CS416 – CPU Scheduling

CS 416: Operating Systems Design, Spring 2011

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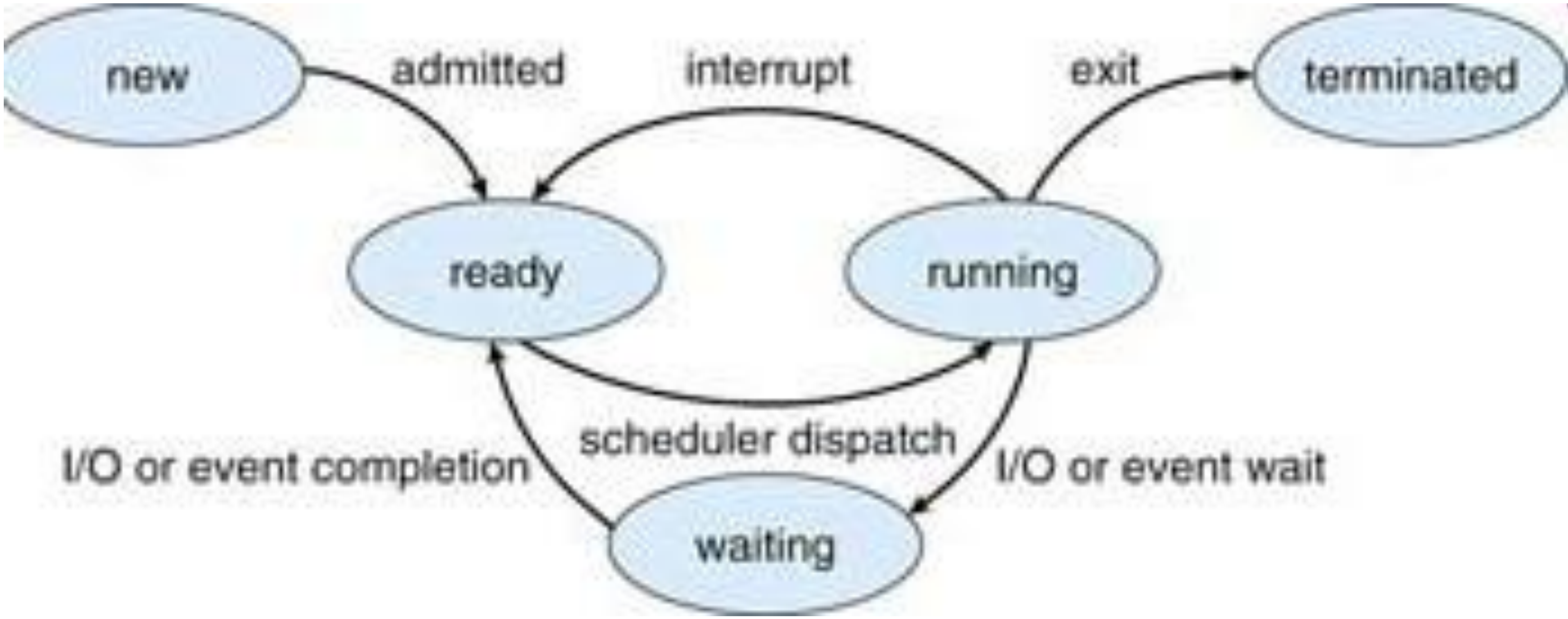
Assumptions

- Pool of jobs contending for the CPU
    - CPU is a scarce resource
- Scheduler mediates between jobs to optimize some performance criteria

Process States



Scheduling

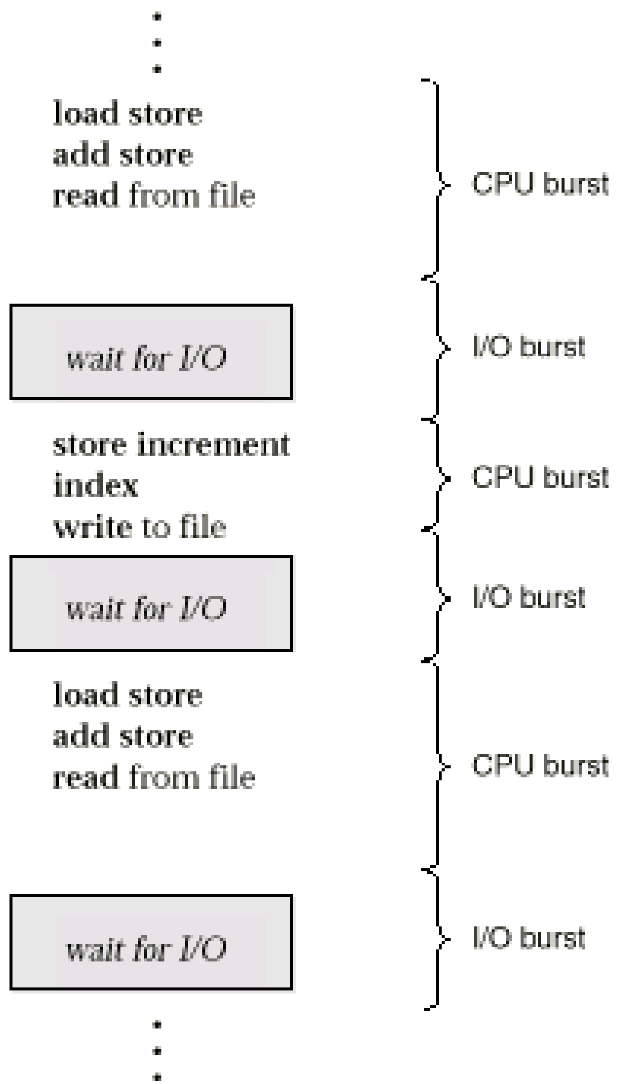
- We have already Discussed Context Switching
  - Context Switching – Mechanism
  - Scheduling – Policy
- Which Thread to run next?
- How to ensure every thread gets a chance to run (**Fairness**)?
- How to prevent **Starvation** ?

- **Process Scheduling** Vs **Thread Scheduling** : If the OS supports kernel level threads, threads are scheduled. If not, processes are scheduled.
  - We will use these terms interchangeably.

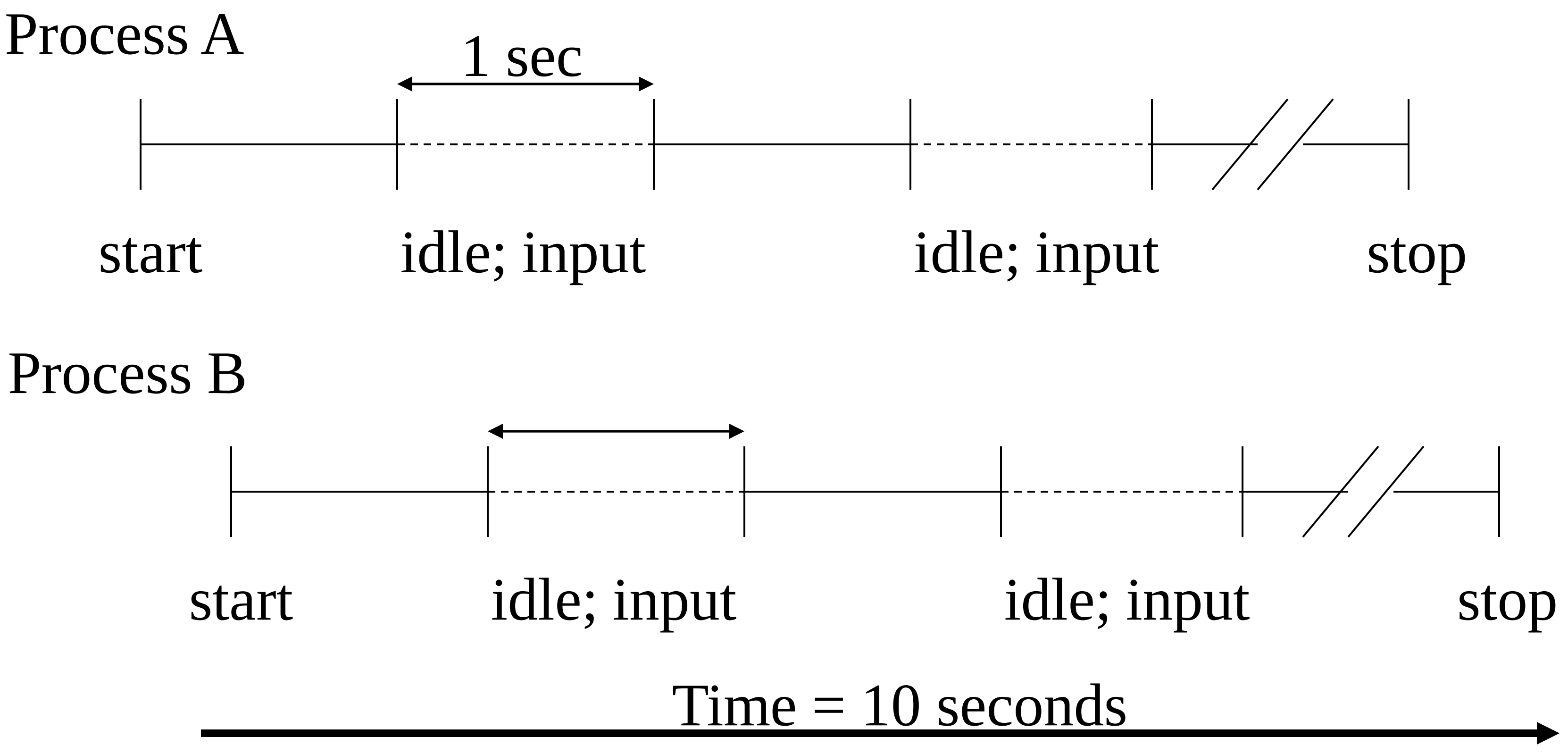
Scheduler

- Scheduler is the OS component that decides which thread to run next on the CPU
- The Scheduler operates on the ready queue
  - Why does it not deal with the I/O queues ?
- When does the scheduler run ?
  - When a threads exits
  - When a thread moves from ready queue to waiting queue (I/O, wait())
  - **When a thread moves from waiting state to ready state(Completion of I/O)**
  - **When a thread moves from running state to ready state (Interrupt)**
- Scheduling can be ***preemptive(forced context-switch)* or *non-preemptive***
- Batch vs Interactive Scheduling
  - Batch: Non-Preemptive and ***No other jobs run if they block***
  - Interactive: Preemptive and other jobs do run if they block

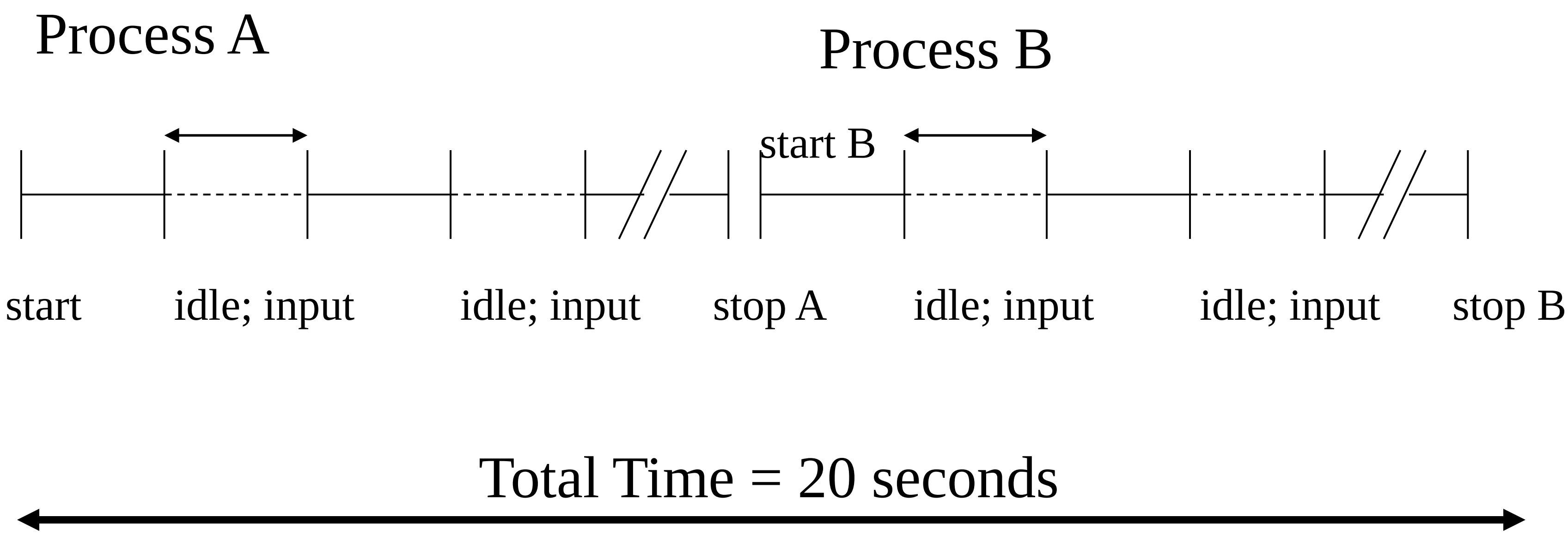
Job Behavior



Multiprogramming Example



Multiprogramming Example (cont)

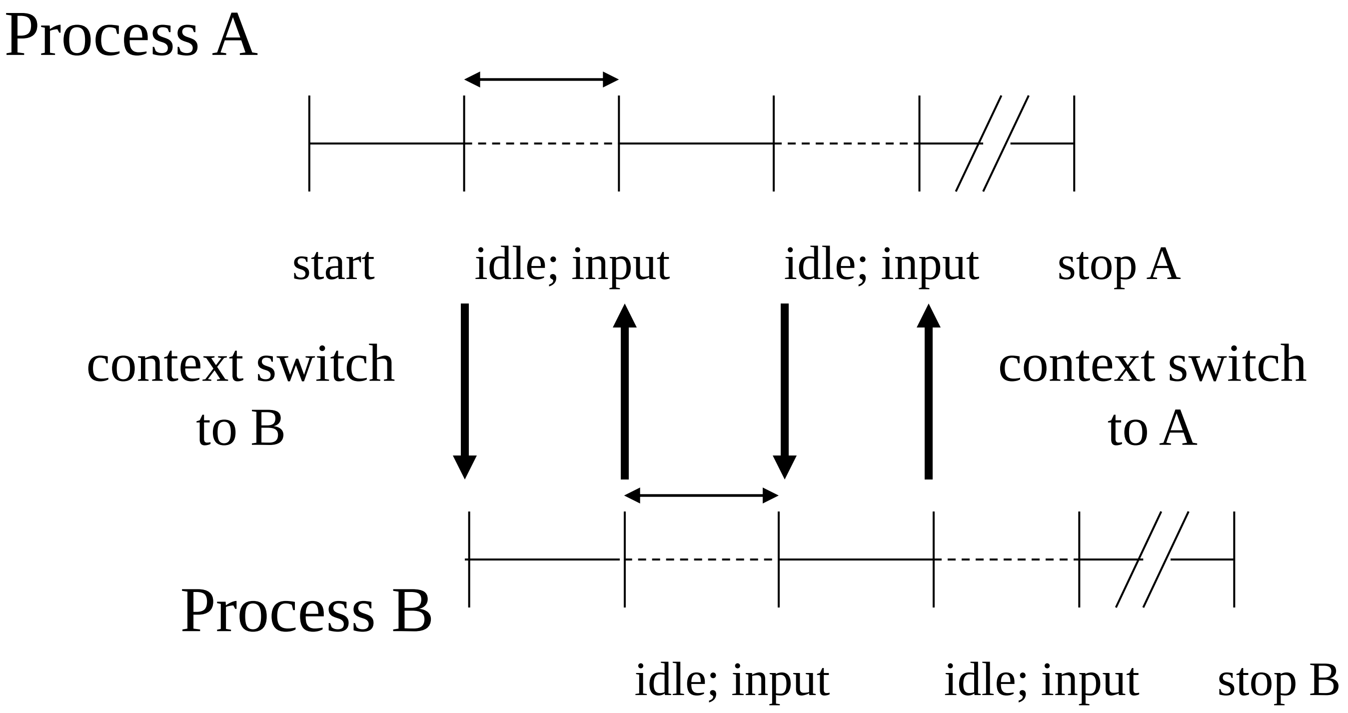


Total Time = 20 seconds

Throughput = 2 jobs in 20 seconds = 0.1 jobs/second

Ave. Waiting Time = (0+10)/2 = 5 seconds

Multiprogramming Example (cont)



Throughput = 2 jobs in 11 seconds = 0.18 jobs/second

Ave. Waiting Time = (0+1)/2 = 0.5 seconds

Scheduling Goals

- Goal of a scheduling policy is to achieve some "optimal" allocation of CPU time in the system
- Possible Goals
  - Maximize CPU Utilization (% of time the CPU is busy)
  - Maximize CPU Throughput (No. of jobs completed per second)

  } System-Oriented Metrics

  - Minimize Turnaround time ($T_{job\_end} - T_{job\_start}$)
  - Minimize Waiting time (Total time spent Waiting on Queues)
    - Which Queue ?
  - Minimize job Response time ($T_{first\_response} - T_{job\_start}$)
- These goals often conflict
  - Batch Systems: Maximize the Job throughput and minimize turnaround time
  - Interactive Systems: Minimize response times of interactive jobs (eg. Editors)

Starvation

- Schedulers often try to eliminate Starvation
  - e.g., If a high priority thread always gets to run before a low-priority thread
  - We say the low priority thread is *starved*
- Not all schedulers have this goal !
  - Sometimes starvation is permitted to achieve other goals
- Example: Real Time Systems
  - Some threads run under a specific deadline
  - In this case it is OK to starve other threads.

(Short-Term) CPU Scheduler

- Selects from among the processes in memory that are ready to execute, and allocates the CPU to one of them.
  - Long term scheduler: decide which processes should be swapped-in/out

Dispatcher

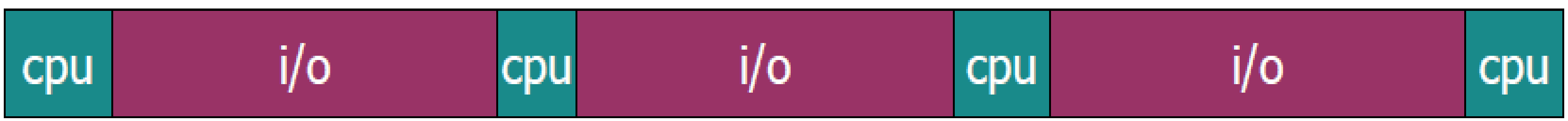
- Dispatcher module gives control of the CPU to the process selected by the short-term scheduler; this involves:
  - switching context
  - switching to user mode
  - jumping to the proper location in the user program to restart that program
- *Dispatch latency* – time it takes for the dispatcher to stop one process and start another running.

Job Behavior

Two broad classes of processes : CPU bound and I/O bound

- CPU Bound:

- I/O Bound

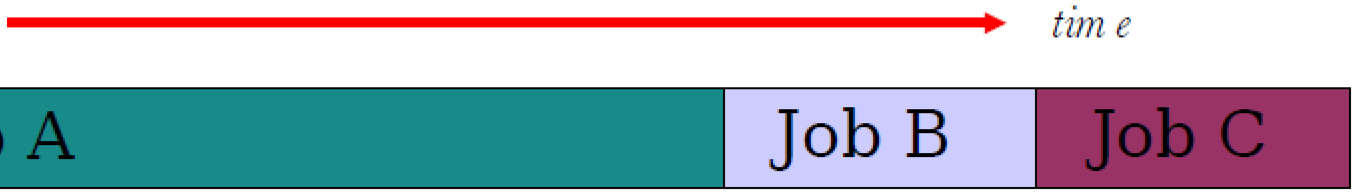


Examples of each Kind:

- CPU Bound: Compiler, Number Crunching, games, MP3 encoder, etc
- I/O Bound: Web browser, database engine, word processor, etc

First-Come-First-Served

- Jobs are scheduled in the order that they arrive
  - Also called FIFO
- Used only for batch scheduling
  - Jobs run to completion – Never blocks or gets context swictched
- Jobs treated equally
  - NO Starvation !
- Whats wrong with FCFS?
  - Short jobs get stuck behind long ones – Increases the waiting time, response time

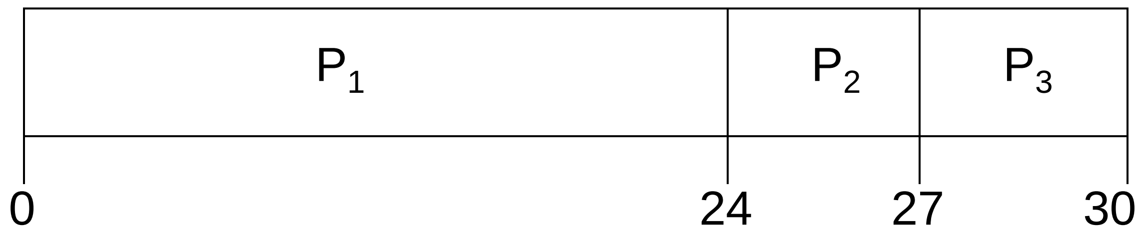


(FCFS) Scheduling - Example

Example:

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:



Waiting time for $P_1 = 0$; $P_2 = 24$; $P_3 = 27$

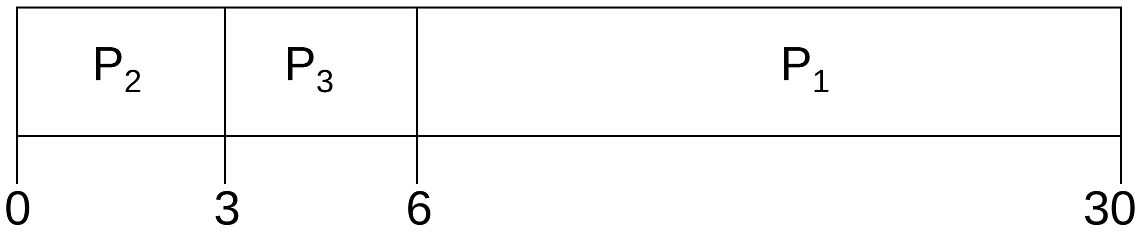
Average waiting time: $(0 + 24 + 27)/3 = 17$

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 $P_1 = 6$; $P_2 = 0$; $P_3 = 3$

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

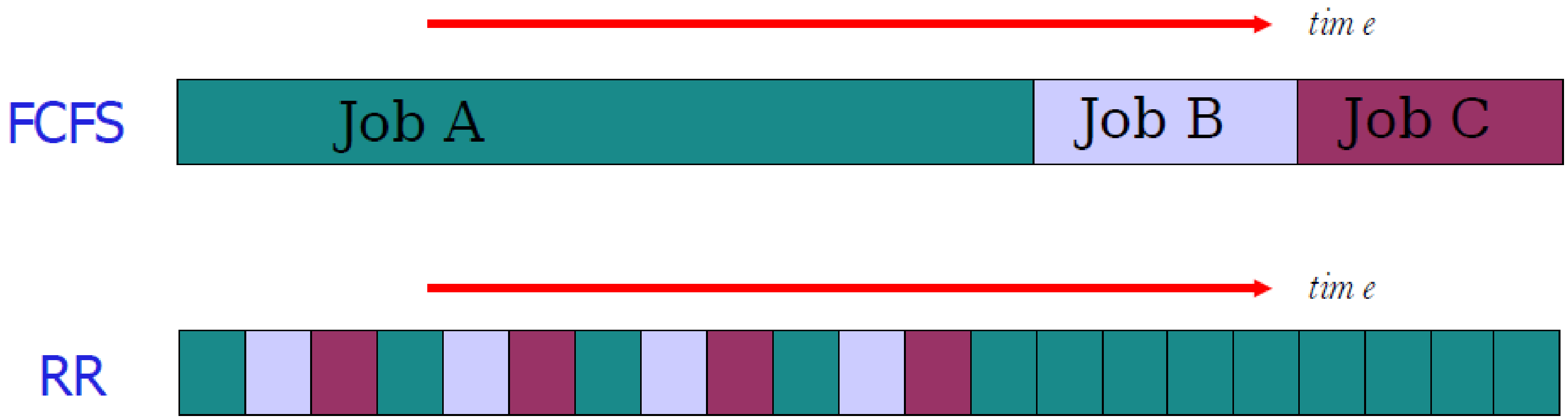
Much better than previous case.

Convoy effect: short process behind long process

- Low CPU and I/O utilization

Round Robin (RR)

- Essentially FCFS with preemption
- A thread runs until it blocks or its **CPU quantum** expires.
- How to determine the ideal CPU quantum?
  - Quantum needs to be large compared to the context switch overhead
  - In modern systems, Quanta range from 10 to 100msec and CS time is < 10 μs



Waiting time for Job A : 8, Job B: 7, Job C: 8

Average Waiting Time = (8+7+8)/3 = 7.66 (Higher than SJF, Lower than FCFS)

Response Time is however the lowest !

Shortest Job First (SJF)

- Schedule Job with shortest expected ***CPU Burst***
  - **This is non-preemptive and will run until it blocks for I/O**
- **Idea:**
  - Running short-CPU-burst jobs first gets them done, and out of the way.
  - Allows their I/O to overlap with each other: more efficient use of the CPU
  - Interactive programs often have a short CPU burst: Good to run them first
- How to predict a process's CPU Burst ?
  - Get a pretty good guess by looking at the history

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

- **We use exponential averaging** $\tau_{n+1} = \alpha \, t_n + (1 - \alpha)\tau_n .$

Examples of Exponential Averaging

$\alpha = 0$

$$\tau_{n+1} = \tau_n$$

Recent history does not count.

$\alpha = 1$

$$\tau_{n+1} = t_n$$

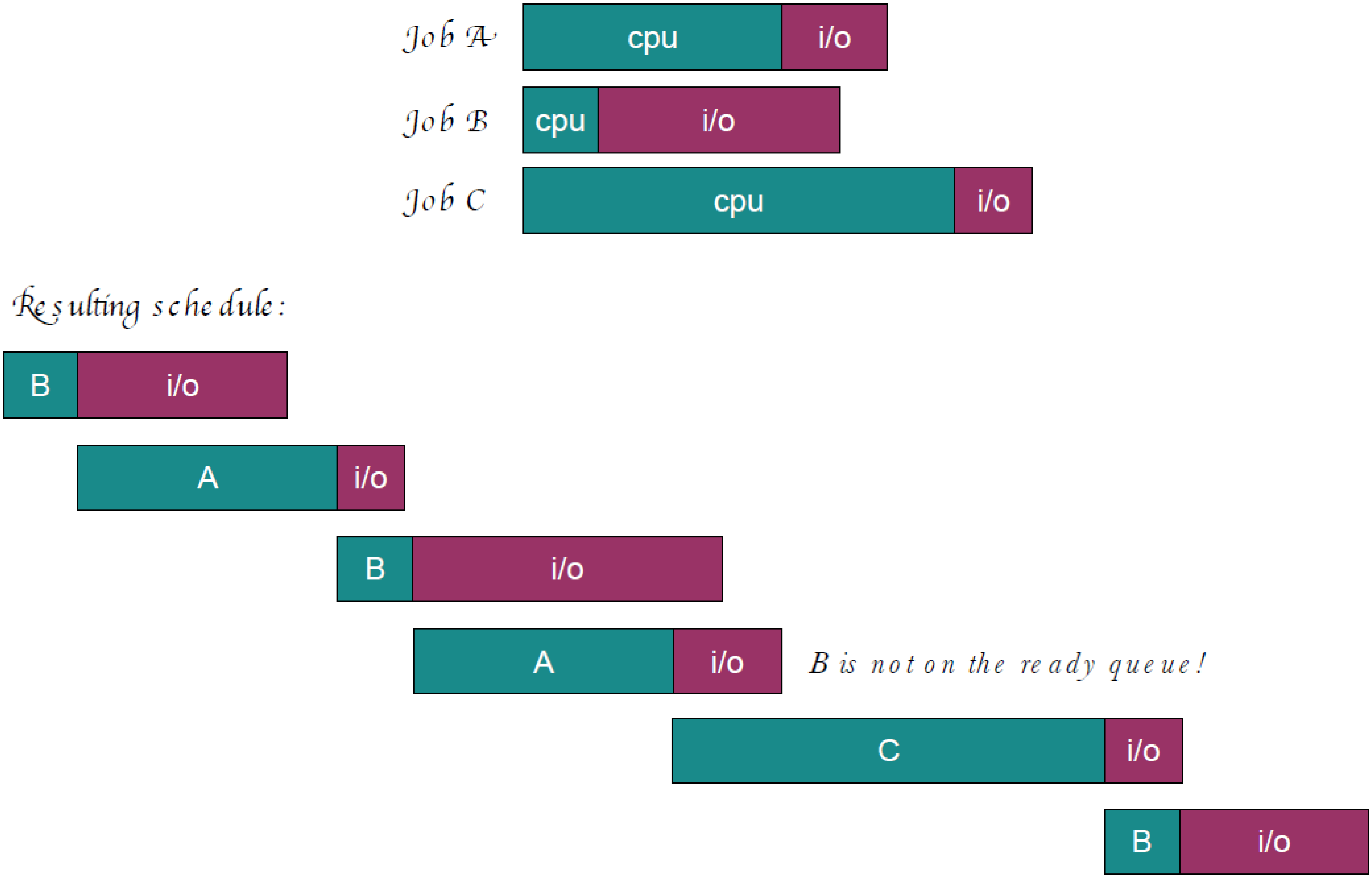
Only the actual last CPU burst counts.

If we expand the formula, we get:

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\, \alpha\, t_{n-1} + \ldots$$
$$+ (1 - \alpha)^j \alpha\, t_{n-j} + \ldots$$
$$+ (1 - \alpha)^{n-1} t_0$$

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

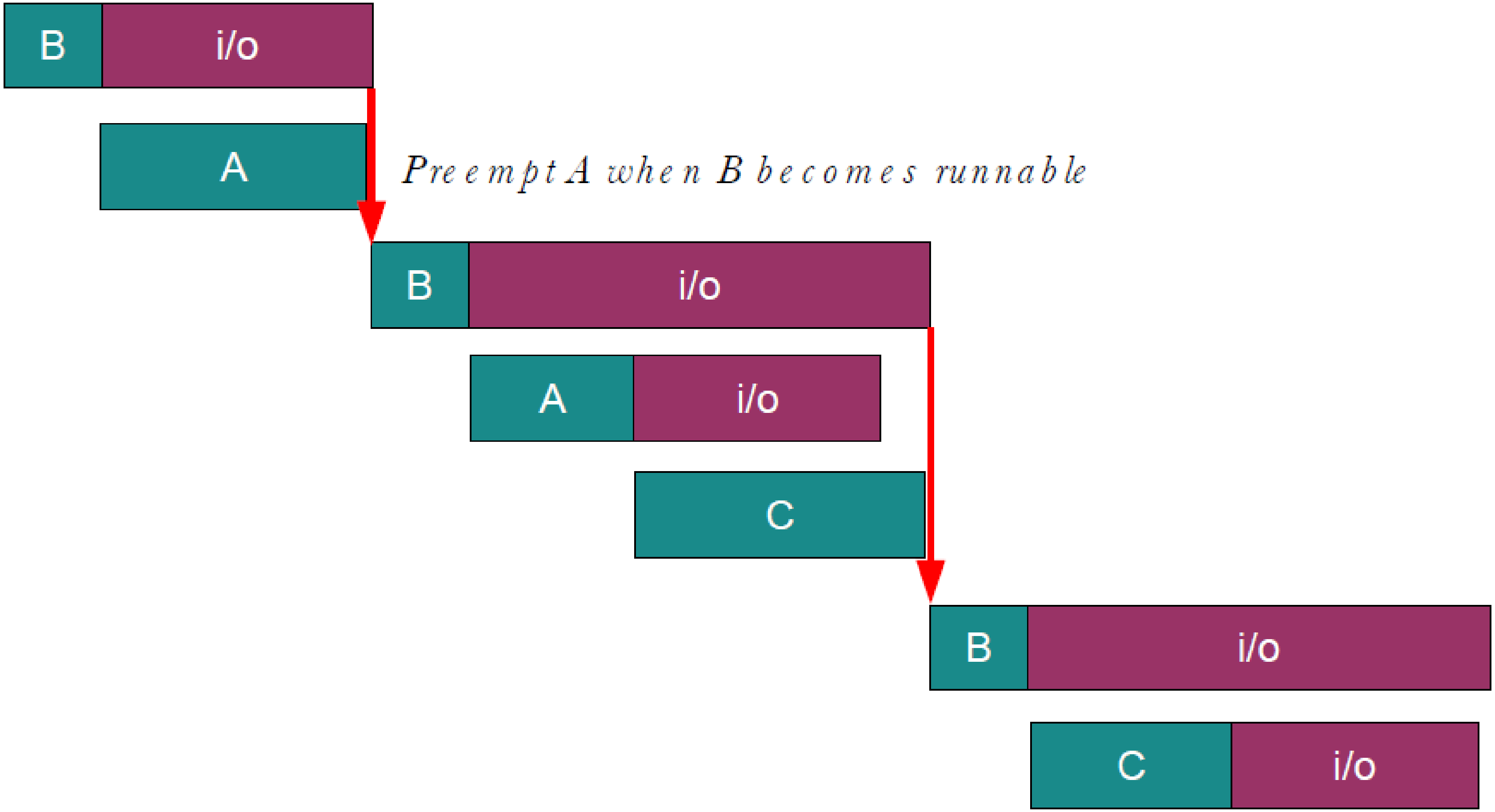
SJF Example



Job A
cpu
i/o
Job B
cpu
i/o
Job C
cpu
i/o
Resulting schedule:
B
i/o
A
i/o
B
i/o
A
i/o
B is not on the ready queue!
C
i/o
B
i/o

Shortest Remaining Time First (SRTF)

- SJF is non-preemptive policy
- Preemptive variant: **Shortest Remaining Time First (SRTF)**
  - If a job becomes runnable with a shorter expected CPU burst, preempt current job and run the new job

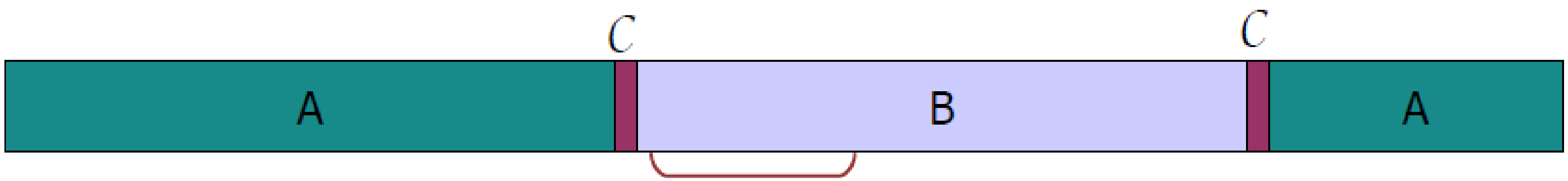


SRTF vs RR

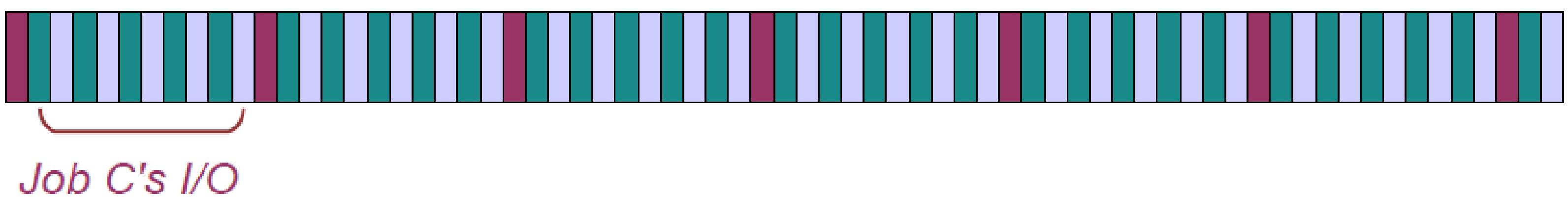
Say we have three jobs:

- Job A and B: both CPU-bound, will run for hours on the CPU with no I/O
- Job C: Requires a 1ms burst of CPU followed by 10ms I/O operation

RR with 25 ms time slice:



RR with 1 ms time slice:



- Lots of pointless context switches between Jobs A and B!

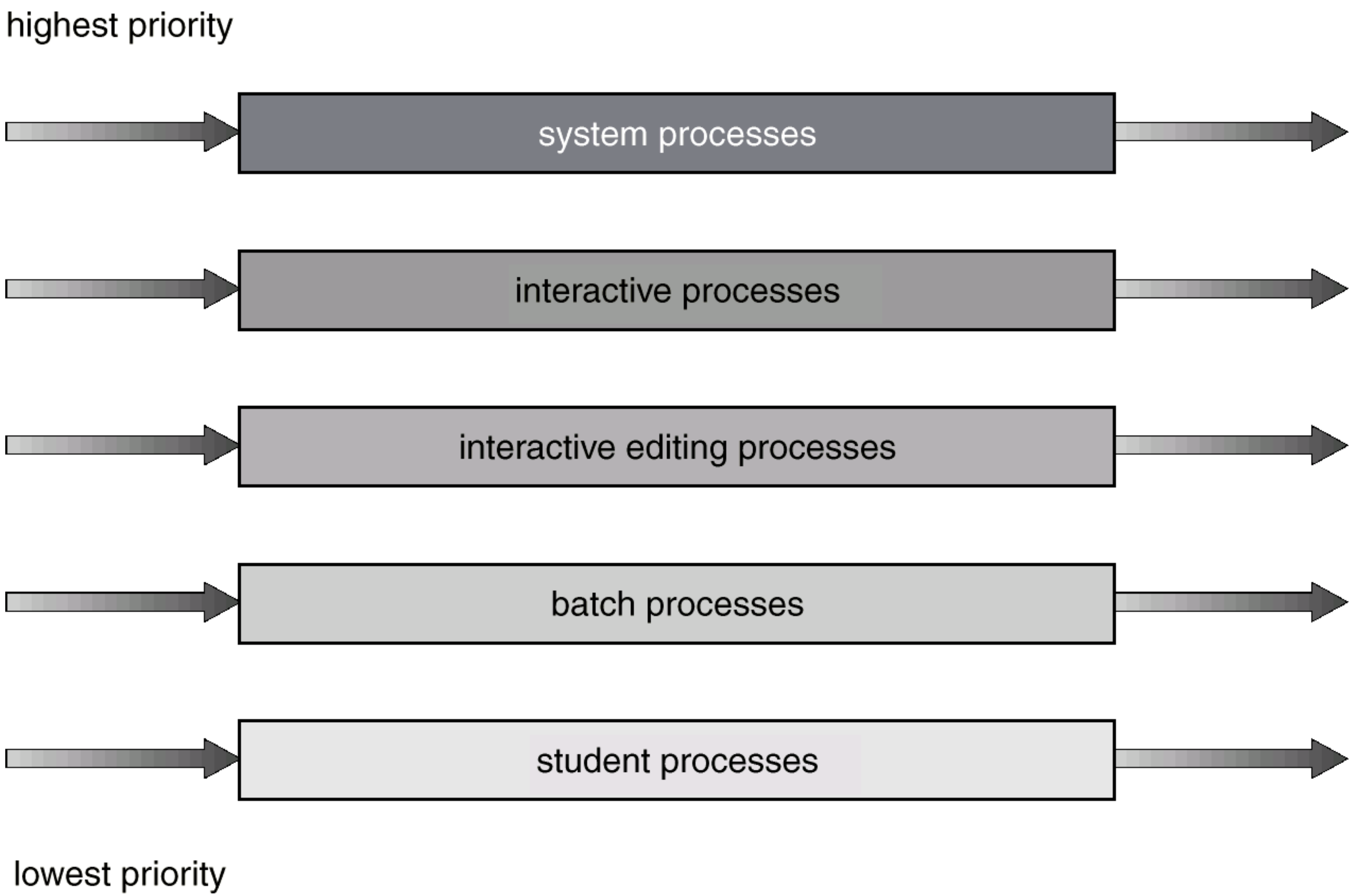
SRTF:

- Job A runs to completion, then Job B starts
- C gets scheduled whenever it needs the CPU

Priority Scheduling

- A priority number (integer) is associated with each process
  - Can be set by User/OS or combination of two.
- The CPU is allocated to the process with the highest priority (smallest integer ≡ highest priority).
  - Preemptive: Whenever higher priority process comes, lower priority process gets preempted.
  - Non-preemptive: Puts the higher priority process at the head of the queue
- SJF is a priority scheduling where priority is the predicted next CPU burst time.
- Problem: **Starvation** – low priority processes may never execute.
- Solution: **Aging** – as time progresses increase the priority of the process.

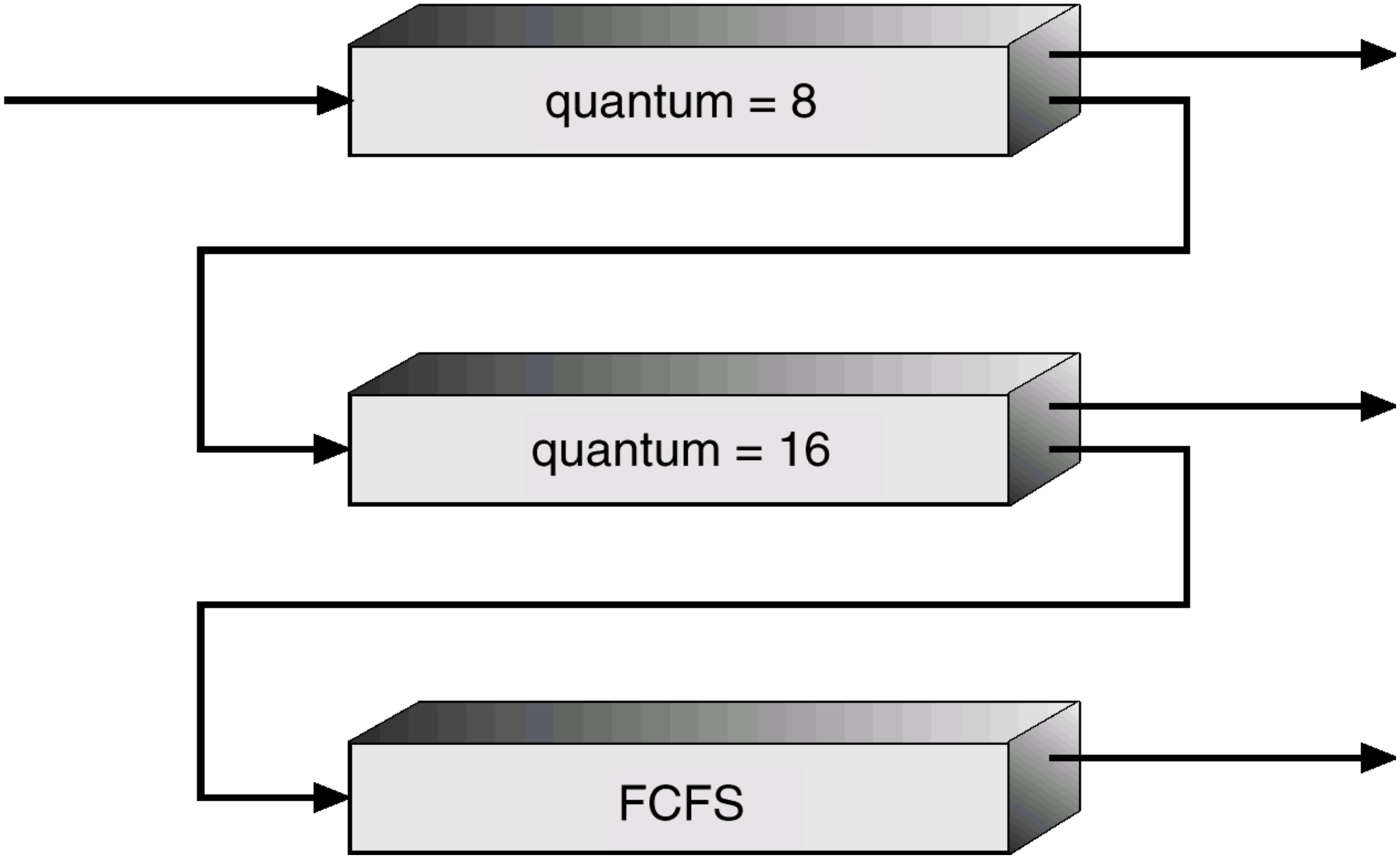
Multi-Level Queue



Multi-Level Queue

- Ready queue is partitioned into separate queues:
  - Could be one queue for each priority level
- Each queue has its own scheduling algorithm,
- Scheduling must be done between the queues.
- Example: 2 Priority Levels (0 -> Foreground, 1-> Background)
  - Fixed priority scheduling: serve all foreground processes and then serve background processes. 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

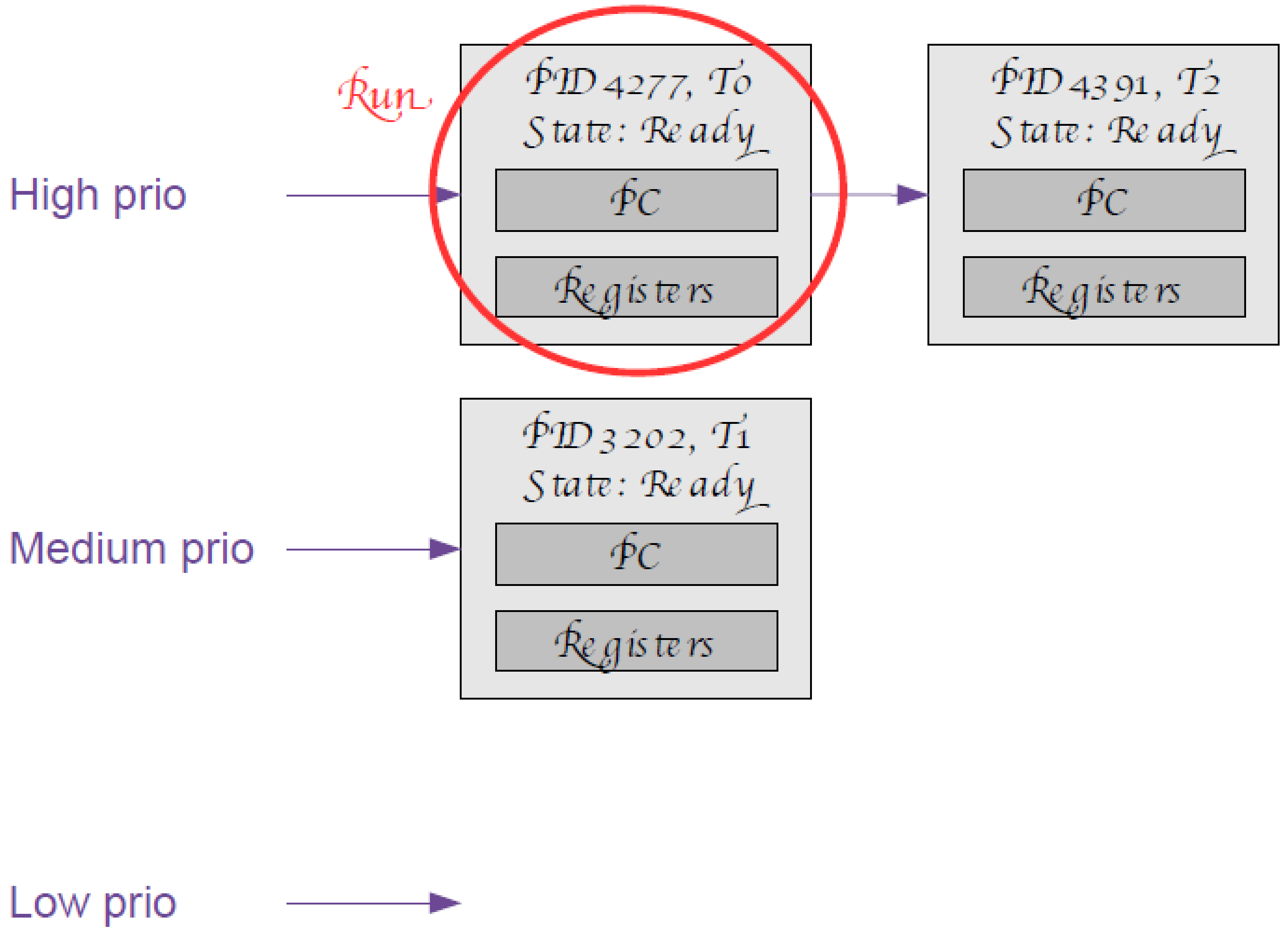
Multi-Level Feedback Queue (MLFQ)



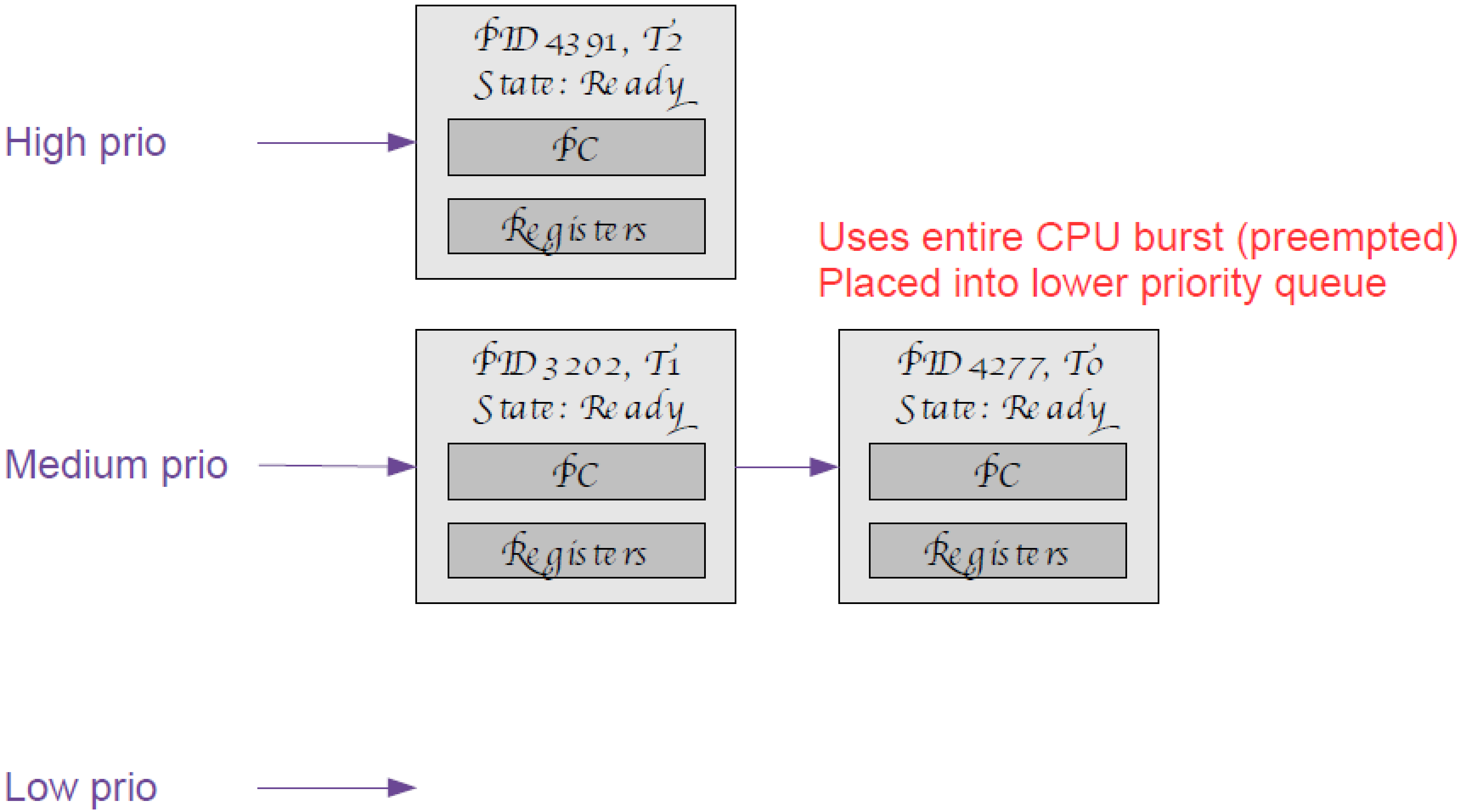
Multi-Level Feedback Queue (MLFQ)

- Observation: Want to give *higher priority to I/O-bound jobs*
  - They are likely to be interactive and need CPU rapidly after I/O completes
  - However, jobs are not always I/O bound or CPU-bound during execution!
    - *Web browser is mostly I/O bound and interactive but, becomes CPU bound when running a Java applet*
- Basic idea: Adjust priority of a thread in response to its CPU usage
  - Increase priority if job has a short CPU burst
  - Decrease priority if job has a long CPU burst (e.g., uses up CPU quantum)
  - Whenever processes with higher priority arrives**, Preempt the lower priority job**
  - **Jobs with lower priorities get longer CPU quantum**
- What is the rationale for this???
  - Don't want to give high priority to CPU-bound jobs...
    - Because lower-priority jobs can't preempt them if they get the CPU.
  - OK to give longer CPU quantum to low-priority jobs:
    - I/O bound jobs with higher priority can still preempt when they become runnable.

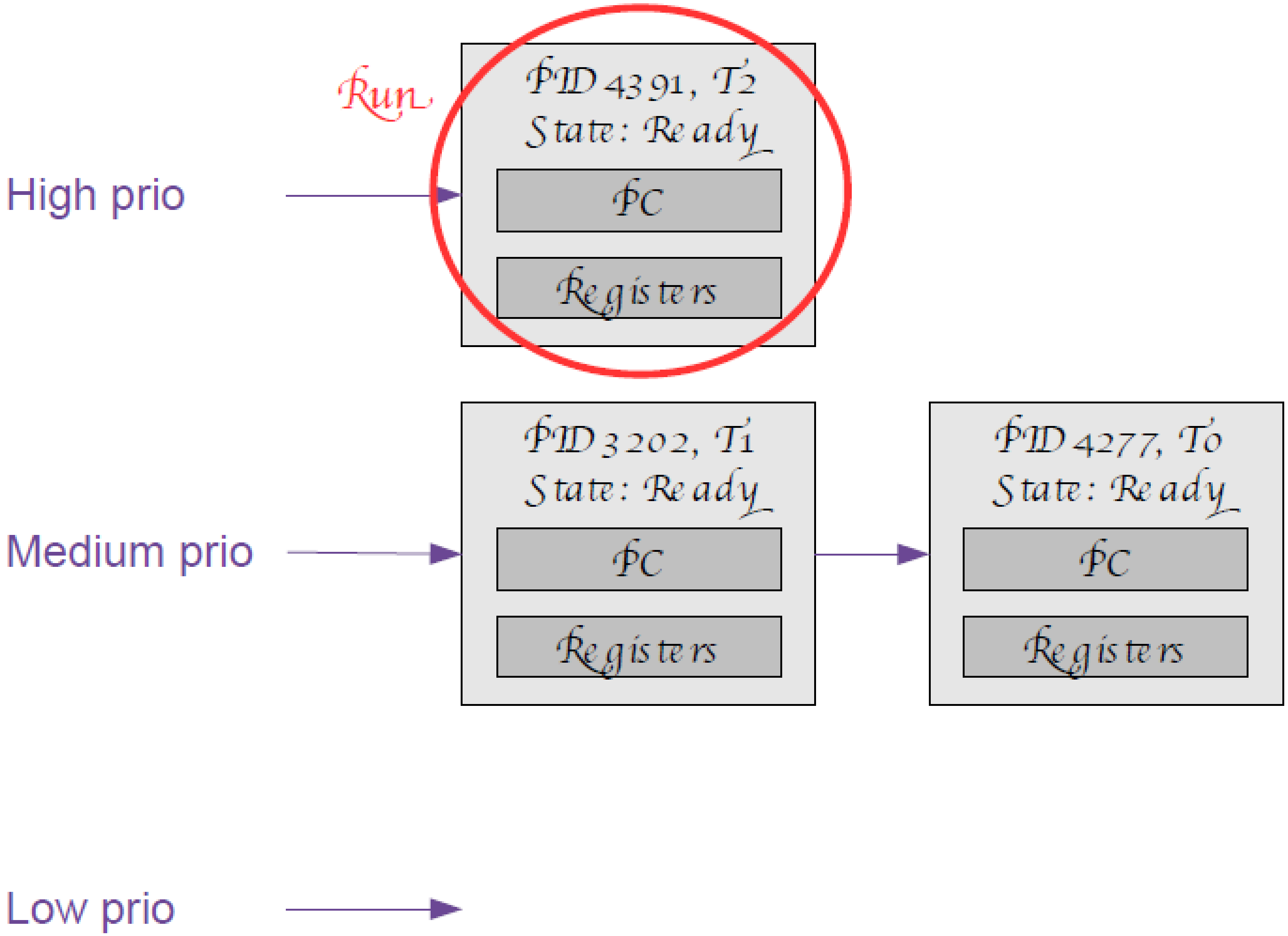
MLFQ Implementation



MLFQ Implementation



MLFQ Implementation



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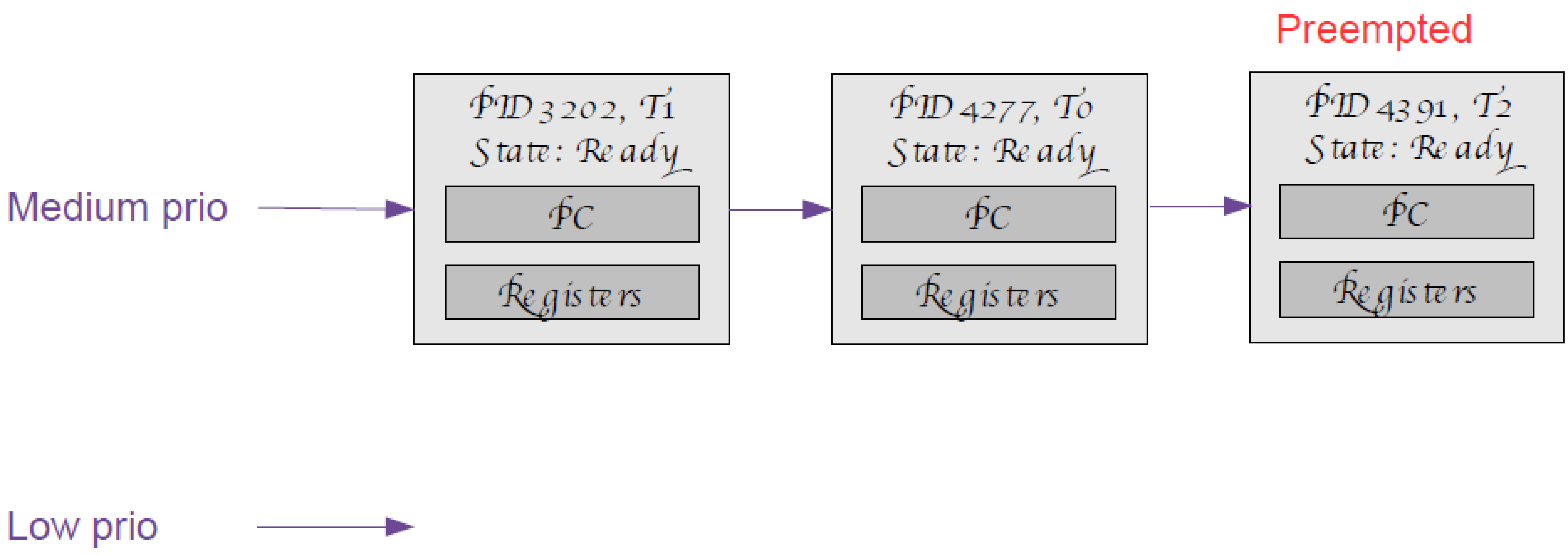

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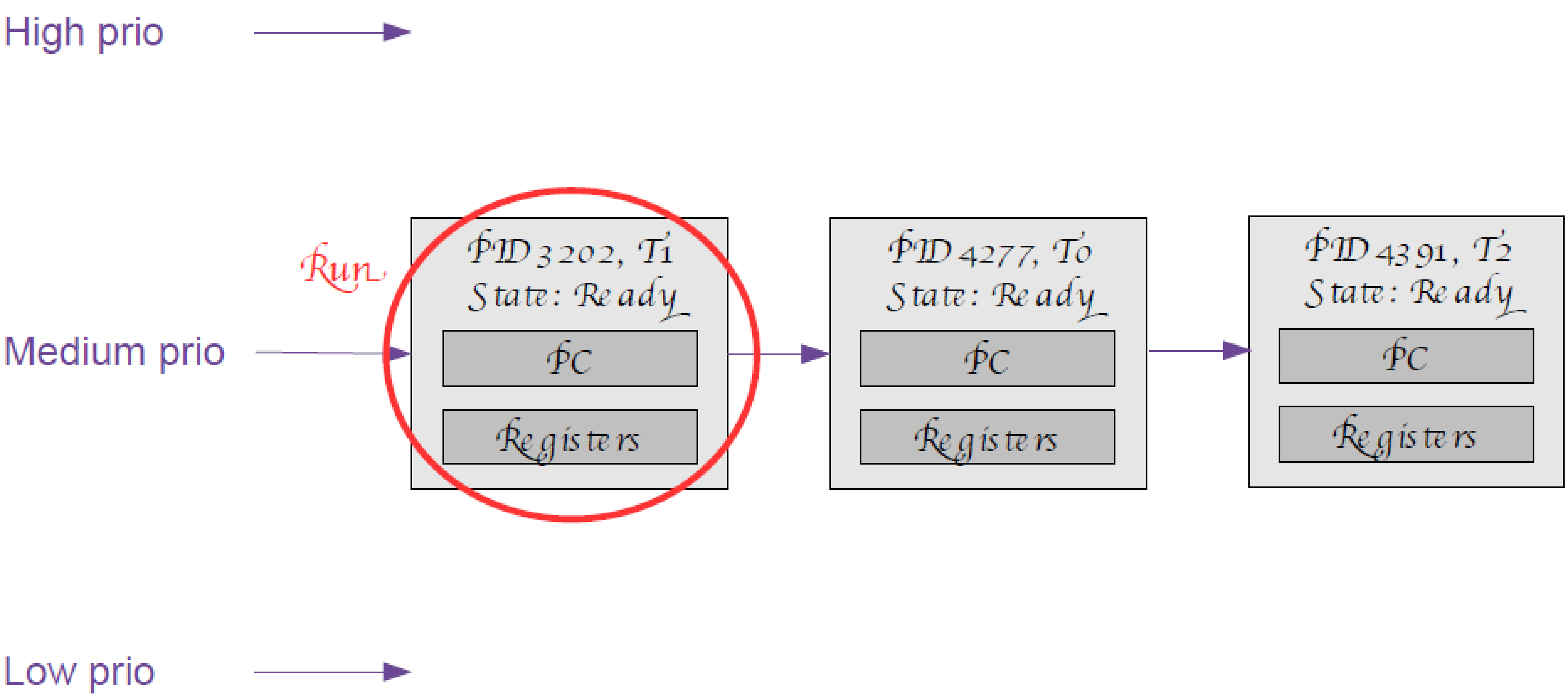

MLFQ Implementation