report

May 3, 2022

1 Operating Systems Report - 231006

1.0.1 Setting Up the Experiments

All of the experiments can be run using the `run.sh` bash script.

```bash
bash run.sh > run.log
```

This creates a new directory for each experiment named `experiment<number>`, this directory contains three subdirectories: * `inputs` - contains the input data (`input_data_<seed>`) and parameters (`input_params_<seed>`) for the experiment * `schedulers` - contains the output files from the experiment from each scheduler under `scheduler/<scheduler>` * `sim_params` - contains the output files from the experiment from each scheduler under `sim_params/<scheduler>_sim_params.prp`

In the following experiments, I make use of the `Experiment` class I created, defined in `experiment.py`.

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

2.1 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 preemptive 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.

2.2 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.

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

exp = Experiment('./experiment1')

print(f"Seeds Used for Experiment 1: {exp.all_seeds()} ")

exp.input_params[1][1]
```

```
Seeds Used for Experiment 1: ['100', '50', '200', '531', '120']
```

[ ]:

param	value
numberOfProcesses	50
staticPriority	0
meanInterArrival	12
meanCpuBurst	10
meanIoBurst	10
meanNumberBursts	6
seed	50

[ ]:
```
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)
```

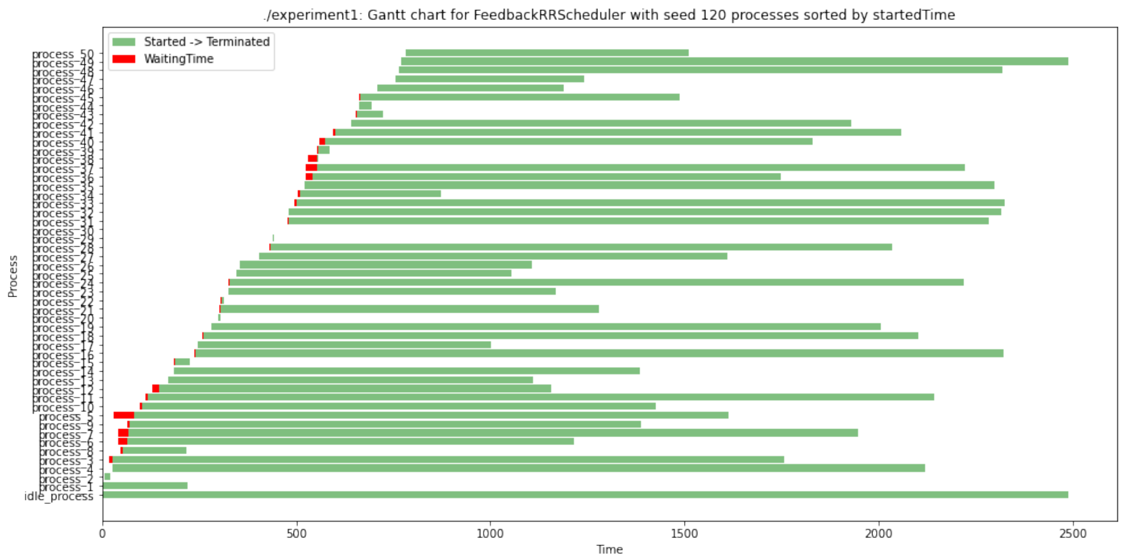
[ ]:

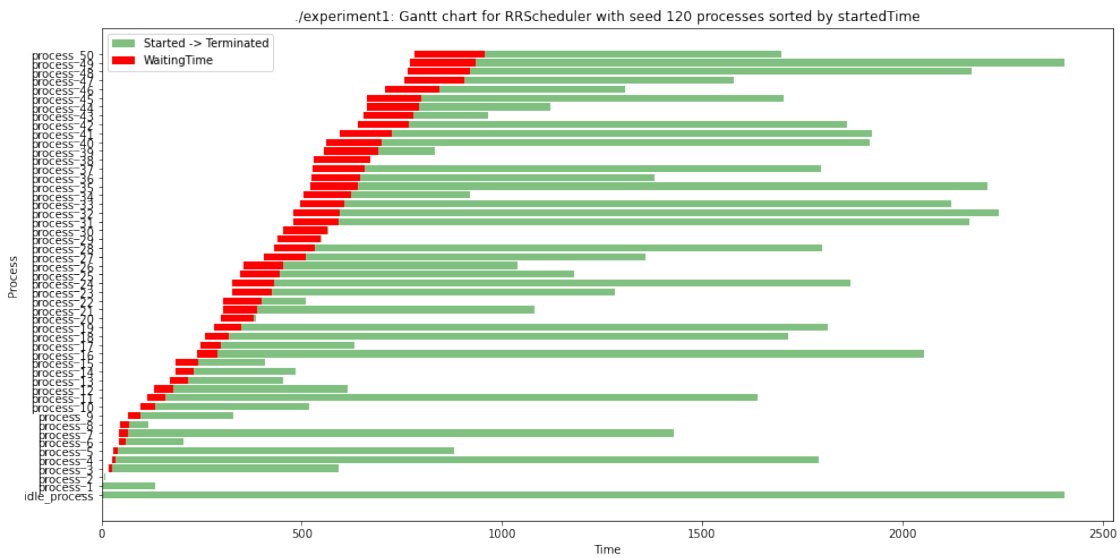
param	value
timeLimit	10000
interruptTime	1
timeQuantum	5
initialBurstEstimate	5
alphaBurstEstimate	0.5
periodic	false

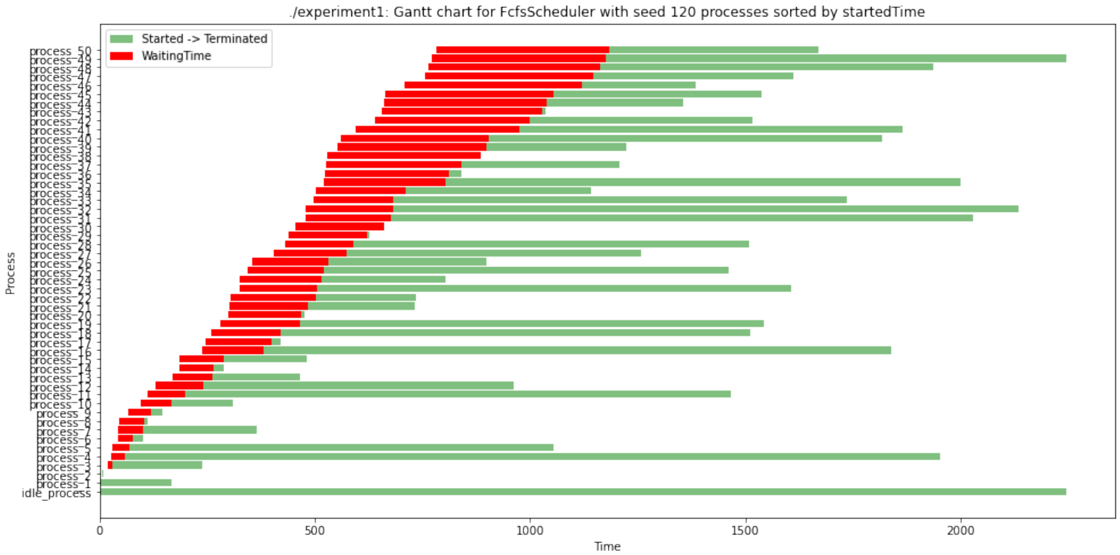
As can be seen above, we use an interrupt time of `1 unit` and a time quantum of `5 units`. I chose these values so ensure that the processes that use RoundRobin (RR) and Feedback Round Robin (FRR) are forced to make a context switch so that they cannot always run for the entire time quantum. I chose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

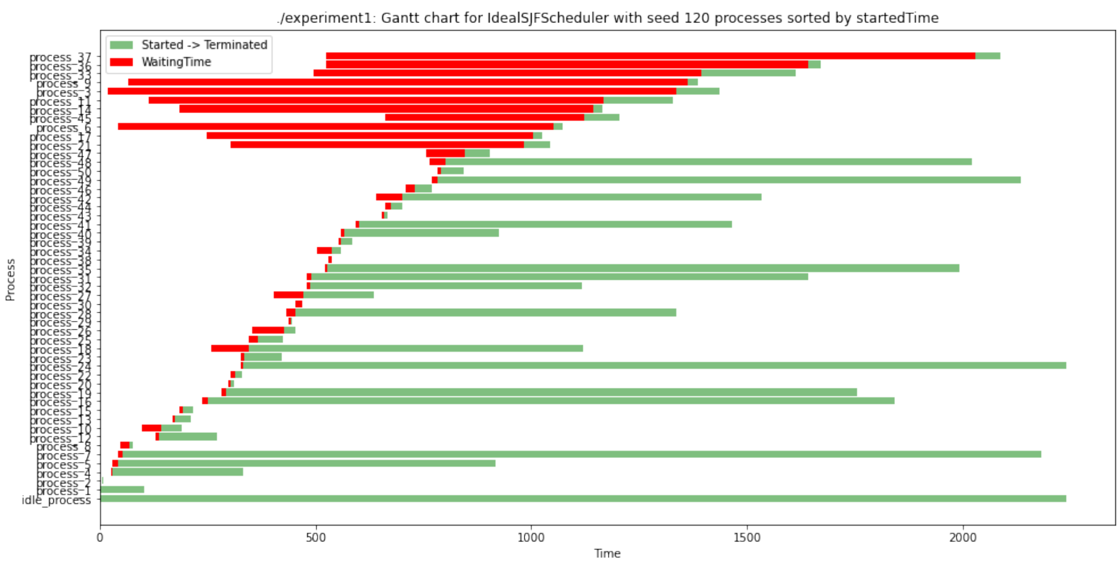
2.3 Results

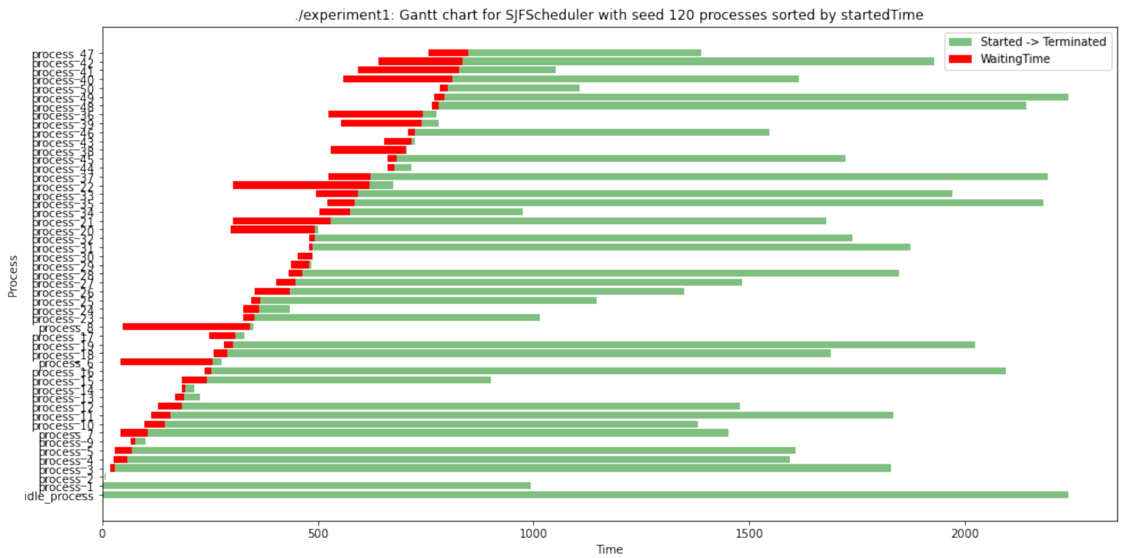
```
[ ]: ## Plotting and Comparing Gantt Charts for Different Schedulers
exp.plot_gantt('FeedbackRRScheduler', '120')
exp.plot_gantt('RRScheduler', '120')
exp.plot_gantt('FcfsScheduler', '120')
exp.plot_gantt('IdealSJFScheduler', '120')
exp.plot_gantt('SJFScheduler', '120')
```






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


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



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.

[ ]:
```
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
```

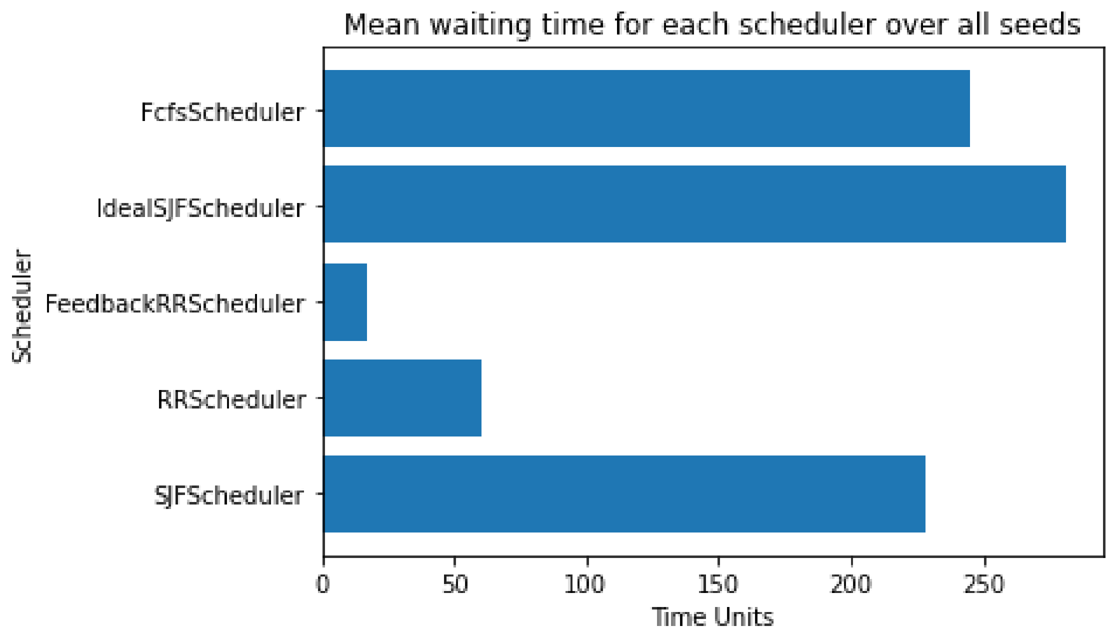
[ ]:

	MeanWaitingTime
SJFScheduler	228.266667
RRScheduler	60.166667
FeedbackRRScheduler	17.062745
IdealSJFScheduler	281.54902
FcfsScheduler	244.913725

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

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

[ ]: 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 is extremely long compared to other algorithms, this is likely down to the emerging of the convoy effect, where smaller processes are forced to wait for larger processes to finish. In addition, the Shortest Job First Algorithm is performing poorly likely as a result of starvation, since longer bursts are run last, these bursts may effect the waiting time if they arrive at similar times to many smaller processes, this effect can be seen in the Gantt charts above.

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

3.1 Introduction

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

[ ]:
```
exp = Experiment('./experiment2')
print(f"Seeds Used for Experiment 2: {exp.all_seeds()} ")
```

```
Seeds Used for Experiment 2: ['1234', '5678', '91011', '151617', '121314']
```

3.2 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`.

3.3 Results

[ ]:
```
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:
```

[ ]:

	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)`

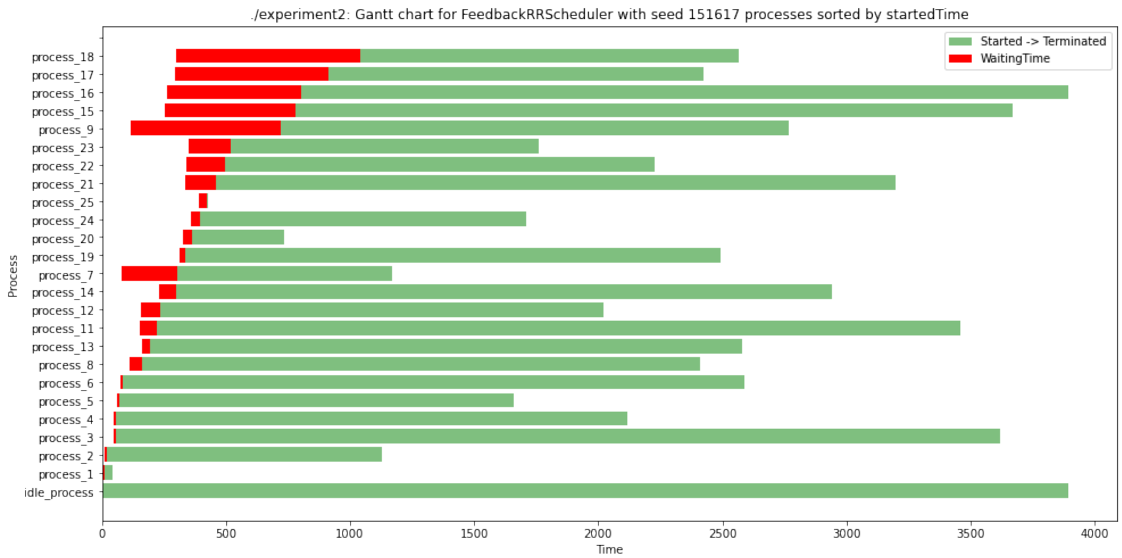
```
[ ]: def new_results():
             return pd.DataFrame(columns=["Seed", "Scheduler", "MeanWaitingTime",␣
      ↪"MeanTurnaroundTime","MeanResponseTime", "CpuUtilization"])

     results = new_results()
```

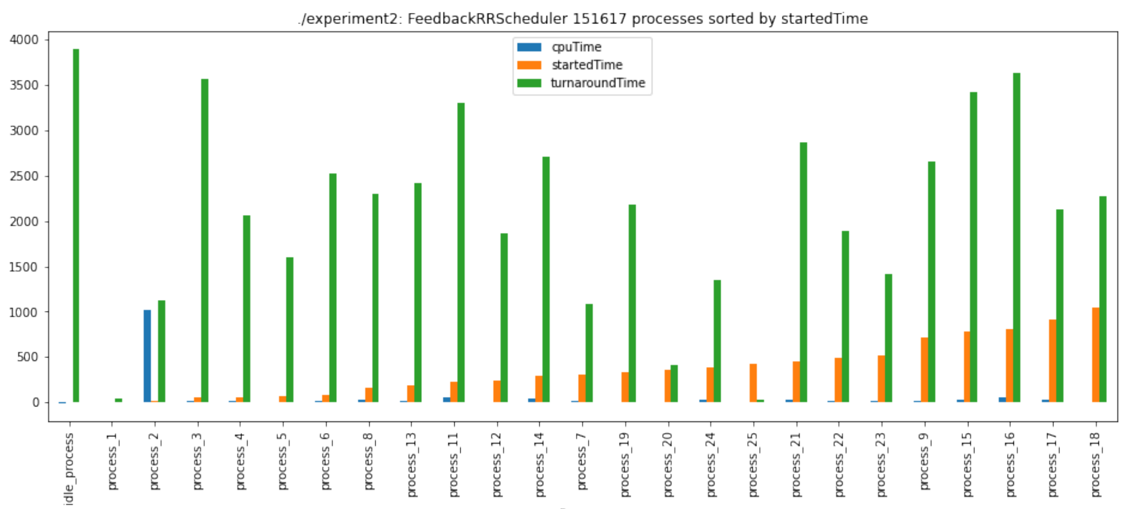
3.3.1 Results for Seed 151617

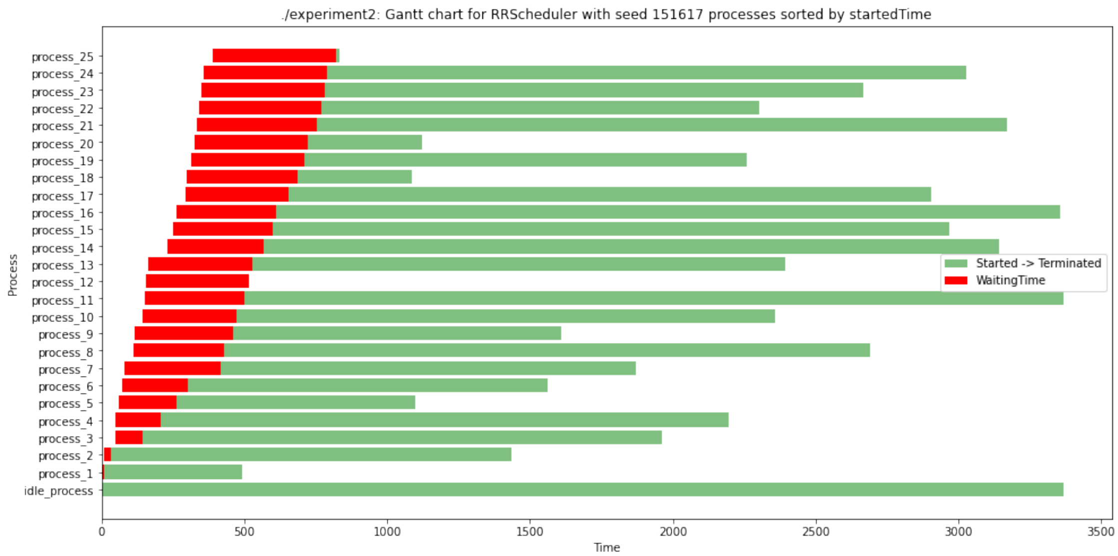
```
[ ]: seed_to_analyse = "151617"
     schedulers = ['FeedbackRRScheduler', 'RRScheduler', 'FcfsScheduler',␣
      ↪'IdealSJFScheduler', 'SJFScheduler']



     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)

             output_for_seed = exp.get_output_for_seed(scheduler, seed_to_analyse)

             results.loc[len(results)] = [
                     seed_to_analyse,
                     scheduler,
                     output_for_seed.waitingTime.mean(),
                     output_for_seed.turnaroundTime.mean(),
                     output_for_seed.responseTime.mean(),
                     util]

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

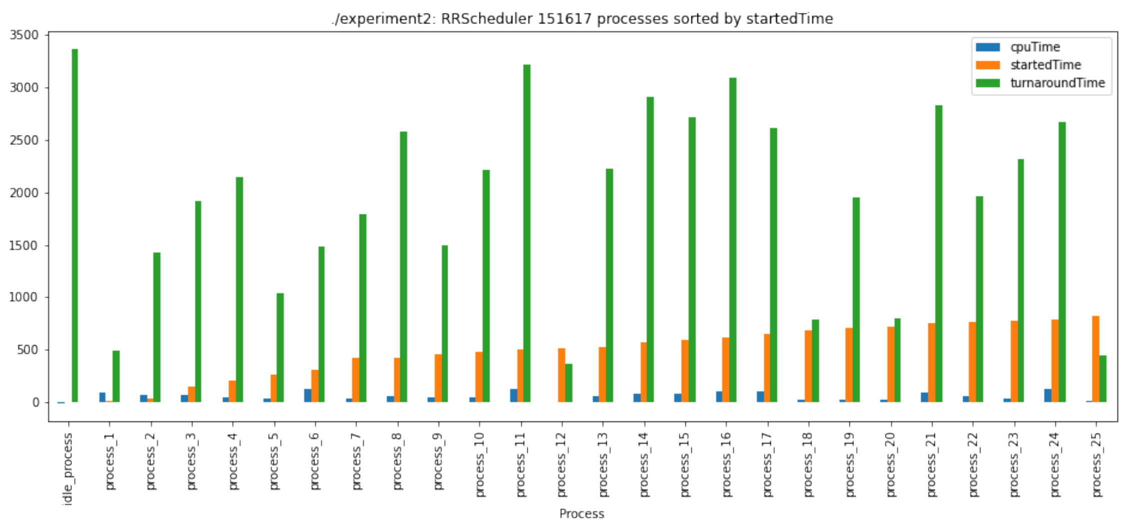
```python
for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

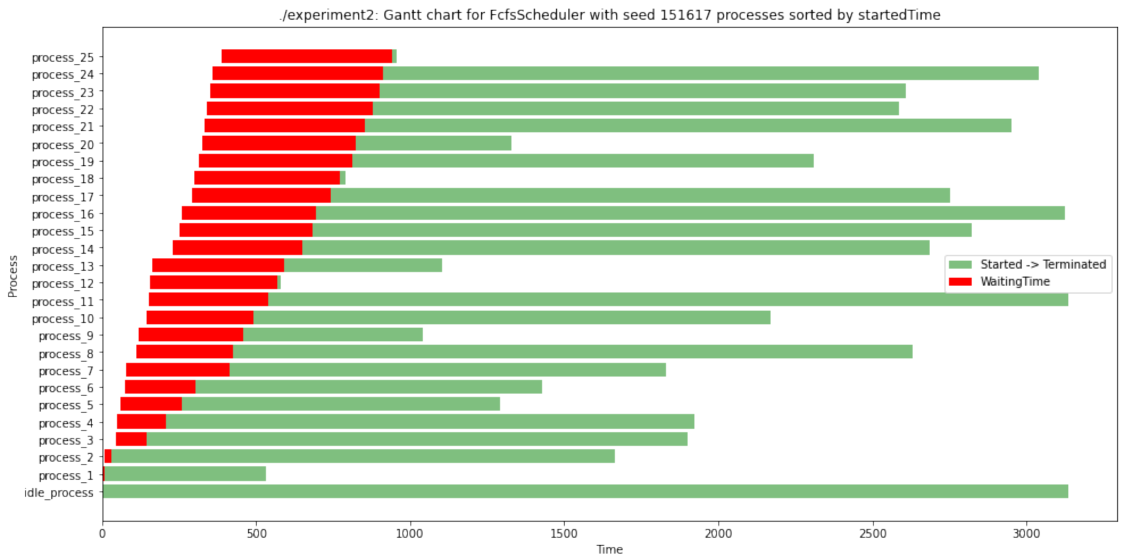
```
CPU Utilization for FeedbackRRScheduler: 98.99%
CPU Utilization for RRScheduler: 98.988%
CPU Utilization for FcfsScheduler: 98.989%
CPU Utilization for IdealSJFScheduler: 98.985%
CPU Utilization for SJFScheduler: 98.997%
```

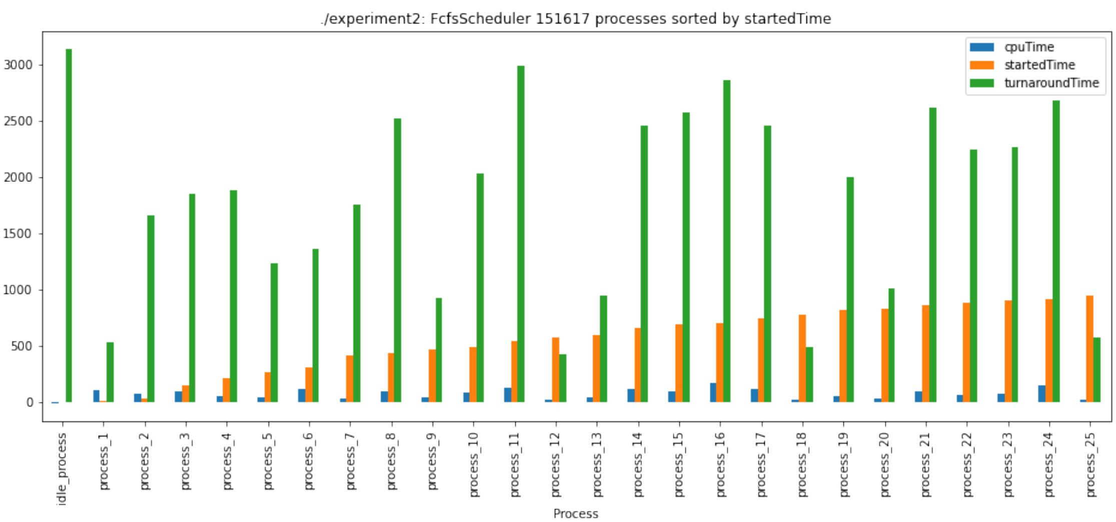


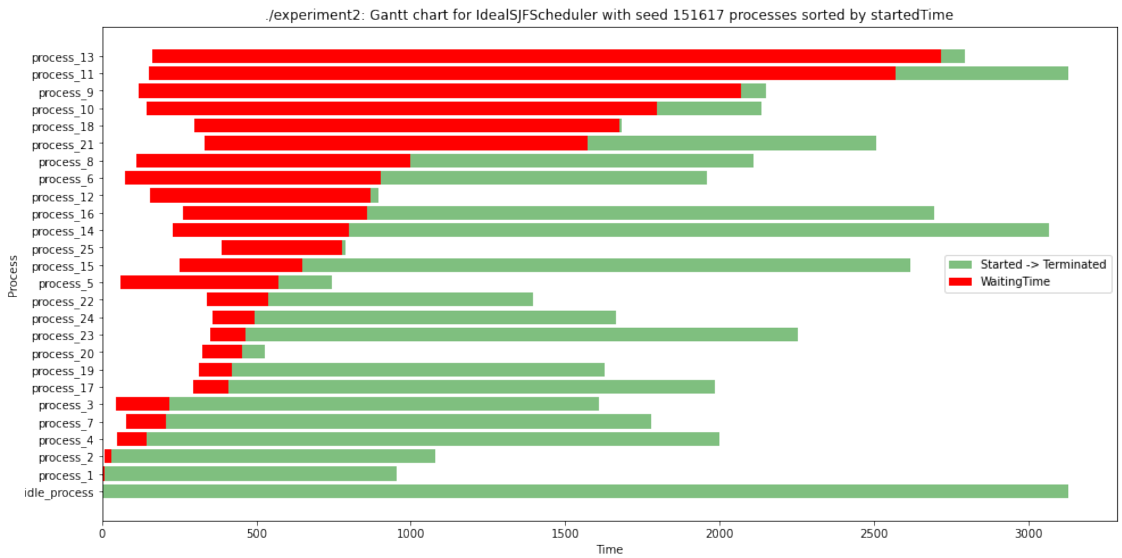


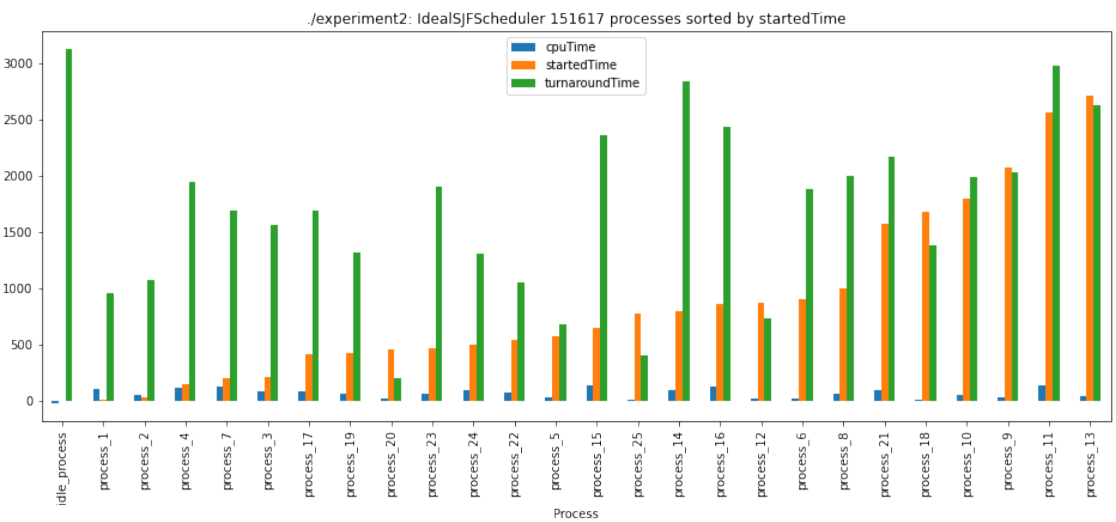

./experiment2: Gantt chart for RRScheduler with seed 151617 processes sorted by startedTime
Process
Time
Started -> Terminated
WaitingTime
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11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

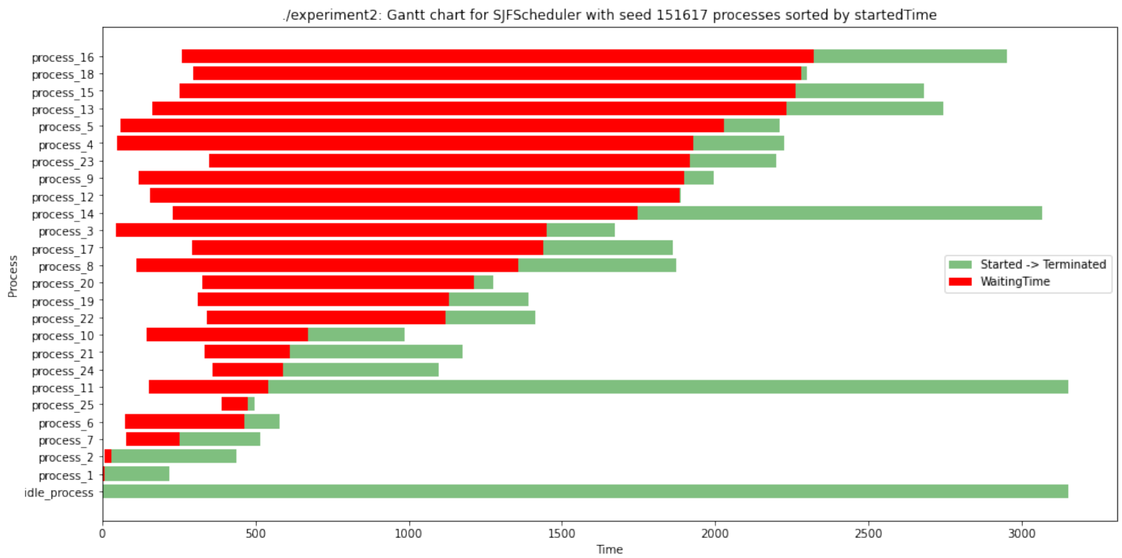

./experiment2: RRScheduler 151617 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
3500
3000
2500
2000
1500
1000
500
0
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14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

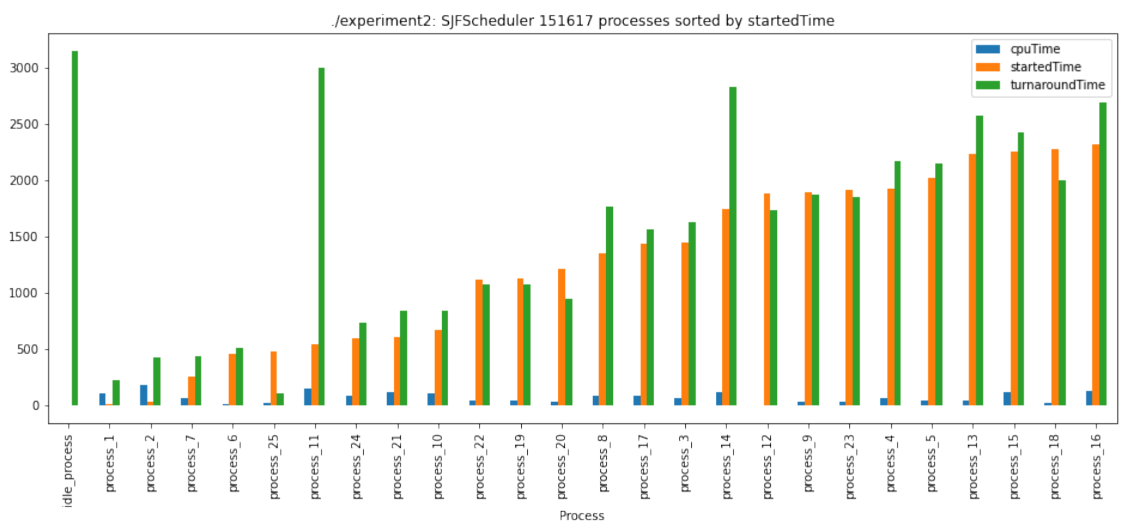

./experiment2: Gantt chart for FcfsScheduler with seed 151617 processes sorted by startedTime
Process
Time
Started -> Terminated
WaitingTime
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11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


./experiment2: FcfsScheduler 151617 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 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
0
500
1000
1500
2000
2500
3000


./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





3.3.2 Results for Seed 91011

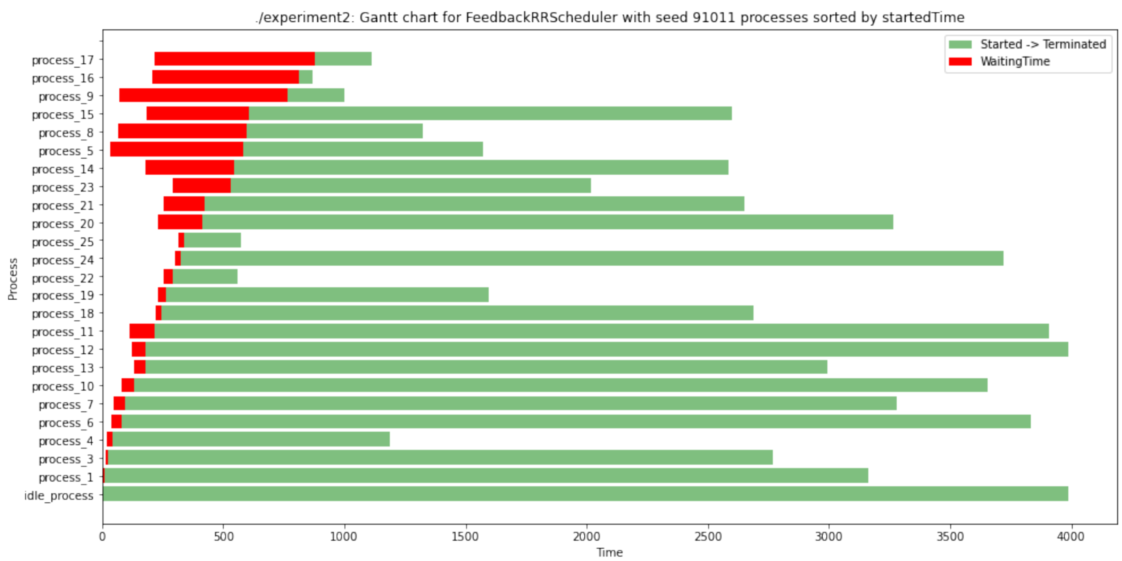
Here it is notable how the FeedbackRRScheduler does not have the highest CPU utilization. As noted in the last experiment, the FeedbackRRScheduler has a large variance in CPU utilization depending on workload in comparison to other algorithms

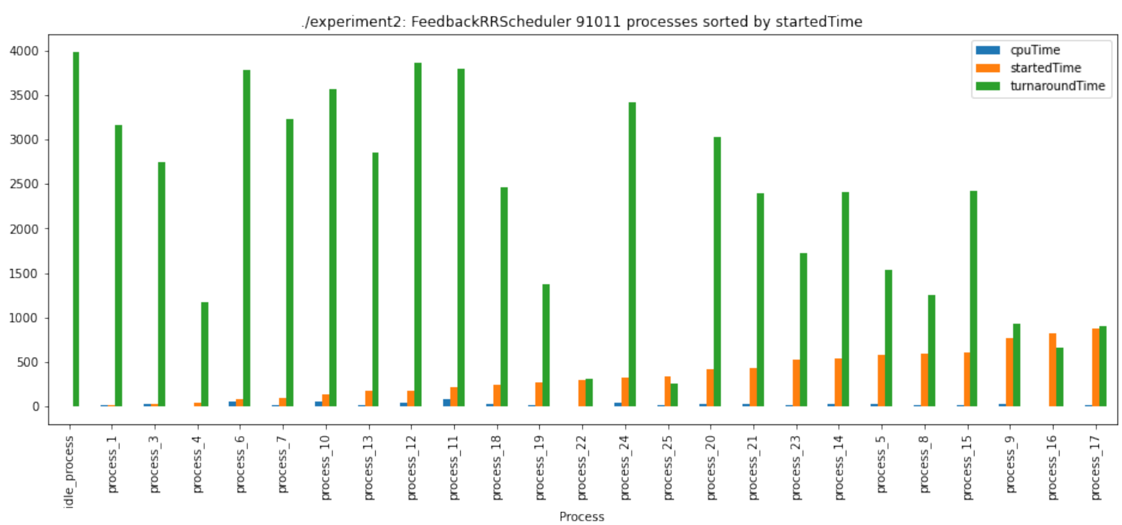
[ ]:
```
seed_to_analyse = '91011'
print("Here it is notable how the FeedbackRRScheduler does not have the highest CPU utilization. As noted in the last experiment, the FeedbackRRScheduler has a large variance in CPU utilization depending on workload in comparison to other algorithms")
```

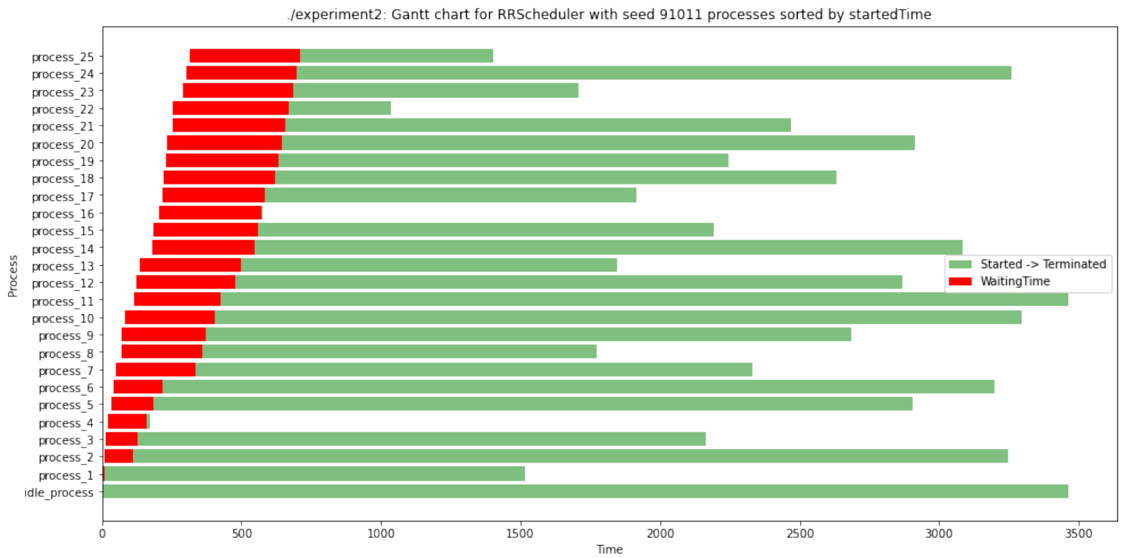
```python
for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

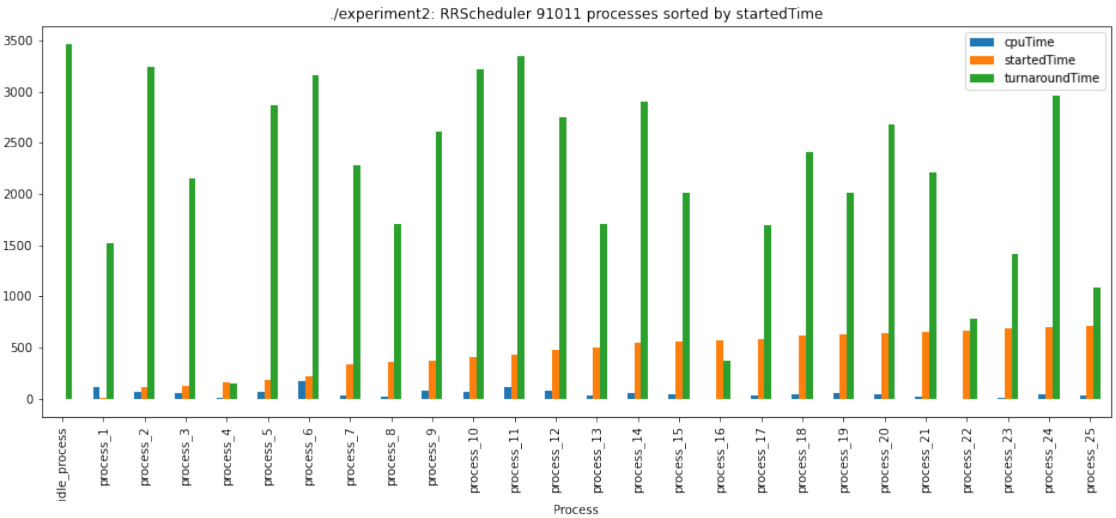
Here it is notable how the FeedbackRRScheduler does not have the highest CPU utilization. As noted in the last experiment, the FeedbackRRScheduler has a large variance in CPU utilization depending on workload in comparison to other algorithms

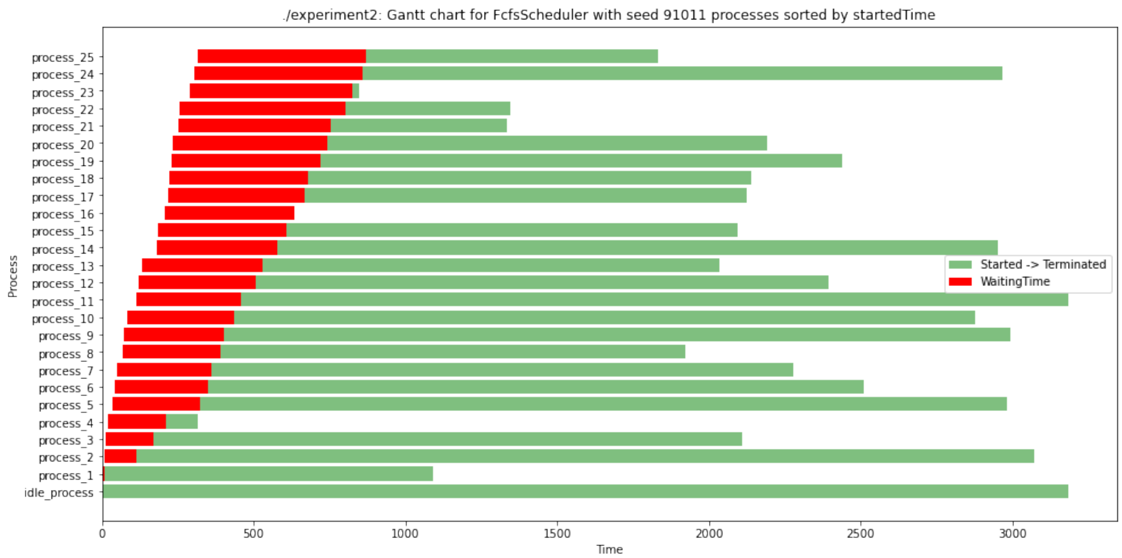
CPU Utilization for FeedbackRRScheduler: 98.985%
CPU Utilization for RRScheduler: 98.995%
CPU Utilization for FcfsScheduler: 98.991%
CPU Utilization for IdealSJFScheduler: 98.995%
CPU Utilization for SJFScheduler: 98.995%



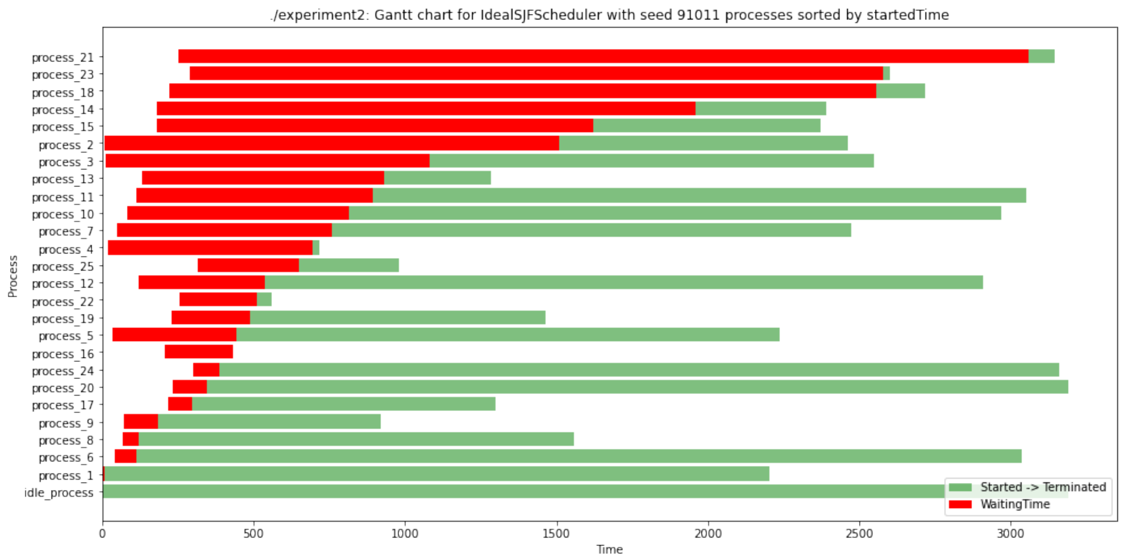



./experiment2: Gantt chart for RRScheduler with seed 91011 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
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

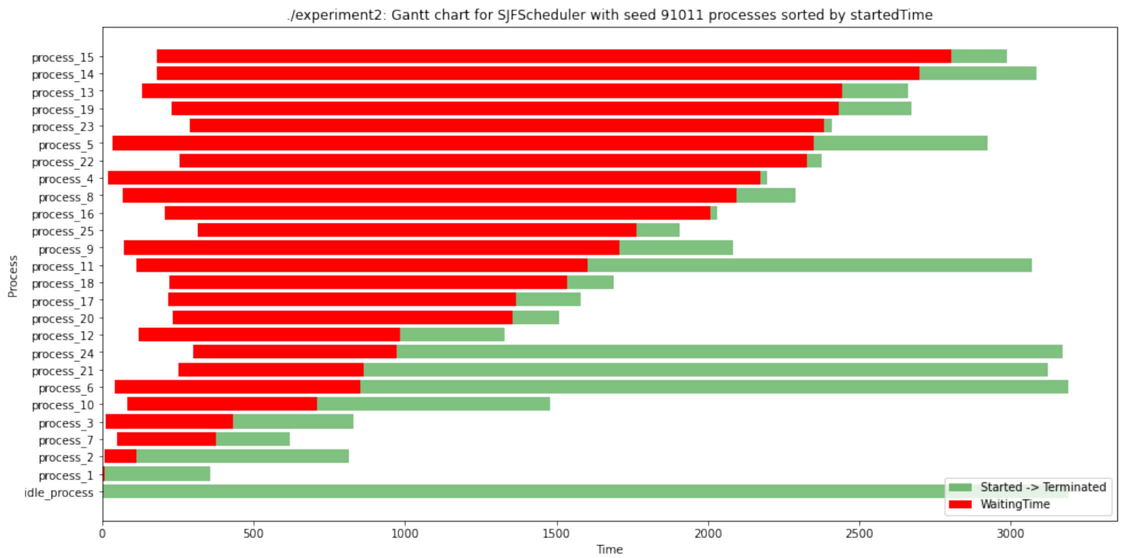

./experiment2: RRScheduler 91011 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
1000
1500
2000
2500
3000
3500
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14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

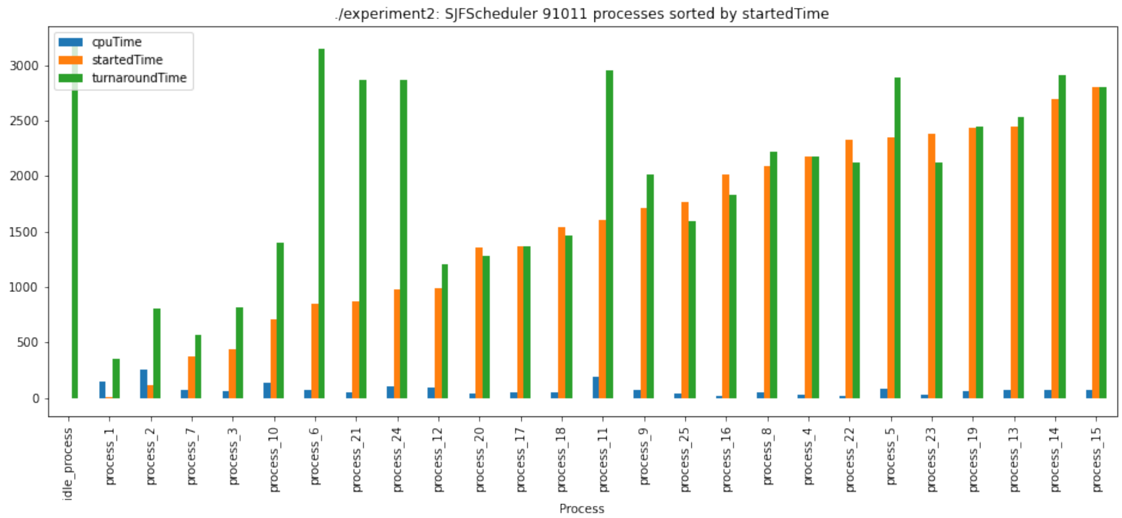

./experiment2: Gantt chart for FcfsScheduler with seed 91011 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11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


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



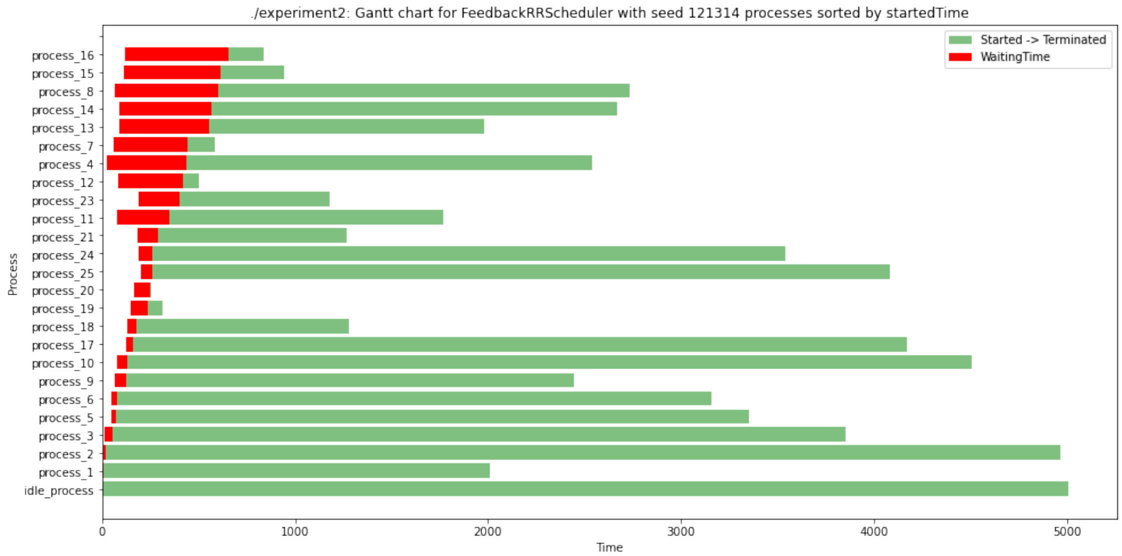


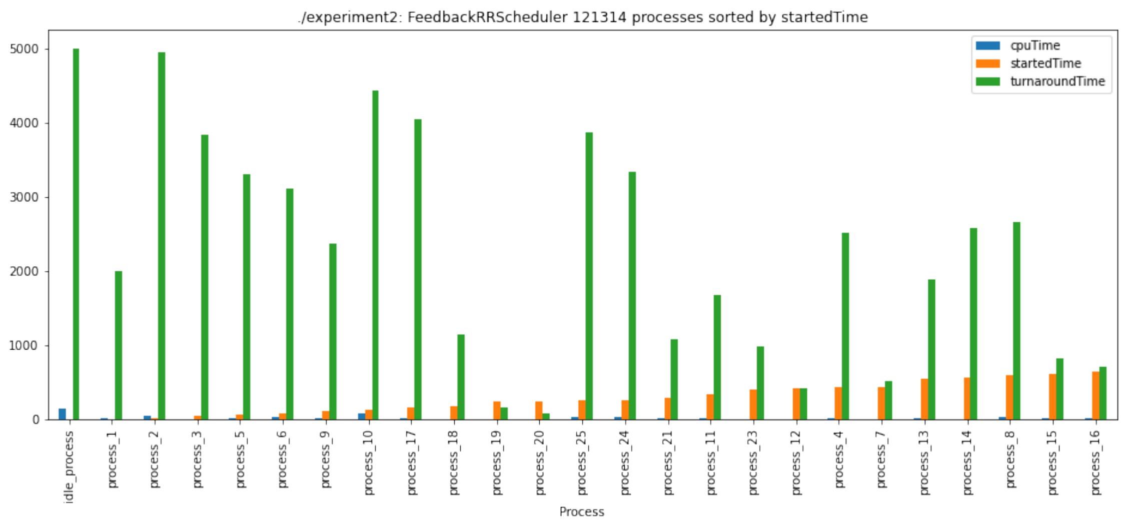
3.3.3 Results for Seed 121314

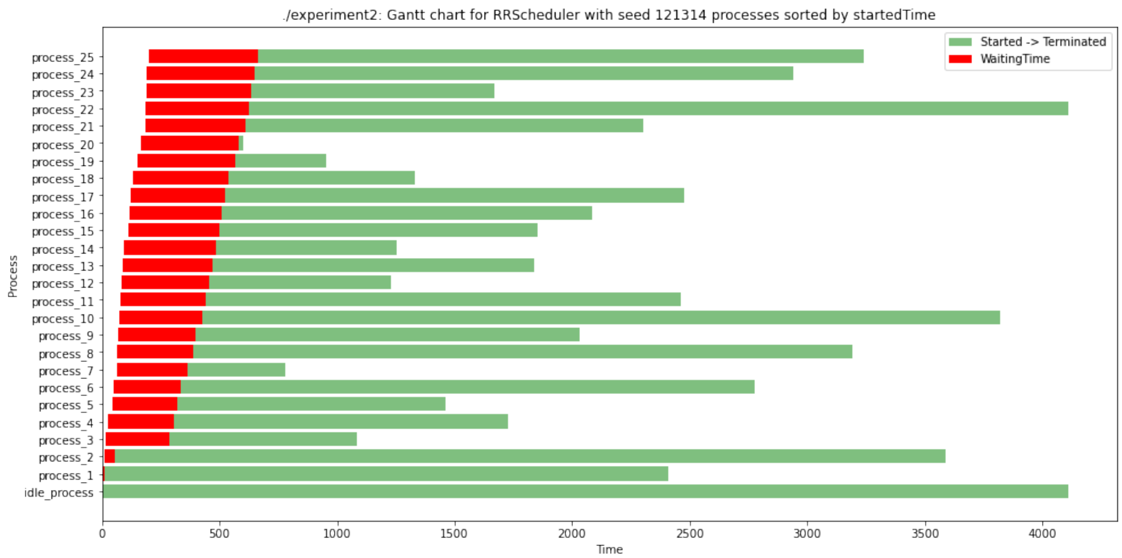
[ ]:
```python
seed_to_analyse = '121314'

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

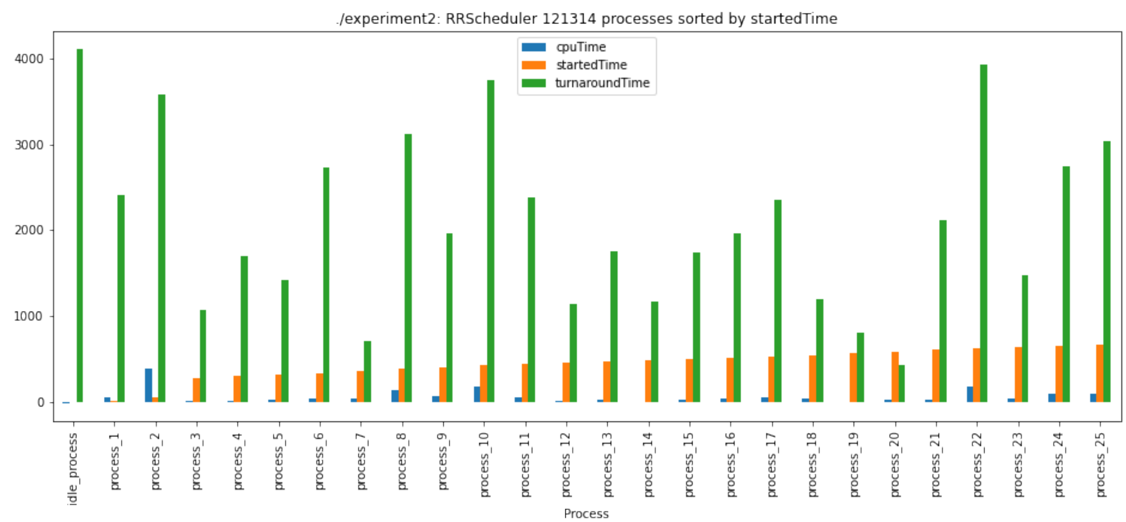
```
CPU Utilization for FeedbackRRScheduler: 99.219%
CPU Utilization for RRScheduler: 98.987%
CPU Utilization for FcfsScheduler: 98.985%
CPU Utilization for IdealSJFScheduler: 98.993%
```

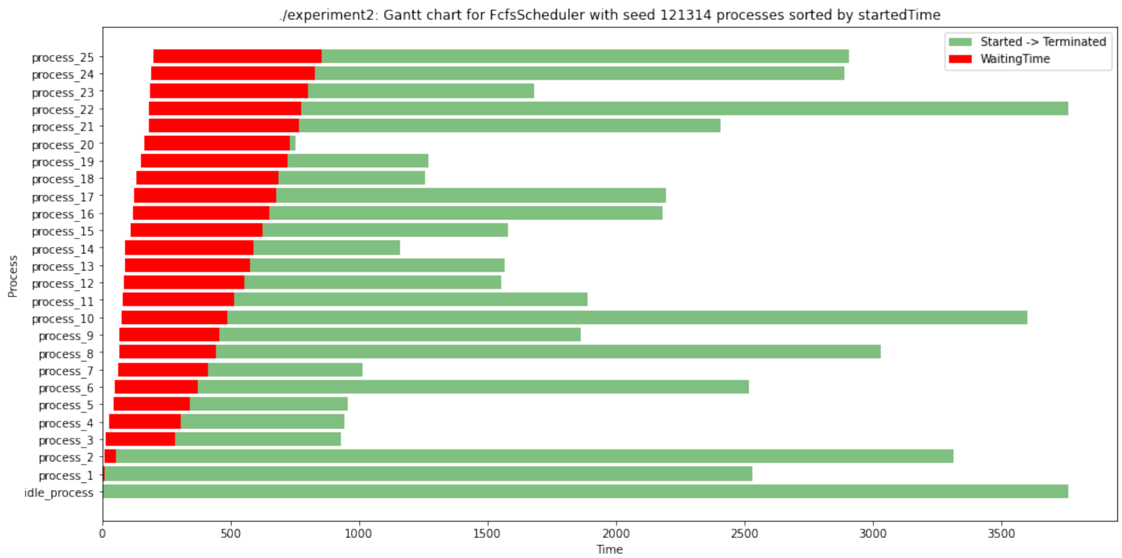
CPU Utilization for SJFScheduler: 98.999%

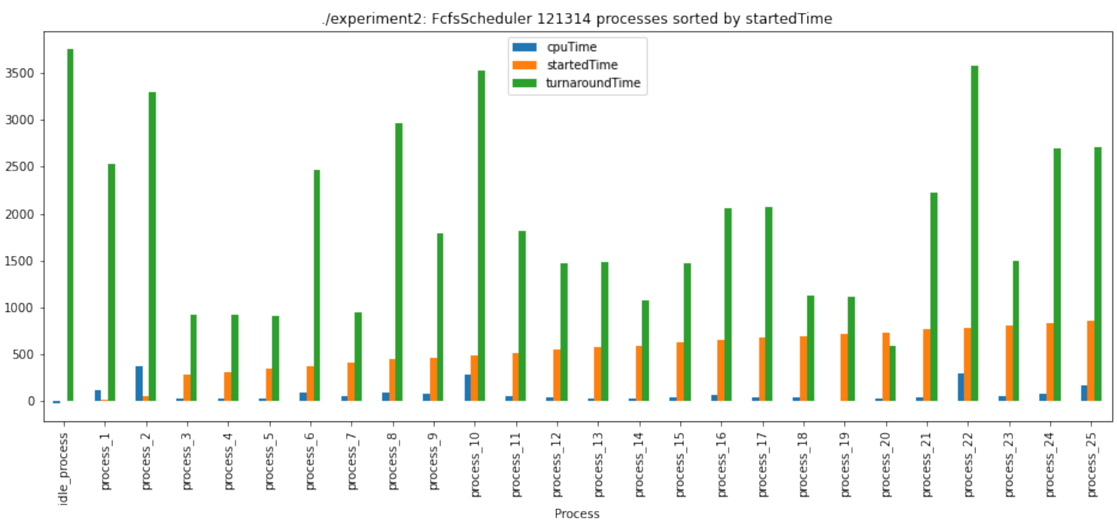


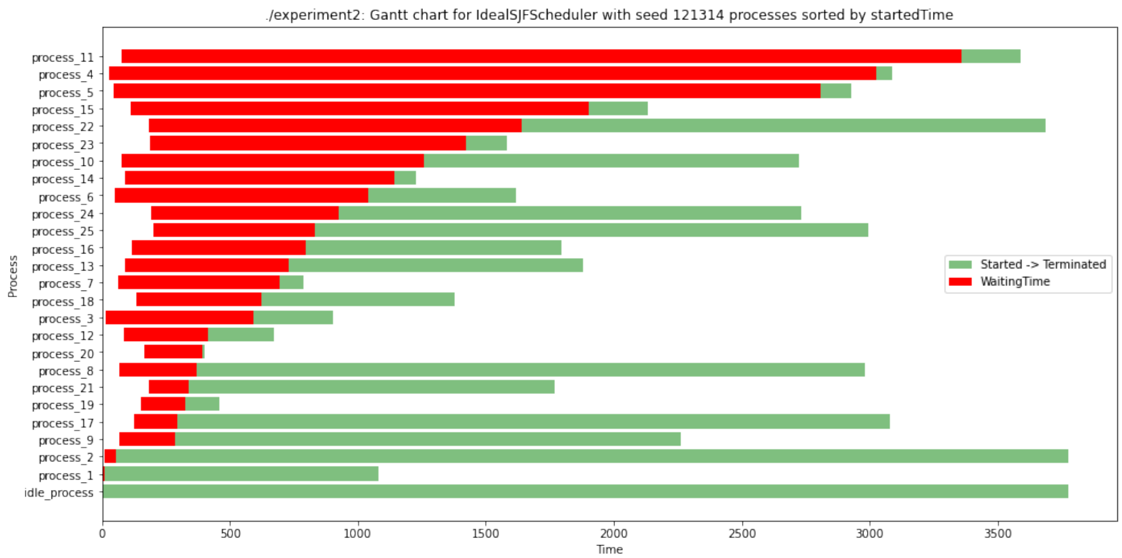


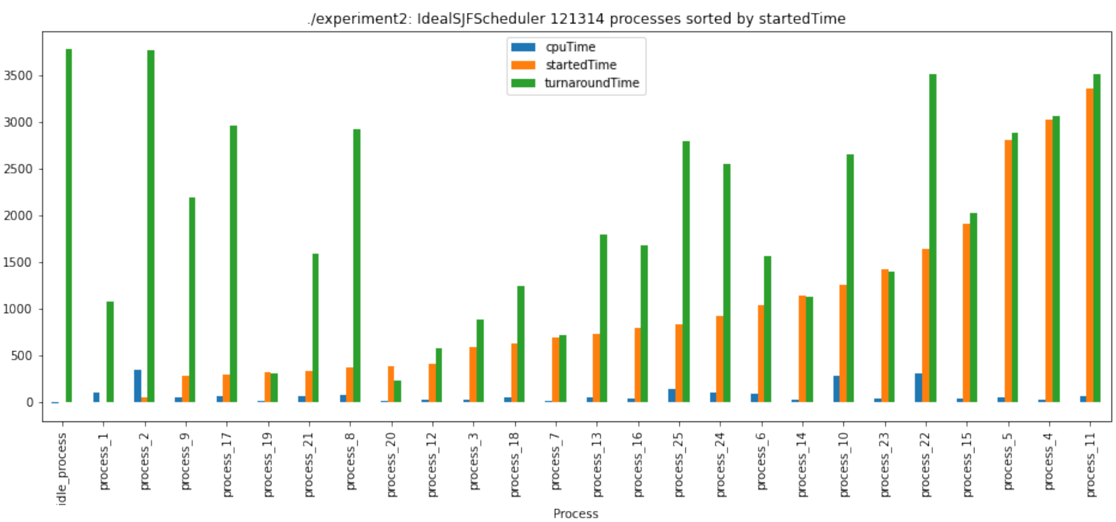

./experiment2: Gantt chart for RRScheduler with seed 121314 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
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

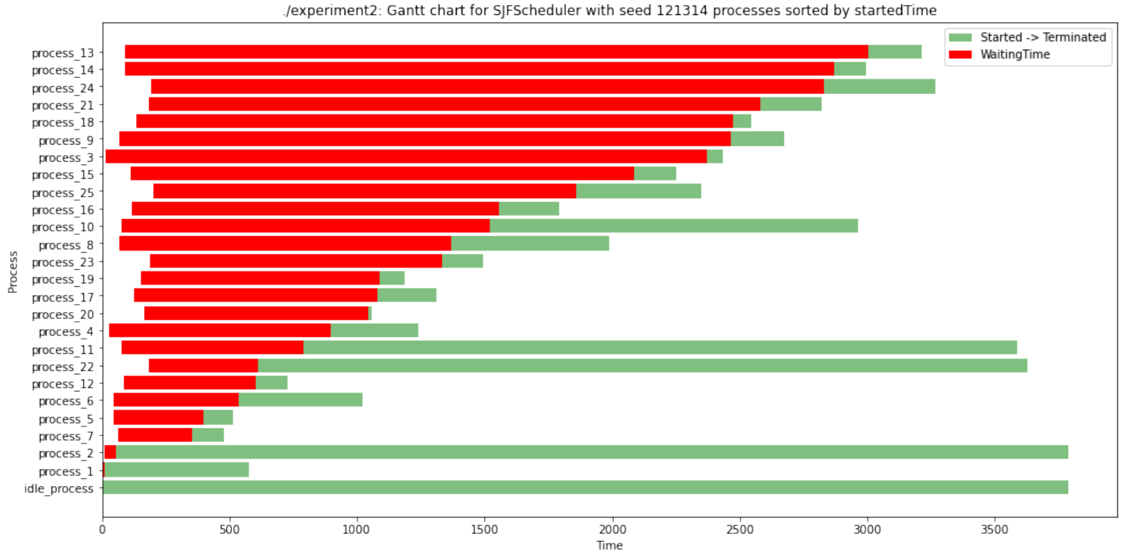

./experiment2: RRScheduler 121314 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
0
1000
2000
3000
4000
Process
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16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

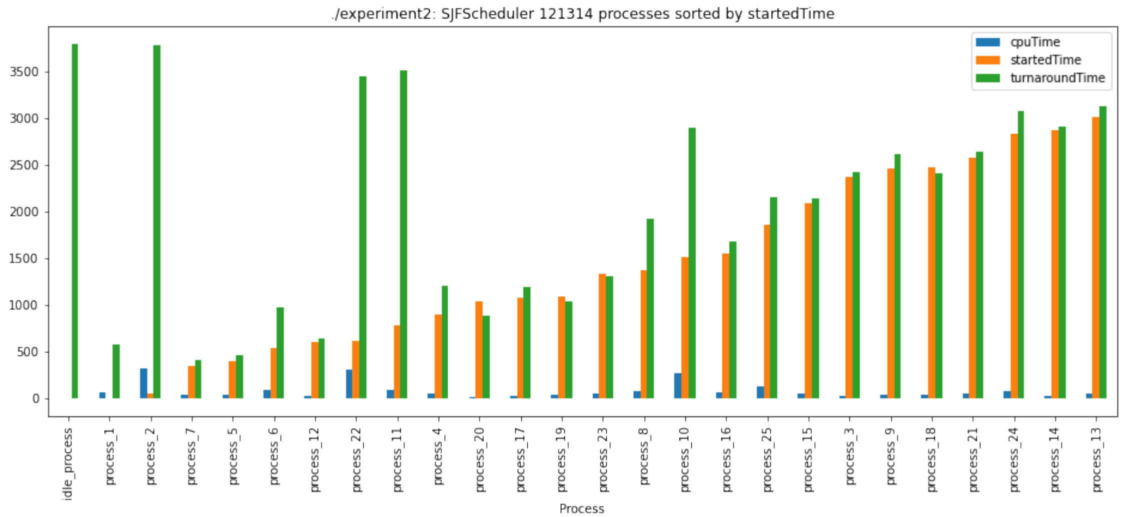

./experiment2: Gantt chart for FcfsScheduler with seed 121314 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
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
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 IdealSJFScheduler with seed 121314 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time


./experiment2: IdealSJFScheduler 121314 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process



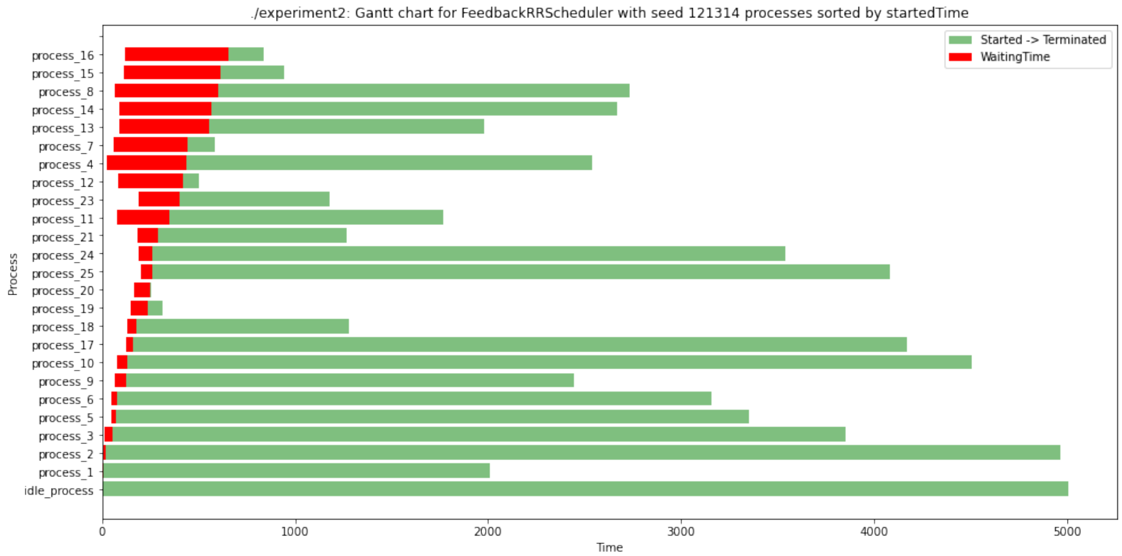


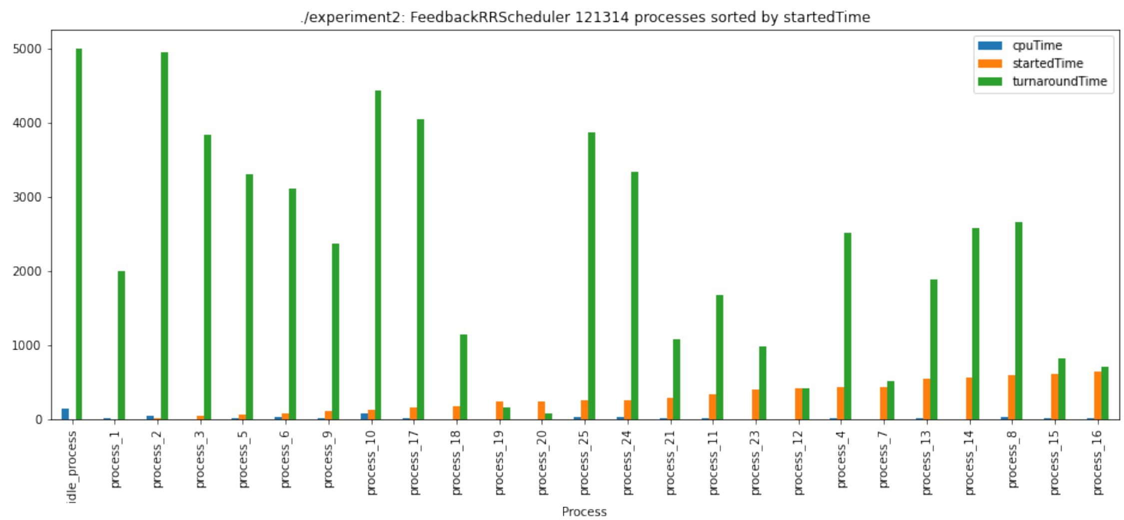
3.3.4 Results for Seed 1234

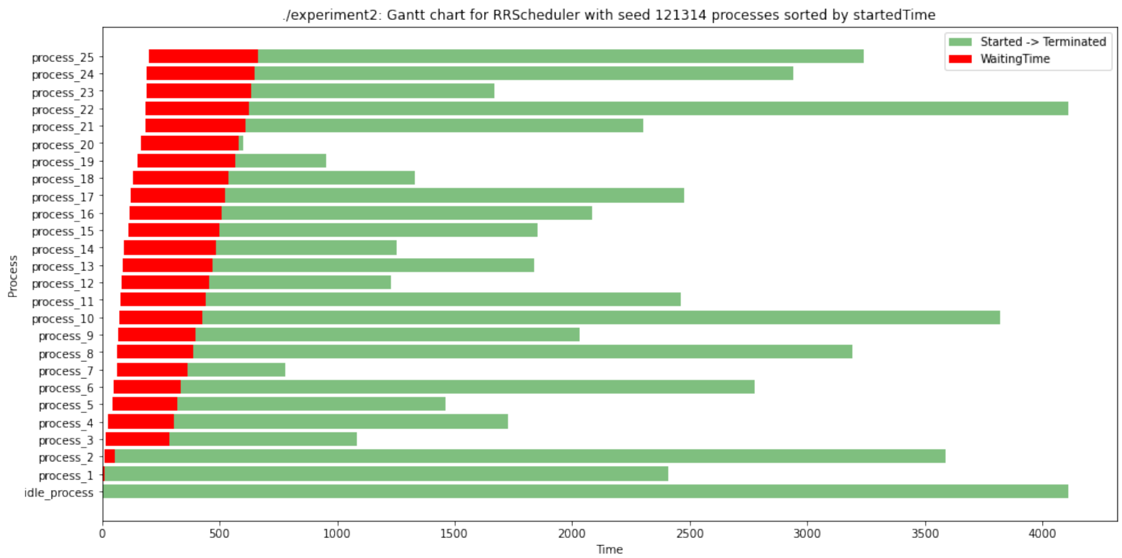
[ ]:
```
seed_to_analyse = '121314'

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

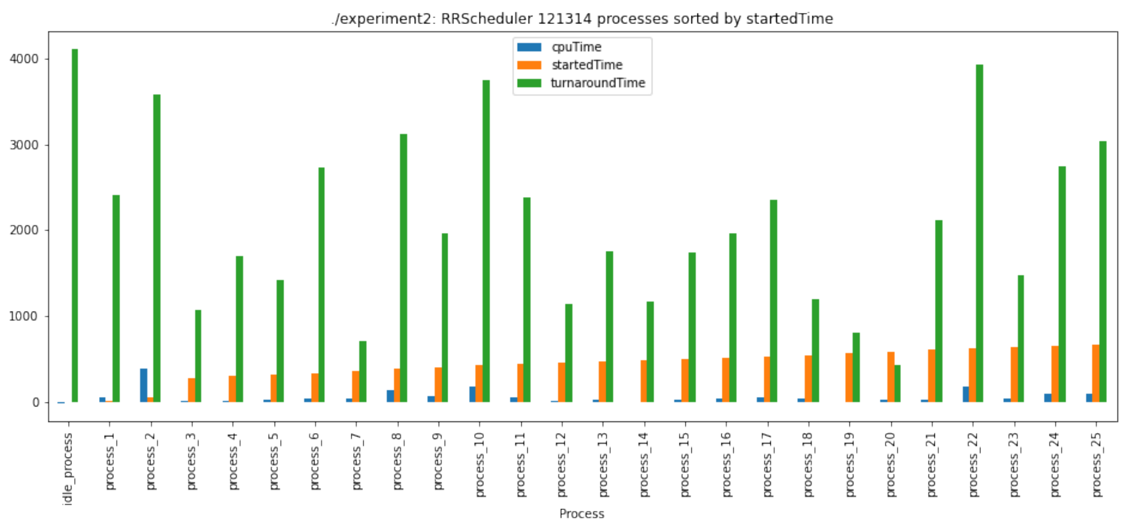
```
CPU Utilization for FeedbackRRScheduler: 99.219%
CPU Utilization for RRScheduler: 98.987%
CPU Utilization for FcfsScheduler: 98.985%
CPU Utilization for IdealSJFScheduler: 98.993%
```

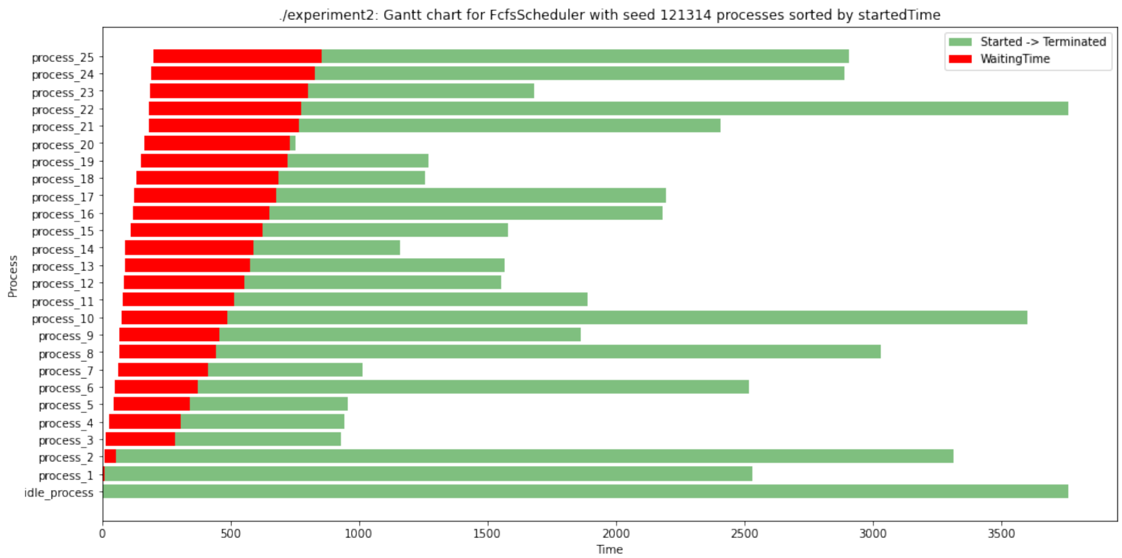
CPU Utilization for SJFScheduler: 98.999%

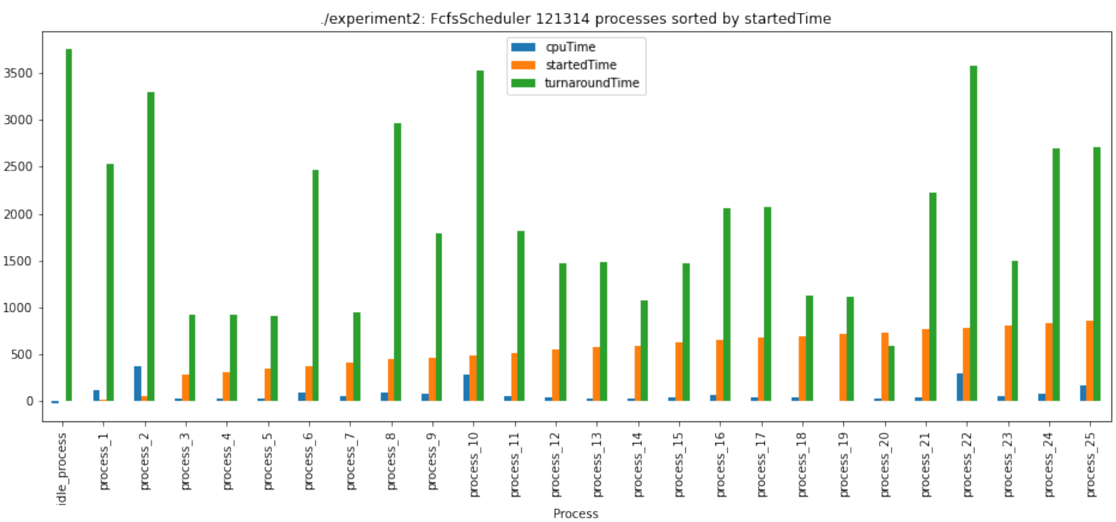


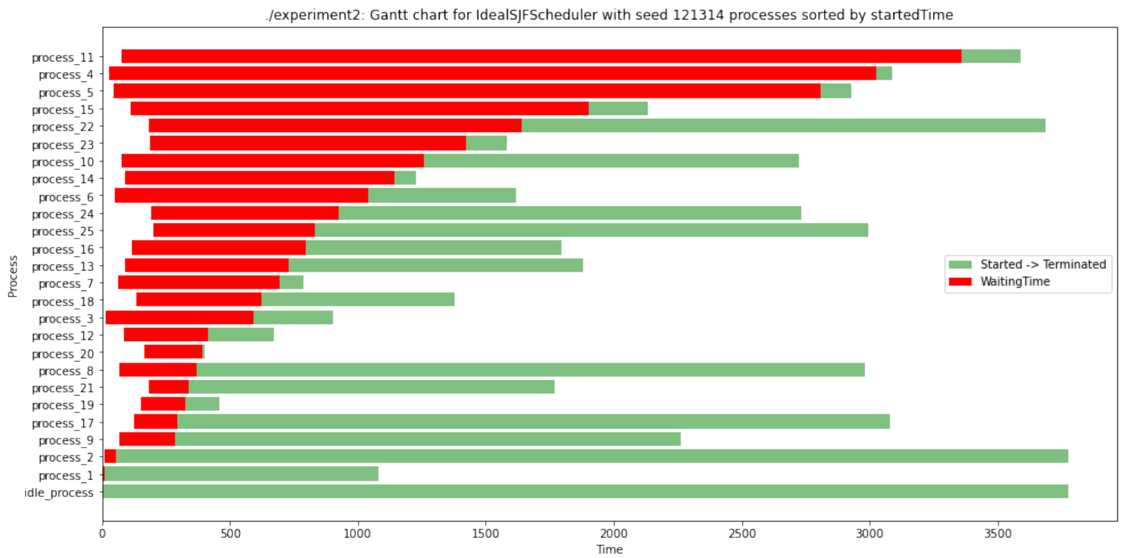


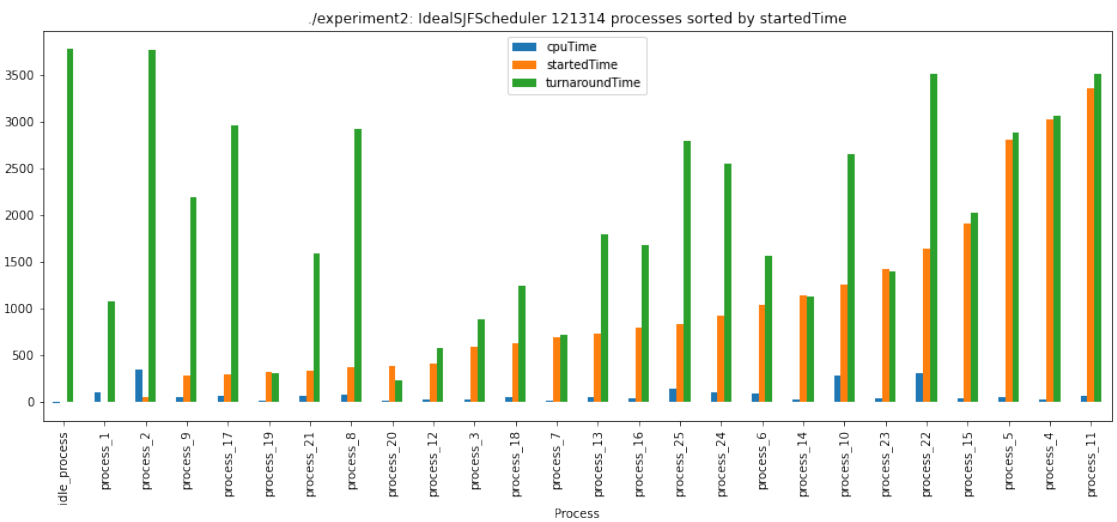

./experiment2: Gantt chart for RRScheduler with seed 121314 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
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
4000

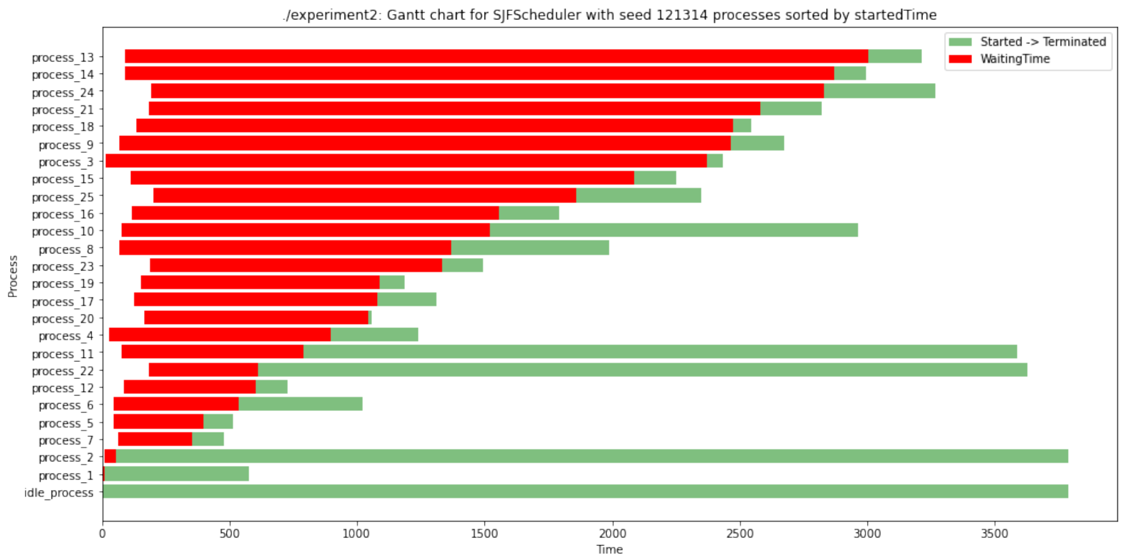

./experiment2: RRScheduler 121314 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
1000
2000
3000
4000
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16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

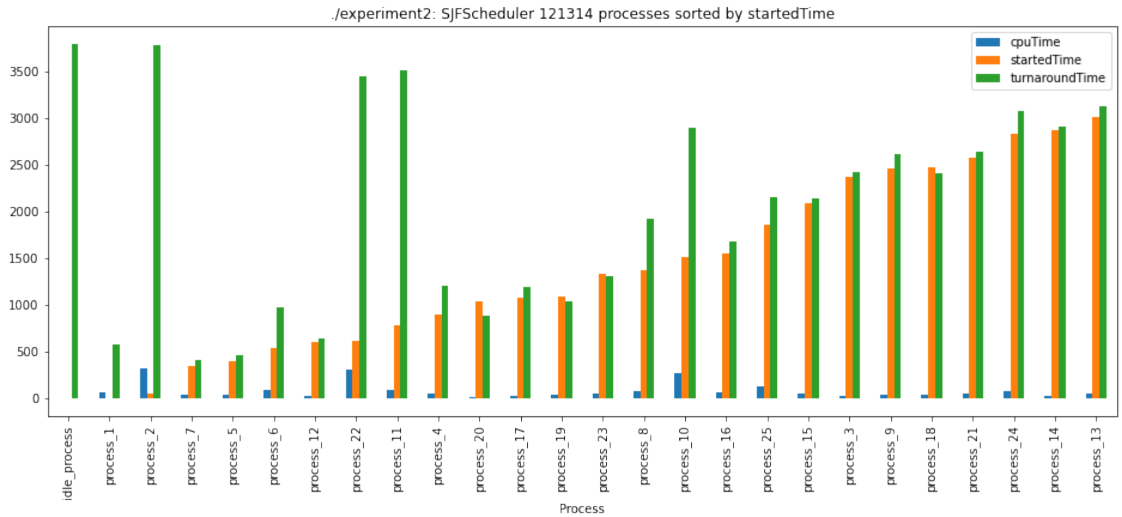

./experiment2: Gantt chart for FcfsScheduler with seed 121314 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11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


./experiment2: Gantt chart for IdealSJFScheduler with seed 121314 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time


./experiment2: IdealSJFScheduler 121314 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process



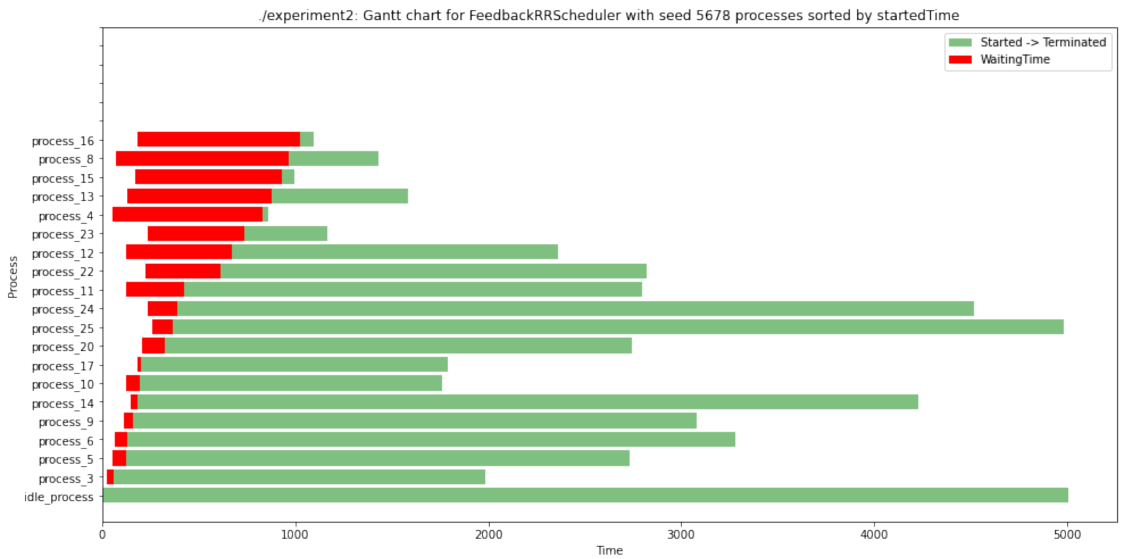


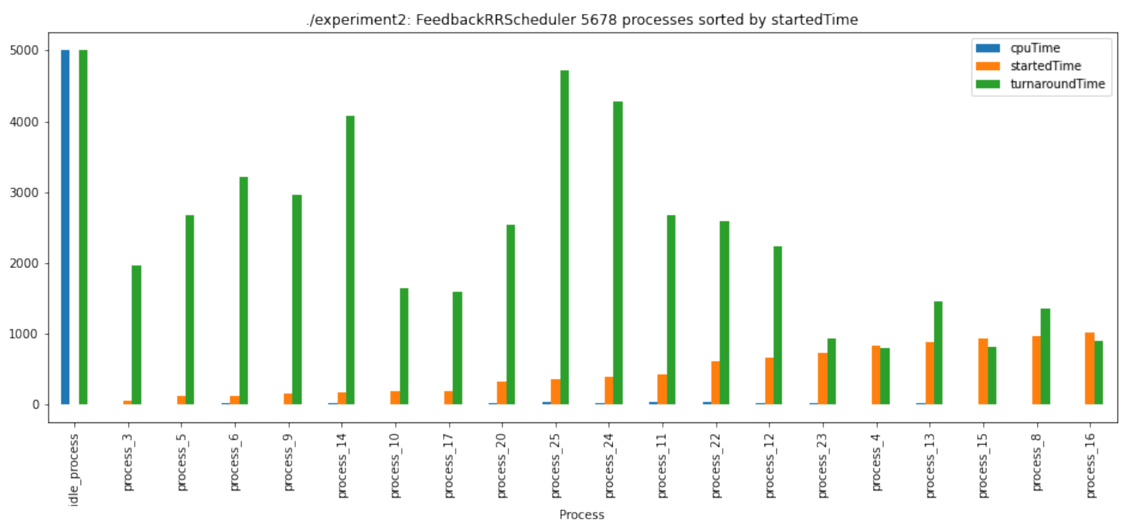
3.3.5 Results for Seed 5678

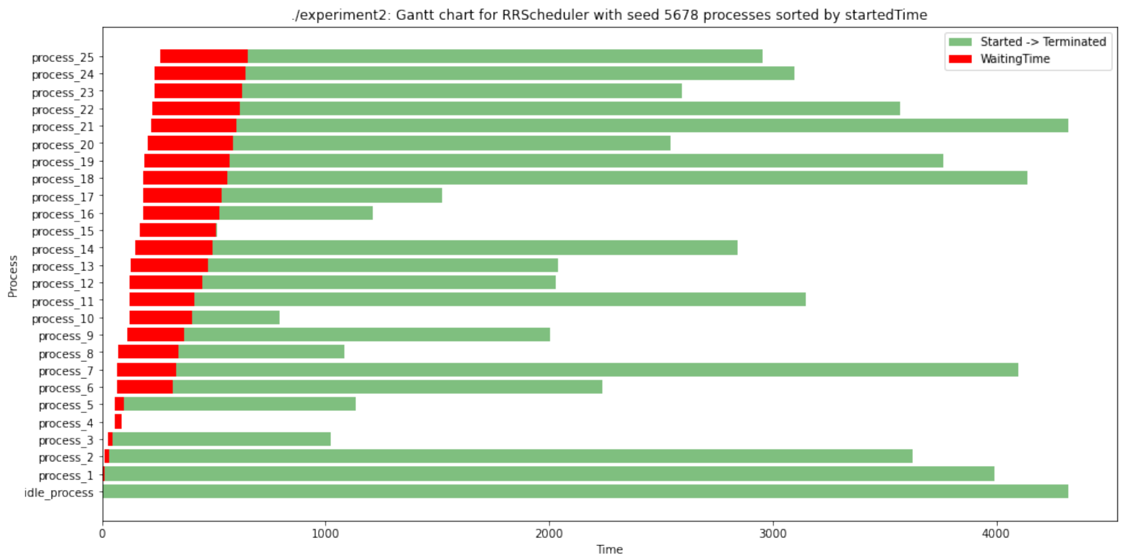
[ ]:
```
seed_to_analyse = '5678'

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

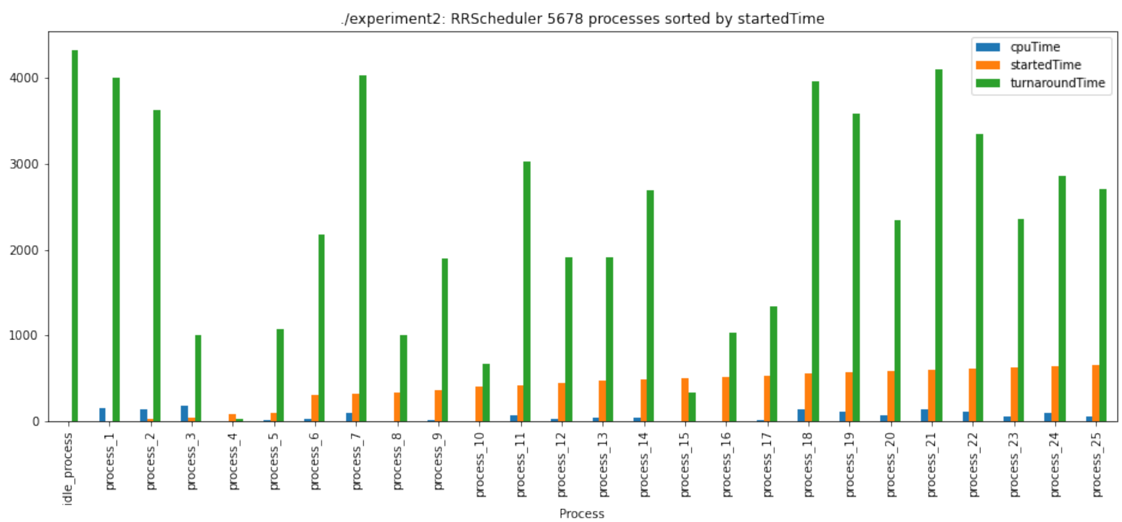
```
CPU Utilization for FeedbackRRScheduler: 99.937%
CPU Utilization for RRScheduler: 99.003%
CPU Utilization for FcfsScheduler: 98.995%
```

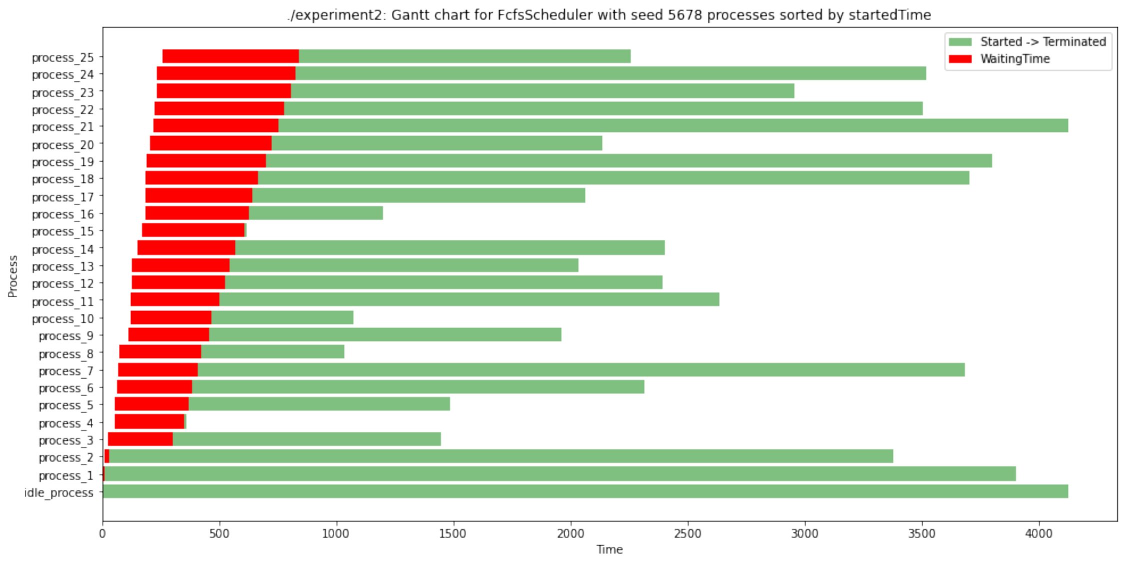
```
CPU Utilization for IdealSJFScheduler: 99.0%
CPU Utilization for SJFScheduler: 98.997%
```

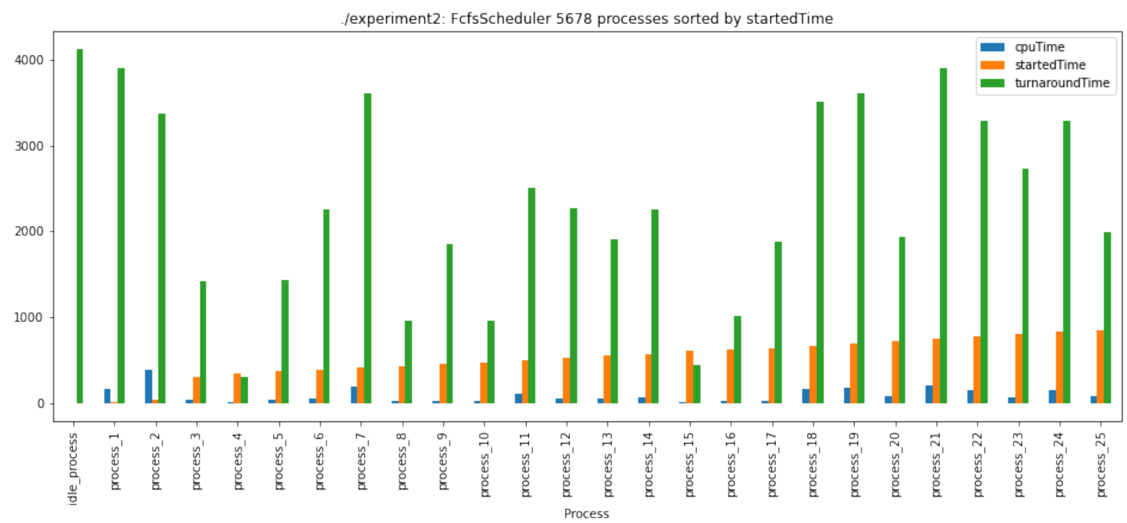


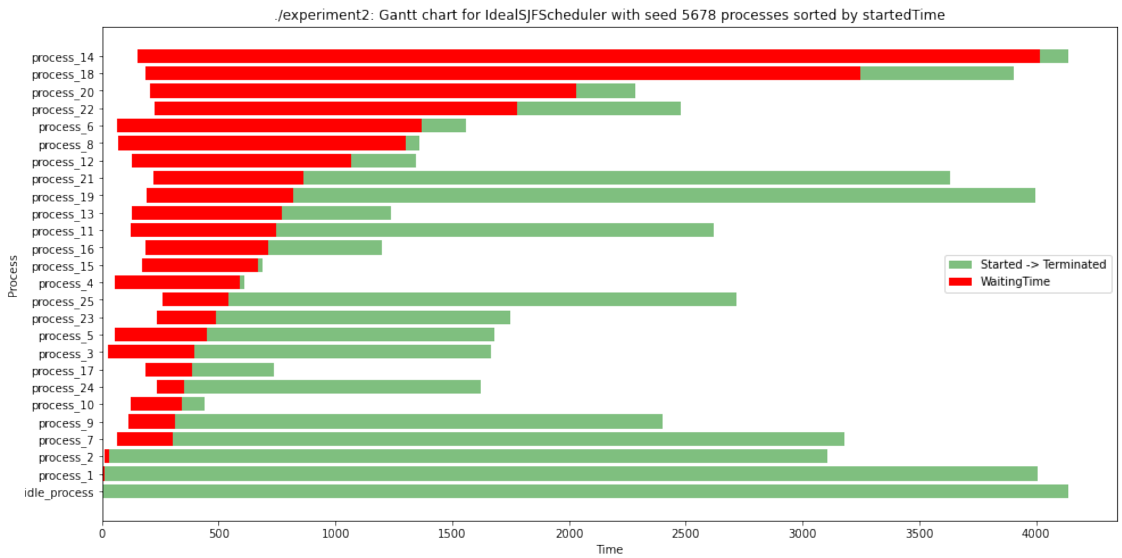


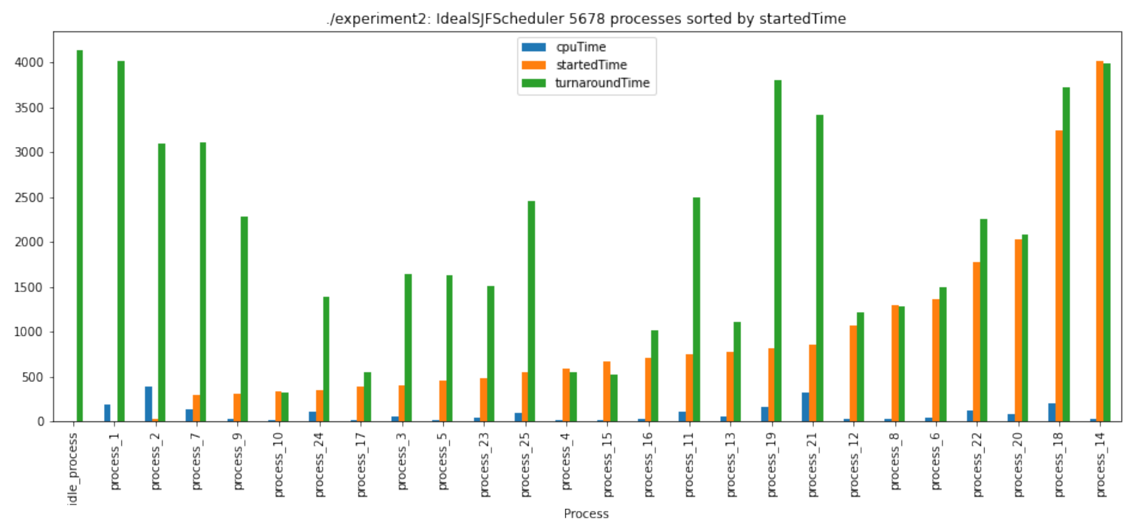

./experiment2: Gantt chart for RRScheduler with seed 5678 processes sorted by startedTime
Started -> Terminated
WaitingTime
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
process_15
process_14
process_13
process_12
process_11
process_10
process_9
process_8
process_7
process_6
process_5
process_4
process_3
process_2
process_1
idle_process
Process
0
1000
2000
3000
4000
Time

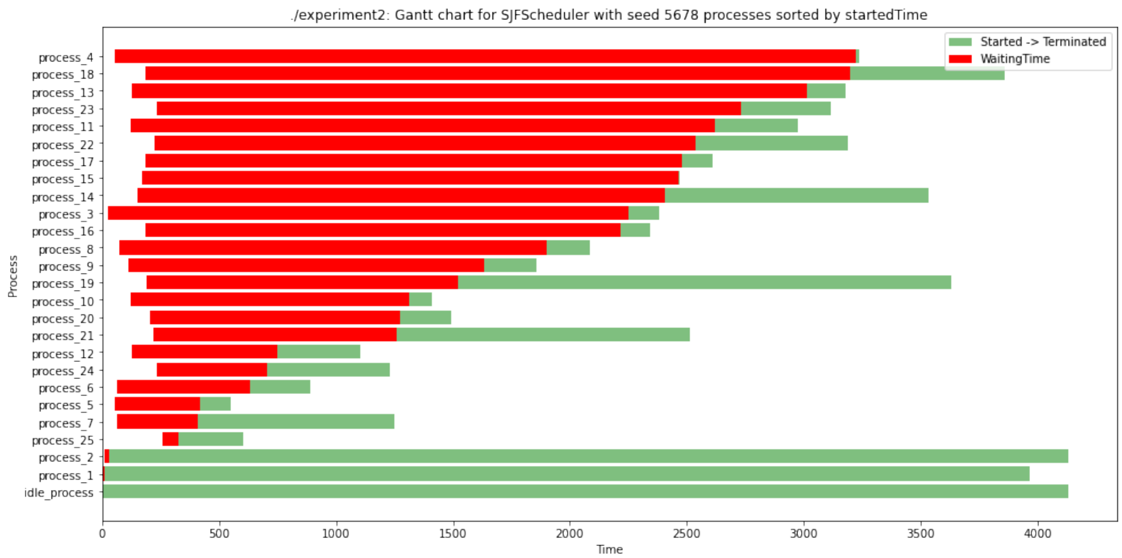

./experiment2: RRScheduler 5678 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
0
1000
2000
3000
4000
idle_process
process_1
process_2
process_3
process_4
process_5
process_6
process_7
process_8
process_9
process_10
process_11
process_12
process_13
process_14
process_15
process_16
process_17
process_18
process_19
process_20
process_21
process_22
process_23
process_24
process_25
Process

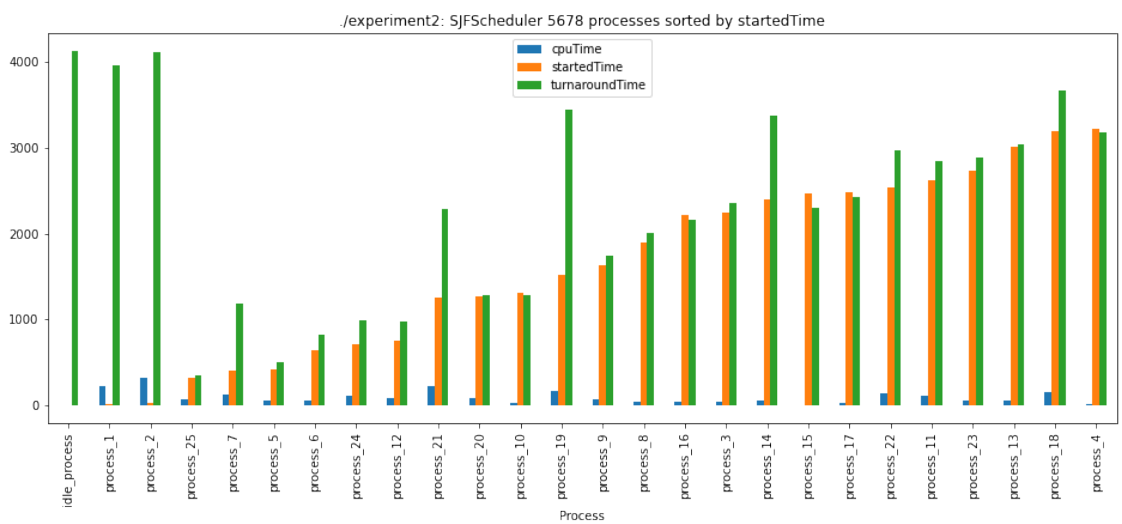

./experiment2: Gantt chart for FcfsScheduler with seed 5678 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time


./experiment2: FcfsScheduler 5678 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process


./experiment2: Gantt chart for IdealSJFScheduler with seed 5678 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time


./experiment2: IdealSJFScheduler 5678 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process





[ ]:
```
## Results of The Experiment
results
```

[ ]:

	Seed	Scheduler	MeanWaitingTime	MeanTurnaroundTime	\
0	151617	FeedbackRRScheduler	174.440000	2108.920000	
1	151617	RRScheduler	307.500000	1955.923077	
2	151617	FcfsScheduler	360.307692	1823.500000	
3	151617	IdealSJFScheduler	672.000000	1706.346154	
4	151617	SJFScheduler	1042.538462	1563.307692	
5	91011	FeedbackRRScheduler	202.920000	2289.960000	
6	91011	RRScheduler	298.769231	2181.192308	

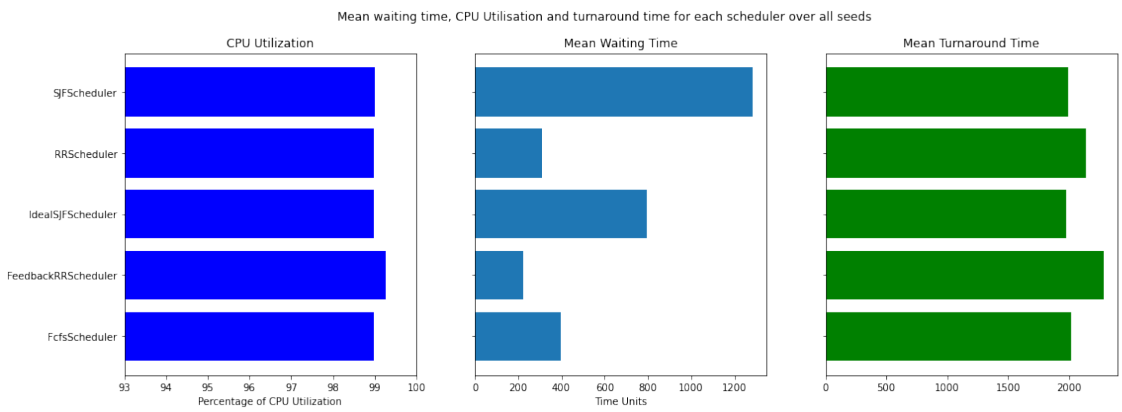
7	91011	FcfsScheduler	365.538462	2007.576923
8	91011	IdealSJFScheduler	749.961538	2008.615385
9	91011	SJFScheduler	1341.538462	1997.153846
10	121314	FeedbackRRScheduler	200.600000	2302.920000
11	121314	RRScheduler	340.076923	2108.192308
12	121314	FcfsScheduler	431.461538	1961.000000
13	121314	IdealSJFScheduler	883.384615	2029.923077
14	121314	SJFScheduler	1288.000000	2045.576923
15	121314	FeedbackRRScheduler	200.600000	2302.920000
16	121314	RRScheduler	340.076923	2108.192308
17	121314	FcfsScheduler	431.461538	1961.000000
18	121314	IdealSJFScheduler	883.384615	2029.923077
19	121314	SJFScheduler	1288.000000	2045.576923
20	5678	FeedbackRRScheduler	328.500000	2424.850000
21	5678	RRScheduler	273.884615	2357.230769
22	5678	FcfsScheduler	389.653846	2334.846154
23	5678	IdealSJFScheduler	784.653846	2118.807692
24	5678	SJFScheduler	1467.500000	2319.884615

	MeanResponseTime	CpuUtilization
0	168.080000	98.989879
1	301.153846	98.988142
2	353.961538	98.988864
3	665.653846	98.984650
4	1036.192308	98.997208
5	197.120000	98.985348
6	292.653846	98.994788
7	359.423077	98.991276
8	743.846154	98.994681
9	1335.423077	98.994681
10	193.520000	99.219076
11	331.769231	98.987425
12	423.153846	98.984755
13	875.076923	98.993043
14	1279.692308	98.999069
15	193.520000	99.219076
16	331.769231	98.987425
17	423.153846	98.984755
18	875.076923	98.993043
19	1279.692308	98.999069
20	323.750000	99.937278
21	265.000000	99.002990
22	380.769231	98.994816
23	775.769231	99.000419
24	1458.615385	98.997021

Now we must calculate the means for each metric for all of our scheduling algorithm over the 5 seeds.

[ ]:
```
means = results.groupby(['Scheduler']).mean()
stds = results.groupby(['Scheduler']).std()
```

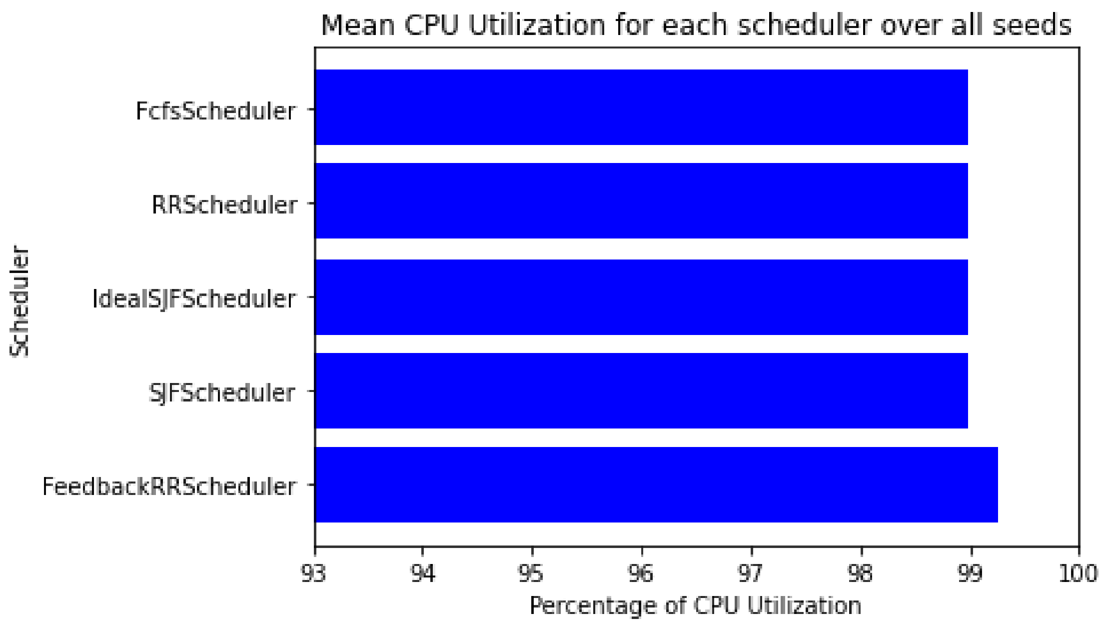
[ ]:
```
fig, (ax1, ax2, ax3) = plt.subplots(1,3, sharey='all',)

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'])

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, whilst the Shortest Job First algorithm suffers from starvation of longer processes.

3.3.6 Comparing CPU Utilization

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

## Std Deviation of the Results


plt.barh(utilisation.index, utilisation['CpuUtilization'], color='b')
plt.title("Mean CPU Utilization for each scheduler over all seeds")
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.

[ ]:
```python
utilisation
```

[ ]:
```
                     CpuUtilization
Scheduler
FeedbackRRScheduler       99.270131
```

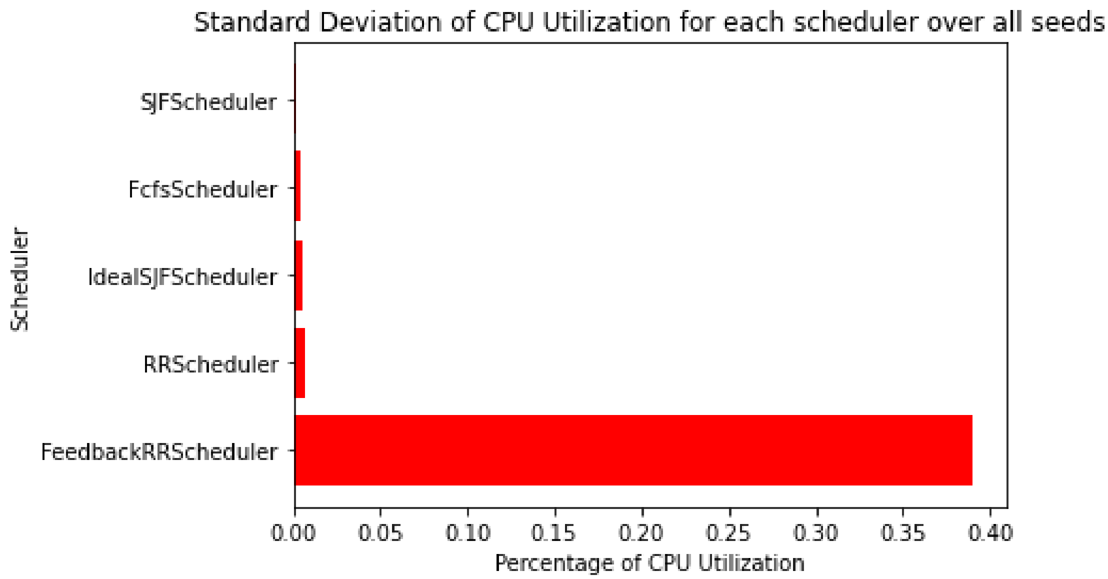
```
SJFScheduler               98.997410
IdealSJFScheduler          98.993167
RRScheduler                98.992154
FcfsScheduler              98.988893
```

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 an improvement over the other algorithms when it comes to maximizing CPU utilization. However, we should take a look at the standard deviation of the CPU utilization for each algorithm to ensure that this conclusion is accurate.

[ ]:
```
utilisation_std = pd.DataFrame(stds.CpuUtilization).
 ↪sort_values('CpuUtilization', ascending=False)

utilisation_std.rename(columns={'CpuUtilization': 'StdDeviation'}, inplace=True)


plt.title("Standard Deviation of CPU Utilization for each scheduler over all␣
 ↪seeds")
plt.barh(utilisation_std.index, utilisation_std['StdDeviation'], color='r')
plt.xlabel("Percentage of CPU Utilization")
plt.ylabel("Scheduler")

utilisation_std
```

[ ]:

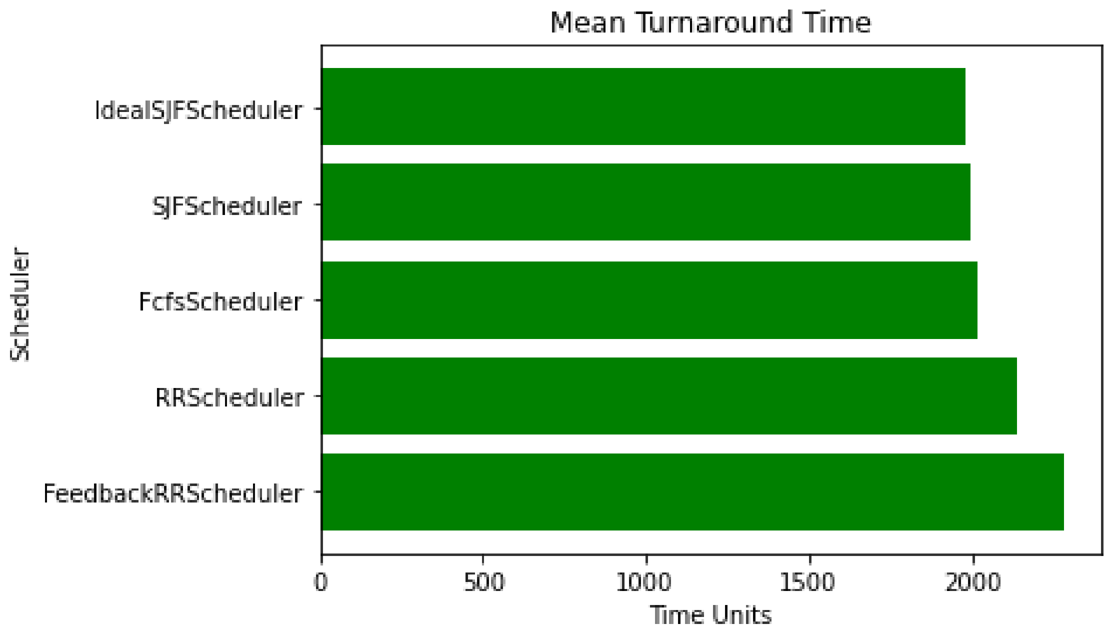
Scheduler	StdDeviation
FeedbackRRScheduler	0.390494
RRScheduler	0.006804
IdealSJFScheduler	0.005645
FcfsScheduler	0.004331
SJFScheduler	0.001813



Notably, we can see that my initial conclusion: that the Feedback Round Robin algorithm was an improvement in terms of CPU utilization may be incorrect. This is since, upon analyzing standard deviation, we can see that the standard deviation for the Feedback Round Robin Scheduler is far higher than any other the others. This shows that the Feedback Round Round Scheduler is not the best algorithm for maximizing CPU utilization, but actually that its CPU utilization varies greatly from seed to seed, implying that the performance of the algorithm is highly dependent on the input parameters/data.

3.3.7 Comparing Average Turnaround Time

[ ]:
```
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()

turnaround
```



[ ]:

Scheduler	MeanTurnaroundTime
FeedbackRRScheduler	2285.914000
RRScheduler	2142.146154
FcfsScheduler	2017.584615
SJFScheduler	1994.300000
IdealSJFScheduler	1978.723077

The above table shows us that the average turnaround time for the pre-emptive Ideal Shortest Job First is the lowest, whilst the non-preemptive version has the next lowest mean turnaround time. The Round Robin Scheduler and Feedback Round Robin Scheduler have the worst average turnaround time, this is due to the fact that the Round Robin algorithms are 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 current burst will not be finished if the time quantum has been reached. Here, the Feedback RR Scheduler performs particularly poorly when it comes to turnaround time even when compared to the simple Round Robin scheduler. This is likely due to the policy of the scheduler which demotes a process once it has reached it's time quantum, this forces longer processes to wait longer than they would have to if the scheduler was using a simple round robin approach.

3.3.8 Conclusion

As was noted above, the Feedback RR Scheduler has the best average CPU utilisation over the 5 seeds, 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 preemptive Shortest Job First algorithm is the most effective. However, it must be noted that when waiting time is concerned, the Shortest Job First Algorithm may suffer from starvation when faced with large workloads with many smaller processes and fewer larger ones.

When considering which algorithm to use, it is important to keep in mind the workload that the scheduler needs to handle. In a system handling consistently small request sizes, with little variation, so that starvation wouldn't be a problem, the best algorithm to opt for is the Shortest Job First algorithm as it will keep CPU utilisation high whilst also ensuring Turnaround time is optimal. If we arent as concerned with turnaround time, a round robin approach makes sense, as it allows us to maximise CPU usage and keep wait times low.

4 Experiment 3 - When dealing with unpredictable & highly varying workloads, which algorithm performs best and can we improve the estimation of burst times from the shortest job first algorithm in this instance?

[ ]:
```
exp = Experiment('./experiment3')
```

4.1 Introduction

For this experiment I am not going to be dealing with the Ideal Shortest Job First scheduler as it is able to preempt the burst time of arriving processes, since we are only dealing with unpredictable workloads, we will use the non-preemptive version of the scheduler as opposed to the pre-emptive version. I will compare the performance of each of the schedulers using highly unpredictable workloads, I will then compare them and analayse their performance, specifically looking to see if we can improve the estimation of the burst time done by the Shortest Job First algorithm.

4.2 Methodology

To effectively analyse how each of the algorithms perform under unpredictable and highly varying workloads, I will compare the CPU Utilisation and Response Time for each of the algorithms over 5 seeds and will also analyse the Gantt Charts for each of the algorithms to compare their performance.

[ ]:
```
print(f"Seeds for Experiment 3: {exp.all_seeds()}")
```

```
Seeds for Experiment 3: ['5124', '1234', '5678', '6789', '91011']
```

4.2.1 Input Parameters

Using each of the above seeds, I will be using the following input parameters for this experiment:

[ ]:
```
exp.input_params[1][1].drop(['seed'])
```

[ ]:
```
                   value
param
numberOfProcesses     30
```

```
staticPriority          0
meanInterArrival       20
meanCpuBurst            5
meanIoBurst            35
meanNumberBursts        4
```

The above input parameters are designed to create input data that is unpredictable due to the large number of processes and the large difference in CPU and IO burst times. I have chosen a high inter-arrival time as I am not attempting to put high strain on the scheduler, I am only interested in how the scheduler performs when it is unaware of the workload and how we can improve the estimation of burst time for highly unpredictable workloads.

4.2.2 Simulator Parameters

I have chosen the following simulator parameters for this experiment. Note the poor estimate for initial burst and relatively high alpha burst times. I would like to look in depth at how these parameters can be optimized to improve the estimation of burst times.

[ ]:
```
exp.sim_params[0].drop(['scheduler'])
```

[ ]:
```
                       value
param
timeLimit               5000
interruptTime             10
timeQuantum               20
initialBurstEstimate      30
alphaBurstEstimate       0.7
periodic               false
```

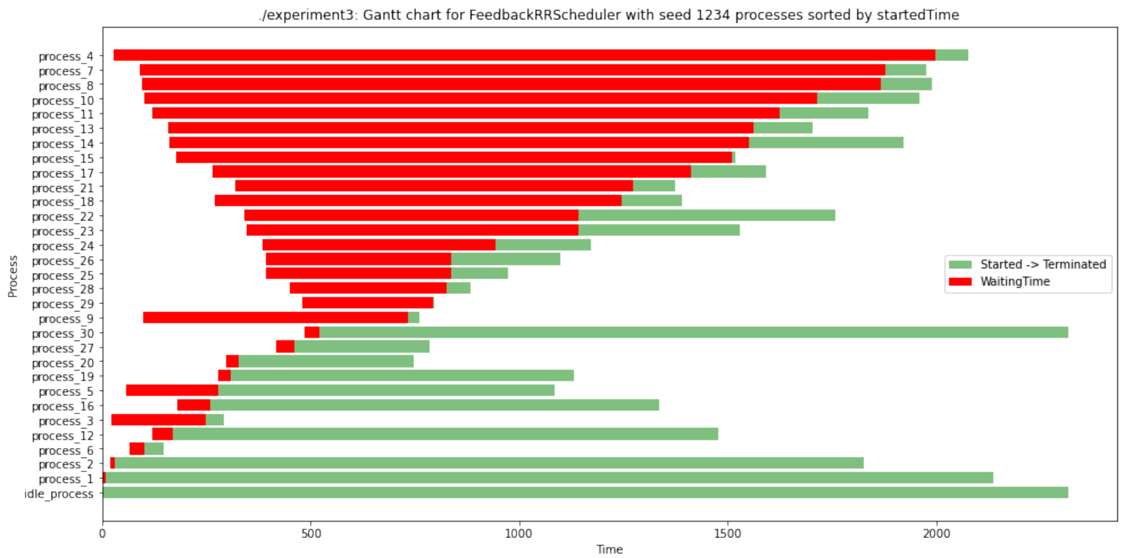
4.3 Results

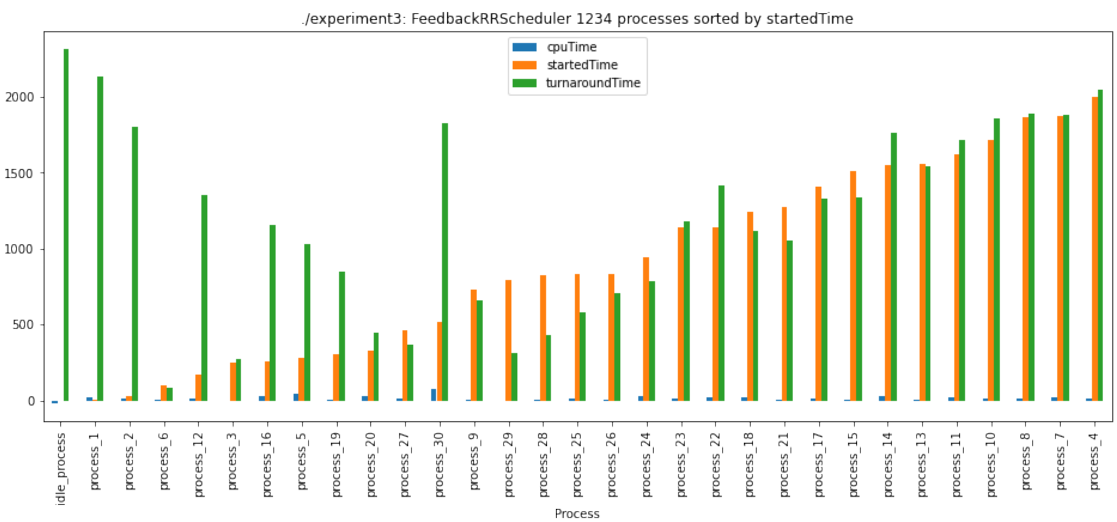
[ ]:
```
results = new_results()
```

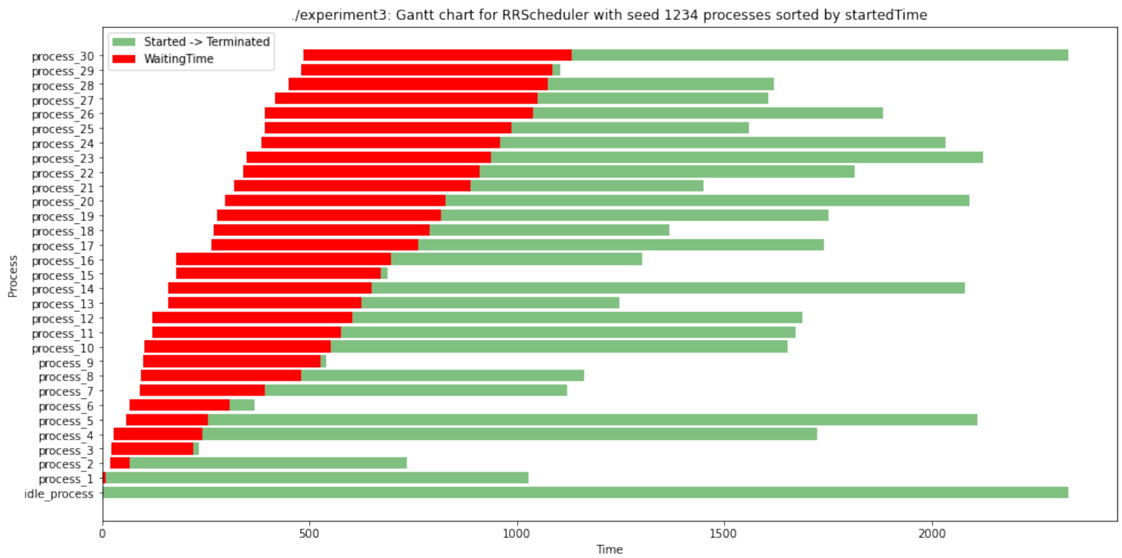
4.3.1 Results for Seed 1234

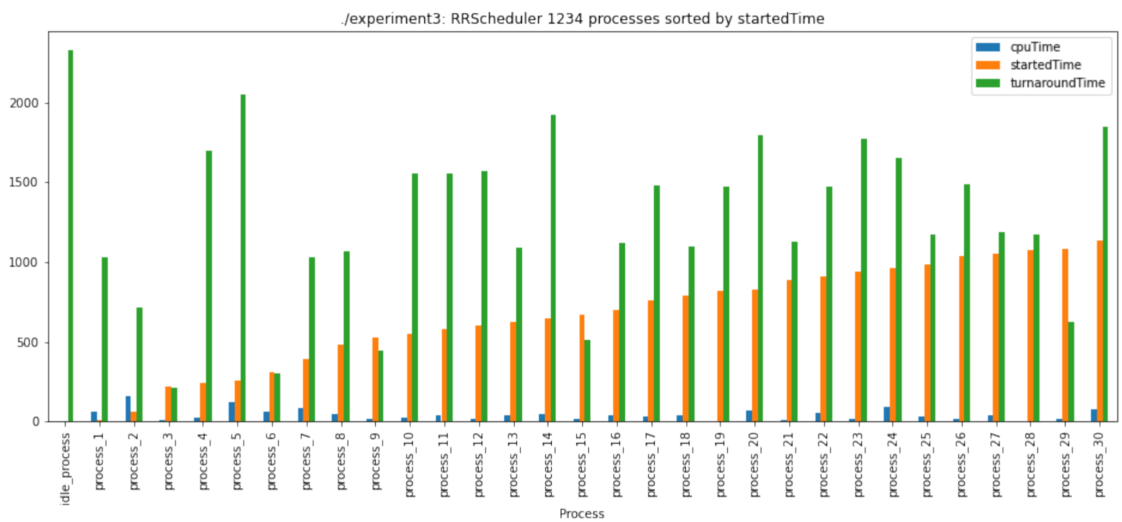
[ ]:
```
seed_to_analyse = '1234'
schedulers = ['FeedbackRRScheduler', 'RRScheduler', 'FcfsScheduler',␣
 ↪'SJFScheduler']
for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

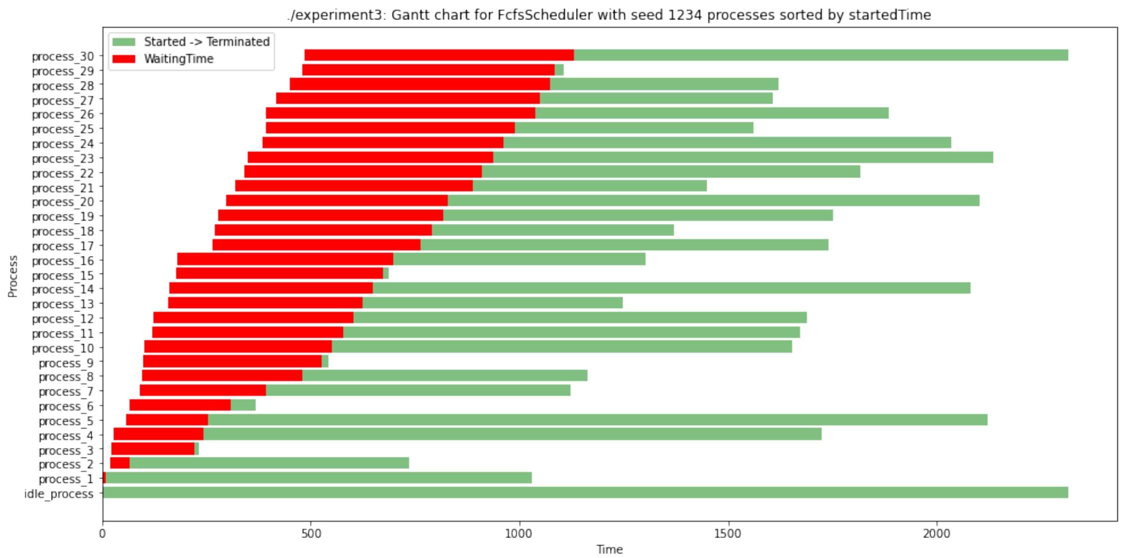
```
CPU Utilization for FeedbackRRScheduler: 98.959%
CPU Utilization for RRScheduler: 99.002%
CPU Utilization for FcfsScheduler: 98.999%
CPU Utilization for SJFScheduler: 98.988%
```

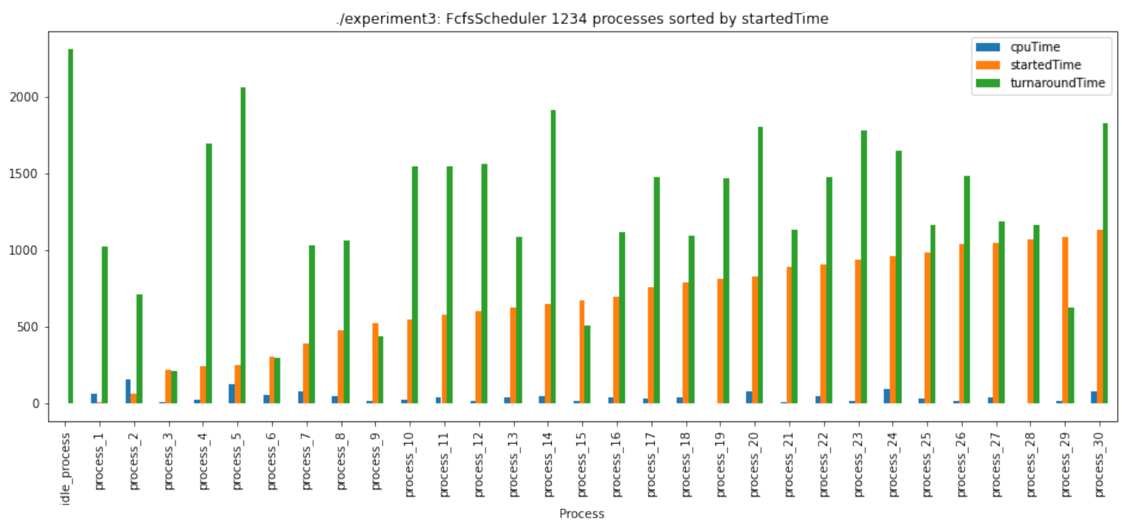

./experiment3: Gantt chart for FeedbackRRScheduler with seed 1234 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time

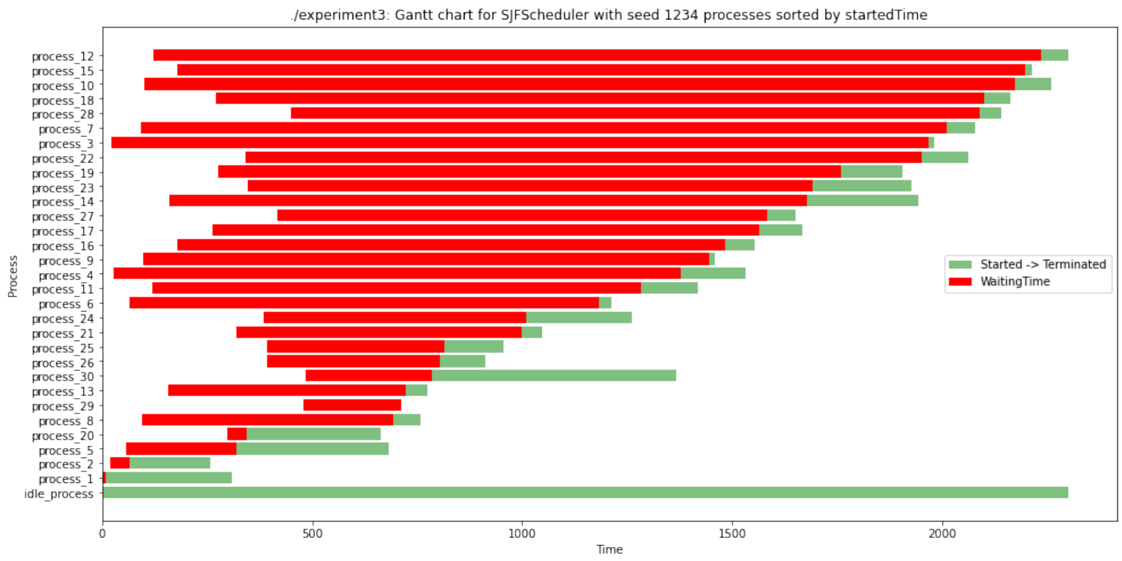

./experiment3: FeedbackRRScheduler 1234 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process

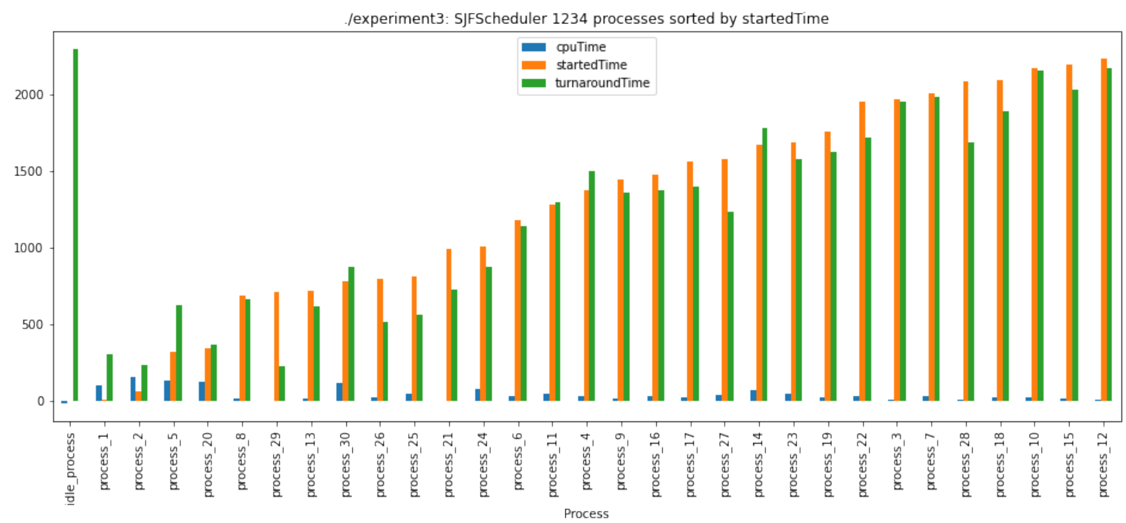

./experiment3: Gantt chart for RRScheduler with seed 1234 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_30
process_29
process_28
process_27
process_26
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
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


./experiment3: RRScheduler 1234 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
1000
1500
2000
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_26
process_27
process_28
process_29
process_30


./experiment3: Gantt chart for FcfsScheduler with seed 1234 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
0
500
1000
1500
2000
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_26
process_27
process_28
process_29
process_30


./experiment3: FcfsScheduler 1234 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
0
500
1000
1500
2000
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
process_26
process_27
process_28
process_29
process_30

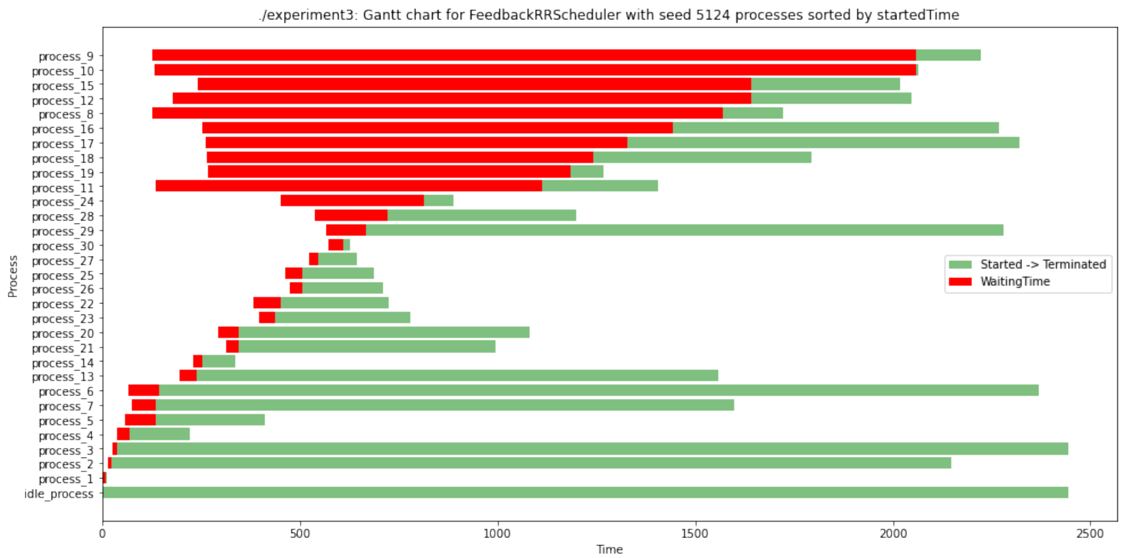


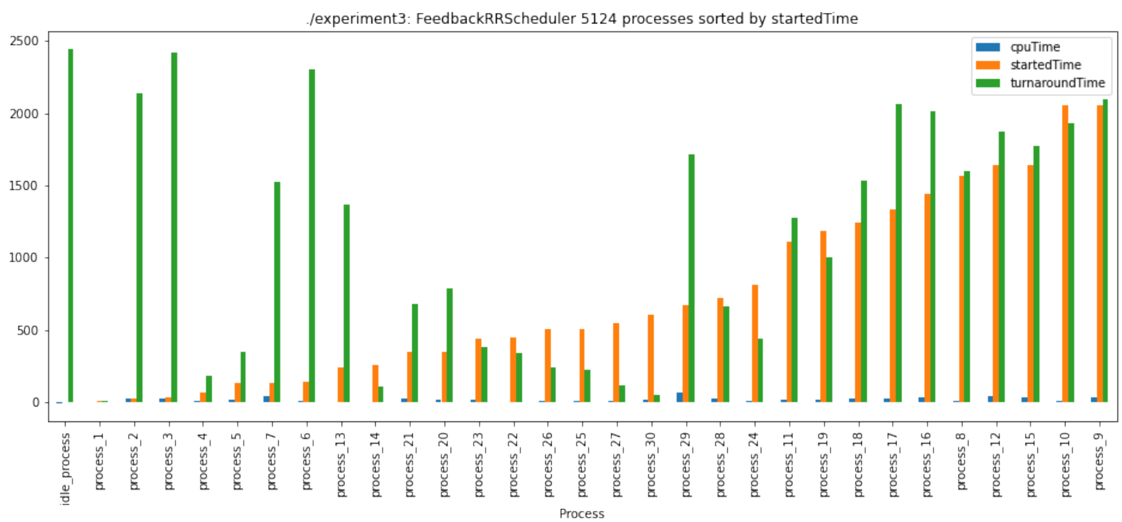


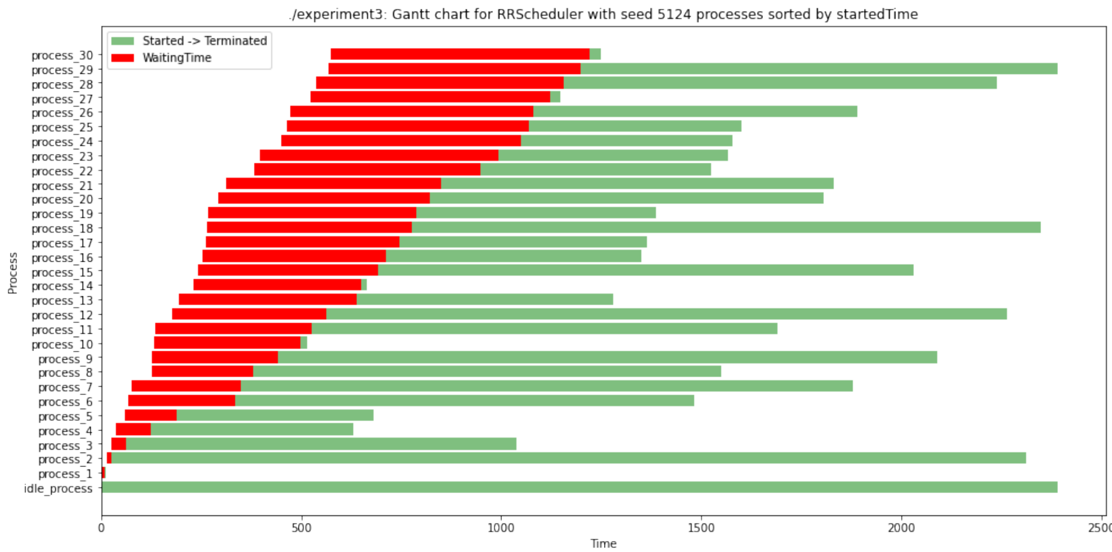
4.3.2 Results for Seed 5124

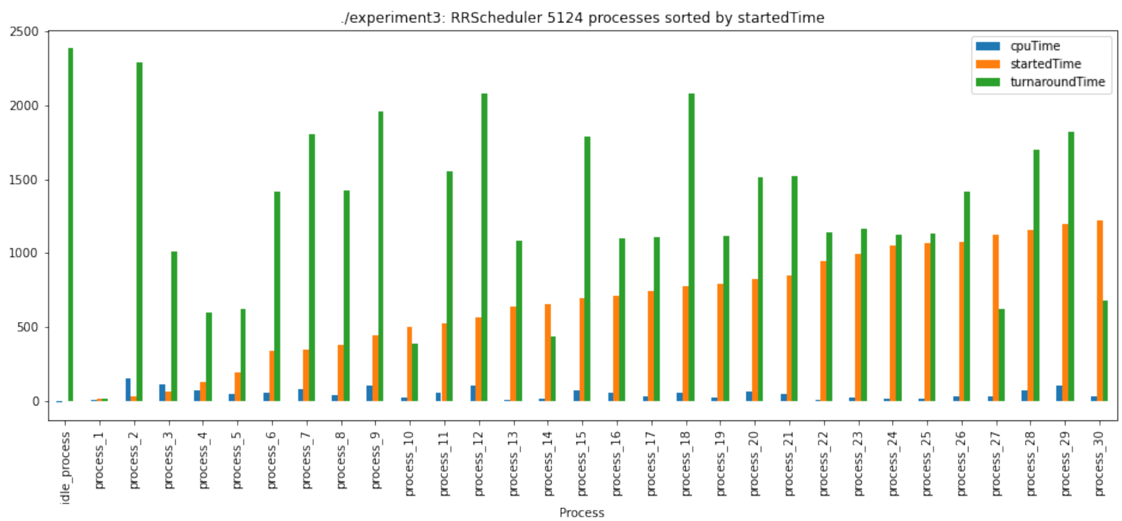
[ ]:
```
seed_to_analyse = '5124'
for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

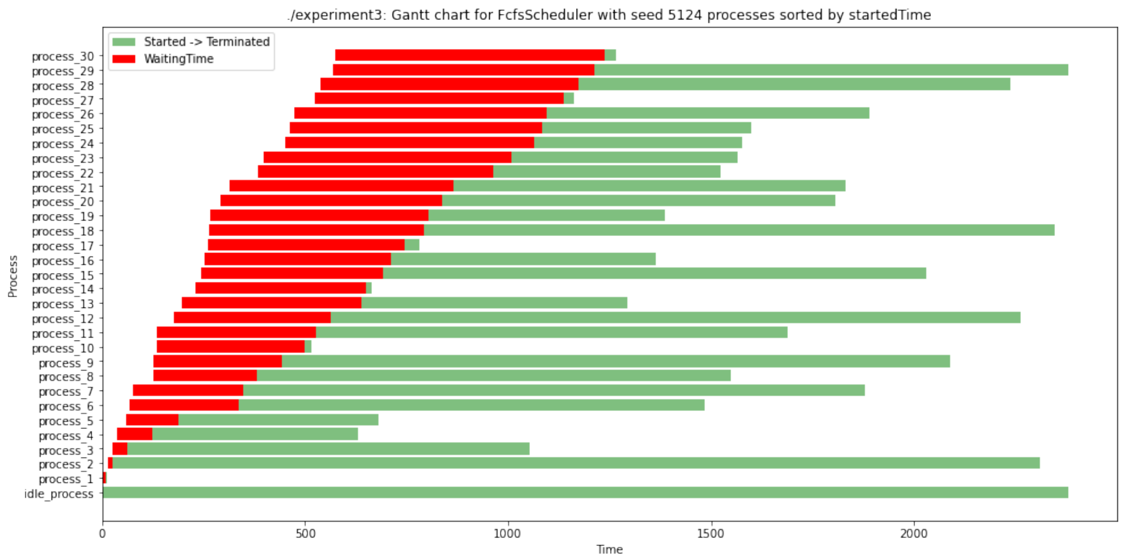
```
CPU Utilization for FeedbackRRScheduler: 98.979%
CPU Utilization for RRScheduler: 98.989%
CPU Utilization for FcfsScheduler: 98.989%
CPU Utilization for SJFScheduler: 98.989%
```

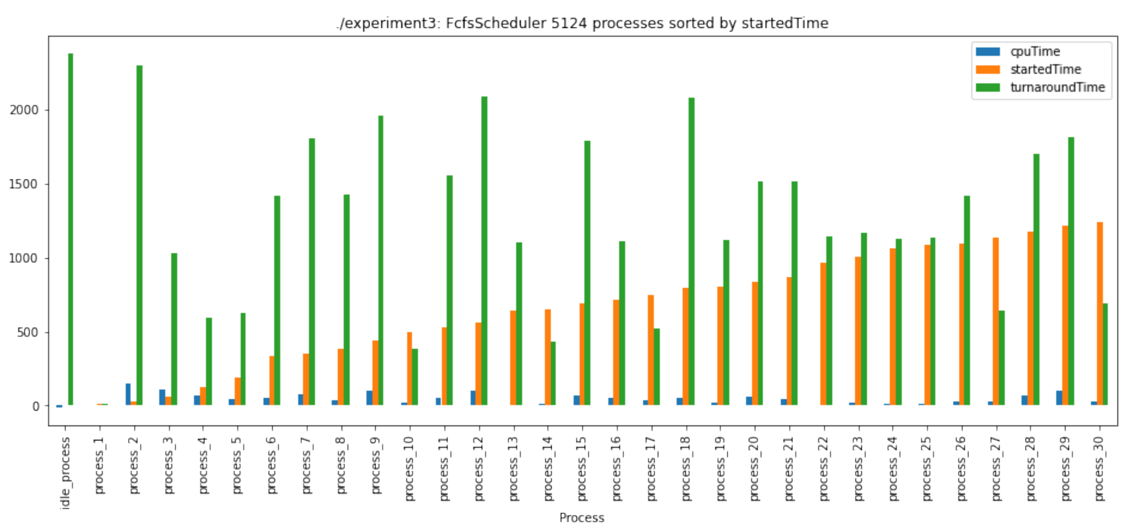

./experiment3: Gantt chart for FeedbackRRScheduler with seed 5124 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time

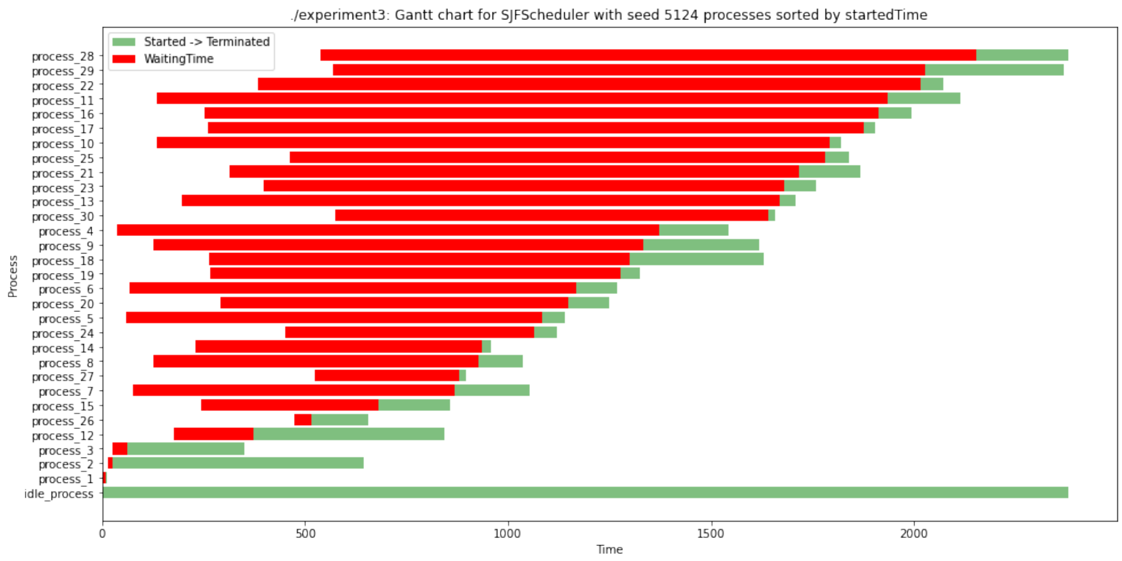

./experiment3: FeedbackRRScheduler 5124 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process

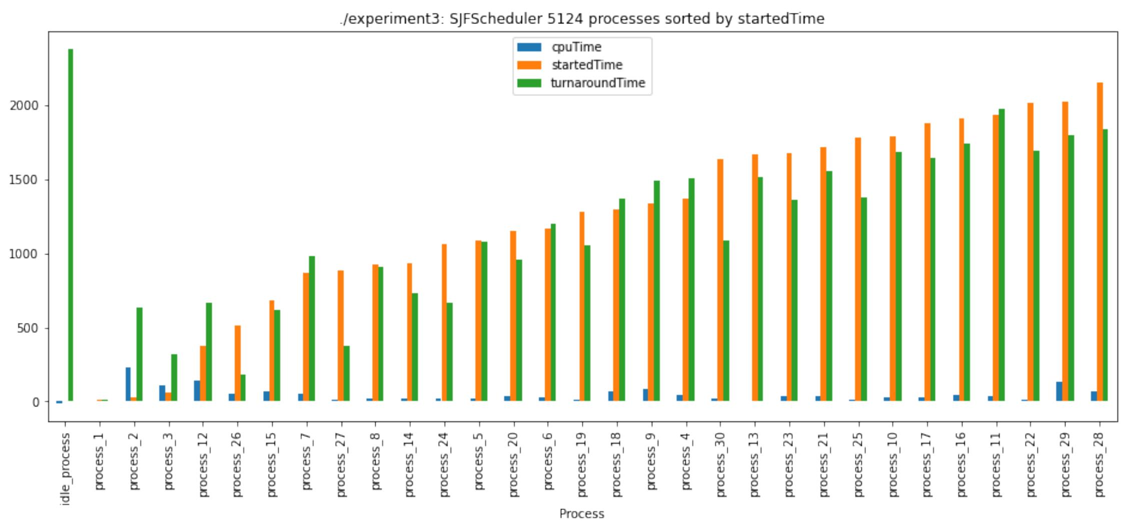

./experiment3: Gantt chart for RRScheduler with seed 5124 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_30
process_29
process_28
process_27
process_26
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
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


./experiment3: RRScheduler 5124 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
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_26
process_27
process_28
process_29
process_30


./experiment3: Gantt chart for FcfsScheduler with seed 5124 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time


./experiment3: FcfsScheduler 5124 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process

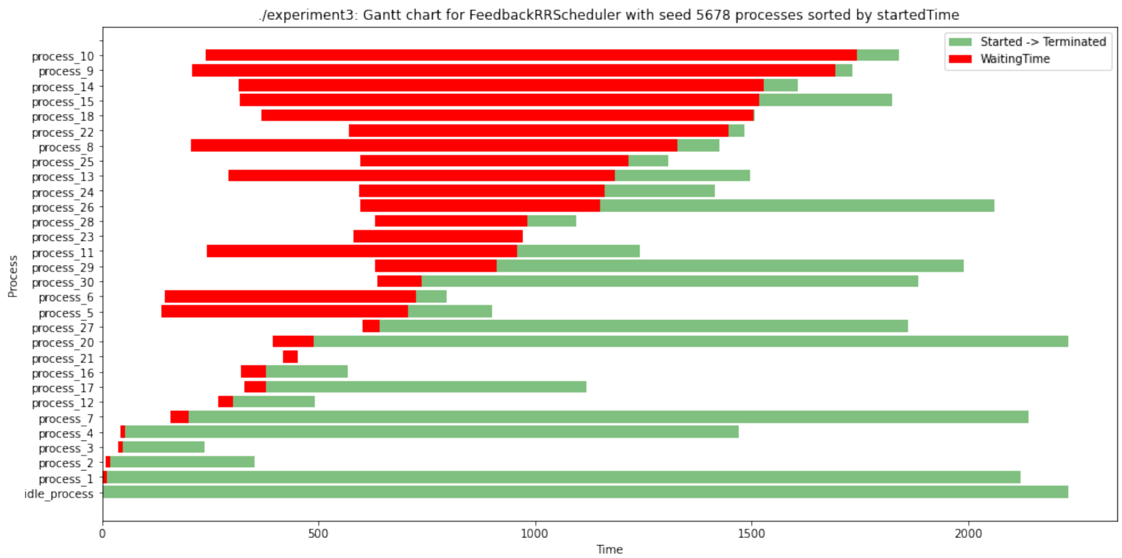


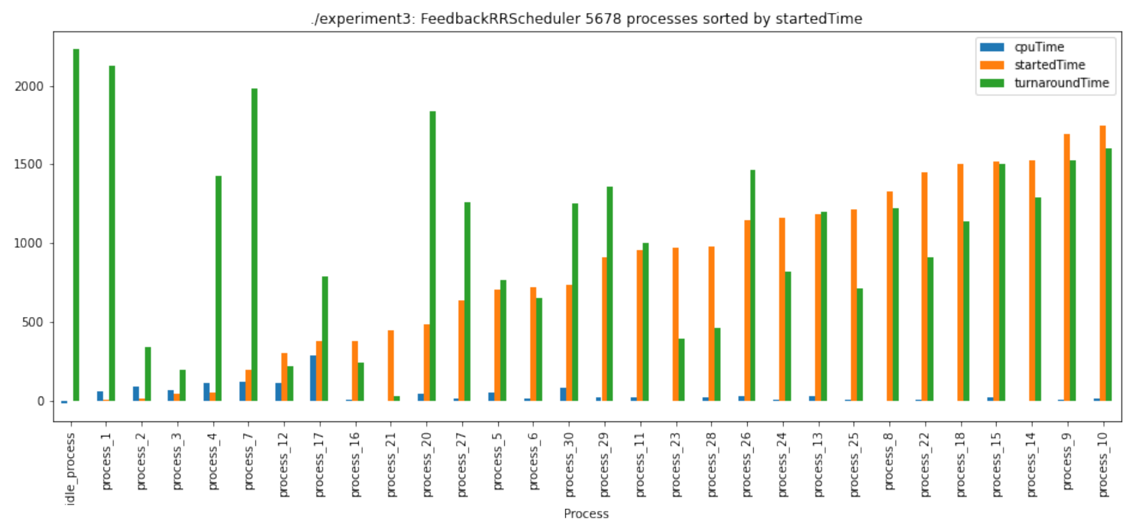


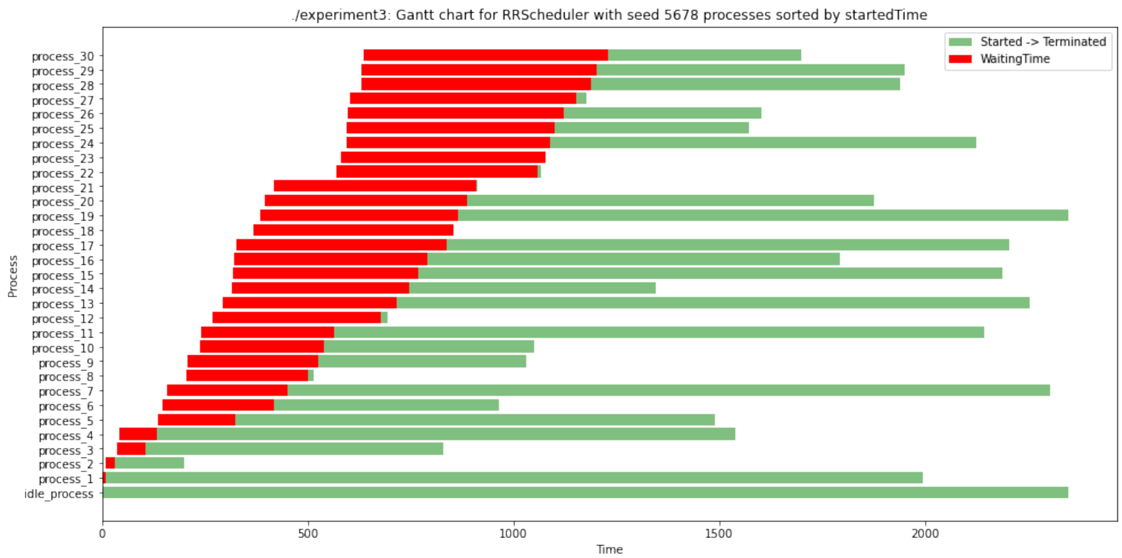
4.3.3 Results for Seed 5678

[ ]:
```
seed_to_analyse = '5678'
for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

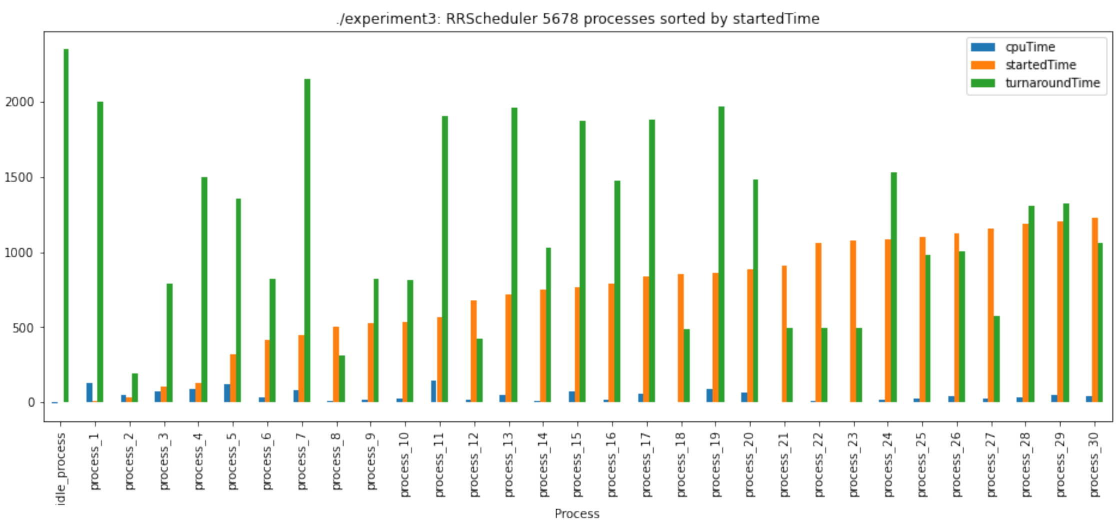
```
CPU Utilization for FeedbackRRScheduler: 98.986%
CPU Utilization for RRScheduler: 98.994%
CPU Utilization for FcfsScheduler: 98.994%
CPU Utilization for SJFScheduler: 98.988%
```


./experiment3: Gantt chart for FeedbackRRScheduler with seed 5678 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_10
process_9
process_14
process_15
process_18
process_22
process_8
process_25
process_13
process_24
process_26
process_28
process_23
process_11
process_29
process_30
process_6
process_5
process_27
process_20
process_21
process_16
process_17
process_12
process_7
process_4
process_3
process_2
process_1
idle_process
0
500
1000
1500
2000

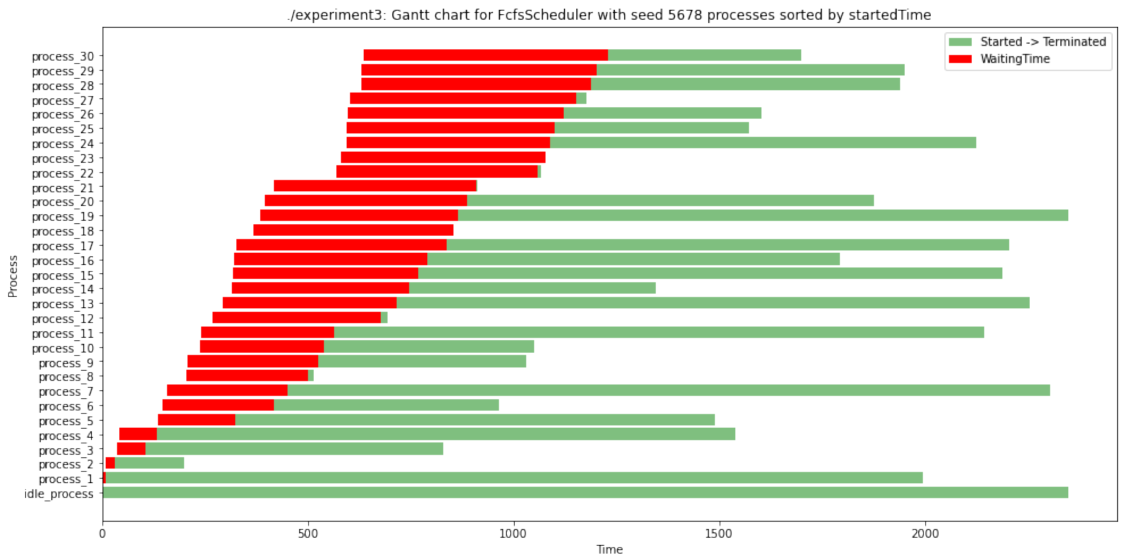

./experiment3: FeedbackRRScheduler 5678 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
0
500
1000
1500
2000
Process
idle_process
process_1
process_2
process_3
process_4
process_7
process_12
process_17
process_16
process_21
process_20
process_27
process_5
process_6
process_30
process_29
process_11
process_23
process_28
process_26
process_24
process_13
process_25
process_8
process_22
process_18
process_15
process_14
process_9
process_10

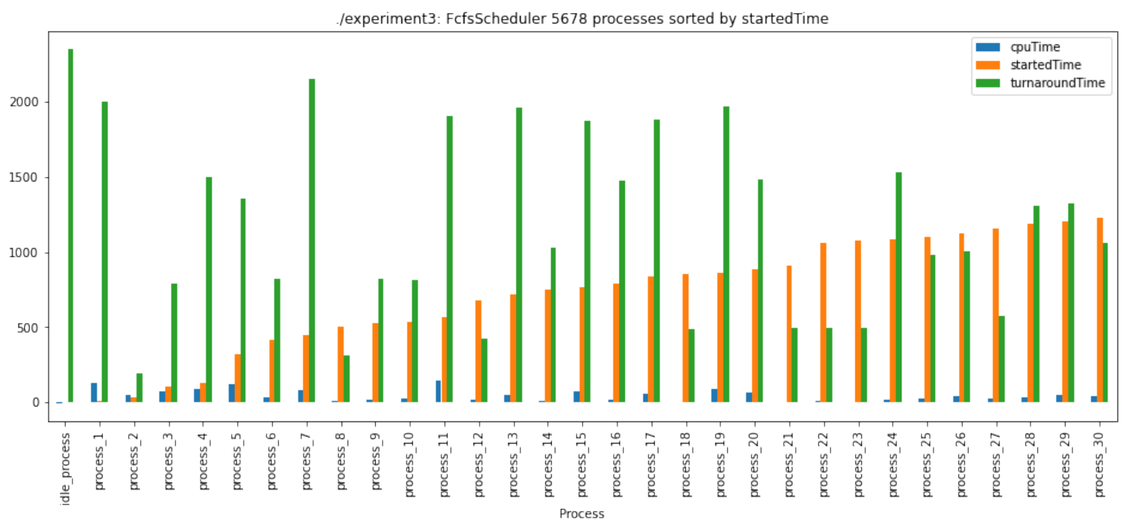


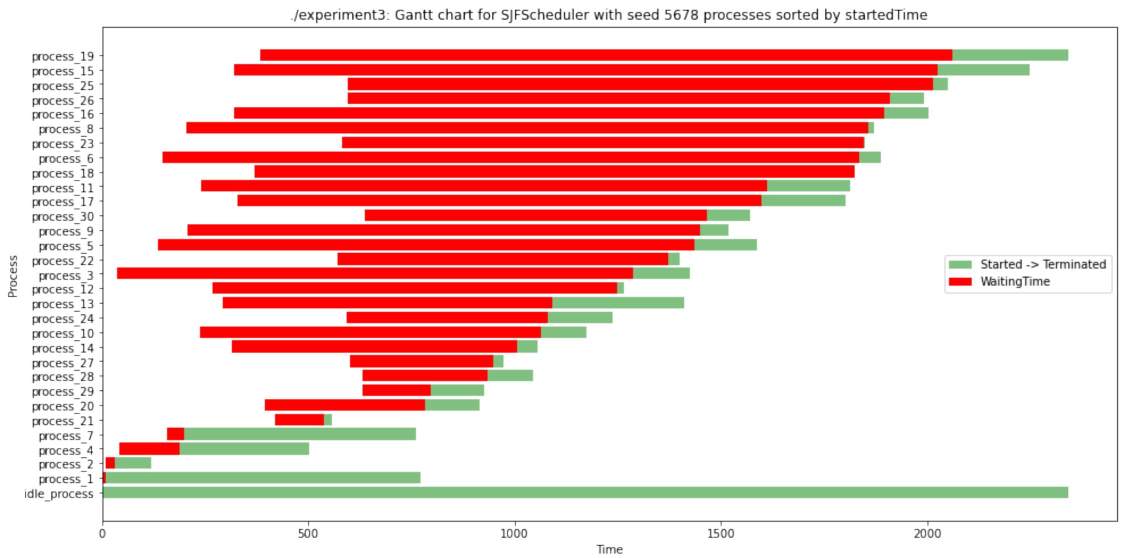
./experiment3: Gantt chart for RRScheduler with seed 5678 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time

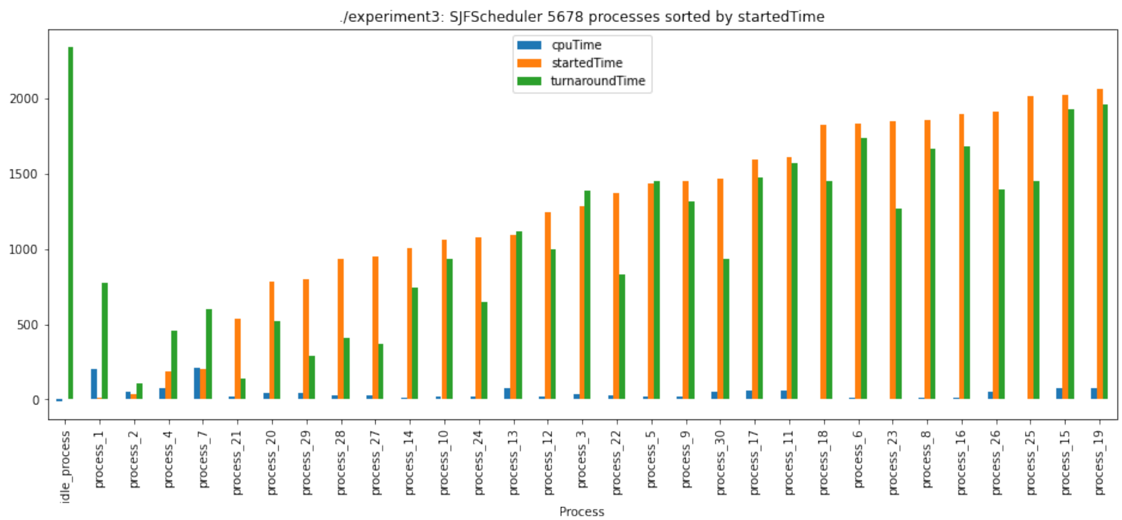


./experiment3: RRScheduler 5678 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process


./experiment3: Gantt chart for FcfsScheduler with seed 5678 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time


./experiment3: FcfsScheduler 5678 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process

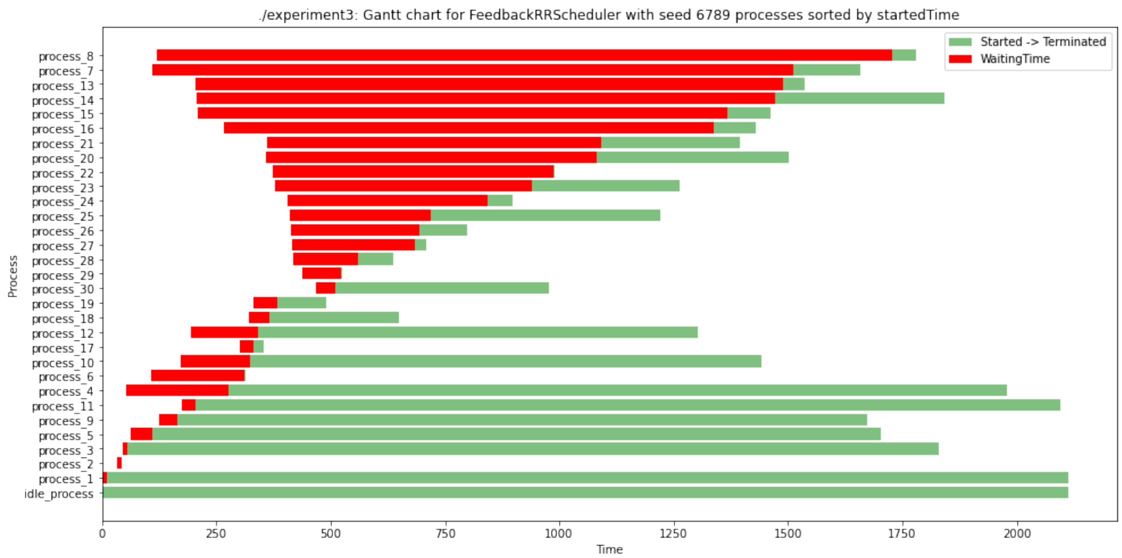


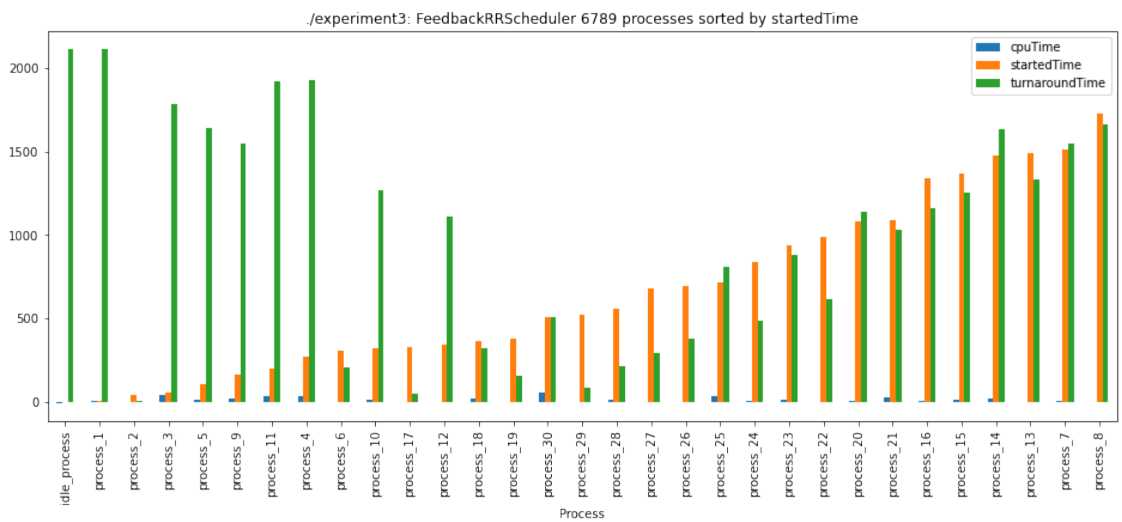


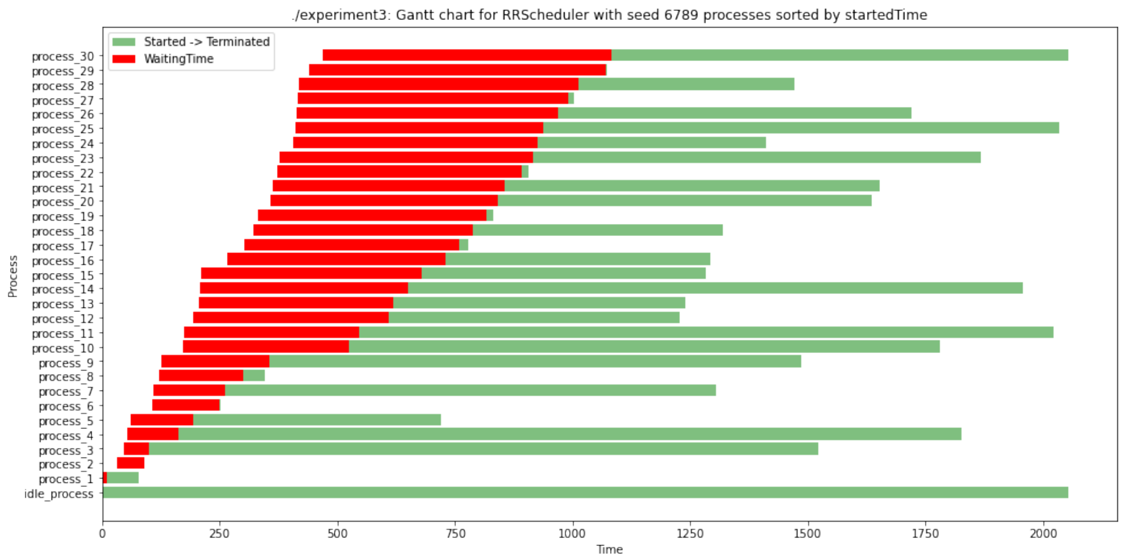
4.3.4 Results for Seed 6789

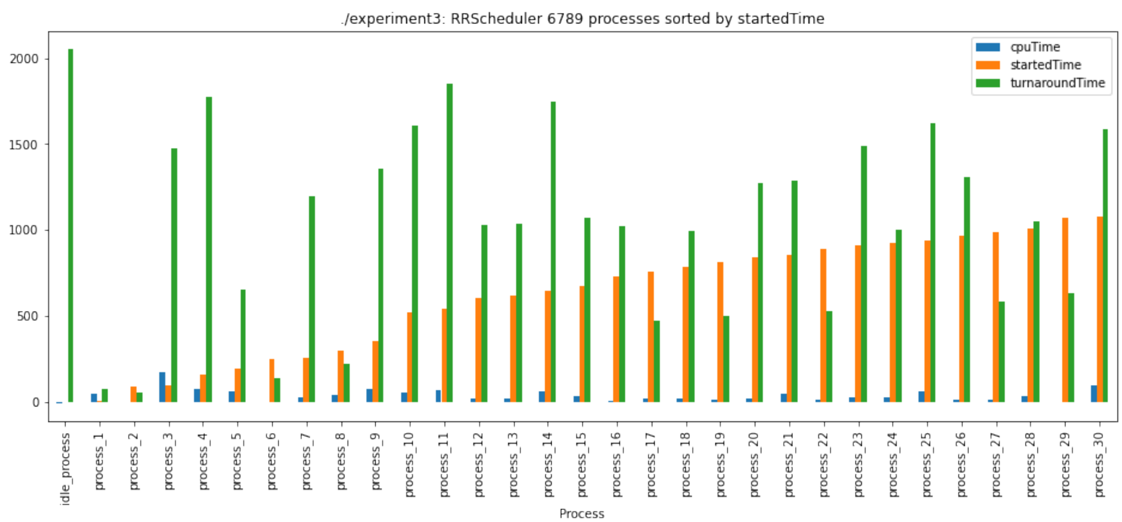
[ ]:
```
seed_to_analyse = '6789'
for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

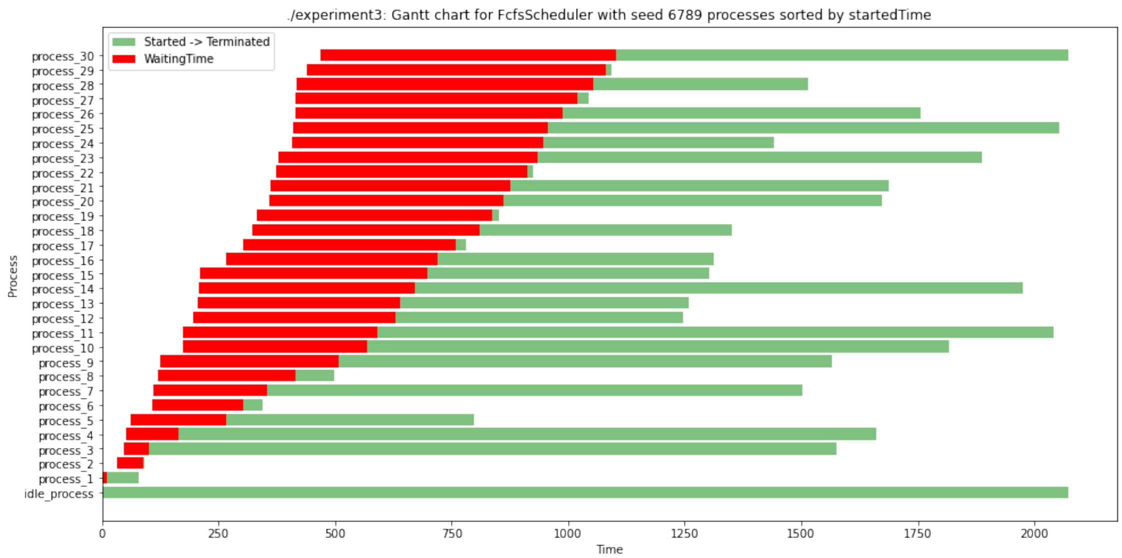
```
CPU Utilization for FeedbackRRScheduler: 98.981%
CPU Utilization for RRScheduler: 98.993%
CPU Utilization for FcfsScheduler: 98.993%
CPU Utilization for SJFScheduler: 98.993%
```

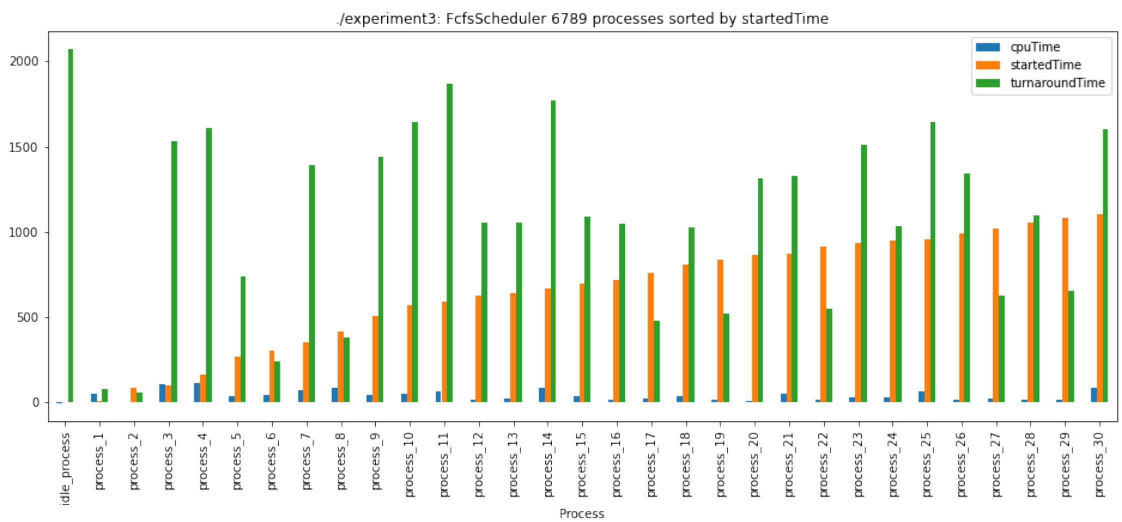

./experiment3: Gantt chart for FeedbackRRScheduler with seed 6789 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_8
process_7
process_13
process_14
process_15
process_16
process_21
process_20
process_22
process_23
process_24
process_25
process_26
process_27
process_28
process_29
process_30
process_19
process_18
process_12
process_17
process_10
process_6
process_4
process_11
process_9
process_5
process_3
process_2
process_1
idle_process
0
250
500
750
1000
1250
1500
1750
2000

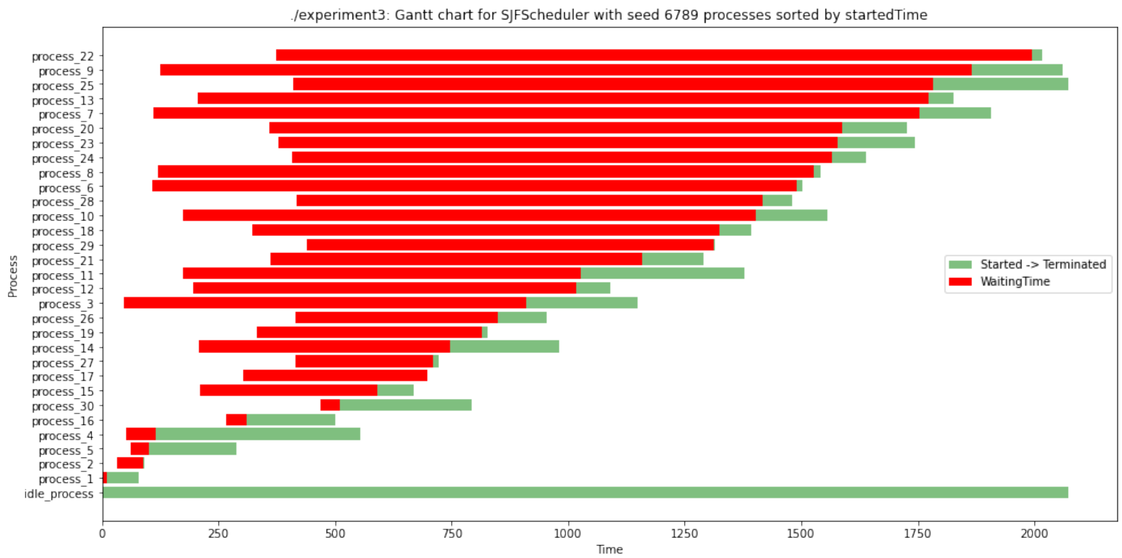

./experiment3: FeedbackRRScheduler 6789 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
1000
1500
2000
idle_process
process_1
process_2
process_3
process_5
process_9
process_11
process_4
process_6
process_10
process_17
process_12
process_18
process_19
process_30
process_29
process_28
process_27
process_26
process_25
process_24
process_23
process_22
process_20
process_21
process_16
process_15
process_14
process_13
process_7
process_8

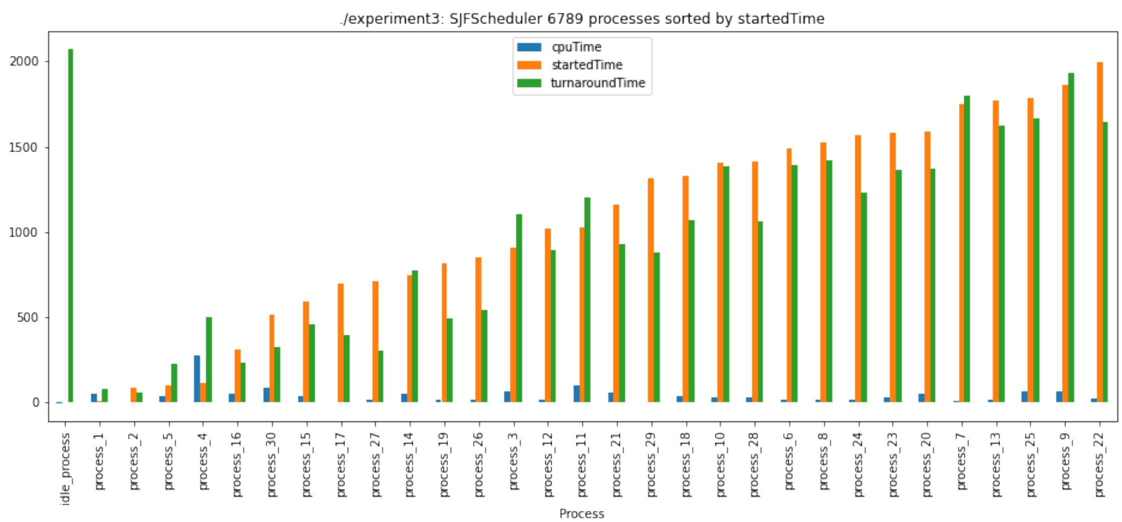

./experiment3: Gantt chart for RRScheduler with seed 6789 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time


./experiment3: RRScheduler 6789 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process


./experiment3: Gantt chart for FcfsScheduler with seed 6789 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
process_26
process_27
process_28
process_29
process_30
0
250
500
750
1000
1250
1500
1750
2000


./experiment3: FcfsScheduler 6789 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
1000
1500
2000

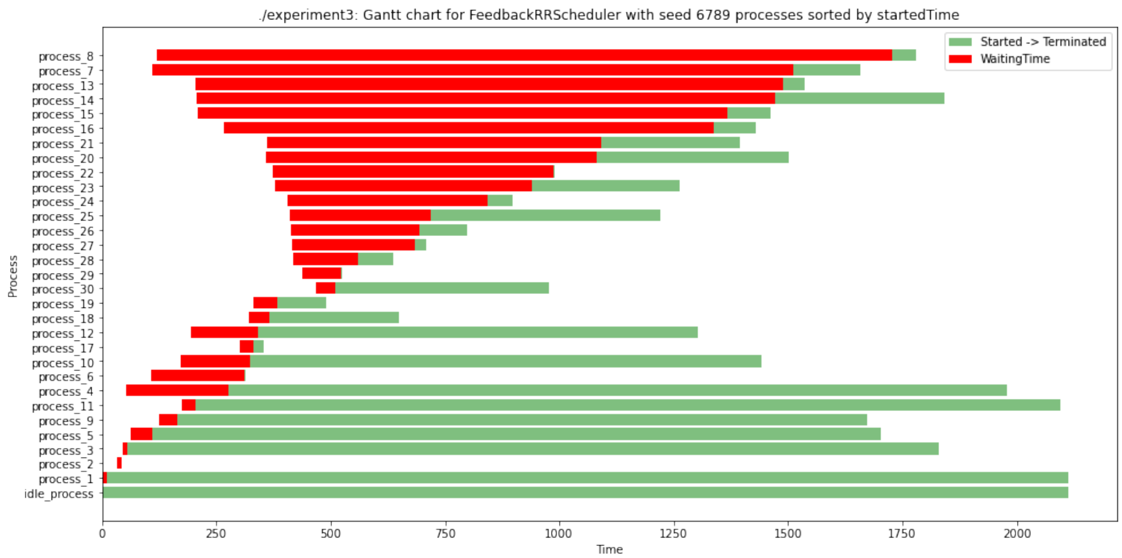


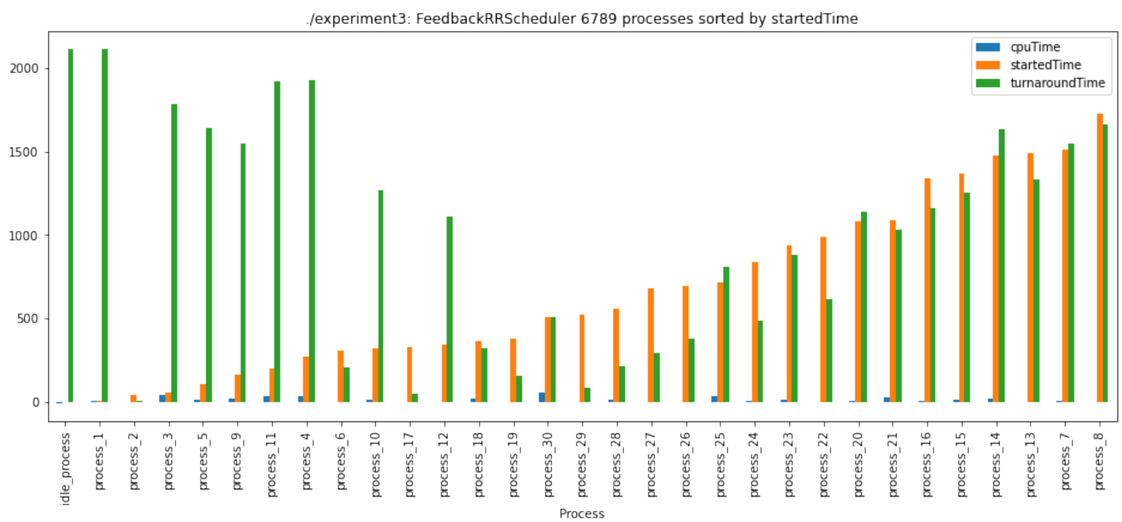


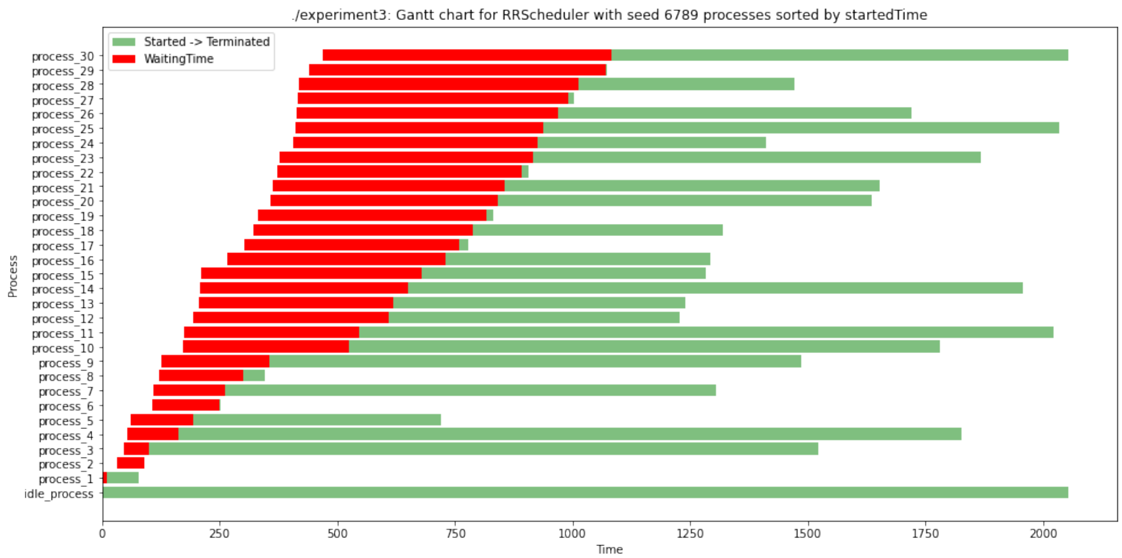
4.3.5 Results for Seed 91011

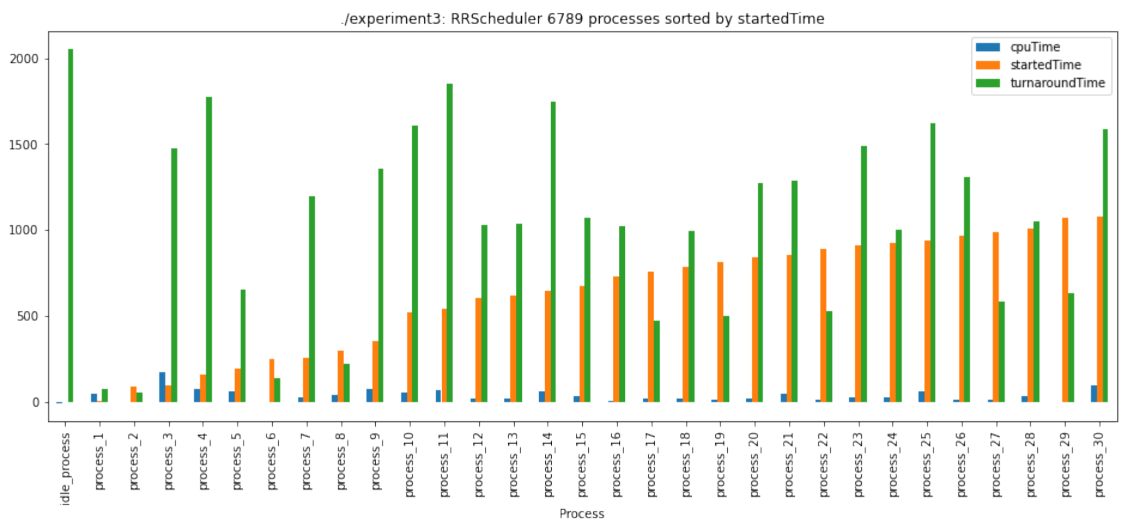
[ ]:
```
for scheduler in schedulers:
        show_results(exp, scheduler, seed_to_analyse)
```

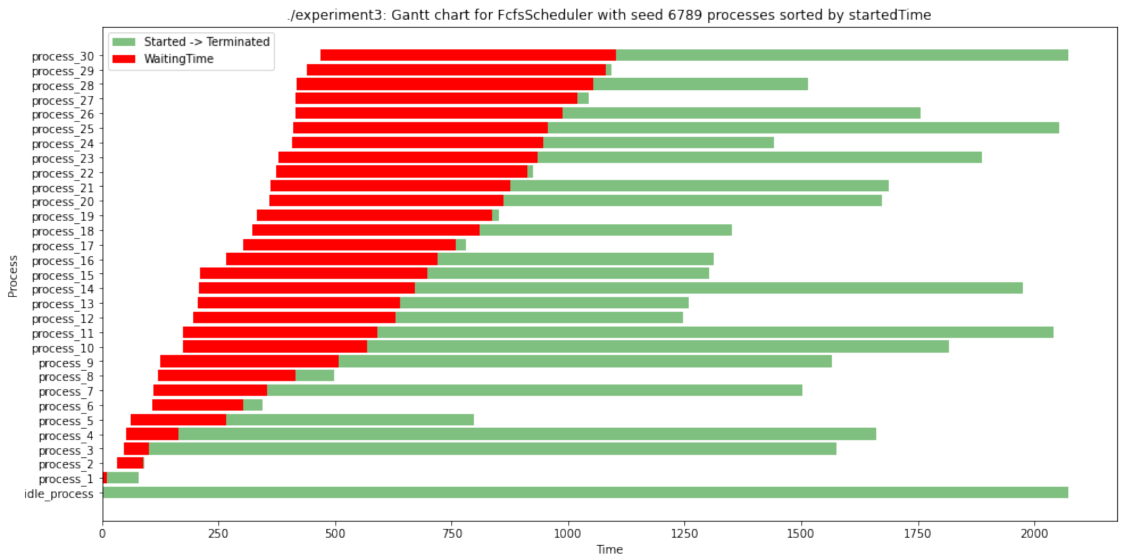
```
CPU Utilization for FeedbackRRScheduler: 98.981%
CPU Utilization for RRScheduler: 98.993%
CPU Utilization for FcfsScheduler: 98.993%
CPU Utilization for SJFScheduler: 98.993%
```

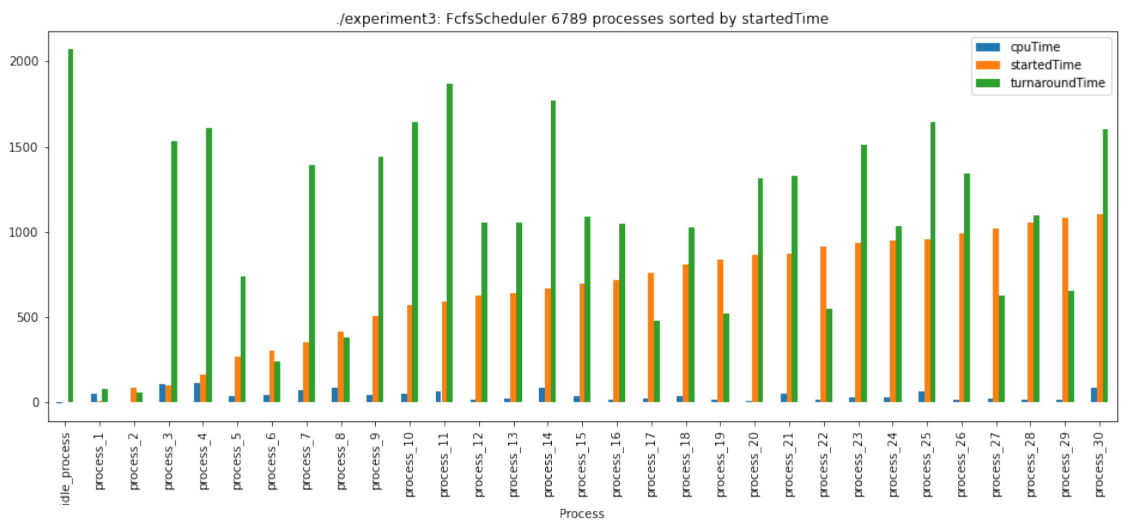

./experiment3: Gantt chart for FeedbackRRScheduler with seed 6789 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time

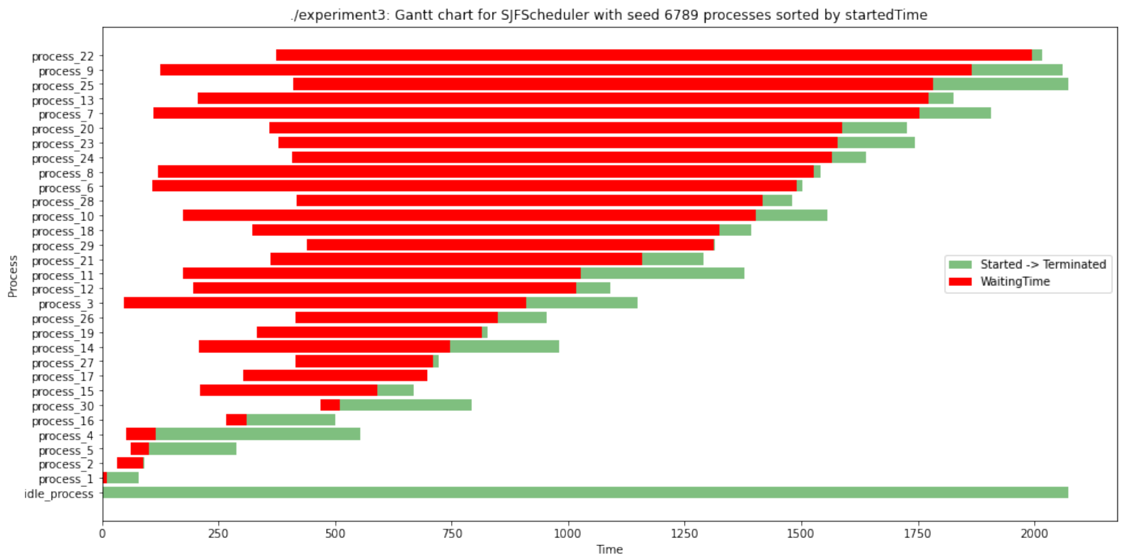

./experiment3: FeedbackRRScheduler 6789 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process

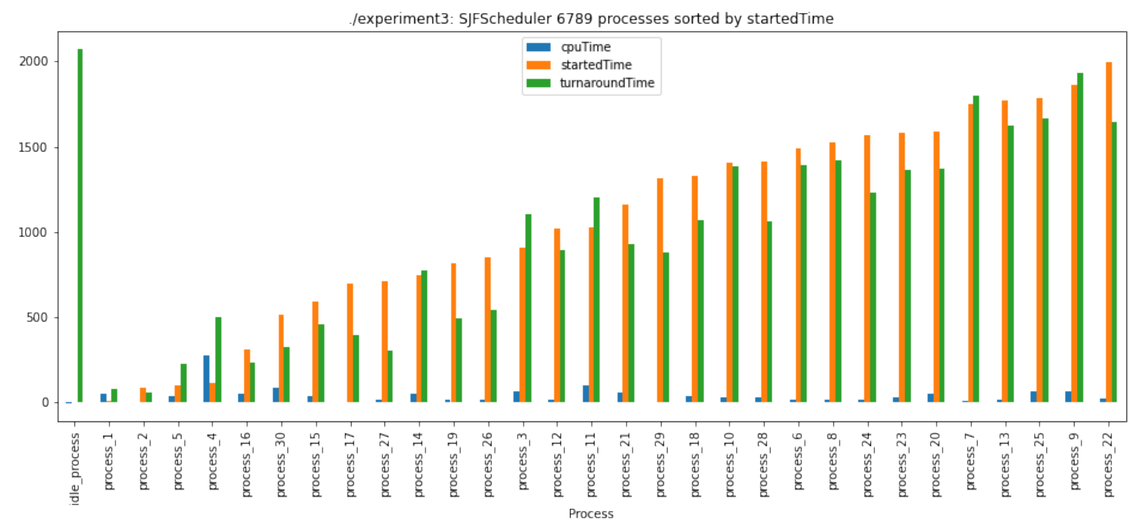

./experiment3: Gantt chart for RRScheduler with seed 6789 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_30
process_29
process_28
process_27
process_26
process_25
process_24
process_23
process_22
process_21
process_20
process_19
process_18
process_17
process_16
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
250
500
750
1000
1250
1500
1750
2000


./experiment3: RRScheduler 6789 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
2000
1500
1000
500
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
process_26
process_27
process_28
process_29
process_30


./experiment3: Gantt chart for FcfsScheduler with seed 6789 processes sorted by startedTime
Started -> Terminated
WaitingTime
Process
Time
process_30
process_29
process_28
process_27
process_26
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
250
500
750
1000
1250
1500
1750
2000


./experiment3: FcfsScheduler 6789 processes sorted by startedTime
cpuTime
startedTime
turnaroundTime
Process
0
500
1000
1500
2000
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_26
process_27
process_28
process_29
process_30





4.3.6 Analysis of Results

Upon examining the Gantt Charts for each of the results, it is clear that the Shortest Job First algorithm is suffering from the convoy effect to some extent, this will be due to the estimations performed by the algorithm, as it is unable to accurately estimate the burst times of the processes since there is so much variation. We will look to improve this.

First, we will compare the Waiting Times, Turnaround Times and CPU Utilisation for each of the algorithms over the 5 seeds.

[ ]:
```
means = results.groupby(['Scheduler']).mean()
stds = results.groupby(['Scheduler']).std()

stds = stds.rename(columns={
        'MeanWaitingTime': 'StdDevWaitingTime',
        'MeanTurnaroundTime': 'StdDevTurnaroundTime',
        'CpuUtilization': 'StdDevCpuUtilization',
        'MeanResponseTime': 'StdDevResponseTime'
})

print("Means of results for each scheduler over all seeds")
means
```

```
Means of results for each scheduler over all seeds
```

[ ]:
```
                               Seed  MeanWaitingTime  MeanTurnaroundTime  \
Scheduler
FcfsScheduler          2.469025e+18       405.593548         1184.083871
FeedbackRRScheduler    2.469025e+18       496.897849         1086.497204
ImprovedSJFScheduler   3.416082e+61       737.735484         1086.070968
NewSJFScheduler        1.024825e+20       737.735484         1086.070968
RRScheduler            2.469025e+18       392.200000         1173.858065
SJFScheduler           2.469025e+18       894.367742         1097.122581

                      MeanResponseTime  CpuUtilization
Scheduler
FcfsScheduler               402.761290       98.993347
FeedbackRRScheduler         494.099355       98.977177
ImprovedSJFScheduler        734.877419       98.992698
NewSJFScheduler             734.877419       98.992698
RRScheduler                 389.367742       98.994001
SJFScheduler                891.535484       98.990124
```

[ ]:
```
print("Standard Deviations of results for each scheduler over all seeds")
stds
```

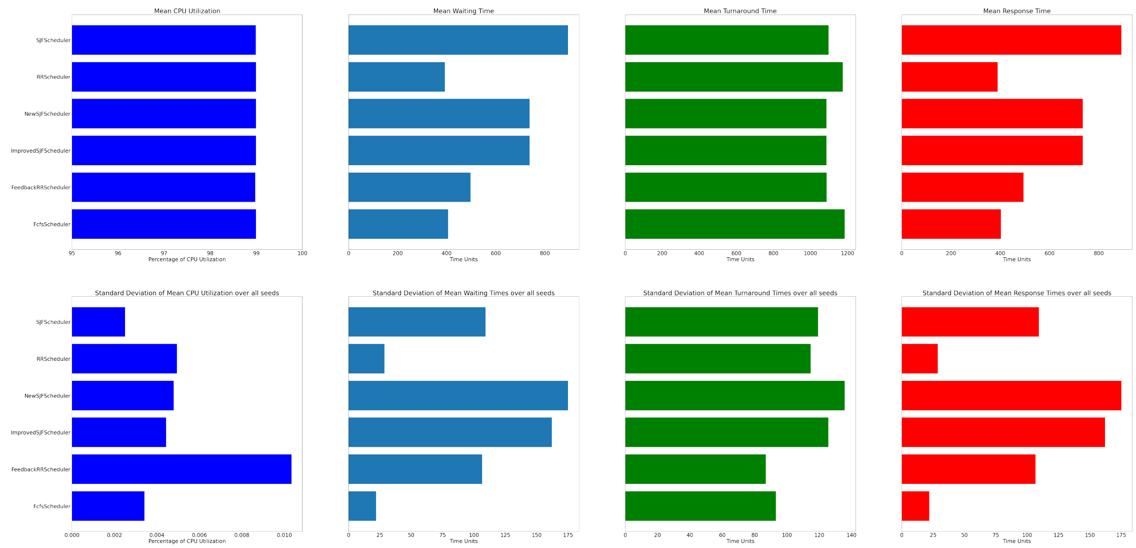
```
Standard Deviations of results for each scheduler over all seeds
```

[ ]:
```
                               Seed  StdDevWaitingTime  StdDevTurnaroundTime  \
Scheduler
FcfsScheduler           2290.385273          21.901071             93.117089
FeedbackRRScheduler     2290.385273         106.481280             86.921470
ImprovedSJFScheduler   35786.034024         161.984403            125.589740
NewSJFScheduler        38653.334522         174.963153            135.652423
RRScheduler             2290.385273          28.646954            114.684487
SJFScheduler            2290.385273         109.270958            119.248487
```

```
                        StdDevResponseTime  StdDevCpuUtilization
Scheduler
FcfsScheduler                    21.949813              0.003414
FeedbackRRScheduler             106.487970              0.010333
ImprovedSJFScheduler            161.957240              0.004438
NewSJFScheduler                 174.933813              0.004793
RRScheduler                      28.657878              0.004939
SJFScheduler                    109.258664              0.002500
```

[ ]:
```
def plot_means_and_std(means, stds):
        fig, (ax1, ax2) = plt.subplots(2,4, sharey='all',)
        fig.set_size_inches(100, 50)


        ax1[0].set_xlabel("Percentage of CPU Utilization")
        ax1[0].barh(means.index, means['CpuUtilization'], color='b')
        ax1[0].set_title("Mean CPU Utilization")
        ax1[0].set_xbound(95, 100)

        ax1[1].set_xlabel("Time Units")
        ax1[1].set_title("Mean Waiting Time")
        ax1[1].barh(means.index, means['MeanWaitingTime'])

        ax1[2].set_title("Mean Turnaround Time")
        ax1[2].barh(means.index, means['MeanTurnaroundTime'], color='g')
        ax1[2].set_xlabel("Time Units")

        ax1[3].set_title("Mean Response Time")
        ax1[3].barh(means.index, means['MeanResponseTime'], color='r')
        ax1[3].set_xlabel("Time Units")

        ax2[0].set_xlabel("Percentage of CPU Utilization")
        ax2[0].barh(means.index, stds['StdDevCpuUtilization'], color='b')
        ax2[0].set_title("Standard Deviation of Mean CPU Utilization over all␣
 ↪seeds")

        ax2[1].set_xlabel("Time Units")
        ax2[1].set_title("Standard Deviation of Mean Waiting Times over all␣
 ↪seeds")
        ax2[1].barh(means.index, stds['StdDevWaitingTime'])

        ax2[2].set_title("Standard Deviation of Mean Turnaround Times over all␣
 ↪seeds")
        ax2[2].barh(means.index, stds['StdDevTurnaroundTime'], color='g')
        ax2[2].set_xlabel("Time Units")
```

```
        ax2[3].set_title("Standard Deviation of Mean Response Times over all␣
↪seeds")
        ax2[3].barh(means.index, stds['StdDevResponseTime'], color='r')
        ax2[3].set_xlabel("Time Units")
plot_means_and_std(means, stds)
```



The above figure shows the means and standard deviations for the CPU Utilisation, Waiting Times and Turnaround Times and Response Times for each of the algorithms over the 5 seeds.

As can be seen above, the Shortest Job First algorithm has the highest average response time and wait time. However, we can also the that the standard deviation on all of these statistics for the Shortest Job First algorithm is very high, which is likely due to the algorithm not being able to accurately estimate the burst times of the processes using the exponential averaging method given the initial parameters it was given.

Above, we can see that the Feedback Round Robin scheduler performs poorly as far as waiting times and turnaround times. This can be seen in the Gantt chart and likely comes from the large number of processes and the large difference in CPU and IO burst times, which is causing the algorithm to demote processes after they have reached their time quantum, which is small in comparison to the average IO burst time.

4.4 Improving the Estimation of Burst Times for the Shortest Job First Algorithm for Highly Varying Workloads

To better predict the estimation of burst times in the non-preemptive shortest job first algorithm, we will look at how the estimation of the next burst time is actually calculated.

We define the initial burst time and alpha burst time as the following.

$$\text{Initial Burst Time - } \tau_0$$

Alpha Burst Time - α

Now, using these values. We can calculate $ _1 $ by the following equation.

$$\tau_1 = (\alpha \cdot \tau_0) \cdot (1 - \alpha)\tau_0$$

More generally, we calculate the next burst time by iterating to calculate $ _n $ for the nth burst.

$$\tau_n = (\alpha \cdot \tau_{n-1}) \cdot (1 - \alpha)\tau_{n-1}$$

Note that after the first burst, we no longer need to use the initial burst time, as we can use the previous burst time to estimate.

We can note that this equation shows us that the α burst time is key to estimation as it signifies (between 0 and 1) how much the burst time is influenced by the previous burst time. In highly varied scenarios, this should be a low value, as the previous burst time will given little indication of the next burst time. Initially for this experiment, we set the α burst time to 0.7, which is quite high, we should make this value lower to improve the estimation of the burst times.

In addition, our initial burst time was set to 30, which is also quite high given that the average CPU burst time is 5 and the average IO burst time is 25. We should make this value the average of these two values which is 15. However, in a real world scenario, we would likely not know what the average CPU/IO burst times are, so we would need to look closer at the workload to determine a good estimation technique.

[ ]:
```
exp3_improved = Experiment('./experiment4')
exp3_improved.sim_params[0].drop(['scheduler'])
```

[ ]:
```
                         value
param
timeLimit                 5000
interruptTime               10
timeQuantum                 20
initialBurstEstimate        15
alphaBurstEstimate         0.4
periodic                 false
```

4.4.1 Results for Updated Estimation of Burst Times

[ ]:
```
new_sjf_results = new_results()
for i, seed in enumerate(exp3_improved.all_seeds()):
        df = exp3_improved.get_output_for_seed('SJFScheduler', seed)
        cpu_util = exp3_improved.
 ↪calculate_cpu_utilization_for_output('SJFScheduler', seed)
        waiting_time = df.waitingTime.mean()
        turnaround_time = df.turnaroundTime.mean()
        response_time = df.responseTime.mean()
```

```
        res = pd.DataFrame({
                'Scheduler': 'NewSJFScheduler',
                'Seed': seed,

                'CpuUtilization': cpu_util,
                'MeanWaitingTime': waiting_time,
                'MeanTurnaroundTime': turnaround_time,
                'MeanResponseTime': response_time
        }, index=[i]);

        new_sjf_results = pd.concat([new_sjf_results, res])



results = pd.concat([results, new_sjf_results], ignore_index=True)
new_sjf_results
```

[ ]:

```
    Seed        Scheduler  MeanWaitingTime  MeanTurnaroundTime  MeanResponseTime  \
0   5124  NewSJFScheduler       965.709677         1252.387097        962.806452
1   1234  NewSJFScheduler       821.322581         1161.709677        818.548387
2   5678  NewSJFScheduler       723.677419         1074.129032        720.741935
3   6789  NewSJFScheduler       491.419355          888.516129        488.645161
4  91011  NewSJFScheduler       686.548387         1053.612903        683.645161

   CpuUtilization
0       98.991573
1       98.998524
2       98.993612
3       98.985413
4       98.994366
```

We will now analyse the results of the updated estimation and compare them to the results of the original estimation.

[ ]:

```
compared_sjfs = pd.concat([results[
        results['Scheduler'] == 'SJFScheduler'],
 new_sjf_results], ignore_index=True)
compared_sjfs.set_index('Seed', inplace=True)
compared_sjfs
```

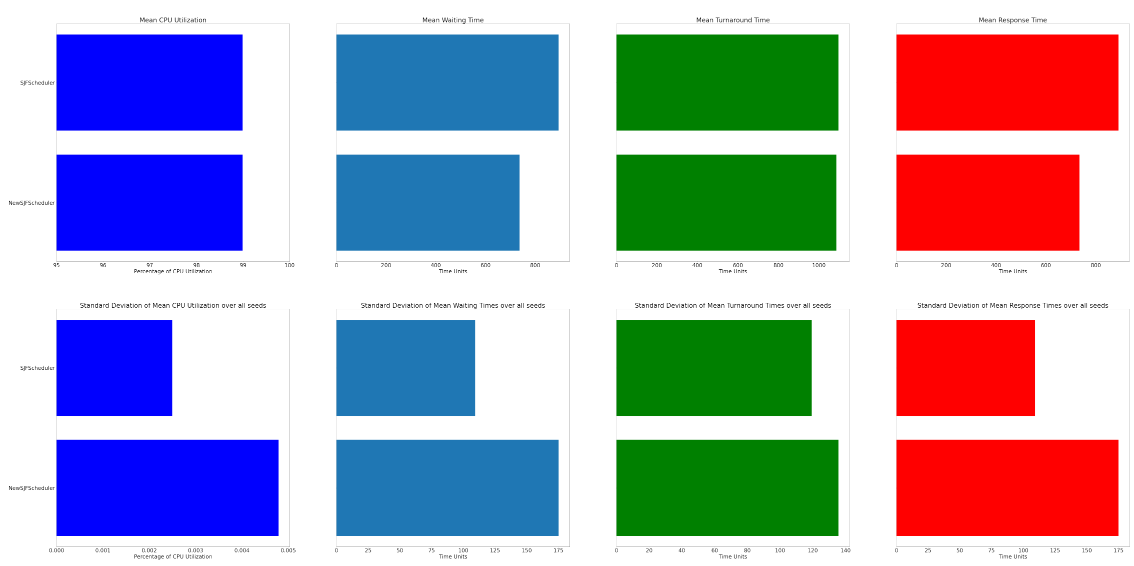
[ ]:

```
             Scheduler  MeanWaitingTime  MeanTurnaroundTime  MeanResponseTime  \
Seed
1234      SJFScheduler      1048.354839         1253.064516       1045.580645
5124      SJFScheduler       956.290323         1173.774194        953.387097
5678      SJFScheduler       878.225806         1095.548387        875.290323
6789      SJFScheduler       794.483871          981.612903        791.709677
6789      SJFScheduler       794.483871          981.612903        791.709677
```

```
5124   NewSJFScheduler      965.709677       1252.387097       962.806452
1234   NewSJFScheduler      821.322581       1161.709677       818.548387
5678   NewSJFScheduler      723.677419       1074.129032       720.741935
6789   NewSJFScheduler      491.419355        888.516129       488.645161
91011  NewSJFScheduler      686.548387       1053.612903       683.645161

      CpuUtilization
Seed
1234       98.987681
5124       98.988966
5678       98.988338
6789       98.992817
6789       98.992817
5124       98.991573
1234       98.998524
5678       98.993612
6789       98.985413
91011      98.994366
```

[ ]:
```
means = compared_sjfs.groupby(['Scheduler']).mean()
stds = compared_sjfs.groupby(['Scheduler']).std()

stds = stds.rename(columns={
        'MeanWaitingTime': 'StdDevWaitingTime',
        'MeanTurnaroundTime': 'StdDevTurnaroundTime',
        'CpuUtilization': 'StdDevCpuUtilization',
        'MeanResponseTime': 'StdDevResponseTime'
})
```

[ ]:
```
plot_means_and_std(means, stds)
```



As can be seen in the above graphs, the New Shortest Job First Scheduler with updated parameters on average performs far better than the original Shortest Job First Scheduler. Since we updated the parameters, we can see that the average waiting time is much lower, as is the mean wait time and mean response time. Turnaround time and CPU Utilisation are seemingly unaffected by the updated parameters.

It is notable that the Standard Deviations for the New Shortest Job First Scheduler are much higher than the original Shortest Job First Scheduler. Since the `alphaBurstEstimate` is much lower than it was previously, this means the scheduler expects more variation in the burst times, so a higher standard deviation is expected for the metrics we have collected.

4.5 Conclusion

In this experiment I have analysed the performance of each of the algorithms when dealing with highly varying workloads. I have discovered that the Round Robin scheduler is generally the best scheduling algorithm for this scenario if minimising response times is key. However, the First-Come-First-Serve algorithm performs well when it comes to minimizing wait time as well as response time, so in a scenario where predicting burst times is not an option, the First-Come-First-Serve algorithm is the best choice.

In addition, I have examined the impacts of changing the parameters for the non-preemptive Shortest Job First scheduler and have seen how we can reduce the `alphaBurstTime` to improve the estimation of burst times when processes vary significantly in their CPU and IO burst times. This experiment has shown me that the Shortest Job First algorithm can certainly be improved to deal with unpredictable workloads and can also handle well workloads where the burst times are similar. However, finding the correct parameters for `initialBurstTime` and `alphaBurstTime` to ensure the best performance is a particularly difficult task, I would be interested to see any machine learning approaches that exist to tune these parameters for specific workloads.