Process Management

Process Scheduling

Lecture 3

Overview

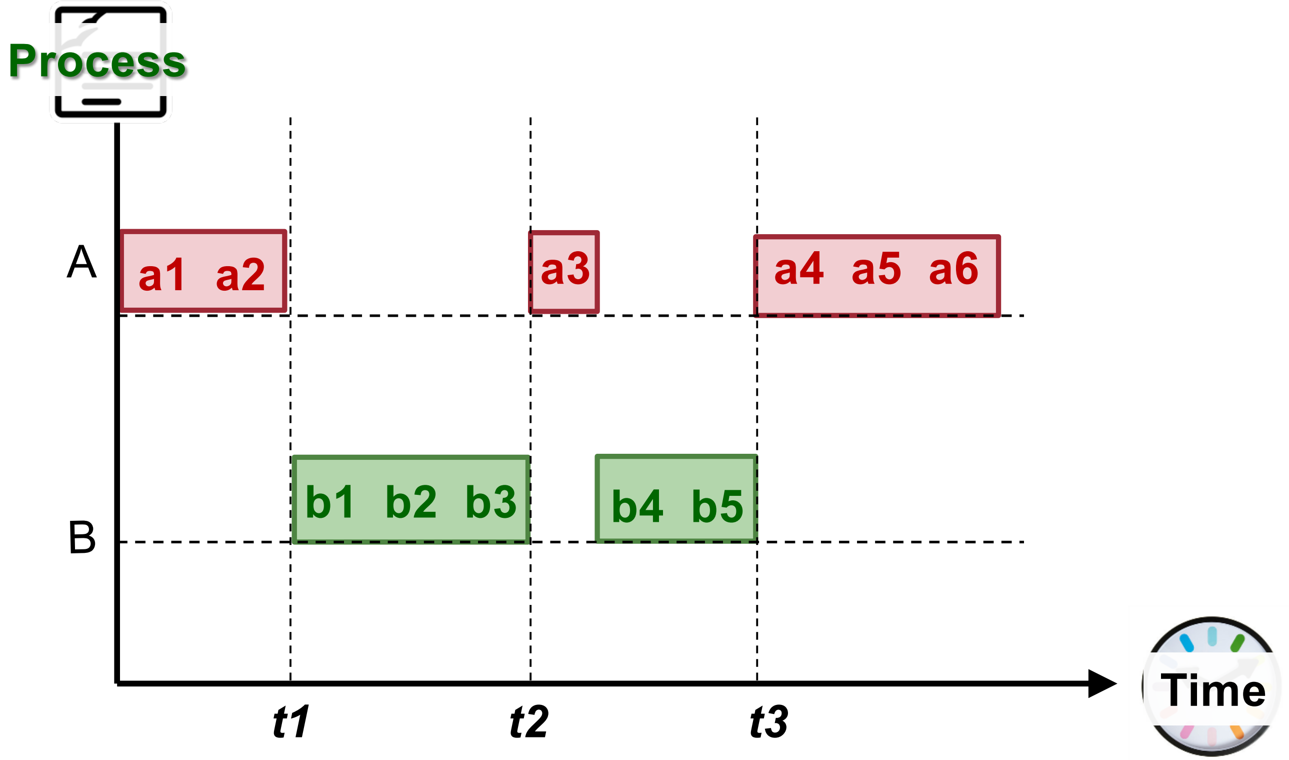
- Concurrent Execution
- Process Scheduling
  - Definition
  - Process behavior
  - Processing environment
  - Criteria for good scheduling
  - Procedure of process scheduling
- Scheduling Algorithms
  - For Batch Processing Systems
  - For interactive Systems

Concurrent Execution

- **Concurrent processes**:
  - Logical concept to cover multitasked processes
  - Could be virtual parallelism:
    - illusion of parallelism (*pseudo-parallelism*)
  - Could be physical (hardware) parallelism
    - E.g., Multiple CPUs / Multi-Core CPU to allow parallel execution of multiple processes

- You can assume the two forms of parallelisms are not distinguished in the following discussion

Concurrency Example (Simplistic)

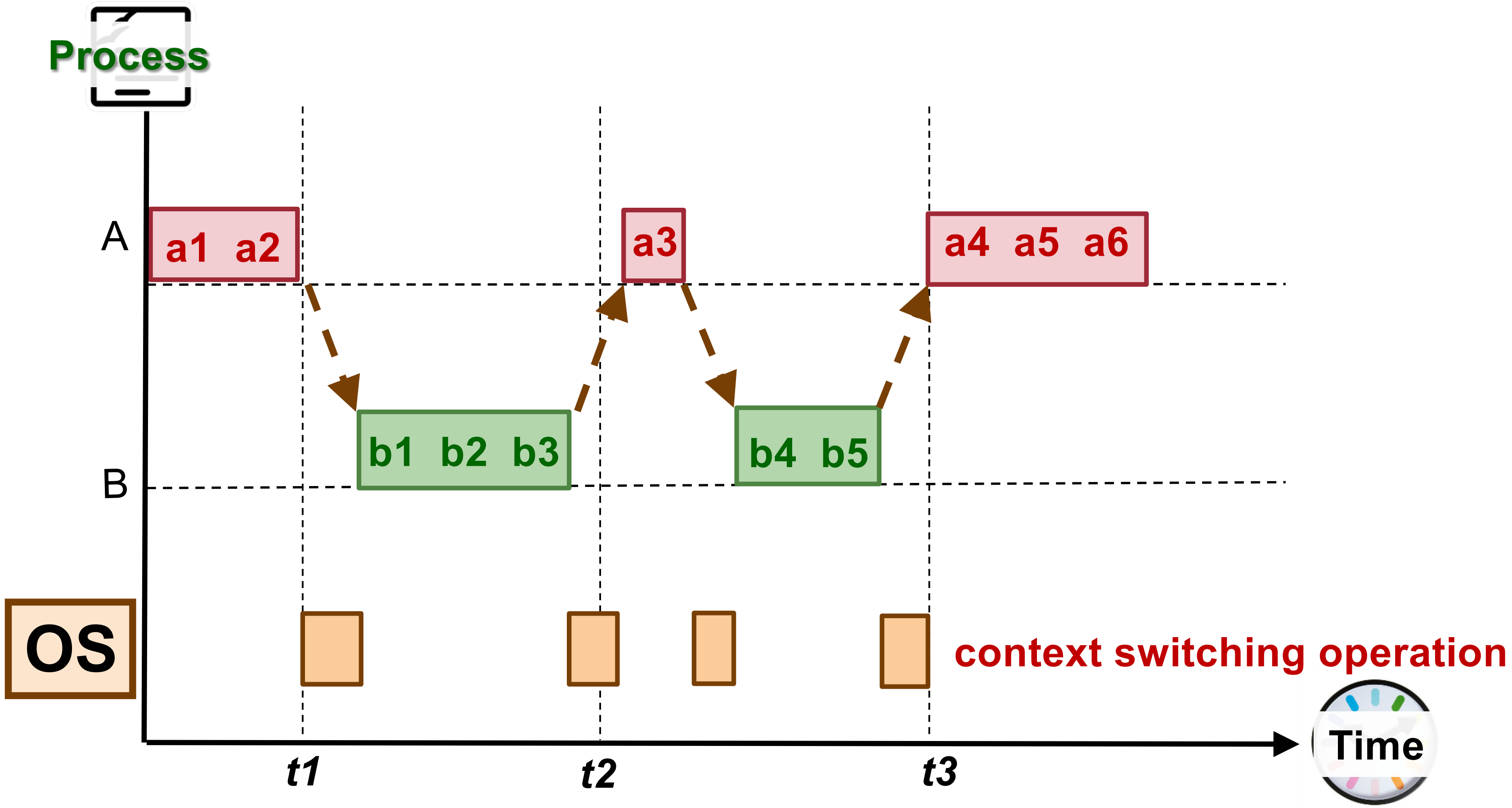


a1-a6:
Instructions of **process A**

b1-b5:
Instructions of **process B**

Concurrent execution on 1 CPU:
Interleave instructions from both processes
Also called **time-slicing**

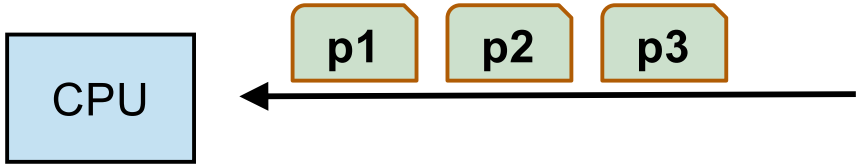
Interleaved Execution (**context switch**)



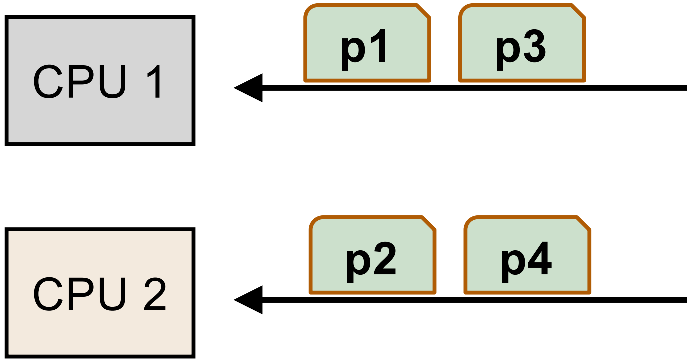
- Multitasking needs to change context between A and B:
  - OS incurs overhead in switching processes

Multitasking OS

- 1 CPU: time-sliced execution of tasks



- Multiprocessor: time-slicing on ***n*** CPUs

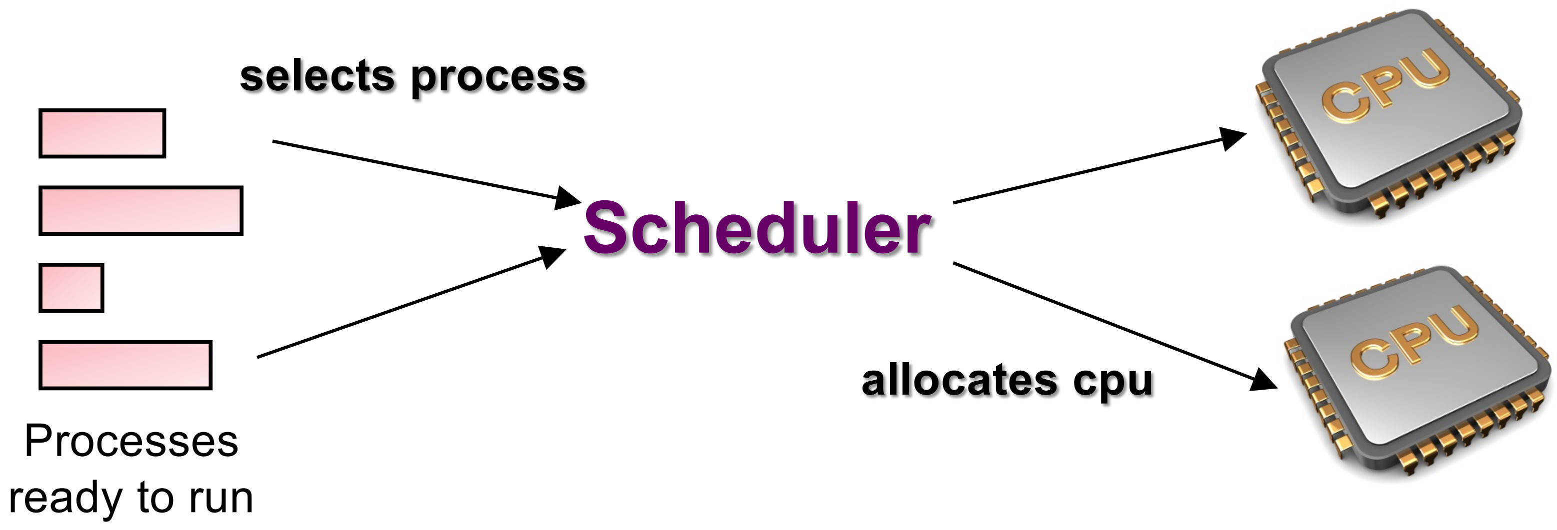


Scheduling in OS: A definition

- Problems with having multiple processes:
  - If ready-to-run process is more than available CPUs, which should be chosen to run?
    - Similar idea in thread-level scheduling
  - Known as the **scheduling problem**

- **Terminology:**
  - Scheduler
    - OS component that makes scheduling decision
  - Scheduling algorithm
    - The algorithm used by scheduler

Scheduling: Illustration



- Each process has different requirements w.r.t. CPU time
  - **Process behavior**
- Many ways to allocate
  - Influenced by the **process environment**
  - Known as **scheduling algorithms**
- A number of **criteria to evaluate the scheduler**

Process Behavior

- A typical process goes through phases of:

CPU-Activity:

- Computation
- E.g., Number crunching
- **Compute-Bound Process** spend majority of its time here

IO-Activity:

- Requesting and receiving sercive from I/O devices
- E.g., Print to screen, read from file, etc
- **IO-Bound Process** spend majority of its time here

Processing Environment

- Three categories:
  1. **Batch Processing:**
     - No user: No interaction required, No need to be responsive
  2. **Interactive** (or Multiprogramming):
     - With active user(s) interacting with the system
     - Should be responsive and consistent in response time
  3. **Real-time processing**:
     - Have deadlines to meet
     - Usually periodic tasks

Criteria for Scheduling Algorithms

- Many criteria to evaluate scheduling algorithm:
  - Largely influenced by the processing environment
  - May be conflicting

Criteria for **all processing environments**:

- **Fairness**:
  - Should get a fair share of CPU time
    - On a per-process basis OR
    - On a per-user basis
  - Also mean **no starvation**
- **Balance:**
  - All parts of the computing system should be utilized

When to perform scheduling?

- Two types of scheduling policies
  - Defined by **when** scheduling is triggered

- **Non-preemptive (Cooperative)**
  - A process stayed scheduled (in running state) until it blocks or give up the CPU voluntarily

- **Preemptive**
  - A process is given a fixed time quota to run
    - possible to block or give up early
  - At the end of the time quota, the running process is suspended
    - Another process get picked if available

Scheduling a Process: Step-by-Step

1
- Scheduler is triggered (OS takes over)

2
- If Context switch is needed:
  - Context of current running process is saved and placed on blocked queue / ready queue

3
- Pick a suitable process **P** to run base on scheduling algorithm

4
- Setup the context for **P**

5
- Let process **P** run

SCHEDULING FOR BATCH PROCESSING

Overview

- On batch processing system:
  - No user interaction
  - Non-preemptive scheduling is predominant
- Scheduling algorithms are generally easier to understand and implement
  - Commonly resulted in variant/Improvement that can be used for other type of systems
- Three algorithms covered:
  - **F**irst-**C**ome **F**irst **S**erved (**FCFS**)
  - **S**hortest **J**ob **F**irst (**SJF**)
  - **S**hortest **R**emaining **T**ime Next (**SRT**)

Criteria for **batch processing**

- **Turnaround time**:
  - Total time taken, i.e. finish-arrival time
  - Related to **waiting time**: time spent waiting for CPU
- **Throughput**:
  - Number of tasks finished per unit time
  - i.e., the rate of task completion
- **CPU utilization**:
  - Percentage of time when CPU is working on a task

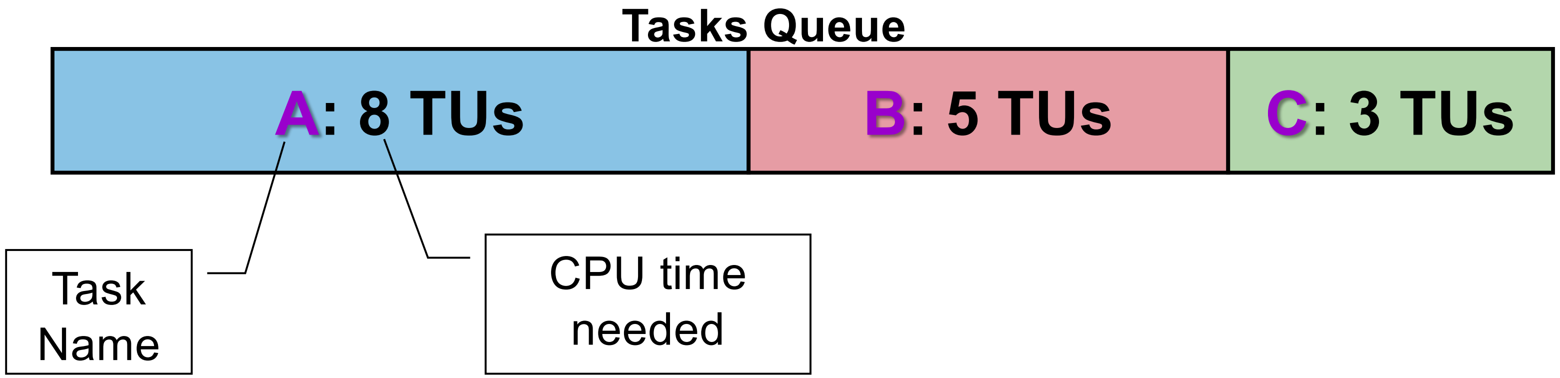
First-Come First-Served: **FCFS**

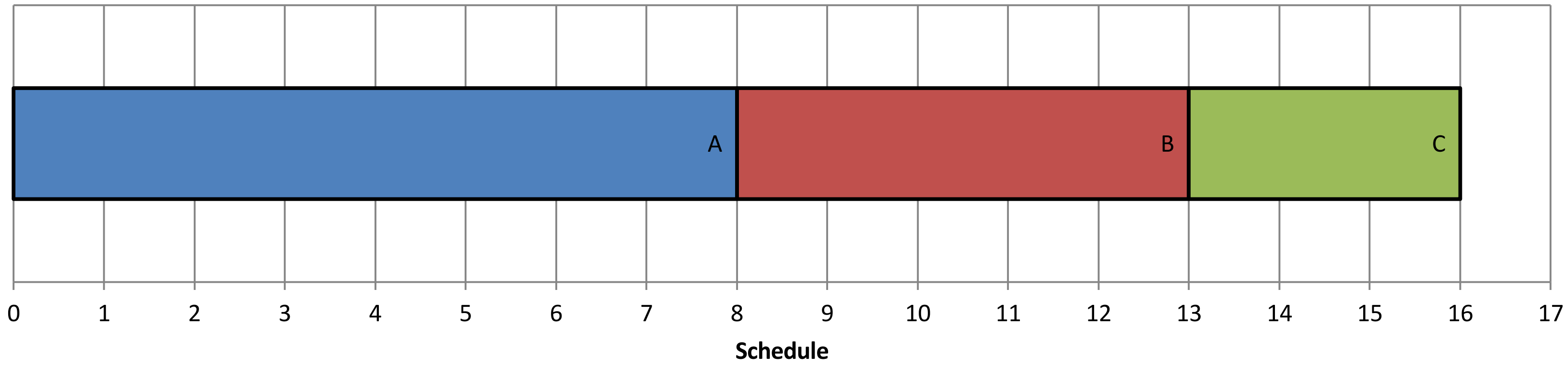
- General Idea:
  - Tasks are stored on a First-In-First-Out (FIFO) queue based on arrival time
  - Pick the first task in queue to run until:
    - The task is done OR the task is blocked
  - Blocked task is removed from the FIFO queue
    - When it is ready again, it is placed at the back of queue
    - i.e., just like a newly arrive task

- Guaranteed to have no **starvation:**
  - The number of tasks in front of task X in FIFO is always decreasing

  ➔ task X will get its chance eventually

First-Come First-Served: Illustration





- The average total waiting time for 3 tasks
  - (0 + 8 + 13)/3 = 7 time units

First-Come First-Served: **Shortcomings**

- Simple reordering can reduce the average waiting time!

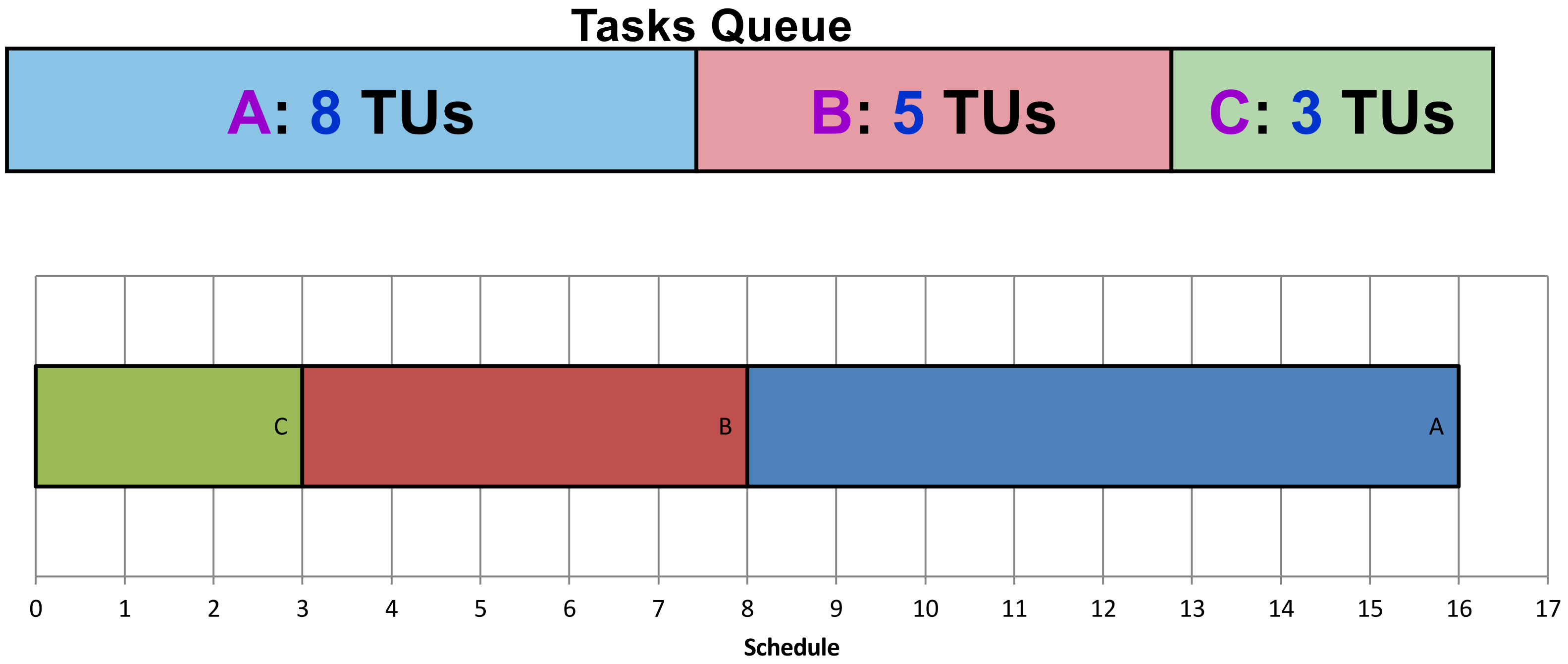
- Also, consider this scenario:
  - First task (task **A**) is CPU-Bound and followed by a number IO-Bound tasks **X**
  - Tasks **A** running
    - All tasks **X** waiting in ready queue (I/O device idling)
  - Tasks **A** blocked on I/O
    - All tasks **X** execute quickly and blocked on I/O (CPU idling)
  - known as **Convoy Effect**

Shortest Job First: **SJF**

- General Idea:
  - Select task with the smallest total CPU time

- Notes:
  - Need to know **total CPU time** for a task in advance
    - Have to "guess" if this info is not available
  - Given a fixed set of tasks:
    - Minimizes average waiting time
  - Starvation is possible:
    - Biased towards short jobs
    - Long job may never get a chance!

Shortest Job First: Illustration



- The average total waiting time for 3 tasks
  - (0 + 3 + 8)/3 = **3.66** Time Units
- Can be shown that SJF **guarantees** smallest average waiting time

Shortest Job First: Predicting CPU Time

- A task usually goes through several phases of CPU-Activity:
  - Possible to guess the future CPU time requirement by the previous CPU-Bound phases

- Common approach (Exponential Average):

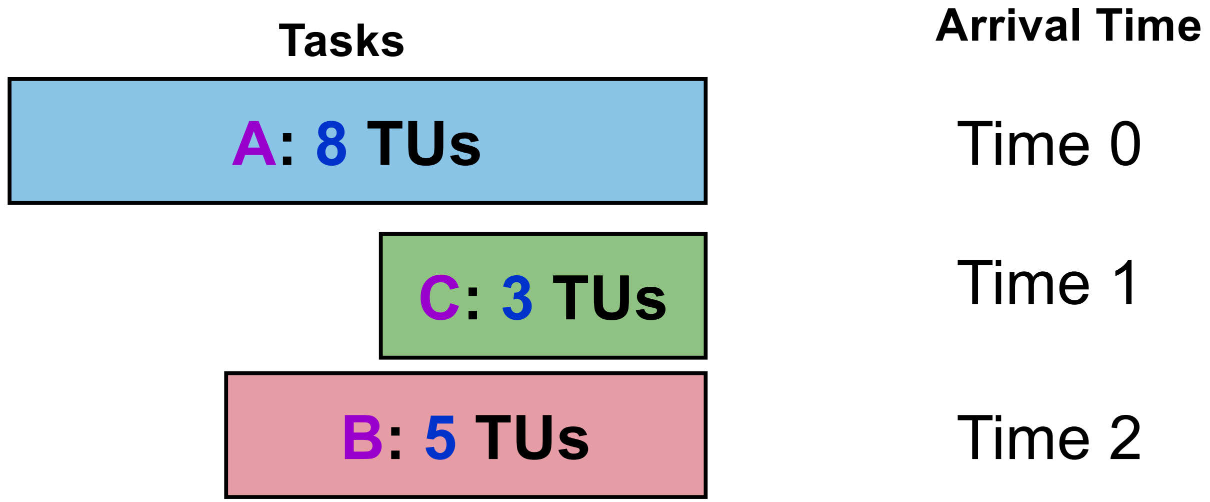
$$\texttt{Predicted}_{n+1} = \alpha\texttt{Actual}_n + (1-\alpha)\,\texttt{Predicted}_n$$

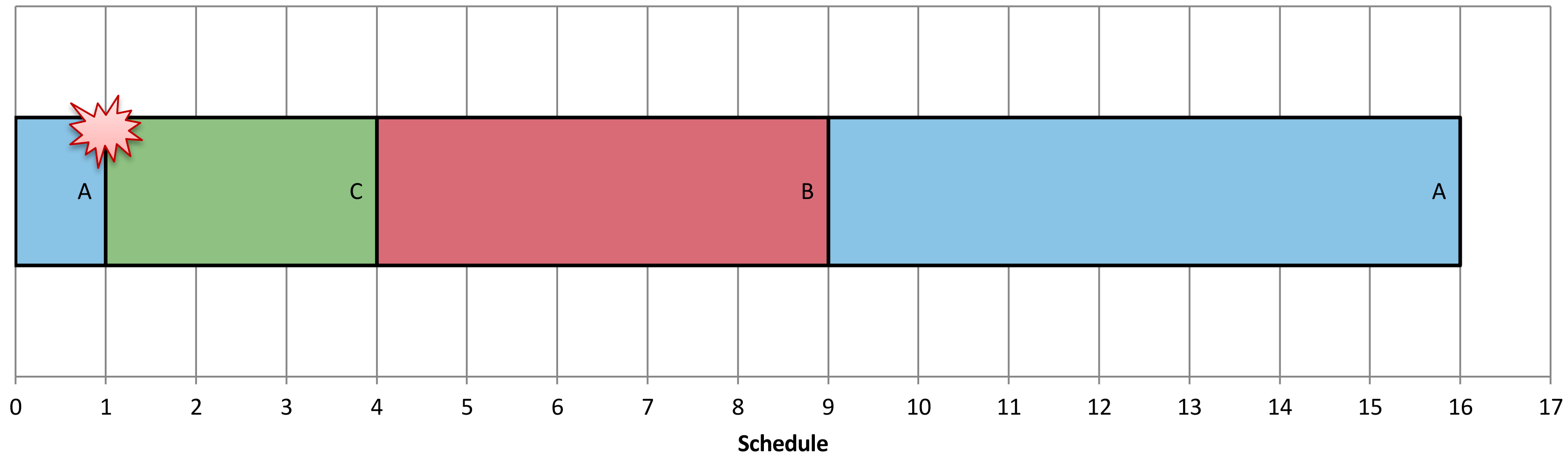
  - $\texttt{Actual}_n$ = The most recent CPU time consumed
  - $\texttt{Predicted}_n$ = The past history of CPU Time consumed
  - α = Weight placed on recent event or past history
  - $\texttt{Predicted}_{n+1}$ = Latest prediction

Shortest Remaning Time: **SRT**

- General Idea:
  - Variation of SJF:
    - Use remaining time
    - Preemptive
  - Select job with shortest remaining (or expected) time
- Notes:
  - New job with shorter remaining time can preempt currently running job
  - Provide good service for short job even when it arrives late

Shortest Remaining Time First: Illustration





SCHEDULING FOR INTERACTIVE SYSTEMS

Criteria for **interactive environment**

- **Response time**:
  - Time between request and response by system
- **Predictability**:
  - Variation in response time, lesser variation == more predictable

Preemptive scheduling algorithms are used to ensure good response time

➔ Scheduler needs to run **periodically**

Ensuring Periodic Scheduler

- Questions:
  - How can the scheduler "take over" the CPU periodically?
  - How can we ensure the user program can never stop the scheduler from executing?

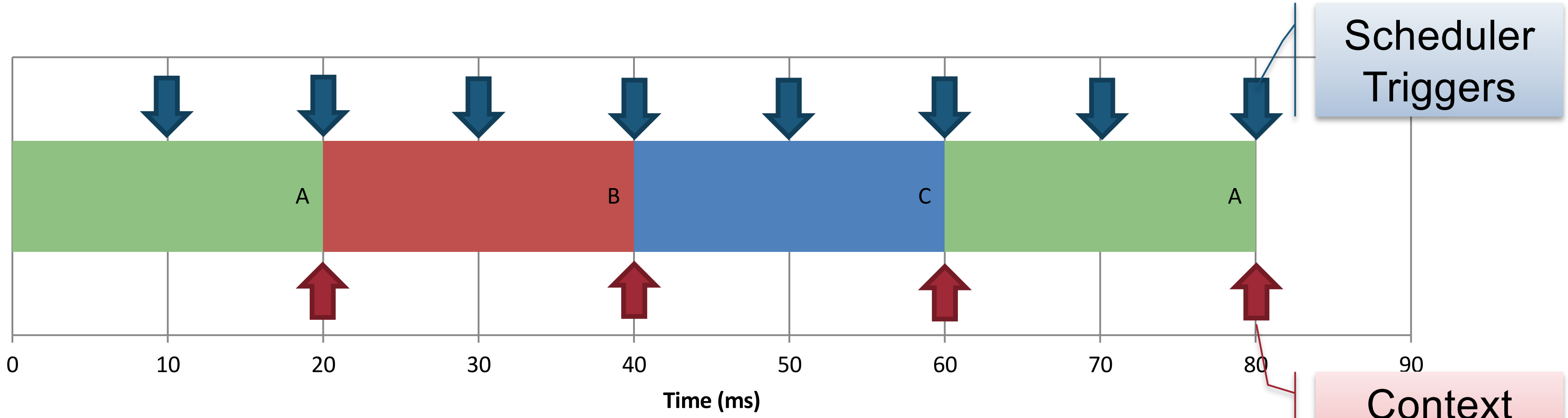
- Ingredients for answer:
  - Timer interrupt = Interrupt that goes off periodically (based on hardware clock)
  - OS ensure timer interrupt cannot be intercepted by any other program

  ➔ Timer interrupt handler **invokes scheduler**

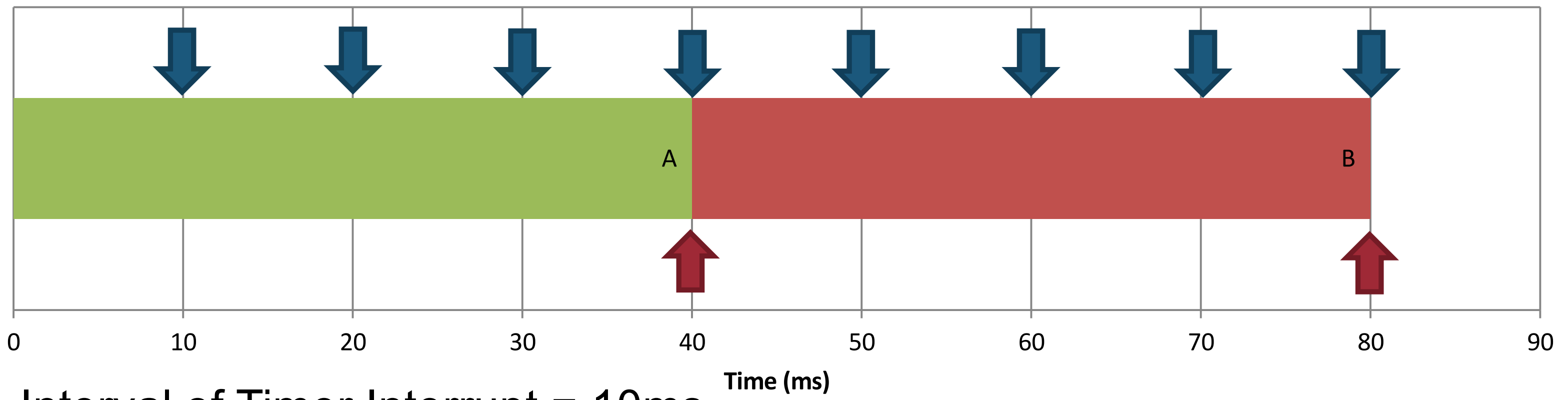
Terminology: Timer & Time Quantum

- Interval of Timer Interrupt (ITI):
  - i.e., the timer period
  - OS scheduler is triggered every timer interrupt
  - Typical values (1ms to 10ms)
- Time Quantum:
  - Execution duration given to a process
  - Could be constant or variable among the processes
  - Must be multiples of interval of timer interrupt
  - Large range of values (commonly 5ms to 100ms)

Illustration: ITI vs Time Quantum



Interval of Timer Interrupt = 10ms
Time Quantum = 20ms



Interval of Timer Interrupt = 10ms
Time Quantum = 40ms

Scheduling Algorithms:

- Algorithms covered:
  1. Round Robin (RR)
  2. Priority Based
  3. Multi-Level Feedback Queue (MLFQ)
  4. Lottery Scheduling

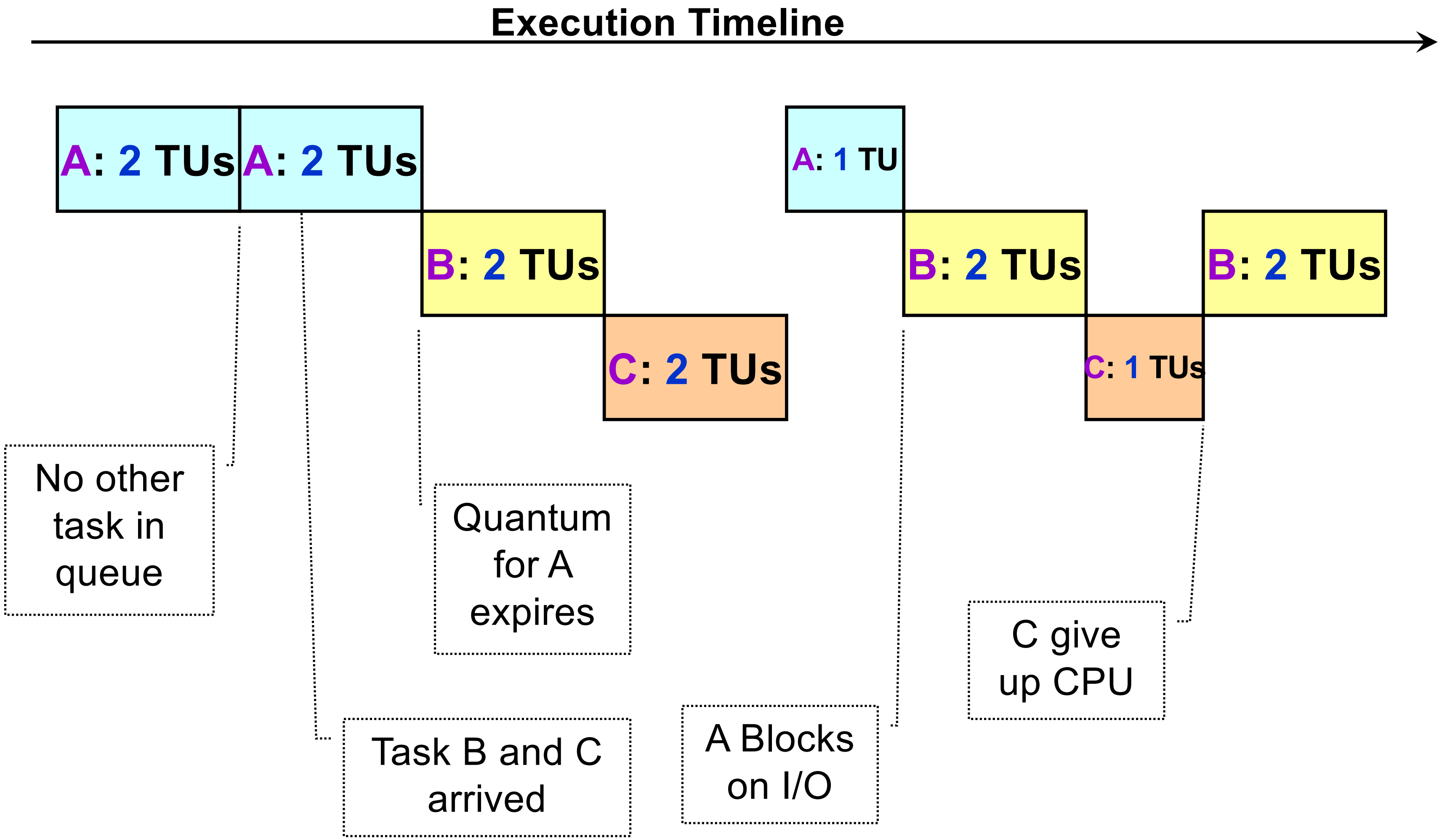
Round Robin: **RR**

- General Idea:
  - Tasks are stored in a FIFO queue
  - Pick the first task from queue front to run until:
    - A fixed **time slice** (**quantum**) elapsed
    - The task gives up the CPU voluntarily
    - The task blocks
  - The task is then placed at the end of queue to wait for another turn
    - Blocked task will be moved to other queue to wait for its request
  - When blocked task is ready again, it is placed at the end of queue

Round Robin: **RR** (cont)

- Notes:
  - Basically a preemptive version of FCFS
  - **Response time guarantee**:
    - Given *n* tasks and quantum *q*
    - Time before a task get CPU is bounded by ***(n-1)q***
  - **Timer interrupt needed:**
    - For scheduler to check on quantum expiry
  - The choice of time quantum duration is important:
    - Big quantum: Better CPU utilization but longer waiting time
    - Small quantum: Bigger overhead (worse CPU utilization) but shorter waiting time

Round Robin: Illustration

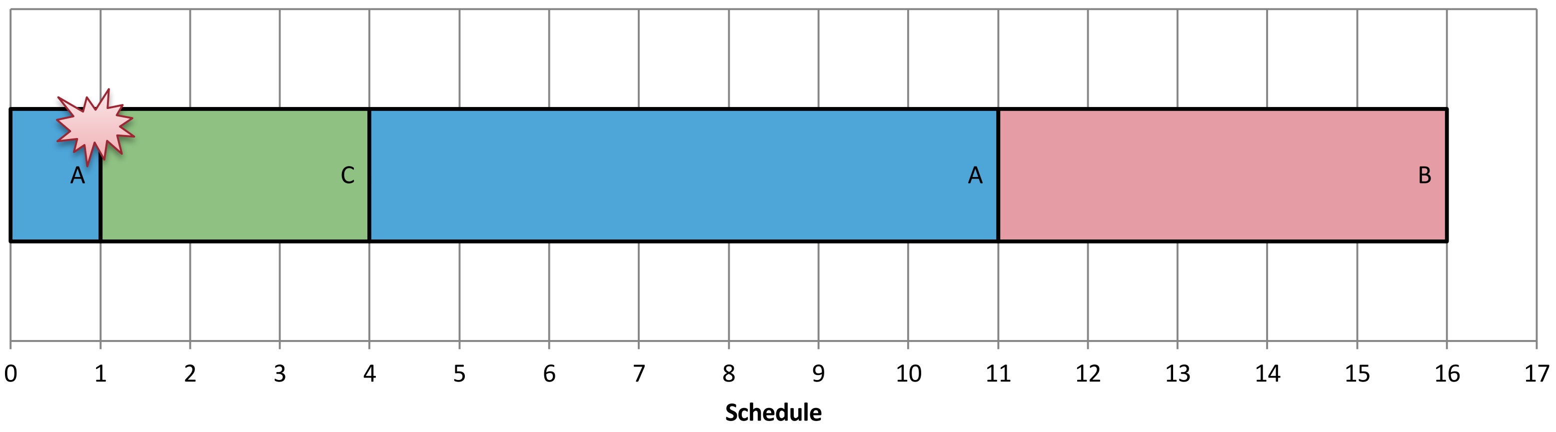


Priority Scheduling

- General Idea:
  - Some processes are more important than others
    - Cannot treat all process as equal
  - Assign a priority value to all tasks
  - Select task with highest priority value
- Variants:
  - Preemptive version:
    - Higher priority process can preempts running process with lower priority
  - Non-preemptive version:
    - Late coming high priority process has to wait for next round of scheduling

Priority Scheduling: Illustration

Tasks	Arrival Time	Priority (1=highest)
A: 8 TUs	Time 0	3
C: 3 TUs	Time 1	1
B: 5 TUs	Time 1	5



Priority Scheduling: Shortcomings

- Low priority process can starve:
  - High priority process keep hogging the CPU
  - Even worse in preemptive variant
- Possible solutions:
  - Decrease the priority of currently running process after every time quantum
    - Eventually dropped below the next highest priority
  - Give the current running process a time quantum
    - This process is not considered in the next round of scheduling
- Generally, it is hard to guarantee or control the exact amount of CPU time given to a process using priority

Priority Scheduling: Priority Inversion

- Consider the scenario:
  - Priority: {A = 1, B=3, C= 5} (1 is highest)
  - Task **C** starts and locks a resource (e.g. file)
  - Task **B** preempts **C**
    - **C** is unable to unlock the file
  - Task **A** arrives and need the same resource as **C**
    - but the resource is locked!
  - ➔ Task **B** continues executes even if Task **A** has higher priority
- Known as **Priority Inversion**:
  - Lower priority task preempts higher priority task

Multi-level Feedback Queue (MLFQ)

- Designed to solve one BIG + HARD issue:
  - How do we schedule without perfect knowledge?
  - Most algorithms requires certain information (process behavior, running time, etc)

- MLFQ is:
  - Adaptive: "Learn the process behavior automatically"
  - Minimizes both:
    - Response time for IO bound processes
    - Turnaround time for CPU bound processes

Adapted from: Operating System – 3 easy pieces

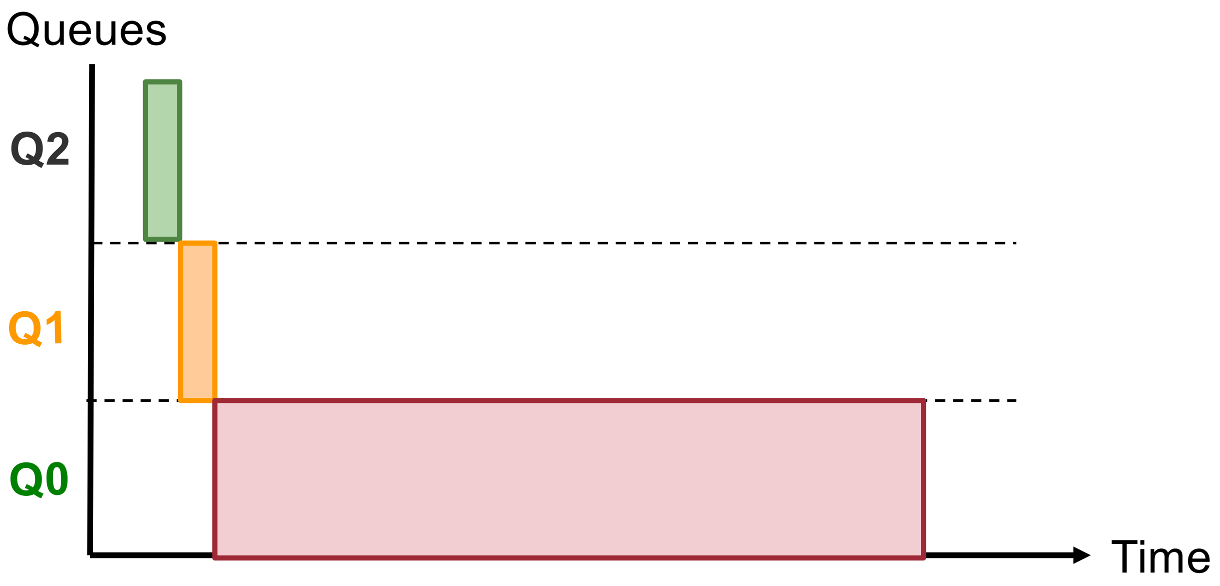
MLFQ: Rules

- Basic rules:
  1. If Priority(A) > Priority(B) ➔ A runs
  2. If Priority(A) == Priority(B) ➔ A and B runs in RR

- Priority Setting/Changing rules:
  1. New job ➔ Highest priority
  2. If a job fully utilized its time slice ➔ priority reduced
  3. If a job give up / blocks before it finishes the time slice ➔ priority retained

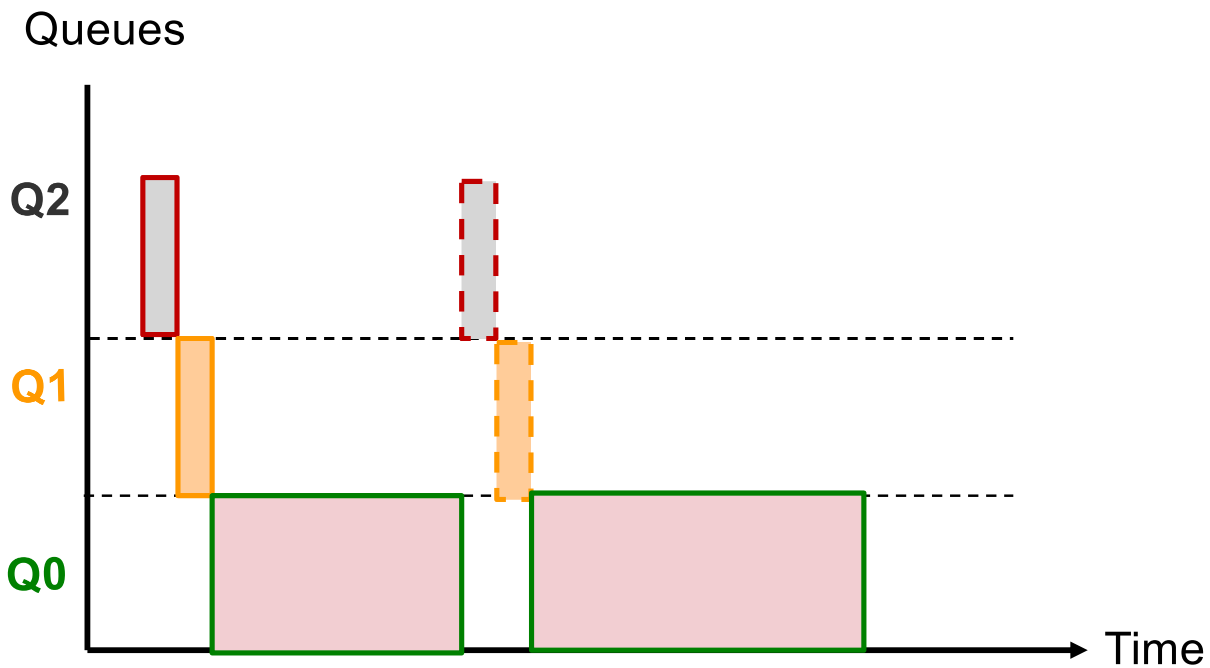
MLFQ: Example 1

- 3 Queues: Q2 (highest priority), Q1, Q0
- A single long running job
  - Try to apply the rules and check your understanding



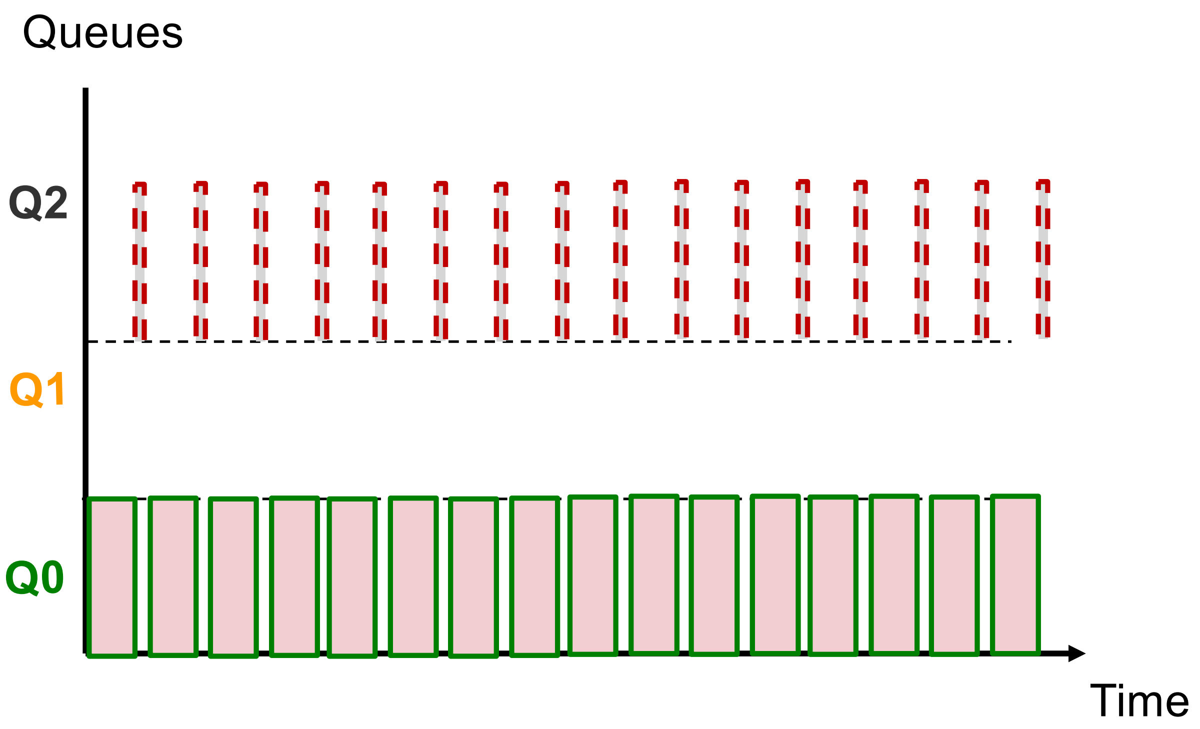
MLFQ: Example 2

- Example 1 + a short job in the middle
  - A short job appears sometime in the middle



MLFQ: Example 3

- Two jobs:
  - A = CPU bound (already in the system for quite some time)
  - B = I/O bound



MLFQ: Questions to ponder

- Can you think of a way to abuse the algorithm? ☺
  - Equivalent question: MLFQ does not work well for what kind combination of jobs?

- What are the ways to rectify the above?

Lottery Scheduling

- General Idea:
  - Give out “lottery tickets” to processes for various system resources
    - E.g. CPU time, I/O device etc
  - When a scheduling decision is needed:
    - A lottery ticket is chosen randomly among eligible tickets
    - The winner is granted the resource
  - In the long run, a process holding **X**% of tickets
    - Can win **X**% of the lottery held
    - Use the resource **X**% of the time

Lottery Scheduling: Properties

- Responsive:
  - A newly created process can participate in the next lottery
- Provides good level of control:
  - A process can be given Y lottery tickets
    - It can then distribute to its child process
  - An important process can be given more lottery tickets
    - Can control the proportion of usage
  - Each resource can have its own set of tickets
    - Different proportion of usage per resource per task
- Simple Implementation

Summary

- Scheduling in OS:
  - Basic definition
  - Factors that affect scheduling
    - Process, Environment
  - Criteria of good scheduling

- Scheduling Algorithms:
  - FCFS, SJF, SRT for Batch Processing System
  - RR, Priority base, Multi-Level Queues, MLFQ and Lottery scheduling for Interactive System

References

- Modern Operating System (4th Edition), Tanenbaum
  - **Chapter 2.4**
- Operating System Concepts (9th Edition), Silberschatz et al.
  - **Chapter 6**
- Operating Systems: Three Easy Pieces
  - http://pages.cs.wisc.edu/~remzi/OSTEP/
  - **Chapters 7, 8, 9**
  - Advanced (optional): chapter 10