Scheduling

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process scheduling

Problem:

We have a set of processes: they all want to execute immediately and they do not want to be interrupted.

Solution:

Let's keep some waiting and let's interrupt them.

Question:

- What metrics are important?
- Does it matter in what order we schedule processes?
- Are there optimal solutions?

The unrealistic assumption ...

Assume we have a set of *jobs*.

- Each job takes an equal amount of time.
- All jobs *arrive* at the same time.
- A job will run to completion.
- The jobs only use the CPU (no I/0 etc).
- The run-time of each job is known.

This is unrealistic - we will relax these requirements.

...every now and then I get a little bit lonely

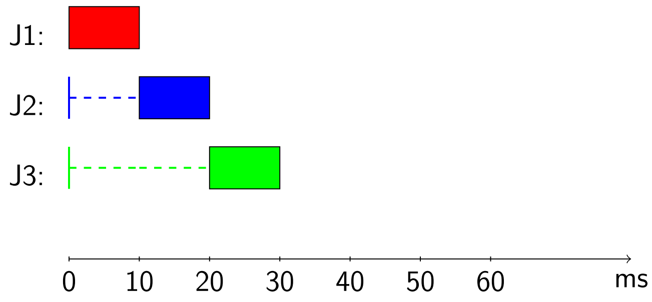
Performance metrics

$$T_{\text{turnaround}} = T_{\text{completion}} - T_{\text{arrival}}$$

How long time does it take to complete the job?

First Come First Serve (FCFS)

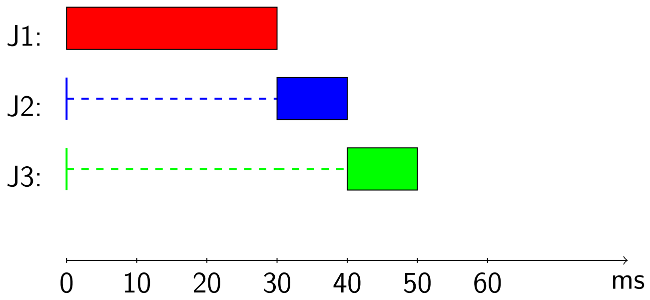
Assume we have three tasks, all *arrive* at time 0 and take 10 ms to execute.



What is the average $T_{\text{turnaround}}$?

Not so good...

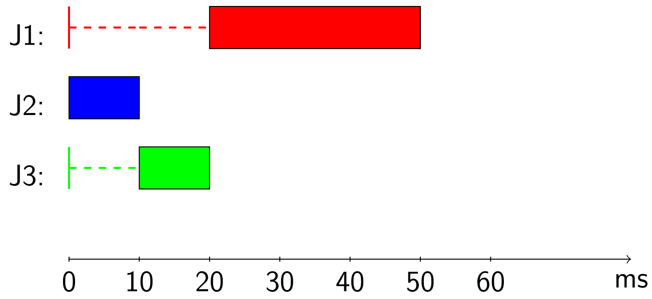
Assume one task takes 30 ms to execute.



What is the average $T_{\text{turnaround}}$? Can we do better?

Shortest Job First (SJF)

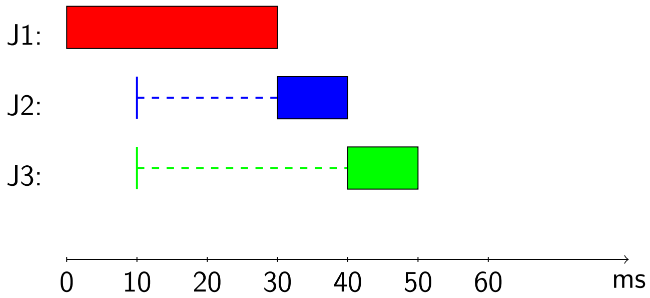
Always schedule the shortest job.



What is the average $T_{\text{turnaround}}$? Problem solved!

What if jobs arrive later?

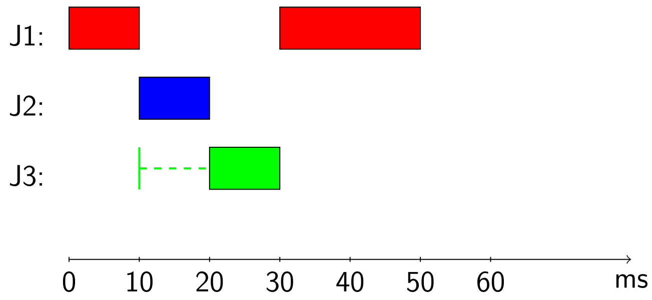
Assume we have three tasks, one arrive at time 0 and takes 30 ms to execute. Two arrive at time 10 and take 10 ms each.



We need to preempt the execution of a job.

Shortest Time-to-Completion First (STCF)

Let's always schedule the task that has the shortest time left to completion.



The policy is also known as Preemptive Shortest Job First (PSJF)

STCF - optimal policy

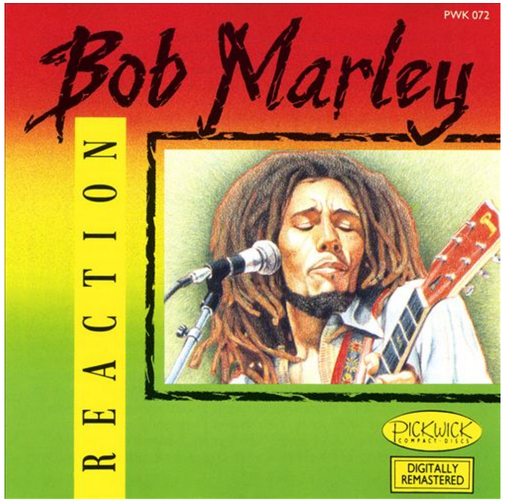
If we actually know the total execution time of each job as they arrive, then ....

Shortest Time-to-Completion First is an optimal policy.

The problem is that we do not know the total execution time aforehand.

There might be more important metrics than turnaround time.

Talk about ...



Response time

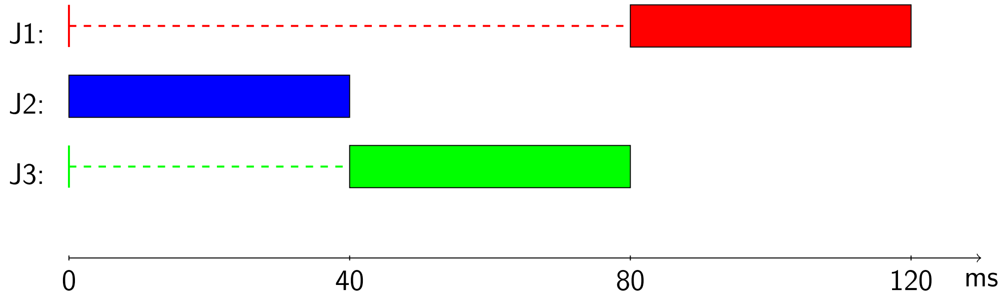
In an interactive environment we might want to minimize *response time*.

$$T_{\text{response}} = T_{\text{first scheduled}} - T_{\text{arrival}}$$

The response might not be completed unless the job completes but it's an ok metrics.

Try Shortest Job First

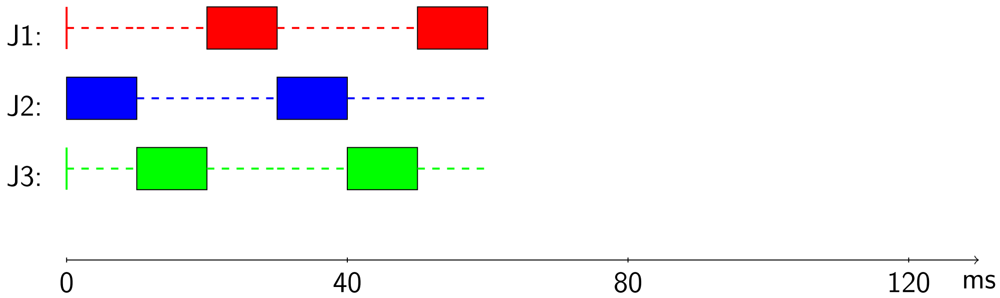
Assume we have three jobs that all arrive at time 0 and all take 40 ms to complete.



What is the average response time?

Round-robin

Preempt a job in order to improve response time, give each job a time-slice of 10 ms.

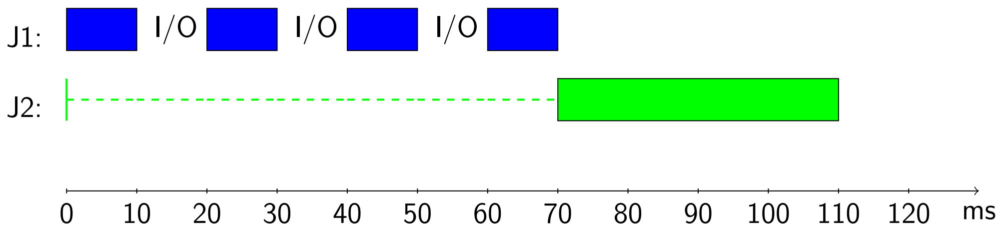


What is the average response time? What is the average turnaround time?

You can't ....

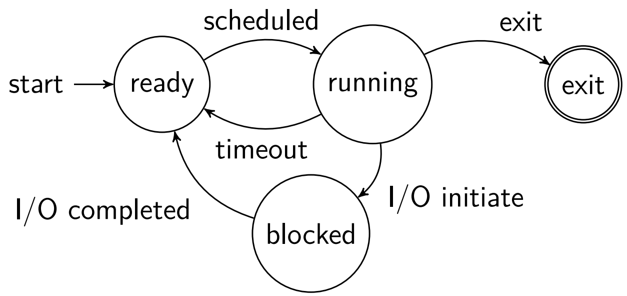
processes do I/O

Assume we have two processes, each take 40 ms of CPU time but one will do I/O-operations every 10 ms.



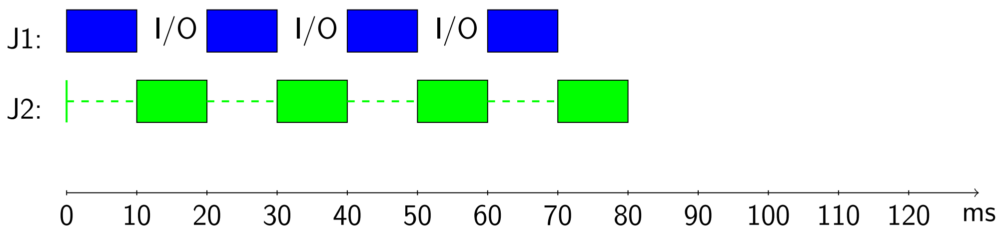
deschedule when initiate I/O

An I/O-operation will take time to complete and we (the CPU) could do some useful work while a process is waiting.



A process is descheduled if it is preempted or if it initiates a I/O-operation.

much better



the challenge

Ideal world:

- Each job takes an equal amount of time.
- All jobs *arrive* at the same time.
- A job will run to completion.
- The jobs only use the CPU (no I/0 etc).
- The run-time of each job is known.

Real world:

- Jobs take different amount of time.
- Jobs arrive at different time.
- We can preempt job.
- Jobs do use I/O.
- Runt-time is not know.
- .... What do we do?

Can we design scheduling policies that give us good turn-around time and short response time?

Multi-level Feedback Queue (MLFQ)

Goals:

- Good turnaround time - scheduled jobs so that jobs with short time to completion are not delayed too much.
- Improve responsiveness of interactive jobs - schedule *interactive processes* more often.

Idea:

- Multiple levels of priority - interactive jobs have higher priority.
- Each level uses round-robin to give processes an equal share.
- Processes can be moved to a higher or lower level depending on their behavior.

How do we identify interactive processes and how do we make sure that they have high priority?

Rules of the game: MLFQ

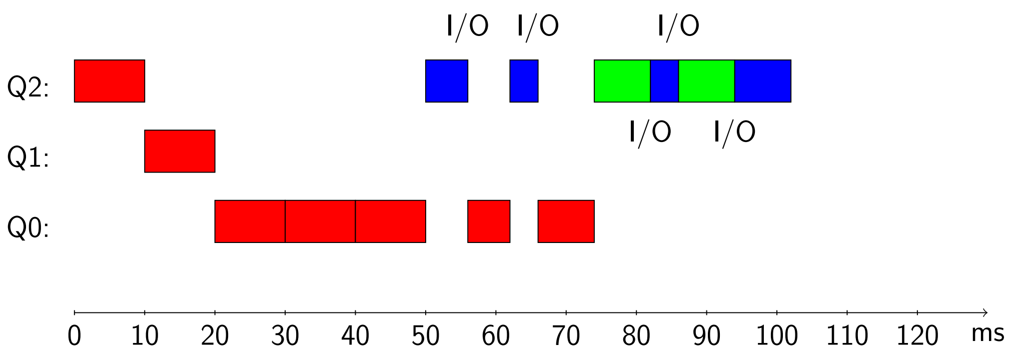
Basic rules:

- Rule 1: if Priority(A) > Priority(B) then A is scheduled for execution.
- Rule 2: if Priority(A) = Priority(B) then A and B are scheduled in round-robin.
- Rule 3: when a new job is created it starts with the highest priority.

Change priority (let's try this)

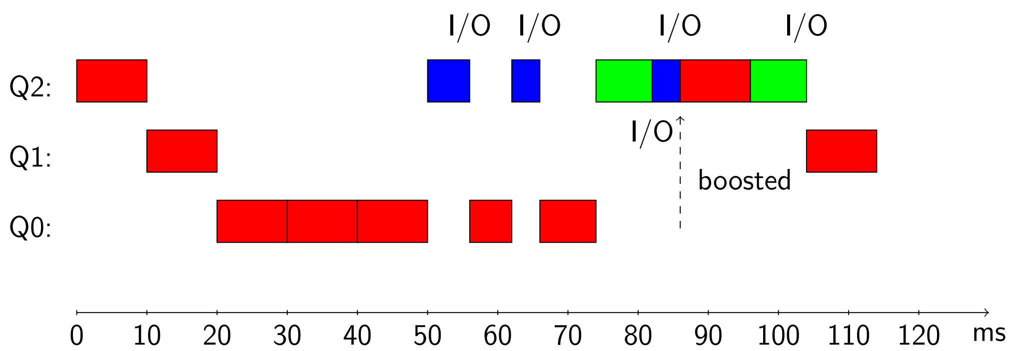
- Rule 4a: a job that has to be preempted (time-slice consumed) is moved to a lower priority.
- Rule 4b: a job that initiates a I/O-operation (or yields) remains on the same level.

fine, no problem ...



boost a job

- Rule 5: after some time, move a job to the highest priority.



trick the scheduler

If the scheduler was constructed given the rules 1-5, how would you write your program?

- Rule 1: if Priority(A) > Priority(B) then A is scheduled for execution.
- Rule 2: if Priority(A) = Priority(B) then A and B are scheduled in round-robin.
- Rule 3: when a new job is created it starts with the highest priority.
- Rule 4a: a job that has to be preempted (time-slice consumed) is moved to a lower priority.
- Rule 4b: a job that initiates a I/O-operation (or yields) remains on the same level.
- Rule 5: after some time, move a job to the highest priority.

let's try this

A job is given a *allotted time*, to consume at each priority level.

- Rule 4: a job that has consumed its allotted time is moved to a lower priority.
- Rule 5: after some time, move all jobs to the highest priority.

tune the scheduler

Setting the parameters:

- How long is a time slice?
- How many queues should there be?
- How long time should a allotted time be in a specified queue?
- How often should a job be boosted to the highest priority?

Change the perspective

What if:

- we stop focusing on *turnaround time* and *reaction* and
- start treating every job in a fair manner.

Give each job fair share.

Justice for all

Proportional share

Let's have a lottery:

and the winner is

We divide the tickets among the jobs: A - 35 tickets, B - 15 tickets and C - 50 tickets.

The scheduler selects a winning ticket by random.

And the winner is: 23, 56, 13, 73, 8, 82, 17, 34, ...

flexibility

- A new job can be given a set of tickets as long as we keep track of how many tickets we have.
- We can give a *user* a set of tickets and allow the user to distribute them among its jobs.
- Each user can have its local tickets and then have a local lottery.
- We could allow each user to create new tickets, i.e. inflation, if we trust each other.

How to implement?

Stand in line

- Each job is given a number that represents the number of tickets it owns.
- All jobs are lined up i a row.
- Pick a random number from zero to the total number of tickets.
- Walk down the line and select the winner.

How does this work?

Why random?

A deterministic approach: stride scheduling

- Each job is given a *stride value*, the higher the stride the lower the priority.
- Each job keeps a *pass value* initially set to 0.
- In each round the job with *the lowest pass value is selected* and ...
- ... the pass value is incremented by its stride value.

A low stride value will make it more likely to be scheduled soon again.

Real-time systems

In real time scheduling we introduce a new requirement: things should be completed within a given time period.

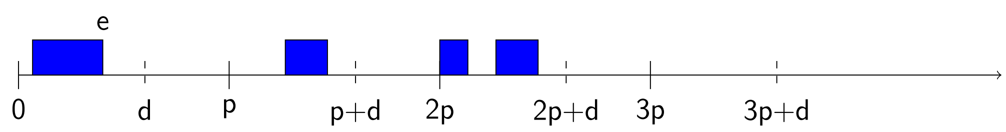
- Hard : all deadlines should be met, missing a deadline is a failure.
- Soft : deadlines could be missed but the application should be notified and be able to take actions.

We often have real-time requirements that are simply met since we happen to have the available resources.

Real-time scheduling

In hard real-time systems, *tasks* are known aforehand and described by a triplet $\langle e, d, p \rangle$

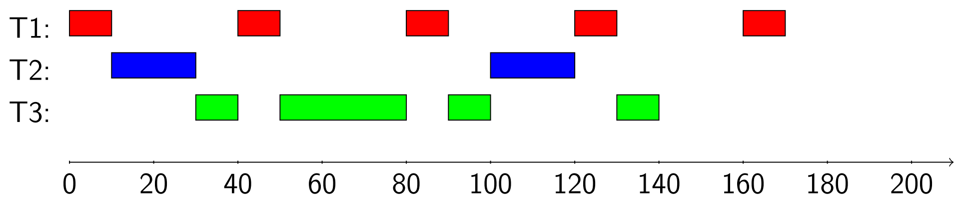
- e: the worst case execution time for the task.
- d: the deadline, when in the future do we need to finish.
- p: the period, how often should the task be scheduled.



$d < p$: constrained, $d = p$ default, $d > p$ several out-standing

Real-time Scheduling

Given a set of tasks: T1: $\langle 10, 30, 40 \rangle$, T2: $\langle 20, 60, 100 \rangle$, T3: $\langle 60, 200, 200 \rangle$: , find the scheduling.



Strategies

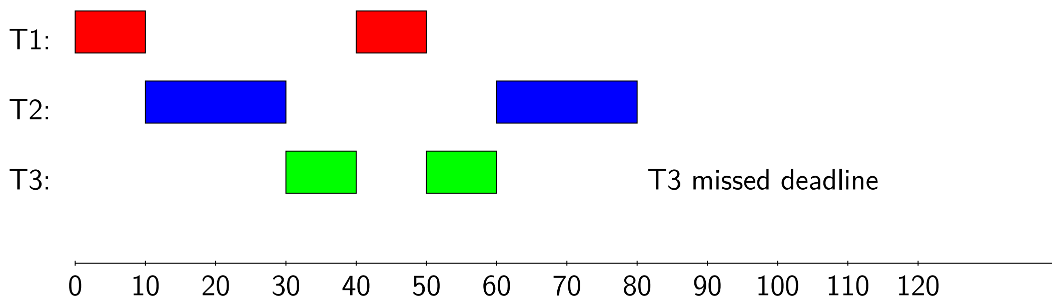
Given that $p = d$ i.e. a task must be completed within its period.

- Rate Monotonic Scheduling (RMS):
  - Schedule the avilable task with the shortest period
  - Always works if utilization is $< 69\%$ (actually less than $n * (2^{1/n} - 1)$), where n is the number of processes) could work for higher loads.
  - Simpler to reason about, easy to implement.
- Earliest Deadline First (EDF):
  - Schedule based on the deadline, more freedom to choose tasks.
  - Always works if utilization is $< 100\%$.
  - Used by Linux in the real-time extension (not in the regular system)

Rate Monotonic Scheduling (RMS)

Assume we have tasks: T1: $\langle 10, 40, 40 \rangle$, T2: $\langle 20, 60, 60 \rangle$, T3: $\langle 30, 80, 80 \rangle$.

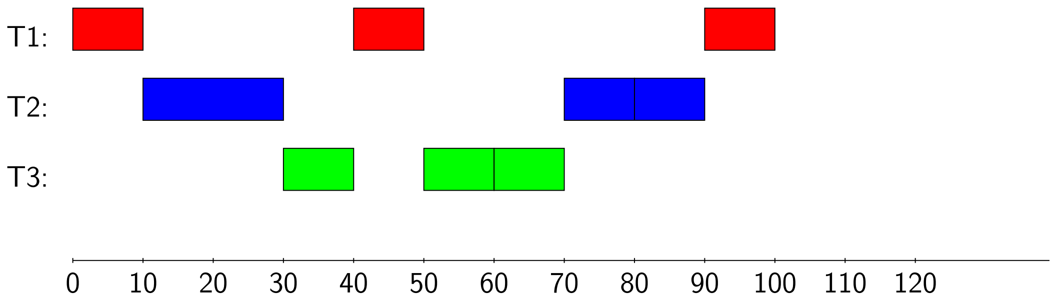
$$10/40 + 20/60 + 30/80 = 6/24 + 8/24 + 9/24 = 23/24$$



Earliest Deadline First (EDF)

Assume we have tasks: T1: $\langle 10, 40, 40 \rangle$, T2: $\langle 20, 60, 60 \rangle$, T3: $\langle 30, 80, 80 \rangle$.

$$10/40 + 20/60 + 30/80 = 6/24 + 8/24 + 9/24 = 23/24$$



problems

With what accuracy can we determine worst case excution time?

Should we be conservative or take a chance?

Can we handle a dynamic set of tasks?

What happens when we have critical resources that are protected by locks?

Multi-core architectures

Scheduling for a multi-core architecture more problematic (or rather more problematic to achieve high utilization).

Why?

Scheduling in Linux

How is scheduling managed in a Linux system?

- O(n) scheduler: the original scheduler, did not scale well.
- O(1) scheduler: multi-level feedback queues, dynamic priority, used up to version 2.6
- CFS: the *completely fair scheduler*, $O(lg(n))$, default today.
- BF scheduler: no I will not tell you what it stands for.

The Completely Fair Scheduler

- Similar to stride scheduler but uses a red-black tree to order processes.
- Will keep processes on the same core if it thinks it's a good choice.
- Scheduling classes:
  - `SCHED_FIFO`, `SCHED_RR`: high priority classes (often called real-time processes)
  - `SCHED_NORMAL`: all the regular interactive processes
  - `SCHED_BATCH`: processes that only run if there are no interactive processes available.
  - `SCHED_IDLE`: if we've got nothing else to do.

Summary Scheduling

- Bonnie Tyler: Turnaround, every now and then ...
- Bob Marley: Talking 'bout reaction
- Rolling Stones: You can't always get what you want.
- Metallica: Justice for all.
- Leif "Loket" Olsson: a lottery might work ok
- Real-time scheduling: if we actually know the maximum execution time, the deadline and the period.
- Multi-core schedulers: you have to think twice before selecting a process.
- Linux: Completely Fair Scheduler, schedules in $O(lg(n))$ time, similar to stride scheduling.