time	0	0	0	0



average waiting time = (0 + 3 + 9 + 16) / 4 = 7

- Same Example, FCFS Schedule:



average waiting time = (0 + 6 + 14 + 21) / 4 = 10.25

SJF Evaluation

- Non-preemptive
- Response time — good for short processes
  - Long processes may have to wait until a large number of short processes finish
  - Provably *optimal* — minimizes average waiting time for a given set of processes
- Throughput — high
- Fairness — penalizes long processes
- Starvation — possible for long processes
- Overhead — can be high (recording and estimating CPU burst times)