Project report: Stage Two
COMP3100 Distributed Systems, S1, 2023

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1 INTRODUCTION

Job scheduling in Distributed Systems is a fundamental process that plays a vital role in the smooth and efficient execution of jobs. Job schedulers rely on various scheduling algorithms to prioritise jobs based on their performance metrics to determine the order in which available servers should execute them [1]. Ultimately, this process creates a schedule that assigns jobs to available servers based on Turnaround Time, Resource Utilisation and Total Rental Cost, ensuring optimal hardware utilisation while eliminating idle time when jobs are processed. As a result, in a Distributed System, job schedulers take charge of job allocation and setting the execution order to ensure that all servers actively occupy and efficiently handle jobs.

During Stage One, a Client-Side Simulator was established in Java to facilitate communication with the Server-Side Simulator (ds-server) to manage the simulation of jobs within a Distributed System. Furthermore, the Largest Round Robin (LRR) algorithm was integrated into the Client-Side Simulator to ensure optimal performance. The LRR algorithm accurately assesses the most suitable server type based on the number of CPU cores that allocate equal time slices to each job in a circular order, allowing each job to run for a certain period before moving on to the next job in the queue. Stage Two, on the other hand, must build on Stage One by implementing one or more new scheduling algorithms that optimise average Turnaround Time without compromising other performance metrics like Resource Utilisation and Server Rental Cost. For example, if the algorithm attempts to reduce the average Turnaround Time by minimising waiting time, it may require additional resources, leading to increased costs. Therefore, I will modify the Client-Side Simulator from Stage One to support the new scheduling algorithm.The new algorithm must also perform better than the existing baseline algorithms (FF, BF, FFQ, BFQ, and WFQ). To develop a better scheduling algorithm, I will evaluate the baseline algorithms' strengths, weaknesses, and overall efficacy to identify areas that require enhancement. Additionally, I will analyse Stage One's Client-Side Simulator to determine where I need to make adjustments to incorporate the new algorithm's logic. Once I have created the new scheduling algorithm, I will conduct testing to fine-tune the implementation and demonstrate its performance.

The following report will define the scheduling problem, clearly indicating my performance objectives and justifying my choice. I will also compare the new algorithm's results with those of the baseline algorithms and discuss their outcomes in detail.

2 PROBLEM DEFINITION

The objective for Stage Two is to modify Stage One's Client-Side Simulator and implement one or more new scheduling algorithms that optimises average Turnaround Time without compromising other performance metrics. When assessing a scheduling algorithm's effectiveness, it is essential to consider the Turnaround Time, which measures the duration between submitting and completing a job, indicating how long it takes to schedule a job. Ensuring the Turnaround Time is optimised can make a big difference in how efficiently and effectively a job's scheduling processes are carried out. For example, optimised Turnaround Time can minimise waiting periods, guarantees prompt completion of critical tasks, and improve resource utilisation due to faster completion times, which ultimately increases the overall productivity within the system [2]. However, due to incompatible and conflicting performance objectives, it is essential to remember that optimising one performance metric might lead to sacrificing the optimisation of other performance metrics. For instance, minimising the average Turnaround Time by minimising waiting time may end up using more resources resulting in higher costs. Therefore, considering the nature of the job and the server's capabilities when designing and implementing a new scheduling algorithm for the existing Client-Side Simulator is vital.

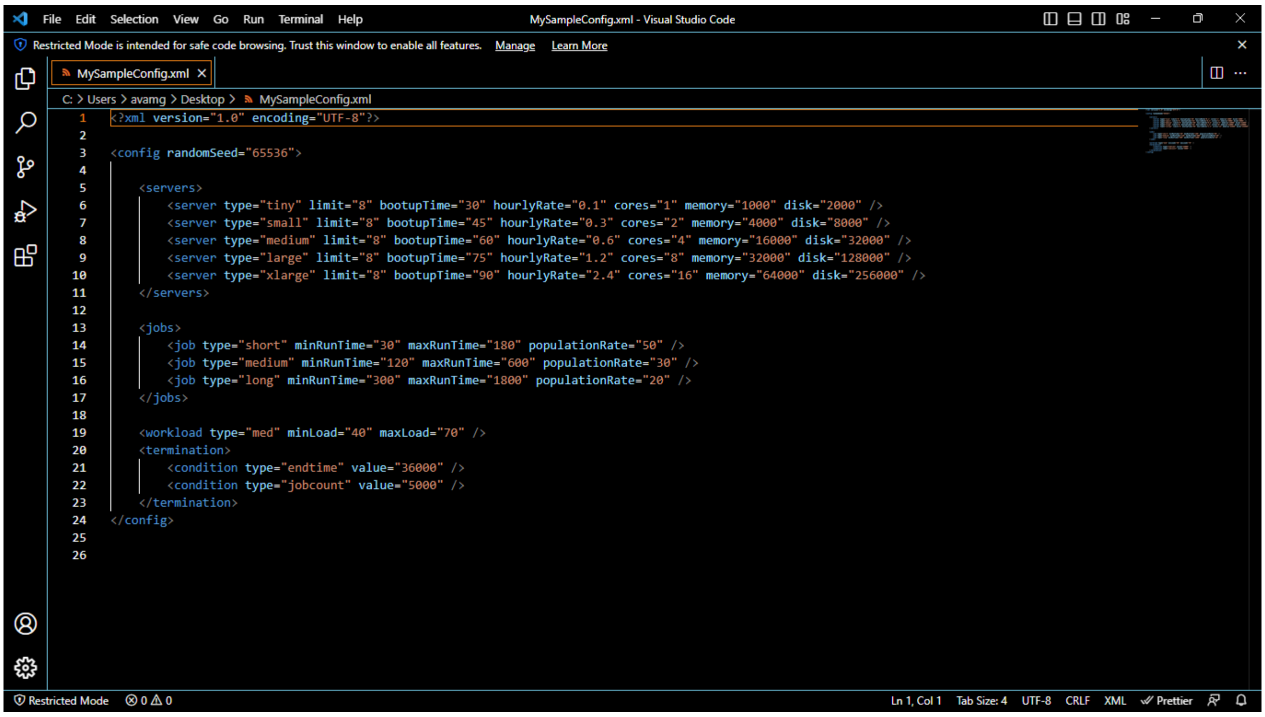
After modifying the Client-Side Simulator with the required implementations, a thorough comparison of results will be conducted by executing the Week 11 ”SAMPLE TEST SUITE FOR STAGE 2” against five established baseline algorithms: First Fit (FF), Best Fit (BF), First Fit with Queuing (FFQ), Best Fit with Queuing (BFQ), and Worst Fit with Queuing (WFQ). These baseline algorithms provide a basis for developing a new scheduling algorithm for my Client-Side Simulator to improve overall system performance regarding Turnaround Time, Resource Utilisation, and Total Rental Cost. The test script will generate three tables, one for each metric. The leftmost column will display the configuration files, followed by the middle column that showcases the results of each baseline algorithm for each configuration file, and the rightmost column that displays the Client-Side Simulator results for each configuration file. Moreover, after the config rows, the script execution will produce a row of averages and several rows with normalised values. These final values will reflect the average outcome of each column, normalised against the average value of that row's algorithm. The last row will present each column's average result against all baseline algorithms' average results. Furthermore, after the test script has finished executing, the output will display three colour values to indicate the performance of the Client-Side Simulator compared to the baseline algorithms. These three colour values are GREEN, YELLOW, and RED.

The aim is to achieve all GREEN, indicating that the Client-Side Simulator has outperformed all baseline algorithms. Overall, the test script output will provide valuable insights into the Client-Side Simulator's performance and will assist me in establishing a solid foundation for designing a better scheduling algorithm than the baseline algorithms, resulting in improved overall system performance.

3 ALGORITHM DESCRIPTION

The following provides a simple example of a scheduling scenario using a sample configuration file to visualise how the Client-Side Simulator should schedule jobs based on an optimised Turnaround Time. The sample configuration file (MySampleConfiguration) is provided in the github repository: https://github.com/avagardiner/COMP3100Project

3.1 SAMPLE CONFIGURATION


File Edit Selection View Go Run Terminal Help
MySampleConfig.xml - Visual Studio Code
Restricted Mode is intended for safe code browsing. Trust this window to enable all features. Manage Learn More
MySampleConfig.xml
C: > Users > avamg > Desktop > MySampleConfig.xml
Restricted Mode ⊗ 0 ⚠ 0
Ln 1, Col 1 Tab Size: 4 UTF-8 CRLF XML ✓ Prettier

```xml
<?xml version="1.0" encoding="UTF-8"?>

<config randomSeed="65536">

    <servers>
        <server type="tiny" limit="8" bootupTime="30" hourlyRate="0.1" cores="1" memory="1000" disk="2000" />
        <server type="small" limit="8" bootupTime="45" hourlyRate="0.3" cores="2" memory="4000" disk="8000" />
        <server type="medium" limit="8" bootupTime="60" hourlyRate="0.6" cores="4" memory="16000" disk="32000" />
        <server type="large" limit="8" bootupTime="75" hourlyRate="1.2" cores="8" memory="32000" disk="128000" />
        <server type="xlarge" limit="8" bootupTime="90" hourlyRate="2.4" cores="16" memory="64000" disk="256000" />
    </servers>

    <jobs>
        <job type="short" minRunTime="30" maxRunTime="180" populationRate="50" />
        <job type="medium" minRunTime="120" maxRunTime="600" populationRate="30" />
        <job type="long" minRunTime="300" maxRunTime="1800" populationRate="20" />
    </jobs>

    <workload type="med" minLoad="40" maxLoad="70" />
    <termination>
        <condition type="endtime" value="36000" />
        <condition type="jobcount" value="5000" />
    </termination>
</config>
```

Figure 1: Screenshot of Sample Configuration File

3.2 SCHEDULING SCENARIO

There are five servers available: Tiny, Small, Medium, Large, and XLarge, each with their own specifications for cores, memory, and disk capacity. The workload type is Medium, with a minimum load of 40 percent and a maximum load of 70 percent. There are Short, Medium, and Long jobs available for scheduling. The Client-Side Simulator successfully establishes a connection with the Server-Side Simulator and authenticates. The Client-Side Simulator sends a 'REDY' message to request a job from the Server-Side Simulator. The Client-Side Simulator receives a short job with unspecified resource requirements. The Client-Side Simulator sends a 'GETS' message to retrieve server capabilities for all available servers. Based on the capabilities, the Client-Side Simulator selects the Tiny server as it has the required resources and no waiting jobs. The Client-Side Simulator sends an 'SCHD' message to schedule the Short job on the Tiny server. The Client-Side Simulator continues receiving and scheduling jobs based on the available server capabilities and job requirements. The Client-Side Simulator receives a Medium job with unspecified resource requirements. The Client-Side Simulator sends a 'GETS' message and determines that the Small server can accommodate the Medium job without any waiting jobs. The Client-Side Simulator schedules the Medium job on the Small server by sending an 'SCHD' message. Next, the Client-Side Simulator receives a Long job with unspecified resource requirements. The Client-Side Simulator sends a 'GETS' message and finds that the Medium server is the only server capable of accommodating the Long job without any waiting jobs. The Client-Side Simulator schedules the Long job on the Medium server by sending an 'SCHD' message. As the simulation progresses, the Client-Side Simulator receives and schedules jobs based on the available server capabilities and job requirements. To minimise the average Turnaround Time, the Client-Side Simulator prioritises servers with matching resources and no waiting jobs. The Client-Side Simulator records the waiting jobs and monitors the servers' workload throughout the scheduling process. The Client-Side Simulator considers the workload type (Medium) and ensures that the servers' load remains between 40 percent to 70 percent. The algorithm keeps scheduling jobs until there are no more available. The Client-Side Simulator sends a 'QUIT' message to end the simulation when no more jobs exist gracefully.

4 IMPLEMENTATION

The existing Client-Side Simulator for Stage One must be modified to accommodate a new algorithm for scheduling jobs to servers with a minimised average Turnaround Time without sacrificing the other performance metrics, such as Resource Utilisation and Server Rental Cost. Additionally, the Client-Side Simulator must perform better than the five baseline algorithms. Like Stage One, the Client-Side Simulator for Stage Two must operate like the reference Client-Side Simulator (ds-client) that can connect with the Server-Side Simulator (ds-server). To accomplish Stage Two, the Client-Side Simulator was written in Java and relies on two built-in Java libraries (java.net and java.io) to manage the input/output and network communication.

The Client-Side Simulator's implementation, including data structures, is detailed in the following section:

The Client-Side Simulator uses a Socket object to specify the server's address ('127.0.0.1') and port number ('50000') to establish a socket connection with the Server-Side Simulator (ds-server). In addition, the Client-Side Simulator uses a DataOutputStream object to send data and a BufferedReader object to receive data to communicate with the Server-Side Simulator (ds-server). The Client-Side Simulator sends a 'HELO' message to the Server-Side Simulator (ds-server) by writing it to the output stream and flushing it to ensure it sends immediately. The Client-Side Simulator receives a response from the Server-Side Simulator (ds-server) by reading a line from the input stream using the readLine method. The Client-Side Simulator retrieves the current user's username using System.getProperty("user.name"). The Client-Side Simulator sends an authentication message to the Server-Side Simulator (ds-server) by writing an 'AUTH' message concatenated with the username to the output stream and flushing it. The Client-Side Simulator receives the authentication response from the Server-Side Simulator (ds-server) by reading a line from the input stream. The Client-Side Simulator proceeds with job scheduling if the authentication response is 'OK', indicating successful authentication. If the authentication response does not show 'OK', authentication has failed, and the Client-Side Simulator displays a message notifying the user of the failure. The Client-Side Simulator sends a 'REDY' message to the Server-Side Simulator requesting a job by writing it to the output stream and flushing it. The Client-Side Simulator receives job information from the Server-Side Simulator by reading a line from the input stream. The Client-Side Simulator initialises variables to store job and server information. The Client-Side Simulator enters a loop to process jobs from the Server-Side Simulator (ds-server) until a 'NONE' message is received, indicating no more jobs. The Client-Side Simulator sends a 'REDY' message to the Server-Side Simulator (ds-server) to request another job by writing it to the output stream and reading the response from the input stream. The Client-Side Simulator checks if the received message contains job information by examining if it contains 'JOBN' or 'JOBP' keywords. If the message contains job information, the Client-Side Simulator parses the job information by splitting the message into spaces and extracting the relevant data. The Client-Side Simulator sends a 'GETS' message to request server capabilities from the Server-Side Simulator (ds-server) based on the job requirements by writing the message to the output stream and flushing the stream. The Client-Side Simulator receives server capabilities from the Server-Side Simulator (ds-server) by reading a line from the input stream. The Client-Side Simulator parses the server capabilities response by splitting the message into spaces and extracting the number of records. The Client-Side Simulator sends an 'OK' message to confirm receiving server capabilities by calling the sendOK helper method, which writes 'OK' to the output stream and flushes the stream. The Client-Side Simulator processes each server capability by reading lines from the input stream, splitting the messages into spaces, and extracting the relevant data. If there are no waiting jobs and the current server has enough resources, the Client-Side Simulator assigns the job to the server by setting the scheduled server type and ID. If no suitable server exists, the Client-Side Simulator assigns the job to the first server in the list. The Client-Side Simulator sends an 'SCHD' message to schedule the job on the selected server by writing the message to the output stream and flushing the stream. The Client-Side Simulator receives the scheduling response from the Server-Side Simulator (ds-server) by reading a line from the input stream. The Client-Side Simulator continues the loop to process the next job or exits the loop if a 'NONE' message is received. The Client-Side Simulator prints a message indicating no more jobs to schedule. The Client-Side Simulator triggers the 'QUIT' message to be sent to the Server-Side Simulator (ds-server) using the 'sendQUIT' helper method. The 'SendQUIT' helper method writes 'QUIT' to the output stream and flushes it. The Client-Side Simulator reads the line from the input stream to obtain the termination response from the Server-Side Simulator (ds-server). Once the Client-Side Simulator terminates, it will print a message that the simulation terminated gracefully. Finally, the Client-Side Simulator closes the connection using outputStream.close() and socket.close().

5 EVALUATION

I conducted a comparative analysis between the Client-Side Simulator and the five baseline algorithms to evaluate the performance of my scheduling algorithm using the Week 11 "SAMPLE TEST SUITE FOR STAGE 2" provided by COMP3100. The test suite includes a results folder containing the reference results for the five baseline algorithms and the S2TestConfigs folder, which contains all the configuration files. Additionally, the test suite includes the files `mark_client.py` and `s2_test.py`.In the upcoming sections, I will discuss the setup of the client-side simulator, compare the results of the Client-Side Simulator with the baseline algorithms, and analyse the positives and negatives of implementing my algorithm into the Client-Side Simulator.

5.1 Simulation Setup

To set up my Client-Side Simulator to compare it with the five baseline algorithms, I used the Week 11 "SAMPLE TEST SUITE FOR STAGE 2". Firstly, I downloaded the file from ilearn and extracted it into the directory with my

Client-Side Simulator, ds-server and ds-client . Then, to access the test suite, I navigated to the terminal's directory using the command `cd /media/sf_Shared/COMP3100Project/Stage2`, which contains all the necessary files to run the script. Next, I compiled my Client-Side Simulator by running `javac client.java`, which generated the `client.class` file in the directory. After compiling `client.java`, I used the command `python3 ./s2 test.py "java client" -n -r results/ref results.json` to execute `S2_test.py`. Despite the need to collect results from the reference client using the relevant algorithms, the script completed quickly. Once the script finished, it printed three tables for Turnaround Time, Resource Utilisation, and Total Rental Cost, which included the results from my Client-Side Simulator in each table.

5.2 COMPARING CLIENT-SIDE SIMULATOR RESULTS TO BASELINE ALGORITHMS RESULTS

Once the script had finished executing, the test script generated three tables: Turnaround Time, Resource Utilisation, and Total Rental Cost. The leftmost column displayed the configuration files, followed by the middle column showcasing the results of each baseline algorithm for each configuration file, and the rightmost column displayed the Client-Side Simulator results for each configuration file. Moreover, after the config rows, the script produced a row of averages and several rows with normalised values. These final values reflected the average outcome of each column, normalised against the average value of that row's algorithm. The last row presented each column's average result against all baseline algorithms' average results. Furthermore, the output displayed two out of the three colour values to indicate the performance of the Client-Side Simulator compared to the baseline algorithms. These two colour values were GREEN and YELLOW. According to the results table below, my Client-Side Simulator performed better than the baseline algorithms in all three performance metrics.

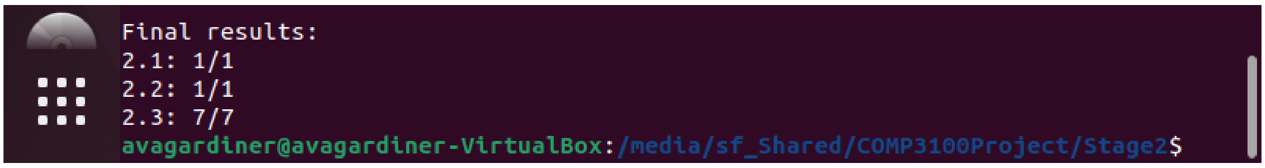
Turnaround Time	FF	BF	FFQ	BFQ	WFQ	Mine
Average	1867.13	2417.27	2559.07	2401.80	9958.40	1397.73
Normalised (FF)	1.0000	1.2946	1.3706	1.2864	5.3335	0.7486
Normalised (BF)	0.7724	1.0000	1.0587	0.9936	4.1197	0.5782
Normalised (FFQ)	0.7296	0.9446	1.0000	0.9385	3.8914	0.5462
Normalised (BFQ)	0.7774	1.0064	1.0655	1.0000	4.1462	0.5820
Normalised (WFQ)	0.1875	0.2427	0.2570	0.2412	1.0000	0.1404
Normalised (Average)	0.4861	0.6294	0.6663	0.6253	2.5928	0.3639

Resource Utilisation	FF	BF	FFQ	BFQ	WFQ	Mine
Average	74.02	69.55	73.49	69.45	68.18	74.37
Normalised (FF)	1.0000	0.9396	0.9928	0.9382	0.9211	1.0047
Normalised (BF)	1.0642	1.0000	1.0566	0.9985	0.9802	1.0693
Normalised (FFQ)	1.0072	0.9465	1.0000	0.9450	0.9278	1.0120
Normalised (BFQ)	1.0659	1.0015	1.0582	1.0000	0.9817	1.0709
Normalised (WFQ)	1.0857	1.0202	1.0779	1.0186	1.0000	1.0908
Normalised (Average)	1.0435	0.9805	1.0360	0.9790	0.9611	1.0484

Total Rental Cost	FF	BF	FFQ	BFQ	WFQ	Mine
Average	526.40	524.82	537.31	531.21	555.13	526.72
Normalised (FF)	1.0000	0.9970	1.0207	1.0091	1.0546	1.0006
Normalised (BF)	1.0030	1.0000	1.0238	1.0122	1.0578	1.0036
Normalised (FFQ)	0.9797	0.9767	1.0000	0.9886	1.0332	0.9803
Normalised (BFQ)	0.9909	0.9880	1.0115	1.0000	1.0450	0.9915
Normalised (WFQ)	0.9483	0.9454	0.9679	0.9569	1.0000	0.9488
Normalised (Average)	0.9840	0.9810	1.0044	0.9930	1.0377	0.9846

- Turnaround Time: The Turnaround Time average is GREEN, suggesting that my Client-Side Simulator has outperformed all baseline algorithms. The average Turnaround Time was 1397.73, compared to the baseline algorithm's average range of 1867.13 to 9958.40. The normalised value demonstrates that my Client-Side Simulator's Turnaround Time is lower or equivalent to the baseline algorithms, ranging from 0.3639 to 0.7486.
- Resource Utilisation: The Resource Utilisation average is GREEN, suggesting that my Client-Side Simulator outperformed all baseline algorithms. The Resource Utilisation of my Client-Side Simulator is higher than the baseline algorithms, with an average of 74.37 compared to the baseline algorithms' average range of 68.18 to 74.02. The normalised value indicates that the Resource Utilisation of my Client-Side Simulator is more significant or equivalent to that of the baseline algorithms, ranging from 0.9611 to 1.0908.
- Total Rental Cost: The Total Rental Cost average is YELLOW, suggesting that my Client-Side Simulator outperformed at least one baseline algorithm. My Client-Side Simulator Total Rental Cost is similar to the baseline algorithms, with

an average of 526.72 vs a range of 524.82 to 555.13 for the baseline algorithms. The normalised results reveal that the Total Rental Cost of my Client-Side Simulator is comparable to the baseline algorithms, ranging from 0.9803 to 1.0578.



```
Final results:
2.1: 1/1
2.2: 1/1
2.3: 7/7
avagardiner@avagardiner-VirtualBox:/media/sf_Shared/COMP3100Project/Stage2$
```

Figure 2: Screenshot of Final Results

The Client's Side Simulator's performance compared to the baseline algorithm's results is further demonstrated in the final results table after the output, which shows that the performance of the Client-Side Simulator has outperformed the five baseline algorithms. The results are broken into three sections: 2.1, 2.2 and 2.3. 2.1 is out of 1, 2.2 is out of one and 2.3 is out of 7. After executing the script, the Client-Side Simulator scored 9 out of 9, indicating that my Client-Side Simulator has outperformed all baseline algorithms without sacrificing Resource Utilisation and Total Rental Cost.

5.3 POSITIVES AND NEGATIVES

The algorithm used in the Client-Side Simulator has both positives and negatives. On the positive side, the Client-Side Simulator creates a socket connection, allowing the Client-Side Simulator and Server-Side Simulator (ds-server) to communicate to enable data transfer. Furthermore, job scheduling is handled by the algorithm, which analyses server capabilities and matches them with the job's needs. As a result, it picks and schedules servers effectively, maximising Resource Utilisation and Turnaround Time. However, there are also some negatives to consider. The Client-Side Simulator does not handle errors or exceptions that may occur during communication very well, which could make troubleshooting problems and recovery from unexpected failures difficult. The scalability is also limited since the algorithm is designed for a single client-server interaction and does not consider scenarios with numerous concurrent clients or server load balancing. Therefore, it might not work well in highly scaled or sophisticated systems. Furthermore, the lack of modularity could make the codebase challenging to maintain and extend over time because the algorithm is implemented in a single class with no apparent separation of responsibilities. Finally, the algorithm may encounter performance issues depending on the amount of job scheduling and server capabilities, resulting in longer execution times and poor resource use.

6 CONCLUSION

To summarise, the success of Distributed Systems relies heavily on job scheduling and prioritisation based on various performance metrics. In Stage Two, I implemented a new scheduling algorithm in the Client-Side Simulator that optimises the average Turnaround Time without compromising other metrics. The Week 11 "SAMPLE TEST SUITE FOR STAGE 2" was used to test the algorithm, and the results were exceptional. The Client-Side Simulator outperformed all baseline algorithms in Turnaround Time and Resource Utilisation and performed better than at least one baseline algorithm in Total Rental Cost. The final results table confirmed that the Client-Side Simulator scored 9 out of 9, surpassing all five baseline algorithms without compromising Resource Utilisation and Total Rental Cost. Overall, the Client-Side Simulator has proven to be a reliable and efficient solution. However, further refining and optimising the new scheduling algorithm by conducting additional testing could enhance its performance by evaluating its performance with larger config files and varying workload types and exploring potential enhancements or modifications based on the observed strengths and weaknesses during the evaluation phase. The rigorous comparison of results from the Week 11 "SAMPLE TEST SUITE FOR STAGE 2" provided valuable insights into the performance of the Client-Side Simulator and laid a strong foundation for developing a better scheduling algorithm, resulting in an improved overall system performance.

References

[1] E. ÅSTRÖM, "Task Scheduling in Distributed Systems," Available: https://www.diva-portal.org/smash/get/diva2:1088396/FULLTEXT01.pdf

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[3] Y. Choon Lee, "distsys-MQ/ds-sim," GitHub, Feb. 28, 2023. https://github.com/distsys-MQ/ds-sim/blob/master/docs/ds-sim_user-guide.pdf

[4] GITHUB LINK: https://github.com/avagardiner/COMP3100Project