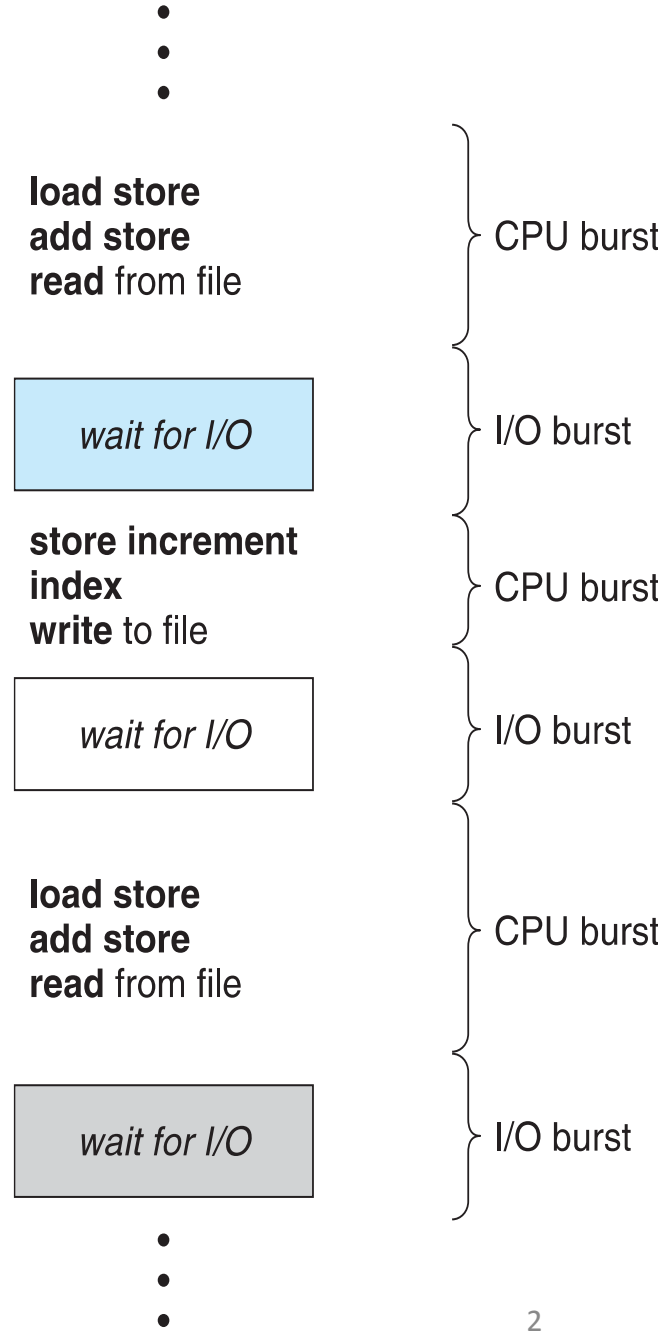
Scheduling

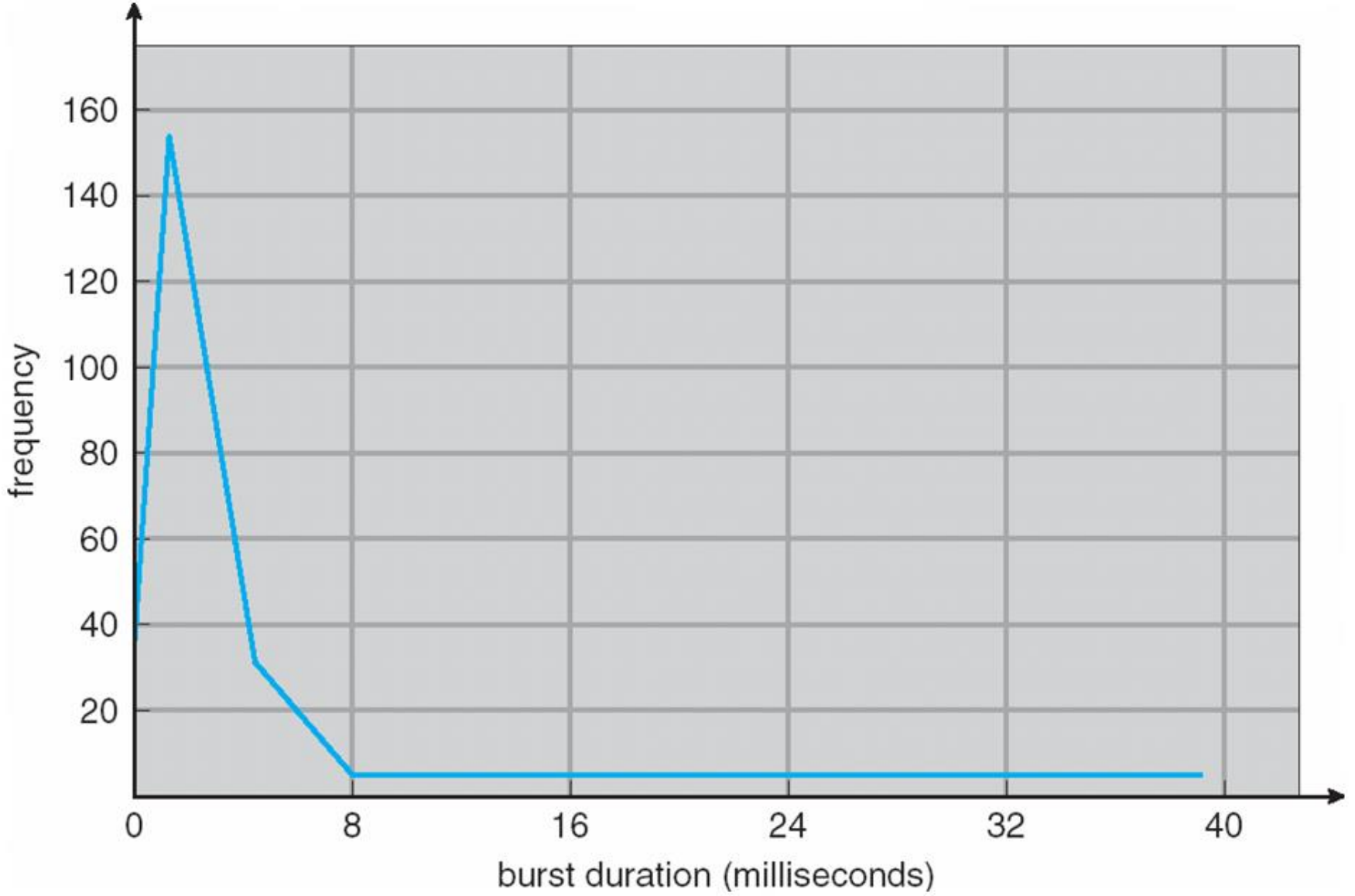
CS 3113

Behavior of a Process

- Maximum CPU utilization obtained with multiprogramming
- CPU–I/O Burst Cycle: Process execution consists of a **cycle** of CPU execution and I/O wait
- **CPU burst** followed by **I/O burst**
- When scheduling a process, the CPU burst distribution is our main concern



A Typical Distribution of CPU-burst Times



CPU Scheduler

- Short-term 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
- Cases 2 and 3 require process preemption

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 continue executing that program
- **Dispatch latency:** time it takes for the dispatcher to stop one process and start another running

Scheduling Criteria

A variety of metrics are possible:

- **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

Possibilities for 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 at time zero: P_1 , P_2 , P_3

The Gantt Chart for the schedule is:

- Waiting time for each: ????
- Average waiting time: ???

First- Come, First-Served (FCFS) Scheduling

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- Suppose that the processes arrive in the order at time zero: P_1 , P_2 , P_3

The Gantt Chart for the schedule is:

- 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:

- Waiting time for all: *????*
- Average waiting time: ???

FCFS Scheduling (Cont.)

Suppose that the processes arrive in the order:

$$P_2 , P_3 , P_1$$

- The Gantt chart for the schedule is:

- Waiting time for all: $P_1 = 6; P_2 = 0, P_3 = 3$
- 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 programmer to tell us

Example of SJF

Process	Burst Time
P_1	6
P_2	8
P_3	7
P_4	3

- SJF scheduling chart

- Average waiting time = ????

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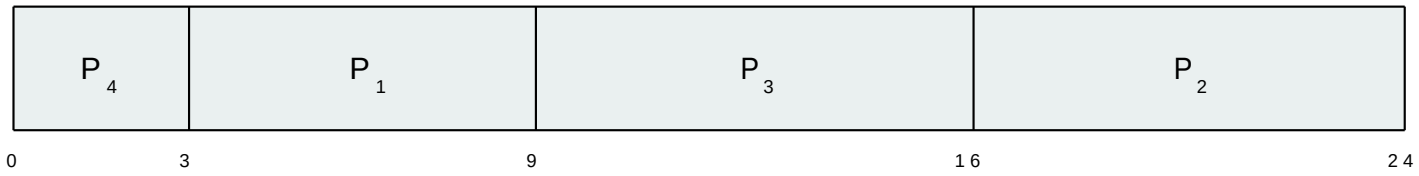
- SJF scheduling chart



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

Estimating Length of Next CPU Burst

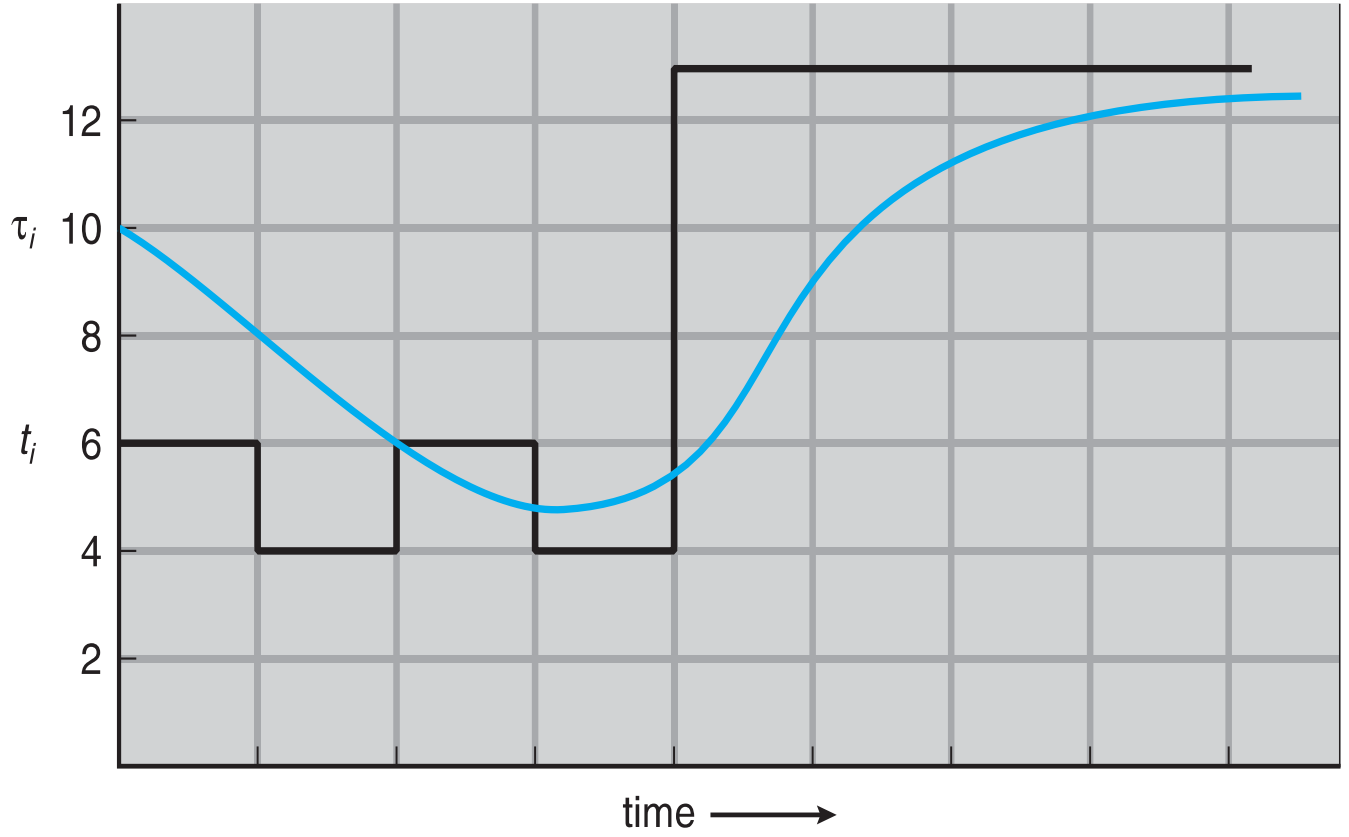
- Can only estimate the length – should be similar to the previous one
  - Then pick process with shortest predicted next CPU burst

- Can be done by using the length of previous CPU bursts, using exponential averaging

1. t_n = actual length of n^{th} CPU burst
2. τ_{n+1} = predicted value for the next CPU burst
3. α, $0 \leq \alpha \leq 1$
4. Define : $\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n$.

- Commonly, α set to ½
- Preemptive version called **shortest-remaining-time-first**

Example Burst Length Predictions



CPU burst (t_i)		6	4	6	4	13	13	13	...
"guess" (τ_i)	10	8	6	6	5	9	11	12	...

Example Cases of Exponential Averaging

- $\alpha = 0$
  - $\tau_{n+1} = \tau_n$
  - Recent history does not count
- $\alpha = 1$
  - $\tau_{n+1} = \alpha\, t_n$
  - Only the actual last CPU burst counts
- If we expand the formula, we get:

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\alpha\, t_{n-1} + \ldots$$

$$+ (1 - \alpha)^j \alpha\, t_{n-j} + \ldots$$

$$+ (1 - \alpha)^{n+1} \tau_0$$

- Since both α and $(1 - \alpha)$ are less than or equal to 1, each successive term has less weight than its predecessor

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

- Average waiting time = ??? msec

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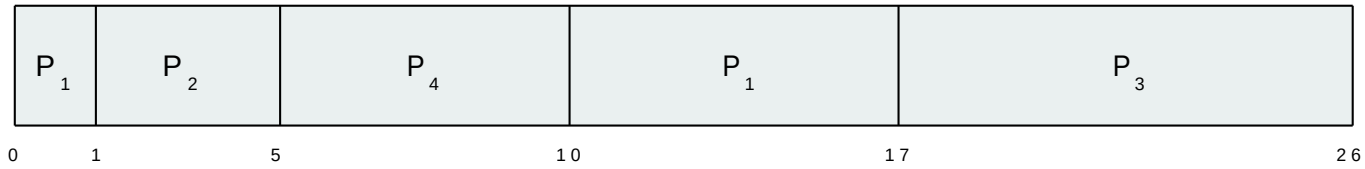

- Average waiting time ??? msec

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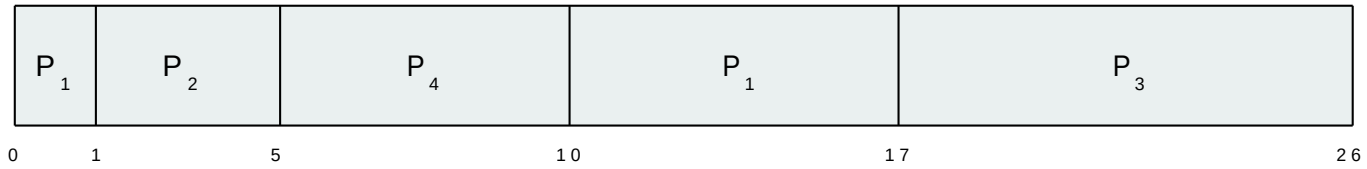

- Average waiting time = [(10-1)+(1-1)+(17-2)+5-3)]/4 = 26/4 = 6.5 msec

Priority Scheduling

- A priority number (integer) is associated with each process
- The CPU is allocated to the process with the highest priority
  - In Unix: smallest integer ≡ highest priority
  - Two versions:
    - Preemptive
    - Nonpreemptive
- SJF is priority scheduling where priority is the inverse of predicted next CPU burst time
- Problem ≡ **Starvation** – low priority processes may never execute
- Solution ≡ **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

- Average waiting time = ??? msec

Example of Priority Scheduling

Process	Burst Time	Priority
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P_2	1	1
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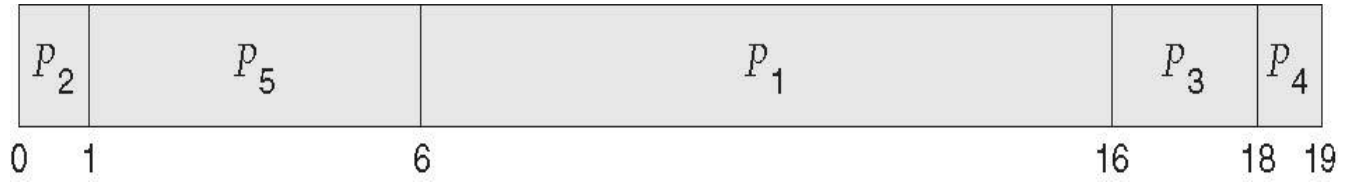
- Priority scheduling Gantt Chart



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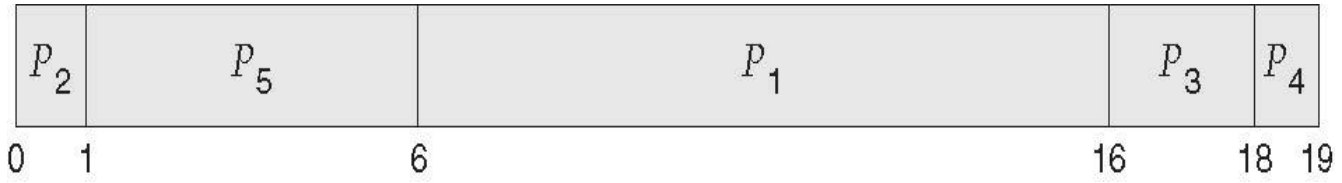
- Priority scheduling Gantt Chart



- Average waiting time = 8.2 msec

Round Robin (RR) Scheduling

- 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.

Round Robin (RR) Scheduling

- Timer interrupts every quantum to schedule next process
- Performance
  - q large $\Rightarrow$ Reduces to FIFO
  - q small $\Rightarrow$ All jobs must use multiple quanta to complete
    - q must be large with respect to context switch time, 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:

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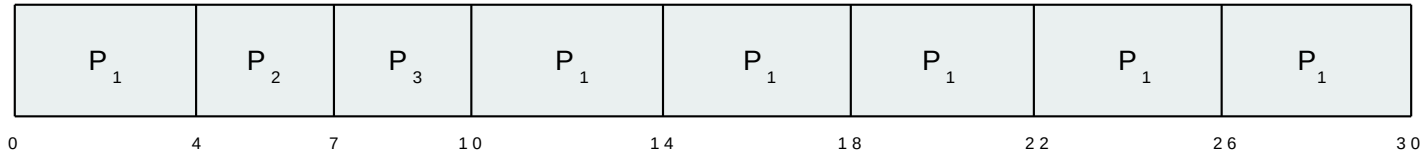
- The Gantt chart is:



Round Robin Notes

- 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

Multilevel Queues

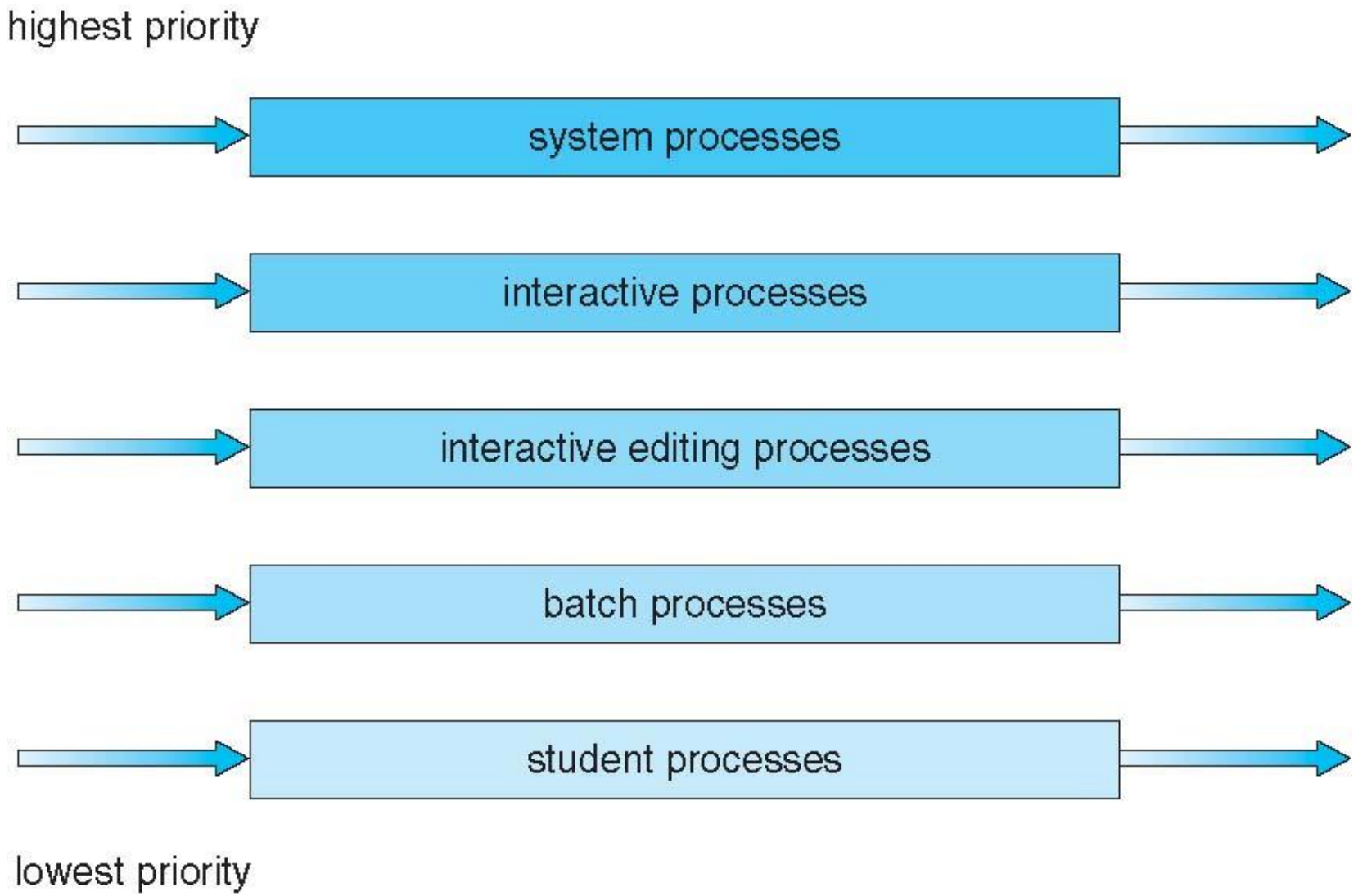
- Ready queue is partitioned into separate queues, e.g.:
  - **foreground** (interactive)
  - **background** (batch)
- Process permanently in a given queue
- Each queue has its own scheduling algorithm. E.g.:
  - Foreground: RR
  - Background: FCFS

Multilevel Queues

Scheduling possibilities between the queues:

- Fixed priority scheduling
  - 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. For example:
  - 80% to foreground in RR
  - 20% to background in FCFS

Multilevel Queue Scheduling

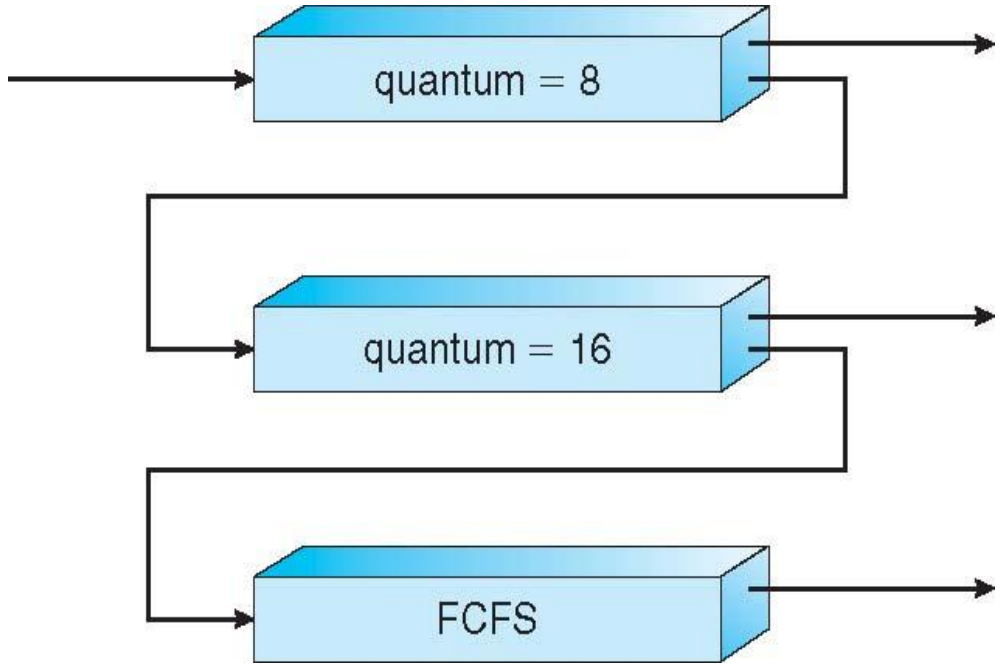


Multilevel Feedback Queue

- A process can move between the various queues (Aging!)
- 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: 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
    - 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

Thread Scheduling

Distinction between user-level and kernel-level threads

- Many-to-one and many-to-many models, the user-space thread library schedules user-level threads to run on a light-weight process (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

Scheduling within the Pthread Library

- API allows the program to specify either PCS or SCS during thread creation
  - PTHREAD_SCOPE_PROCESS schedules threads using PCS scheduling
  - PTHREAD_SCOPE_SYSTEM schedules threads using SCS scheduling
- Options can be limited by OS: Linux and Mac OS X only allow PTHREAD_SCOPE_SYSTEM

Pthread Scheduling API: Determining Default Scope

```
#include <pthread.h>
#include <stdio.h>
#define NUM_THREADS 5
int main(int argc, char *argv[]) {
   int i, scope;
   pthread_t tid[NUM THREADS];
   pthread_attr_t attr;
   /* get the default attributes */
   pthread_attr_init(&attr);
   /* first inquire on the current scope */
   if (pthread_attr_getscope(&attr, &scope) != 0)
      fprintf(stderr, "Unable to get scheduling scope\n");
   else {
      if (scope == PTHREAD_SCOPE_PROCESS)
         printf("PTHREAD_SCOPE_PROCESS");
      else if (scope == PTHREAD_SCOPE_SYSTEM)
         printf("PTHREAD_SCOPE_SYSTEM");
      else
         fprintf(stderr, "Illegal scope value.\n");
   }
```

Pthread Scheduling API

```
   /* set the scheduling algorithm to PCS or SCS */
   pthread_attr_setscope(&attr, PTHREAD_SCOPE_SYSTEM);
   /* create the threads */
   for (i = 0; i < NUM_THREADS; i++)
      pthread_create(&tid[i],&attr, runner, NULL);
   /* now join on each thread */
   for (i = 0; i < NUM_THREADS; i++)
      pthread_join(tid[i], NULL);
}
/* Each thread will begin control in this function */
void *runner(void *param)
{
   /* do some work ... */
   pthread_exit(0);
}
```

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 for scheduling, alleviating the need for data sharing
- **Symmetric multiprocessing (SMP):** each processor is self-scheduling
  - All processes in common ready queue, or
  - Each processor has its own private queue of ready processes
- **Processor affinity:** process has affinity for processor on which it is currently running
  - **soft affinity**
  - **hard affinity**
  - Variations including **processor sets**

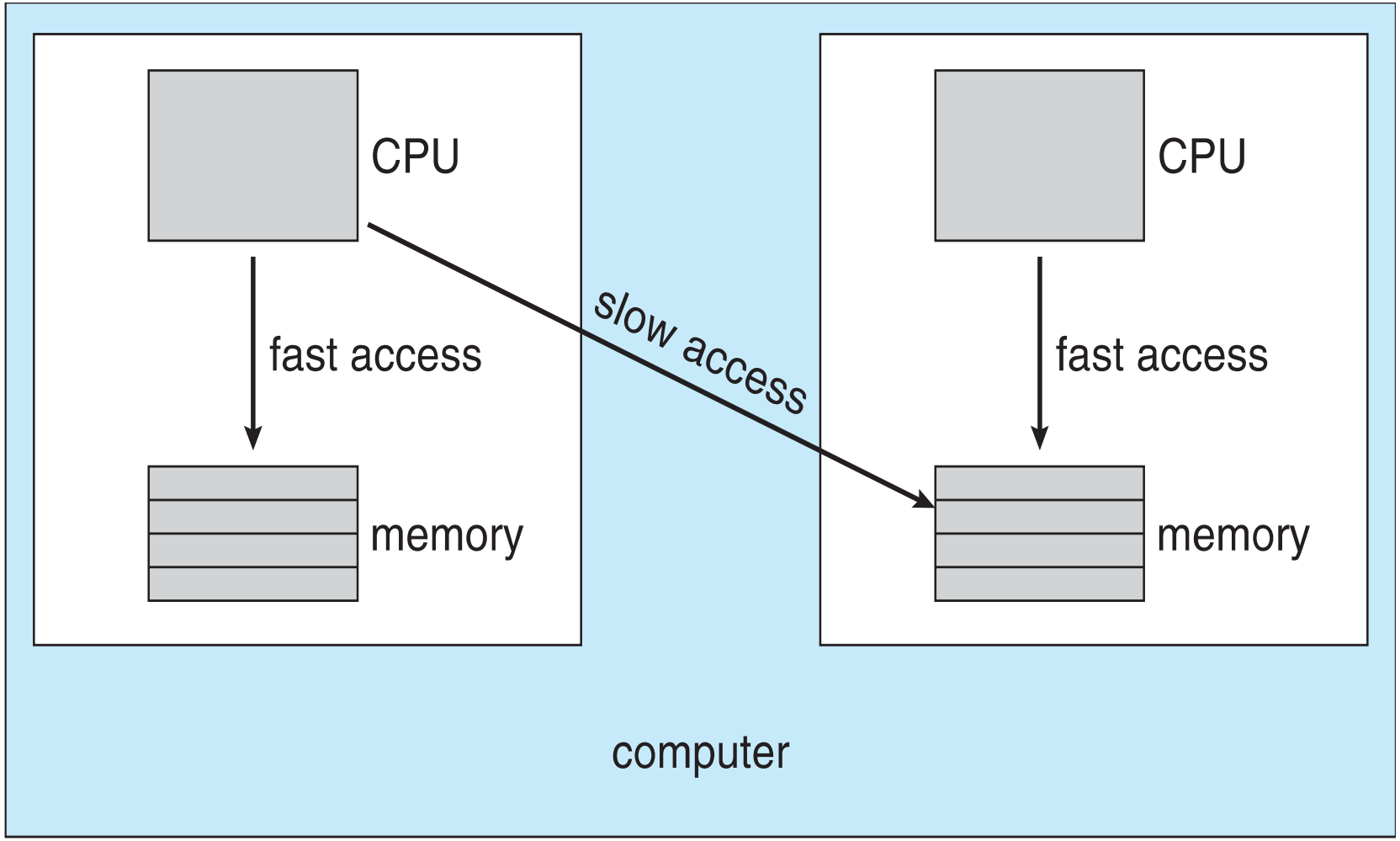
Multiple-Processor Scheduling: Load Balancing

If SMP, need to keep all CPUs loaded for efficiency

- **Load balancing** attempts to keep workload evenly distributed
- **Push migration:** periodic task checks load on each processor, and if found pushes task from overloaded CPU to other CPUs
- **Pull migration:** idle processors pulls waiting task from busy processor

NUMA and CPU Scheduling

NUMA: Non-Uniform Memory Allocation



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