CS162
Operating Systems and Systems Programming
Lecture 10

Scheduling
Core Concepts and Classic Policies

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https://cs162.org/

Slides based on prior slide decks from David Culler, Ion Stoica, John Kubiatowicz, Alison Norman and Lorenzo Alvisi

Goals for Today

- What is scheduling?
- What makes a good scheduling policy?
- What are existing schedulers and how do they perform?

The Scheduling Loop!

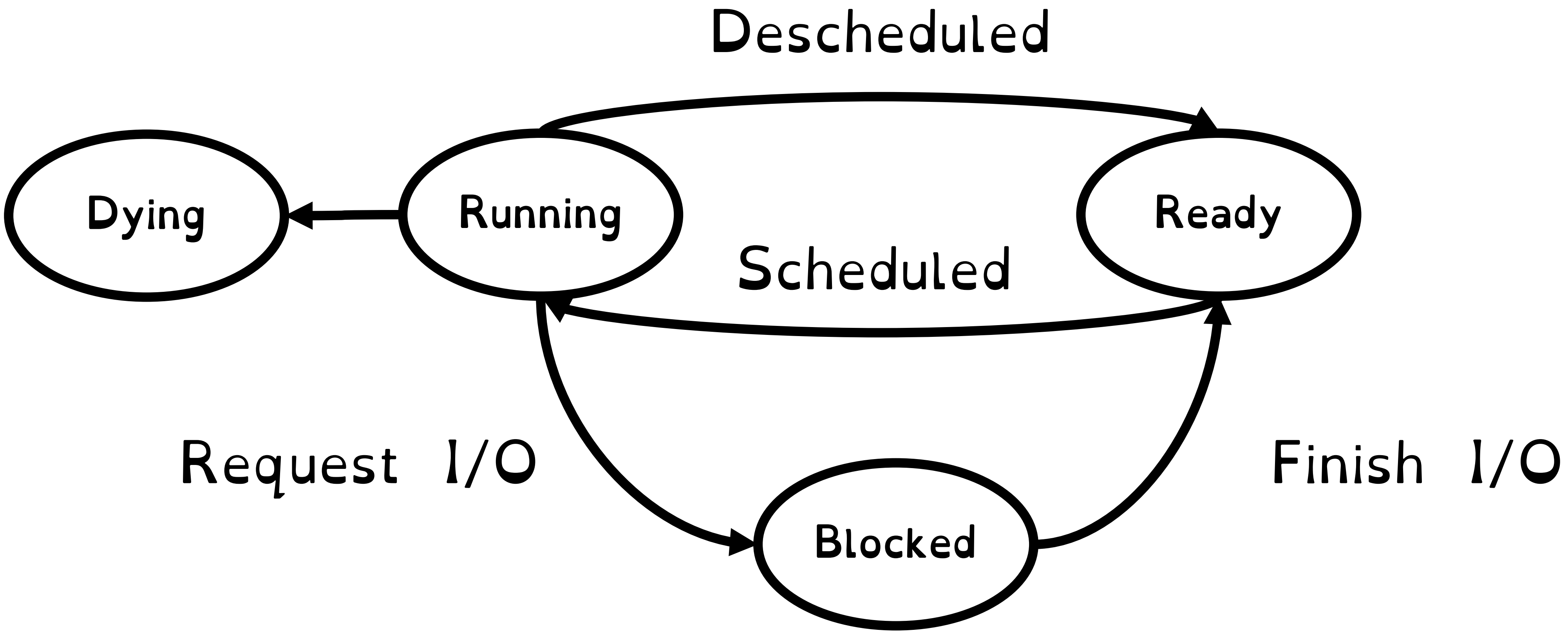
```
if (readyThreads(TCBs) ) {
        nextTCB = selectThread(TCBs);
        run(nextTCB);
} else {
        run_idle_thread();
}
```

1. Which task to run next?

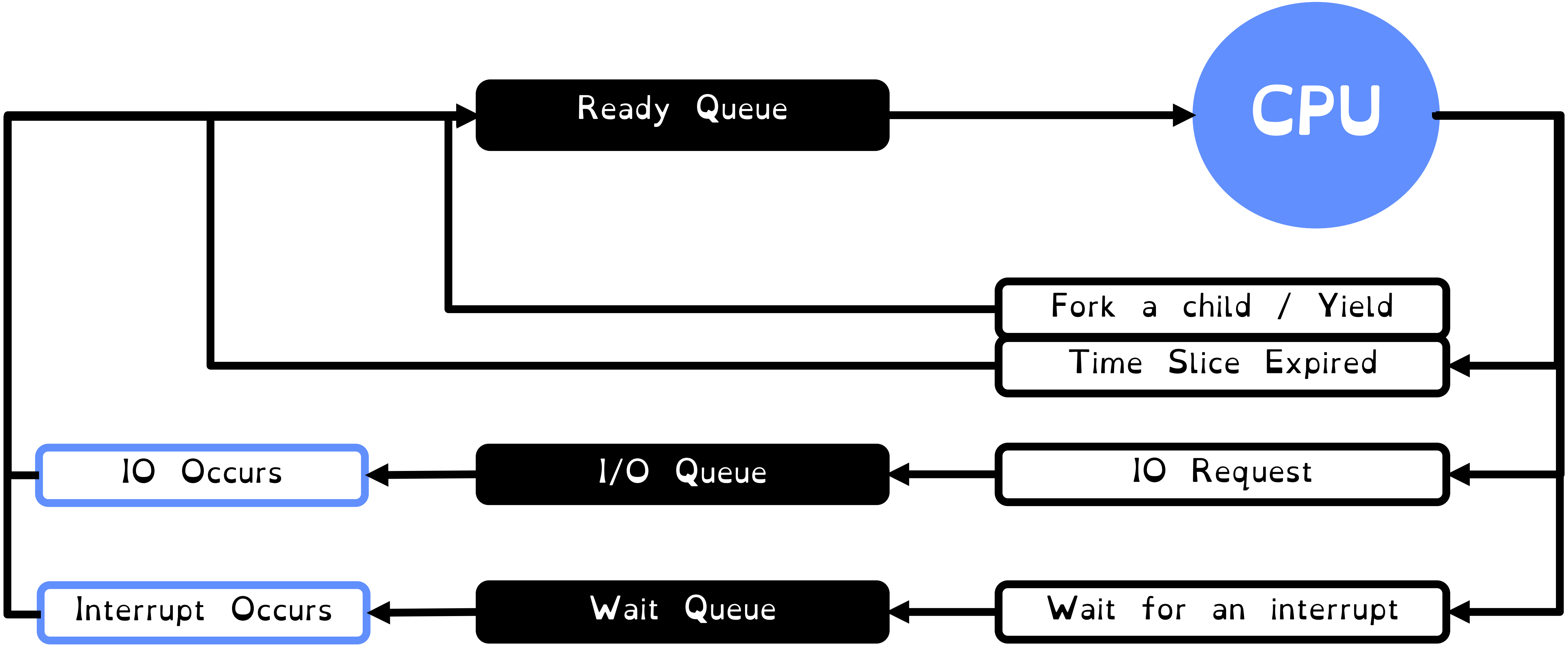
2. How frequently does this loop run?

3. What happens if `run` never returns?

Recall: Thread Life Cycle



Recall: What triggers a scheduling decision?



What makes a good scheduling policy?

A hopeless Queue.

The Queue For the UK Queen

6 miles (10 KM) long.

Visible from Space.

A bad but more realistic queue.

The DMV

What makes a good scheduling policy?

What does the DMV care about?

What do individual users care about?

Important Performance Metrics

Response time (or latency).

User-perceived time to do some task

Throughput.

The rate at which tasks are completed

Scheduling overhead.

The time to switch from one task to another.

Predictability.

Variance in response times for repeated requests.

Important Performance Metrics

Fairness

Equality in the performance perceived by one task

Starvation

The lack of progress for one task, due to resources being allocated to different tasks

Sample Scheduling Policies

Assume DMV job A takes 1 second, job B takes 2 days

Policy Idea: Only ever schedule users with Job A

What is the metric we are optimizing?
A) Throughput B) Latency C) Predictability D) Low-Overhead

Can the schedule lead to starvation?
A) Yes B) No

Is the schedule fair?
A) Yes B) No

Sample Scheduling Policies

Assume DMV consists only of jobs of type A.

Policy Idea: Schedule jobs randomly

What is the metric we are optimizing?
A) Throughput B) Latency C) Predictability D) Low-Overhead

Can the schedule lead to starvation?
A) Yes B) No

Is the schedule fair?
A) Yes B) No

Sample Scheduling Policies

Assume DMV consists only of 100 different types of jobs. Some jobs need Clerk A, some Clerks A&B, others Clerk C.

Policy Idea Every time schedule a job, compute all possible orderings of jobs, pick one that finishes quickest

What is the metric we are optimizing?
A) Throughput B) Latency C) Predictability D) Low-Overhead

Can the schedule lead to starvation?
A) Yes B) No

Is the schedule fair?
A) Yes B) No

Scheduling Policy Goals/Criteria

Minimise Latency

Maximise Throughput

While remaining fair and starvation-free

Useful metrics

Waiting time for P

Total Time spent waiting for *CPU*

Average waiting time

Average of all processes' wait time

Response Time for P

Time to when process gets first scheduled

Completion time

Waiting time + Run time

Average completion time

Average of all processes' completion time

Assumptions

Threads are independent!

One thread = One User

Unrealistic but simplify the problem
so it can be solved

Only look at work-conserving scheduler
=> Never leave processor idle if work to do

Workload Assumptions

A workload is a set of tasks for some system to perform, including how long tasks last and when they arrive

Compute-Bound

Tasks that primarily perform compute

Fully utilise CPU

IO Bound

Mostly wait for IO, limited compute

Often in the Blocked state

First-Come, First-Served (FCFS)

Run tasks in order of arrival.

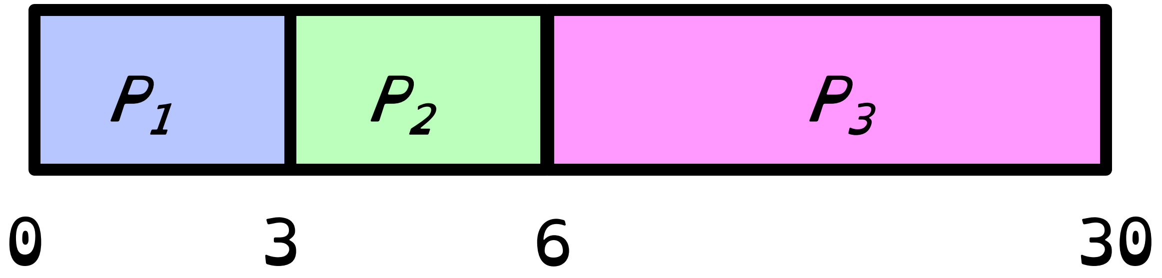
Run task until completion (or blocks on IO).
No preemption

This is the DMV model.

Also called FIFO

First-Come, First-Served (FCFS)

Process	Burst Time
P_1	3
P_2	3
P_3	24

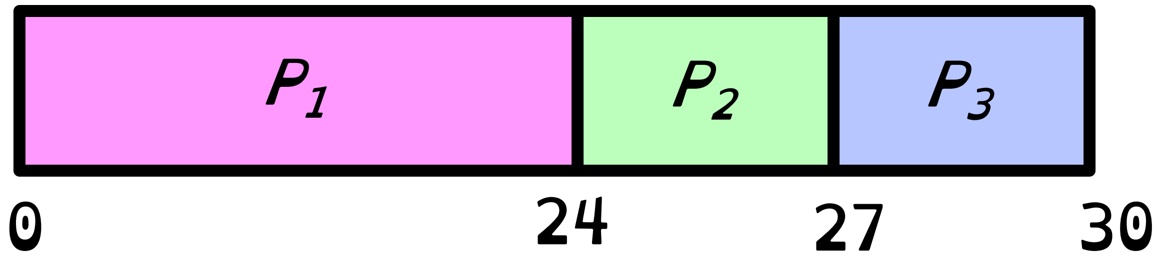


What is the average completion time? $\left(\frac{3+6+30}{3} = 13\right)$

What is the average waiting time? $\left(\frac{0+3+6}{3} = 3\right)$

First-Come, First-Served (FCFS)

Process	Burst Time
P_3	24
P_2	3
P_1	3



What is the average completion time? $\left(\frac{24+27+30}{3} = 27\right)$

What is the average waiting time? $\left(\frac{0+24+27}{3} = 17\right)$

The Convoy Effect

FIFO/FCFS very sensitive to arrival order

Convoy effect

Short process stuck behind long process

Lots of small tasks build up behind long tasks

FIFO is non-preemptible

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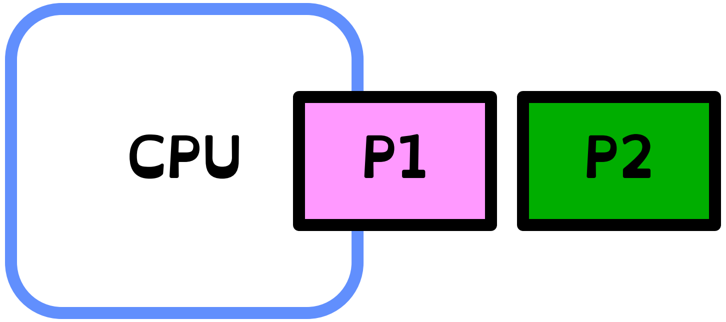

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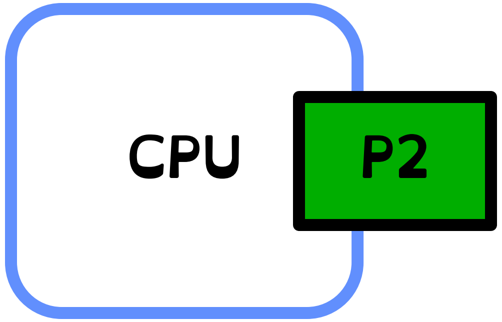

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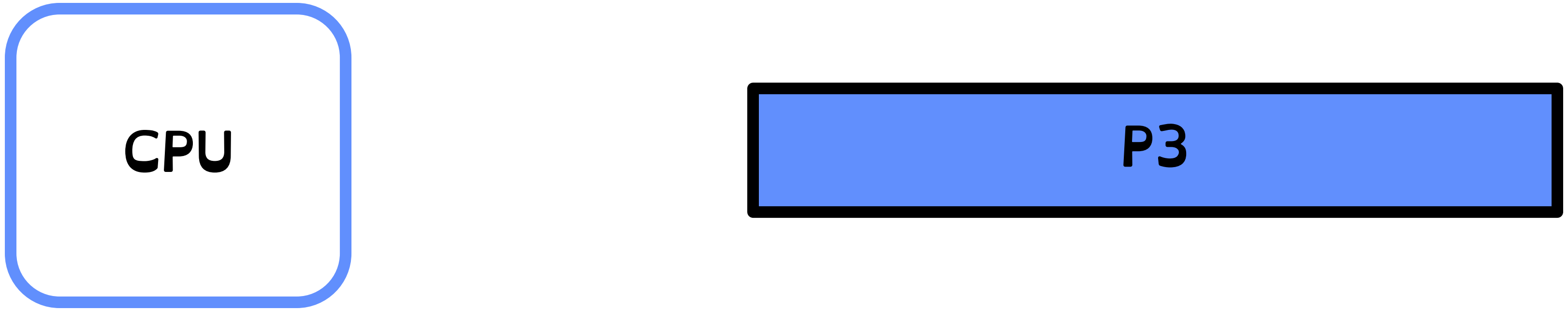

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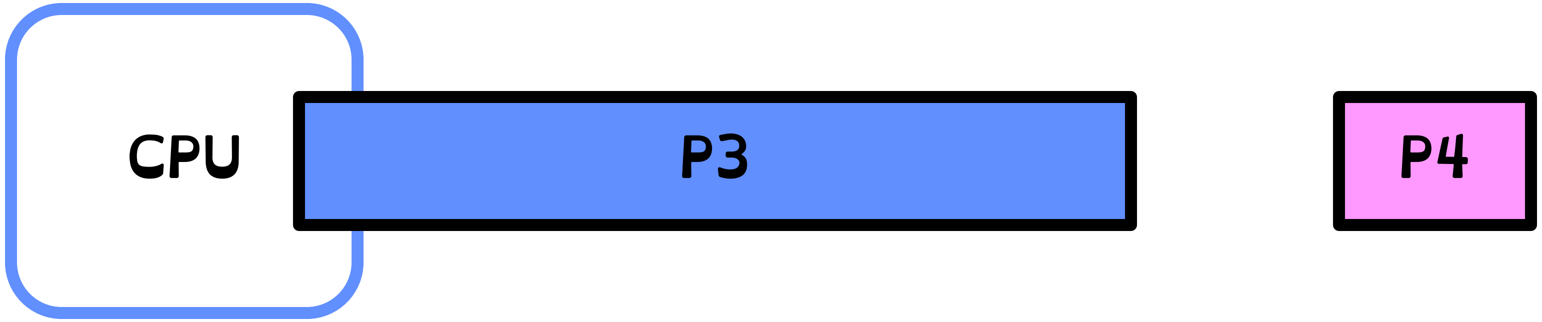

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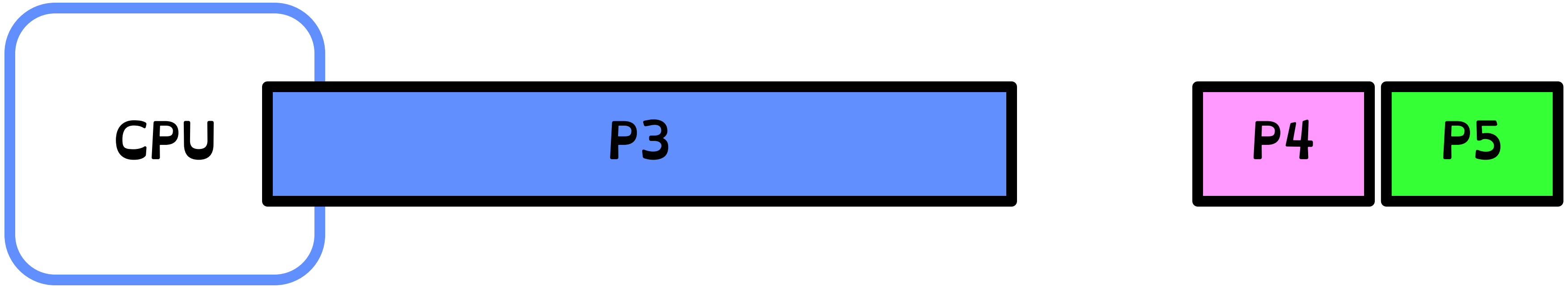

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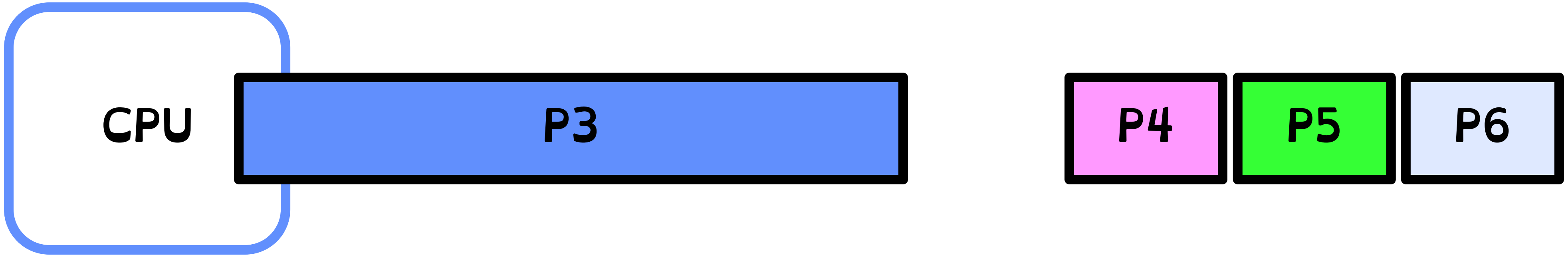

The Convoy Effect

FIFO/FCFS very sensitive to arrival order

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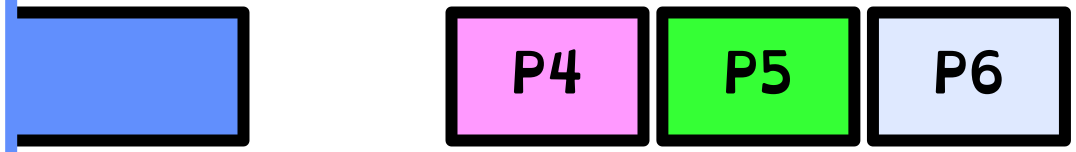
FIFO is non-preemptible

Can FIFO lead to starvation?



FCFS/FIFO Summary

The good

Simple
Low Overhead
No Starvation

The bad

Sensitive to arrival order (poor predictability)

The ugly

Convoy Effect.
Bad for Interactive Tasks

Shortest Job First

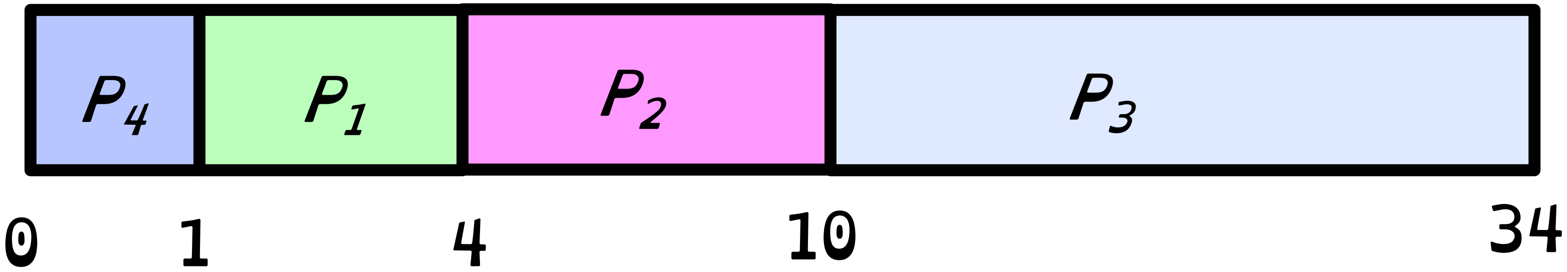
How can we minimise average completion time?

By scheduling jobs in order of estimated completion time

This is the "10 items or less" line at Safeway

Shortest Job First

Process	Burst Time
P_1	3
P_2	6
P_3	24
P_4	1



What is the average completion time? $\left(\frac{1+4+10+34}{4} = 12.25\right)$

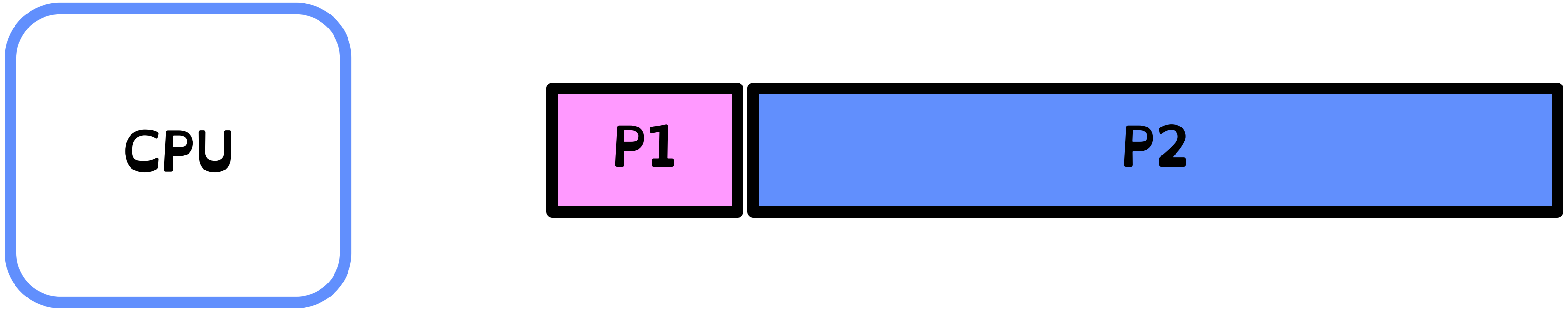
Can prove that SJF generates optimal average completion time if all jobs arrive at the same time

Are we done?

Can SJF lead to starvation?

Yes

Any scheduling policy that always favours a fixed property for scheduling leads to starvation



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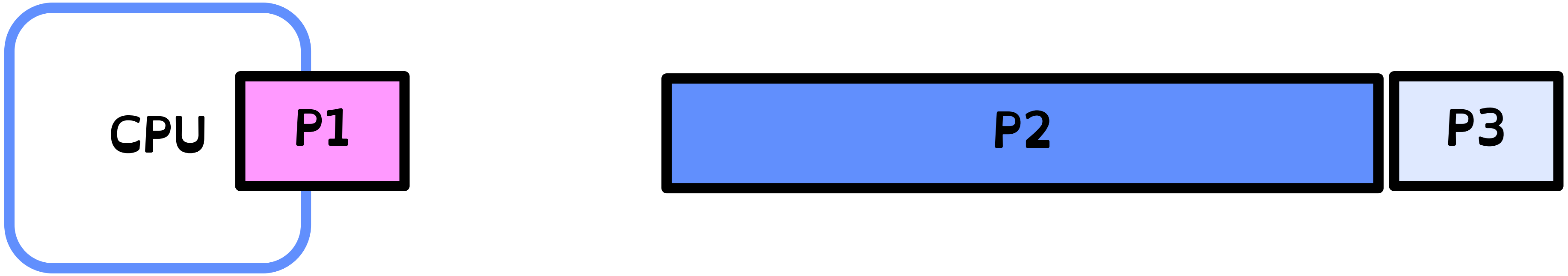

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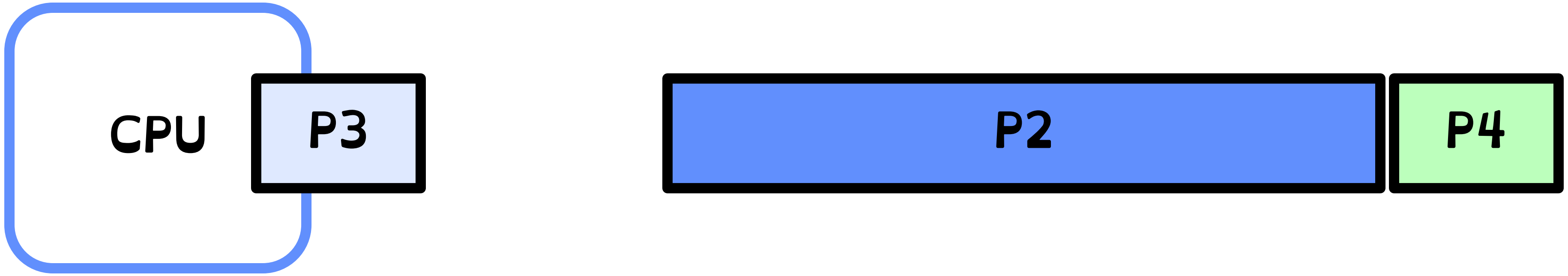
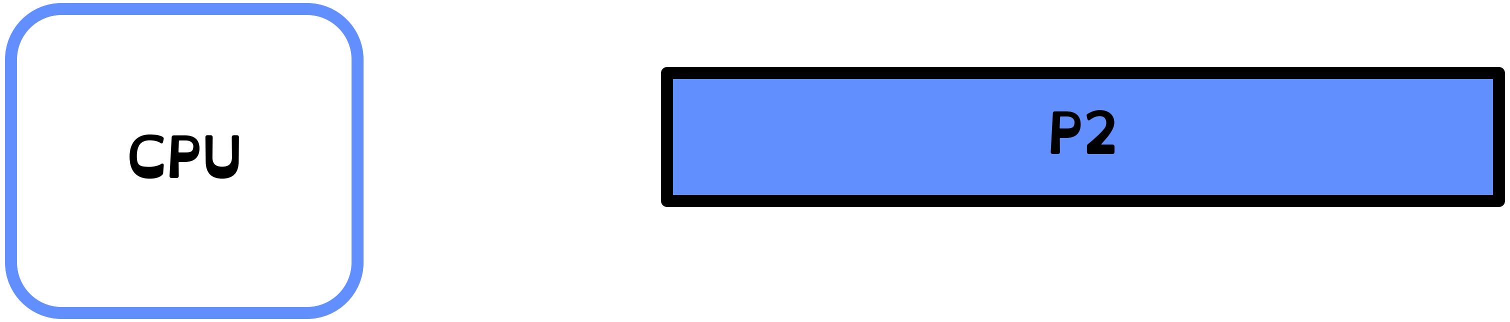


Are we done?

Is SFJ subject to the convoy effect?

Yes

Any non-preemptible scheduling policy suffers from convoy effect



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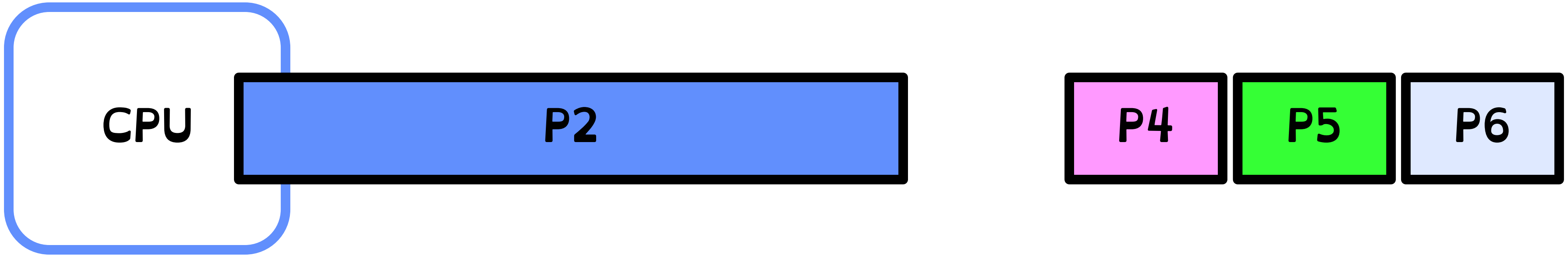


SJF Summary

The good

Optimal Average Completion Time when jobs arrive simultaneously

The bad

Sensitive to arrival order (poor predictability)

The ugly

Can lead to starvation!

Requires knowing duration of job

Shortest Time to Completion First (STCF)

Introduce the notion of preemption

A running task can be de-scheduled before completion.

STCF

Schedule the task with the least amount of time left

Shortest Time to Completion First (STCF)

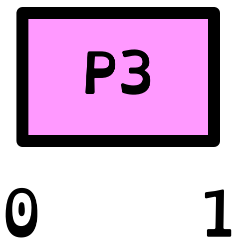
STCF

Schedule the task with the least amount of time left

Process	Burst Time (left)	Arrival Time
P_1	3	10
P_2	6	1
P_3	24	0
P_4	16	20

Shortest Time to Completion First (STCF)

Process	Burst Time (left)	Arrival Time
P_1	3	10
P_2	6	1
P_3	24	0
P_4	16	18



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Process	Burst Time (left)	Arrival Time
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P_2	6	1
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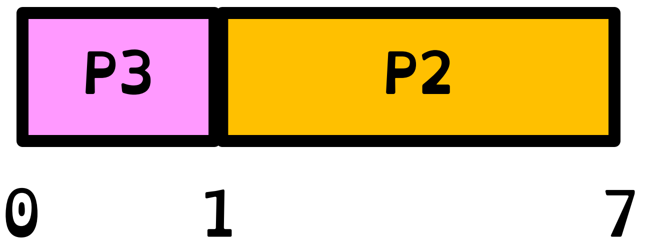
P_4	16	18



Shortest Time to Completion First (STCF)

Process	Burst Time (left)	Arrival Time
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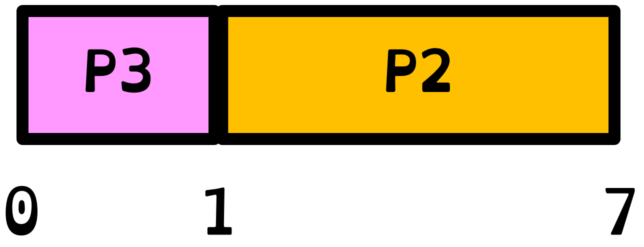
P_2	0	1
P_3	23	0
P_4	16	18

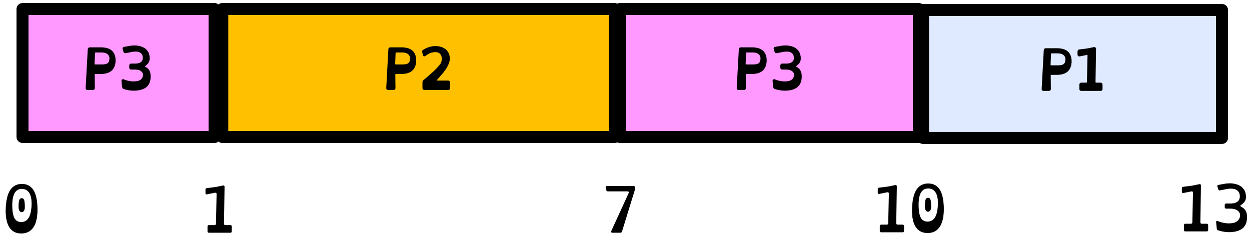


Shortest Time to Completion First (STCF)

Process	Burst Time (left)	Arrival Time
P_1	3	*10*
P_2	0	*1*
P_3	20	*0*
P_4	16	*18*

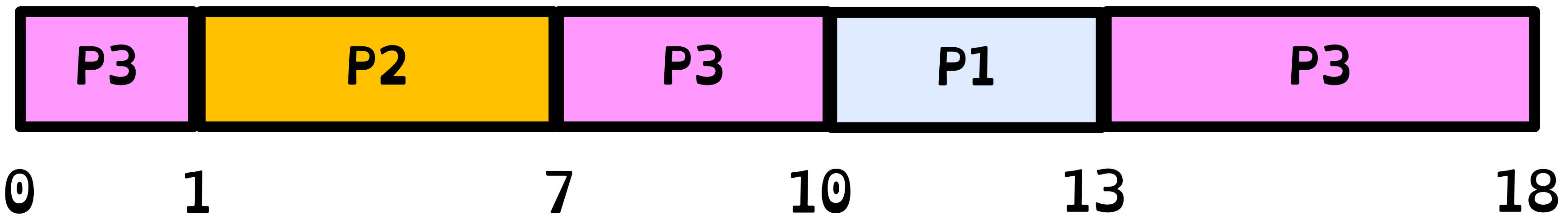
Shortest Time to Completion First (STCF)

Process	Burst Time (left)	Arrival Time
P_1	0	10
P_2	0	1
P_3	20	0
P_4	16	18



Shortest Time to Completion First (STCF)

Process	Burst Time (left)	Arrival Time
P_1	0	10
P_2	0	1
P_3	15	0
P_4	16	18



Shortest Time to Completion First (STCF)

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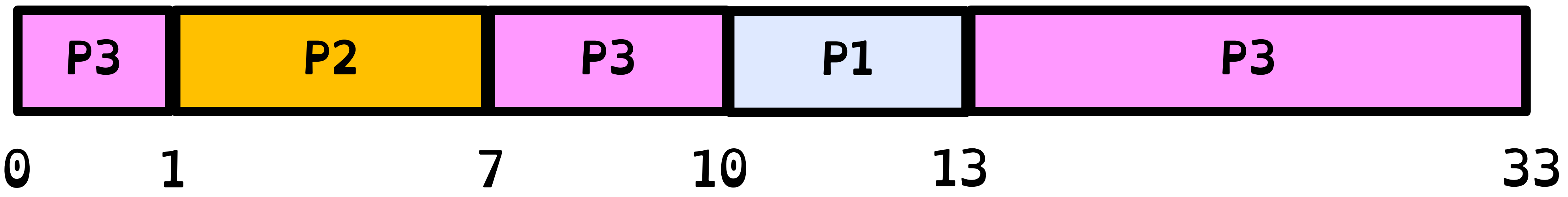
P_2	0	1
P_3	0	0
P_4	15	18



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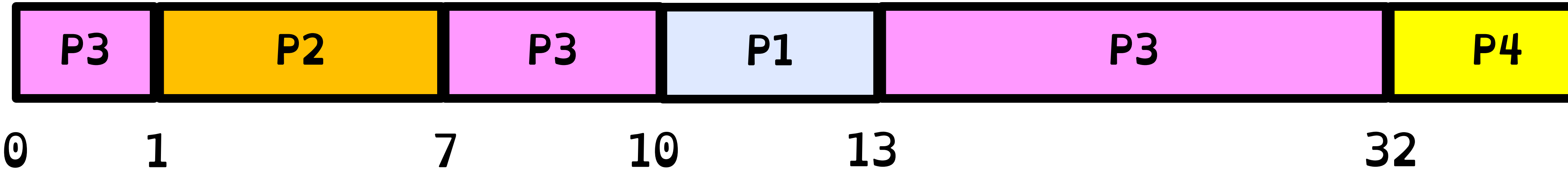


Are we done?

Can STCF lead to starvation?

Yes

Any scheduling policy that always favours a fixed property for scheduling leads starvation

No change!

Are we done?

Is STCF subject to the convoy effect?

No!

STCF is a preemptible policy

STCF Summary

The good

Optimal Average Completion Time Always

The bad

The ugly

Can lead to starvation!

Requires knowing duration of job

Taking a step back

Property	FCFS	SJF	STCF
Optimise Average Completion Time		✓	✓
Prevent Starvation	✓		
Prevent Convoy Effect			✓
Psychic Skills Not Needed	✓		

Can we design a non-psychic, starvation-free scheduler with good response time?

Round-Robin Scheduling

RR runs a job for a **time slice**
(a scheduling quantum)

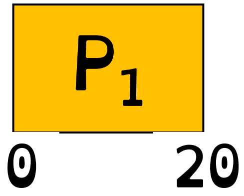
Once time slice over,
Switch to next job in ready queue.
=> Called time-slicing

RR with Time Quantum = 20

Process	Burst Time
P_1	53
P_2	8
P_3	68
P_4	24

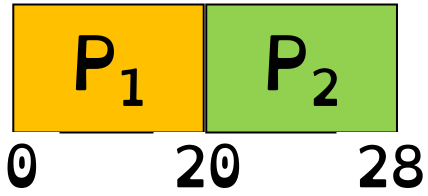
RR with Time Quantum = 20

Process	Burst Time
P_1	53 => 33
P_2	8
P_3	68
P_4	24



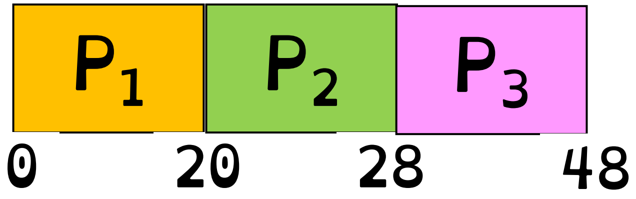
RR with Time Quantum = 20

Process	Burst Time
P_1	33
P_2	8 => 0
P_3	68
P_4	24



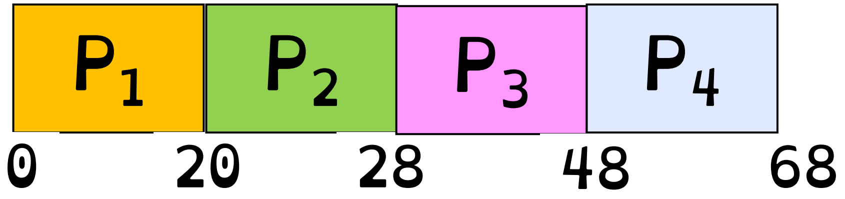
RR with Time Quantum = 20

Process	Burst Time
P_1	33
P_2	0
P_3	68 => 48
P_4	24



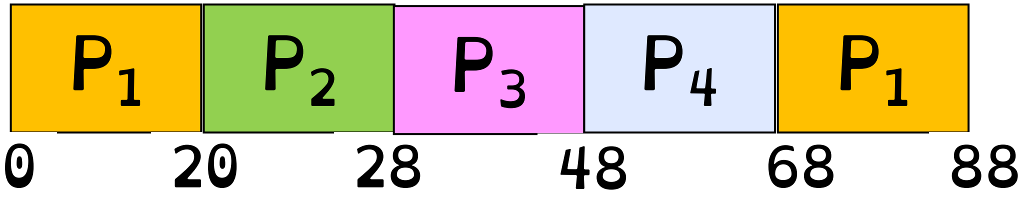
RR with Time Quantum = 20

Process	Burst Time
P_1	33
P_2	0
P_3	48
P_4	24 => 4



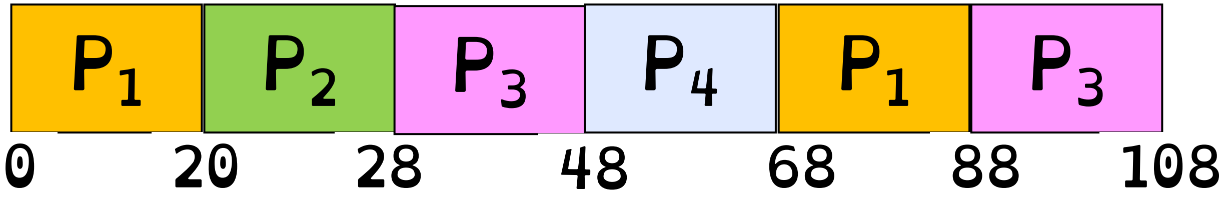
RR with Time Quantum = 20

Process	Burst Time
P_1	33 => 13
P_2	0
P_3	48
P_4	4



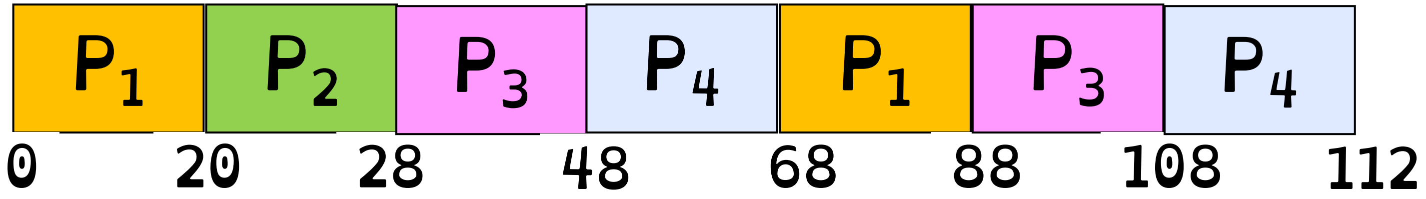
RR with Time Quantum = 20

Process	Burst Time
P_1	13
P_2	0
P_3	48 => 28
P_4	4



RR with Time Quantum = 20

Process	Burst Time
P_1	13
P_2	0
P_3	28
P_4	4 => 0



RR with Time Quantum = 20

Waiting time

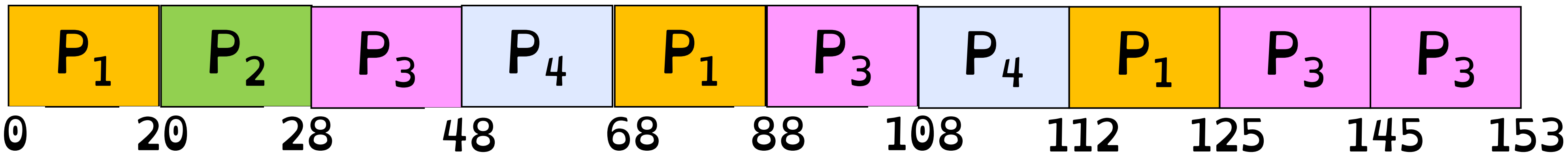
- $P_1= 0 + (68-20)+(112-88)=72$
- $P_2=(20-0)=20$
- $P_3=(28-0)+(88-48)+(125-108)+0=85$
- $P_4=(48-0)+(108-68)=88$

Average waiting time

$$(\frac{72+20+85+88}{4} = 66.25)$$

Average completion time

$$(\frac{125+28+153+112}{4} = 104.25)$$

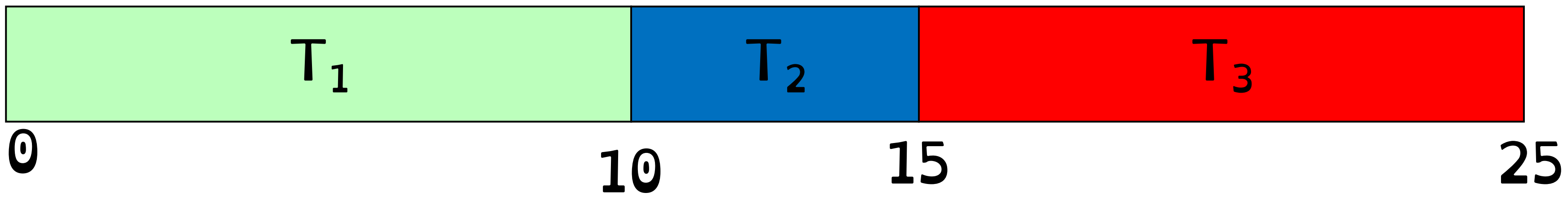


Decrease Completion Time

- T_1: Burst Length 10
- T_2: Burst Length 5

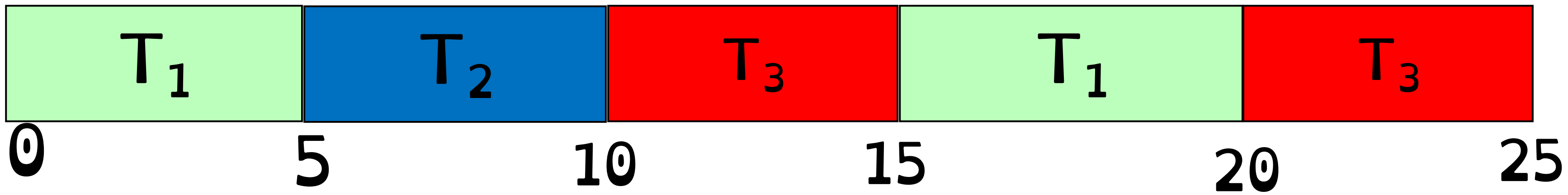
T_3: Burst Length 10

$Q = 10$



Average Completion Time = (10 + 15 + 25)/3 = 16.7

$Q = 5$



Average Completion Time = (20 + 10 + 25)/3 = 18.3

Switching is not free!

Small scheduling quantas lead to
frequent context switches
- Mode switch overhead
- Trash cache-state

q must be large with respect to context switch,
otherwise overhead is too high

Are we done?

Can RR lead to starvation?

No

No process waits more than $(n\text{-}1)q$ time units

Are we done?

Can RR suffer from convoy effect?

No

Only run a time-slice at a time

RR Summary

The good

Bounded response time

The bad

Completion time can be high (stretches out long jobs)

The ugly

Overhead of context switching

Taking a step back

Property	FCFS	SJF	STCF
Optimise Average Completion Time		✓	✓
Prevent Starvation	✓		
Prevent Convoy Effect			✓
Psychic Skills Not Needed	✓		

Taking a step back

Property	FCFS	SJF	STCF	RR
Optimise Average Completion Time		✓	✓	
Optimise Average Response Time				✓
Prevent Starvation	✓			✓
Prevent Convoy Effect			✓	✓
Psychic Skills Not Needed	✓			✓

FCFS and Round Robin Showdown

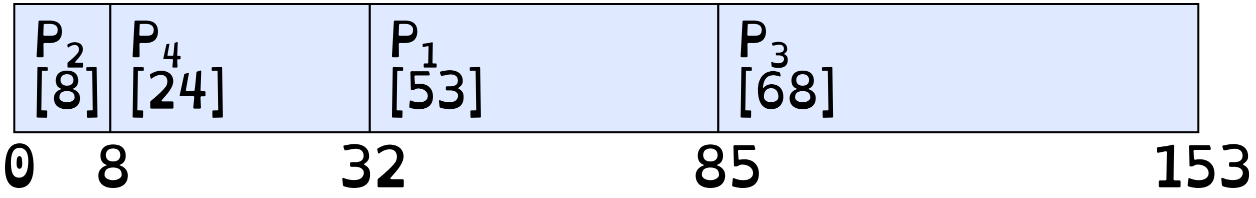
Assuming zero-cost context-switching time,
is RR always better than FCFS?

10 jobs, each take **100**s of **CPU** time
RR scheduler quantum of **1**s
All jobs start at the same time

Job #	FIFO	RR
1	100	991
2	200	992
…	…	…
9	900	999
10	1000	1000

Earlier Example with Different Time Quantum

Best FCFS:



Quantum	P1	P2	P3	P4	Average
Best FCFS	85	8	16	32	69.5
Q=1	137	30	153	81	100.5
Q=5	135	28	153	82	99.5
Q=8	133	16	153	80	99,5
Q=10	135	18	153	92	104.5
Q=20	125	28	153	112	104.5
Worst FCFS	121	153	68	145	121.75