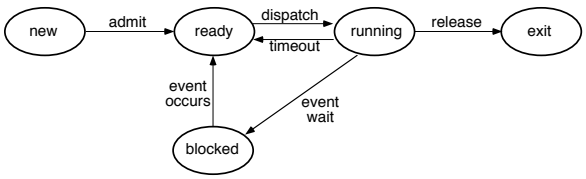
CPU Scheduling



- The *CPU scheduler* (sometimes called the *dispatcher* or *short-term scheduler*):
  - Selects a process from the ready queue and lets it run on the CPU
    - Assumes all processes are in memory, and one of those is executing on the CPU
  - Crucial in multiprogramming environment
    - Goal is to maximize CPU utilization
- *Non-preemptive* scheduling — scheduler executes only when:
  - Process is terminated
  - Process switches from running to blocked

Process Execution Behavior

- Assumptions:
  - One process per user
  - One thread per process
  - Processes are independent, and compete for resources (including the CPU)
- Processes run in CPU - I/O burst cycle:
  - Compute for a while (on CPU)
  - Do some I/O
  - Continue these two repeatedly
- Two types of processes:
  - CPU-bound — does mostly computation (long CPU burst), and very little I/O
  - I/O-bound — does mostly I/O, and very little computation (short CPU burst)

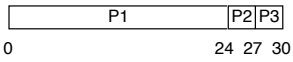
First-Come-First-Served (FCFS)

- Other names:
  - First-In-First-Out (FIFO)
  - Run-Until-Done
- Policy:
  - Choose process from ready queue in the order of its arrival, and run that process non-preemptively
    - Early FCFS schedulers were overly non-preemptive: the process did not relinquish the CPU until it was finished, even when it was doing I/O
    - Now, non-preemptive means the scheduler chooses another process when the first one terminates or blocks
- Implement using FIFO queue (add to tail, take from head)

FCFS Example

- Example 1:

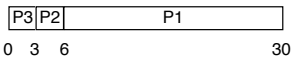
Process (Arrival Order)	P1	P2	P3
Burst Time	24	3	3
Arrival Time	0	0	0



average waiting time = (0 + 24 + 27) / 3 = 17

- 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

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

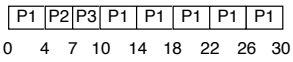
Round-Robin

- 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:

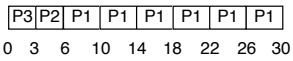
Process (Arrival Order)	P1	P2	P3
Burst Time	24	3	3
Arrival Time	0	0	0



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

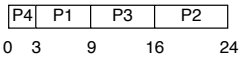
Shortest-Job-First (SJF)

- 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

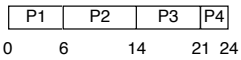
- SJF Example:

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)

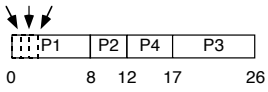
Shortest-Remaining-Time (SRT)

- SRT is a preemptive version of SJF (OSC just calls this preemptive SJF)
- Policy:
  - Choose the process that has the smallest next CPU burst, and run that process preemptively…
    - (until termination or blocking, or
    - until a process enters the ready queue (either a new process or a previously blocked process))
  - At that point, choose another process to run if one has a smaller expected CPU burst than what is left of the current process' CPU burst

SJF & SRT Example

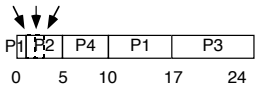
- SJF Example:

Process (Arrival Order)	P1	P2	P3	P4
Burst Time	8	4	9	5
Arrival Time	0	1	2	3



average waiting time = (0 + (8–1) + (12–3) + (17–2)) / 4 = 7.75

- Same Example, SRT Schedule:



average waiting time = ((0+(10–1) + (1–1) + (17–2) + (5–3)) / 4 = 6.5

SRT Evaluation

- Preemptive (at arrival of process into ready queue)
- Response time — good
  - Provably *optimal* — minimizes average waiting time for a given set of processes
- Throughput — high
- Fairness — penalizes long processes
  - Note that long processes eventually become short processes
- Starvation — possible for long processes
- Overhead — can be high (recording and estimating CPU burst times)

Priority Scheduling

- Policy:
  - Associate a priority with each process
    - Externally defined, based on importance, money, politics, etc.
    - Internally defined, based on memory requirements, file requirements, CPU requirements vs. I/O requirements, etc.
    - SJF is priority scheduling, where priority is inversely proportional to length of next CPU burst
  - Choose the process that has the highest priority, and run that process either:
    - preemptively, or
    - non-preemptively
- Evaluation
  - Starvation — possible for low-priority processes
    - Can avoid by *aging* processes: increase priority as they spend time in the system

Multilevel Queue Scheduling

- Policy:
  - Use several ready queues, and associate a different priority with each queue
  - Choose the process from the occupied queue that has the highest priority, and run that process either:
    - preemptively, or
    - non-preemptively
  - Assign new processes permanently to a particular queue
    - Foreground, background
    - System, interactive, editing, computing
  - Each queue can have a different scheduling policy
    - Example: preemptive, using timer
      - 80% of CPU time to foreground, using RR
      - 20% of CPU time to background, using FCFS

Multilevel Feedback Queue Scheduling

- Policy:
  - Use several ready queues, and associate a different priority with each queue
  - Choose the process from the occupied queue with the highest priority, and run that process either:
    - preemptively, or
    - non-preemptively
  - Each queue can have a different scheduling policy
  - Allow scheduler to move processes between queues
    - Start each process in a high-priority queue; as it finishes each CPU burst, move it to a lower-priority queue
    - Aging — move older processes to higher-priority queues
    - Feedback = use the past to predict the future — favor jobs that haven't used the CPU much in the past — close to SRT!

CPU Scheduling in UNIX using Multilevel Feedback Queue Scheduling

- Policy:
  - Multiple queues, each with a priority value (low value = high priority):
    - Kernel processes have negative values
      - Includes processes performing system calls, that just finished their I/O and haven't yet returned to user mode
    - User processes (doing computation) have positive values
  - Choose the process from the occupied queue with the highest priority, and run that process preemptively, using a timer (time slice typically around 100ms)
    - Round-robin scheduling in each queue
  - Move processes between queues
    - Keep track of clock ticks (60/second)
    - Once per second, add clock ticks to priority value
    - Also change priority based on whether or not process has used more than it's "fair share" of CPU time (compared to others)