Scheduling

What is Scheduling?

- On a multi-programmed system
  - We may have more than one *Ready* process
- On a batch system
  - We may have many jobs waiting to be run
- On a multi-user system
  - We may have many users concurrently using the system

- The ***scheduler*** decides who to run next.
  - The process of choosing is called *scheduling.*

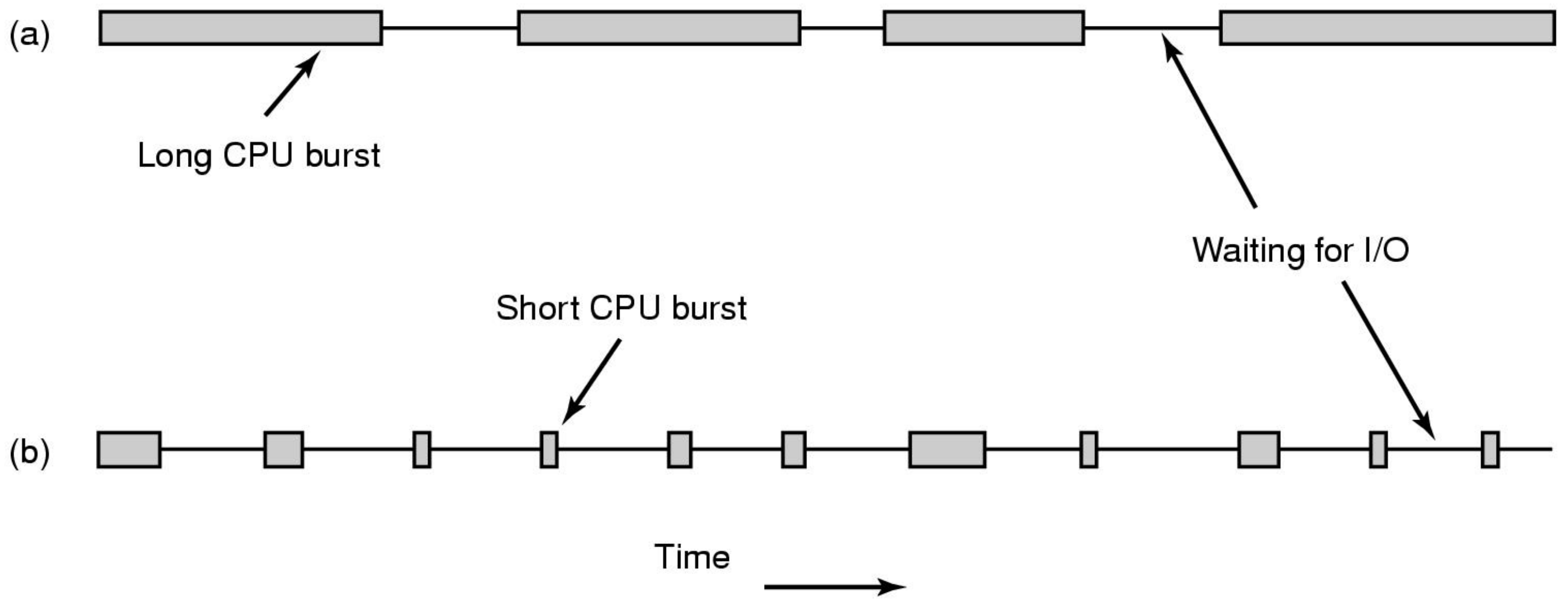
Is scheduling important?

- It is not in certain scenarios
  - If you have no choice
    - Early systems
      - Usually batching
      - Scheduling algorithm simple
        - » Run next on tape or next on punch tape
  - Only one thing to run
    - Simple PCs
      - Only ran a word processor, etc.…
    - Simple Embedded Systems
      - TV remote control, washing machine, etc.…

Is scheduling important?

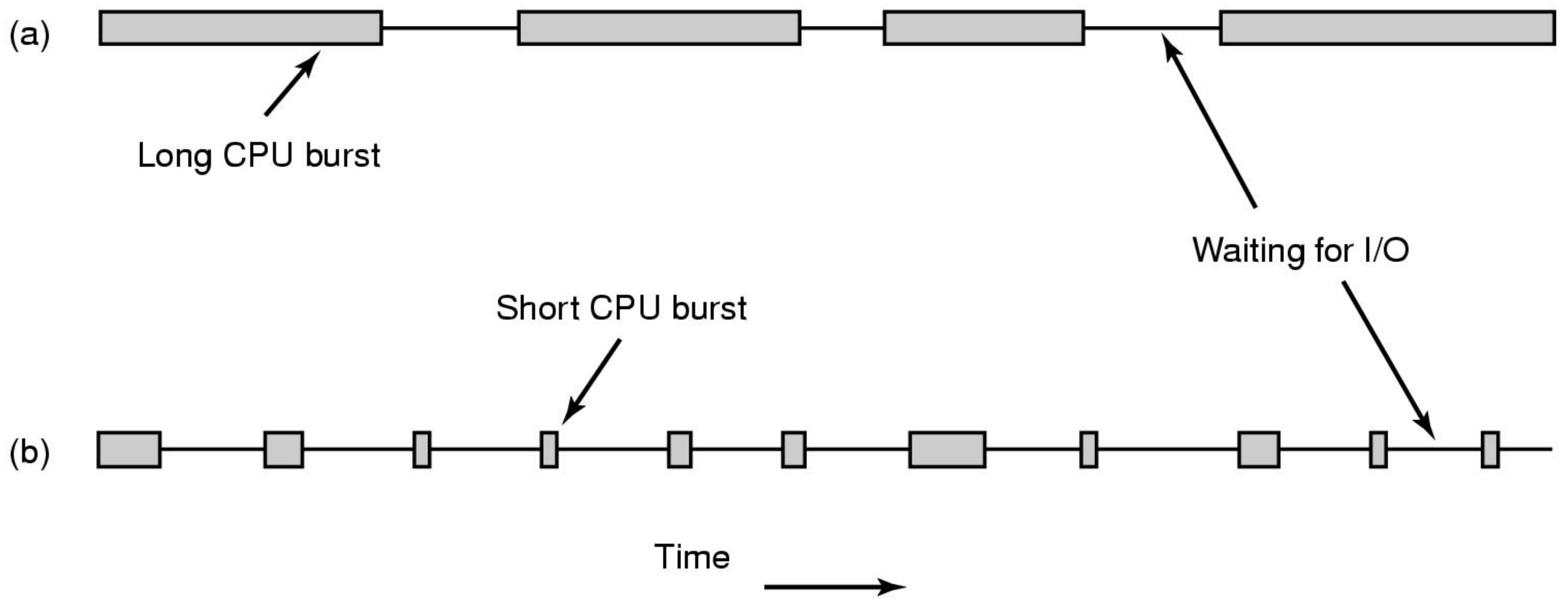
- It is in most realistic scenarios
  - Multitasking/Multi-user System
    - Example
      - Email daemon takes 2 seconds to process an email
      - User clicks button on application.
    - Scenario 1
      - Run daemon, then application
        - » System appears really sluggish to the user
    - Scenario 2
      - Run application, then daemon
        - » Application appears really responsive, small email delay is unnoticed
- Scheduling decisions can have a dramatic effect on the perceived performance of the system
  - Can also affect correctness of a system with deadlines

Application Behaviour



- Bursts of CPU usage alternate with periods of I/O wait

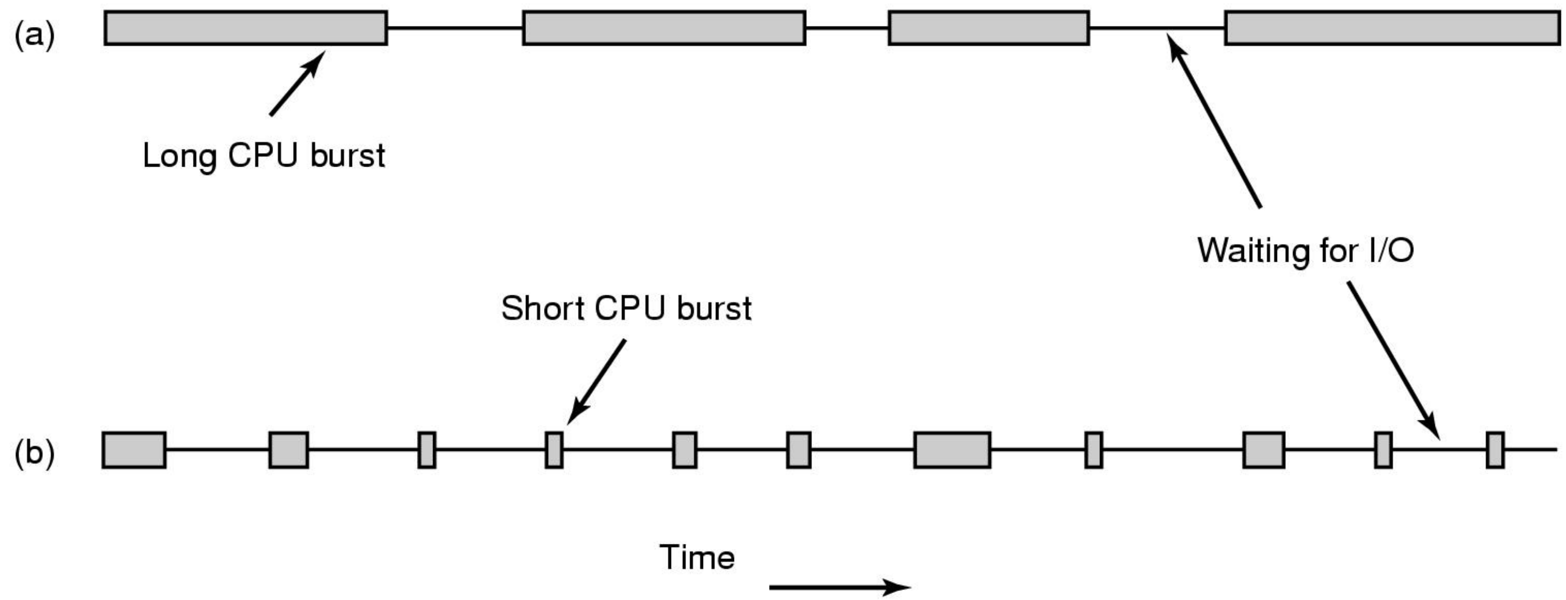
Application Behaviour



a) CPU-Bound process

- Spends most of its computing
- Time to completion largely determined by received CPU time

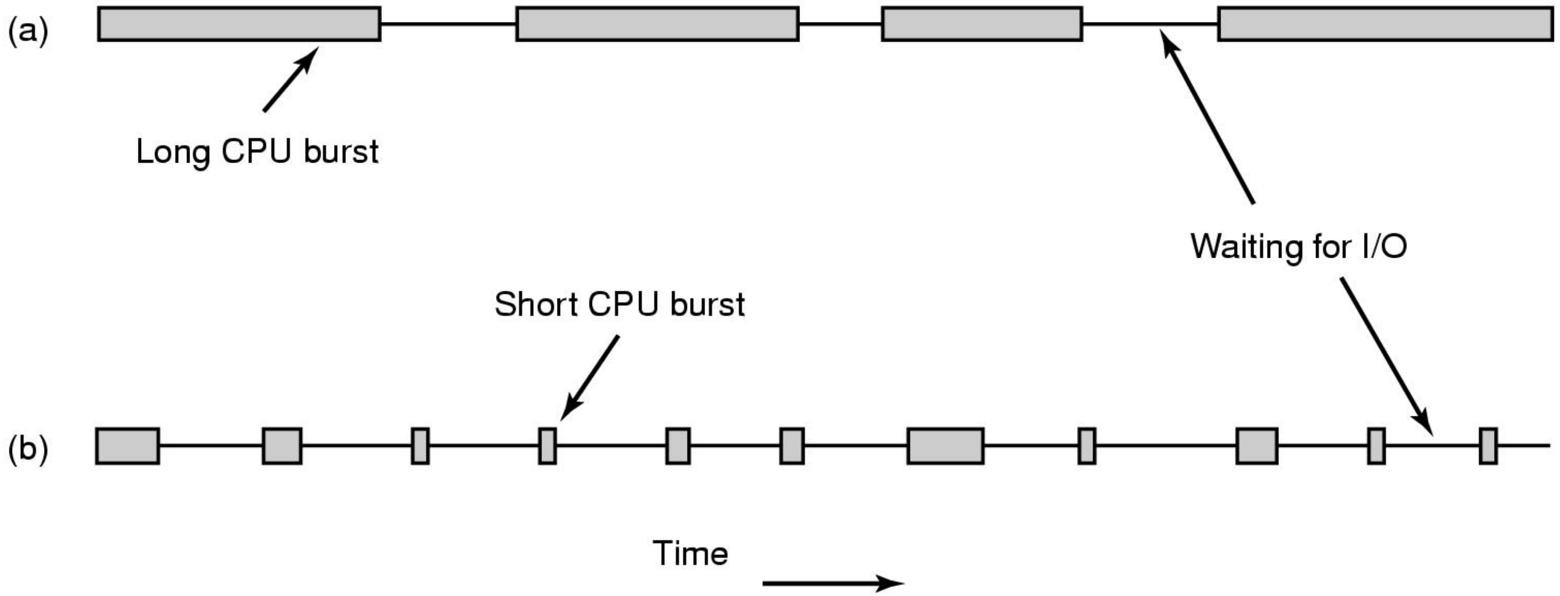
Application Behaviour



b) I/O-Bound process

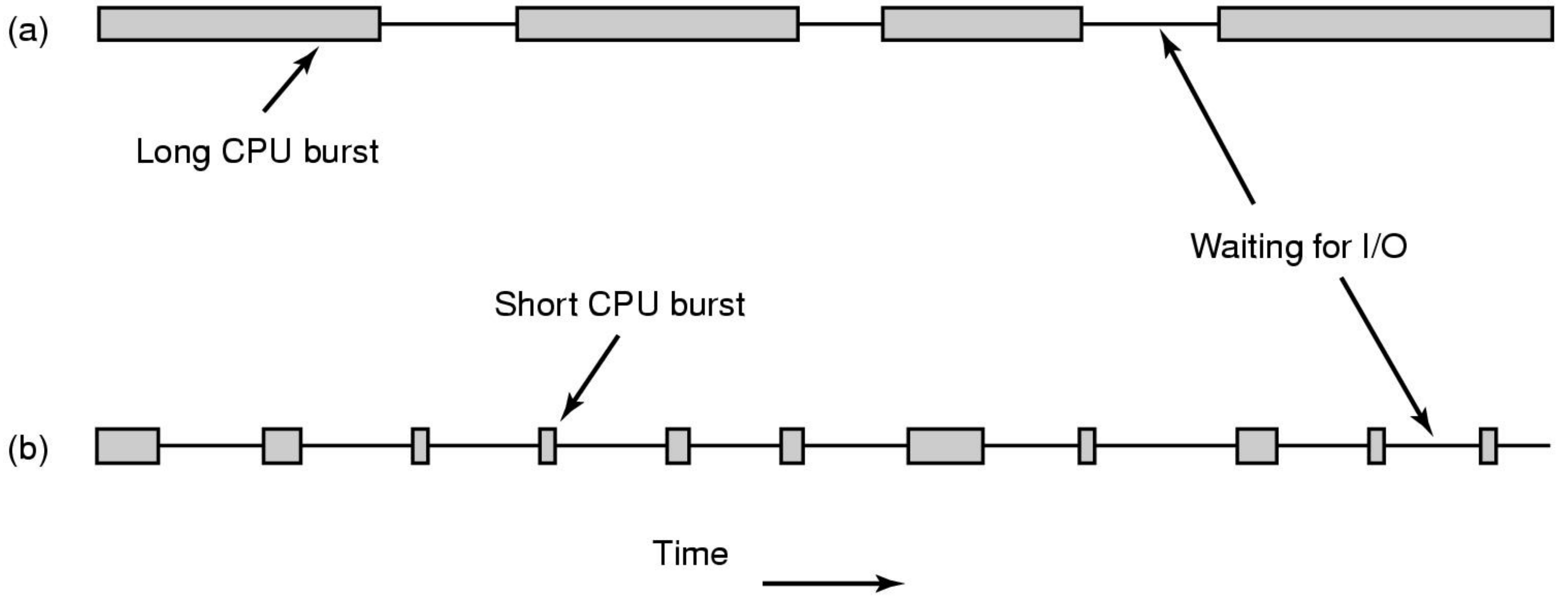
- Spend most of its time waiting for I/O to complete
  - Small bursts of CPU to process I/O and request next I/O
- Time to completion largely determined by I/O request time

Observations



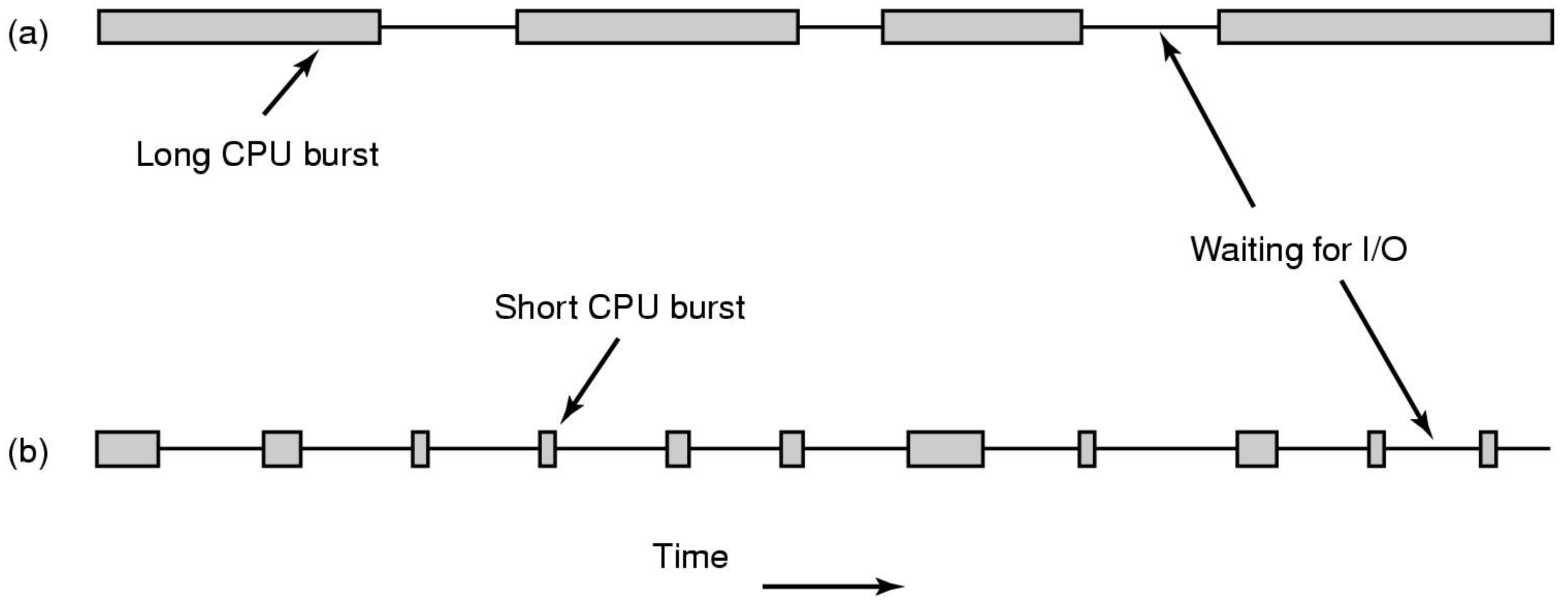
- Generally, technology is increasing CPU speed much faster than I/O speed
  - ⇒ CPU bursts becoming shorter, I/O waiting is relatively constant
  - ⇒ Processes are becoming more I/O bound

Observations



- We need a mix of CPU-bound and I/O-bound processes to keep both CPU and I/O systems busy
- Process can go from CPU- to I/O-bound (or vice versa) in different phases of execution

Observations



- Choosing to run an I/O-bound process delays a CPU-bound process by very little
- Choosing to run a CPU-bound process prior to an I/O-bound process delays the next I/O request significantly
  - No overlap of I/O waiting with computation
  - Results in device (disk) not as busy as possible

⇒ Generally, favour I/O-bound processes over CPU-bound processes

When is scheduling performed?

- A new process
  - Run the parent or the child?
- A process exits
  - Who runs next?
- A process waits for I/O
  - Who runs next?
- A process blocks on a lock
  - Who runs next? The lock holder?
- An I/O interrupt occurs
  - Who do we resume, the interrupted process or the process that was waiting?
- On a timer interrupt? (See next slide)

- Generally, a scheduling decision is required when a process (or thread) can no longer continue, or when an activity results in more than one ready process.

Preemptive versus Non-preemptive Scheduling

- Non-preemptive
  - Once a thread is in the *running* state, it continues until it completes, blocks on I/O, or voluntarily yields the CPU
  - A single process can monopolised the entire system
- Preemptive Scheduling
  - Current thread can be interrupted by OS and moved to *ready* state.
  - Usually after a timer interrupt and process has exceeded its maximum run time
    - Can also be as a result of higher priority process that has become *ready* (after I/O interrupt).
  - Ensures fairer service as single thread can't monopolise the system
    - Requires a timer interrupt

Categories of Scheduling Algorithms

- The choice of scheduling algorithm depends on the goals of the application (or the operating system)
  - No one algorithm suits all environments
- We can roughly categorise scheduling algorithms as follows
  - Batch Systems
    - No users directly waiting, can optimise for overall machine performance
  - Interactive Systems
    - Users directly waiting for their results, can optimise for users perceived performance
  - Realtime Systems
    - Jobs have deadlines, must schedule such that all jobs (mostly) meet their deadlines.

Goals of Scheduling Algorithms

- All Algorithms
  - Fairness
    - Give each process a *fair* share of the CPU
  - Policy Enforcement
    - What ever policy chosen, the scheduler should ensure it is carried out
  - Balance/Efficiency
    - Try to keep all parts of the system busy

Goals of Scheduling Algorithms

- Batch Algorithms
  - Maximise *throughput*
    - Throughput is measured in jobs per hour (or similar)
  - Minimise *turn-around time*
    - Turn-around time (T_r)
      - difference between time of completion and time of submission
      - Or waiting time (T_w) + execution time (T_e)
  - Maximise *CPU utilisation*
    - Keep the CPU busy
    - Not as good a metric as overall throughput

Goals of Scheduling Algorithms

- Interactive Algorithms
  - Minimise *response time*
    - Response time is the time difference between issuing a command and getting the result
      - E.g selecting a menu, and getting the result of that selection
    - Response time is important to the user's perception of the performance of the system.
  - Provide *Proportionality*
    - Proportionality is the user expectation that short jobs will have a short response time, and long jobs can have a long response time.
    - Generally, favour short jobs

Goals of Scheduling Algorithms

- Real-time Algorithms
  - Must meet deadlines
    - Each job/task has a deadline.
    - A missed deadline can result in data loss or catastrophic failure
      - Aircraft control system missed deadline to apply brakes
  - Provide Predictability
    - For some apps, an occasional missed deadline is okay
      - E.g. DVD decoder
    - Predictable behaviour allows smooth DVD decoding with only rare skips

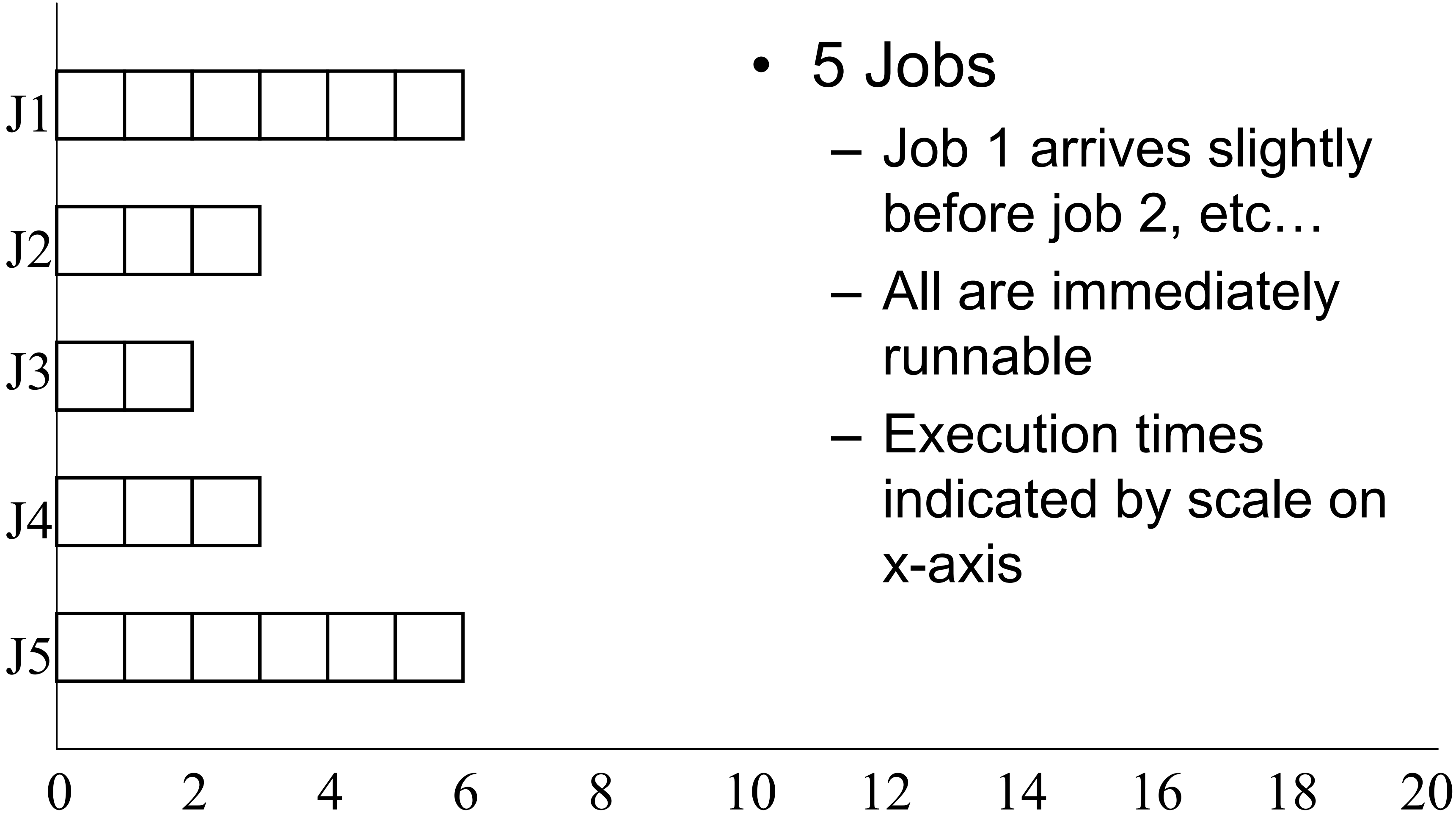
Scheduling Algorithms

Batch Systems

First-Come First-Served (FCFS)

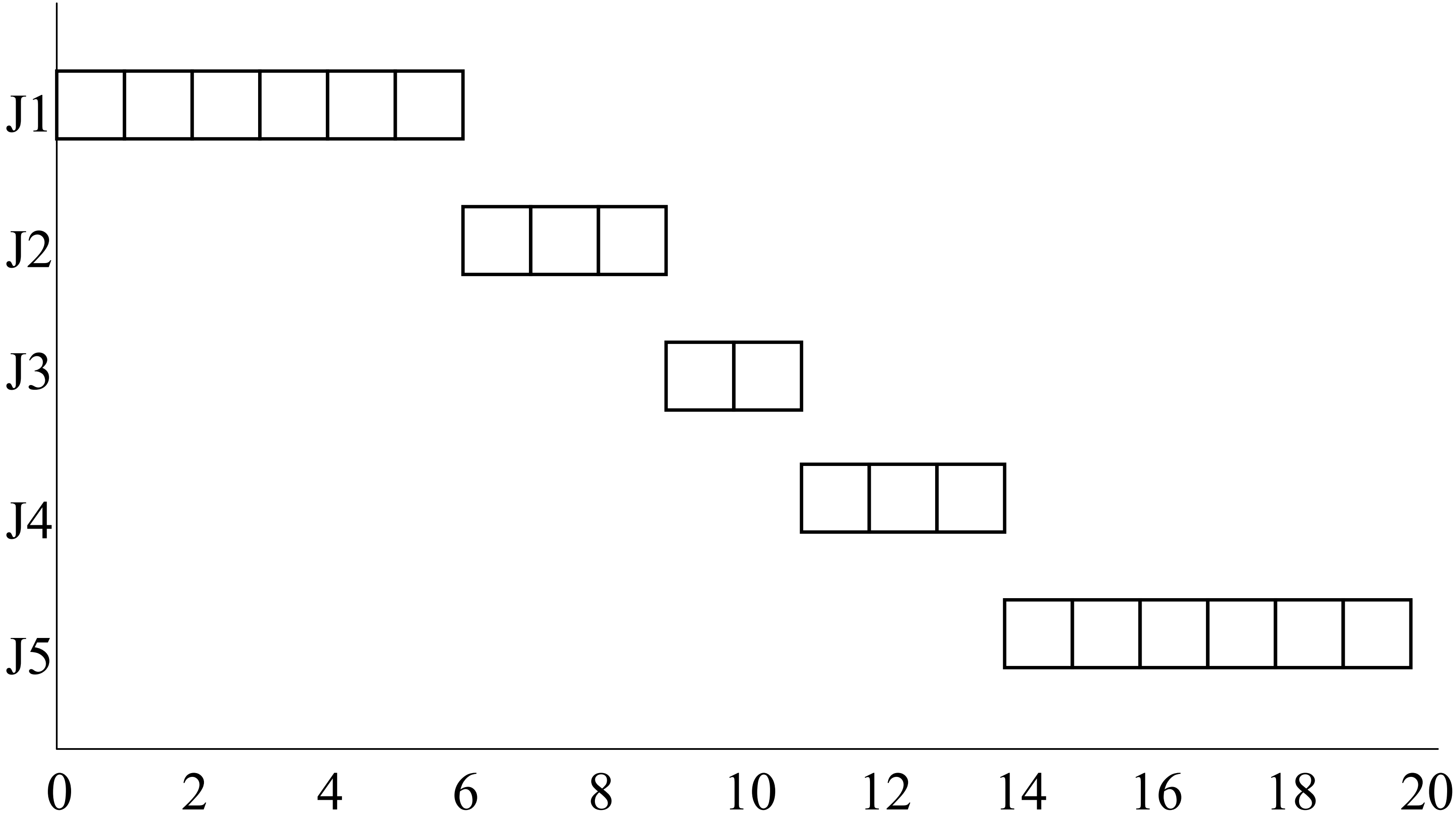
- Algorithm
  – Each job is placed in single queue, the first job in the queue is selected, and allowed to run as long as it wants.
  – If the job blocks, the next job in the queue is selected to run
  – When a blocked jobs becomes ready, it is placed at the end of the queue

Example



- 5 Jobs
  - Job 1 arrives slightly before job 2, etc…
  - All are immediately runnable
  - Execution times indicated by scale on x-axis

FCFS Schedule



FCFS

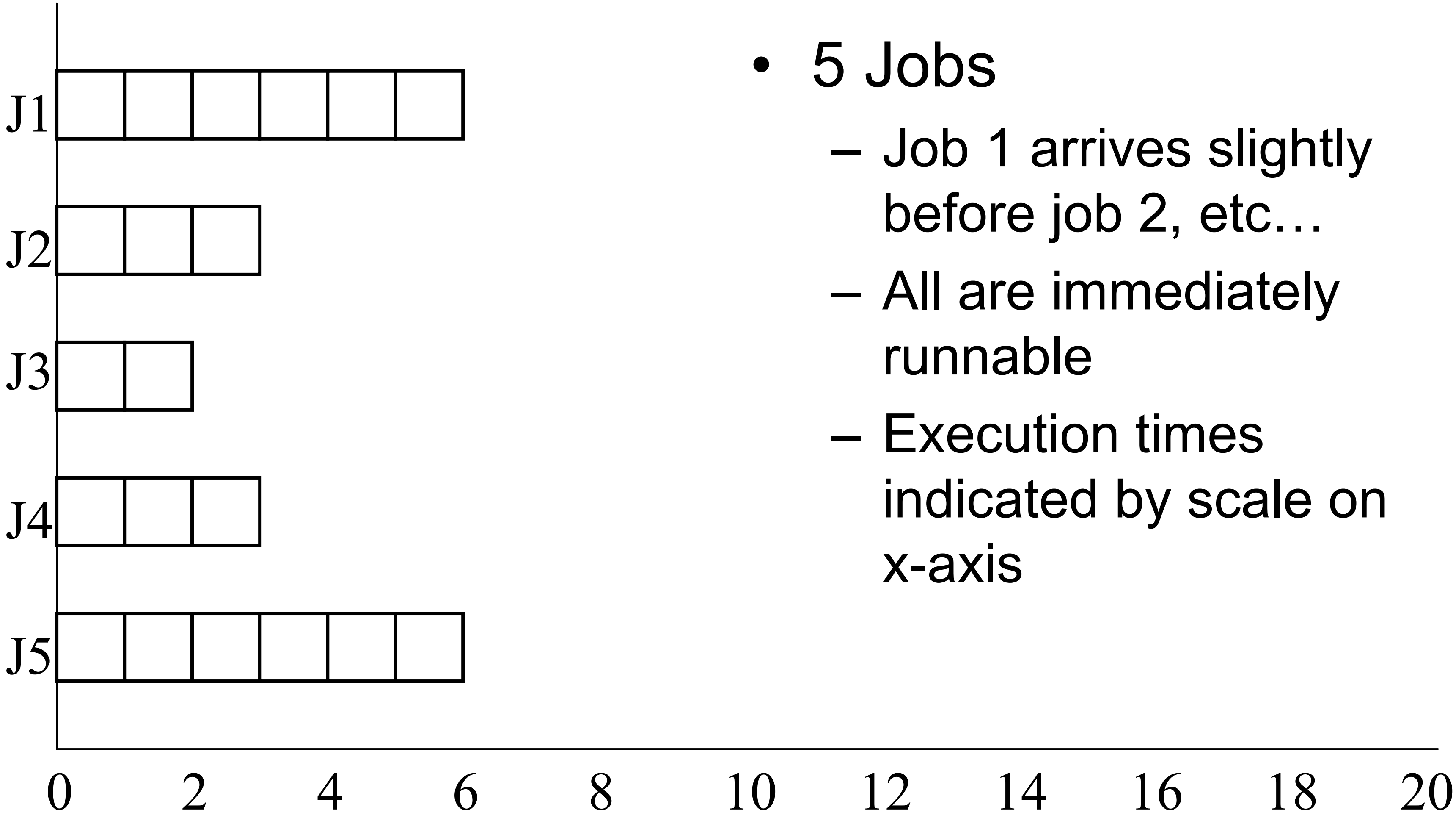
- Pros
  - Simple and easy to implement
- Cons
  - I/O-bound jobs wait for CPU-bound jobs

  ⇒Favours CPU-bound processes
    - Example:
      - Assume 1 CPU-bound process that computes for 1 second and blocks on a disk request. It arrives first.
      - Assume an I/O bound process that simply issues a 1000 blocking disk requests (very little CPU time)
      - FCFS, the I/O bound process can only issue a disk request per second
        - » the I/O bound process take 1000 seconds to finish
      - Another scheme, that preempts the CPU-bound process when I/O-bound process are ready, could allow I/O-bound process to finish in 1000* average disk access time.

Shortest Job First

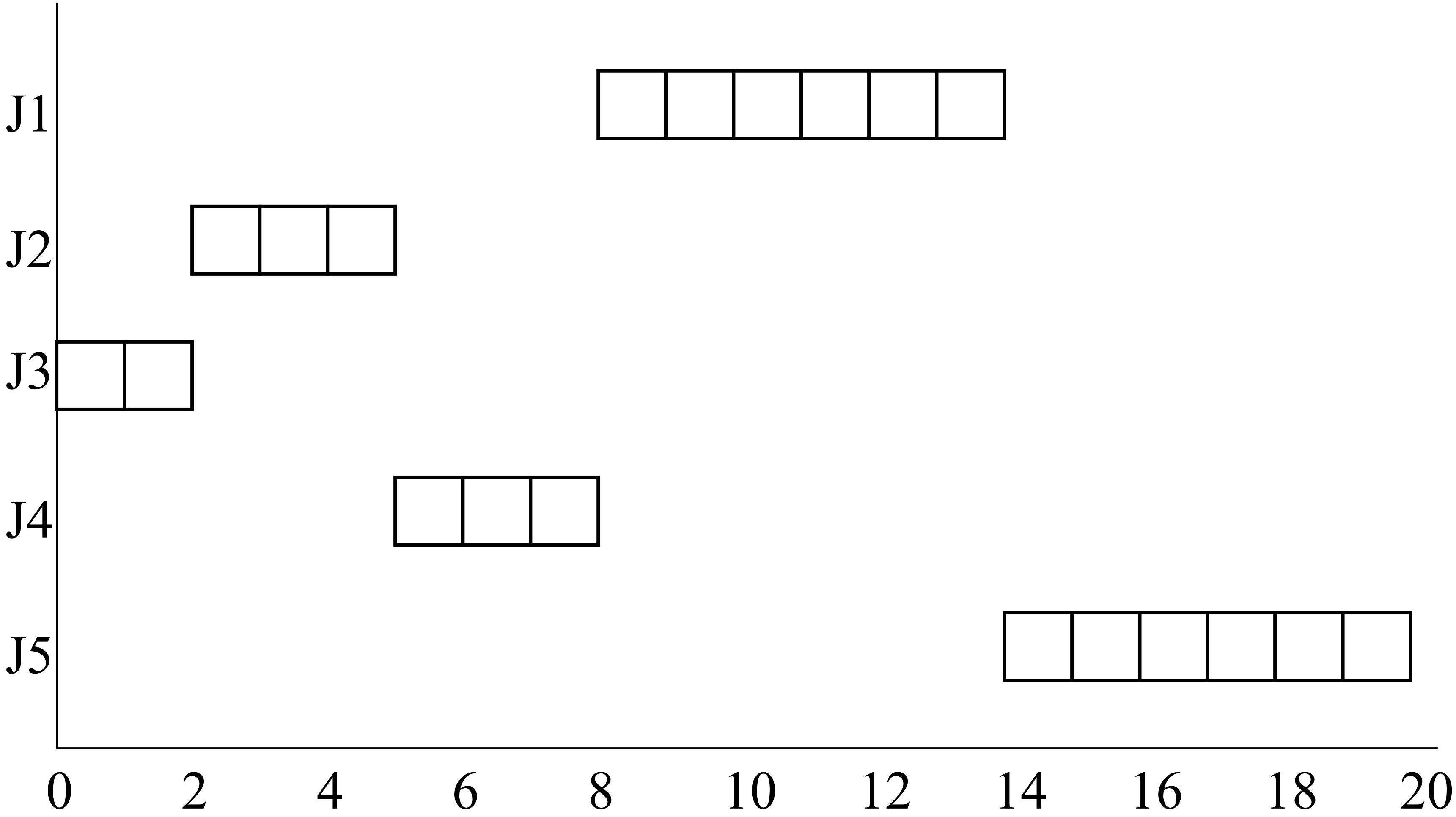
- If we know (or can estimate) the execution time *a priori,* we choose the shortest job first.
- Another non-preemptive policy

Our Previous Example



- 5 Jobs
  - Job 1 arrives slightly before job 2, etc…
  - All are immediately runnable
  - Execution times indicated by scale on x-axis

Shortest Job First



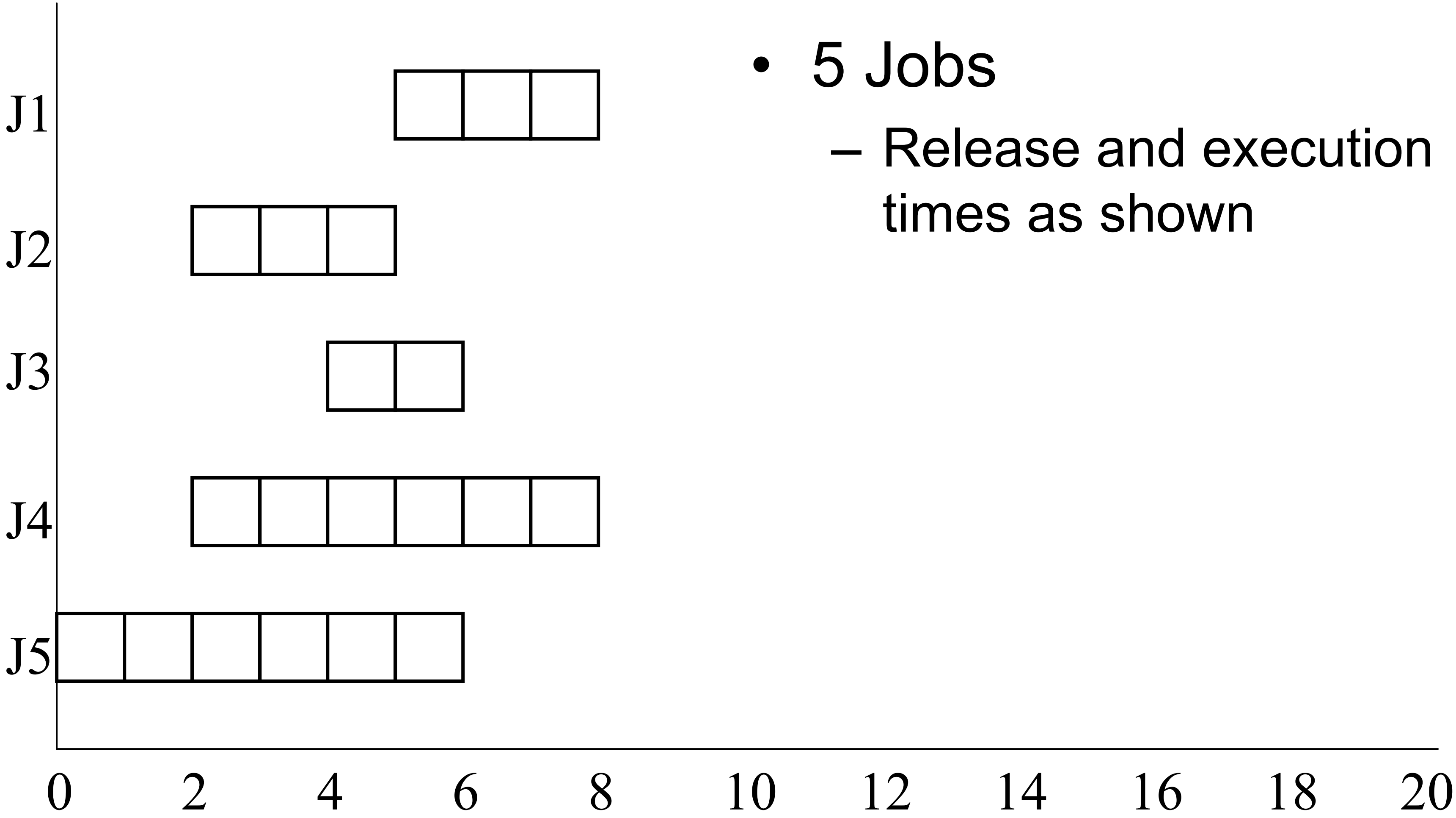
Shortest Job First

- Con
  - May starve long jobs
  - Needs to predict job length
- Pro
  - Minimises average turnaround time (if, and only if, all jobs are available at the beginning)
  - Example: Assume for processes with execution times of *a, b, c, d.*
    - *a* finishes at time *a*, *b* finishes at *a* + *b,* *c* at *a* + *b* + *c,* and so on
    - Average turn-around time is (4*a* + 3*b* + 2*c* + *d*)/4
    - Since *a* contributes most to average turn-around time, it should be the shortest job.

Shortest Remaining Time First

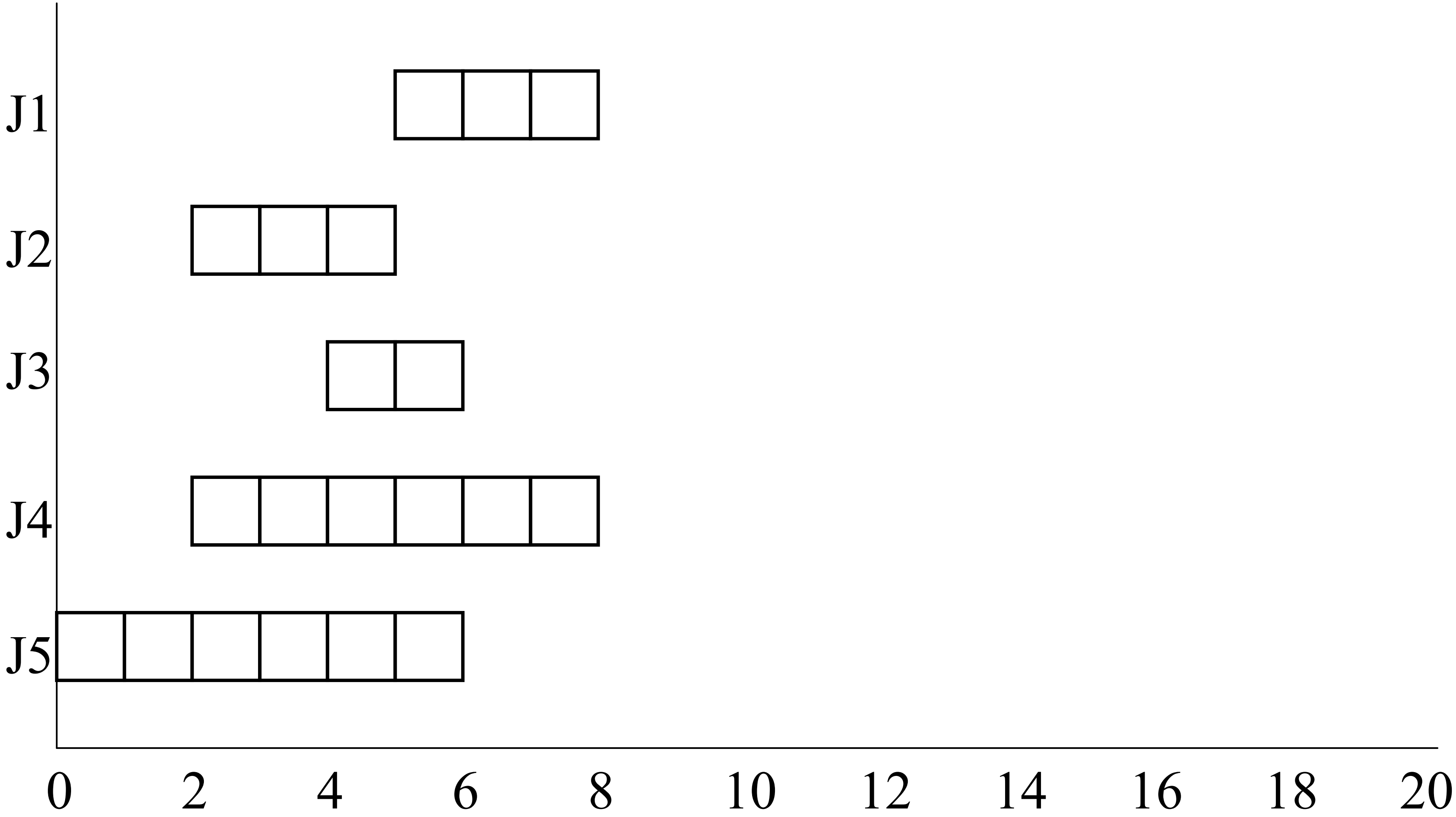
- A preemptive version of shortest job first
- When ever a new jobs arrive, choose the one with the shortest remaining time first
  - New short jobs get good service

Example

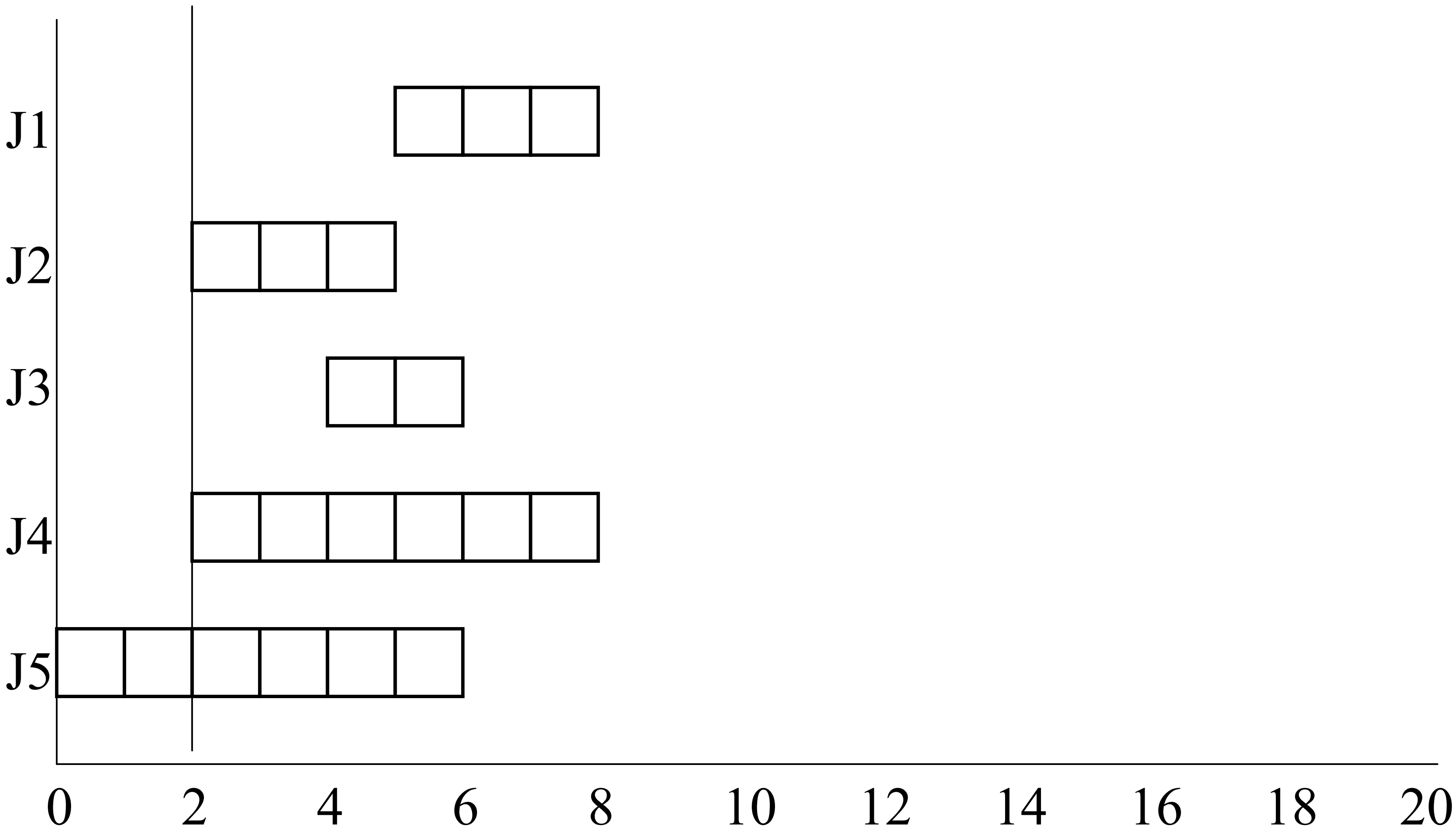


- 5 Jobs
  - Release and execution times as shown

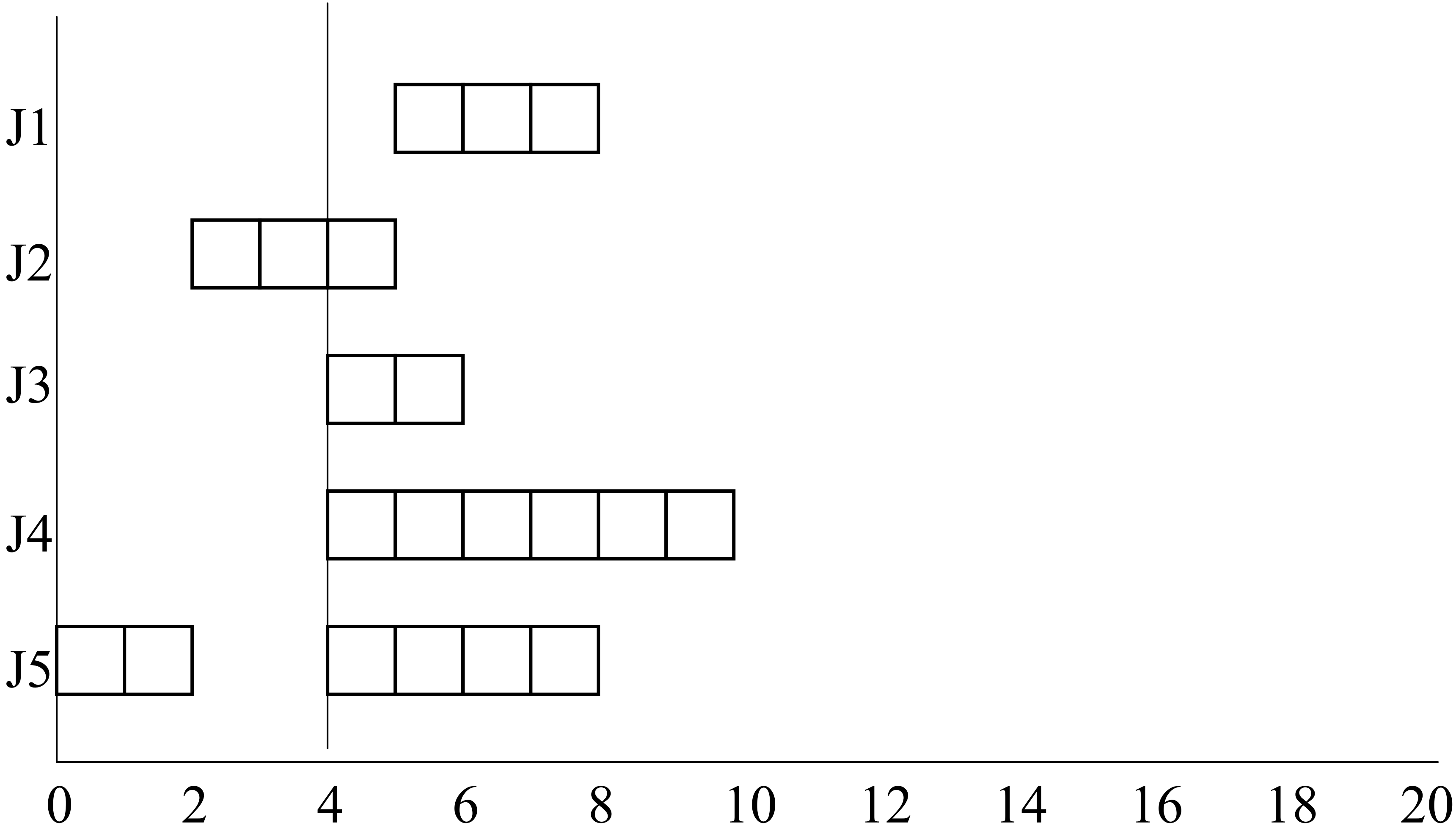
Shortest Remaining Time First



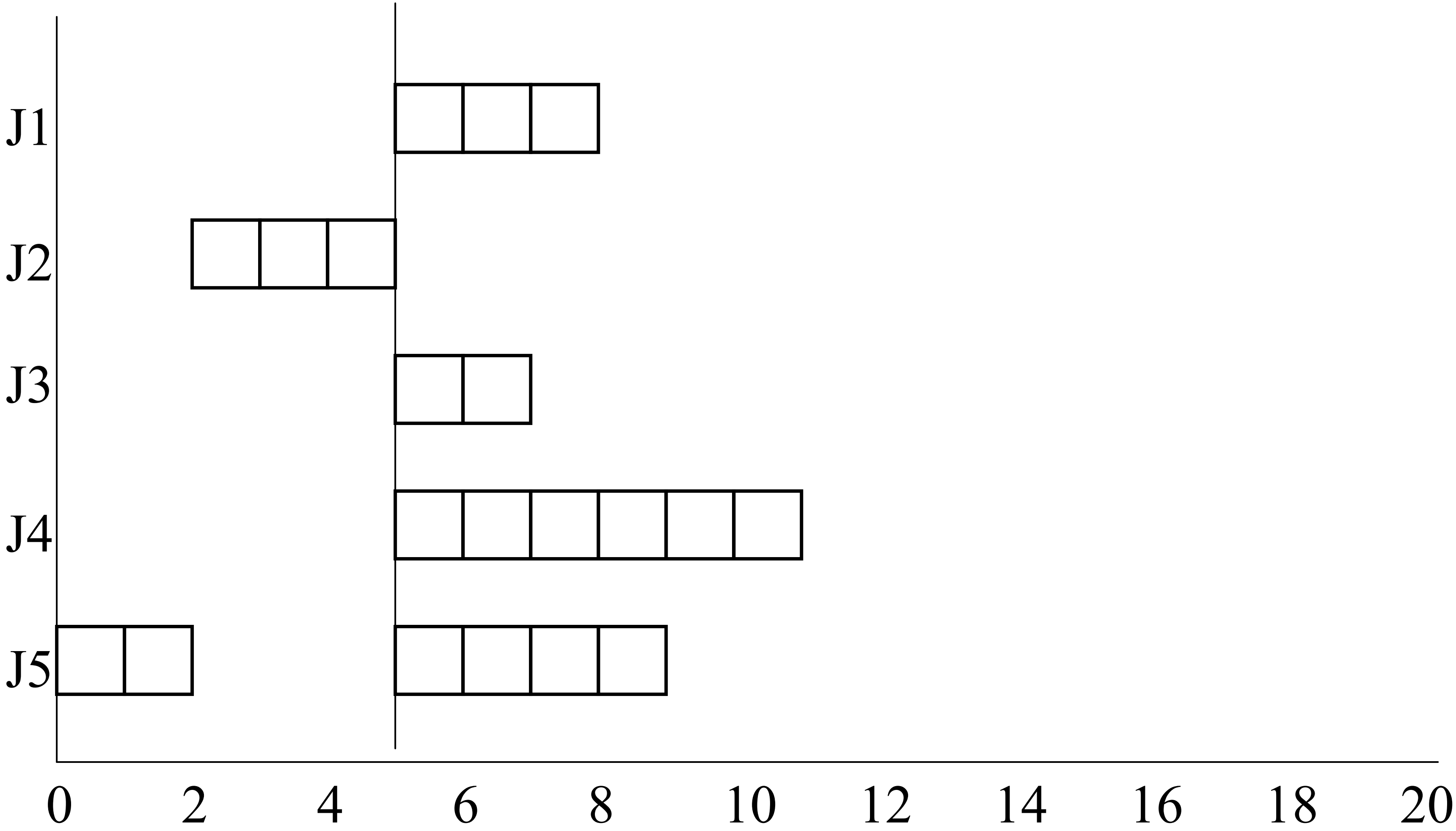
Shortest Remaining Time First



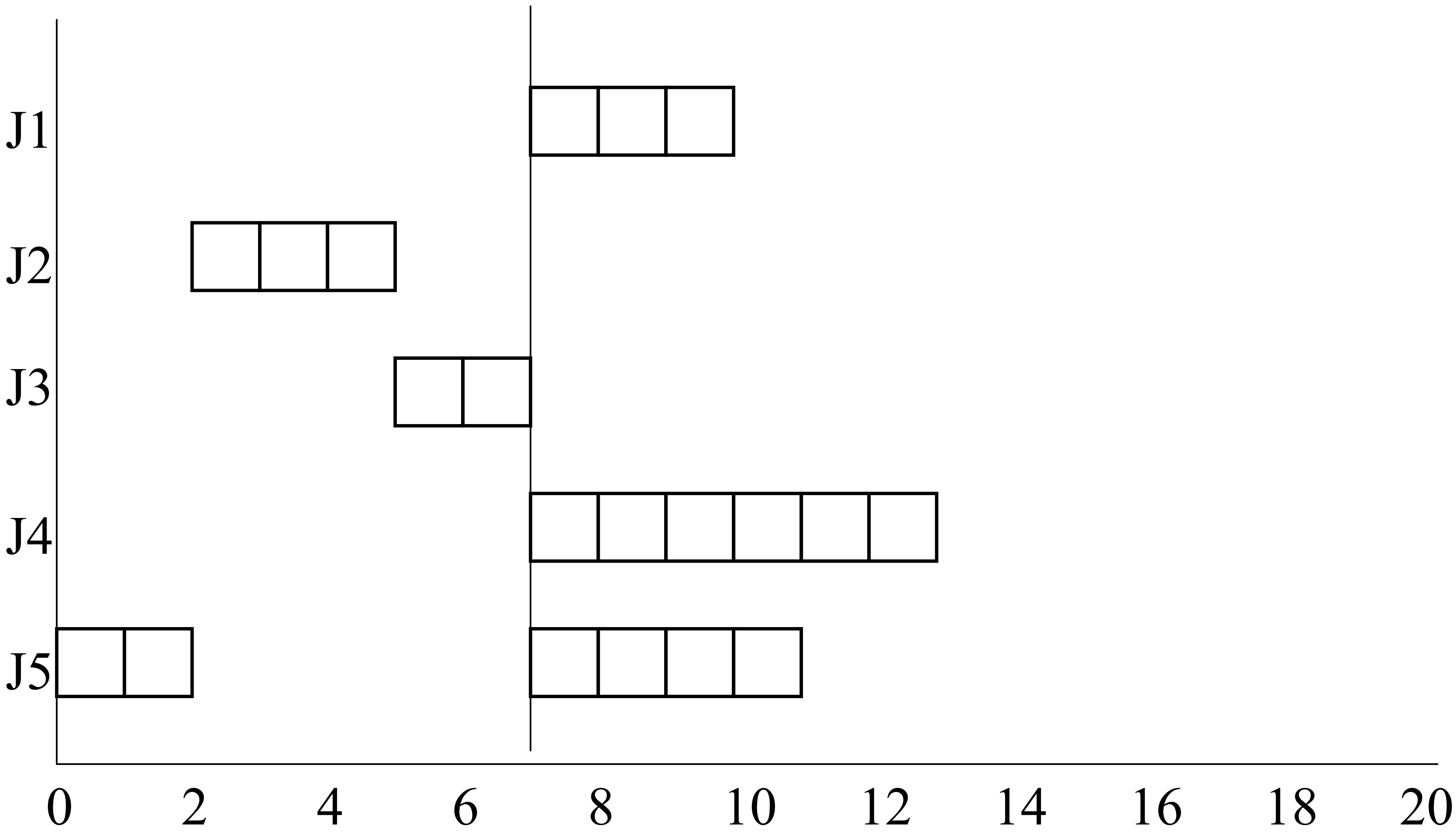
Shortest Remaining Time First



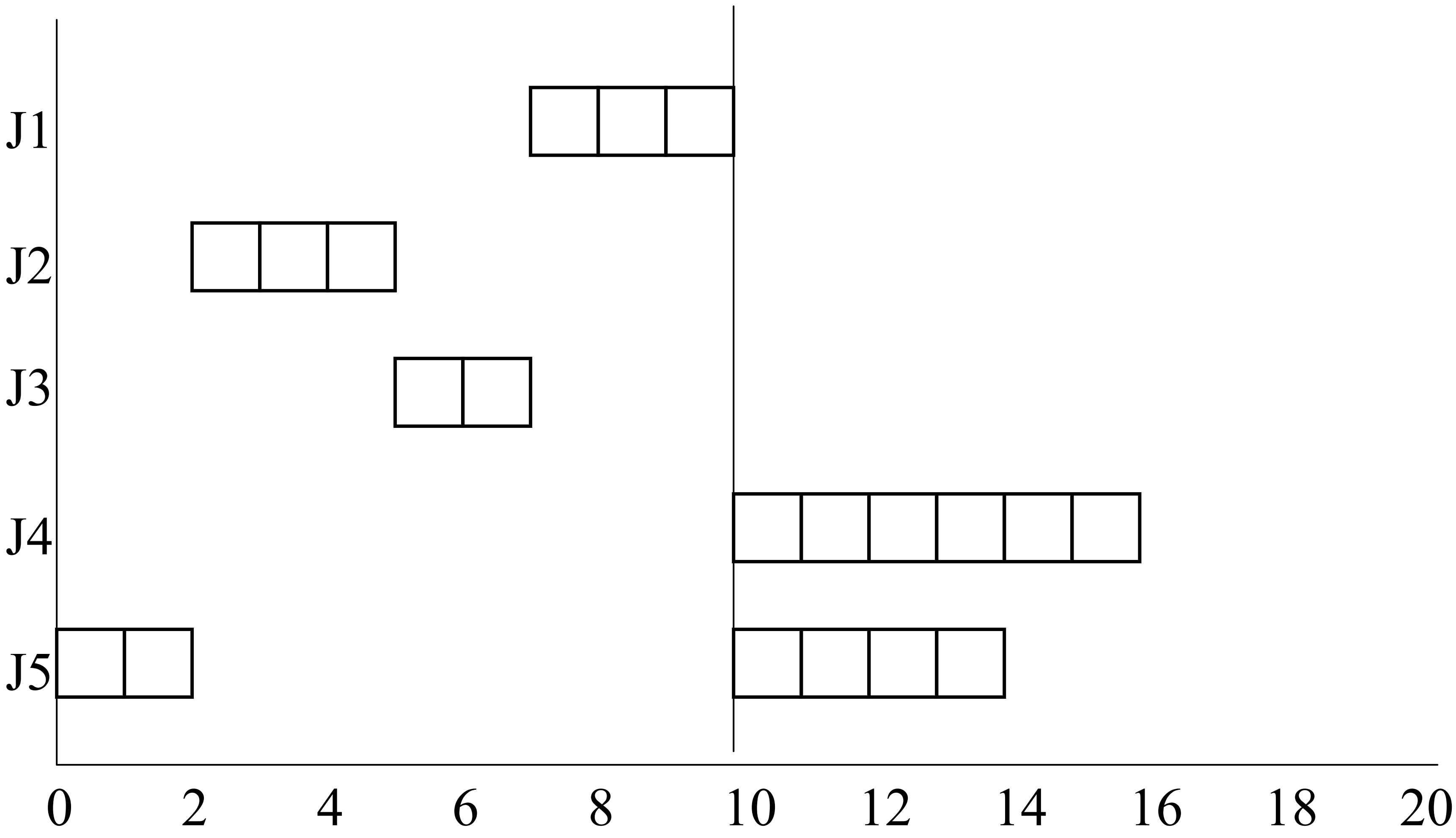
Shortest Remaining Time First



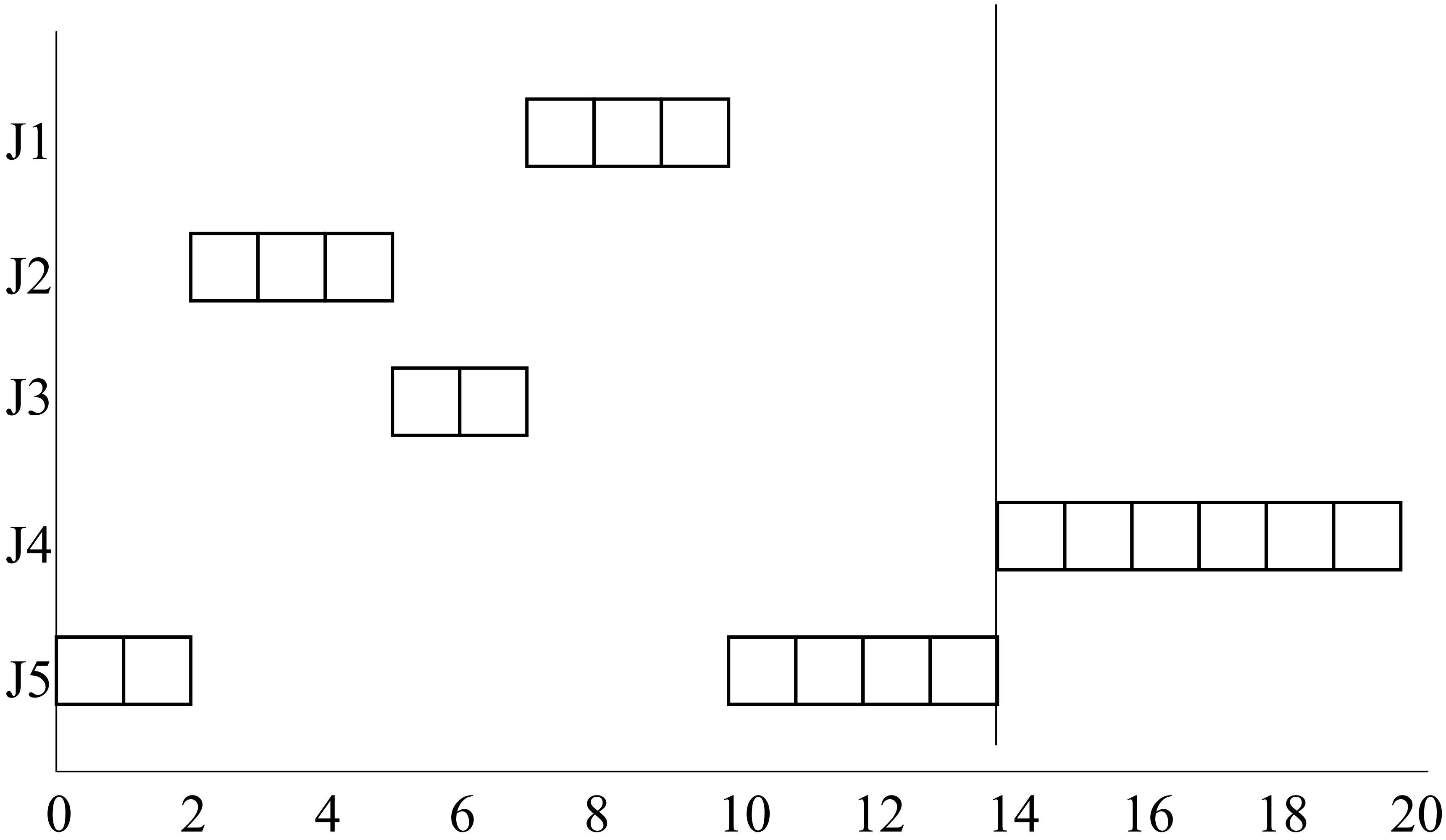
Shortest Remaining Time First



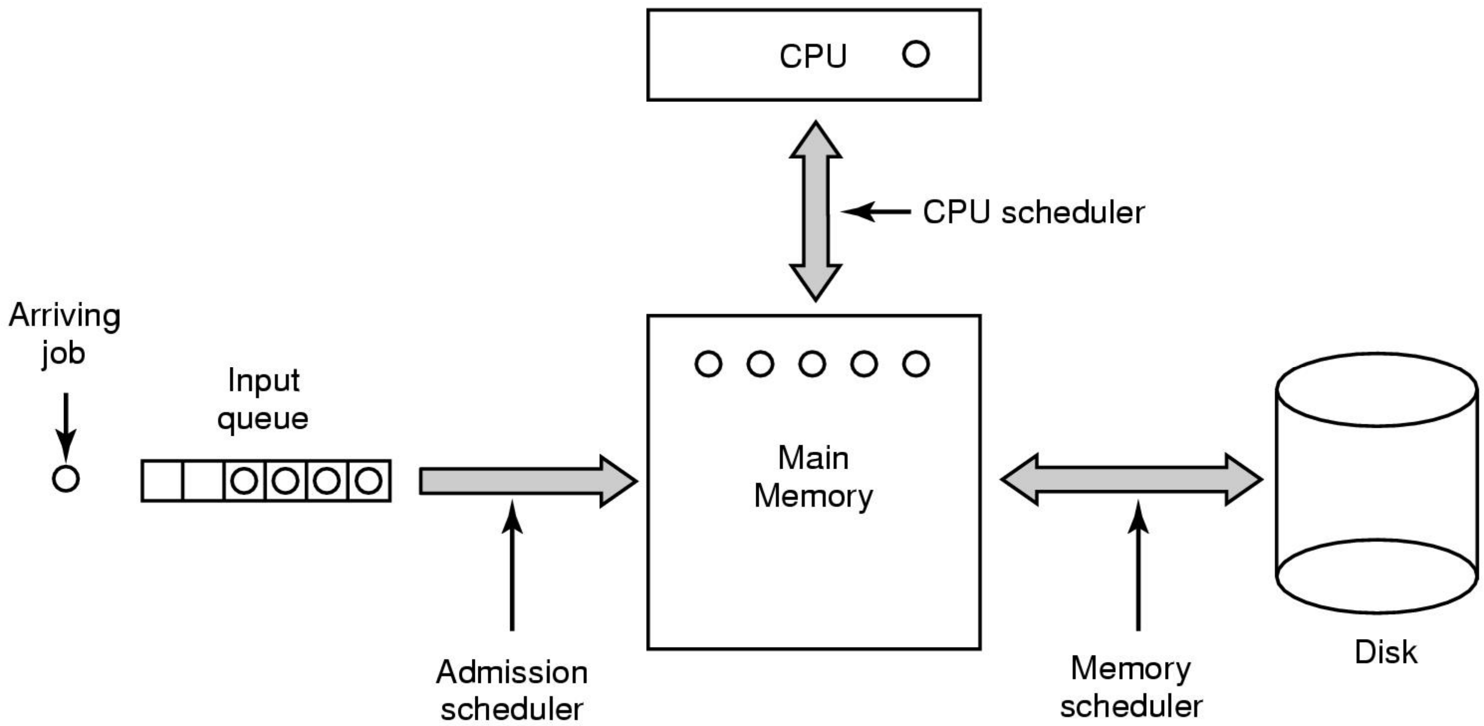
Shortest Remaining Time First



Shortest Remaining Time First



Scheduling in Batch Systems



Three level scheduling

Three Level Scheduling

- Admission Scheduler
  - Also called *long-term* scheduler
  - Determines when jobs are *admitted* into the system for processing
  - Controls degree of multiprogramming
  - More processes $\Rightarrow$ less CPU available per process

Three Level Scheduling

- CPU scheduler
  – Also called *short-term* scheduler
  – Invoked when ever a process blocks or is released, clock interrupts (if preemptive scheduling), I/O interrupts.
  – Usually, this scheduler is what we are referring to if we talk about a *scheduler*.

Three Level Scheduling

- Memory Scheduler
  - Also called *medium-term* scheduler
  - Adjusts the degree of multiprogramming via suspending processes and swapping them out