CPU scheduling

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(partly based on slides of Le Thanh Van)

Outline

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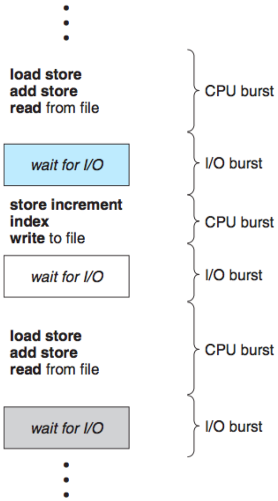
1. Basic concepts
2. Scheduling algorithms
   - Scheduling criteria
   - Scheduling algorithms
3. Multiple-processor scheduling
4. Real-time scheduling
5. Algorithm evaluation

Why do we need CPU scheduling ? (1)

- Maximum CPU "utilization" obtained with multiprogramming

Why do we need CPU scheduling ? (1)

- Maximum CPU "utilization" obtained with multiprogramming
- Process execution consists of a cycle of CPU execution (CPU bound) and I/O wait (I/O bound)
  - CPU burst
  - I/O burst



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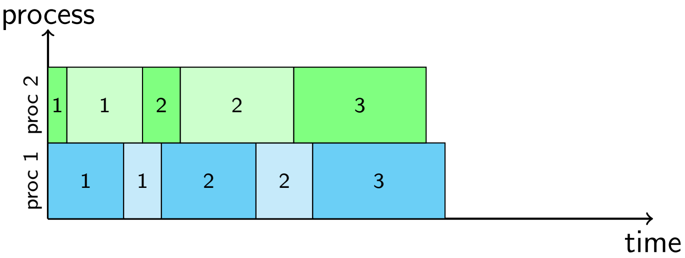

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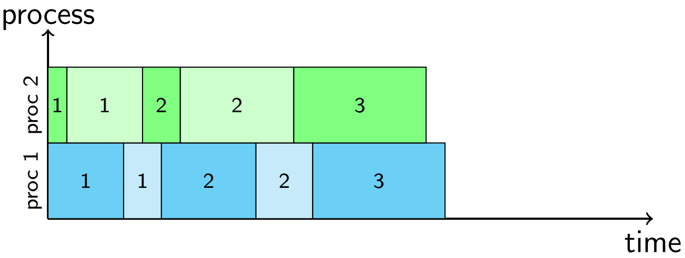

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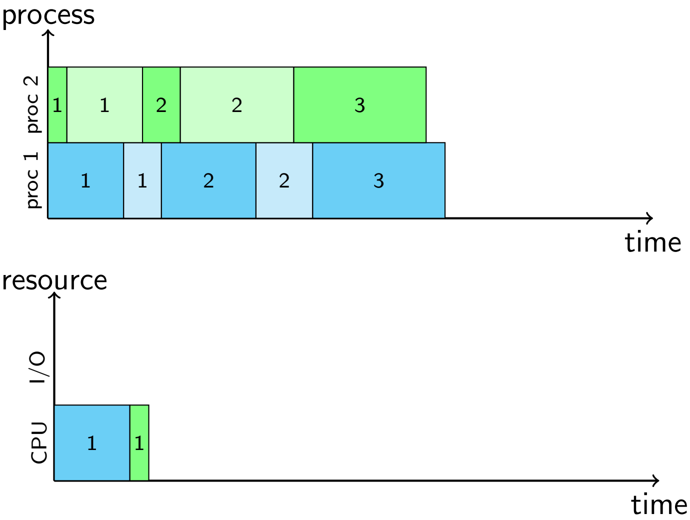

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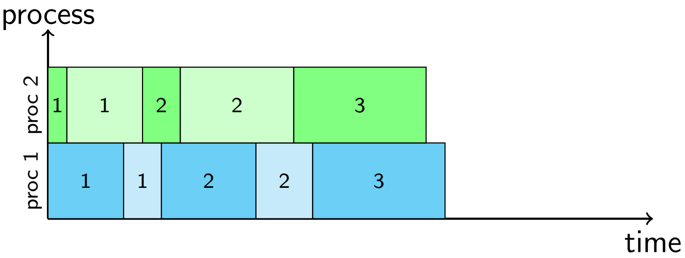

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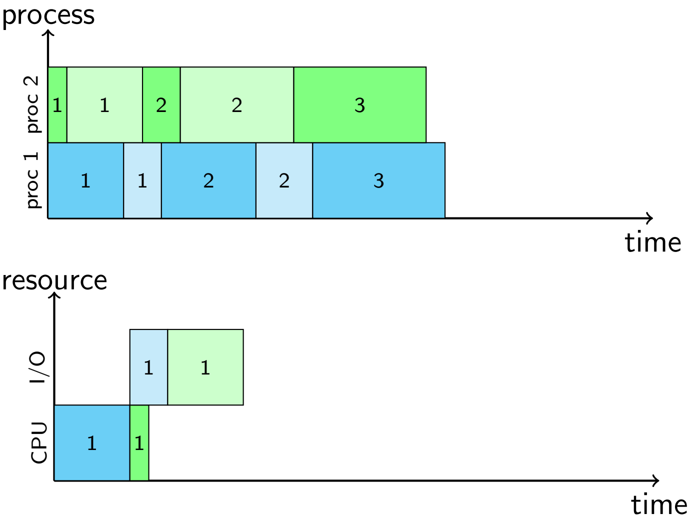

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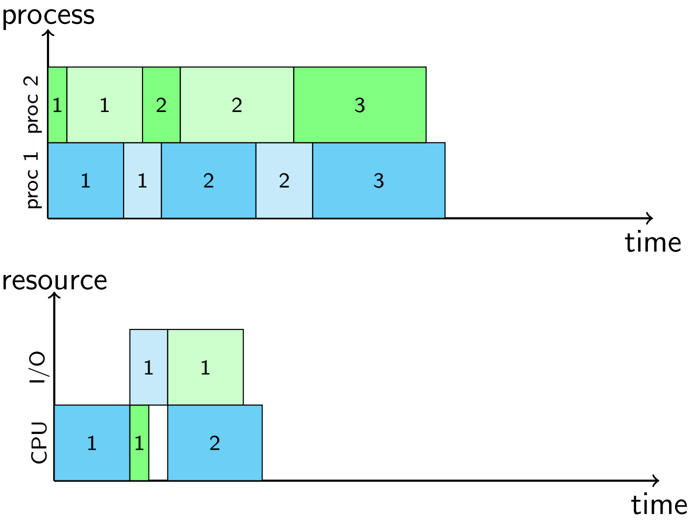

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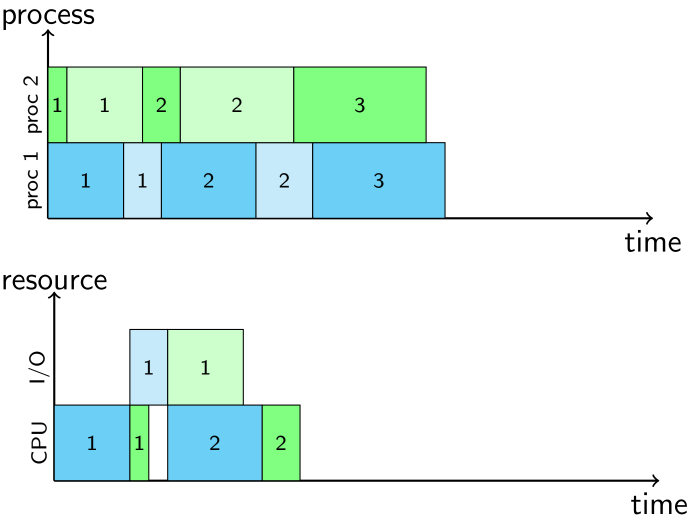

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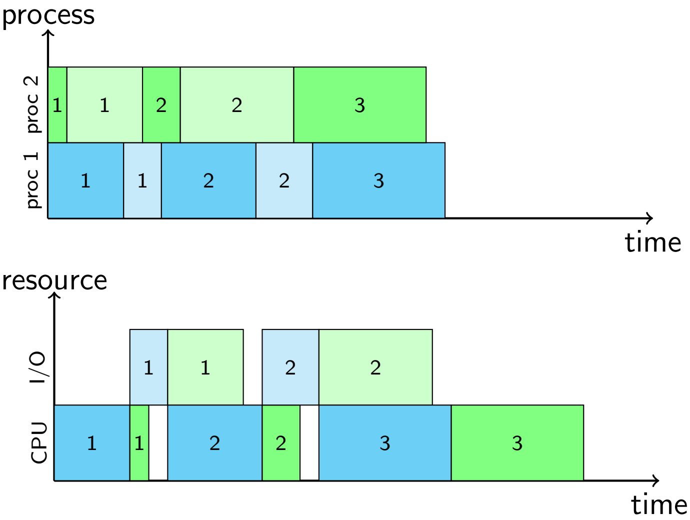

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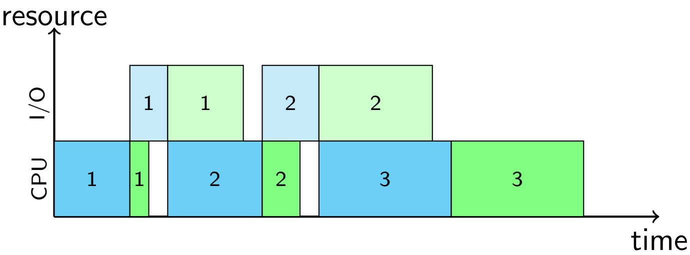

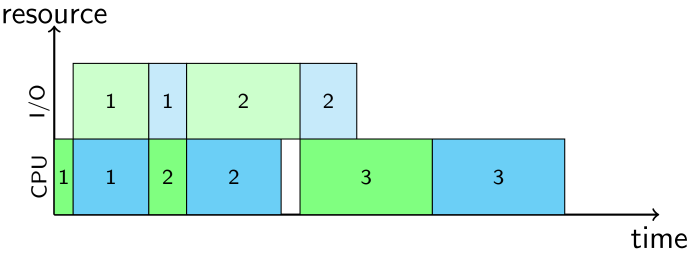

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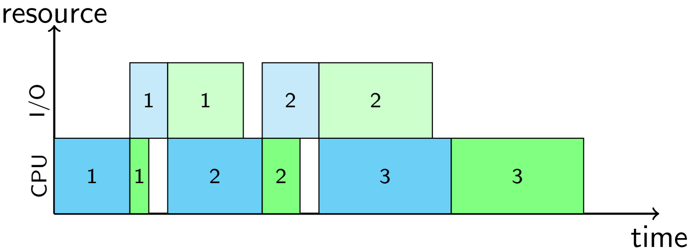
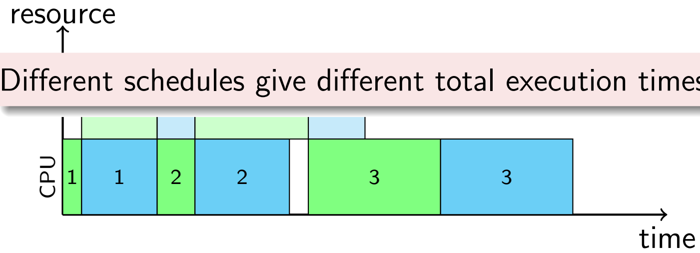
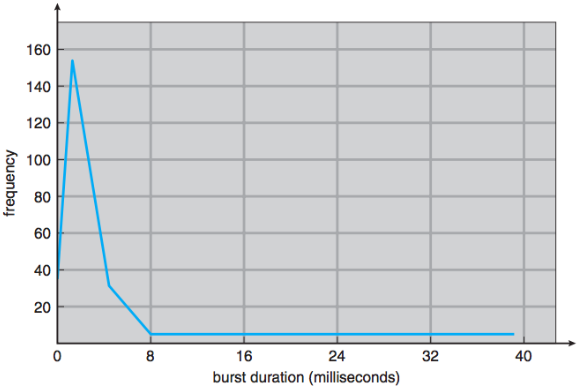




Different schedules give different total execution times

CPU burst distribution



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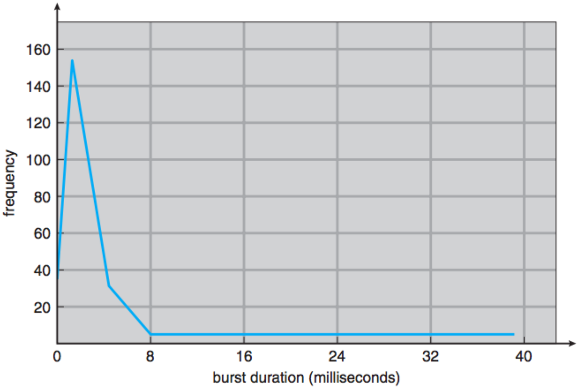

Distribution can be important in the selection of an appropriate CPU-scheduling algorithm

CPU scheduler

Short-term scheduler (CPU scheduler)

When CPU is idle, the scheduler selects a process in the ready queue to be executed next

- Ready queue is not necessarily first-in, first-out (FIFO)
- PCBs are used to store processes in queues

Preemptive vs. nonpreemptive scheduling

CPU scheduling decisions take place in one of 4 following cases

1. a process switches from running state to waiting state
2. a process switches from running state to ready state
3. a process switches from waiting state to ready state
4. a process terminates

Preemptive vs. nonpreemptive scheduling

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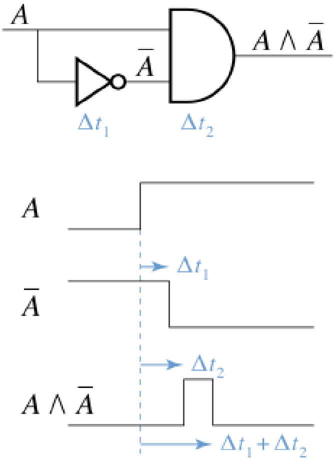
- **Cases 1 & 4**: scheduler has to (no choice) choose another ready process for execution. → nonpreemptive or cooperative
- **Cases 2 & 3**: preemptive scheduling. Better, but can lead to race conditions

What is race condition ?



Dispatcher

Dispatcher

A module that gives control of CPU to the process selected by CPU scheduler

Functions of dispatcher

- Switching context
- Switching to user mode
- Jumping to proper location in the user program to restart the program

Dispatch latency should be kept small

Outline

Scheduling criteria

Different criteria suggested for comparing different CPU scheduling algorithms

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- Optimize the average measure
- Optimize the minimum or maximum values

  Example: minimize the maximum response time

First come, first served (FCFS) scheduling (1)

Process	Burst time	Arrival time
P_1	24	0
P_2	3	0
P_3	3	0

Suppose the processes arrive in the order: P_1, P_2, P_3.

First come, first served (FCFS) scheduling (1)

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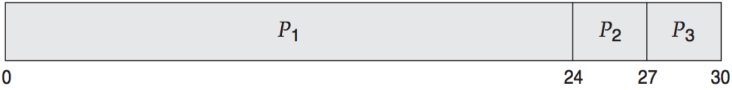
Then for FCFS scheduling, Gantt chart is as follows



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

First come, first served (FCFS) scheduling (2)

Suppose the processes arrive in the order: P_2, P_3, P_1.
Then, Gantt chart is as follows

- Waiting time: $P_1 = 6, P_2 = 0, P_3 = 3$
- Average waiting time: $(6 + 0 + 3)/3 = 3$ (much better)
- convoy effect: all other processes wait for one big process gets off the CPU

Shortest-Job-First (SJF) scheduling

- Each job associated with a time length of its next CPU burst
- Idea: Firstly choosing the job which has shortest time length
- SJF is optimal - giving a minimum average waiting time for a given set of jobs

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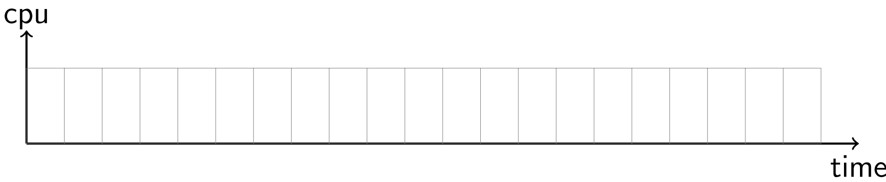
- Idea: Firstly choosing the job which has shortest time length
- SJF is optimal - giving a minimum average waiting time for a given set of jobs
- 2 schemes:
  - Nonpreemptive: once given to the CPU, the process cannot be preempted until completing its CPU burst
  - Preemptive: if a new process arrives with smaller CPU burst length than remaining time of current executing process, preempt.
    $\Rightarrow$ Its new name is Shortest-Remaining-Time-First (SRTF).

Nonpreemptive Shortest-Job-First (SJF) scheduling

Example

Process	Arrival time	Burst time
P_1	0	6
P_2	1	3
P_3	2	7
P_4	3	4

Then for nonpreemptive SJF scheduling, Gantt chart is as follows



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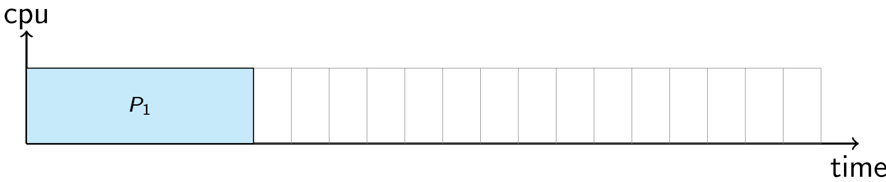

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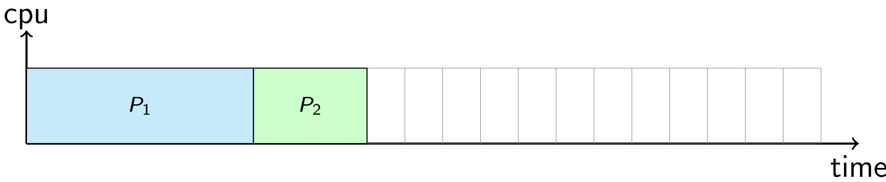

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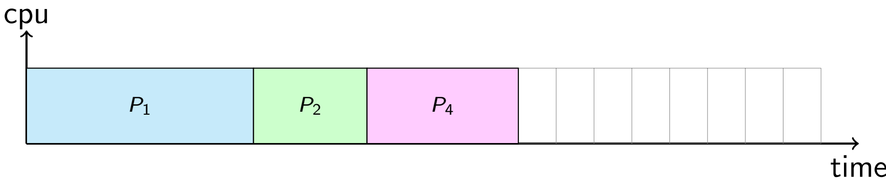

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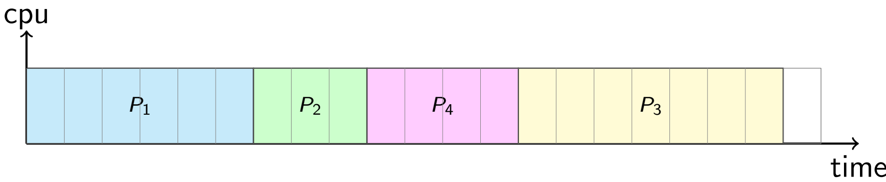

- Average waiting time: $((0-0)+(6-1)+(13-2)+(9-3))/4 = 5.5$

Preemptive Shortest-Job-First scheduling (SRTF)

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- Average waiting time: $((8-1)+(1-1)+(13-2)+(4-3))/4 = 4.75$

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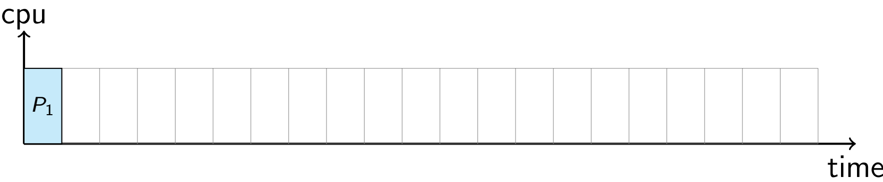

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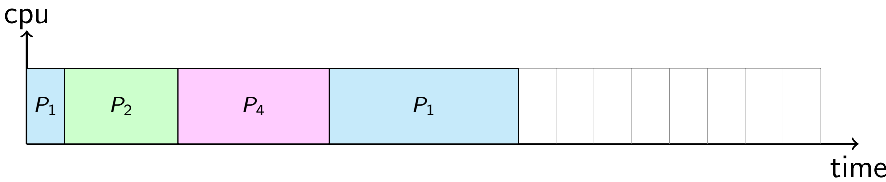

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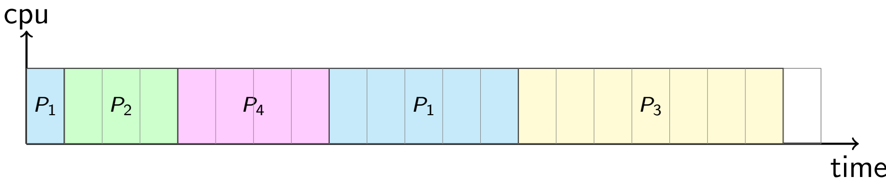

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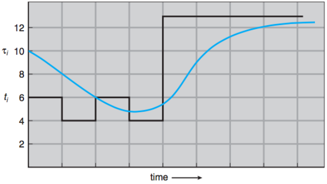
- Next CPU burst = exponential average of measured lengths of previous CPU bursts



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

$$\tau_{n+1} = \alpha t_n + (1 - \alpha)\tau_n$$

in which

- $0 \leq \alpha \leq 1$
- t_n: length of nth CPU burst (recent history)
- τ_n: predicted length of nth CPU burst (past history)

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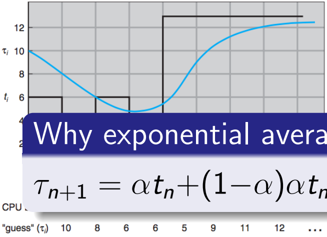

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in which

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Why exponential average ?

$$\tau_{n+1} = \alpha t_n + (1-\alpha)\alpha t_{n-1} + \ldots + (1-\alpha)^j \alpha t_{n-j} + \ldots + (1-\alpha)^{n+1}\tau_0$$

history)

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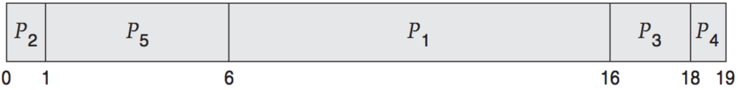
P_3	2	4
P_4	1	5
P_5	5	2



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SJF as a special case of priority scheduling

Priority $=$ CPU burst time

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  - *Internally defined*: using some measurable quantities
    Example: time limit, memory requirement, ratio of I/O burst to CPU burst
  - *Externally defined*: set by criteria outside OS
    Example: importance of process, type/amount of funds for computer usage

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Indefinite blocking (starvation)

- Low-priority processes can wait indefinitely
- Solution to starvation is aging which involves gradually increasing the priority of processes that waiting too long.

Round-robin (RR) scheduling

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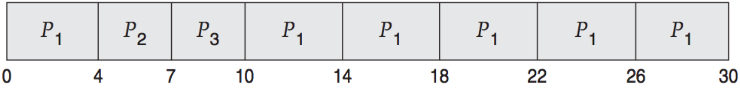
  time quantum $= q$ (time units)
  $\rightarrow$ no process waits more than $(n-1)q$ time units
- Performance
  - q large $\rightarrow$ FCFS
  - q small $\rightarrow$ overhead is too high due to context switching

Round-robin (RR) scheduling

Example

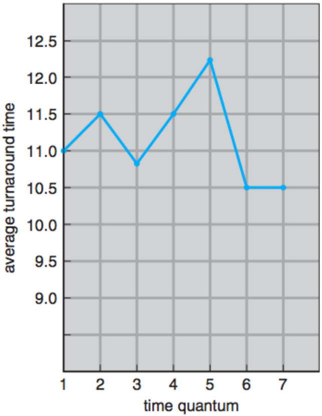
Process	Burst time
P_1	24
P_2	3
P_3	3

Time quantum $= 4$



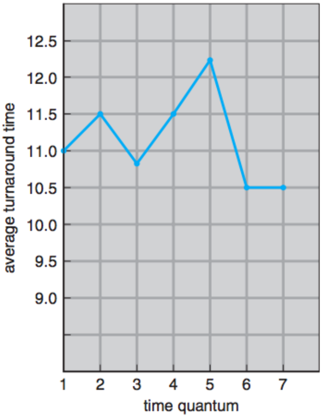
- Average waiting time:
  $((10 - 4) + (4 - 0) + (7 - 0))/3 = 5.66$

On turnaround time



process	time
P_1	6
P_2	3
P_3	1
P_4	7

On turnaround time



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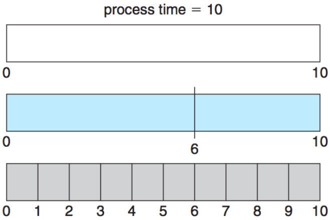
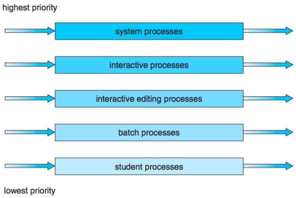
On context switches



quantum	context switches
12	0
6	1
1	9

Multilevel queue scheduling

- Ready queue is partitioned separate queues according to different response-time requirement: foreground (interactive) processes and background (batch) processes.



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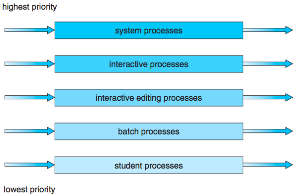
- Each queue has its own scheduling algorithm. For example
  - RR for foreground queue
  - FCFS for background queue
- Scheduling is needed between the queues
  - Fixed preemptive scheduling $\rightarrow$ starvation
  - Time slice: each queue is assigned an amount of time

    For example: 80% for foreground queue; 20% for background queue

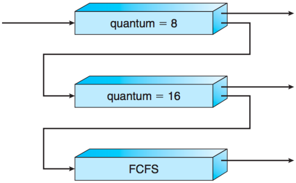


Multilevel feedback queue scheduling

Multilevel feedback

A multilevel queue scheduling but allowing a process to move between queues.

- Separating processes according to their CPU burst times
  - Process with much CPU time moved to low-priority queue
  - Process waiting too long in low-priority queue moved to higher priority queue



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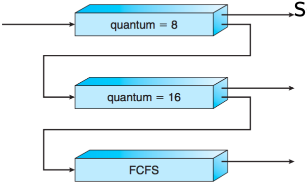
  - Process waiting too long in low-priority queue moved to higher priority queue

Parameters of multilevel feedback queue scheduling:



- number of queues
- scheduling algorithm for each queue
- method to upgrade a process to higher queue; method to demote (giáng cấp) a process to lower queue
- method to choose which queue to put a process for service

- Three queues
  - Q_0 - quantum $= 8$
  - Q_1 - quantum $= 16$
  - 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

Outline

Multiple-processor scheduling

Challenges

Scheduling on multiple-processor systems are more complex

- Homogeneous processors within a multiprocessor
- Load sharing among multiple CPUs
- Asymmetric multiprocessing: only one processor accesses the system data structures, alleviating the need for data sharing
  Most OSs are using symmetric multiprocessing
- Processor affinity (thân thuộc): a process is not migrated to another one than currently running
  Migration could lead to cache invalidation or repopulation.

Load balancing

Load balancing

Keeping the workload evenly distributed across all processors

- Only necessary on systems where each processor has its own private ready queue
- Load balancing vs. processor affinity
- Load balancing can be performed in 2 forms
  - push migration
  - pull migration

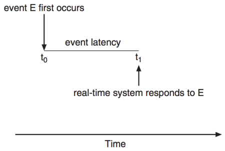
Outline

Real-time scheduling

Real-time scheduling

- Hard read-time systems: required to complete a critical task within a guaranteed amount of time
- Soft real-time computing: requires that critical processes receive priority over less fortunate ones

- Event latency kept small in order to increase responsiveness to events (minimizing latency)



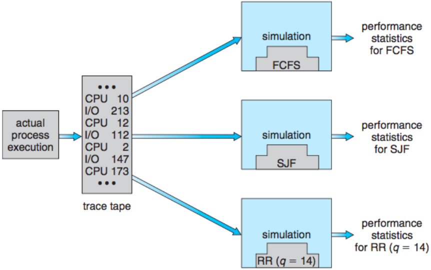
- Real-time system must have priority-based scheduling with preemption

Outline

1. Basic concepts
2. Scheduling algorithms
   - Scheduling criteria
   - Scheduling algorithms
3. Multiple-processor scheduling
4. Real-time scheduling
5. Algorithm evaluation

Algorithm evaluation

- Deterministic modeling: takes a particular predetermined workload and defines the performance of each algorithm for that workload
- Queueing models
- Computer simulation (e.g., by discrete-event simulation)



Homeworks

1. Read materials on Multiple processor scheduling & Realtime-scheduling: textbook, slides (Nguyen Thanh Son)