Scheduling I

- Introduction to scheduling
- Scheduling algorithms

Role of Dispatcher vs. Scheduler

- Dispatcher
  - Low-level mechanism
  - Responsibility: context switch

- Scheduler
  - High-level policy
  - Responsibility: deciding which process to run

- Could have an allocator for CPU as well
  - Parallel and distributed systems

When to schedule?

- When does scheduler make decisions?
  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

- Minimal: nonpreemptive
  - ?

- Additional circumstances: preemptive
  - ?

Overview of scheduling algorithms

- Criteria: workload and environment
- Workload
  - Process behavior: alternating sequence of CPU and I/O bursts
  - CPU bound v.s. I/O bound
- Environment
  - Batch v.s. interactive?
  - Specialized v.s. general?

Scheduling performance metrics

- Min waiting time: don't have process wait long in ready queue
- Max CPU utilization: keep CPU busy
- Max throughput: complete as many processes as possible per unit time
- Min response time: respond immediately
- Fairness: give each process (or user) same percentage of CPU

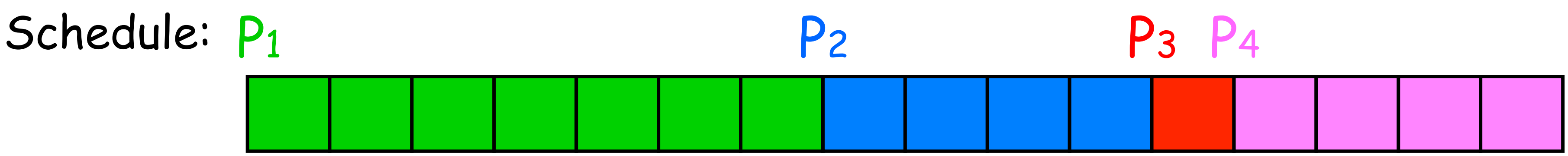
First-Come, First-Served (FCFS)

- Simplest CPU scheduling algorithm
  - First job that requests the CPU gets the CPU
  - Nonpreemptive
- Implementation: FIFO queue

Example of FCFS

Process	Arrival Time	Burst Time
P_1	0	7
P_2	0	4
P_3	0	1
P_4	0	4

- Gantt chart

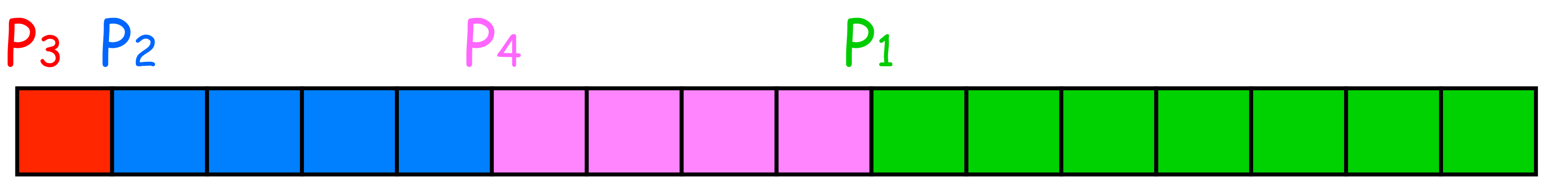


- Average waiting time: $(0 + 7 + 11 + 12)/4 = 7.5$

Example of FCFS: different arrival order

Process	Arrival Time	Burst Time
P_1	0	7
P_2	0	4
P_3	0	1
P_4	0	4

Arrival order: P_3 P_2 P_4 P_1



- Average waiting time: (9 + 1 + 0 + 5)/4 = 3.75

FCFS advantages and disadvantages

- Advantages
  - Simple
  - Fair
- Disadvantages
  - waiting time depends on arrival order
  - Convoy effect: short process stuck waiting for long process
  - Also called head of the line blocking

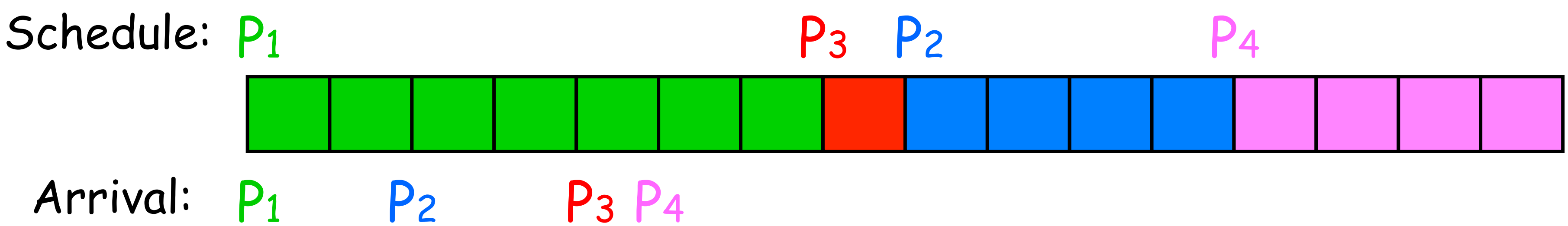
Shortest Job First (SJF)

- Schedule the process with the shortest time
- FCFS if same time

Example of SJF (w/o preemption)

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

- Gantt chart



- Average waiting time: (0 + 6 + 3 + 7)/4 = 4

SJF Advantages and Disadvantages

- Advantages
  - Minimizes average wait time. Provably optimal if no preemption allowed
- Disadvantages
  - Not practical: difficult to predict burst time
    - Possible: past predicts future
  - May starve long jobs

Shortest Remaining Time First (SRTF)

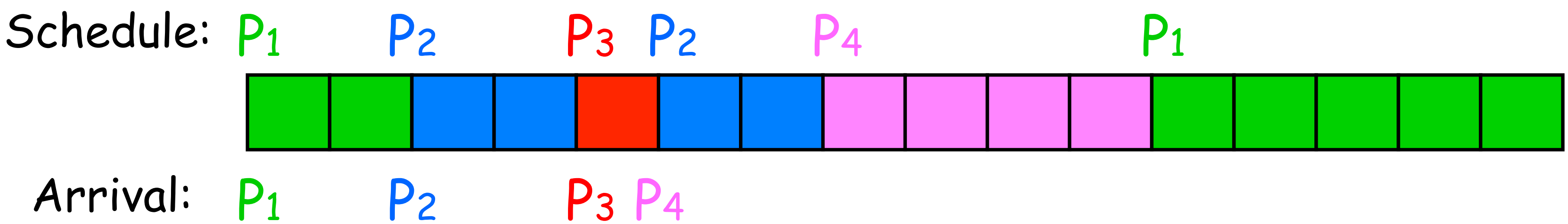
- If new process arrives w/ shorter CPU burst than the remaining for current process, schedule new process
  - SJF with preemption

- Advantage: reduces average waiting time
  - Provably optimal

Example of SRTF

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

- Gantt chart



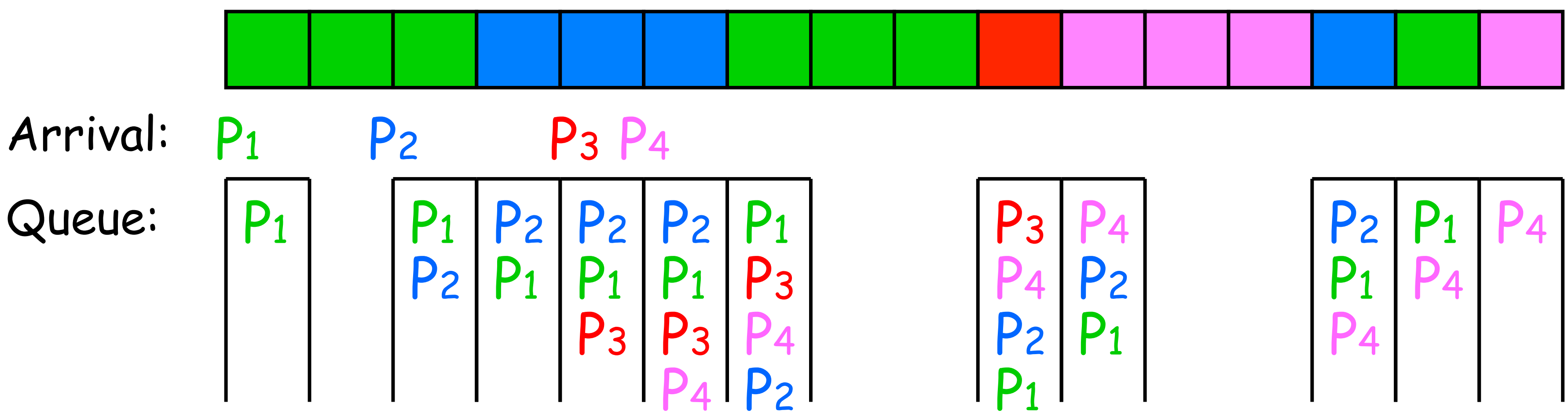
- Average waiting time: (9 + 1 + 0 + 2)/4 = 3

Round-Robin (RR)

- Practical approach to support time-sharing
- Run process for a time slice, then move to back of FIFO queue
- Preempted if still running at end of time-slice
- How to determine time slice?

Example of RR: time slice = 3

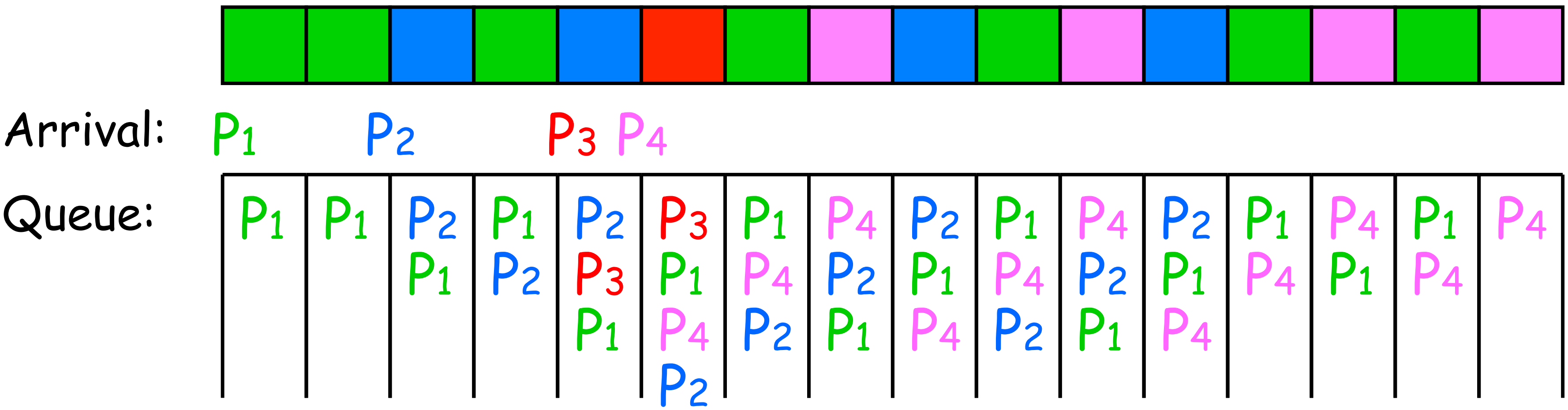
Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4



- Average waiting time: (8 + 8 + 5 + 7)/4 = 7
- Average response time: (0 + 1 + 5 + 5)/4 = 2.75
- # of context switches: 7

Smaller time slice = 1

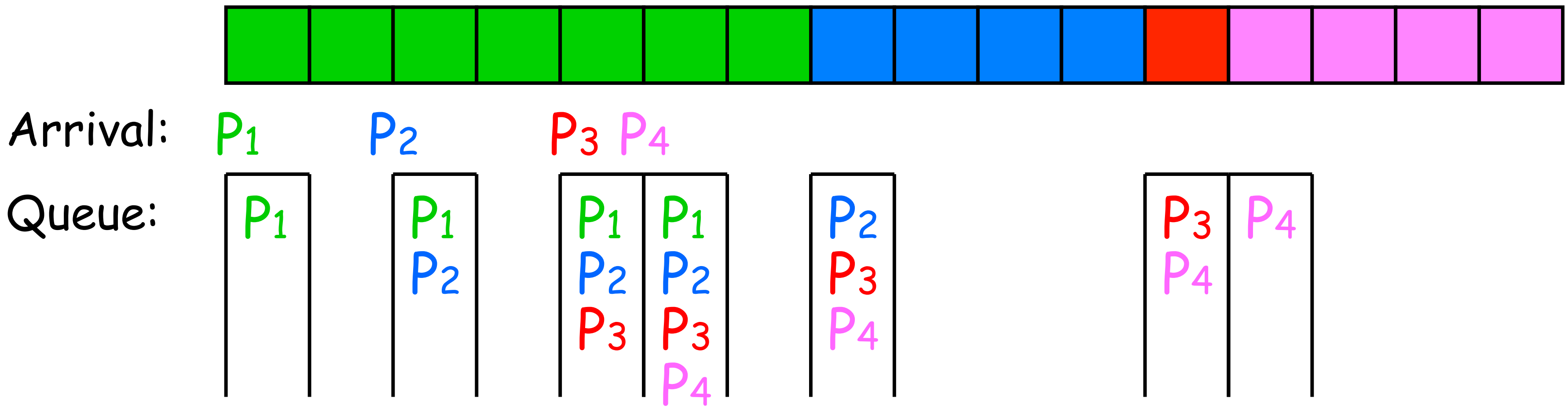
Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4



- Average waiting time: (8 + 6 + 1 + 7)/4 = 5.5
- Average response time: (0 + 0 + 1 + 2)/4 = 0.75
- # of context switches: 14

Larger time slice = 10

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4



- Average waiting time: (0 + 5 + 7 + 7)/4 = 4.75
- Average response time: same
- # of context switches: 3 (minimum)

RR advantages and disadvantages

- Advantages
  - Low response time, good interactivity
  - Fair allocation of CPU across processes
  - Low average waiting time when job lengths vary widely

- Disadvantages
  - Poor average waiting time when jobs have similar lengths
    - Average waiting time is even worse than FCFS!
  - Performance depends on length of time slice
    - Too high ➔ degenerate to FCFS
    - Too low ➔ too many context switches, costly

Priorities

- A priority is associated with each process
  - Run highest priority ready job (some may be blocked)
  - Round-robin among processes of equal priority
  - Can be preemptive or nonpreemptive
- Representing priorities
  - Typically an integer
  - The larger the higher or the lower?

Setting priorities

- Priority can be statically assigned
  - Some always have higher priority than others
  - Problem: starvation
- Priority can be dynamically changed by OS
  - Aging: increase the priority of processes that wait in the ready queue for a long time

```
for(pp = proc; pp < proc+NPROC; pp++) {
        if (pp->prio != MAX)
                pp->prio++;
        if (pp->prio > curproc->prio)
                reschedule();
}
```

This code is taken almost verbatim from 6th Edition Unix, circa 1976.

Priority inversion

- High priority process depends on low priority process (e.g. to release a lock)
  - Another process with in-between priority arrives?

> P1 (low): lock(my_lock) (gets my_lock)
>
> P2(high): lock(my_lock)
>
> P3(medium): while (…) {}
>
> P2 waits, P3 runs, P1 waits
>
> P2's effective priority less than P3!

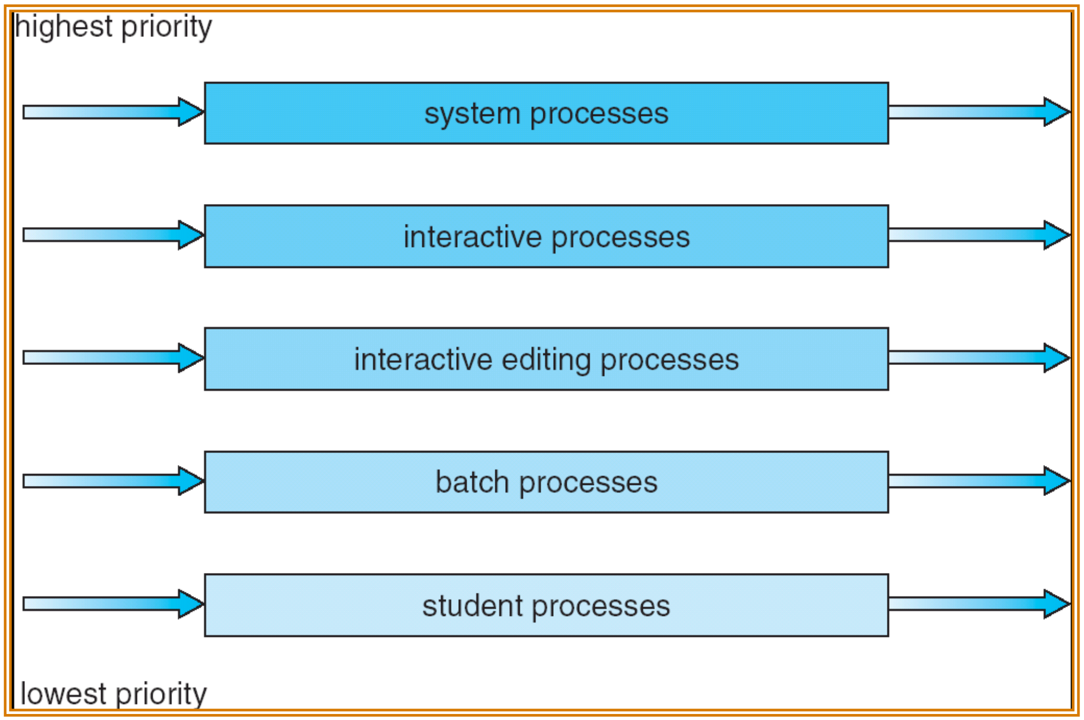
- Solution: priority inheritance
  - Inherit highest priority of waiting process
  - Must be able to chain multiple inheritances
  - Must ensure that priority reverts to original value
- Google for "mars pathfinder priority inversion"

Backup slides

Multilevel Queue

- Ready queue is partitioned into separate queues:
  foreground (interactive)
  background (batch)
- 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



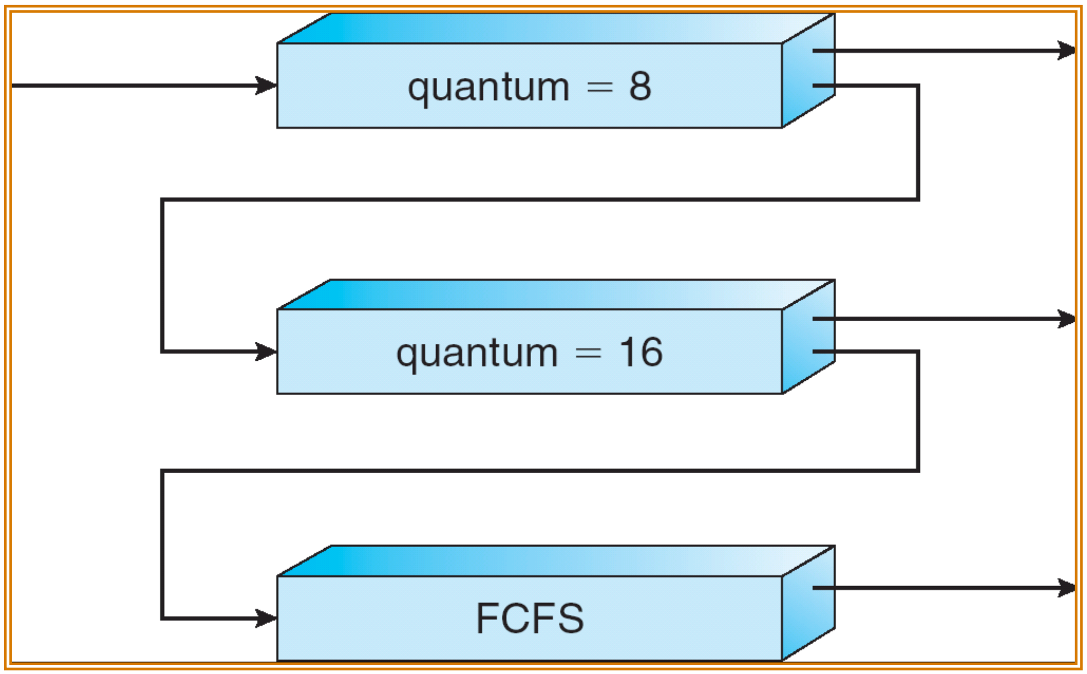
Multilevel Feedback Queue

- 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



Example of RR with Time Slice = 20

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

- The Gantt chart is:

P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_1	P_3	P_3	
0	20	37	57	77	97	117	121	134	154	162

- Typically, higher average turnaround than SJF, but better *response*

Example of RR with Time Slice = 20

Process	Arrival Time	Burst Time
P_1	0	400
P_2	20	60
P_3	20	60

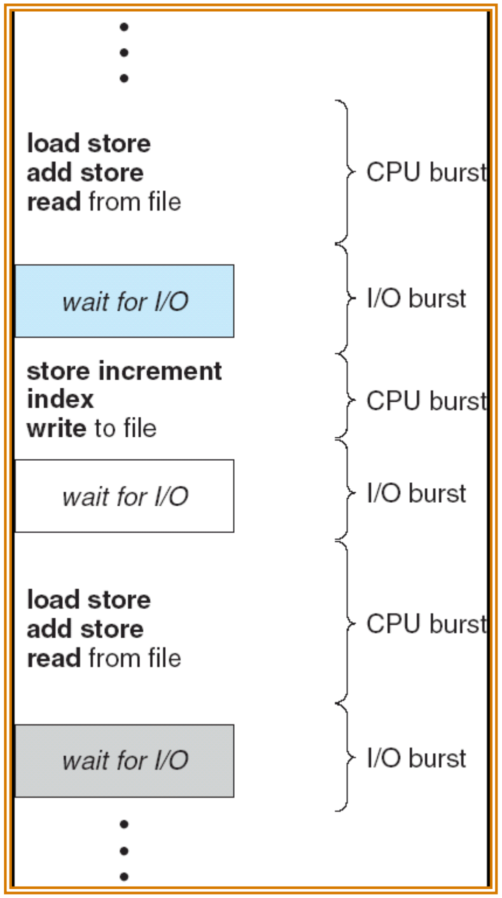
- The Gantt chart is:

P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1

0 20 40 60 80 100 120 140 160 180 200

- Average waiting time:
- Compare to FCFS and SJF:

Alternating Sequence of CPU And I/O Bursts



Time slice and Context Switch Time