CPU Scheduling

Alternating Sequence of CPU and I/O Bursts

load store
add store
read from file
} CPU burst

wait for I/O
} I/O burst

store increment
index
write to file
} CPU burst

wait for I/O
} I/O burst

load store
add store
read from file
} CPU burst

wait for I/O
} I/O burst
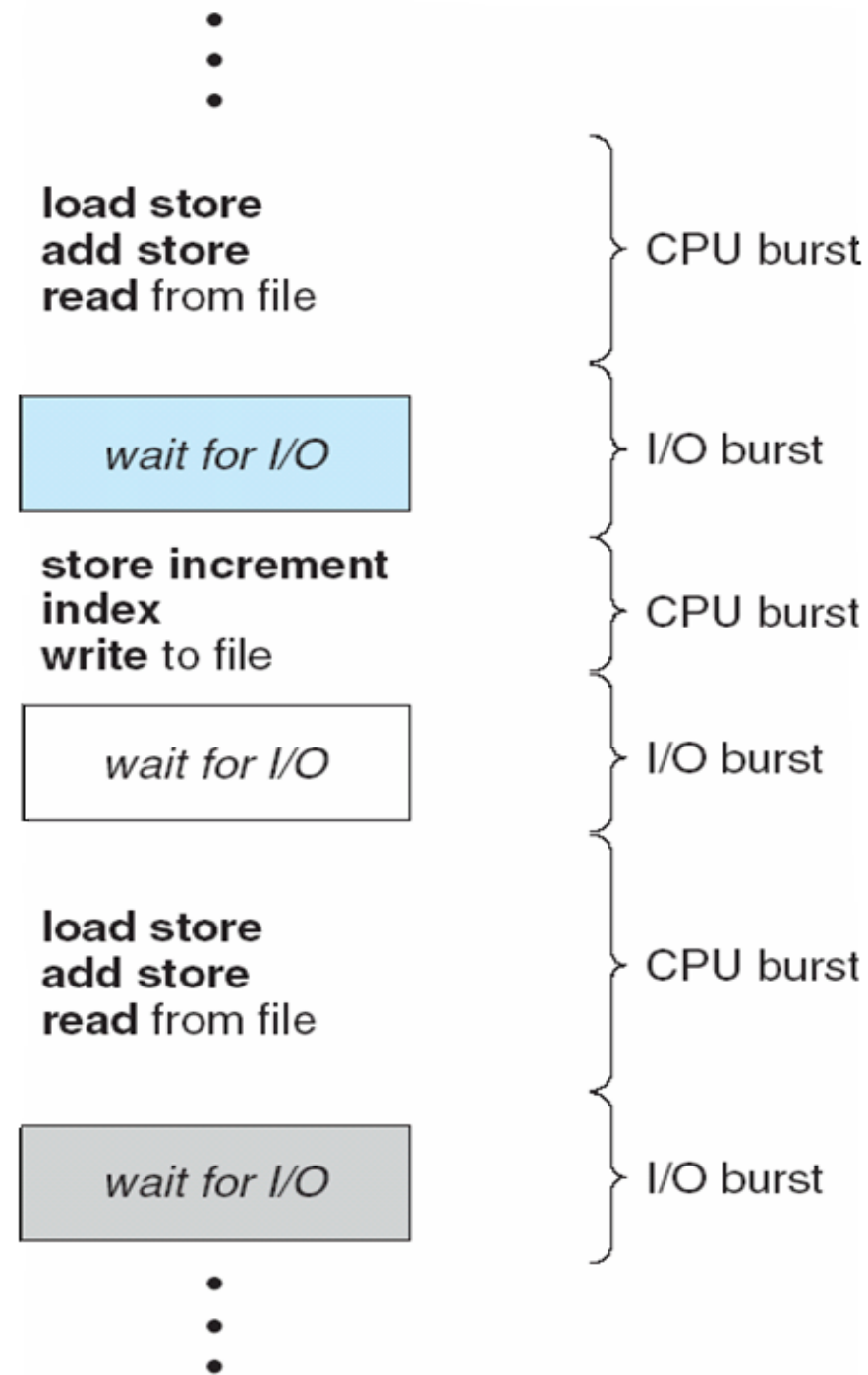
CPU Scheduler

- Selects from among the processes in ready queue, and allocates the CPU to one of them
  - Queue may be ordered in various ways
- CPU scheduling decisions may take place when a process:
  1. Switches from running to waiting state
  2. Switches from running to ready state
  3. Switches from waiting to ready
  4. Terminates
- Scheduling under 1 and 4 is **nonpreemptive**
- All other scheduling is **preemptive**
  - Consider access to shared data
  - Consider preemption while in kernel mode
  - Consider interrupts occurring during crucial OS activities

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** – time it takes for the dispatcher to stop one process and start another running

Scheduling Criteria

- **CPU utilization** – keep the CPU as busy as possible

- **Throughput** – # of processes that complete their execution per time unit

- **Turnaround time** – amount of time to execute a particular process

- **Waiting time** – amount of time a process has been 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 output (for time-sharing environment)
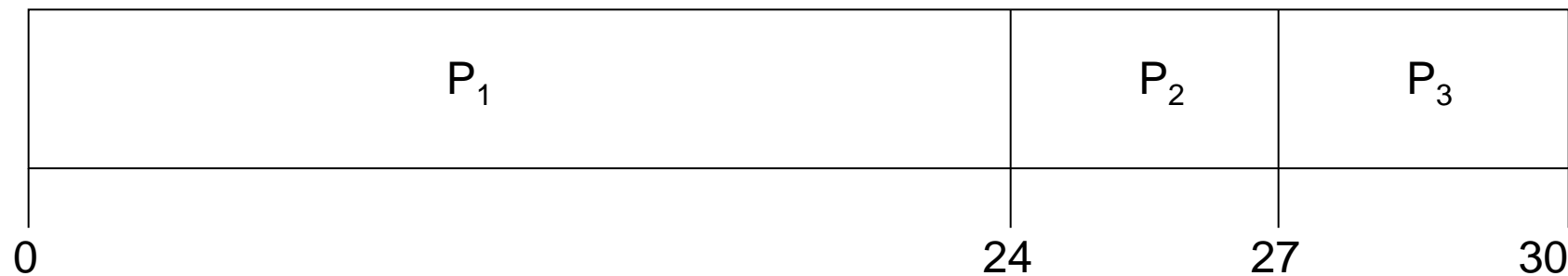
Scheduling Algorithm Optimization Criteria

- Max CPU utilization

- Max throughput

- Min turnaround time

- Min waiting time

- Min response time

First-Come, First-Served (FCFS) Scheduling

Process	Burst Time
P_1	24
P_2	3
P_3	3

- Suppose that the processes arrive in the order: P_1 , P_2 , P_3
  The Gantt Chart for the schedule is:

P_1		P_2	P_3
0	24	27	30

- Waiting time for P_1 = 0; P_2 = 24; P_3 = 27
- Average waiting time: (0 + 24 + 27)/3 = 17

FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order:

$$P_2, P_3, P_1$$

- The Gantt chart for the schedule is:

P$_2$	P$_3$	P$_1$

0   3   6   30

- Waiting time for $P_1 = 6$; $P_2 = 0$, $P_3 = 3$
- Average waiting time: $(6 + 0 + 3)/3 = 3$
- Much better than previous case
- **Convoy effect** - short process behind long process
 - Consider one CPU-bound and many I/O-bound processes

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

- SJF is optimal – gives minimum average waiting time for a given set of processes
  - The difficulty is knowing the length of the next CPU request
  - Could ask the user

Example of SJF

Process   Burst Time

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3

- SJF scheduling chart

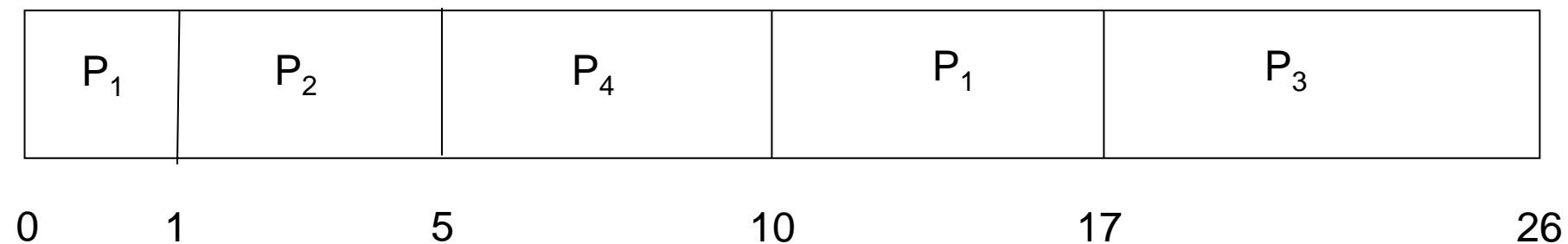| P_4	P_1	P_3	P_2

0   3   9   16   24
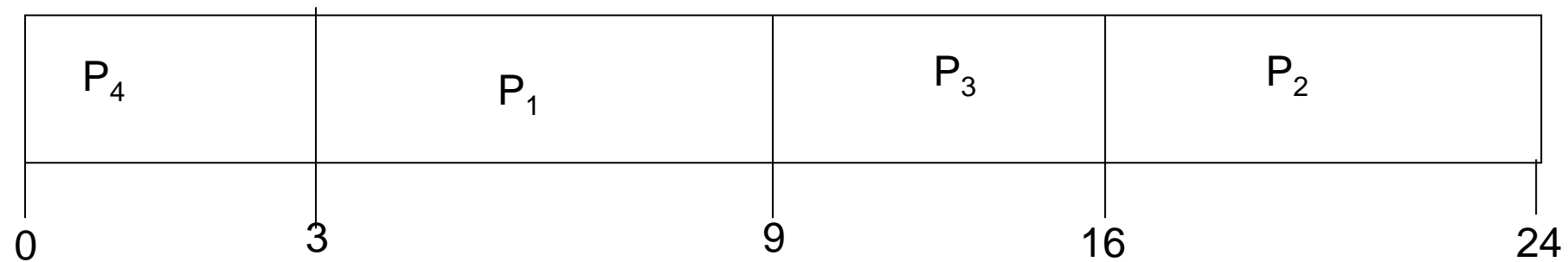
- Average waiting time = (3 + 16 + 9 + 0) / 4 = 7

Example of Shortest-remaining-time-first

- Now we add the concepts of varying arrival times and preemption to the analysis

Process	*Arrival* Time	Burst Time
P_1	0	8
P_2	1	4
P_3	2	9
P_4	3	5

- *Preemptive* SJF Gantt Chart

P₁	P₂	P₄	P₁	P₃

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0    1         5              10            17                 26
```

- Average waiting time = [(10-1)+(1-1)+(17-2)+5-3)]/4 = 26/4 = 6.5 msec

Priority Scheduling

- A priority number (integer) is associated with each process

- The CPU is allocated to the process with the highest priority (smallest integer $\equiv$ highest priority)
  - Preemptive
  - Nonpreemptive

- SJF is priority scheduling where priority is the inverse of predicted next CPU burst time

- Problem $\equiv$ **Starvation** – low priority processes may never execute

- Solution $\equiv$ **Aging** – as time progresses increase the priority of the process

Example of Priority Scheduling

Process	Burst Time	Priority
P_1	10	3
P_2	1	1
P_3	2	4
P_4	1	5
P_5	5	2

- Priority scheduling Gantt Chart

P_2	P_5	P_1	P_3	P_4

0   1   6   16   18   19
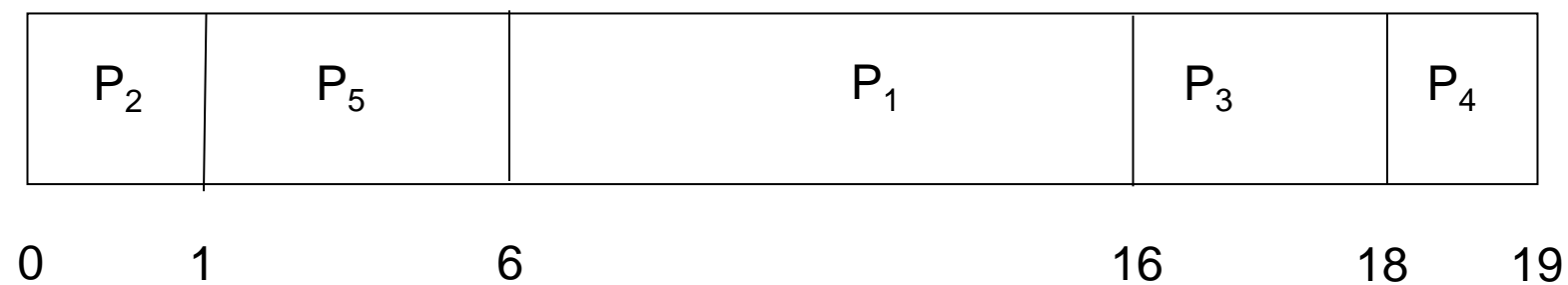
- Average waiting time = 8.2 msec

Round Robin (RR)

- Each process gets a small unit of CPU time (**time quantum** q), 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.
- Timer interrupts at every quantum to schedule next process
- Performance??
  - q large $\Rightarrow$ FIFO
  - q small $\Rightarrow$ q must be large with respect to context switch, otherwise overhead is too high

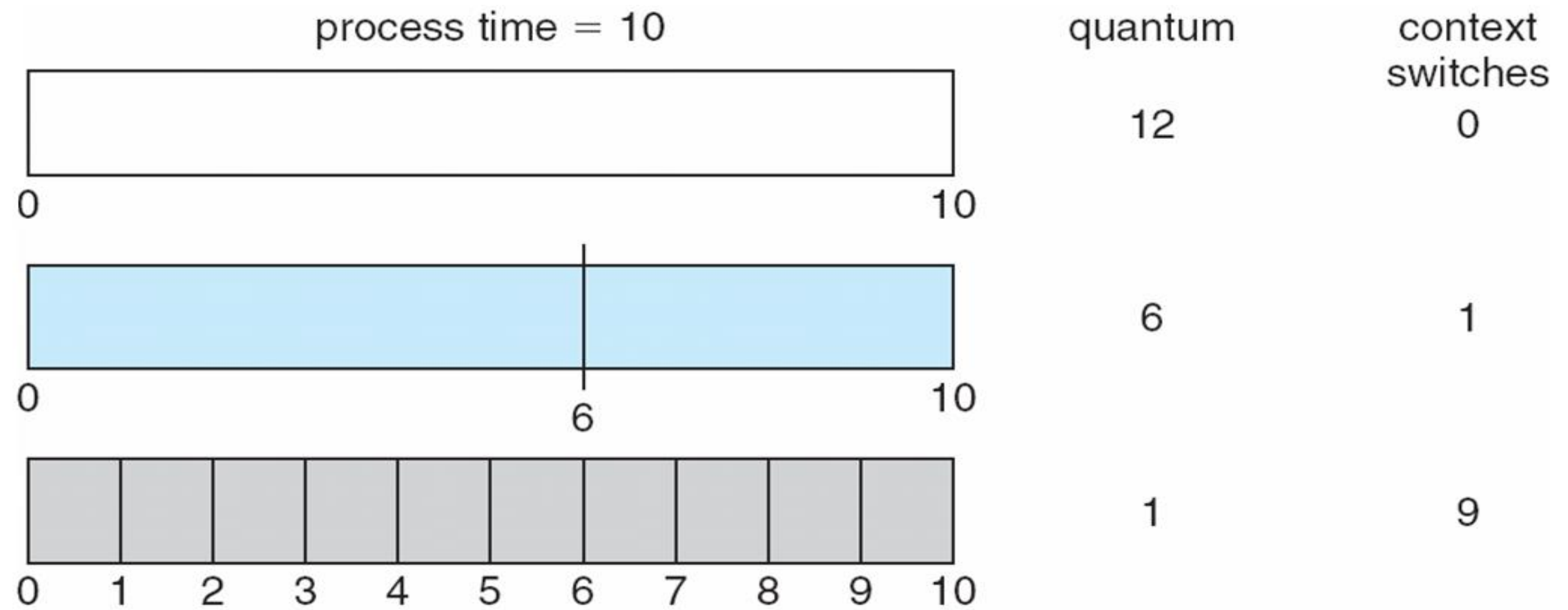# Example of RR with Time Quantum = 4

Process	Burst Time
P_1	24
P_2	3
P_3	3

- The Gantt chart is:

P_1	P_2	P_3	P_1	P_1	P_1	P_1	P_1

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0      4      7      10     14     18     22     26     30
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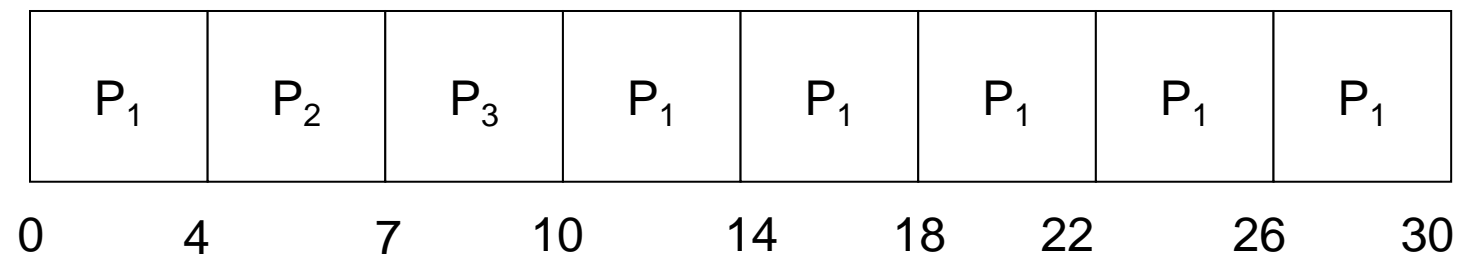
- Typically, higher average turnaround than SJF, but better *response*
- q should be large compared to context switch time
- q usually 10ms to 100ms, context switch < 10 usec

Time Quantum and Context Switch Time

Multilevel Queue

- Ready queue is partitioned into separate queues, eg:
  - foreground (interactive)
  - background (batch)
- Process permanently in a given queue
- Each queue has its own scheduling algorithm:
  - foreground – RR
  - background – FCFS
- Scheduling must be done between the queues:
  - Fixed priority scheduling; (i.e., 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

Multilevel Queue Scheduling

highest priority

→ system processes →

→ interactive processes →

→ interactive editing processes →

→ batch processes →

→ student processes →
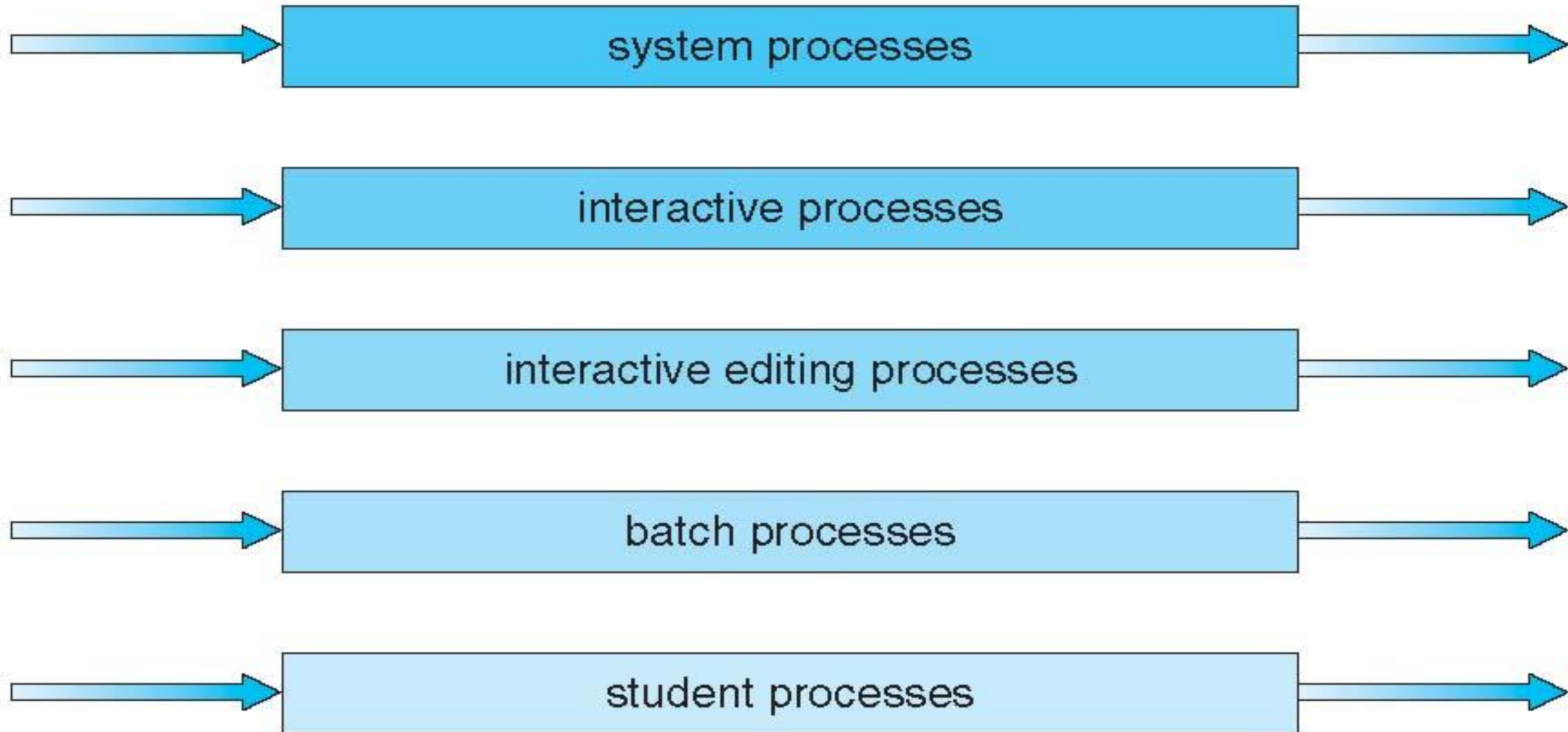
lowest priority

Multilevel Feedback Queue

- A process can move between the various queues; aging can be implemented this way

- Multilevel-feedback-queue 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

Example of Multilevel Feedback Queue

- Three queues:
  - Q_0 – RR with time quantum 8 milliseconds
  - Q_1 – RR time quantum 16 milliseconds
  - Q_2 – FCFS

- Scheduling
  - A new job enters queue Q_0 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 Q_1
  - At Q_1 job is again served FCFS and receives 16 additional milliseconds
    - If it still does not complete, it is preempted and moved to queue Q_2

Multilevel Feedback Queues
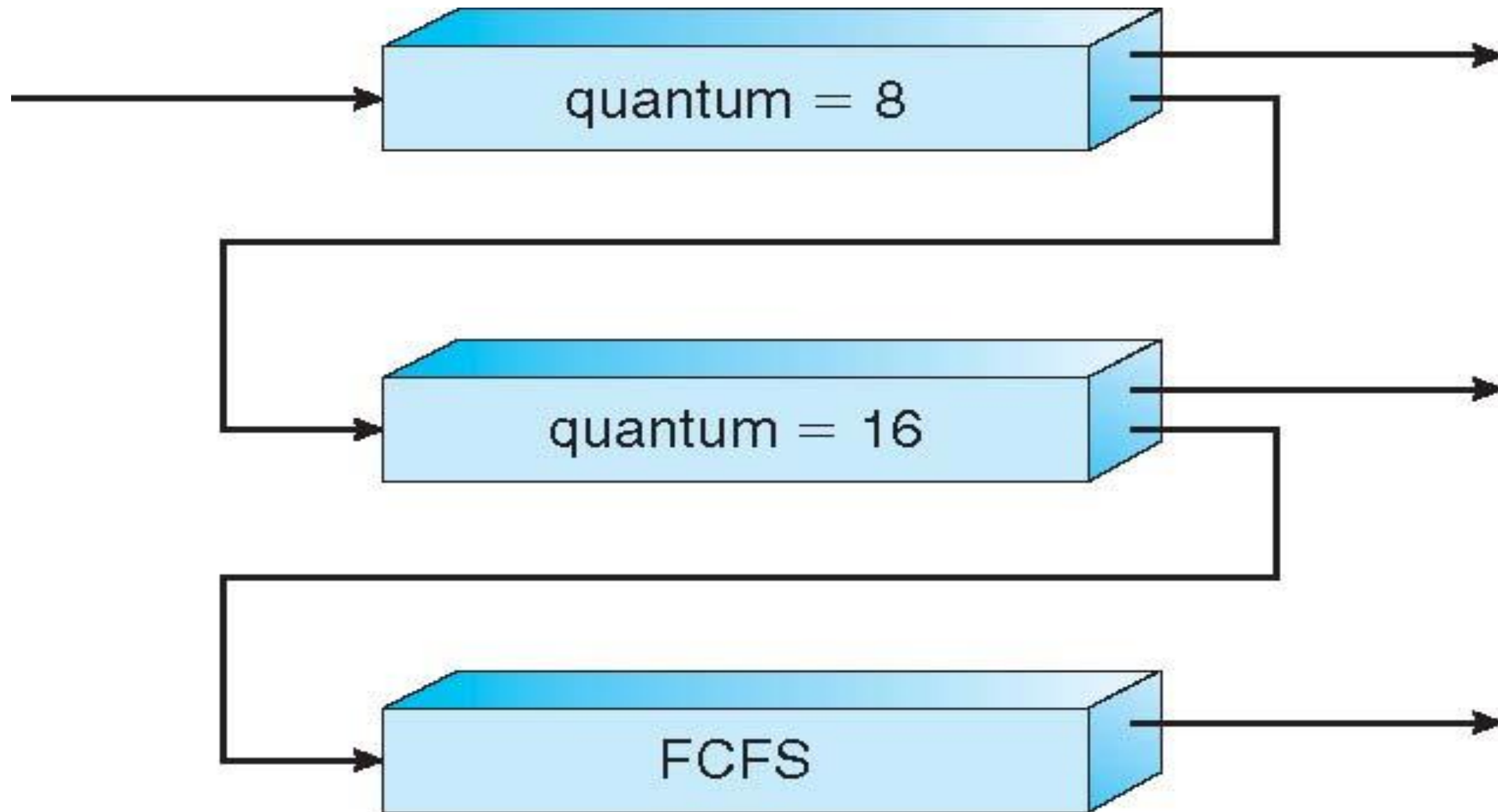
Thread Scheduling

- Distinction between user-level and kernel-level threads

- When threads supported, threads scheduled, not processes

- Many-to-one and many-to-many models, thread library schedules user-level threads to run on LWP

  – Known as **process-contention scope (PCS)** since scheduling competition is within the process

  – Typically done via priority set by programmer

- Kernel thread scheduled onto available CPU is **system-contention scope (SCS)** – competition among all threads in system

Multiple-Processor Scheduling

- CPU scheduling more complex when multiple CPUs are available

- **Homogeneous processors** within a multiprocessor

- **Asymmetric multiprocessing** – only one processor accesses the system data structures, alleviating the need for data sharing

- **Symmetric multiprocessing (SMP)** – each processor is self-scheduling, all processes in common ready queue, or each has its own private queue of ready processes
  - Currently, most common

- **Processor affinity** – process has affinity for processor on which it is currently running
  - **soft affinity**
  - **hard affinity**
  - Variations including **processor sets**

NUMA and CPU Scheduling
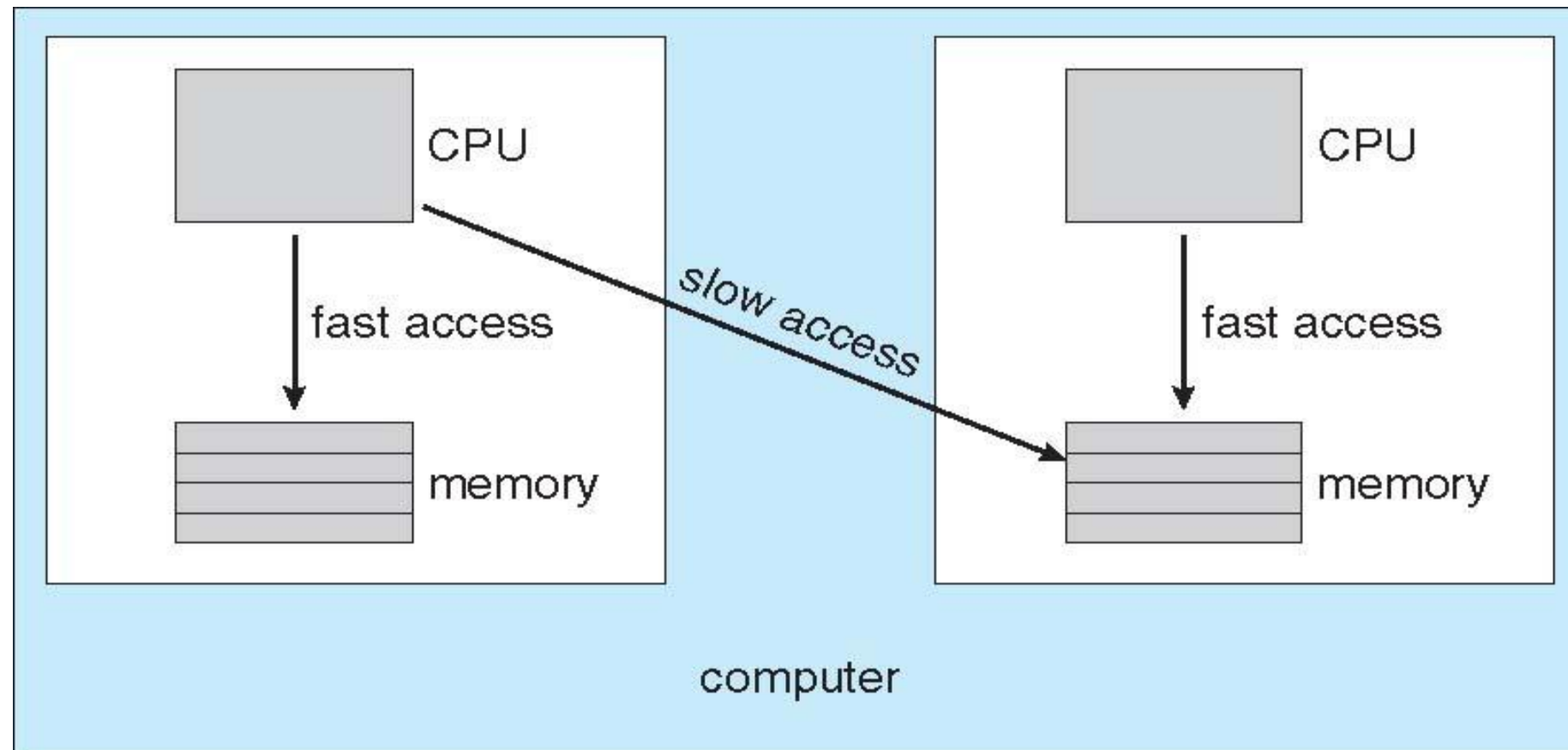
Note that memory-placement algorithms can also consider affinity

Multicore Processors

- Recent trend to place multiple processor cores on same physical chip

- Faster and consumes less power

- Multiple threads per core also growing
  - Takes advantage of memory stall to make progress on another thread while memory retrieve happens

Multithreaded Multicore System