report

April 30, 2022

1 Operating Systems Report - 231006

1.1 Experiment 1 - Comparing the average wait time for each algorithm

1.1.1 Introduction

In this experiment, I look to find out which scheduling algorithm is best used when it comes to minimizing the average waiting time. I hypothesise that the best scheduling algorithm for minimising wait time is the Multilevel Feed Back Queue with Round Robin, which, is the pre-emptive and when using a time quantum, is able to context switch from longer processes when they exceed the time quantum. I expect that shortest job first with exponential averaging will perform poorly compared to the other scheduling algorithms owing to the fact that it is non-preemptive.

1.1.2 Methodology

In order to test which algorithm has the best average waiting time, I will run the experiment (and all subsequent experiments) using the `run.sh` script. This will run the experiment for each scheduling, for each scheduling algorithm, we will choose 5 different seeds so that we can get a stable average waiting time. Inputs generated by the bash script are stored in `/experiment1/inputs` and the simulator parameters used are stored in `/experiment1/sim_params/`. Outputs are stored in `/experiment1/schedulers/[scheduler]` The only variation in the parameters is the scheduling algorithm used. I will calculate the average waiting time across all 5 seeds for each scheduling algorithm and then compare the average waiting times for each scheduling algorithm, this way I can see which algorithm has the best average waiting time.

[1]:
```python
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
from experiment import Experiment

exp = Experiment('./experiment1')

print("Seeds Used: ")
print("Input Params of experiment with seed " + exp.get_input(1)[0])

exp.input_params[1].head()
```

```
Seeds Used:
Input Params of experiment with seed 120
```

```
[1]:                      value
param
numberOfProcesses        50
staticPriority            0
meanInterArrival         12
meanCpuBurst             10
meanIoBurst              10
```

```
[2]: print("Simulation params of experiment: (note scheduler is missing as it will␣
     ↪be changing)")
     exp.sim_params[0].drop(['scheduler'])
```

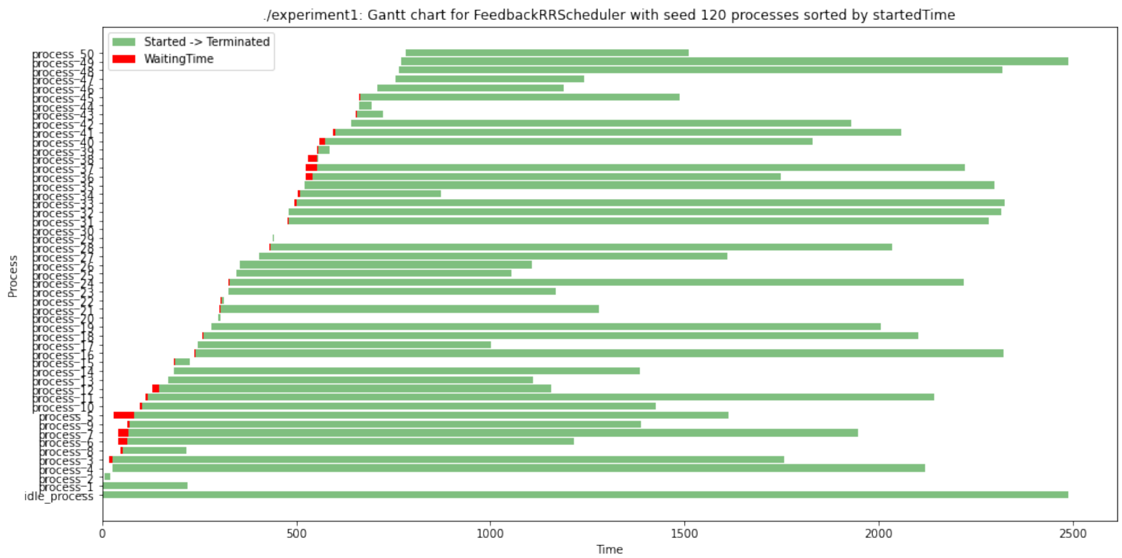
```
Simulation params of experiment: (note scheduler is missing as it will be
changing)
```

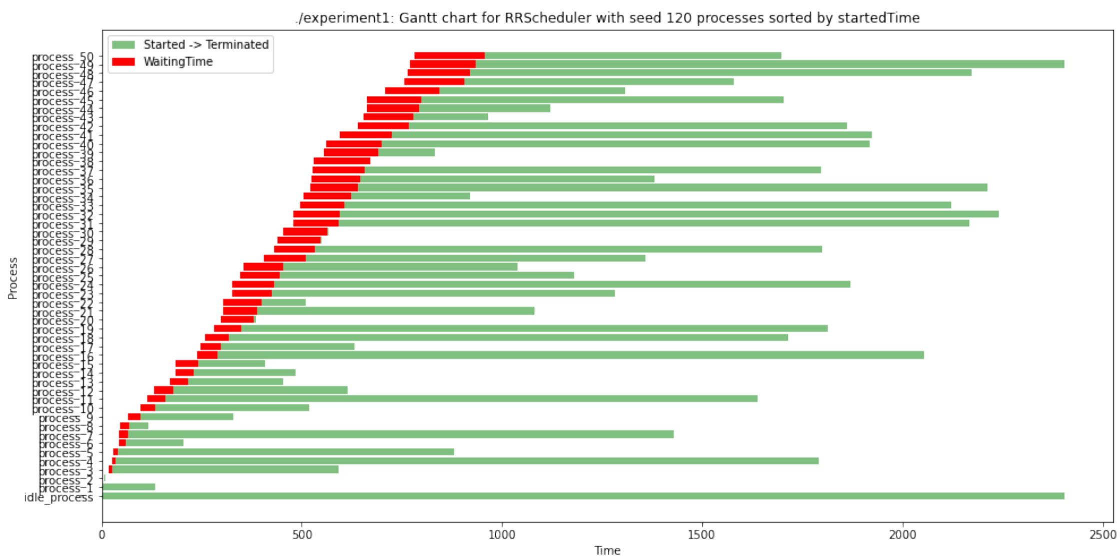
```
[2]:                        value
param
timeLimit                  10000
interruptTime                  1
timeQuantum                    5
initialBurstEstimate           5
alphaBurstEstimate           0.5
periodic                   false
```

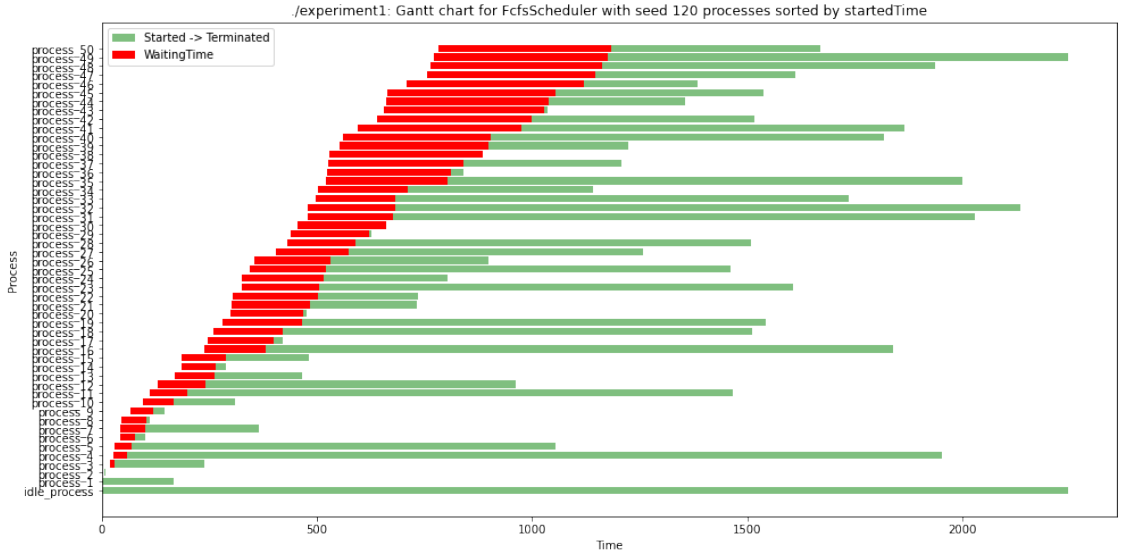
As can be seen above, we use an interrupt time of `1 unit` and a time quantum of `5 units`. I chose these values so ensure that the processes that use RoundRobin (RR) and Feedback Round Robin (FRR) are forced to make a context switch so that they cannot always run for the entire time quantum. I chose the ratio 1:5 to reduce too much overhead in the system to try and get a fair comparison.

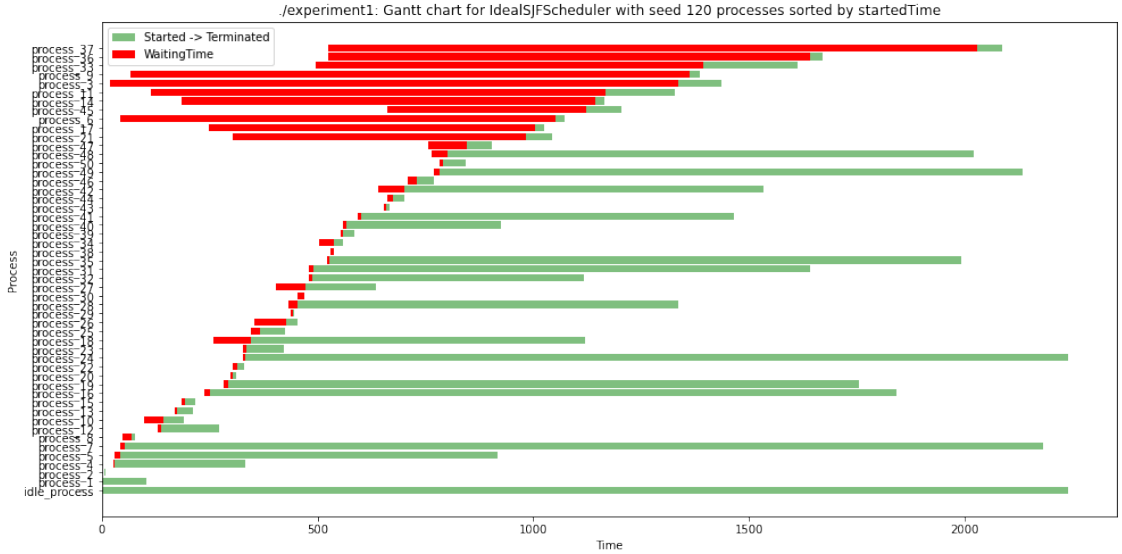
1.1.3 Results

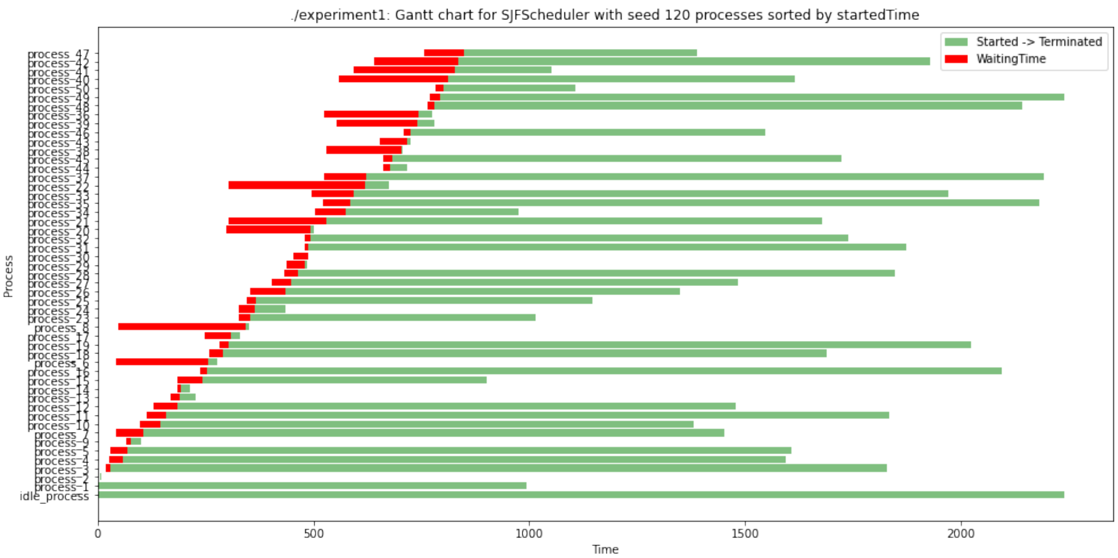
```
[3]: ## Plotting and Comparing Gantt Charts for Different Schedulers
     exp.plot_gantt('FeedbackRRScheduler', '120')
     exp.plot_gantt('RRScheduler', '120')
     exp.plot_gantt('FcfsScheduler', '120')
     exp.plot_gantt('IdealSJFScheduler', '120')
     exp.plot_gantt('SJFScheduler', '120')
```


./experiment1: Gantt chart for FeedbackRRScheduler with seed 120 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
0
500
1000
1500
2000
2500
idle_process


./experiment1: Gantt chart for RRScheduler with seed 120 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
0
500
1000
1500
2000
2500
idle_process


./experiment1: Gantt chart for FcfsScheduler with seed 120 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
0
500
1000
1500
2000
idle_process


./experiment1: Gantt chart for IdealSJFScheduler with seed 120 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
0
500
1000
1500
2000
idle_process



As can clearly be seen from the above example, the wait time on the Feedback Round Robin (FRR) algorithm is the lowest, followed by the Round Robin Algorithm algorithm. To validate this result, I will look across multiple different seeds and analyse the average waiting time for each scheduling algorithm.

[4]:
```
meanWaitingTimes = exp.get_output_col('waitingTime').mean()
meanWaitingTimes

newCols = set(meanWaitingTimes.index.map(lambda x: x.split('_')[0]))
stats = pd.DataFrame(index=newCols, columns=["MeanWaitingTime"])

# Calculating the means for each scheduler
for scheduler in newCols:
        matching = [col for col in meanWaitingTimes.index if scheduler in col]
        meanOfScheduler = meanWaitingTimes[matching].mean()

        stats['MeanWaitingTime'][scheduler] = meanOfScheduler
stats
```

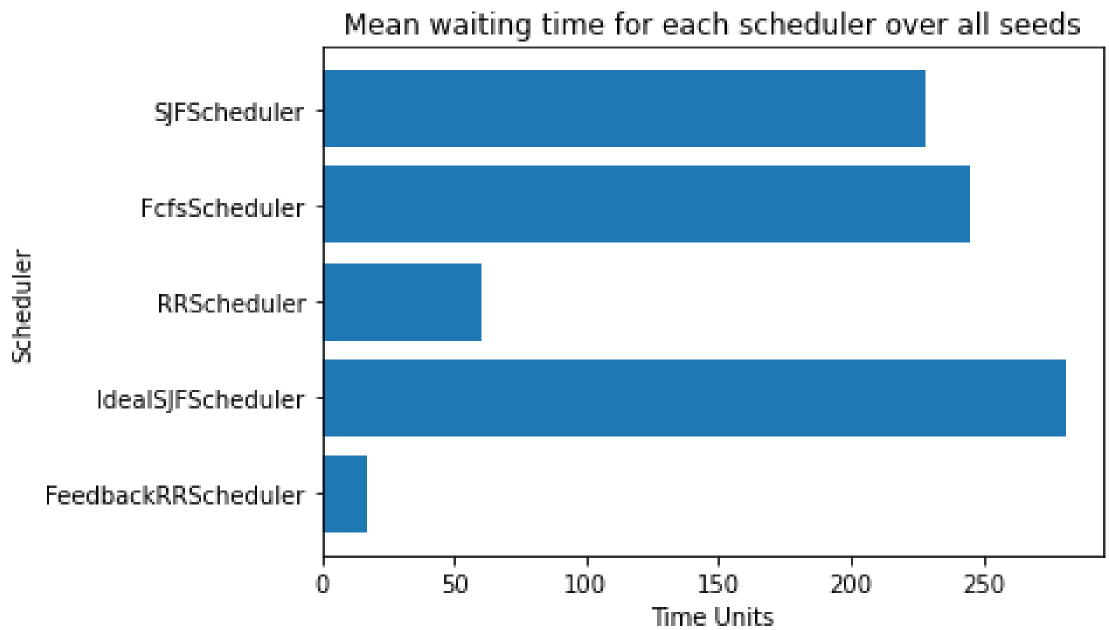
[4]:

	MeanWaitingTime
FeedbackRRScheduler	17.062745
IdealSJFScheduler	281.54902
RRScheduler	60.166667
FcfsScheduler	244.913725
SJFScheduler	228.266667

[5]:
```
plt.barh(stats.index, stats['MeanWaitingTime'])
plt.title("Mean waiting time for each scheduler over all seeds")
```

```
plt.xlabel("Time Units")
plt.ylabel("Scheduler")
```

[5]: Text(0, 0.5, 'Scheduler')



As can be seen above, the `FeedbackRRScheduler` algorithm which uses round robin and a multi-level queue that demotes the process and returns it to the back of the queue when it has reached its time quantum has the best average waiting time when given the same input as the other algorithms, this is followed by the Round Robin algorithm. This shows a multi-level feedback queue with the Round Robin algorithm as the best algorithm for minimising average waiting time.

It is important to note that we must take into account the fact that the time quantum and small interrupt time is key to ensuring that a multi-level feedback queue with this approach outperforms the Ideal Shortest Job First algorithm. In cases where the time quantum is higher than the interrupt time, the multi-level feedback queue will outperform or match the Ideal Shortest Job First algorithm.

I am interested by the impact of the time quantum and interrupt time on the average waiting time for each scheduling algorithm and how the keen to look into how performance of Ideal Shortest Job First and the multi-level feedback queue compare.

It can also be noted that the waiting time for both the First Come First Serve and Shortest Job First algorithms is extremely long compared to other algorithms, this is likely down to the emerging of the convoy effect, where larger processes are forced to wait for smaller processes to finish. I am interested to see whether the non-preemptive Shortest Job First algorithm can have its input parameters tuned to perform better under this type of scenario.

1.2 Experiment 2 - Which scheduling algorithm is most effective for maximizing CPU utilization whilst minimizing average turnaround time?

1.2.1 Introduction

I am interested it finding out what scheduling algorithm is most effective for maximizing CPU utilization whilst minimizing average turnaround time.

[6]:
```python
exp = Experiment('./experiment2')
exp
```

[6]: <experiment.Experiment at 0x11f1f12b0>

1.2.2 Methodology

To analyse how different algorithms perform, I use the following parameters:

Input Parameters

```
numProcesses=25
interArrivalTime=10
meanIoBurstTime=24
meanCpuBurstTime=4
meanNumBursts=10
```

The mean IO burst time I have chosen to be substantially higher than the mean CPU burst time, this is to ensure that the workload is high and varied so that the convoy effect is more likely to occur.

Simulator Parameters

```
timeLimit=5000
interruptTime=10
timeQuantum=4
initialBurstEstimate=14
alphaBurstEstimate=0.5
periodic=false
```

I have initially chosen these values to try and give the exponential averaging algorithm a good chance initially, will an initial burst time of `14` and an alpha burst time of `0.5`.

[7]:
```python
shortest_job_first_output = [o[1] for o in exp.get_output('SJFScheduler')]

print("Example of shortest job first output:")
shortest_job_first_output[3]
```

```
Example of shortest job first output:
```

[7]:

	id	priority	createdTime	startedTime	terminatedTime	cpuTime	\
process_1	1	0	0	10	221	105	
process_2	2	0	9	31	440	183	

process_25	25	0	389	476	498	22
process_7	7	0	80	253	515	62
process_6	6	0	74	463	581	12
process_10	10	0	145	673	986	106
process_24	24	0	359	591	1098	90
process_21	21	0	334	612	1175	115
process_20	20	0	326	1212	1277	33
process_19	19	0	313	1131	1391	40
process_22	22	0	341	1119	1414	46
process_3	3	0	47	1449	1674	64
process_17	17	0	294	1438	1863	81
process_8	8	0	111	1357	1874	87
process_12	12	0	156	1884	1887	3
process_9	9	0	118	1897	1995	34
process_23	23	0	351	1917	2198	28
process_5	5	0	61	2027	2209	45
process_4	4	0	48	1928	2223	69
process_18	18	0	299	2282	2299	17
process_15	15	0	252	2260	2681	113
process_13	13	0	163	2233	2743	44
process_16	16	0	261	2321	2950	127
process_14	14	0	230	1747	3065	120
process_11	11	0	152	543	3151	150
idle_process	0	0	0	0	3151	-5

	blockedTime	turnaroundTime	waitingTime	responseTime
process_1	2	221	12	10
process_2	6	431	28	22
process_25	0	109	87	87
process_7	10	435	183	173
process_6	2	507	391	389
process_10	6	841	534	528
process_24	12	739	244	232
process_21	14	841	292	278
process_20	1	951	887	886
process_19	5	1078	823	818
process_22	5	1073	783	778
process_3	4	1627	1406	1402
process_17	7	1569	1151	1144
process_8	9	1763	1255	1246
process_12	0	1731	1728	1728
process_9	1	1877	1780	1779
process_23	6	1847	1572	1566
process_5	2	2148	1968	1966
process_4	10	2175	1890	1880
process_18	0	2000	1983	1983
process_15	13	2429	2021	2008

```
process_13             1          2580         2071          2070
process_16            18          2689         2078          2060
process_14            10          2835         1527          1517
process_11            21          2999          412           391
idle_process           0          3151            0             0
```

I will first examine the Gantt Charts for each scheduling algorithm with these parameters. To calculate CPU utilization, I intend to use the following formula (as defined in `experiment.py`):

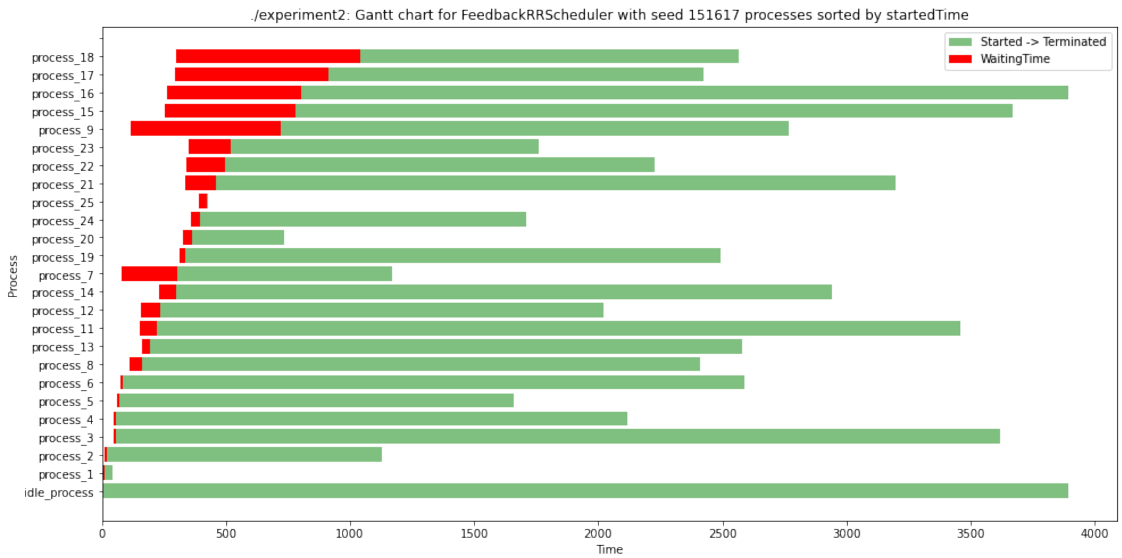
`CPU utilization = 100 - (total_cpuTime - total_idleTime / total_time)`

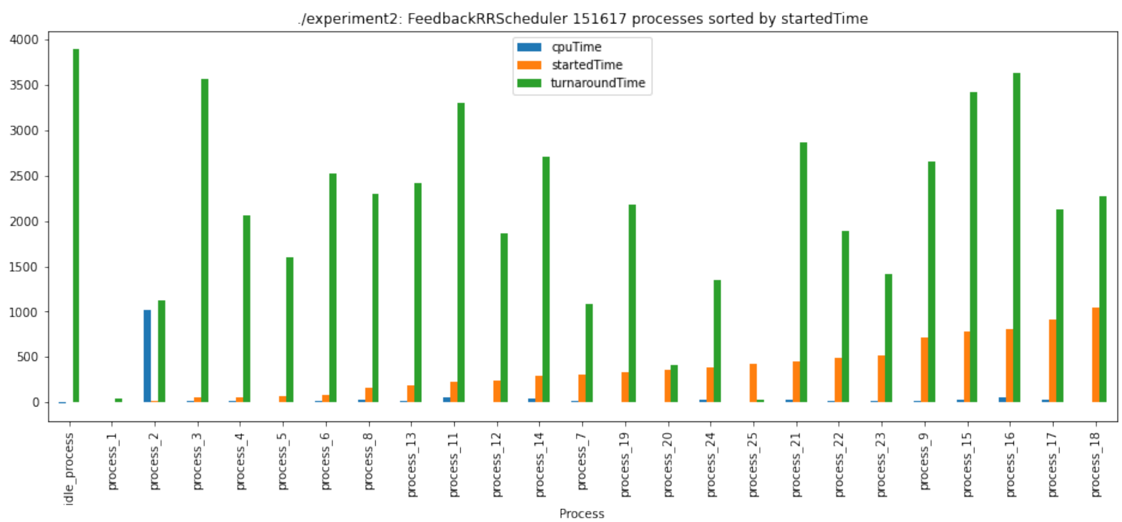
[8]:
```python
results = pd.DataFrame(columns=["Seed", "Algorithm", "MeanWaitingTime",␣
↪"MeanTurnaroundTime", "CpuUtilization"])
```

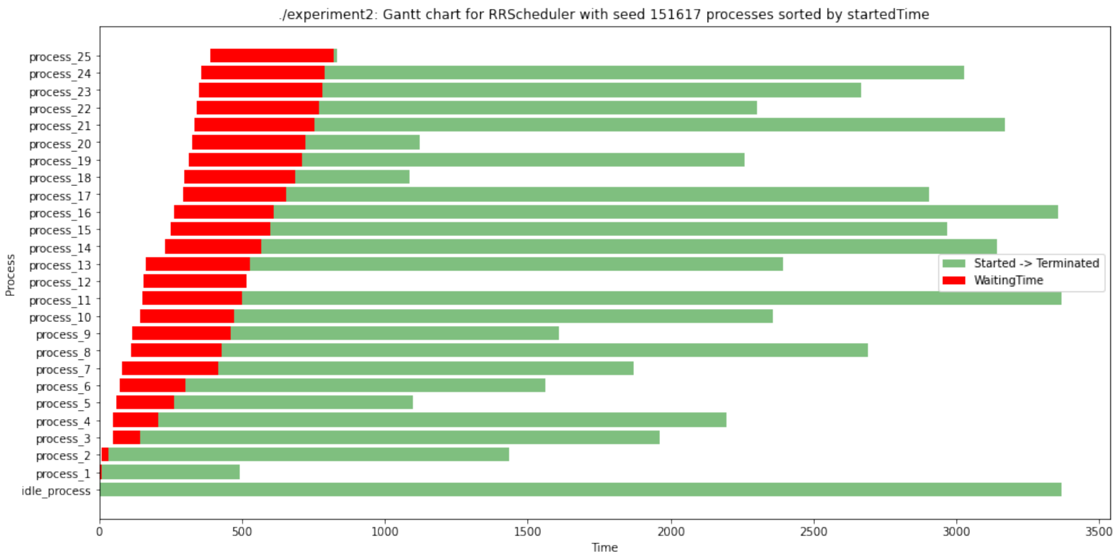
1.2.3 Results for Seed 15167

[9]:
```python
seed_to_analyse = "151617"
schedulers = ['FeedbackRRScheduler', 'RRScheduler', 'FcfsScheduler',␣
↪'IdealSJFScheduler', 'SJFScheduler']

def show_results(exp, scheduler, seed_to_analyse):
        exp.plot_gantt(scheduler, seed_to_analyse)
        exp.plot_cols_for_output(scheduler, seed_to_analyse)
        util = exp.calculate_cpu_utilization_for_output(scheduler,␣
↪seed_to_analyse)
        results.loc[len(results)] = [seed_to_analyse, scheduler, exp.
↪get_output_for_seed(scheduler, seed_to_analyse).waitingTime.mean(), exp.
↪get_output_for_seed(scheduler, seed_to_analyse).terminatedTime.mean() - exp.
↪get_output_for_seed(scheduler, seed_to_analyse).startedTime.mean(), util]

        print(f"CPU Utilization for {scheduler}: {util.round(3)}%")

for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

```
CPU Utilization for FeedbackRRScheduler: 98.99%
CPU Utilization for RRScheduler: 98.988%
CPU Utilization for FcfsScheduler: 98.989%
CPU Utilization for IdealSJFScheduler: 98.985%
CPU Utilization for SJFScheduler: 98.997%
```


./experiment2: Gantt chart for FeedbackRRScheduler with seed 151617 processes sorted by startedTime
Started -> Terminated
WaitingTime
process_18
process_17
process_16
process_15
process_9
process_23
process_22
process_21
process_25
process_24
process_20
process_19
process_7
process_14
process_12
process_11
process_13
process_8
process_6
process_5
process_4
process_3
process_2
process_1
idle_process
Process
0
500
1000
1500
2000
2500
3000
3500
4000
Time


./experiment2: FeedbackRRScheduler 151617 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
4000
3500
3000
2500
2000
1500
1000
500
0
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_8
process_13
process_11
process_12
process_14
process_7
process_19
process_20
process_24
process_25
process_21
process_22
process_23
process_9
process_15
process_16
process_17
process_18
Process


./experiment2: Gantt chart for RRScheduler with seed 151617 processes sorted by startedTime
Process
Time
Started -> Terminated
WaitingTime
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
process_10
process_9
process_8
process_7
process_6
process_5
process_4
process_3
process_2
process_1
idle_process
0
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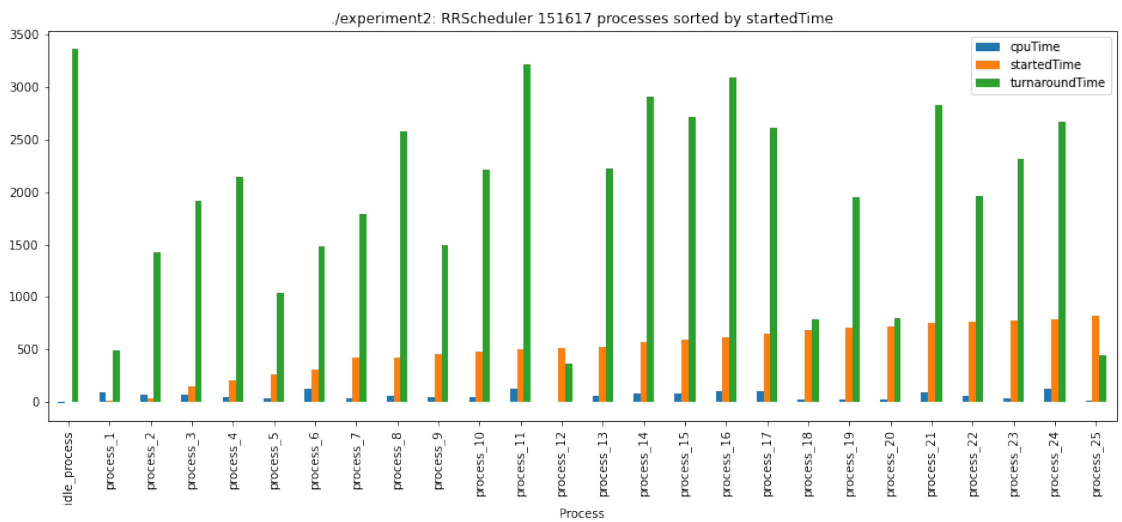
2000
2500
3000
3500


./experiment2: RRScheduler 151617 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
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2000
2500
3000
3500
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
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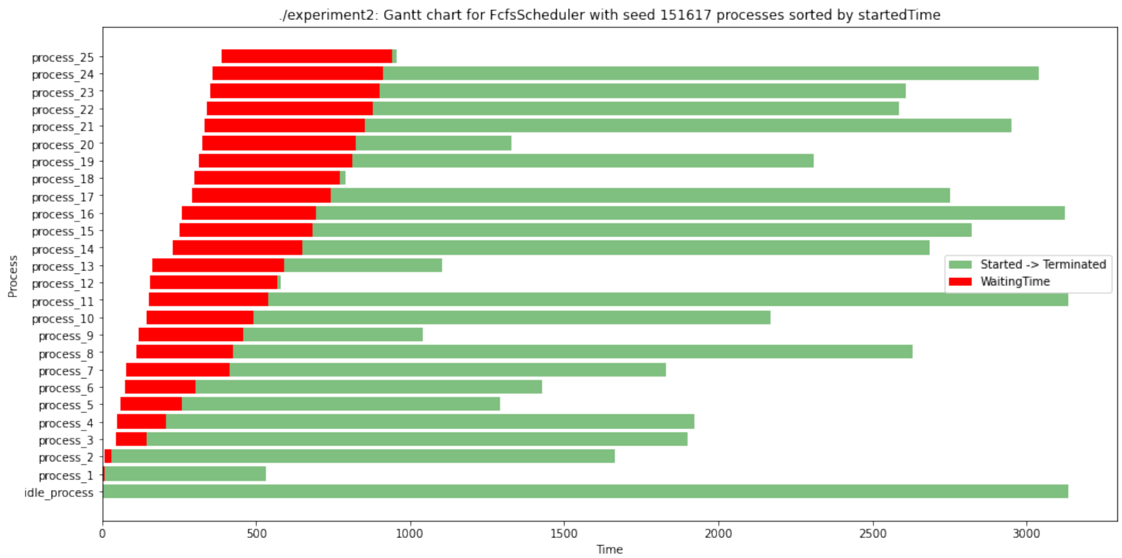
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25


./experiment2: Gantt chart for FcfsScheduler with seed 151617 processes sorted by startedTime
Process
Time
Started -> Terminated
WaitingTime
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
process_10
process_9
process_8
process_7
process_6
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process_4
process_3
process_2
process_1
idle_process
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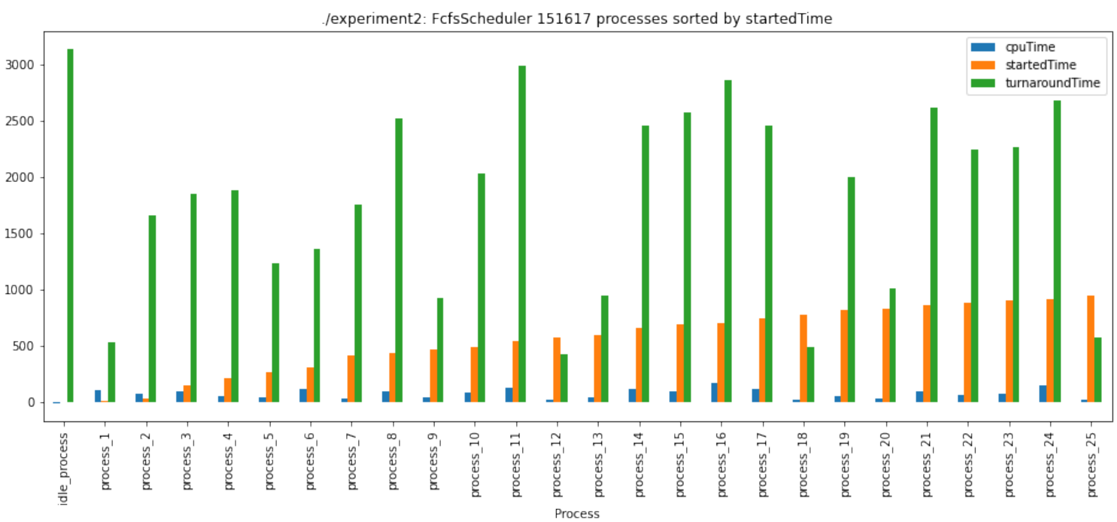
./experiment2: FcfsScheduler 151617 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
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500
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1500
2000
2500
3000
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
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process_11
process_12
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process_14
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process_19
process_20
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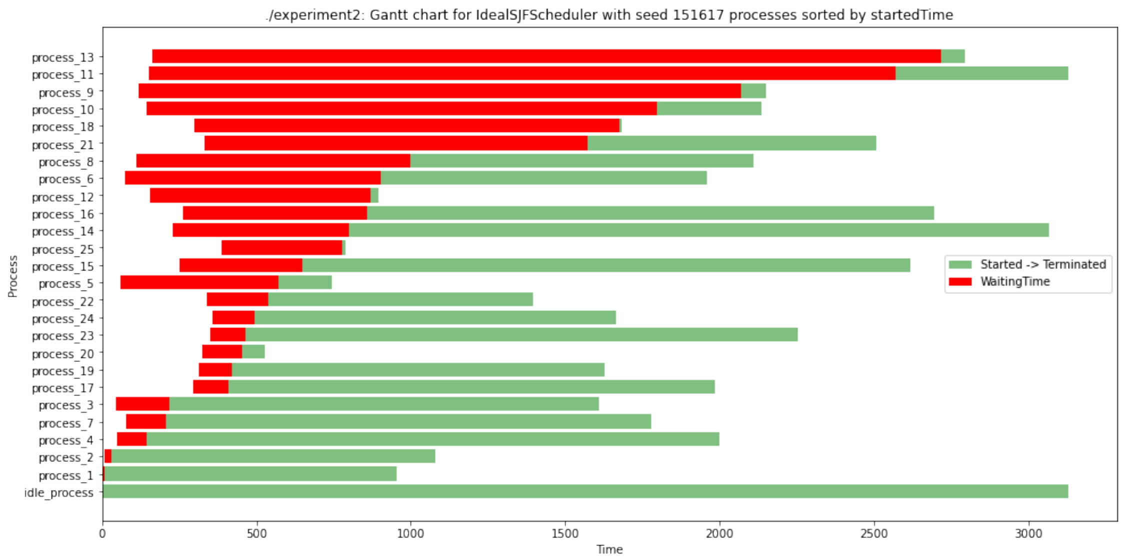
process_22
process_23
process_24
process_25


./experiment2: Gantt chart for IdealSJFScheduler with seed 151617 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_13
process_11
process_9
process_10
process_18
process_21
process_8
process_6
process_12
process_16
process_14
process_25
process_15
process_5
process_22
process_24
process_23
process_20
process_19
process_17
process_3
process_7
process_4
process_2
process_1
idle_process
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2500
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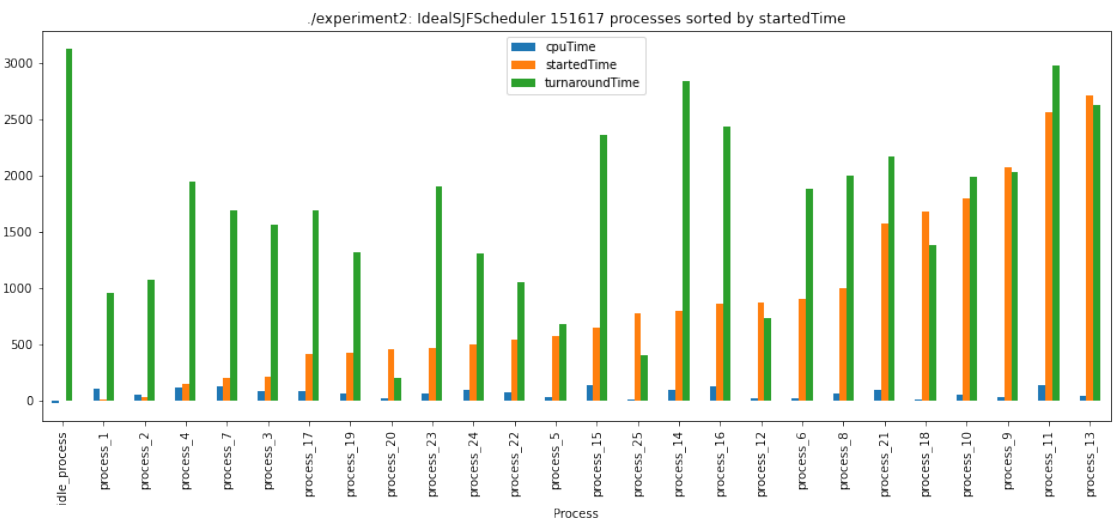
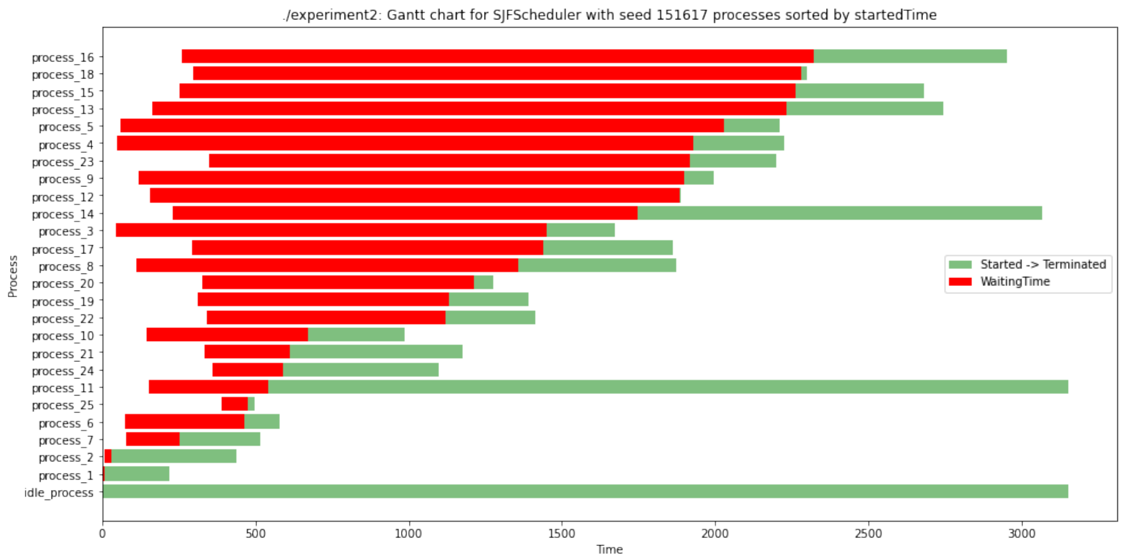
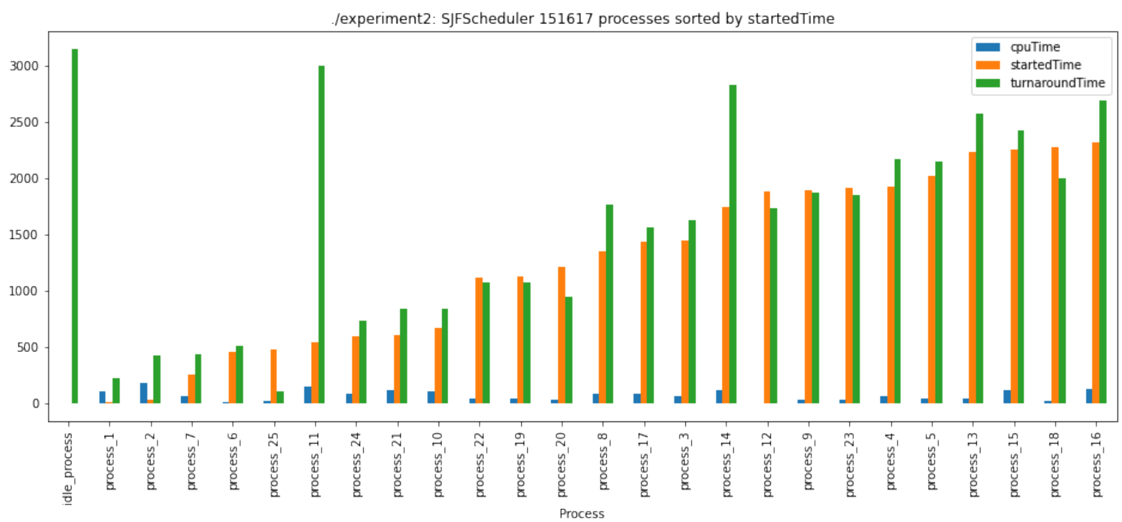

./experiment2: IdealSJFScheduler 151617 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
1000
1500
2000
2500
3000
idle_process
process_1
process_2
process_4
process_7
process_3
process_17
process_19
process_20
process_23
process_24
process_22
process_5
process_15
process_25
process_14
process_16
process_12
process_6
process_8
process_21
process_18
process_10
process_9
process_11
process_13



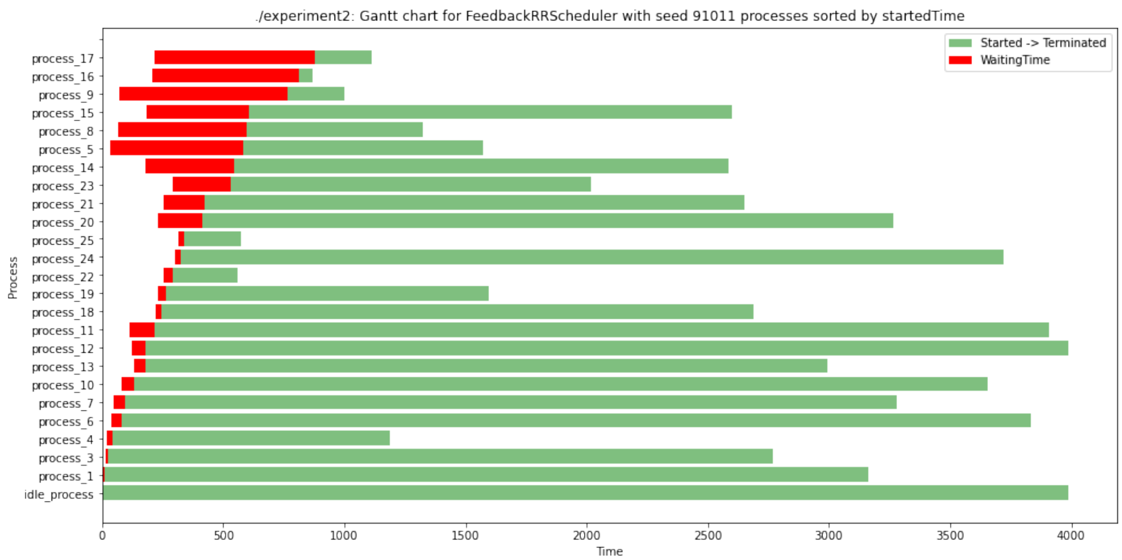


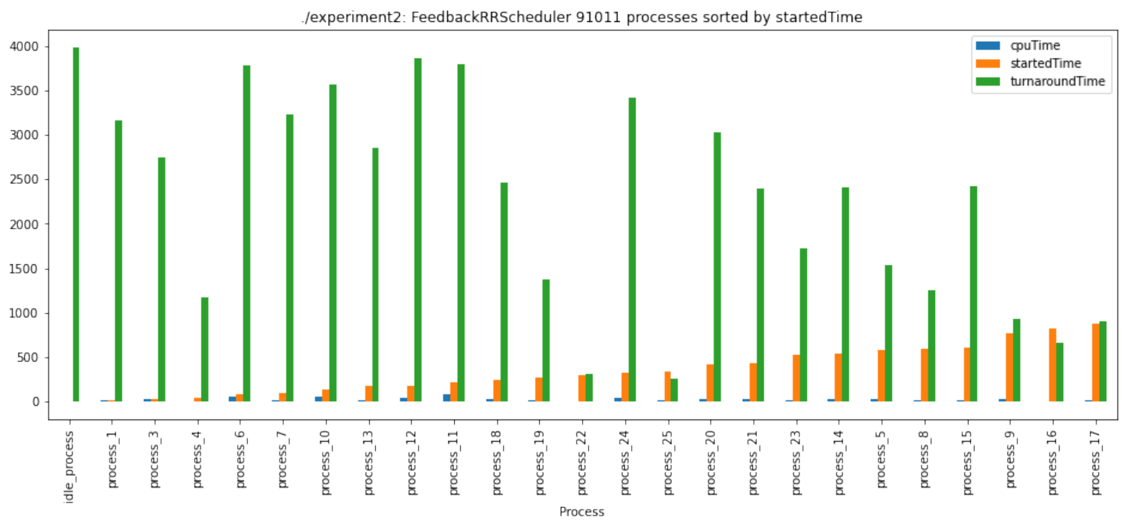
1.2.4 Results for Seed 91011

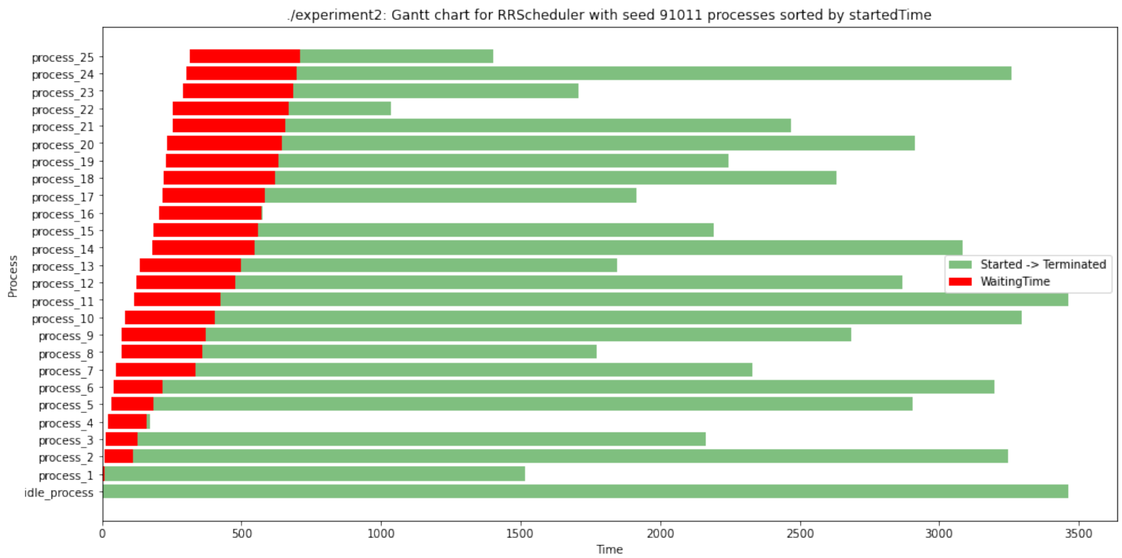
[10]:
```
seed_to_analyse = '91011'

for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

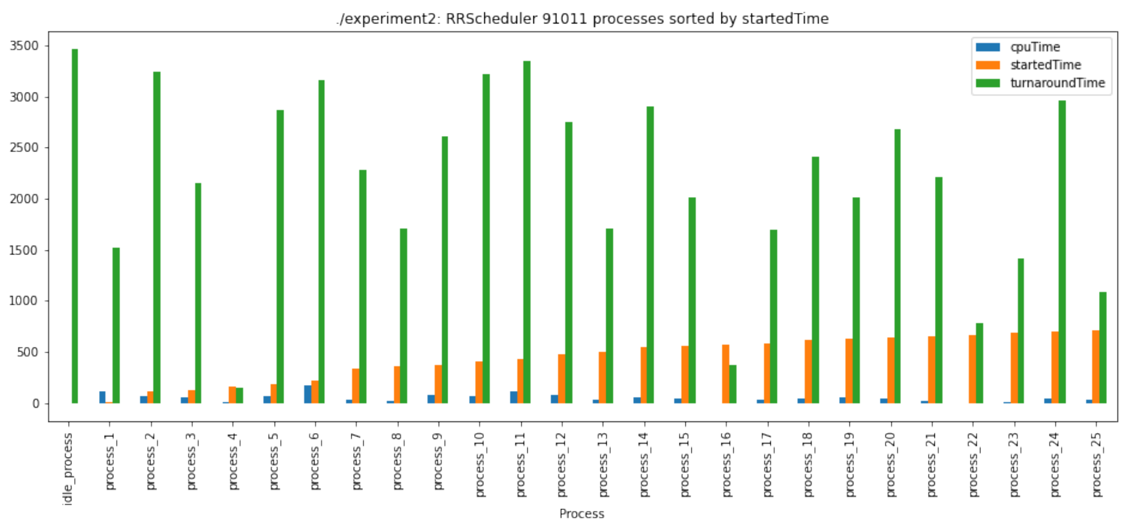
```
CPU Utilization for FeedbackRRScheduler: 98.985%
CPU Utilization for RRScheduler: 98.995%
CPU Utilization for FcfsScheduler: 98.991%
CPU Utilization for IdealSJFScheduler: 98.995%
```

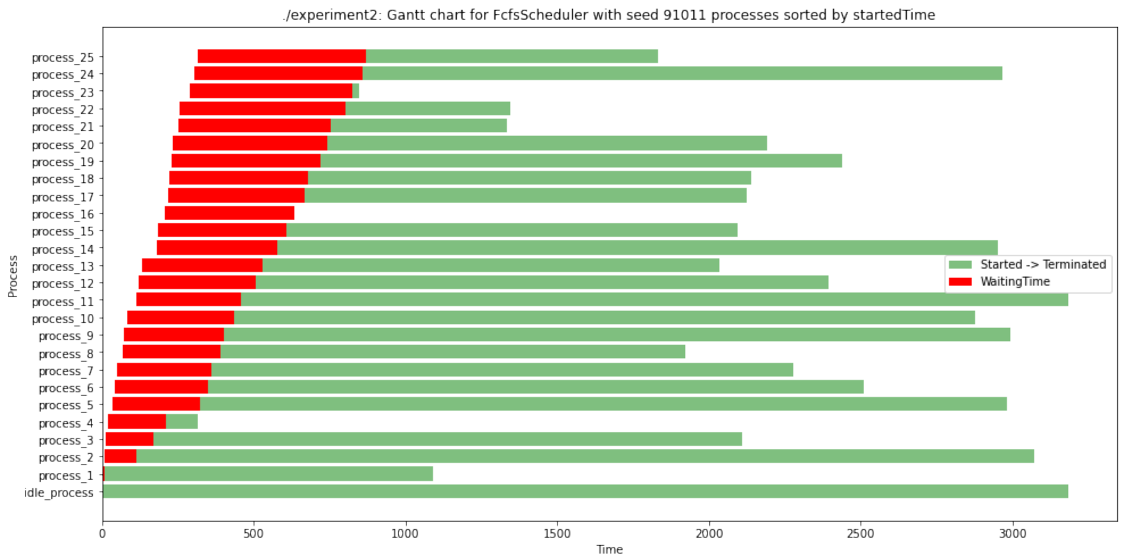
```
CPU Utilization for SJFScheduler: 98.995%
```



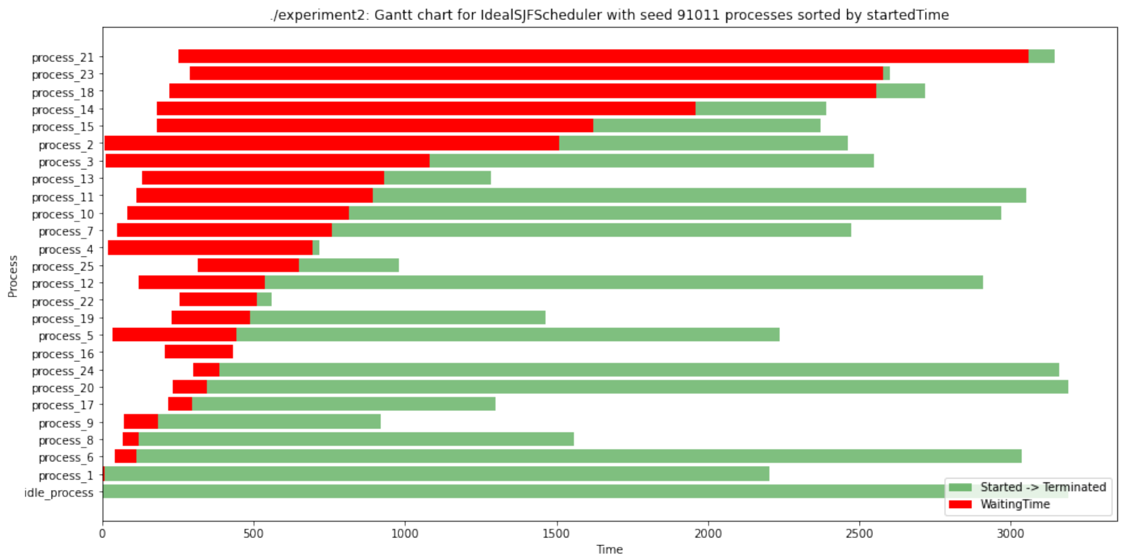


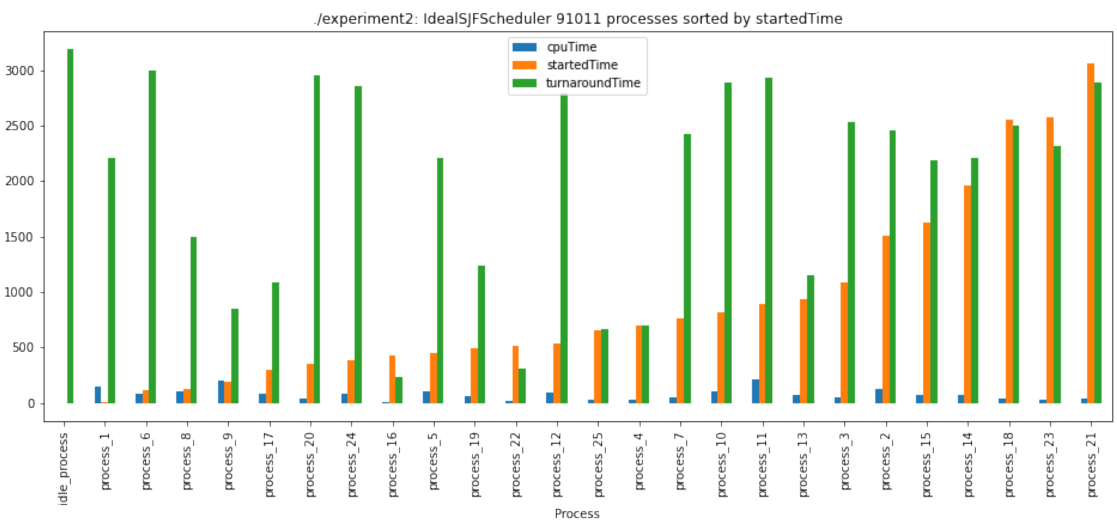

./experiment2: Gantt chart for RRScheduler with seed 91011 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
process_10
process_9
process_8
process_7
process_6
process_5
process_4
process_3
process_2
process_1
idle_process
0
500
1000
1500
2000
2500
3000
3500

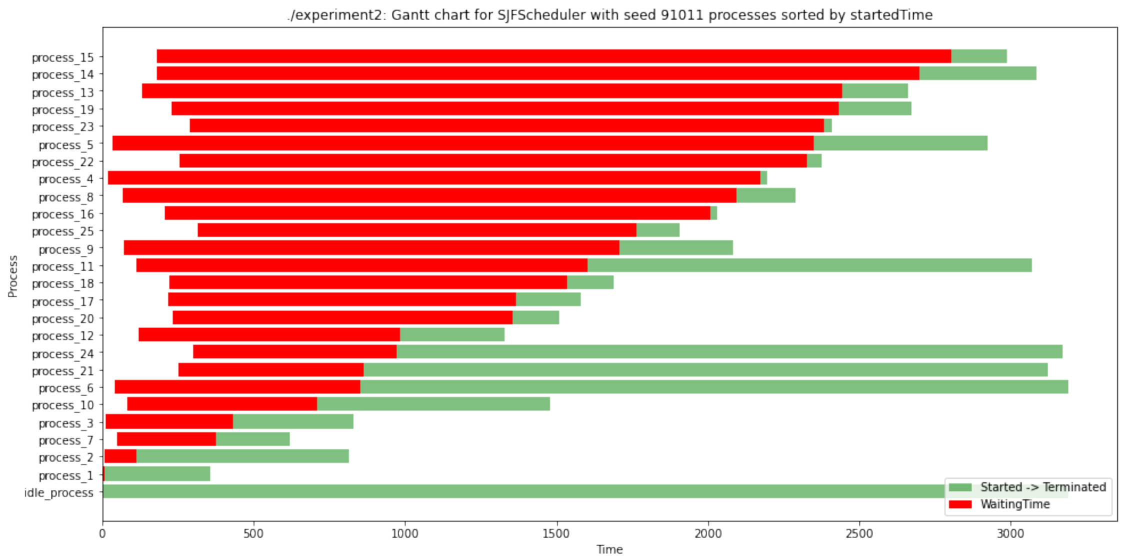

./experiment2: RRScheduler 91011 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
3500
3000
2500
2000
1500
1000
500
0
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25

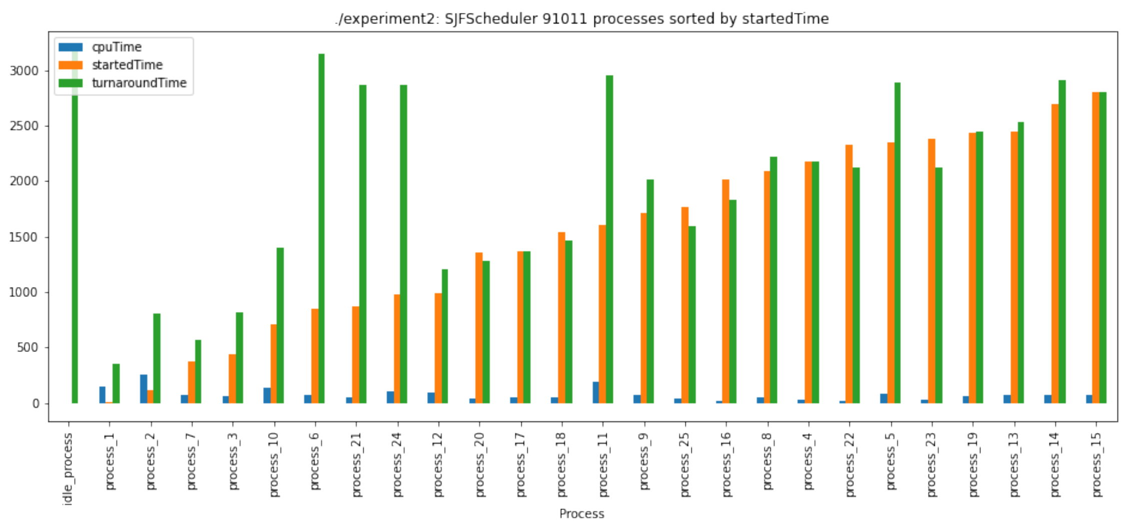

./experiment2: Gantt chart for FcfsScheduler with seed 91011 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
process_10
process_9
process_8
process_7
process_6
process_5
process_4
process_3
process_2
process_1
idle_process
0
500
1000
1500
2000
2500
3000


./experiment2: FcfsScheduler 91011 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
1000
1500
2000
2500
3000
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25


./experiment2: Gantt chart for IdealSJFScheduler with seed 91011 processes sorted by startedTime
Process
Time
Started -> Terminated
WaitingTime


./experiment2: IdealSJFScheduler 91011 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process



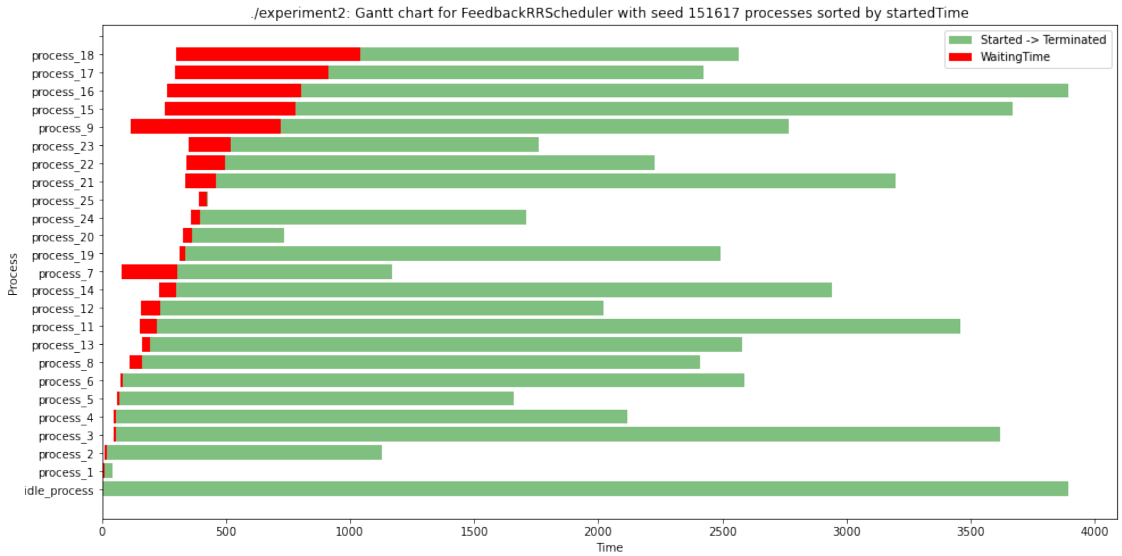


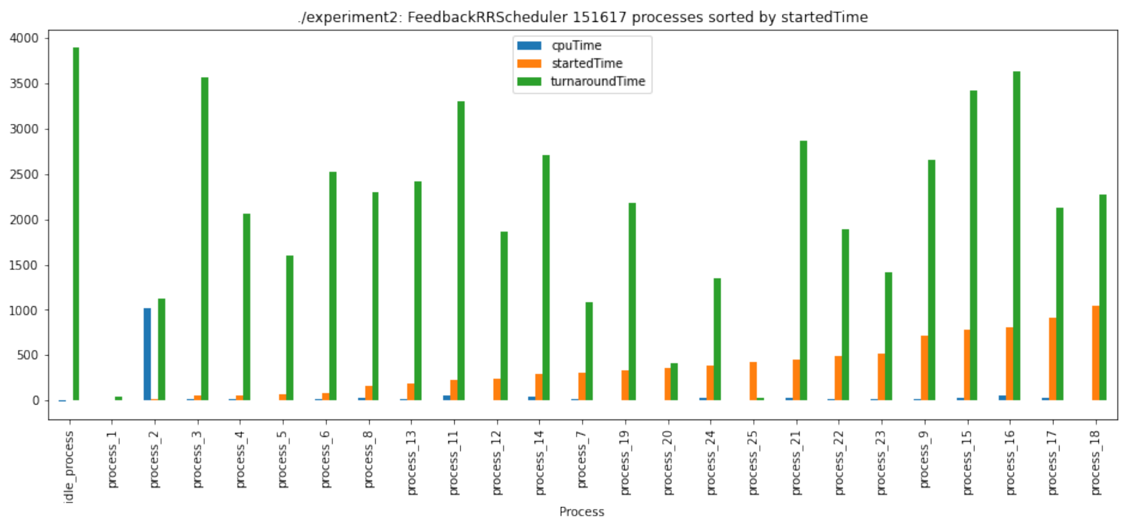
1.2.5 Results for Seed 151617

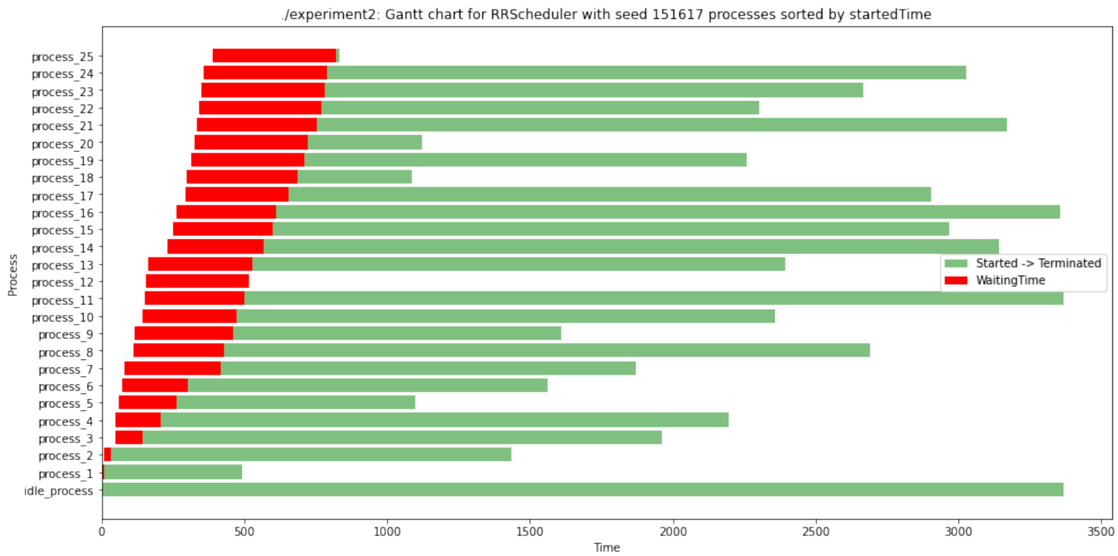
[11]:
```python
seed_to_analyse = '151617'

for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

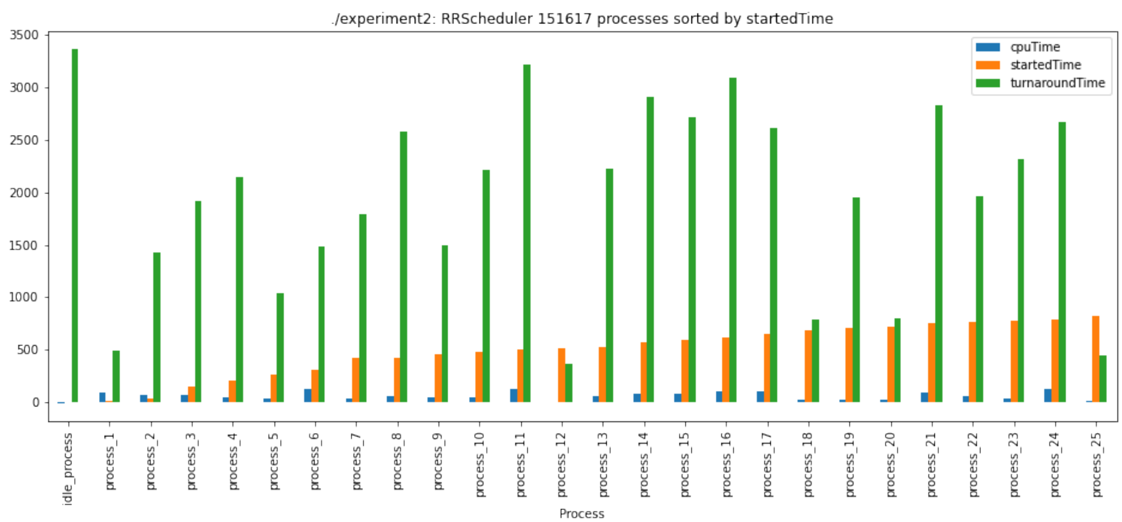
```
CPU Utilization for FeedbackRRScheduler: 98.99%
CPU Utilization for RRScheduler: 98.988%
CPU Utilization for FcfsScheduler: 98.989%
CPU Utilization for IdealSJFScheduler: 98.985%
```

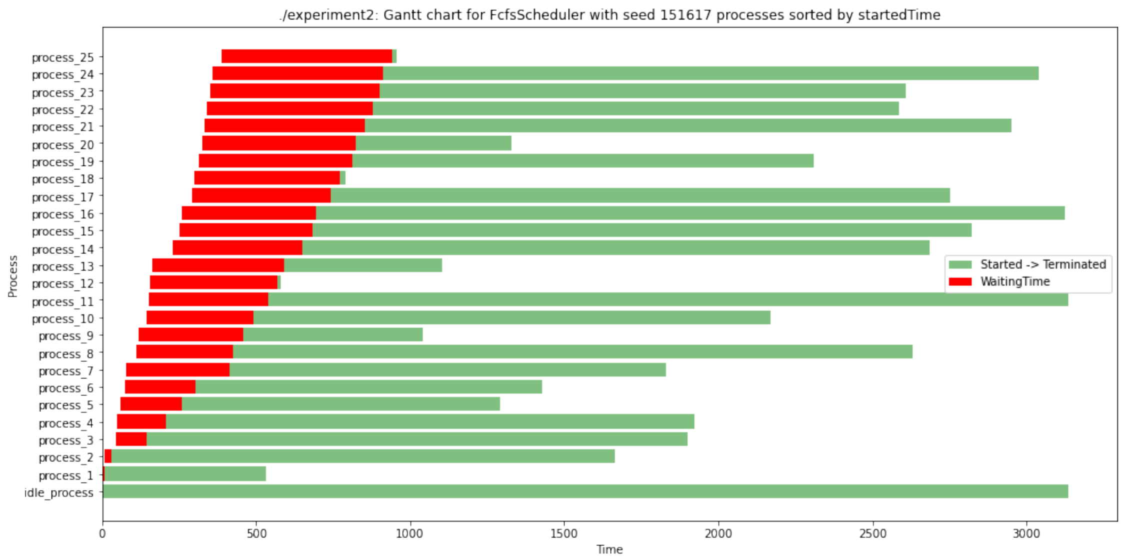
CPU Utilization for SJFScheduler: 98.997%

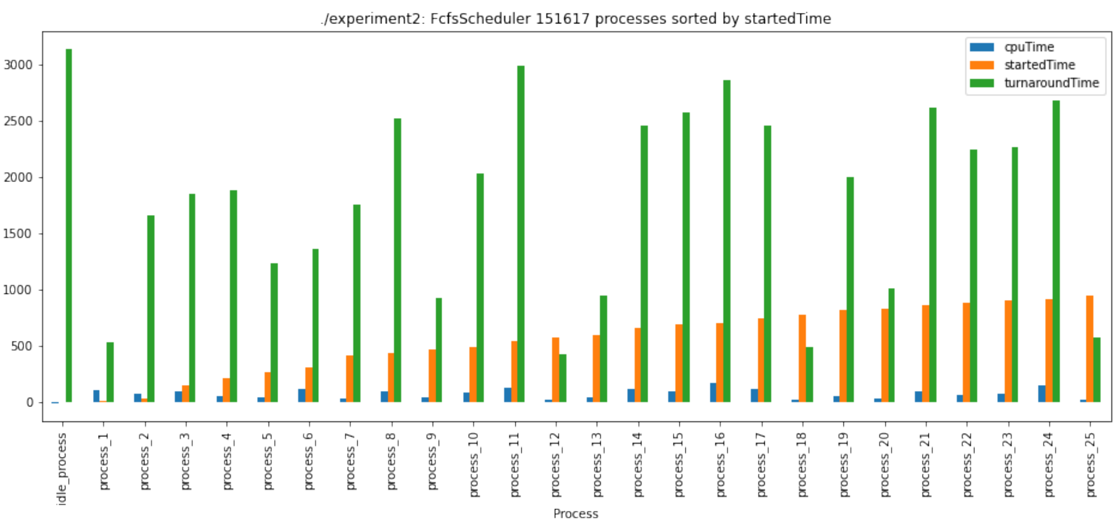


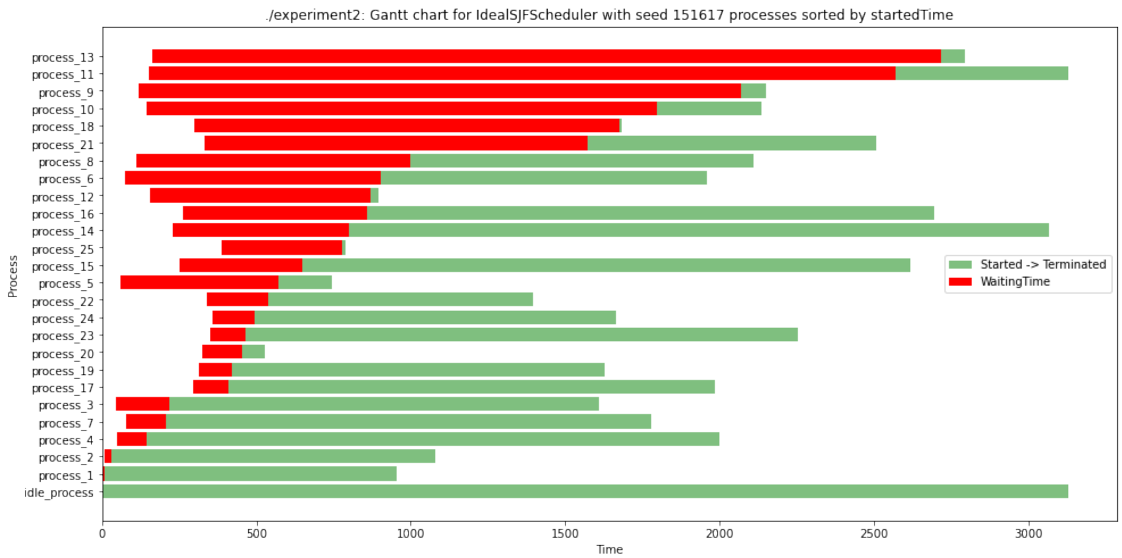


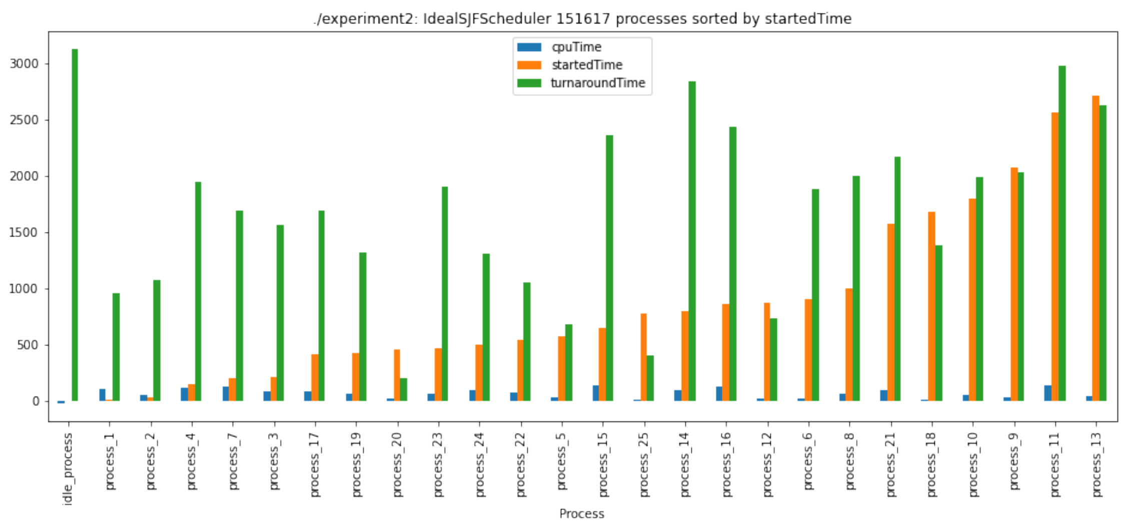

./experiment2: Gantt chart for RRScheduler with seed 151617 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25
0
500
1000
1500
2000
2500
3000
3500

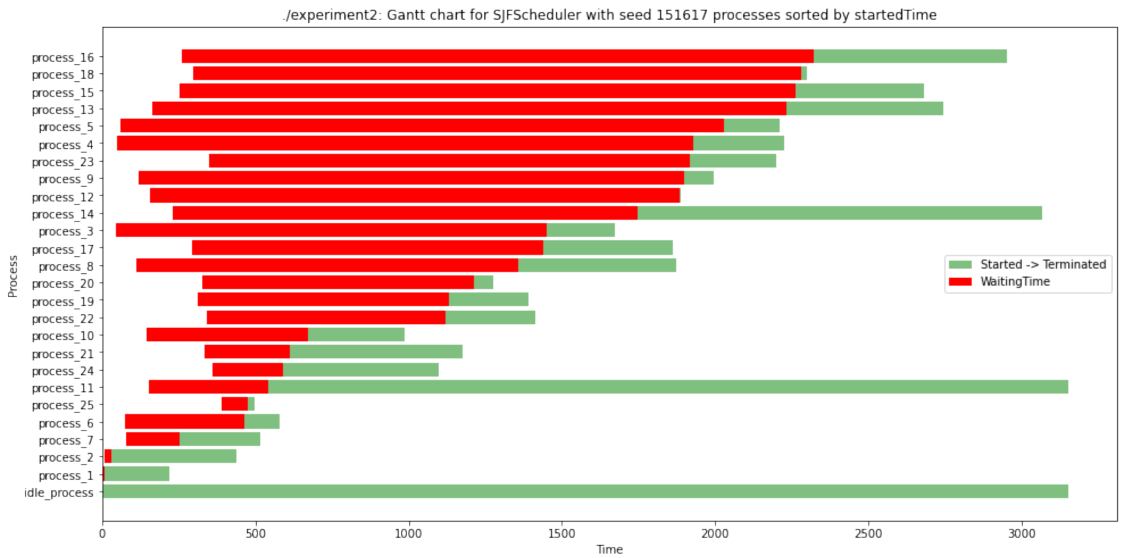

./experiment2: RRScheduler 151617 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
1000
1500
2000
2500
3000
3500
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25

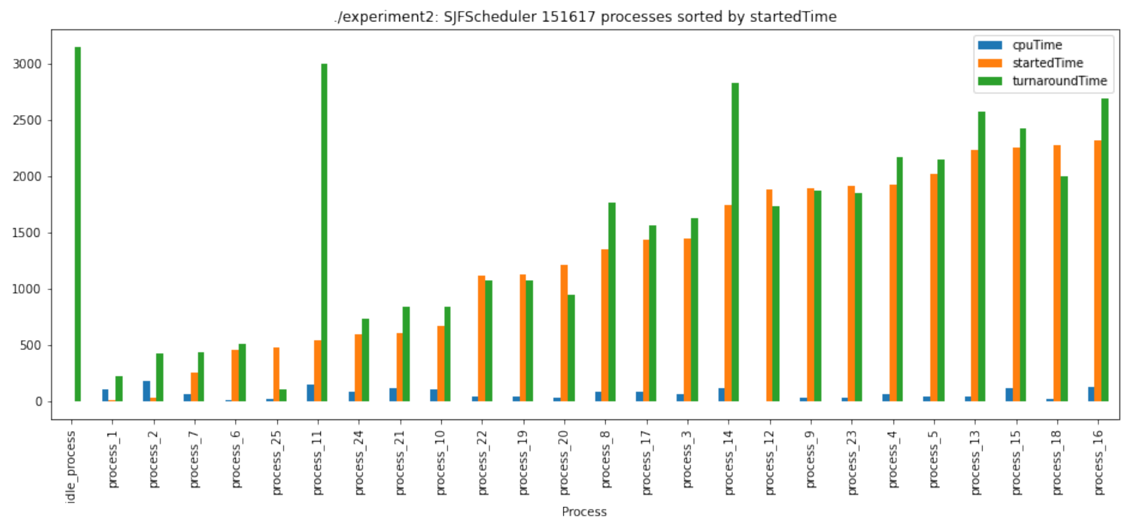

./experiment2: Gantt chart for FcfsScheduler with seed 151617 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time


./experiment2: FcfsScheduler 151617 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process


./experiment2: Gantt chart for IdealSJFScheduler with seed 151617 processes sorted by startedTime
process_13
process_11
process_9
process_10
process_18
process_21
process_8
process_6
process_12
process_16
process_14
process_25
process_15
process_5
process_22
process_24
process_23
process_20
process_19
process_17
process_3
process_7
process_4
process_2
process_1
idle_process
Process
Started -> Terminated
WaitingTime
0
500
1000
1500
2000
2500
3000
Time


./experiment2: IdealSJFScheduler 151617 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
3000
2500
2000
1500
1000
500
0
idle_process
process_1
process_2
process_4
process_7
process_3
process_17
process_19
process_20
process_23
process_24
process_22
process_5
process_15
process_25
process_14
process_16
process_12
process_6
process_8
process_21
process_18
process_10
process_9
process_11
process_13
Process



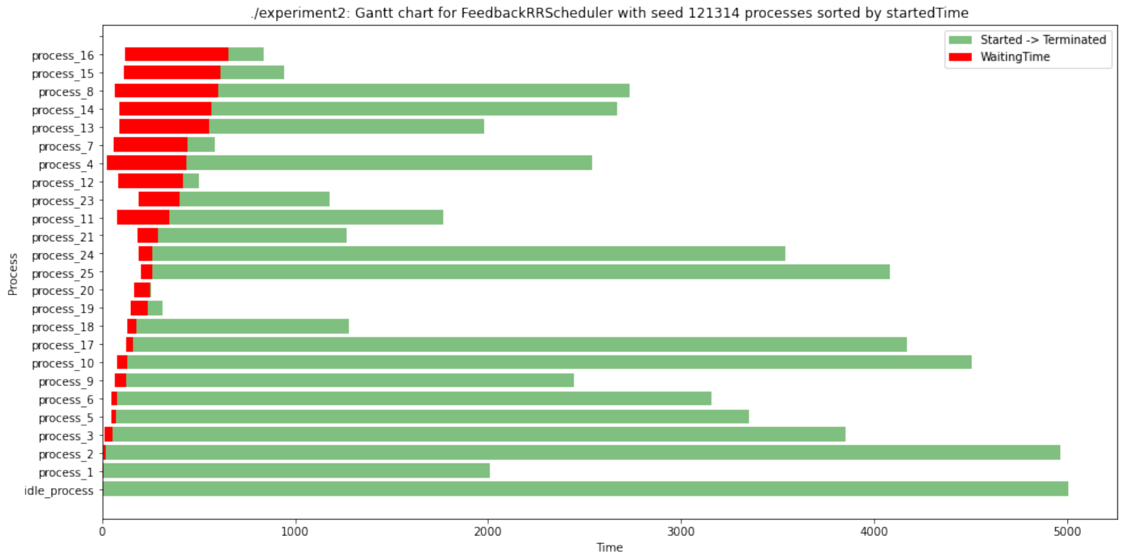


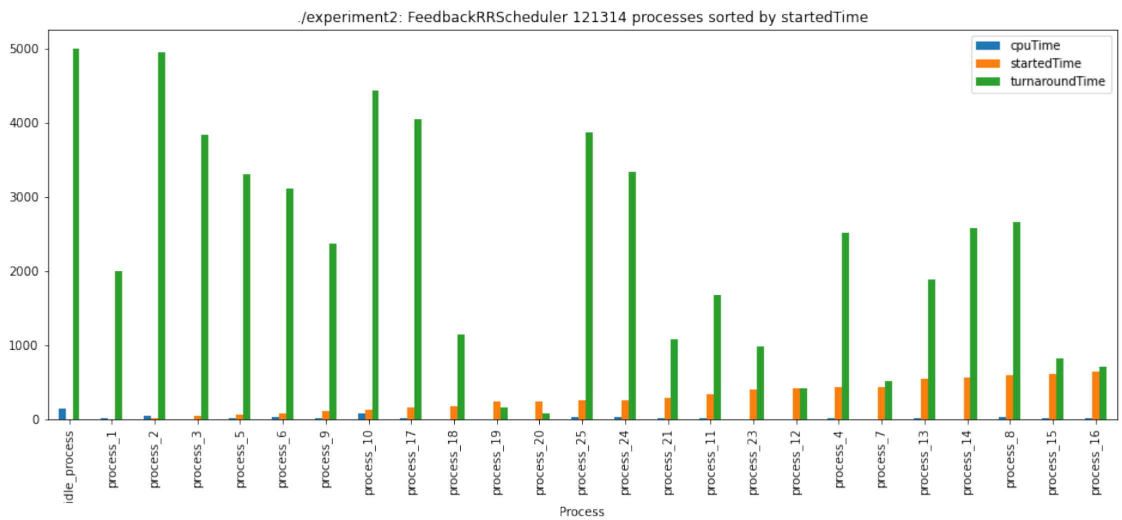
1.2.6 Results for Seed 121314

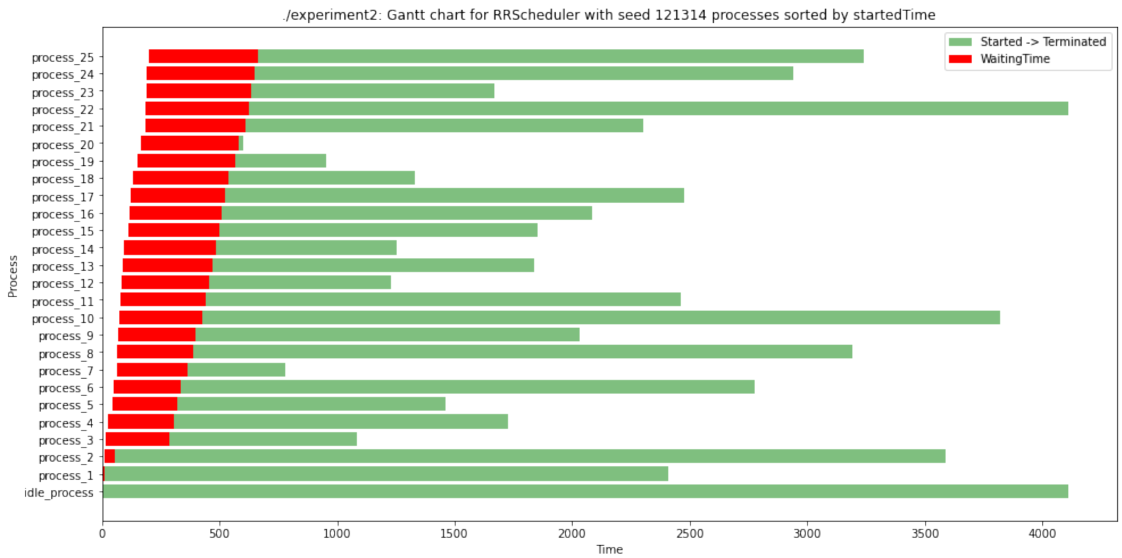
[12]:
```
seed_to_analyse = '121314'

for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

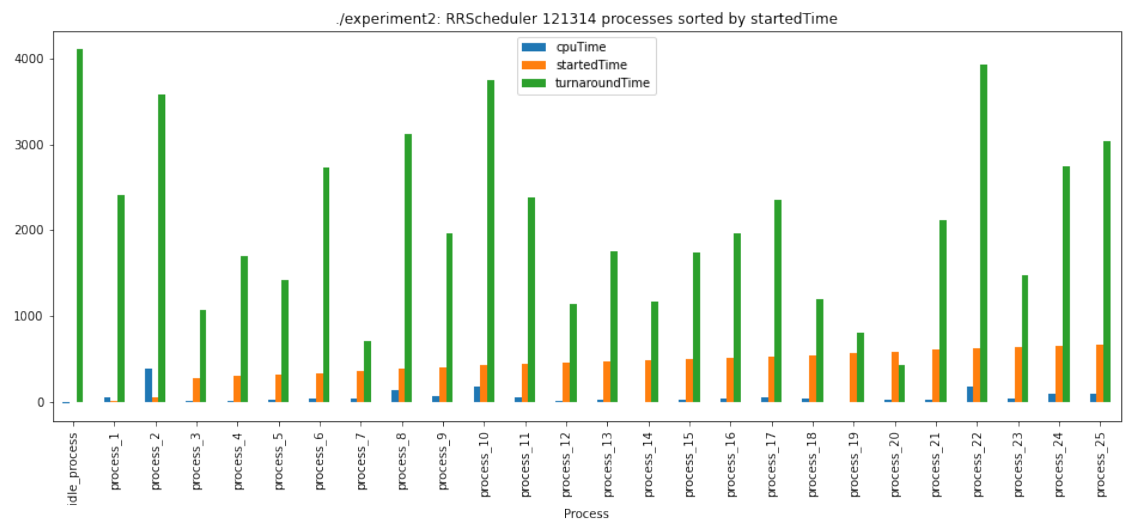
```
CPU Utilization for FeedbackRRScheduler: 99.219%
CPU Utilization for RRScheduler: 98.987%
CPU Utilization for FcfsScheduler: 98.985%
CPU Utilization for IdealSJFScheduler: 98.993%
```

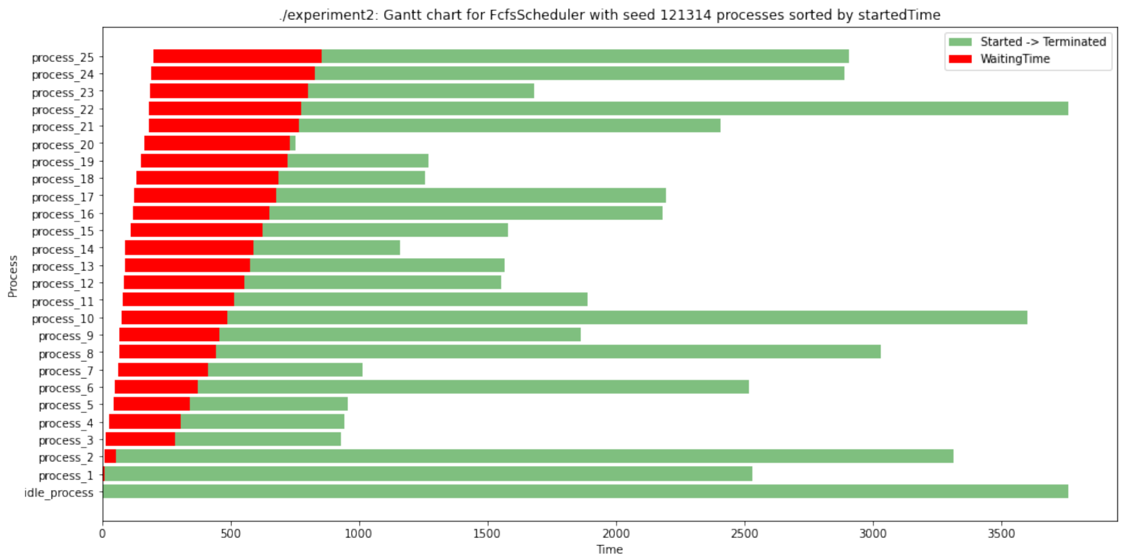
CPU Utilization for SJFScheduler: 98.999%

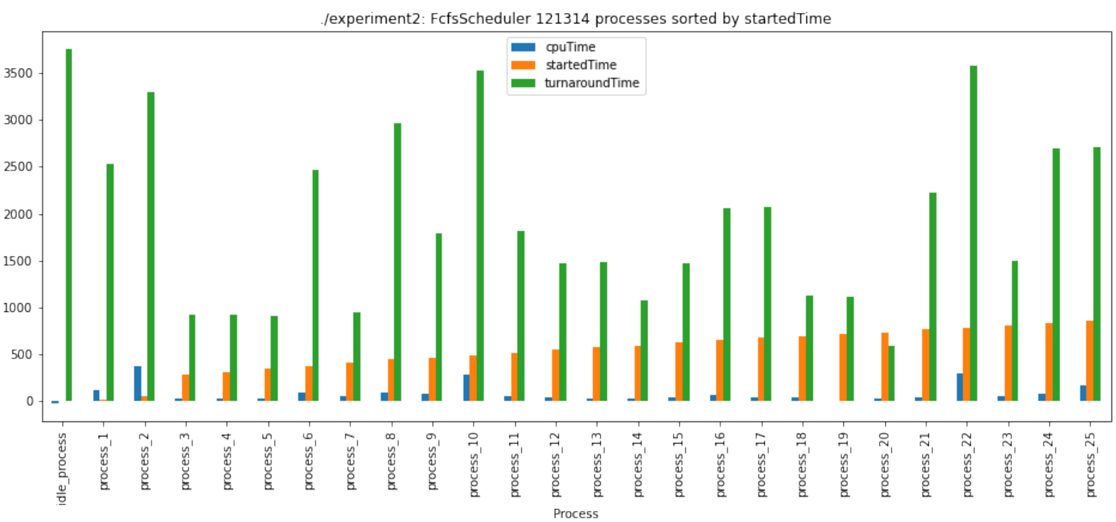


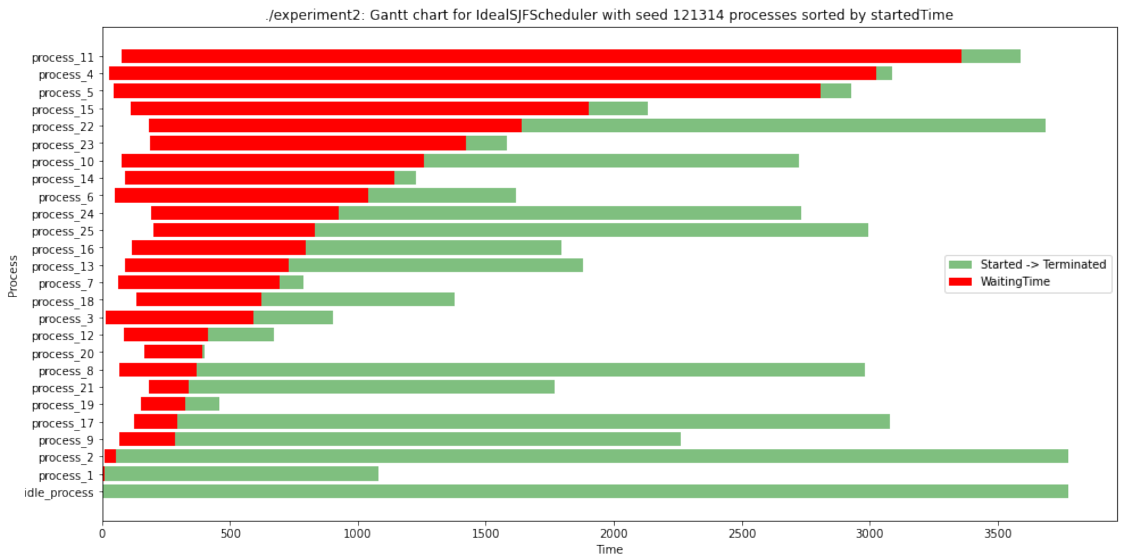


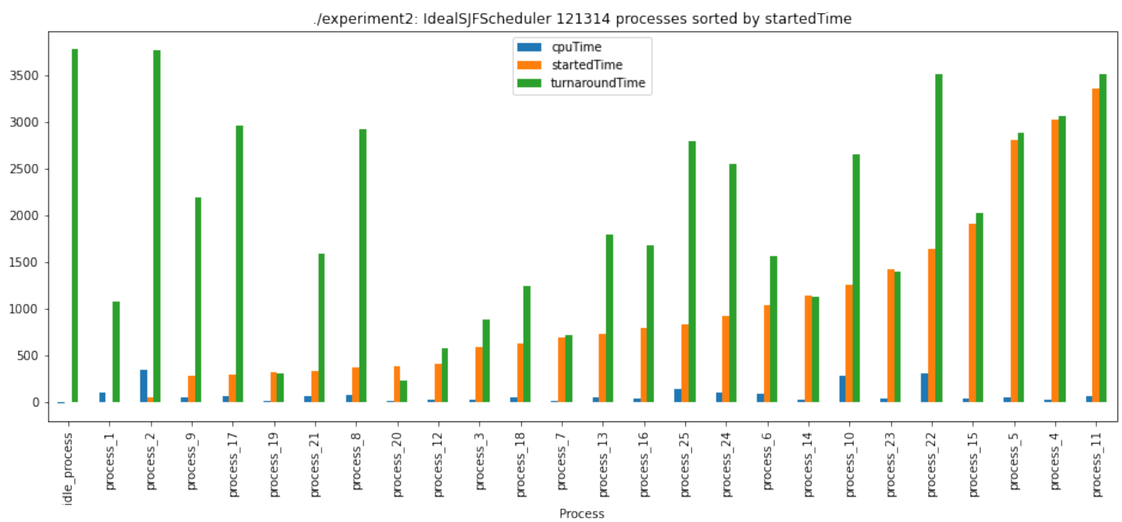

./experiment2: Gantt chart for RRScheduler with seed 121314 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
process_10
process_9
process_8
process_7
process_6
process_5
process_4
process_3
process_2
process_1
idle_process
0
500
1000
1500
2000
2500
3000
3500
4000

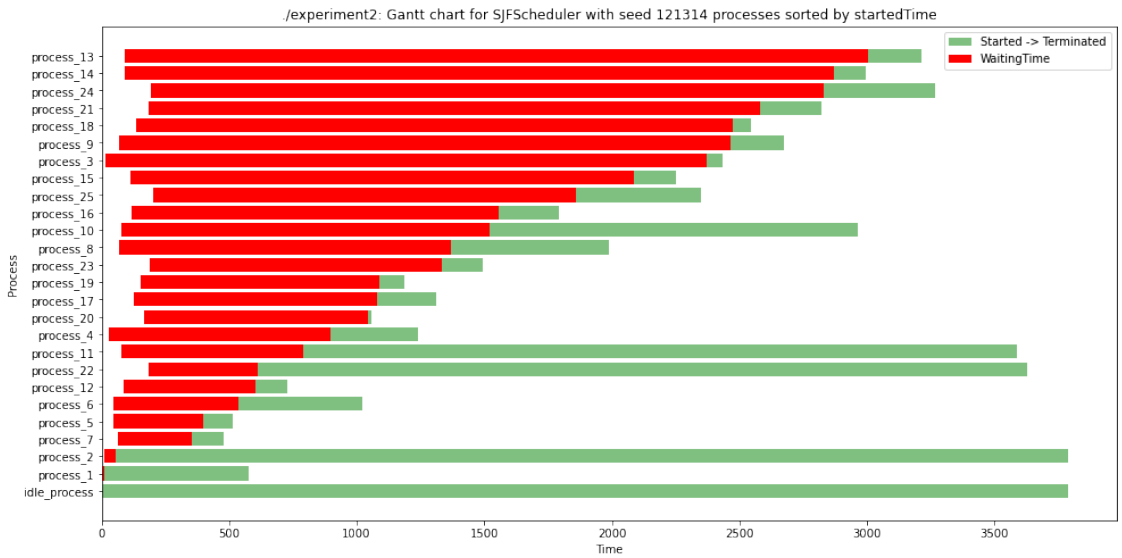

./experiment2: RRScheduler 121314 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
4000
3000
2000
1000
0
Process
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25

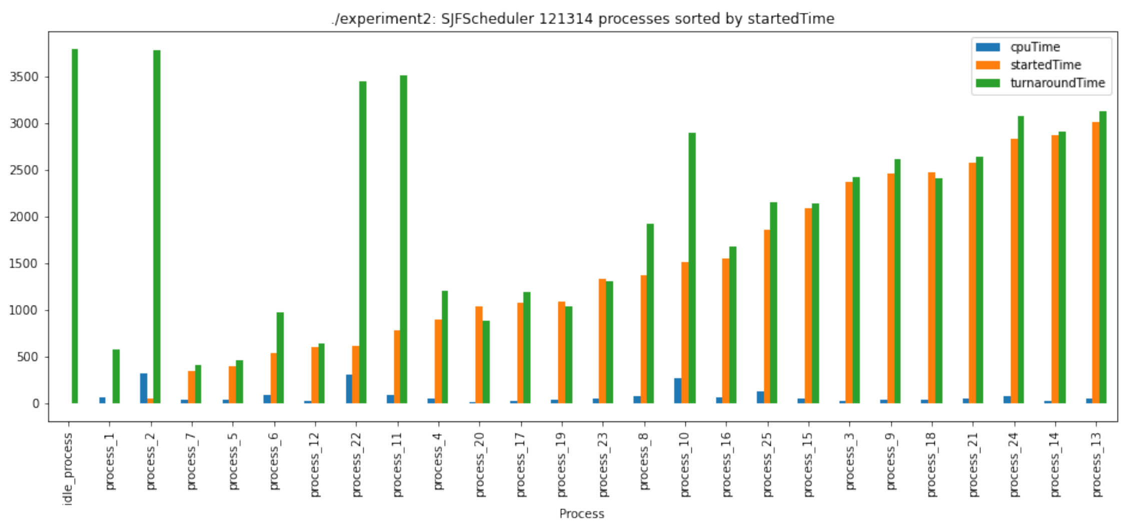

./experiment2: Gantt chart for FcfsScheduler with seed 121314 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
process_10
process_9
process_8
process_7
process_6
process_5
process_4
process_3
process_2
process_1
idle_process
0
500
1000
1500
2000
2500
3000
3500


./experiment2: FcfsScheduler 121314 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
3500
3000
2500
2000
1500
1000
500
0
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25
Process


./experiment2: Gantt chart for IdealSJFScheduler with seed 121314 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_11
process_4
process_5
process_15
process_22
process_23
process_10
process_14
process_6
process_24
process_25
process_16
process_13
process_7
process_18
process_3
process_12
process_20
process_8
process_21
process_19
process_17
process_9
process_2
process_1
idle_process
0
500
1000
1500
2000
2500
3000
3500


./experiment2: IdealSJFScheduler 121314 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
0
500
1000
1500
2000
2500
3000
3500
idle_process
process_1
process_2
process_9
process_17
process_19
process_21
process_8
process_20
process_12
process_3
process_18
process_7
process_13
process_16
process_25
process_24
process_6
process_14
process_10
process_23
process_22
process_15
process_5
process_4
process_11
Process



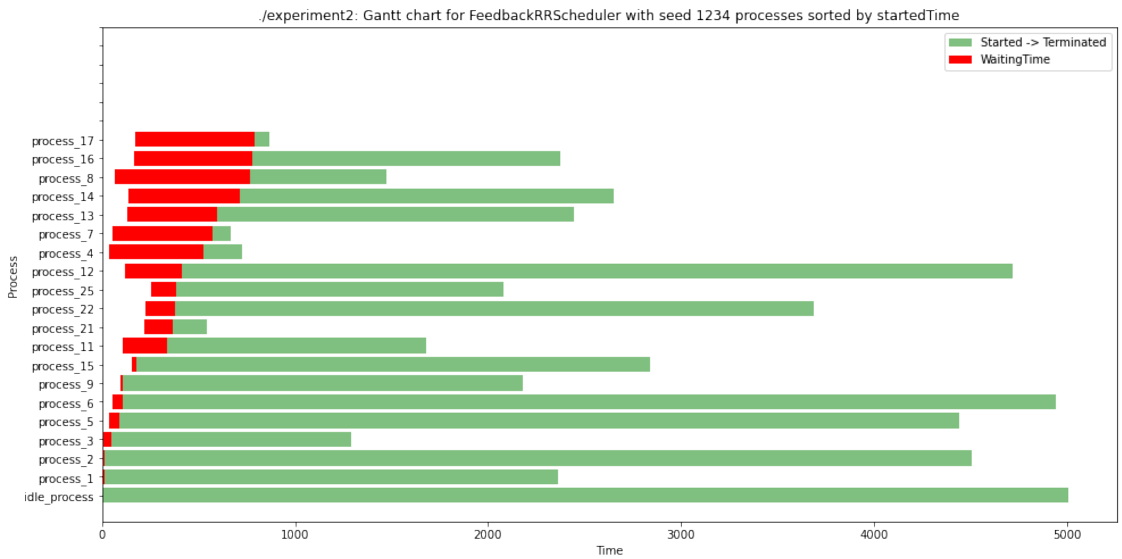


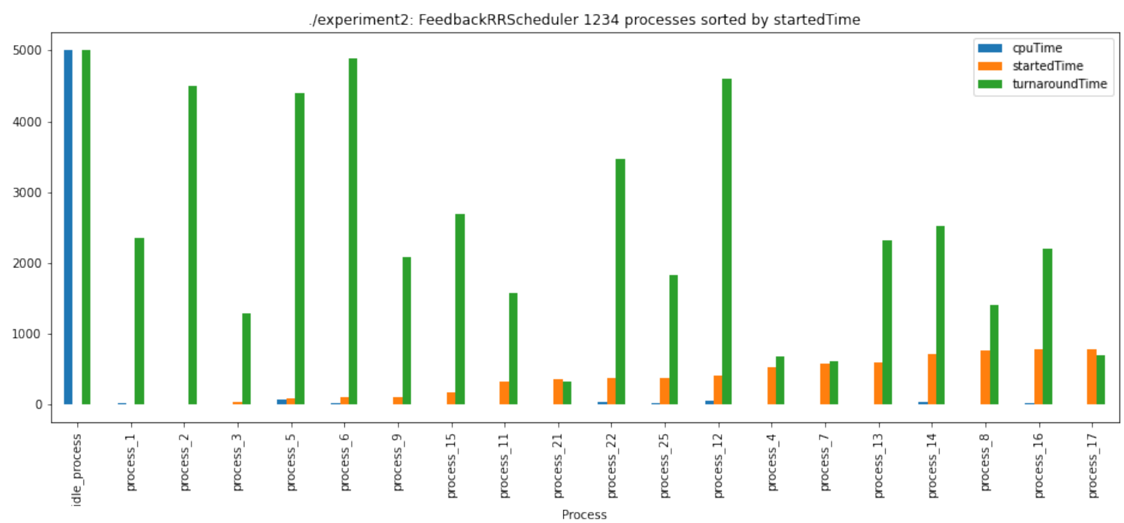
1.2.7 Results for Seed 1234

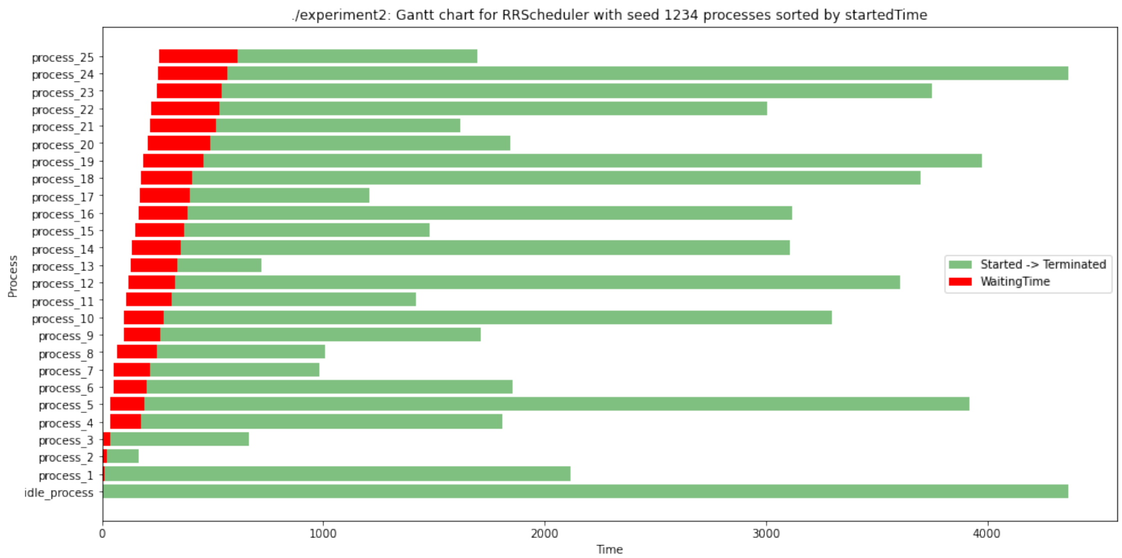
[13]:
```
seed_to_analyse = '1234'

for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

```
CPU Utilization for FeedbackRRScheduler: 99.929%
CPU Utilization for RRScheduler: 99.003%
CPU Utilization for FcfsScheduler: 98.997%
```

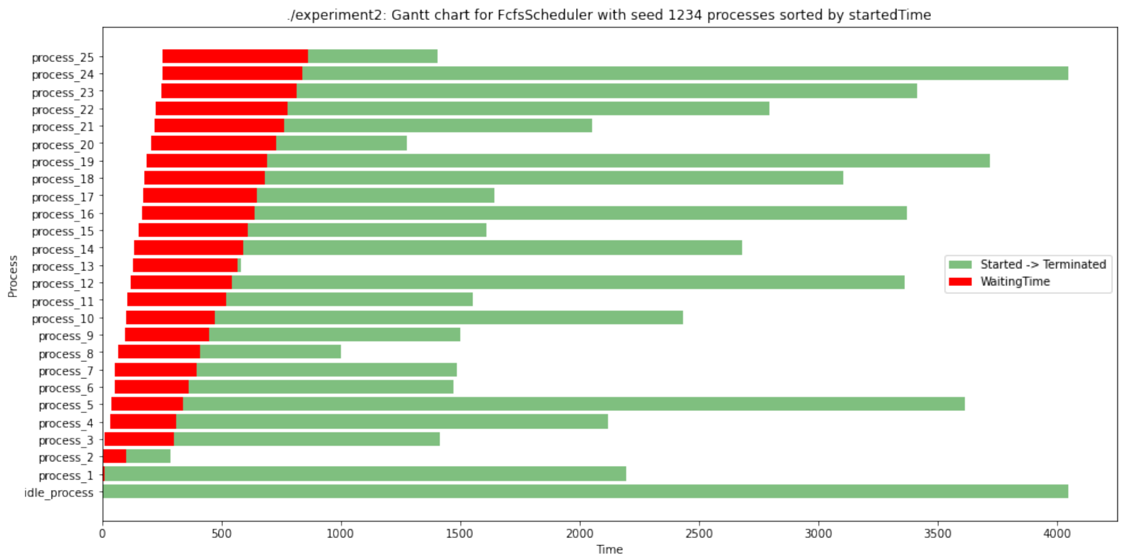
```
CPU Utilization for IdealSJFScheduler: 98.997%
CPU Utilization for SJFScheduler: 98.997%
```

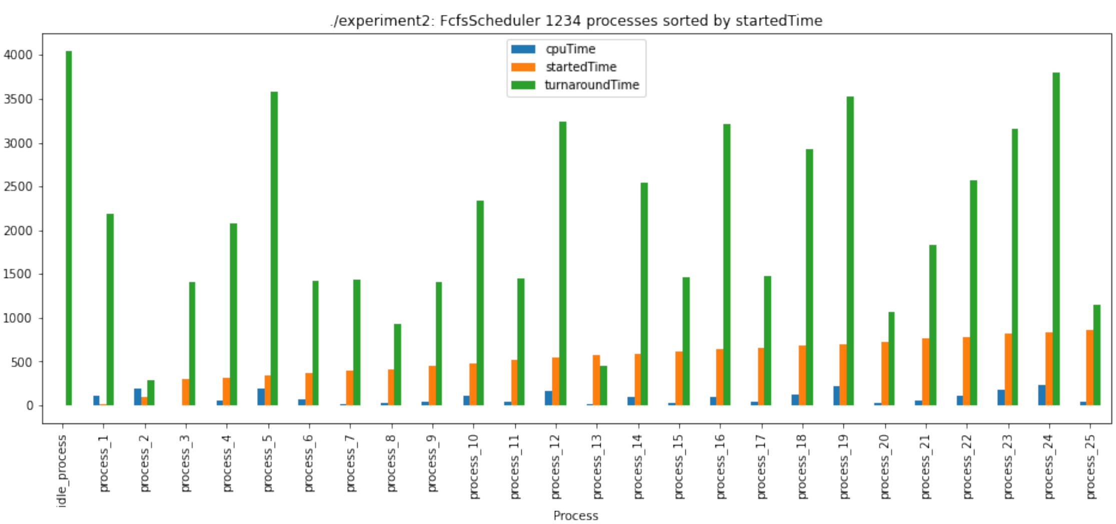


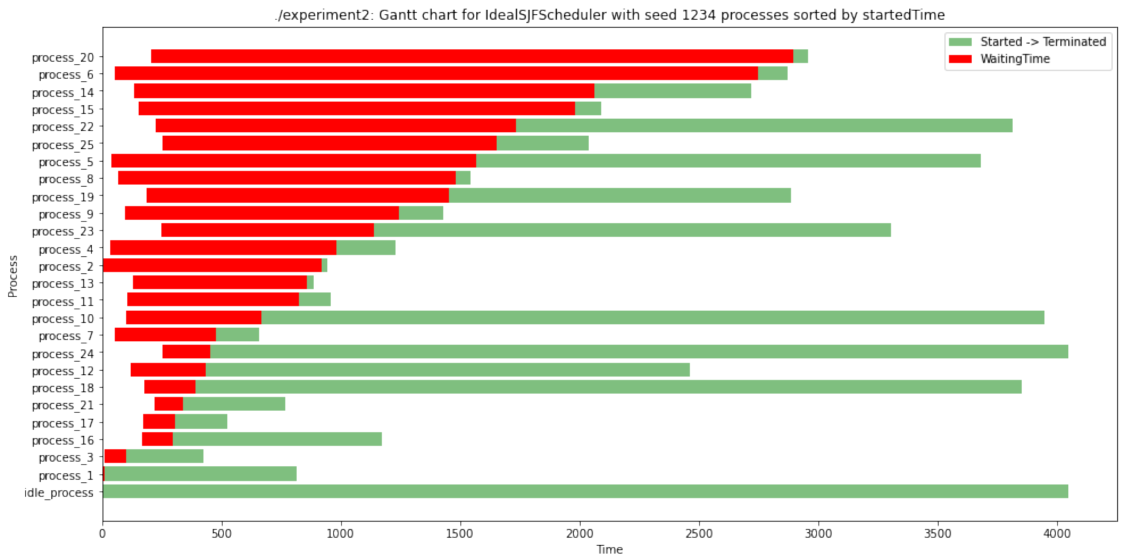


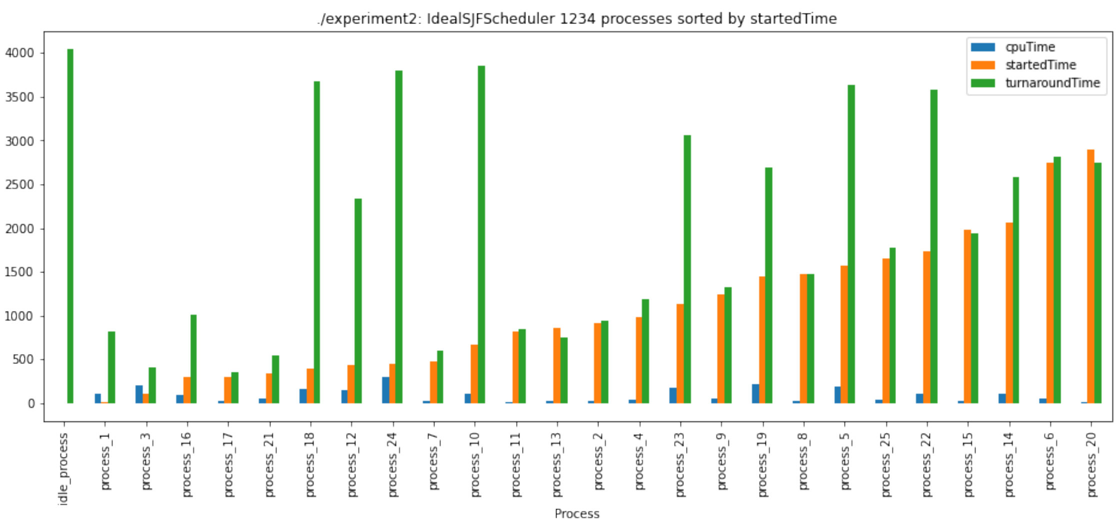

./experiment2: Gantt chart for RRScheduler with seed 1234 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
process_10
process_9
process_8
process_7
process_6
process_5
process_4
process_3
process_2
process_1
idle_process
0
1000
2000
3000
4000

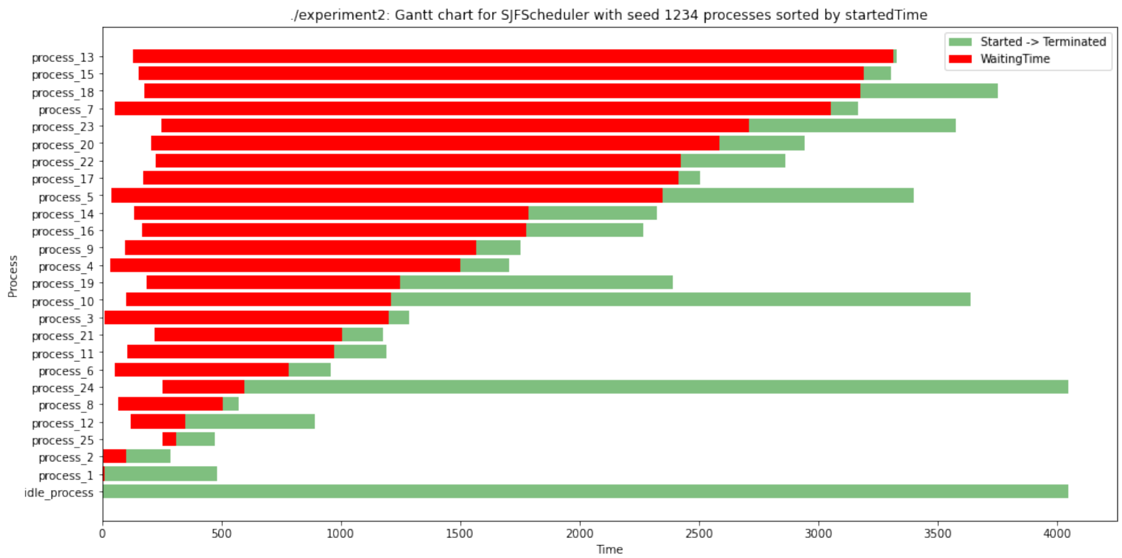

./experiment2: RRScheduler 1234 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
0
1000
2000
3000
4000
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25
Process

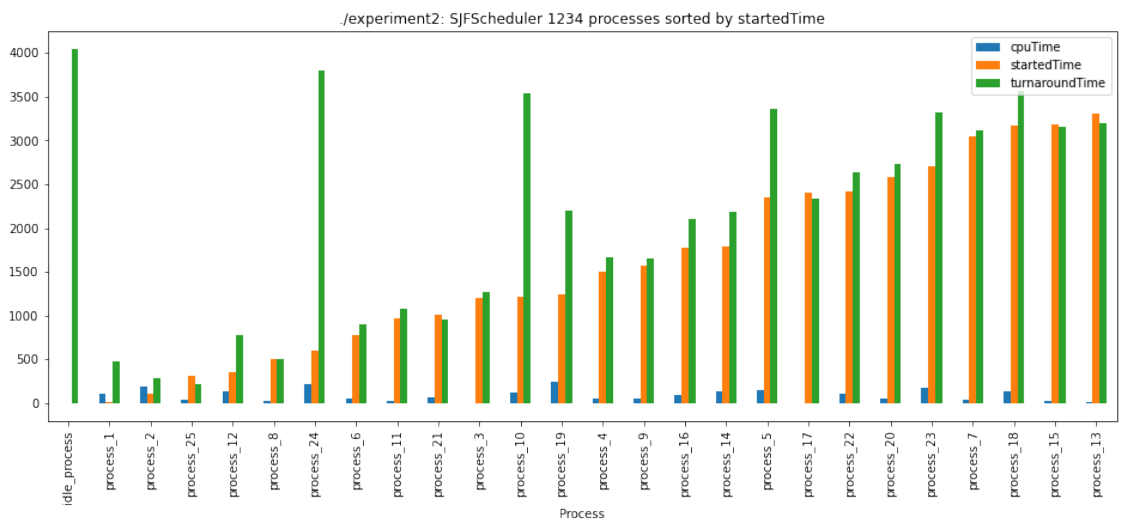

./experiment2: Gantt chart for FcfsScheduler with seed 1234 processes sorted by startedTime
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
process_10
process_9
process_8
process_7
process_6
process_5
process_4
process_3
process_2
process_1
idle_process
Process
Started -> Terminated
WaitingTime
0
500
1000
1500
2000
2500
3000
3500
4000
Time


./experiment2: FcfsScheduler 1234 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
4000
3500
3000
2500
2000
1500
1000
500
0
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25
Process


./experiment2: Gantt chart for IdealSJFScheduler with seed 1234 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_20
process_6
process_14
process_15
process_22
process_25
process_5
process_8
process_19
process_9
process_23
process_4
process_2
process_13
process_11
process_10
process_7
process_24
process_12
process_18
process_21
process_17
process_16
process_3
process_1
idle_process
0
500
1000
1500
2000
2500
3000
3500
4000


./experiment2: IdealSJFScheduler 1234 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
1000
1500
2000
2500
3000
3500
4000
idle_process
process_1
process_3
process_16
process_17
process_21
process_18
process_12
process_24
process_7
process_10
process_11
process_13
process_2
process_4
process_23
process_9
process_19
process_8
process_5
process_25
process_22
process_15
process_14
process_6
process_20





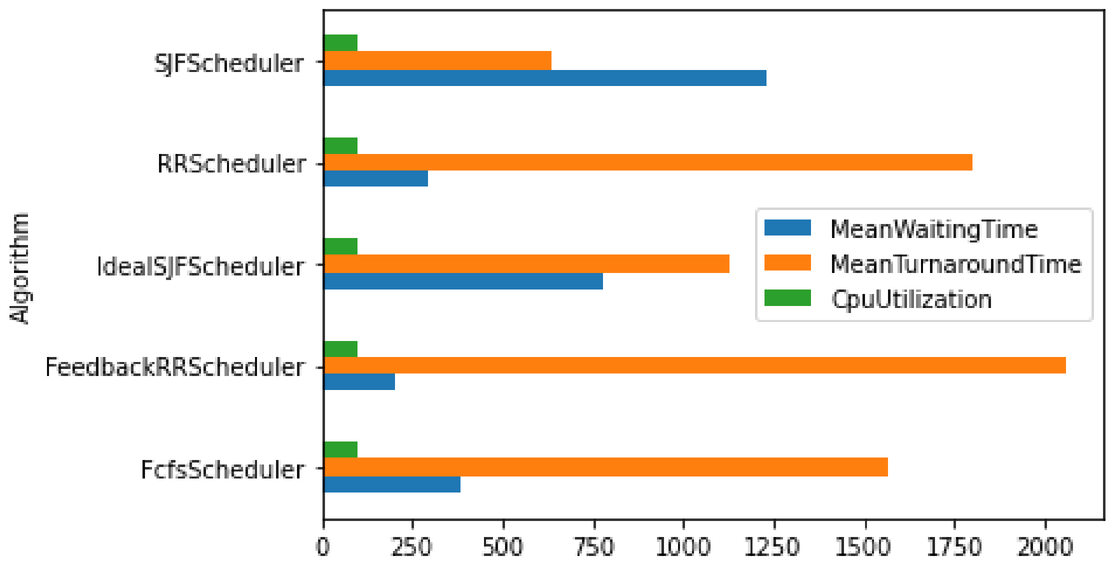
[14]:
```
means = results.groupby(['Algorithm']).mean()
means
```

[14]:

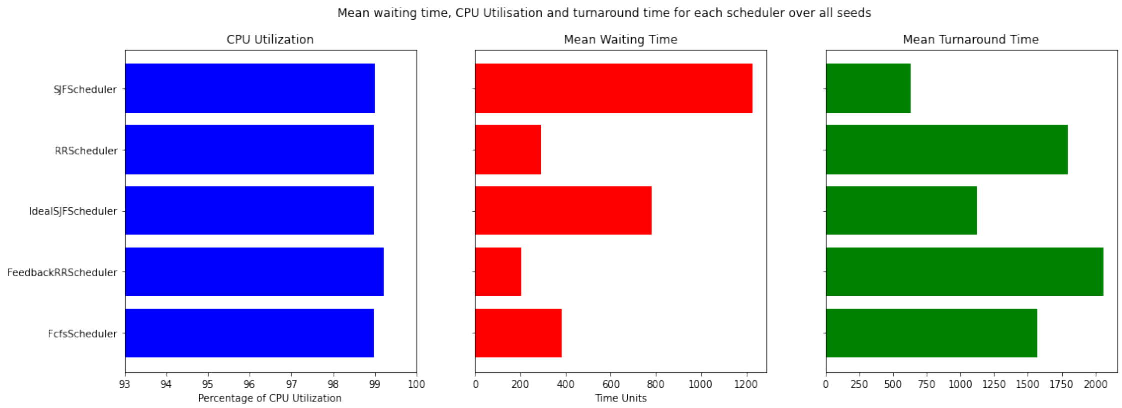
Algorithm	MeanWaitingTime	MeanTurnaroundTime	CpuUtilization
FcfsScheduler	383.853846	1569.269231	98.990222
FeedbackRRScheduler	202.940000	2059.794000	99.222625
IdealSJFScheduler	780.130769	1123.630769	98.990813
RRScheduler	291.369231	1796.838462	98.992204
SJFScheduler	1228.492308	636.292308	98.997018

[15]:
```
means.plot.barh()
```

[15]: <AxesSubplot:ylabel='Algorithm'>



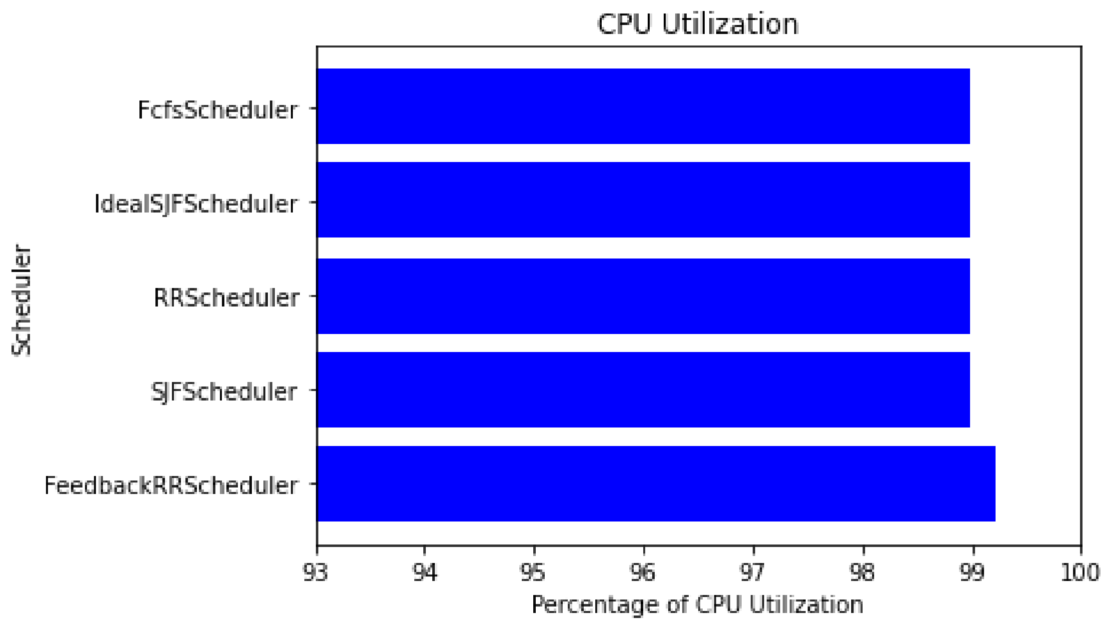
[22]:
```
fig, (ax1, ax2, ax3) = plt.subplots(1,3, sharey='all',)

fig.set_size_inches(18, 6)

fig.suptitle("Mean waiting time, CPU Utilisation and turnaround time for each␣
↪scheduler over all seeds")

ax1.set_xlabel("Percentage of CPU Utilization")
ax1.barh(means.index, means['CpuUtilization'], color='b')
ax1.set_title("CPU Utilization")
ax1.set_xbound(93, 100)

ax2.set_xlabel("Time Units")
ax2.barh(means.index, means['MeanWaitingTime'], color='r')
ax2.set_title("Mean Waiting Time")

ax3.barh(means.index, means['MeanTurnaroundTime'], color='g')
ax3.set_title("Mean Turnaround Time")
ax2.set_xlabel("Time Units")

plt.show()
```



The results above outline the Mean CPU Utilization, Mean Waiting Time and Mean Turnaround Time for each scheduling algorithm over all seeds. As we saw in the previous experiment, the Mean Waiting Time for the Feedback Round Robin (FRR) algorithm is the lowest.

1.2.8 Comparing CPU Utilization

[21]:
```
utilisation = pd.DataFrame(means.CpuUtilization).sort_values('CpuUtilization',␣
↪ascending=False)

plt.barh(utilisation.index, utilisation['CpuUtilization'], color='b')
plt.title("CPU Utilization")
plt.xlabel("Percentage of CPU Utilization")
plt.ylabel("Scheduler")

plt.xlim(93, 100)

plt.show()
```



Above we can see that CPU Utilization for each of the different algorithms is very similar, with FRR having the highest CPU utilization but only slightly higher than the other algorithms. We can see in better detail below how the CPU Utilization of each of the algorithms compares from the table below.

[18]:
```
utilisation
```

[18]:

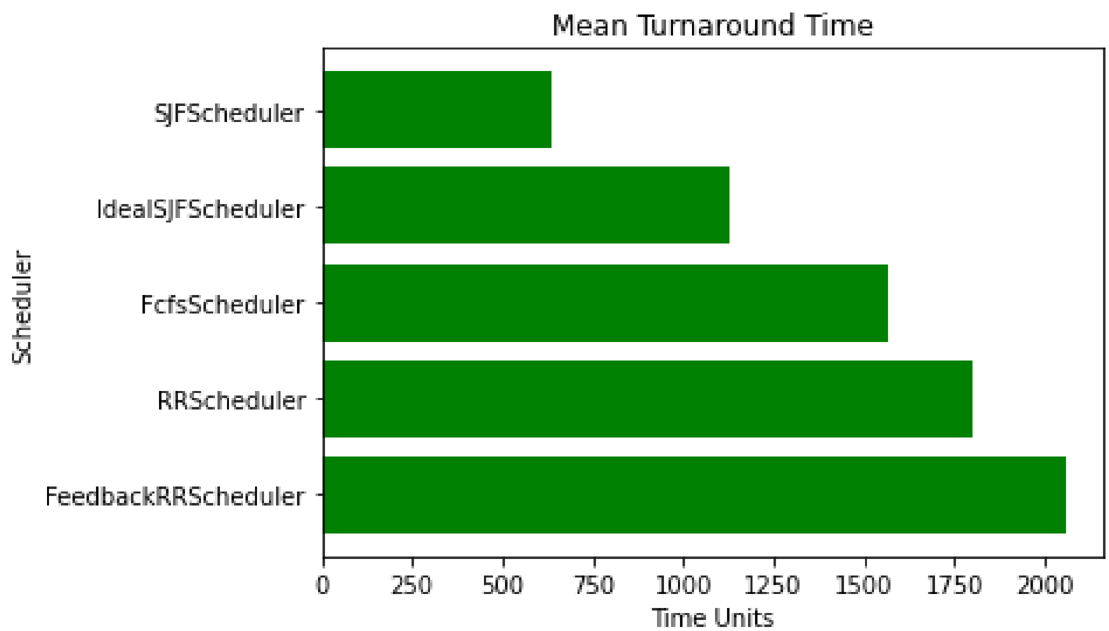
Algorithm	CpuUtilization
FeedbackRRScheduler	99.222625
SJFScheduler	98.997018
RRScheduler	98.992204
IdealSJFScheduler	98.990813
FcfsScheduler	98.990222

Looking at the above table, the FRR algorithm has the best average CPU utilization over all the seeds leading by about `0.223%` compared to the Shortest Job First Algorithm. Comparing the utilisation of the other algorithms, we can see that this is by far the largest margin between two consecutive algorithms. With each of the other algorithms only differing by less than `0.01%`. This leads us to the conclusion that the Multilevel Feedback Queue is a substantial improvement over the other algorithms when it comes to maximizing CPU utilization.

1.2.9 Comparing Average Turnaround Time

[20]:
```
turnaround = pd.DataFrame(means.MeanTurnaroundTime).
 ↪sort_values('MeanTurnaroundTime', ascending=False)

plt.barh(turnaround.index, turnaround['MeanTurnaroundTime'], color='g')
plt.title("Mean Turnaround Time")
plt.xlabel("Time Units")
plt.ylabel("Scheduler")

plt.show()
```

[20]: Text(0, 0.5, 'Scheduler')



The above table shows us that the average turnaround time for Shortest Job First is by far the best. Whilst the Round Robin Scheduler and Feedback Round Robin Scheduler have the worst average turnaround time, this is due to the fact that the Shortest Job First algorithm is using a time quantum to ensure that the processes are forced to context switch even if they have not yet terminated. This means that in Round Robin algorithms, the processes will not be able to run for the entire time quantum, and the processes will have to be forced to context switch. This is why turnaround time is the worst for the Round Robin Scheduler and the Feedback Round Robin Scheduler.

The ordering of the mean turnaround times for Shortest Job First and Ideal Shortest Job First is interesting, since the ideal shortest job first algorithm should perform better than the estimating Shortest Burst Algorithm due to the Ideal algorithm having knowledge about future bursts. However, the reason Ideal Shortest Job First Scheduler performs worse than the Shortest Job First

Algorithm is because the Ideal Shortest Job First Algorithm is preemptive and allows for context switches whilst a process is in the middle of a burst, whilst the Shortest Job First Algorithm is non-preemptive and does not allow for context switches while a process is in the middle of a burst, this means Ideal SJFS is more likely to be able to complete a burst before the Shortest SJF completes a burst and therefore has a lower average turnaround time.

1.2.10 Conclusion

As was noted above, the Feedback RR Scheduler has the best average CPU utilisation over the 5 seeds, however this is followed by the Shortest Job First algorithm.

The Shortest Job First algorithm has the best average turnaround time over the 5 seeds whilst the Feedback RR Scheduler has the worst average turnaround time. This leads us to the conclusion that if the goal is to maximize CPU utilization whilst also minimising average turnaround time, the non-preemptive Shortest Job First algorithm is the most effective.

[ ]:
```

```