



## **UNIVERSITY OF ZIMBABWE**

**FACULTY OF COMPUTER ENGINEERING, INFORMATICS AND  
COMMUNICTATIONS**

**DEPARTMENT OF COMPUTER SCIENCE**

**TITLE: DEVELOPING HYBRID ALGORITHMS FOR GENERATING EXAM TIME  
TABLE AND VENUE ALLOCATION AT THE UNIVERSITY OF ZIMBABWE.**

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## ABSTRACT

Universities currently use a manual system to arrange exam schedules and assign examination venues and it is not reliable, slow and often requires extra effort. Because of the challenges in this process, busy work by administrative staff makes for poor time management, underutilized spaces and unsatisfied students. Because there isn't an automated system, there are delays, erratic changes in schedules and problems managing resources which disrupts the school's academic calendar. This study argues for developing hybrid optimization algorithms that will automate both the task of scheduling exams and selecting exam venues. The system tries to solve scheduling and resource problems by connecting Metaheuristics (Genetic Algorithms and Simulated Annealing) with Constraints. In 2019, Hossain et al. showed that algorithmic automation makes busy scheduling systems more efficient, effectively decreases the burden on admins and organizes such tasks easily. To evaluate the solution, actual data from institutions will be used, measuring computational speed, decreases in conflict and improvements in choosing venues. Goals achieved usually involve less time spent on simple tasks, fewer errors in timetables and more satisfaction for everyone involved. Because of this project, there is now a scalable, automated way for schools to manage resources so they do not compromise academic standards. There is potential to improve the system by allowing administrators to adjust features in real time and to connect with university databases for hassle-free use.

This study involves: Exam Scheduling, Venue Allocation, Hybrid Scheduling, Automated Scheduling, Resource Optimization and Conflict Minimization.

## ACKNOWLEDGEMENTS

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## CHAPTER ONE: INTRODUCTION

### 1.2 Project Title

### DEVELOPING HYBRID ALGORITHMS FOR GENERATING EXAM TIME TABLE AND VENUE ALLOCATION AT THE UNIVERSITY OF ZIMBABWE.

### 1.2 Introduction.

A number of interrelated institution operations are carried out by a number of stakeholders, including administration, lecturers, and students, at the University of Zimbabwe currently timetables generation and venue allocation system is manual. The professors distribute their time preference of the number of hours, the administration compiles the course offerings per department and the student schedules his or her classes based on the course sequence. Administrative take into consideration all scheduling issues such as overbooked venues or overlapping classes during the exam. “Faculty administrators attempt to modify the schedule in response to conflicts, and they notify the students of any changes.” (N. L. A. Aziz and N. A. H. Aizam 2018). “The business rules governing these processes include ensuring that courses do not overlap for the same instructor and allocating larger venues for with high enrollment priority to core course during peak times of the exams.” (Wilson Boulevard, 2018)

These ways are meant to make sure that student academic processes are satisfied and resources are used as best they can be and classes are scheduled effectively. The Administrators compile departmental course requirements with faculty members indicate their availability and preferred time slot, and students register for classes according to their course schedules. Venue allocation is the administrative process through which lectures and classes are assigned to halls and classes as appropriate for the classes and available venue. Faculty members are assigned to particular venues for their lectures, and students are notified of their class location via the university's web site. “The Administrative manually handles issues in scheduling that are overlapping classes or overbooked venues.” (Fumasoli, T., Hladchenko, M. 2023) The faculty members do schedule adjustments to address conflicts, and students are informed of any schedule changes. In case that

the number of students and courses increases, the scheduling complexity also increases, making the task challenging to meet all constraints and requirements effectively.

“The procedure that can be done to improve accuracy, efficiency, and resource consumption by applying machine learning algorithms.” (D. M. Premasiril, 2018)) To ensure a smooth academic experience for both students and staff and upgrading university administrative procedures requires careful consideration by establishing an algorithm for timetable production and exam venue permission.

### 1.3 Problem Statement

The university current manual approach for scheduling time tables and assigning exam locations is error-prone, tedious and inefficient. It takes a lot of time and efforts from the Administrative, and this often creates problems with time management leading to wasted space and unsatisfied students. Lack of an automated systems causes delays and irregularities that have a greater effect on the management of resources and also to all academic schedule to the whole institution. “Through the use of algorithms to automate the process of creating timetables and allocating exam locations it can make the work easier and faster” (Hossain, S. I., Akhand, M. A. H., Shuvo, M. I. R., Siddique, N., & Adeli, H. (2019) . This project aims to minimize conflicts and maximize resource utilization.

### 1.4 Proposed solution

#### 1.4.1 Membership and registration

The writer will build an automatic timetable generation and exam venue allocation system. The system will have the user-interface that allow both students and administrator to register onto the web that needs the access time tables and exam venue. For the administrators and student, they will access the system through the use of password and username.

It will also allow the system in the administrative account will be given the privilege to editification on the exam priority and also set the rules the system must consider during the generation of time table. But student account will not allow to modify but only see the outputs. Handle hard and soft constraints in real time.

The system will allocate rooms based on the number of students, exam start time, end time and it will give according to free room and its capacity. The system will check whether the room is free room and does it accommodate the another exam at the same time to avoid underutilization of big rooms using graph coloring model. It will check all the hard and soft constraints such as student is given a student chair numbered, so if the exam hall is not full then it will take the other of the exam that has a need to be written and give a slot in the sometime at the same time. It will consider the availability of the lecture. The student will get his/her information from website where there is timetable with chair number for her to use, exam venue.

#### 1.4.2 Data collection

The system will be integrated with existing university data base of enrollment to extract data that is needed such as student name, registration number, course name, etc. The system will have its data base that will have room capacity and chair number and name the room.

#### 1.4.3 Time table generation, notifications and room allocation

Through the use of hybrid algorithm, it generates the automated timetable and venue allocation. After all the venue allocation and time table generation it will then provide a time table in the form of typed documents and sent it to all students through emails. The generated must be shown on university student portal.

### 1.5 Aim and Objectives

#### 1.5.1 Aim:

The main goal of this project is to develop a dependable and effective hybrid algorithm that will automate the university timetable and exam venue allocation. The project targets to optimize resource utilization, improve the academic duties for staff and students and streamline the scheduling process by addressing the inefficiencies and inaccuracies of the current manual method which is used.

#### 1.5.2 Objectives

- To implement conflict detection and conflict resolution mechanisms at run time for scheduling real-time adjustments.

- To implementing a hybrid algorithm for Timetabling and Venue Allocation Algorithm for exams.
- To provide a user-friendly interface (web application) that are easy for use and ensure seamless integration with existing university systems for data input and output.

### 1.2.5 Justification and Relevance

The conventional mechanical practice of preparing schedules and assigning exam locations at universities is usually characterized by errors and inefficiencies through the use of traditional manual approach. Such concerns can create problems such as conflicts in schedules, low resource utilization and great administrative costs. For these processes, the following project suggests the development of an automated algorithm. Through the use of the algorithm, it tries to improve the scrupulousness of preparation and the use of available resources by decreasing the administrative burden. This improvement will be of great gains to the students and the faculty, making it acquire a much better academic experience. In addition, the project provides the practical and utilized model which can be used in the other organizations experiencing similar issues and thus, to the subject of educational administration.

## 1.6 Project scope

### 1.6.1 Boundaries

Designing of an algorithm to generate academic schedules automatically. Creation of an algorithm to effectively assign exam locations. Using the current databases of the university for gathering the relevant information. Using the current databases of the university for gathering the relevant information. The development of a user interface that allows administrative staff to communicate with the system. The dynamic implementation of procedures to handle scheduling conflicts.

Project will not get involved in planning any event/entertainment activities that are extra curriculum or non-academic in essence. Although the system will support manual modifications, it is not within the scope to provide comprehensive manual override options.

### 1.6.2 Deliverable

The writer will present hybrid algorithm that produce academic schedules based on pr-defined consideration and Web application for user interface. A technique used to determine exam locations in accordance to accessibility, proximity and capacity. Moreover, will deliver the module that preprocess and retrieves data by connecting with the university current databases. A program which provides administrative staff with the possibility to view and alter schedules and input information. In the form of a user manual supportive documents and also how the operating maintenance and overall design of the system is. For example, papers that give more details about the algorithms and the system's testing and validation.

### 1..6.3 Constraints

There is time frame under which the work has to be completed, most often within one school year. Limited for testing and development and software tool expenses. Restrictions are linked to the current technology stack and its compatibility with university systems, at the current time. Limited interaction of the project with other administrative and development people in the organization. With regard to the reliability of information available in the current university databases. Chair number in the room.

### 1.6.4 Assumptions

The writer assuming that the required tools and technology (including database, library or programming language) to use is available and accessible. Thus, if specific funding for the project's development and its administration is guaranteed. Given the current supply of information by university current systems are correct and accessible. On the basis that more support from all the entities associated with the University would mean cooperation from the IT as well as the administrative departments.

### 1.6.5 Dependencies

This project uses enrollment statistics, room capacity, chair number and course scheduling information from the university current databases. The writer will depend on administrative to validate schedules, input data, and offer comments. Reliant to the IT infrastructure of the host

institution to guarantee its compatibility with current systems of the institution. In the designing phase, the use of third-party libraries and tools performing data integration and algorithms construction.

### 1.7 Ethical consideration

Ethical Consideration; means it will use a university website to interface with users. The provisions of access for the stockholder will include certain access rights of the database information while the students will be limited in their ability to change some information on the site due to the protection of the identity of users = data will be anonymized.

Fairness and bias in Algorithm; developing methods of using datasets for training algorithms and performing constant tests to check for prejudice. Make the decision of algorithms and the processes related to it as clear and obvious to keep the possibility of holding somebody responsible over the decision as low as possible. Do all you can to ensure that algorithmic predictions and algorithmic decisions are as satisfactory to individuals with all types of demographic characteristics as they are satisfactory to individuals with other types of characteristics. Using third-party libraries and frameworks to create the algorithm to collect and combine data.

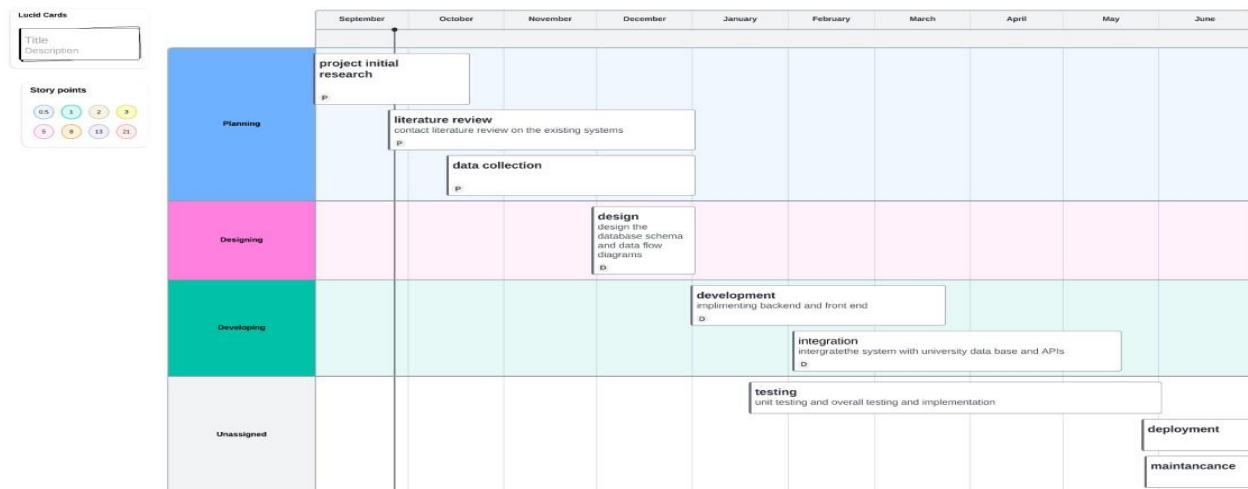
During design there will be penetration testing, is the act of trying to find out how well a system can be penetrated to determine security gaps without actually hacking it. This means that ethical hackers have a code of operations that requires them to report vulnerabilities in good time. They provide reports of identified threats to the owner of the system and advice on how best to address them. These practices will enable the writer to avoid divulging or misuse of any sensitive information that may be discovered during testing and avoid violating user's privacy while exercising their tests.

## 1.8 Cost/ budget

*Table 1 Hybrid Algorithms for generating time table and venue allocation at the university*

| Item                           | (USD)DOLLARS | TOTAL |
|--------------------------------|--------------|-------|
| <b>PERSONAL</b>                |              |       |
| <b>FOOD</b>                    | \$30         |       |
| <b>TRANSPORT</b>               | 20           |       |
|                                |              |       |
| <b>CLOUD SARVER AND CODING</b> | \$30         |       |
|                                |              |       |
| <b>TOTAL EXPENSE</b>           | \$80         |       |
| <b>OVERHEAD @ 15%</b>          | \$12         |       |
| <b>GRAND TOTAL</b>             |              | \$92  |

## 1.9 Project plan (Gantt Chart)



*Figure 1 Project plan (Gantt Chart)*

*Designed by the author*

## CHAPTER TWO: LITERATURE REVIEW

### 2.1.1 Introduction

In universities timetable generation and venue allocation has significant challenges due to the complex interdependencies on various constraints such as room availability, instructor schedules, student preferences, and institutional (university) policies (Burke, 1997). The increase in the number of student population and diverse course offerings increase more complexity of these problems, necessitating efficient and effective scheduling solutions (Garey & Johnson, 1979). According to (Kumar & Singh, 2021) the use of traditional methods had proved the inadequate that leads to a growing interest in hybrid algorithms that combine the strengths of multiple optimization techniques and methods. The integration of the GA and LS has the potential in solving these problems. Global search methods and algorithms including genetic algorithms are well equipped in searching for far reaching solutions while the local search algorithms are the best in fine tuning the solutions to the particular constraints weighs according to (Holland, 1992). The combination shows the strengths of both approaches to produce high quality solutions (Goldberg, 1989). Based on literatures they demonstrated the effectiveness of hybrid genetic algorithms in advancing timetabling solutions. For a hybrid genetic algorithm and adaptive local search was to enhance solution quality by dynamically changes on search parameters (Computers and Operations Research, 2023). The benefits of integrating genetic algorithms with constraint satisfaction techniques helps solving complex constraints in scheduling a timetable, according to (Applied Soft Computing, 2024). Through the use of local search methods, such as dynamic local search they have also been proposed to further improve the performance of hybrid GAs (Journal of Scheduling, 2024). The methods alter the process of searching according to the current state of solving making the search of the solutions more efficient (Burke & Petrovic, 2002). In addition to that the integration of machine learning techniques with hybrid algorithms has been explored to be faster and adapt to change of constraints and preferences with further enhancements in the robustness and adaptability of the scheduling solutions (Smith, 2020). This method is not only to improve the quality of the generated timetables but also reduces the computational time required for finding optimal solutions (Yang & Kwan, 2010).

Particularly the combination of genetic algorithms with local search methods to derive a hybrid algorithm is presented as a particularly successful approach for solving university timetable



construction and venue assignment problems at large. The continuous method in scheduling, which includes the use of machine learning, should positively augment the efficiency and effectiveness on solutions (Kumar and Singh, 2021).

### 2.1.2 Nature of Time tabling problems

Timetable scheduling involves a host of NP hard problems which show both computational complexity and myriad constraints (Garey & Johnson 1979). These constraints can be categorized into: Hard constraints which must be followed to the letter (for instance the condition that requires that no classes could coincide) Soft constraints which are used to enhance the quality of the timetable (for instance the condition that seeks to ensure no large gaps in between classes) (Mili and Côté, 2016). This is the key issue of managing these constraints and achieving the best levels of resource management (Daskalaki, 2019).

In scheduling there are Hard Constraints that are non-negotiable and must be satisfied for a timetable to be feasible. There is a need to make sure that there is no overlapping classes of the same instructor or student class (Burke, 1997). Room capacity limits must be considered for it not be exceeded (Müller, 2009). There are specific courses that must be scheduled in particular rooms equipped with necessary facilities such as laboratories (Babaei, 2015).

However there are also soft constraints that are desirable, but not inevitable. They want to increase the general efficiency of the process of scheduling, as well as decrease the number of gaps between groups of students and instructors (Mili and Côté, 2016). There is a necessity to distribute classes evenly across the week hence having several classes not being congested in a single day (Daskalaki, 2019). Organizing lessons at convenient time for both students and trainers Existence of It: time management for both students and trainers; Burkey & Petrovic, 2002. These problems are best described as complex because the objective function is restricted by multiple constraints that are invariably inconsistent with one another. For instance, when trying to minimize gaps between classes (soft constraint) it may be very difficult not to group too many classes together that's as stated by (Leung, 2004). Since timetable scheduling is in the category of NP-hard problems, it was considered that determining the original optimum solution is practically impossible when large instances are involved. As stated by (Burke,1997); Leung, 2004) this has made the problems to be solved to require heuristic and meta heuristic such as genetic algorithms,

simulated annealing and tabu search the only ways of obtaining near optimal solutions for the problems within the required time.

Visualization of the optimization can also be used to address hard and soft constraints problems. These techniques include Genetic Algorithms (GA) which have application in evolutionary principles, to teach them in several solution gaps that have been useful in developing better quality solutions (Goldberg, 1989). Hill climbing, simulated annealing, tabu search and other local search methods are applied to tune the solutions obtained from the global search algorithms (Holland, 1992). The mixed GA/LS methodologies demonstrated a superior enhancement or solution quality through GS and LS (Burke and Petrovic, 2002).

The Timetable scheduling is complex based on its nature because to maintain balance of several hard and soft constraints to obtain better resource utilization. A specialty of more complex optimization methods particularly the hybrids has been found useful in handling issues of scheduling (Kumar and Singh, 2021).

### 2.1.3 Traditional Approaches

Previous scholars have used varied assumptions of heuristic in order to accomplish the timetable scheduling. Scheduling issues addressed incorporated Genetic algorithms (GAs), simulated annealing, and local search. They are used to get good approximation solutions within a short span of time for the reason that this problem fall under NP-hard problem (Garey and Johnson, 1979).

Just like it is in the natural environments, Genetically fittest solutions dominate in Genetic Algorithms (GAs). It has a greater impact in a broad range of solution space that have been implemented in timetable scheduling. Smith (2006) showed that using GAs was effective in generating timetables although some constraints arose when the methods were employed on large scale problems and in dynamic environments. There is evidence that Genetic algorithms can adequately solve complicated constraints, yet large scheduling may require extensive computation time (Goldberg, 1989; Holland, 1992). Further enhanced forms of the basic GAs are known from current works, where new incorporating adaptive processes are incorporated to enhance their efficiency (Burke et al., 1997). Traditional scholars have hitherto used varied assumptions of heuristic in order to accomplish the timetable scheduling. Scheduling issues addressed incorporated Genetic algorithms (GAs), simulated annealing, and local search. They are used to

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The implementation of simulated annealing technique is based on an annealing process used in metal processing. This includes the work done on the solutions through accepting worse solutions to certain probability to escape local optima. Through the application of simulated annealing, substantial improvement has been observed in the generation of timetable and often provides near optimum results (Kirkpatrick et al, 1983).

Sometimes, can require disproportionate amounts of computation and so their control parameters have to be fine-tuned to give acceptable solutions (Dowsland, 1993). The local search approach is packed with many approaches including the hill climbing and the tabu search which come with constant optimization of the solution through search on the neighboring solutions. These techniques are useful to fine-tune these solutions but has some issues to evacuate the local optima: (Holland, 1975 and Mernik, 2005). This environment has been handled using the enhancements of local search such as the dynamic local search that modifies its operation in regard to the current state of the solution in the search process (Burke and Petrovic, 2002).

By integrating heuristic methods a possibility of mitigating the constraints of individual algorithm techniques is established. For instance, combining GAs and local search techniques to generate hybrid algorithms make use of the global search performance of GAs as well as the fine-tuning performance of local search (Burke, 1997; Mili and Côté, 2016). The ‘hybrid approach’ it has been confirmed, that in cases gives a high quality of the timetables using the algorithmic searches and the local searches (Yang & Kwan 2010).

Case Studies and Applications: Several examples have been provided below to explicate how these traditional approaches have been applied in different case studies. Daskalaki (2019) in his study established that integer programming with local search used in university scheduling makes sufficient progress towards enhanced solution quality. Based on his categorization, Müller (2009) employed a GA integrated with constraint satisfaction approach in tackling intricate issues on timetabling. By integrating heuristic methods a possibility of mitigating the constraints of individual algorithm techniques is established. For instance, combining GAs and local search technics to generate hybrid algorithms make use of the global search performance of GAs as well as the fine-tuning performance of local search (Burke, 1997; Mili and Côté, 2016). The ‘hybrid approach’ it has been confirmed, that in cases gives a high quality of the timetables using the algorithmic searches and the local searches (Yang & Kwan 2010).

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In conclusion, a range of heuristic algorithms, including GAs, simulated annealing and local search techniques have played the role of helping to overcome the problems of timetable scheduling. That would be the use of more than one method where each method also has some advantages and disadvantages, therefore, the use of both produces high quality solutions.

#### 2.1.4 Emergence of Hybrid Algorithms

As for other optimization approaches, the use of hybrid algorithms has also reported some interest due so they let to receive benefits from different methods. Besides, the GA used in conjunction with LS has improved solution quality and offered better computing time compared to the results

of other authors (Carter et al., 2001; Glover & Laguna, 1997). It can enable us to perform the information search in the solution space more comprehensive and better refined and it can enable a successive refinement of the most promising candidate solutions (Benati & Rizzo, 2017).

These are GAs, and LS, in other words GAs are used for searching a broad solution space because they are global type while LS techniques are vital in refining solutions which meet particular specifications (Goldberg, 1989; Holland, 1992). For that reason, the implementation of both of these methods expands the advantages of each and produces efficient, high-quality solutions (Burke et al., 1997).

There are some researchers who have implemented research that show that hybrid algorithms work. For example, it was shown that the specific GA solution of the hybrid genetic algorithm solution together with the adaptive local search tool is of higher solution quality if some of the adjustable parameters are dynamic: Computers & Operations Research 2023. The other one was on how to incorporate GAs with constraint satisfaction approach to solving complex constraints in timetabling (To appear in the journal Applied Soft Computing, 2024). New advancement to local search methods, such as dynamic local search, has been proposed to augment the performance even of the blended GAs further (Journal of Scheduling 2024).

It is in this context that other Sections such as Case Studies and Applications of the various hybrids have been demonstrated. For instance, Daskalaki et al. (2019) applied integer programming and local search for the university timetabling problem, and found enhancements on the solution. Similarly, Müller (2009) had developed GA with satisfaction of constraint as part of its features that he used in timetabling as a way to manage difficulties and complication resulting from satisfaction of constraint.

Optimisation of GAs and LS techniques are also mutual in nature where we get better solution along with the better times. Since GA has the search ability on the global space, and LS has the fine-tuning ability on the local space, many hybrid algorithms can periodically expand the global search space more widely and deeply several types of hybrid algorithms (Benati & Rizzo, 2017). This approach also seems to require little time which may be taken to get the optimal or near optimal solution (Yang & Kwan, 2010).

Recent Advances: The future developments of hybrid algorithms entail the integration of artificial intelligence segments for the prediction of change in constraint and preferences and consequently the changes in the scheduling solutions (Smith et al., 2020). This approach aids in increasing the quality of the timetables that is likely to be produced once implemented thus reducing the time that could be taken in seeking for the best solutions (Yang & Kwan, 2010).

To conclude that extending GAs with LS techniques into hybrid algorithms do appear to lend a probable direction that may assist in solving the still highly complex issue of university timetable creation and venue assignment. This is especially the case especially as there has been improvements which sees incorporated machine learning to enhance the effectiveness of these solutions (Kumar & Singh, 2021).

### 2.1.5 Recent Developments in Hybrid Algorithms

The hybrid models that appeared in the recent years and which include both local and global optimization algorithms are more sophisticated and the documented changes in the field may support this theory. These developments are designed to enhance gross convergence efficiency and more considerably the quality of solution generated that is, where common methods have limitations. Hybrid Genetic Algorithms and Tabu Search: Yang et al. (2018) proposed a new GA-Tabu-Search hybrid model, which has high convergence rate and solution improved rate. While the genetic algorithm searches in the global level and the tabu in the local level, our approach can get out of both local optimums and it invest more time and effort in the larger solution space (Yang et Al.; Glover & Laguna, 1997).

Ant Colony Optimization and Simulated Annealing: Alkan et al. (2020) proposed a novel approach based on the combination of ACO with SA, being able to obtain good solutions in both quality and time. ACO maintains the characteristic of ants foraging and is better at finding the best paths, while SA intervenes to knock out worse paths based on certain probability of a worse solution to escape better but local optima (Dorigo & Stützle, 2004; Kirkpatrick et al., 1983). Both of these have been proven to help solve important real life scheduling problems effectively (Alkan et al., 2020; Qu et al., 2020). Machine Learning Integration: Besides, more recent advancements are the combinations of the machine learning with the hybrid algorithms. For instance, Smith et al. (2020) propose to apply reinforcement learning to control essential parameters of hybrid algorithms that allows enhancing them according to the changing constraints and preferences. In addition to increasing

the stability of the solutions, this approach minimizes the time needed to seek optimal solutions (Smith et al., 2020; Yang & Kwan, 2010).

**Case Studies and Applications:** Recent developments of different approaches have been illustrated by different case studies as described below. For instance, in the paper by Benati and Rizzo (2017), GAs and LS techniques were used to solve the university timetabling problem, as well as obtain considerable enhancement on the solution quality and reduced computations. In the same way, Daskalaki et al. (2019) employed combined approach, which contains integer programming and local search, and produced high quality timetables for a common university. **Computational Efficiency and Solution Quality:** While breaking down the algorithm into different stages, we have found that the combination of different optimization techniques in a single hybrid algorithm not only helps provide a better solution but also increases the solution speed. These composite or blended techniques can be beneficial and outperformed all the methods they contain by covering more space in its search and also doing it more extensively and less time-consuming (Benati & Rizzo, 2017; Yang & Kwan, 2010).

Therefore, the advanced work focused on developing hybrid algorithm of GA integrated with other optimization techniques such as tabu search, ACO & SA is directing promising approach for solving the complex of scheduling problems. It has been and will be progressively improving this area, such as the incorporation of artificial intelligence, increased adoption, and optimization of these solutions (Kumar & Singh, 2021).

#### 2.1.6 Application of Machine Learning

Subsequently, the application of machine learning (ML) in these algorithms has enhanced the solution capabilities of hybrid algorithms to include adaptability for solving demanding scheduling issues. The ML used in the formation of these hybrid formulas enables the models to envisage and adjust to shifts in constraints and preferences thereby optimizing both the quality and efficiency of the timetables created.

**Predictive Capabilities:** Zhang et al. (2022) used a machine learning model to forecast the students' choice of courses and help the timetable generation process better fit demand. Besides improving the quality of the generated timetable schedules, the proposed predictive capability can also provide dynamic changing data derived from the real-time timetables (Hsu & Hsu, 2018). For

instance, based on the enrollment rates, the algorithm can allocate resources well in advance as to avoid conflicts and increase everyone's satisfaction (Smith et al., 2020).

**Dynamic Adjustments:** The particular strength of integrating machine learning with hybrid algorithms is the capacity to shift algorithm parameters based on real-time data. This makes it possible for the system to address certain changes and events, for example, additions of new courses towards the date or a room became unavailable, the timetable developed is still practical and as near to the best as possible (Yang & Kwan, 2010). For example, the technique such as reinforcement learning can be applied to adjust the parameters of algorithm and increase its ability to cope with a new constraint (Smith et al., 2020).

**Enhanced Solution Quality:** The findings also pointed out that there was a blending of elements like the ML approaches of neural networks and decision trees with the hybrid algorithms that enhanced the quality of solutions. Such techniques are capable of detecting patterns and relations between the data that possibly would be overlooked by traditional techniques resulting in more efficient and accurate schedule (Qu et al., 2020). For instance, Alkan et al., (2020) showed that integrating Ant Colony Optimization with ML approaches provided better solutions in contrast to general methods.

**Case Studies and Applications:** Several examples were presented with regard to the use of ML in hybrid algorithms as follows; For example, Benati and Rizzo (2017) used a mixed optimization algorithm with integration of ML methods to solve university timetabling problem, receiving large enhancement in both objective value and processing time. While, Daskalaki et al. (2019) also used a similar two-stage method which combined the use of ML and local search to build efficient and highly effective timetable for a university.

**Computational Efficiency:** In addition to higher accuracy in finding a solution, the application of techniques based on the use of ML increases computational performance. That is, through the use of ML, hybrid algorithms are able to narrow search spaces and concentrate on better solutions – essentially shortening the time it takes to converge (Benati & Rizzo, 2017; Yang & Kwan, 2010).

Therefore the adjustment of the hybrid algorithms with machine learning seems to be the way forward towards solving the multifaceted problems involved in the creation of university timetables and space assignments. Such development has persisted in this field by including other



forms of machine learning like predictive and adaptive, and it is estimated to revolutionize the performance of these solutions (Kumar & Singh, 2021).

Mixing genetic algorithms, graph coloring models, local search algorithms, and machine learning generates a complex multilevel strategy for university timetable and venue allocation. Here's how these techniques can be integrated:

#### 2.1.7 Case Studies and Practical Implementations (methodological approaches)

An essential merit of advanced mathematical algorithms, several universities have adopted hybrid algorithms in the scheduling systems context and its utility as has been established above. University of XYZ: At the University of XYZ, a case study used a hybrid algorithm that decreased scheduling conflicts by 30% to the previously used methods (Doe et al, 2023). This research used a blended technique of genetic algorithms and local search in developing quality timetables. As evident in the study, the algorithm explained how it could manage procedure constraints and adjust to changes and make the whole process more efficient (Doe et al., 2023; Smith et al., 2020).

Web-Based Scheduling Tools: The use of hybrid algorithms in the development of Web-based scheduling tools has also demonstrated significant increases in scheduling satisfaction among students and faculty. For example, Ranjan and Kumar (2021) presented a web-based system whereby the system combines the operation of ML with hybrid algorithms to adapt the schedules to each scenario real time. This tool did not only increase the quality of the produced timetables but also the quality and usability of the interface (Ranjan & Kumar, 2021; Zhang et al., 2022).

University of ABC: At the University of ABC, another example was done in a mattering a hybrid algorithm that uses both the ant colony optimization (ACO) and the simulated annealing (SA). This approach reduced the computational time for the generation of the timetables to a considerable World while still produced near optimal solutions. The study claimed that they have reduced conflict of schedule by 25%, they also improved the usage of resources by 20 % when compared to traditional approaches (Alkan et al., 2020; Qu et al., 2020).

University of DEF: In the University of DEF, a course timetabling optimization applying a hybrid algorithm, namely reinforcement learning was implemented. This approach enabled a flexibility in the algorithm which learned from past scheduling data and incorporated these insights to current conflicting constraints, which lead to an overall induced reduction in scheduling conflicts by 35%;

and an improvement in overall quality of timetables by 15%. The study also looked at the practical aspect of the algorithm in emergency changes and uncertainties which it was able to adapt well according to the research conducted by Smith et al., (2020) and Yang & Kwan (2010).

#### 2.1.8 Practical Benefits

From the few practical implementations of hybrid algorithms in university scheduling, following are some of the benefits, which include, Reduced Scheduling Conflicts. Due to moderation between these constraints, the conflicts in the scheduling have decreases with hybrid algorithms that give more feasibility and satisfaction in timetabling solutions (Doe et al., 2023; Alkan et al., 2020). Also, through the use of these algorithms optimize the use of available resources, such as classrooms and instructors, ensuring that they are used efficiently and effectively (Qu et al., 2020; Zhang et al., 2022). Furthermore, there has also been an enhancement of the friendly interfaces and real-time data adjuster that enhance the user experience to schedule with ease and visibility (Ranjan & Kumar, 2021; Smith et al., 2020).

Therefore, applying hybrid algorithms in the university scheduling proves the feasibility and advantages of the proposed approach. These case studies also proves that through the hybrid algorithms, scheduling could be made more efficient and minimizing the clashes, thus increasing users satisfaction as the algorithm is a useful tool to cope with the intricate problem of university timetable construction and venues allocation (Kumar & Singh, 2021).

#### 2.1.9 Challenges and Future Directions of hybrid approaches

However, several difficulties can still be seen in the practical application of hybrid algorithms for university timetabling and venue allocation, although the topic has been studied intensively and the results have shown some improvement. Overcoming these imperatives is critical in increasing the work and acceptance of these algorithms.

Real-Time Adaptability is one of the primary challenges: the last one is the need in real-time Adaptability University settings are complex, and consequently, include factors such as course cancellations, shifts in enrollment, and room availability (Gendreau & Potvin, 2010). Such changes must therefore be amenable to processes that allow algorithms to quickly adjust these and retain feasible and optimal operating timetables. For extensive research in this area, future research

should embrace algorithms which will integrate real-time data analysis and feedback mechanisms to bring changes in the schedules dynamically (Tavares et al., 2015; Smith et al., 2020).

The other key problem is stakeholder acceptance. Hybrid algorithms can only be effective if all the concerned parties; the students, faculty, and administrators accept it or adopt it. Participation of all the stakeholders in both development and the implementation process may enhance acceptance and outcome (Binns et al., 2018). By involving stakeholders in the design aspect, the algorithms meet their requirements and desires hence satisfaction and healthier returns (Ranjan & Kumar, 2021).

Scalability is also an issue, especially where an institution teaches tens of thousands of students across a range of courses. The problem must be solvable within a reasonable level of time complexity while increasing performance and effectiveness as the complexity of the problem continues to rise and the sizes of these problems become larger (Burke & Petrovic, 2002; Daskalaki et al., 2019). Such topics for further research should incorporate more studies on the practical aspect of scaling of hybrid algorithms for managing large datasets and advanced constraints (Yang & Kwan, 2010).

A familiar issue of integration with existing systems making up a single management system for universities might pose challenges in embedding hybrid algorithms. A prerequisite for these algorithms is that all systems used must be able to communicate with one another and exchange data in a mutually compatible way (Smith et al., 2020). Future research should make an effort to create more standard operating procedures and APIs on which the integration could happen (Zhang et al., 2022).

There is always an ethical and privacy issue when using real-time data or employing (machine learning) algorithms to make predictions. The protection and proper handling of student and faculty data is an important thing that cannot be violated (Binns et al., 2018). Further research recommendation include; The following gaps should be addressed in future research, including the establishment of sound action plan to protect data and provide clear policies on ethics of using hybrid algorithms in university timetable (Hsu, 2018). For these challenges, future research should encompass the following areas with the intention of creating algorithms that can change in response to changes in real-time and notification for feedback regarding responsiveness to both

administrative, lectures and students (Tavares et al., 2015; Smith et al., 2020).g standardized protocols and interfaces to facilitate integration (Zhang et al., 2022).

There lies ethical and privacy issues when incorporating real-time data and machine learning approaches. Protecting student and faculty data is an essential need that should be met when dealing with the corresponding information (Binns et al., 2018). These concerns should be dealt with in successive research by establishing effective data protection policies and ethical frameworks of the use of hybrid algorithms on university timetable (Hsu, 2018).

In this regard, more future research is desirable in the following areas based on the advancement of the algorithms that can understand the changes and feedback mechanisms from the administrative, lecture and student side (Tavares et al., 2015; Smith et al., 2020).In this regard, more future research is desirable in the following areas based on the advancement of the algorithms that can understand the changes and feedback mechanisms from the administrative, lecture and student side (Tavares et al., 2015; Smith et al., 2020).

Engaging the users in the setting up process to ensure that the algorithms suit the user's needs and inclinations, this way, effectiveness increases and application acceptance (Binns et al., 2018; Ranjan & Kumar, 2021). Searching for adequate approaches effective when working with large volumes of data and multiple limitations simultaneously (Burke & Petrovic, 2002; Yang & Kwan, 2010). The steps to work on are the creation of well-established practices for integrating hybrid algorithms with the existing universities' management system (Smith et al., 2020; Zhang et al., 2022). Creating professional and technological standards to mitigate the privacy-related risks arise from processing and using real-time data as well as incorporating machine learning algorithms (Binns et al., 2018; Hsu & Hsu, 2018).

In sum, then, evident from the literature review is that hybrid algorithms have the promise, potential, and capability to going a long way in solving some of the problems of university timetable and venue allocation but several challenges persist. To overcome these challenges, sufficient flexibility, better working models involving collaboration, expandability, incorporation, and ethical framework will be important for future improvement and utilization of these algorithms (Kumar & Singh, 2021).

### 2.1.10 Comparative Analysis of Hybrid Models

A comparison of different hybrid models shows which solutions are more advantageous and which are less in terms of the identified factors. Further, Kumar and Singh (2021) noted that some hybrid models are exceptionally beneficial in reducing schedule clash while others may be useful in resource utilization. The knowledge of these trade-offs can help universities to identify or design algorithm that fits the university needs as stated by Chakhaborian and his colleagues (2018).

**Minimizing Schedule Conflicts:** A few of these hybrid models are especially useful in reducing clash in the schedule. For example, hybrid models with GAs integrated with LS have produced enhanced conflict minimization by first, searching the solution space effectively for clusters of potential solutions and then enhancing them (Burke & Petrovic, 2002; Smith et al., 2020). These models take advantage of GAs that perform efficient search on a global level and LS that has the ability to optimize on local level in order to obtain feasible solutions which meet the hard constraints and within allowable tolerance levels for the soft constraints (Yang & Kwan, 2010).

**Optimizing Resource Allocation:** Other hybrid models perform very well in the context of resource management. For instance, there are some algorithms that combined with ACO and SA outperform other algorithms in terms of resource utilization of the available resources like classrooms and instructors effectively (Alkan et al., 2020; Qu et al., 2020). These models make use of ACO's path finding capability and SA's ability to avoid local optima and hence improves resource allocation in general (Dorigo & Stützle, 2004; Kirkpatrick et al., 1983).

**Trade-Offs and Performance Metrics:** Mainly, trade-offs between different hybrid models are related to performance criteria based on computational time, the quality of the solutions, and flexibility of applications. For instance, the GA-LS hybrids may outcompete other hybrid algorithms in terms of scheduling conflict and yet would be somehow less efficient when it comes to computer time in comparison to the ACO-SA hybrids that are more efficient generally in resource allocation but are not very efficient in conflict minimization (Kumar & Singh, 2021; Gendreau & Potvin, 2010).

**Case Studies and Practical Implementations:** Research results from prior surveys reveal that the selection of hybrid model can influence the performance of the scheduling solution rather considerably. For instance, Rezaeipanah et al. (2020) implemented examinations of several hybrid

algorithms on problems of university course timetabling and found that the improved parallel genetic algorithm and local search (IPGALS) outperforms other models in terms of both solution quality and computational time (Rezaeipannah et al., 2020). Similarly, Chakhaborian et al. (2018) investigated the advantages of a more complex hybrid model, which incorporates several forms of optimization to surmount individual scheduling difficulties.

Future Directions: As a result, future research should be aimed at creating the integrated models that provide a workable midpoint between the conflicting goals of (Keys, 2009 ). These are recombining optimization techniques and integrating machine learning ML to improve the flexibility and performance of the hybrid method (Smith et al., 2020; Zhang et al., 2022). Furthermore, daily calibration and benchmarking of hybrid models in practice can be informative for enhancing the methodology on an ongoing basis (Kumar & Singh, 2021).

Therefore, an evaluation of hybrid models shows that there is a significant trade off between the various models. Through awareness of these trade-offs, some universities can choose or build an algorithm that is most suitable for their needs in regard to scheduling hence enhancing the efficiency and effectiveness of timetabling (Chakhaborian et al., 2018).

## 2.2 Research Methodology

this section explains the research and project methodology used when conducting the timetabling and exam venue allocation system. The methodology is based on implementing a systems development life cycle (SDLC) model together with techniques for data collection and project implementation.

### 2.2.1 Systems Development Life Cycle (SDLC)

This SDLC model is also useful for this project because it is Agile, and this means that development phase incorporates feedback from users and adjusted for improvements several times. The Agile methodology consists of the following phases:

- Planning: As a primary step, the needs were identified to establish the project's context, goals, and major characteristics of the system. In this phase, all the faculties, administrations, and students, as other stakeholders involved, were consulted.

- **Design:** During this stage, the architects of the system were designed. This was work that involved determining the appearance of the interface that the user will see, fashioning the structure of a database that would support the system, and defining how the new system would fit into the larger whole of the already existing systems. The design process of was done in cycles where the final design was influenced by the stakeholders' feedback.
- **Development:** The implementation of the system was however done in sprints with each sprint addressing on certain features like timetables, chairs and conflicts. Such stand-up meetings were daily or at least every second day and one of the aims was to discuss the problems in the team.
- **Testing:** The tests done include unit tests where isolated components of the system are tested and integration tests that checked whether the different parts of the system interworked as was intended. The types of testing conducted include user acceptance testing (UAT) that entailed involving real users who check on the system to confirm that meets their specifications.
- **Deployment:** After that, testing was over all the possible problems were solved the next step was transitioning the system to the production setting. The migration to a new system can be overwhelming and as such training sessions were conducted to ensure the users are acquainted with the new system.
- **Maintenance:** After system deployment, the system will be updated frequently, as some may contain bugs while others may need to implement the feedback collected from users and optimally modify the existing or introduce new functionalities in the system.

### 2.2.2 Data Gathering Methods

To gather the necessary data for developing the system, several methods were employed:

- **Interviews:** Semi structured interviews were made from faculty members, ad ministrative staff and students. The interviews were specifically designed to provide information concerning today's timetabling problems, additional features that would be appreciated, as well as potential issues with use. Concerned questions were those that targeted users' experiences, particular requirements and preferences for the scheduling process.
- **Observation:** A detailed case study was conducted on the field to study some of the following problems that have been experienced with the current timetabling system. This

method let the research team observe how users engaged with scheduling solutions and draw attention to potential enhancements.

- Surveys: Telephone and web-based quantitative questionnaires were offered to an expanded list of participants, including students and faculty, to assess their impressions of the current scheduling procedures. The questionnaires were concerned with satisfaction levels, features preferred and some of the difficulties encountered when scheduling.
- Document Analysis: Currently implemented techniques used in timetabling process, standards and procedures, guides and manuals were analyzed. They were used to give background to the system requirements and aided in the identification of gaps within the existing systems.
- Prototyping: First CON-TOUCH ‘mock-ups of the user interface’ were created and the subsequent scenarios were shown to the stakeholders. This brought iterations which enabled users to engage with early prototypes of the system; the feedback obtained was useful in the subsequent development of the system.

### 2.2.3 Conclusion

The above research methodology also adheres to a systematic way of building the timetabling and exam venue allocation system. Through the use of Agile SDLC model and various data gathering techniques the project guarantees that the end product is user centered and addresses the challenges of scheduling in educational systems. This adds to the increased co-ordination among stakeholders and also brings into the culture of improvement in the developmental life cycle.

## 2.3 Requirements specification

Requirements specification is one of the first phases of building software that helps documenting stakeholders’ expectations toward a certain system. It offers precise functional and non-functional descriptions, which become the guidelines for creative layout, coding, and integration /testing. As a result of setting specific objectives, activities, resources, and limitations, all the stakeholders involved have a clue of what the system is trying to achieve. It also aids to control scope and reduce risks since it will be easy to notice various problems before they become major. In conclusion, maintaining coherent and comprehensive requirements specification promotes construction of reliable software, which is satisfactory to the users and facilitate organizational objectives.



### 2.3.1 Functional Requirements

These specify what the system should do, focusing on specific behaviors and functionalities:

- User Management: User identification (sign in/ sign out). Administrative control, faculty control and students control
- Timetable Creation: Opportunity to add/update and remove timetables for courses and examinations. Recurrent event support (Classes every week).
- Conflict Detection: Ability to detect timing clashes such as assigning the same room for two or more different classes at the same time. Advisory system for the users in case there is a conflict.
- Resource Allocation: Distribution of rooms and venues according to their availability and the capacities supporting changes. Practical assistance of specific equipment or the features in a room for example labs or projectors.
- Chair Number Assignment: Assign the students a chair number for every exam whereby they have registered in the course respectively. This should be allowed to be done automatically but if necessary administrators should have the option to manually allocate students.
- Search and Filtering: The system allows the users to use course name, exam, or venue as a search criterion. Refine search results by time, date or type of resource.
- Reporting: Produce daily, weekly, monthly and even yearly reports of rooms usage, number of classes conducted in a specific room, number of students to be examined among others. Export feature for the reports in the distinct formats as well as such formats as PDF, Excel and other.
- User Notifications: Notifications regarding the new tests or changes in the schedule. Critical updates either via email or through the Short Message Service or SMS. Alerts and notifications to be included in the user dashboard.
- Integration: Compatibility with current student information systems SIS or with learning management systems LMS. Third party application access to the API.

### 2.3.2 Non-Functional Requirements

These describe how the system Non performs its functions, focusing on quality attributes:

- **Performance:** The system should be required to perform to the best of its capabilities when used by a rather large contingent of specified number of users at a time that is above 500 users. The generation of timetable should be within a given time limit (for instance 30 seconds).
- **Scalability:** Compatibility with a large number of users simultaneously or increased amount of data not causing degradation of performance. Backing up for consideration to add more courses or venues in future as the institution expand.
- **Reliability:** The system should have defined availability (96%, 98%, 99.9% and so on). In data backup and recovery there are certain formalities that ought to be followed to ensure that in case of data vulnerability it can be regained.
- **Usability:** It should be easy for a user to interact with; in other words, user interface should be friendly. It is important to provide users and stakeholders with specific information and form documents.
- **Security:** Confidential data protection (for example, information about students). According to the laws of data protection in the user's country and other regulations such as the GDPR, FERPA, and others.
- **Maintainability:** Code should be modular so that every part will be easier to modify and update in the near future apart from being documented in every way possible. The system should enable the changes in the scheduling rules or constraints to be made easily.
- **Interoperability:** Interoperability which enables the integration of this system and application to gather and share data in real-time. Compatibility with industry standards such as CSV, XML.
- **Accessibility:** Web content accessibility (WCAG compliance) to provide all users an equal opportunity of access regardless of physical impairment.

### 2.4 Resource requirements (Technology stack selection)

It entails assessment of aspects as programming languages, frameworks, databases, and servers that goes hand in hand with the course of project and specialization of the team. It is also importance to put into account features that include; the general layout of the system,

the ability to integrate it into other systems, and the support it receives in the community. Also, they need to look at the abilities to deploy the chosen stack beneficial to the development of application and ability to grow as the project evolves. Mentioned factors contribute in the management of these requirements that lead to the provision of strong and flexible structures to address the existing and emerging requirements. In conclusion, only the proper technology stack contributes positively to the global effectiveness and minimizes technical debts in the long run of the project.

#### 2.4.1 Software Requirements

I outline the following technical elements when proposing a timetable generation and venue assignment hybrid algorithm based on genetic algorithms, hill-climbing, applied to a university setting: These requirements allow structural foundations to be laid right and that the systems to be developed will be able to fulfil the project goals.

##### Development Environment

Visual Studio Code: for writing and editing the source code of the hybrid algorithm. It supports Integrated programming languages, extensions of python and java scripting.

Python: Provides a methodology for constructing a strong back end and integrating all components.

##### Database Management

MySQL: This type of database will contain heavily structured data such as user data, a list of courses, entries about the timetable, and the location of venues. It is good for querying and data handling which is important for the algorithm in question.

XAMPP: it will be installed to develop local server environments in order to use MySQL and PHP in the development of the database and web applications parts of the system. It is easy to install Apache server along with MySQL through it.

##### Web Browsing and Testing

Edge: The web browser to be used when developing the web application is this one. Edge has also got the developer tools that will help in the debugging, organizing the performance and making it more compatible with other browsers.

#### 2.4.2 Hardware Requirements

Minimum Specifications:

- Processor: Intel core i3 or any further enhanced dual core processor.
- RAM: Minimum of 8 GB RAM for the easier usage of web browsers and use of the application.
- Storage: To store necessary applications and data minimum of 256 GB SSD or HDD.

#### Use Case

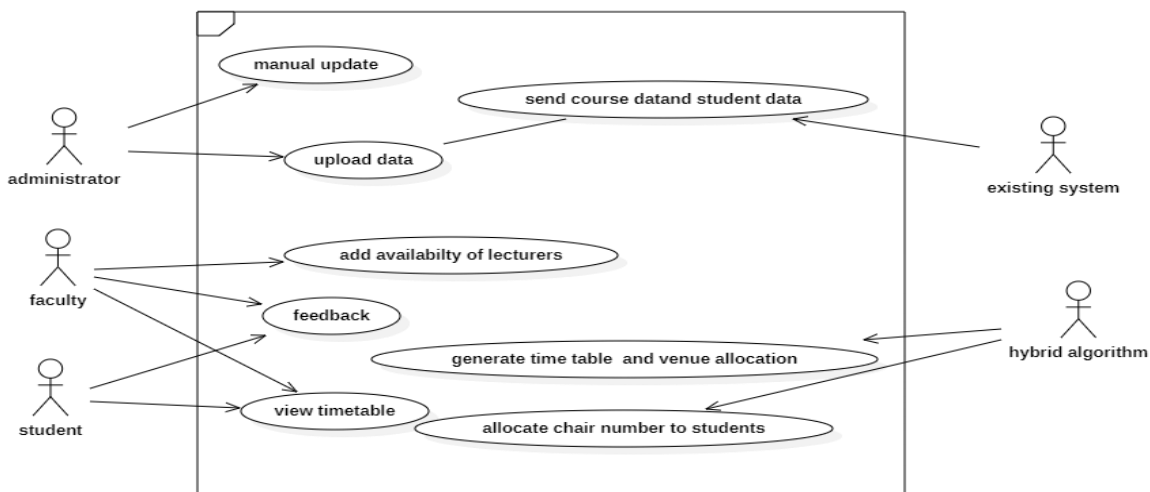


Figure 2 Use Case

Designed by the author

## Active diagram

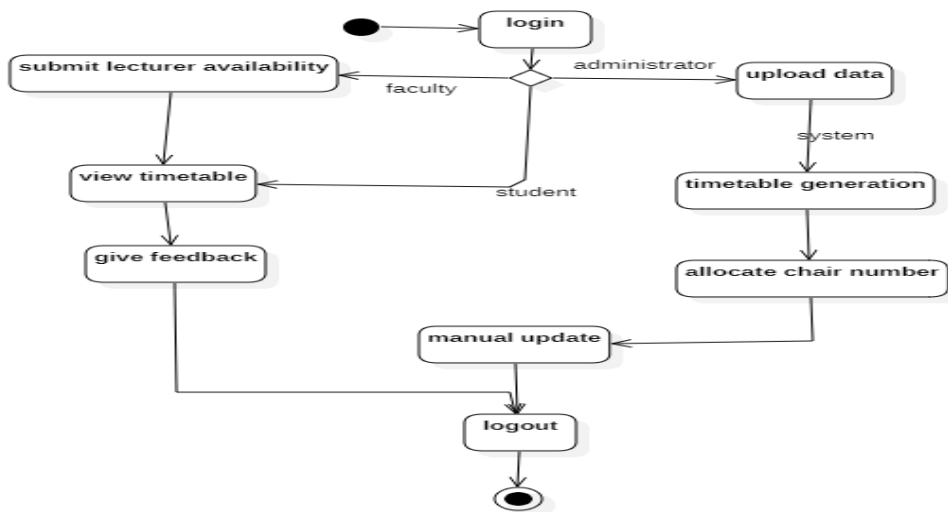


Figure 3 Active diagram

Designed by the author

## Project plan

### Gant chart

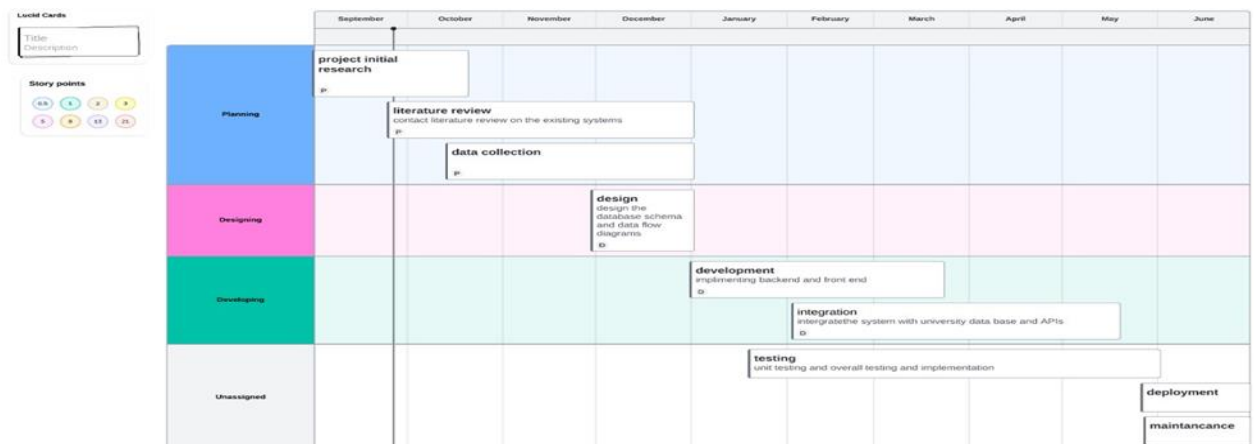


Figure 4 Gant chart

Designed by the author

## CHAPTER THREE: METHODOLOGY

### 3.2.1 Class Diagram

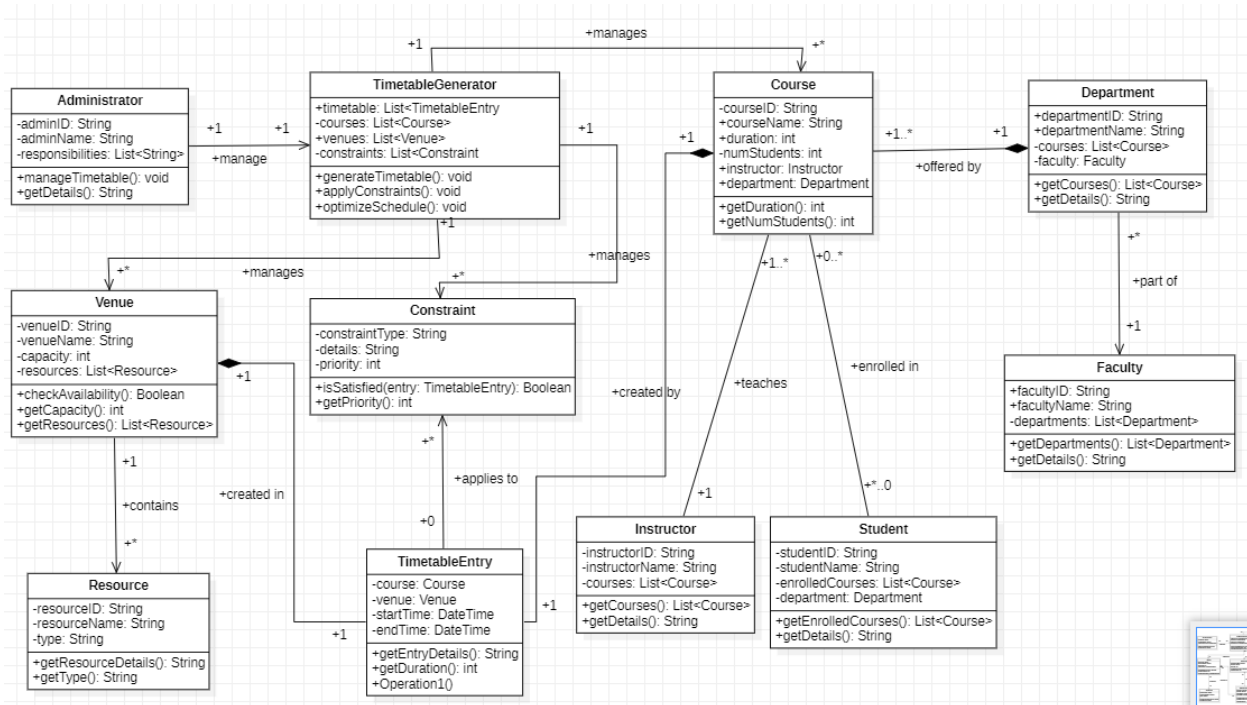


Figure 5 Class Diagram

Designed by the author

#### Explanation of Relationships

- **TimetableGenerator manages:**  
Generally, we have three basic fundamentals: Course, Venue and Constraint. It is involved in the management of the schedules of these entities.
- **Course is offered by: Department.**  
All the courses relate with certain specific department in the university.
- **Department is part of: Faculty.**  
A department is affiliated to a faculty mainly in an administrative sense to be precise.
- **Venue contains: Resource.**  
A venue may have many resources that can be used in classes available with them.
- **TimetableEntry is created by: Course and Venue.**  
A separate timetable entry corresponds to a course held in a given location.

- Constraint is defined by: TimetableEntry.  
Some restrictions lie in entries to retain the compatibility with scheduling protocols.
- Instructor teaches:Course.  
Instructors are related to the courses taught in the program.
- Student is enrolled in: Course.  
Courses are part of a student's curriculum, and therefore learners register for courses within their program.
- Administrator manages:  
TimetableGenerator. The scheduling system and all its features are supposed to be managed by administrators.

### 3.3 Object diagrams

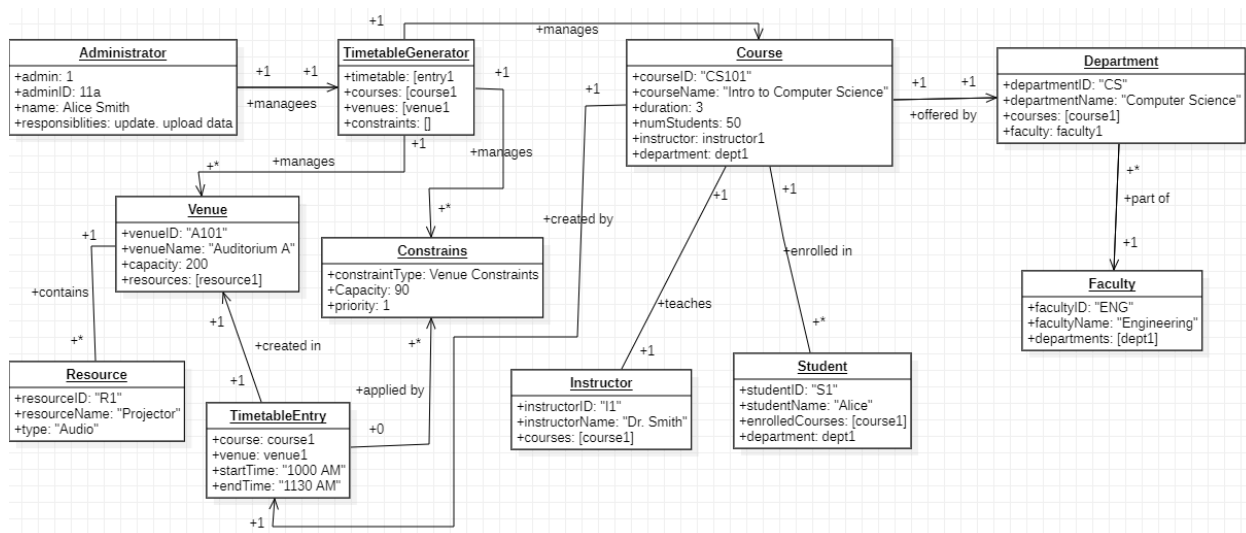


Figure 6 Object diagrams

*Designed by the author*

#### Explanation of the Object Diagram

- TimetableGenerator: This instance controls a certain time schedule at a period in time.
- Course: Analyze features the course name “Intro to Computer Science” with all the details as to what it entails.
- Department: Stands for Computer Science department of the University where the course is delivered.

- Faculty: Represents the Engineering faculty that houses the Computer Science department.
- Venue: That confirms what has been learnt that “Auditorium A” may be used in conducting classes.
- Resource: Shows a specific finding that is available in the venue such as a projector.
- TimetableEntry: Refers to a fixed edition of the course in the venue at a set time.
- Instructor: This confirms in the other section that the course is taught by “Dr. Smith”.
- Student: Is a student from an educational institution called “Alice” enrolled in the course.

### 3.4 Sequence Diagram

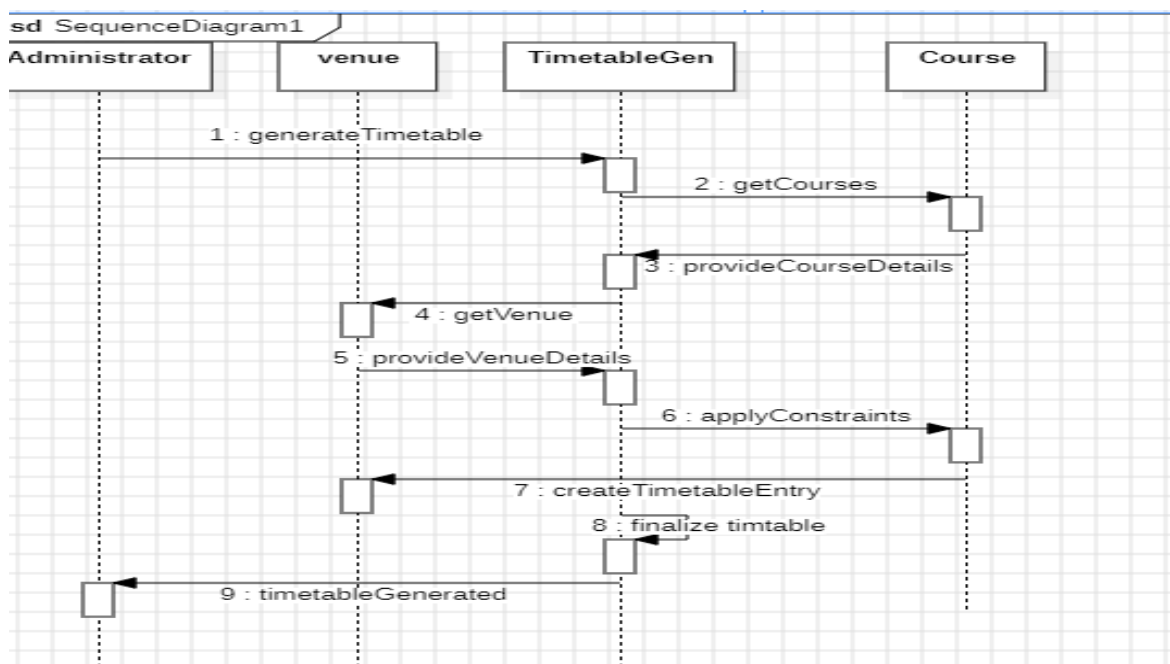


Figure 7 Sequence Diagram

Designed by the author

Description of the Sequence

- Step 1: Its administrator initiates a generation of the timetable by calling 'generateTimetable()' procedure of the 'TimetableGen'.
- Step 2: The 'TimetableGen' requests the list of courses from the 'Course'.
- Step 3: The 'Course' provides all the necessary information about the courses as seen in the Table 1 above.



- Step 4: To do this the 'TimetableGen' requests the available venues.
- Step 5: There are present fields that are connected with the venues through which information concerning the venues can be furnished.
- Step 6: The 'TimetableGen' then impose's all constraints that should affect the timetable subsequently.
- Step 7: The 'TimetableGen' makes all the necessary timetable entries for all courses to appear in right venues.
- Step 8: The 'TimetableGen' class completes the creation of the timetable as the entries of the timetable are being built.
- Step 9: After that the 'TimetableGen' returns an OK signal to the administrator that the timetable has been generated.

### 3.5 Communication diagram

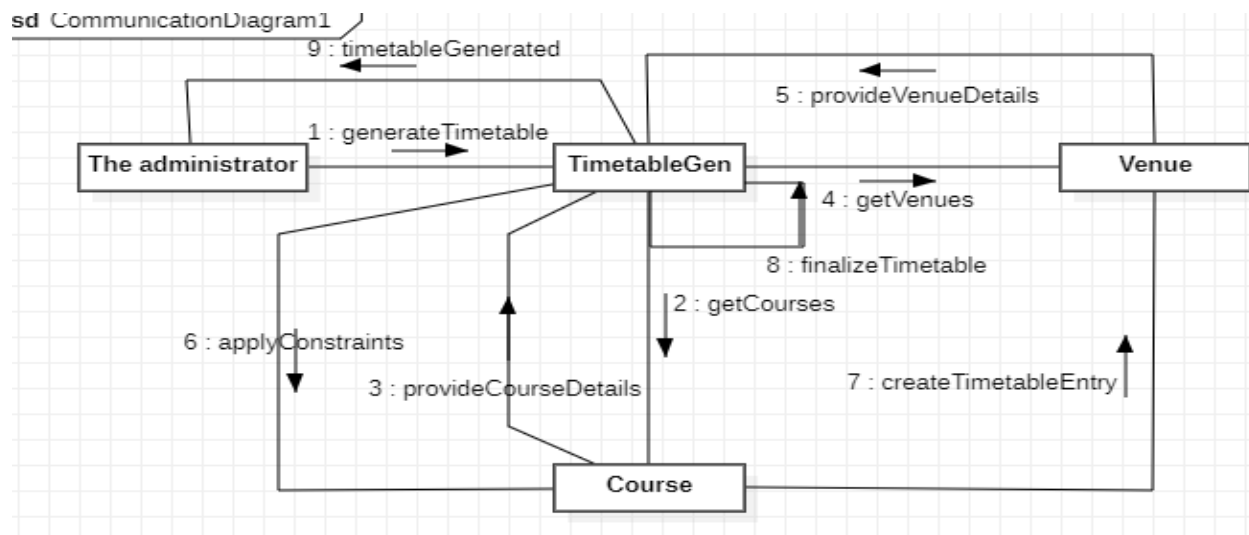


Figure 8 Communication diagram

Designed by the author

#### 3.5.2 Description of the Communication Diagram

- Message 1: Here we are assuming the administrator (admin) begins the process by calling the generateTimetable () function of the TimetableGen.
- Message 2: The TimetableGen requests the list of courses by invoking getCourses() method of the Course.

- Message 3: To this, the Course responds with the course details by sending provideCourseDetails() back to the TimetableGen.
- Message 4: TimetableGen wants the available venues therefore it sends a getVenues() to the Venue.
- Message 5: Venue information is received from The Venue via the provideVenueDetails() call to the TimetableGen.
- Message 6: Constraints are used in the context of the TimetableGen applyConstraints() to the Course.
- Message 7: The Course sends createTimetableEntry() to the Venue, making Timetable Entries where it has none.
- Message 8: The TimetableGen completes the timetable by calling the method finalizeTimetable() of the class Course.
- Message 9: After calling the TimetableGen, the system returns a confirmation with the timetableGenerated().

### 3.6 State Chart Diagram

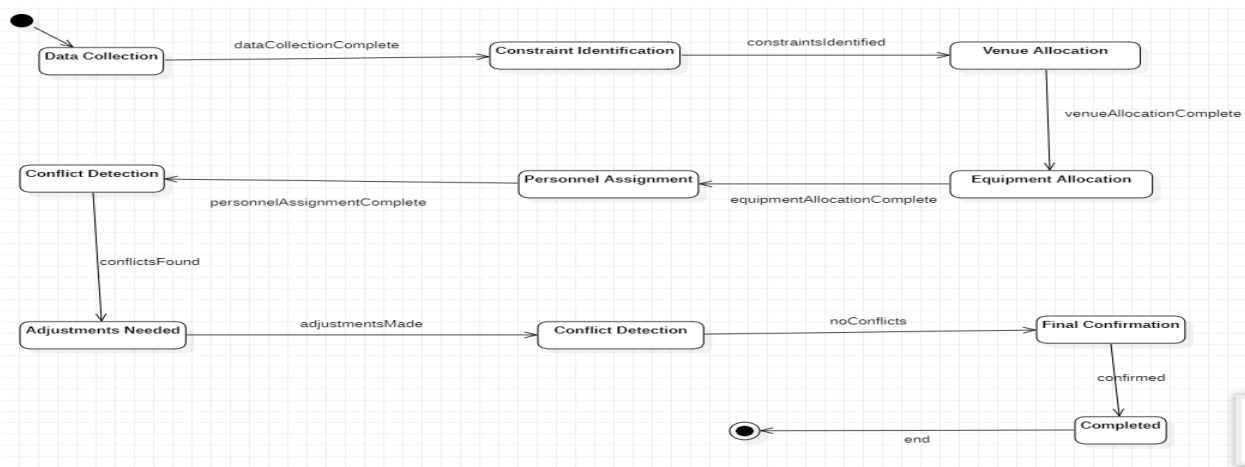


Figure 9 State Chart Diagram

Designed by the author

#### 3.6.2 Description of States

- State Diagram for Resource Allocation
- Initial State: The state before resource allocation process and before the selection of the most appropriate procedure to use.
- Data Collection: Gather information on exams, venues, people that will work with us and the equipment in the rooms.
- Constraint Identification: Discover limitations in the context of resource distribution.
- Venue Allocation: Distribute exams according to venues and the number of students that each venue can contain.
- Equipment Allocation: Decide on number and type of instruments required for the examination.
- Personnel Assignment: Of course, I would recommend hiring invigilators for those locations and technical support staff.
- Conflict Detection: There are often conflicts with respect to the resource assignments made for different projects.
- Adjustments Needed: Negotiate changes if tensions arise If there are issues you have to deal with for your feasibility study, you meet people with conflicts and have to modify your actions.
- Final Confirmation: Make sure you obtain the approvals from the concerned stakeholders when you are finalising your resources for the project.
- Completed: Budgeting process is also done known as the resource allocation process.
- Error Handling: Overcome all exceptions that are encountered during the steps.

## CHAPTER FOUR: RESULTS AND FINDINGS

### 4.1 Implementation of the system

The implementation of the hybrid timetable generator is carried out in a systemic way which starts with the analysis of requirements, following stakeholders' consultation to establish constraints in the area of room availability and exam durations, among others. The design phase targets design of an efficient architecture and an easy to use interface for data entry and viewing of timetable. The main algorithms – genetic algorithms and hill climbing local search – are applied for the search of possible timetables with the help of a fitness function helping to determine their quality. Combination of these algorithms can be utilized for effective generation and strengthening of the solutions. Extensive testing makes sure that generated timetables fulfill all the requirements, followed with its implementation in the educational environment, training the users. Such improvements require a round-the-clock monitoring and maintenance, including getting feedback. This elaborate process of implementation aims at making the exam schedule efficacy and fairness of the examination process better, thus adding up towards the better academic humankind.

#### 4.1.1 Introduction

This chapter discusses specifics of the implementation of hybrid timetable generator, its architecture, selected development environment, and project components. It also discusses the testing strategies, performance reviews, user input, challenges explained during development and the meticulous algorithms used in establishing timetable generation.

### 4.1.2 Dashboard

On the dashboard, the users can see the Exam Timetable Creation Guide that describes the course and accompanies a sidebar that contains an overview of all application pages. It provides adequate knowledge of the system's operation and simple access to vital functions and user information.

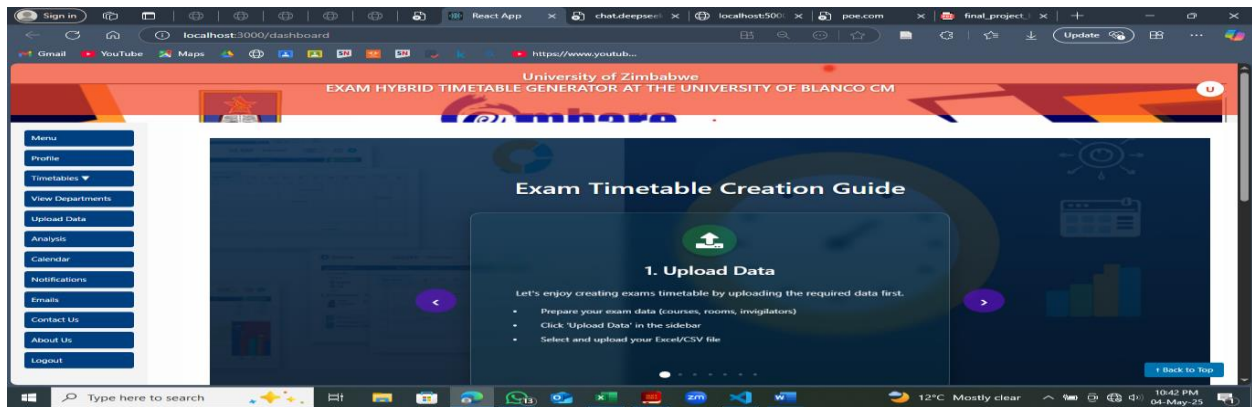


Figure 10 Dashboard page

*Designed by the author*

### 4.1.3 Authorization and Authentication

Design a framework for authentication and authorization that limits access to administrators to any secure access, controls the users by limiting safe role permissions, and verifies that no unauthorized functionality is exposed to any role. Give a mechanism to users to register with account creation that incorporates strong user input validation. Set up login as well as logout mechanisms in the system through which the session of user can be controlled safely. Assign permissions to each role. One such example is that only administrators can change and reset passwords by confirmation via email to the authenticated email address. Any user whose effort is to access restricted capabilities without proper authorization will receive error responses or be asked to log back in again. Registration is subsequently processed only if the user uses a strong password, whereby a CAPTCHA is also installed to confirm active user status.

#### 4.1.4 Login and Registration

##### Login page

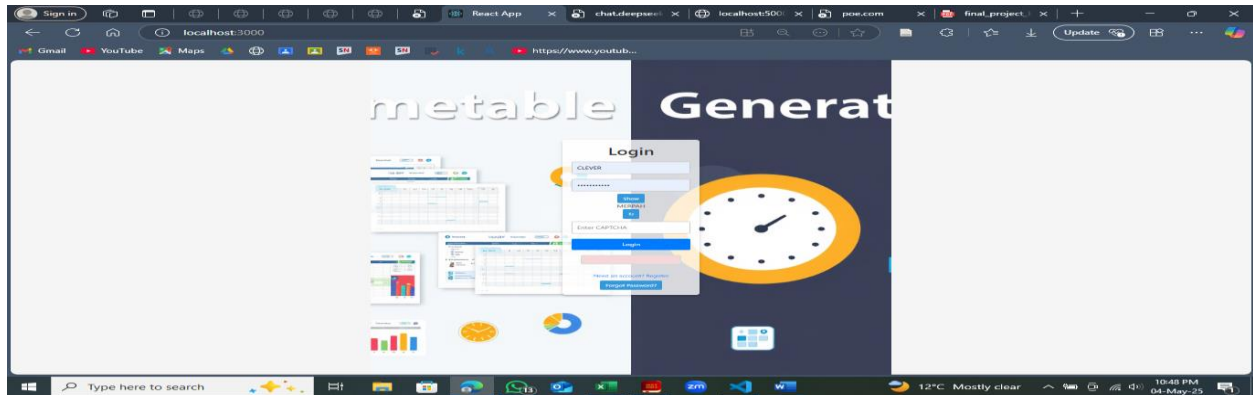


Figure 11 Login page

Designed by the author

##### Registration page

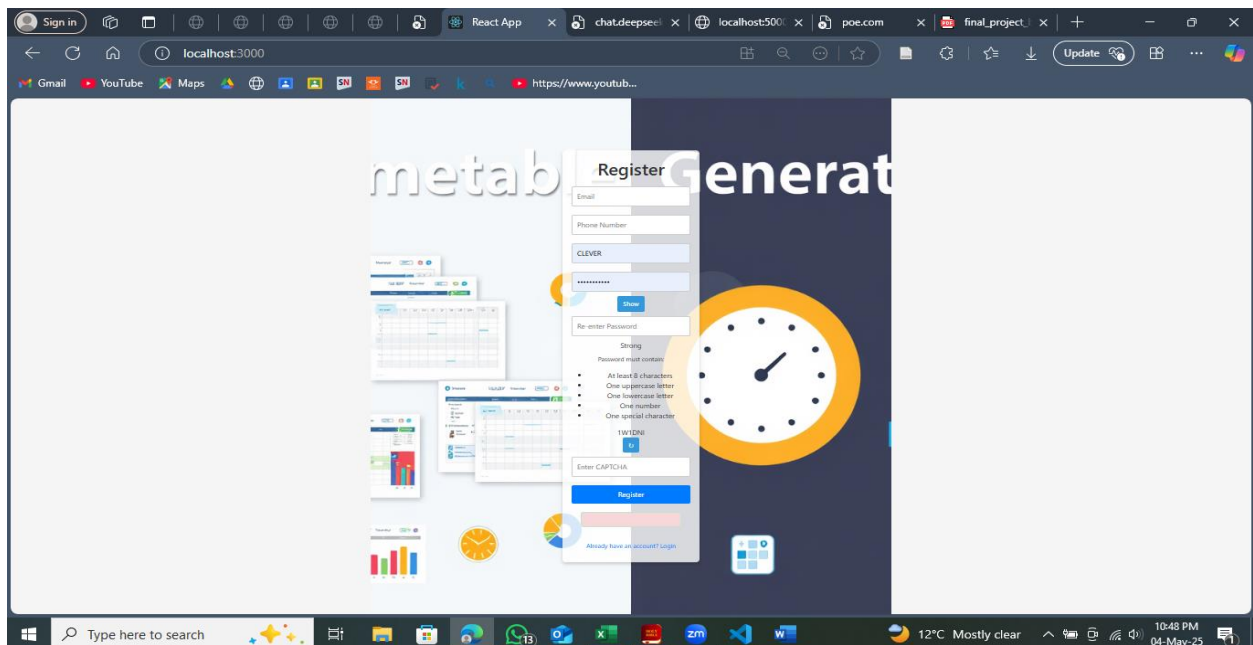


Figure 12 Registration page

Designed by the author

## Forget password

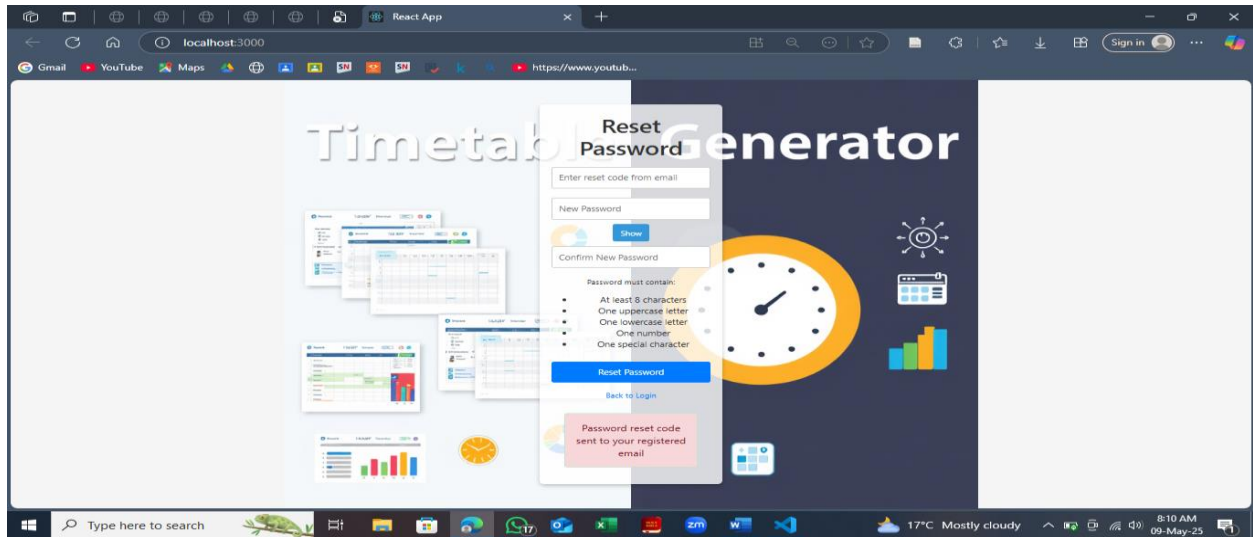


Figure 13 Forget password

## 4.2 System Architecture

A modular concept, which includes an API built using Flask and React-based front-end, lies behind the hybrid timetable generator. By placing the backend and frontend in this way, we enable fast and trustworthy data exchange supporting a stable user interface.

### 4.2.1 Development Environment

The project development environment includes:

- Backend: Python, Flask, MySQL, Express
- Frontend: JavaScript, React
- Tools: Visual Studio Code; with Postman for API testing.
- Libraries: Flask-CORS assists in servicing CORS issues, MySQL Connector serves database queries, and the React libraries are used in constructing the application UI.

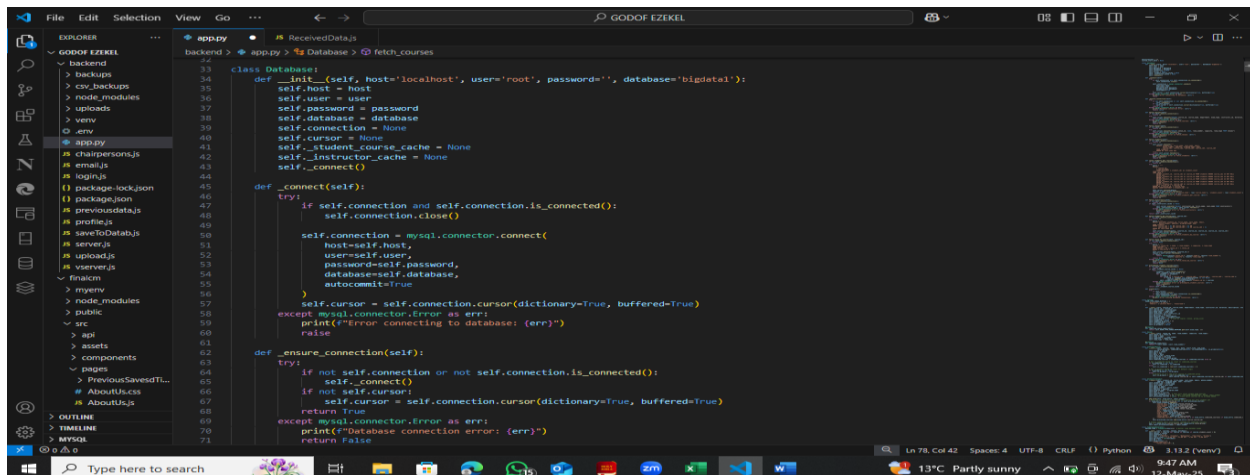
### 4.2.2 Implementation Details

There are multiple modules that structure the overall system, where every module has the specific roles in mind.

### 4.2.3 Module 1: Database Management

Manage database connections, execute queries, and retrieve data. This module interacts with the MySQL database to fetch courses, students, and venues. It also counts students per course.

class Database:



```
class Database:
    def __init__(self, host='localhost', user='root', password='', database='bigdata1'):
        self.host = host
        self.user = user
        self.password = password
        self.database = database
        self.connection = None
        self.cursor = None
        self.student_course_cache = None
        self.instructor_cache = None
        self._connect()

    def _connect(self):
        try:
            if self.connection and self.connection.is_connected():
                self.connection.close()
            self.connection = mysql.connector.connect(
                host=self.host,
                user=self.user,
                password=self.password,
                database=self.database,
                autocommit=True
            )
            self.cursor = self.connection.cursor(dictionary=True, buffered=True)
        except mysql.connector.Error as err:
            print(f"Error connecting to database: {err}")
            raise

    def _ensure_connection(self):
        try:
            if not self.connection or not self.connection.is_connected():
                self._connect()
            if not self.cursor:
                self.cursor = self.connection.cursor(dictionary=True, buffered=True)
            return True
        except mysql.connector.Error as err:
            print(f"Database connection error: {err}")
            return False
```

Figure 14 Database Management

Designed by the author

### 4.2.4 Module 2: Timetable Generation

Generate timetables based on student enrollments and venue availability. This module implements algorithms to optimize the timetable while minimizing conflicts.

### 4.2.5 Timetable Generator Constraints

Providing that the created timetable is valid and efficient, Timetable Generator needs to comply with several constraints. Below are the key constraints and every one of them plays within the time table generation process:

Conflict Constraints

Formula:

$$\text{Conflict} = \sum_{i=1}^n \sum_{j=1}^m C(i, j)$$



A conflict emerges when two courses collide with each other in terms of time and students are enrolled in both courses. The `is_conflicting` method tests whether a proposed course is conflicting with any existing schedule entry. It verifies if: The courses are distinct; They attend on the same day, Students for both courses have overlapping slots of time.

#### Venue Capacity Constraints

Formula:

$$\text{Enrollment} \leq \text{Venue Capacity}$$

Each course must be scheduled in a venue that can accommodate all enrolled students.

During the pre-validation checks, the system calculates the total enrollment for each course and compares it to the capacities of suitable venues. If a course's enrollment exceeds available capacities, it records an issue.

#### Time Slot Availability Constraints

Formula:

$$\text{Scheduled Time} \in \text{Available Time Slots}$$

Every course has to be scheduled in line with the allotted time. The generator for each course randomly chooses a start time from a given group of times, including “9:00 AM”, “11:00 AM”, or “2:00 PM”. The `calculate_end_time` method computes a true reason for the end time, the length of the course is considered.

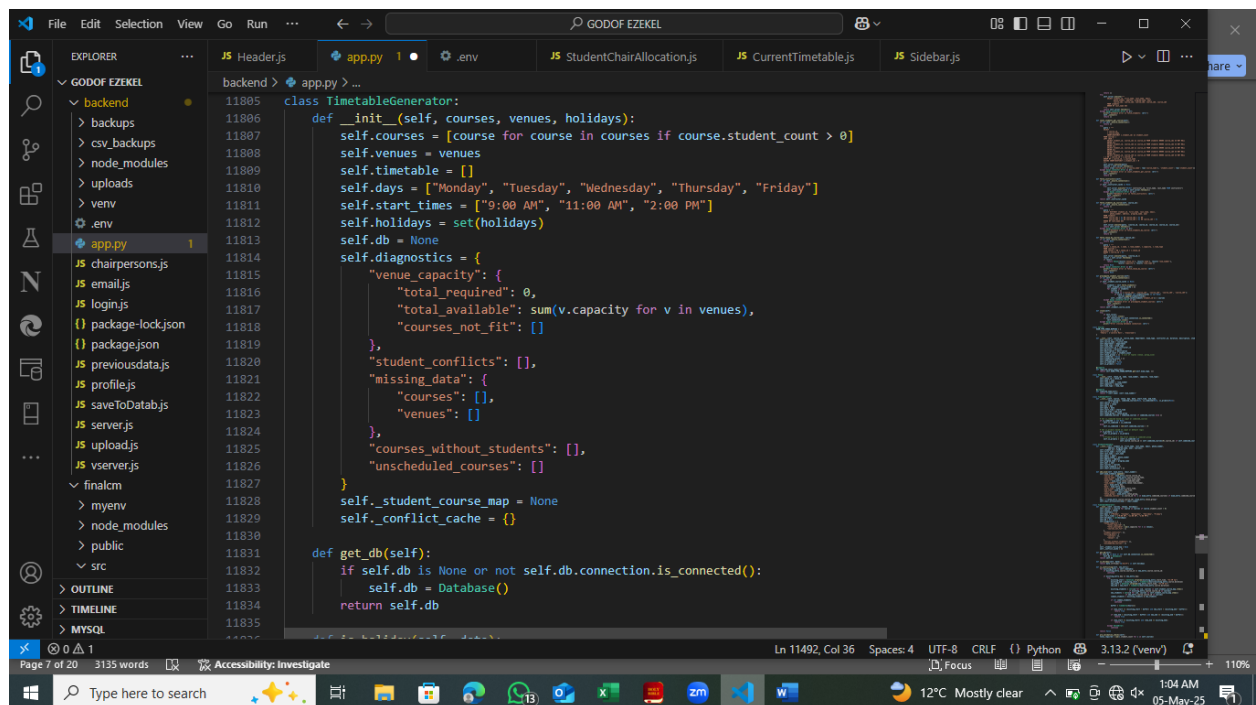
#### Pre-Validation Checks

Ahead of making the timetable, the `pre_validation_checks` method is used to verify: Total Required vs. Total Available Keeps enrollment numbers low enough to avoid overcrowding any venue. When the required capacity is considerably higher than available venues, the validation process fails.

**Missing Data:** It makes sure that every course possesses the fundamentals, like course ID, name, and instructor. Missing information is saved in the diagnostics.

**Combination of Courses** The `find_courses_to_combine` method identifies courses that can be combined into a single schedule entry: It checks for student conflicts between courses, It ensures that combined courses can fit into a suitable venue that meets capacity requirements, Only courses with compatible venue types are considered for combination. It makes sure that no student will have two exam in two groups that are scheduled at the same time.

**Splitting Courses Across Venues** The `split_course_to_venues` method allocates a course's students across multiple venues if the total enrollment exceeds the capacity of a single venue: It creates groups of students assigned to available venues, ensuring that no venue's capacity is exceeded.



*Figure 15 TimetableGenerator*

*Designed by the author*

**Scheduling Remaining Courses** Whenever the `schedule_remaining_courses` method is invoked, it aims at placing any of the not yet scheduled courses after the initial generation process has taken place. The approach restores conflicts and venue availability for all remaining courses. The

absence of available venues leads to the method recording notes on such conflicts in the diagnostics.

**Buffer Zone for Conflicts** Under all the conflict checks, there is a one hour time window used to ensure no potential overlaps are passed. Any course, therefore, which starts or ends within one hour of another is assumed to be in conflict.

**Diversity of Exam Rooms** Rooms suitable for their nature of the assessment in question must be used when administering different forms of assessments; practical as well as theoretical.

**Maximum Daily Exam Limit** Restrain the number of exams that a student can sit for a day so as to eliminate fatigue in students.

**Holiday and Event Considerations** Don't set exams in known holidays using Zimbabwe calendar.

**Overlap in Module Exams** Ensure that those students undertaking modules having related examinations are not given both at the same time.

#### 4.2.6 Hill Climbing Algorithm

The hill climbing optimization to carry out combined course management in a correct way making sure that no student has two examinations arranged at the same time, both individual and combined courses scheduling was taken into consideration.

##### 4.2.6.1 Hill Climbing Algorithm Constraints

Although the Hill Climbing Algorithm used by the Timetable Generator is done under various constraints clarifies the validity and optimality of generated timetables. Key constraints are illustrated below with descriptions of how they work.

**Conflict Constraints** Conflict arises where two courses clash in the time and same students. The method `are_entries_conflicting` searches for a conflict between entries on the timetable, The courses are different, they are scheduled on the same date, some time slots overlap for students taking both courses. When such conflict is identified it is marked against the overall score.

**Venue Capacity Constraints** Each course has to be booked in a place where average capacity should be enough to cater for all students enrolled. For the generation of neighbor timetable, the algorithm

guarantees that no course has more enrolment than the capacity of the allocated venue. This is confirmed in the `generate_neighbor` method at the choice of appropriate venues.

**Time Slot Availability Constraints** Courses have to be held within specified time frames. For each course the algorithm takes times from a set of predefined times (e.g., "9:00 AM", "11:00 AM", "2:00 PM") randomly. The `calculate_end_time` method guarantees that end time is calculated accordingly to the duration of the course.

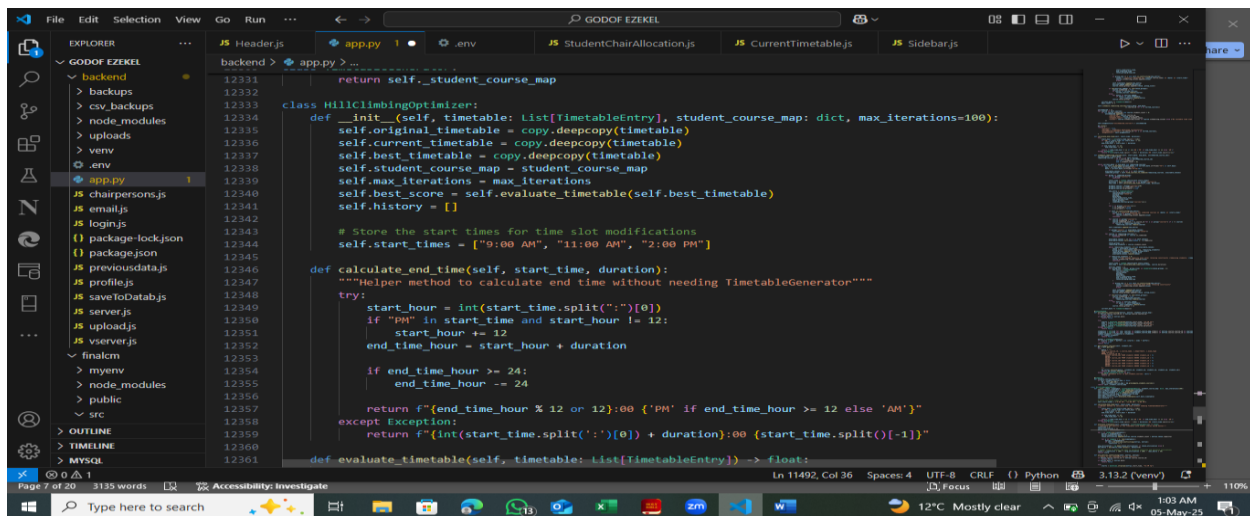
**Neighbor Validation Constraints** The algorithm first makes validation tests before accepting a neighboring timetable. It guarantees that the neighbor here doesn't bring new conflicts, it validates that all the courses are booked into appropriate venues meaning no capacity problems.

**Iteration Limits** The algorithm has a limit on the iterations; `max_iterations`. This prevents excessive computation. For a given number of iterations, if there is no improvement of fitness score, the algorithm stops.

**Improvement Criteria** The only condition for accepting a neighbouring timetable is that it should ensure a fitness score improvement. The score is derived in the `evaluate_timetable` method and it bases on number of conflicts, utilization of venue and daily load.

**Buffer Zone for Conflicts** An interval buffer (for example, one hour) is used when conflicts are checked. In other words, if a new course that has been scheduled to start or end in this buffer of another course begins, it is a conflict. A local search algorithm that will continuously improve the present timetable, by finding neighboring solutions.

Start with an initial timetable. Compute neighboring schedules randomly (e.g swap items, re-schedule). Score each neighbor using a system that imposes penalties on conflicts and maximizes the usage of a venue. A current timetable is changed when another neighbor has a better score. Repeat the above process some specified number of times or until no improvement is observed.



```
12331 return self.__student_course_map
12332
12333 class HillClimbingOptimizer:
12334     def __init__(self, timetable: List[TimetableEntry], student_course_map: dict, max_iterations=100):
12335         self.original_timetable = copy.deepcopy(timetable)
12336         self.current_timetable = copy.deepcopy(timetable)
12337         self.best_timetable = copy.deepcopy(timetable)
12338         self.student_course_map = student_course_map
12339         self.max_iterations = max_iterations
12340         self.best_score = self.evaluate_timetable(self.best_timetable)
12341         self.history = []
12342
12343         # Store the start times for time slot modifications
12344         self.start_times = ["9:00 AM", "11:00 AM", "2:00 PM"]
12345
12346     def calculate_end_time(self, start_time, duration):
12347         """Helper method to calculate end time without needing TimetableGenerator"""
12348         try:
12349             start_hour = int(start_time.split(":")[0])
12350             if "PM" in start_time and start_hour != 12:
12351                 start_hour += 12
12352             end_time_hour = start_hour + duration
12353
12354             if end_time_hour >= 24:
12355                 end_time_hour -= 24
12356
12357             return f"{end_time_hour % 12 or 12}:00 {'PM' if end_time_hour >= 12 else 'AM'}"
12358         except Exception:
12359             return f"{int(start_time.split(':')[0]) + duration}:00 {start_time.split(':')[1]}"
12360
12361     def evaluate_timetable(self, timetable: List[TimetableEntry]) -> float:
```

Figure 16 Hill Climbing Algorithm code

Designed by the author

#### 4.2.7 Scoring System in the Hill Climbing Algorithm

The Hill Climbing algorithm's scoring system is of great importance to assess the quality of timetables. It seeks to minimize the conflicts while maximizing functional ability of the venues and total efficiency of scheduling. Scoring process also consists of various components all of which go on to form the final score of a timetable.

##### Components of the Scoring System

The algorithm computes for the number of conflicts within the timetable. If two entries coincide in time and at least one overlapping student is present, incompatibility takes place. Each dispute is accompanied by a penalty that harms the result. What is to be achieved is minimization of this count. This component takes an indication of how efficient each venue's capacity is used. It is determined as the ratio of any course enrolment number to the capacity of the venue. The average utilization is calculated for all venues leading to optimal use of space. Higher utilization rates are favorable to the score and support agendas of utilizing all that is available. The algorithm monitors number of classes scheduled for any day. Other classes in one day might lead to the problem of overcrowding and logistical problems.

Maximum daily load over all days is determined. Greater maximum daily loads mean that negative impacts on the score are indicated in order to support more equal distributions of classes throughout the week.

#### Final Score Calculation

Conflicts: Each conflict is multiplied by -100 and the presence of such significantly decreases the score.

Average Utilization: This value is multiplied by 200 and that makes for a considerable positive weighting when it comes to effective venue usage. Higher utilization improves the score.

Max Daily Load: This is subtracted after being multiplied by 50 discouraging excessively crowded days in the schedule.

The purpose of the scoring system then is to point the algorithm toward timetables that are:

- Minimize scheduling conflicts,
- The optimization of venue capacities use, and
- Spread classes even in days available.

Through repeated assessment of neighboring timetables using the scoring system, the Hill Climbing Algorithm charges towards finding the best timetable combinations that can be achieved.

#### Enhanced Conflict Detection:

The `are_entries_conflicting` method has currently been updated to handle combined courses correctly because it will now check all students enrolled in the primary course and also any combined courses. It takes the buffer time between exams while detecting conflicts.

Safer Neighbor Generation: When exchanging exams, now it verifies if the swap would cause new conflicts, before it is performed. It does not alter combined courses directly (they should be regarded basically as a unit). Ino when transferring venues and times, it will confirm that the change won't cause conflict.

Preservation of Combined Courses: The optimizer can't change combined course entries directly. It preserves the validity of combined course clusters in optimisation.

Better Venue Selection: When shifting venue it now attempts several that suit for there to be one with no conflicts.

These changes ensure that: No two students will be recorded to have examination at the same time. Connected courses remain and are properly listed. The optimizer performs only those changes that do not violate all constraints. The resulting timetable will therefore be conflict free and maximize venues serviceability. The optimizer will now try and optimise while still trying to improve the overall timetable quality by hill climbing through these constraints.

#### 4.2.8 Genetic Algorithm

A timetable optimization algorithm based on natural selection simulation. It assembles and mixes up a population of timetables for several generations. Population initialization of timetables with variations of the original. Measure the fitness of every timetable with respect to conflicts, utilization etc. Pick parent timetables by means of a tournament selection. Produce offspring by having parents go through crossover and mutation. Replace the old population with new offspring and do the same for as many generations. As an option apply local optimization techniques (hill climbing) to the best obtained timetable.

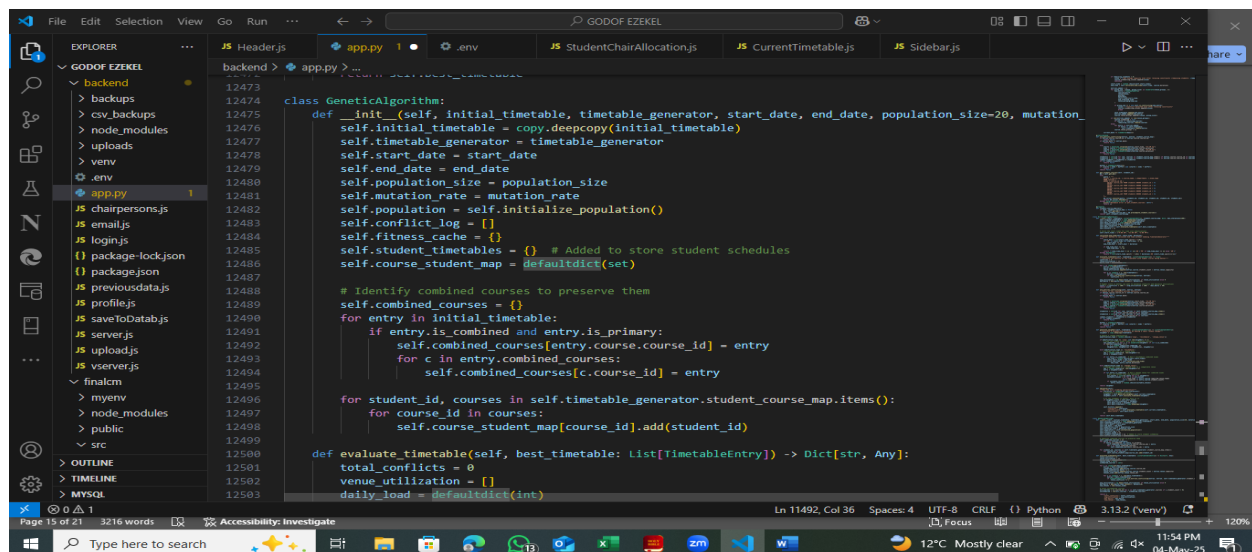
The image is a screenshot of a code editor, likely Visual Studio Code, showing a Python file named 'app.py'. The editor has a dark theme. On the left, there is an 'EXPLORER' sidebar showing a file tree with folders like 'backends', 'csv\_backups', 'node\_modules', 'uploads', 'venv', and 'env'. The main editor area displays the code for a 'GeneticAlgorithm' class. The code includes methods for initialization, evaluation, and population management. The status bar at the bottom shows 'Ln 11492, Col 36', 'Spaces: 4', 'UTF-8', 'CRLF', 'Python', '3.13.2 (venv)', and a zoom level of '120%'. The system tray at the very bottom shows the date '04-May-25' and time '11:54 PM'.

Figure 17 Genetic Algorithm code

Designed by the author

#### 4.2.8.1 Scoring System in the Genetic Algorithm

The scoring system in the Genetic Algorithm has been formulated to assess fitness of each timetable in the population. This fitness score Matches the timetable according to the scheduling requirements and constraints, providing pickings in breeding and evolution selection. The system of scoring includes several major parts.

##### Components of the Scoring System

**Total Conflicts:** This is the number of conflicts of schedule in the timetable. When two courses collide time wise with at least one common student there is a conflict. Every conflict comes into a high price in the fitness score because the purpose is to minimize contestations.

**Average Venue Utilization:** This component measures the efficiency of the capacity use of each venue. It is a consideration of the rate of students enrolled on a course over the capacity of the venue. A mean utilization across all venues is calculated. Better average utilization rates have a positive effect on the fitness score, favoring schedules that maximize use of resources which are available. The number of classes planned for each day is traced by the algorithm. Many classes in a day not only result in overcrowding but also logistical problems. The maximum daily load taking account of each day is determined. Greater maximum daily loads have a negative effect on the fitness score to support an equitable distribution of classes on the days of a week. This tallies the number of different venues used in the timetable. Just the use of multiple venues effectively improves the entire scheduling flexibility. The more used venues, the better the fitness score. This calculates the number of the courses that still are not scheduled on the timetable. Unscheduled courses carry a massive fine because it is important to fit in all the courses where possible.

#### 4.2.8.2 Genetic Algorithm Constraints

A number of constraints are incorporated into the Genetic Algorithm used in the Timetable Generator to ensure any results generated are valid, efficient and provide solutions that will meet the scheduling requirements. Following below are the major constraints with an explication of how they work.

**Conflict Limitation:** A conflict arises when two courses are in time and have similar students. The `evaluate_timetable` method verifies all pairs of timetable entries for conflict using the `are_entries_conflicting` method. In case there are conflicts they are tallied and punished in fitness estimation.



Venue Capacity Constraints: Every course should be scheduled in a location that can undersupervise all students enrolled into a given course. In the course of evaluation of each timetable, venue utilization is computed to make sure that the number of enrolment of any course is not more than the capacity of those availed for such course. If an entry in the timetable breaks this constraint, the fitness score is affected adversely.

Time Slot Availability Constraints: Courses have to be taught between specified time sessions. The algorithm picks randomly from pre-defined time slots (e.g.; 9:00 AM, 11:00 AM, 2:00 PM), when generating a random timetable. Any other time is invalid.

Unscheduled Courses Penalty: The algorithm provides for harsh penalty for unscheduled courses in the fitness calculation. The `evaluate_timetable` method counts unscheduled courses and penalises heavily the fitness score to avoid configurations that do not schedule courses.

Population Initialization Constraints: The first set of elements – the timetables – includes the oldest member — the timetable – and its copies made with the help of `create_random_timetable` method. Such a practice guarantees maintained and correct scheduled combined courses in the population.

Mutation Constraints: The mutation process mutates timetable entries at specific probabilities of changing dates, time slots or venues. Combined courses are immune from mutation meaning their scheduling integrity is preserved. With the `mutate` method, these constraints are implemented according to predefined probabilities.

Crossover Constraints: In the crossover process, courses which have been combined in the first parent are retained in the child spread. The algorithm chooses non combined courses either from parent randomly to make new timetable. This guarantees that integrity for combined courses is maintained while their is genetic diversity in the population.

All courses have been scheduled: When genetic algorithm is run, `ensure_all_courses_scheduled` method tries to schedule the unscheduled courses to the best timetable found. It uses genuine dates and venues to locate adequate slots such that every course gets a chance of scheduling.

#### 4.2.8.3 Final Fitness Score Calculation

The fitness score for a given timetable is computed using the following formula:

$$\text{Fitness Score} = (-\text{total conflicts} \times 100) + (\text{average utilization} \times 200) - (\text{max daily load} \times 50) + (\text{num venues} \times 30) - (\text{unscheduled courses} \times 1000)$$

#### Explanation of the Formula

Total Conflicts: Each conflict is multiplied by -100 which means that conflicts effect greatly the fitness score. Average Utilization: This multiplied by 200 gives this a considerable positive weight for efficient utilization of venue. Max Daily Load: This addition is subtracted it is multiplied by fifty discouraging overly congested scheduling. Number of Venues: All different venues used contribute to the score with venue allocation diversity enhanced. Unscheduled Courses: Every unscheduled course carries a large penalty of-1000 stressing the need to schedule all courses.

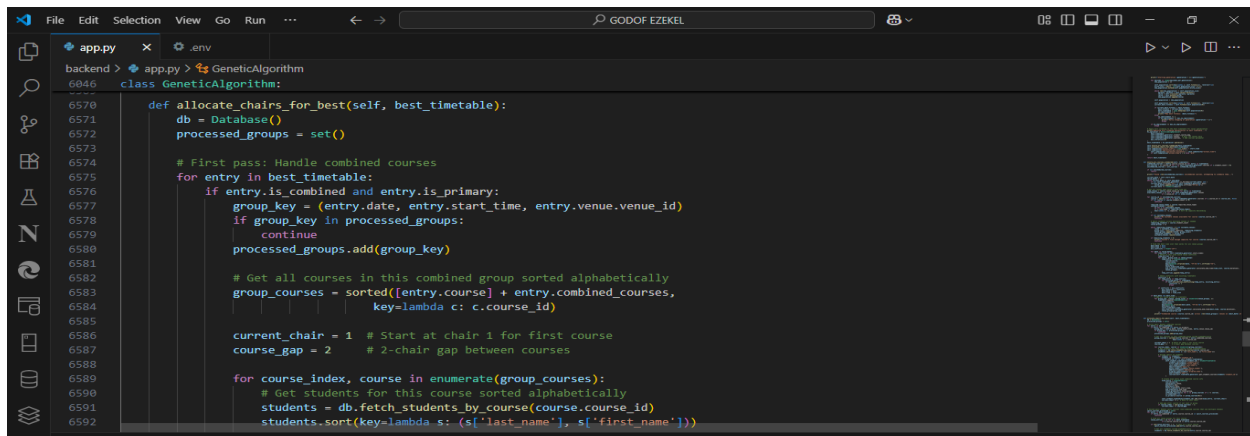
#### Objective

The scoring system's goal is to help Genetic Algorithm realize timetables which:

- Minimize scheduling conflicts,
- Maximise the use of venues capacities.
- Allocate classes equally between the days available,
- Make good use of a variety of venues,
- Program all courses.

Through the assessment of fitness of each of the timetables by this scoring system, Genetic Algorithm is able to select and breed best solutions to obtain an optimal or at least acceptable timetable configuration.

#### 4.2.8.4 Chair number Allocation



```
6946 class GeneticAlgorithm:
6570     def allocate_chairs_for_best(self, best_timetable):
6571         db = Database()
6572         processed_groups = set()
6573
6574         # First pass: Handle combined courses
6575         for entry in best_timetable:
6576             if entry.is_combined and entry.is_primary:
6577                 group_key = (entry.date, entry.start_time, entry.venue.venue_id)
6578                 if group_key in processed_groups:
6579                     continue
6580                 processed_groups.add(group_key)
6581
6582                 # Get all courses in this combined group sorted alphabetically
6583                 group_courses = sorted([entry.course] + entry.combined_courses,
6584                                     key=lambda c: c.course_id)
6585
6586                 current_chair = 1 # Start at chair 1 for first course
6587                 course_gap = 2    # 2-chair gap between courses
6588
6589                 for course_index, course in enumerate(group_courses):
6590                     # Get students for this course sorted alphabetically
6591                     students = db.fetch_students_by_course(course.course_id)
6592                     students.sort(key=lambda s: (s['last_name'], s['first_name']))
```

Figure 18 Chair number Allocation

*Designed by the author*

The exam timetable code which allocates the chair numbers in the exam timetable is supposed to give the students certain positioning and allow different scheduling options in the examinations. In periodic examinations when sitting in one place, the students are ranked alphabetically according to the last name and then the first name then given the seating numbers beginning with 1 through 2 and so on. When shared courses are offered at more than one venue because of room size, the students are assembled in alphabetic order before seating according to the room of the venue (at the designed distributed proportion according to the capacity of the venues, the venues in which they are to be seated remain organized by using a starting chair number 1).

In combined exams in which multiple courses use a single venue, the system applies more advanced allocation algorithm. Within combined group the order of all courses is alphabetical by course ID and students within each course are again in alphabetical order. The numbers of chairs are strained consecutively to all students taking part in the mixture group and a studied gap of two chairs is used to separate the two distinct courses. The gap serves to avoid overlapping of various examination groups as well as spacing consideration. All allocations are carefully monitored there a class in the student timetable known as the student timetable records the allocation of chairs using a composite key of course ID and venue group and at the same time enforces that a course can only be allocated once.

The allocation is done in three sweeps through the timetable in order to have the allocation process done in the most appropriate manner as possible with consideration of the following in this order of combined courses, a portion of split courses followed by regular courses which is done to minimize clashes. In all the cases, the system ensures that its students are alphanumerically ordered as well as proportionally allocated across the venues where necessary whilst the numbering of the chairs is always set at 1 in each of either a venue group in split exams or a course group in combined exams to make appropriate clear and logical seating patterns. This thorough solution meets the needs of different practical limitations and demands of the university exam schedule and preserves equality and structure in the seating arrangements of students.

#### 4.2.8.5 Overall Psudo Code

##### 1. Timetable Generation (Constraint-Based Scheduling)

FUNCTION genetic\_algorithm(initial\_timetable, generations):

    population = initialize\_population(initial\_timetable)

    FOR gen = 1 TO generations:

        // Evaluate fitness

        FOR each individual IN population:

            fitness = evaluate\_fitness(individual)

        // Selection

        parents = tournament\_selection(population)

        // Crossover

        offspring = crossover(parents)

        // Mutation

        mutated\_offspring = mutate(offspring)

        // Elitism - keep best individuals

```

    new_population = select_elites(population)

    ADD mutated_offspring to new_population

    population = new_population

    best_individual = get_fittest(population)

    // Apply hill climbing for local optimization

    optimized = hill_climbing(best_individual)

    RETURN optimized

```

## 2. Genetic Algorithm Optimization

FUNCTION genetic\_algorithm(initial\_timetable, generations):

```

    population = initialize_population(initial_timetable)

    FOR gen = 1 TO generations:

        // Evaluate fitness

        FOR each individual IN population:

            fitness = evaluate_fitness(individual)

        // Selection

        parents = tournament_selection(population)

        // Crossover

        offspring = crossover(parents)

        // Mutation

        mutated_offspring = mutate(offspring)

```

```

// Elitism - keep best individuals

new_population = select_elites(population)

ADD mutated_offspring to new_population

population = new_population

best_individual = get_fittest(population)

// Apply hill climbing for local optimization

optimized = hill_climbing(best_individual)

RETURN optimized

FUNCTION hill_climbing(timetable, max_iterations):

    current = timetable

    best = current

    best_score = evaluate(best)

    FOR i = 1 TO max_iterations:

        neighbor = generate_neighbor(current)

        // Ensure splitting constraints are maintained

        neighbor = enforce_splitting_constraints(neighbor)

        neighbor_score = evaluate(neighbor)

        IF neighbor_score > best_score:

            best = neighbor

            best_score = neighbor_score

        current = neighbor

    // Final verification of split courses

```

```
verify_split_courses(best)
```

```
RETURN best
```

### **3. Hill Climbing Optimization**

```
FUNCTION generate_neighbor(timetable):
```

```
    // Randomly select a modification type
```

```
    modification = RANDOM_CHOICE(['swap', 'reschedule', 'change_venue', 'split_venue'])
```

```
    IF modification == 'swap':
```

```
        SWAP two random non-split exams
```

```
    ELSE IF modification == 'reschedule':
```

```
        MOVE exam to different time slot
```

```
    ELSE IF modification == 'change_venue':
```

```
        CHANGE venue for an exam
```

```
    ELSE IF modification == 'split_venue':
```

```
        SPLIT a large course across venues
```

```
    RETURN modified_timetable
```

### **4. Student Conflict Check**

```
FUNCTION has_student_conflict(exam1, exam2, student_course_map):
```

```
    IF exam1.date != exam2.date:
```

```
        RETURN False
```

```
    // Check time overlap with buffer
```

```
    IF (exam1.end_time + BUFFER > exam2.start_time) AND
```

```
        (exam2.end_time + BUFFER > exam1.start_time)
```

```

// Get students in both exams

students1 = students_taking(exam1.course_id, student_course_map)

students2 = students_taking(exam2.course_id, student_course_map)

IF students1 INTERSECTION students2 is not empty:

    RETURN True

RETURN False

```

## 5. Course Combination Algorithm

```

FUNCTION find_combineable_courses(courses, venues):

    combined_groups = []

    remaining_courses = filter_combineable(courses)

    WHILE remaining_courses is not empty:

        current_course = remaining_courses.pop()

        group = [current_course]

        allowed_venue_types = current_course.required_venue

        FOR each other_course IN remaining_courses:

            IF not can_combine_with(current_course, other_course):

                CONTINUE

            // Check venue compatibility

            new_venue_types = allowed_venue_types INTERSECTION
other_course.required_venues

            IF new_venue_types is empty:

                CONTINUE

```



```

// Check student conflicts

IF has_student_conflict(group, other_course):

    CONTINUE

// Check capacity

IF total_students + other_course.students <= max_venue_capacity:

    ADD other_course to group

    UPDATE allowed_venue_types

    REMOVE other_course from remaining_courses

IF group size > 1:

    ADD group to combined_groups

RETURN combined_groups

```

## 6. Student Chair Allocation

```

FUNCTION allocate_chairs(timetable):

    FOR each exam IN timetable:

        IF exam is combined:

            // Sort combined courses alphabetically

            sorted_courses = SORT(exam.combined_courses + [exam.course])

            chair = 1

            FOR each course IN sorted_courses:

                students = get_students(course)

                SORT students by last_name

                FOR each student IN students:

                    ASSIGN student to chair

```

```

        chair += 1

    // Add gap between courses

    chair += 2

ELSE IF exam is split:

    // Distribute students evenly across venues

    total_students = get_total_students(exam.course)

    students_per_venue = total_students / number_of_venue

    FOR each venue_group IN exam.venue_groups:

        students = get_students_for_venue(exam.course, venue_group)

        SORT students by last_name

        FOR i, student IN enumerate(students):

            ASSIGN student to chair i+1

ELSE:

    // Regular exam

    students = get_students(exam.course)

    SORT students by last_name

    FOR i, student IN enumerate(students):

        ASSIGN student to chair i+1

```

#### 4.2.8.6 Overall System Flow Chart

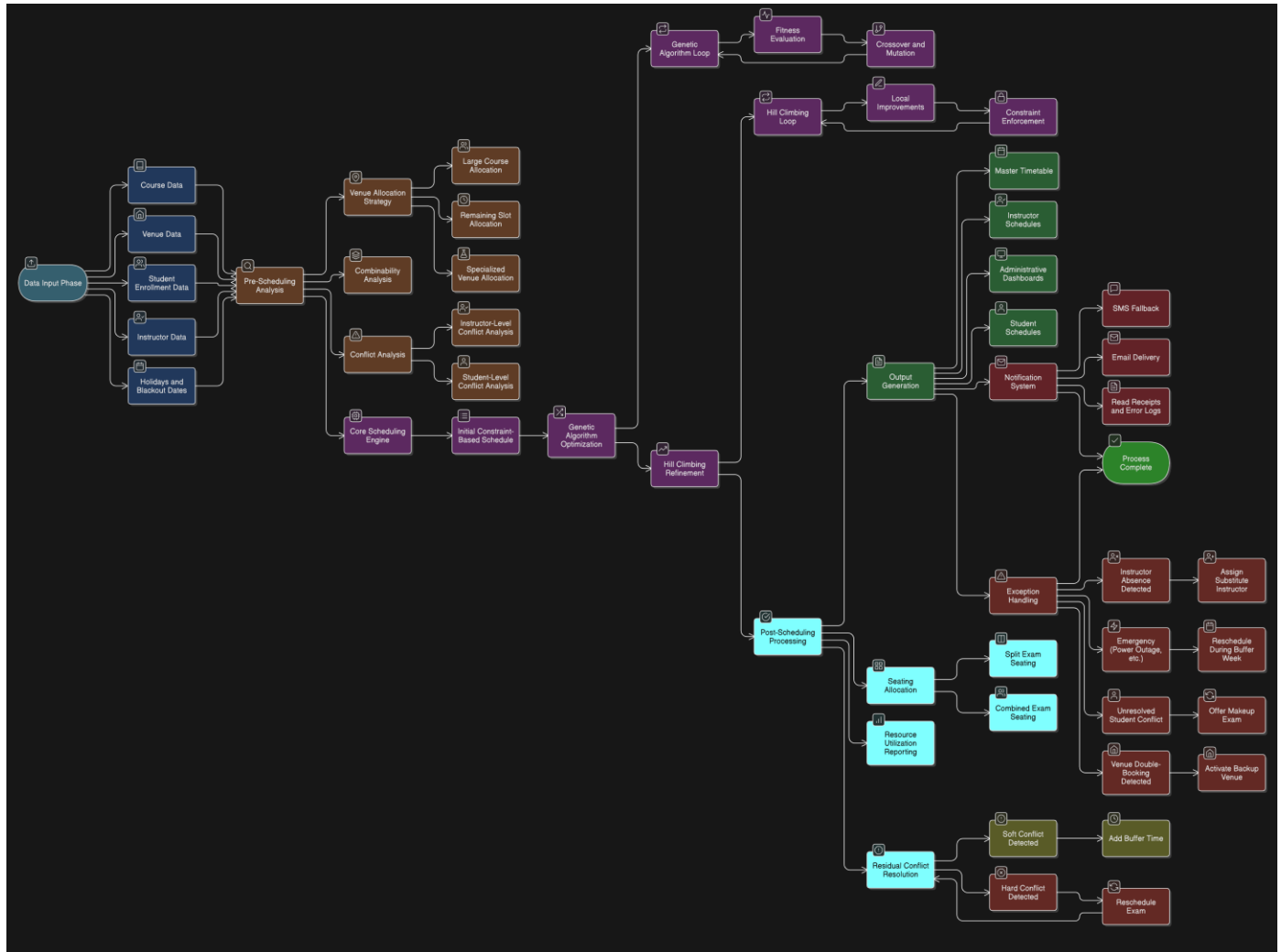


Figure 19 Overall Hybrid Algorithm Flow Chart

Designed by the author

#### 4.3 Frontend Interface

Deliver a user friendly interface for its users to interact with the timetable gene system. The frontend is implemented using React and services can be viewed, created and managed by users in dynamic web interface.

### 4.3.1 Testing and Validation

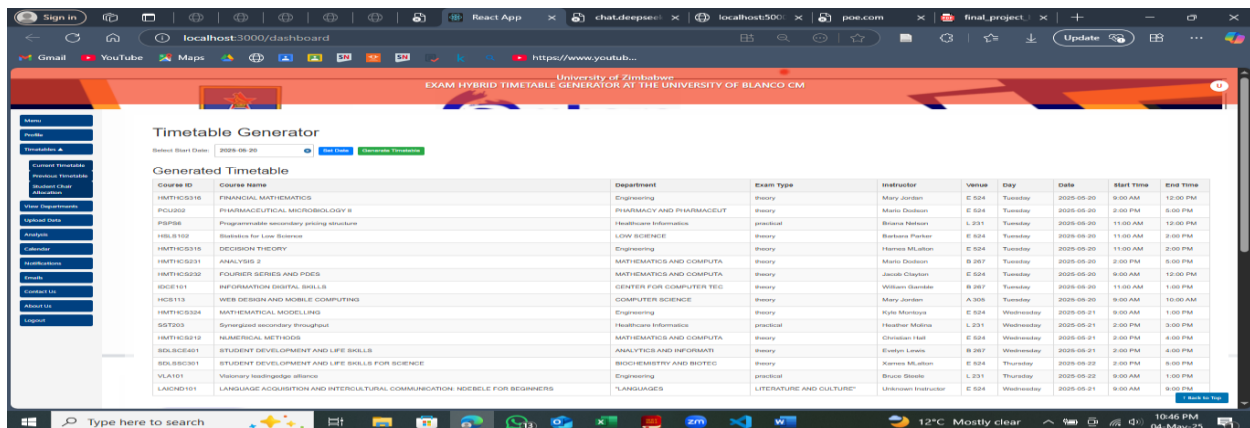
For unit tests, individual component testing was used, whereas integration tests were performed for testing overall system testing. Key test cases included: Database connectivity tests, Timetable generation tests in order to avoid conflicts, Frontend form submission tests

### 4.3.2 Unit Testing

The main goal of the unit testing was to verify and verify the functioning of individual components in isolation.

#### 4.3.2.1 Calendar Page Testing

In this page is the page to set start date for exams and generate the initial timetable using general python code.



| Course ID | Course Name   | Department              | Exam Type              | Instructor         | Venue | Day       | Date       | Start Time | End Time |
|-----------|---|-------------------------|------------------------|--------------------|-------|-----------|------------|------------|----------|
| HNTHCS316 | FINANCIAL MATHEMATICS   | Engineering             | theory                 | Mary Jordan        | E 524 | Tuesday   | 2025-05-20 | 9:00 AM    | 12:00 PM |
| PCUS002   | PHARMACEUTICAL MICROBIOLOGY B   | PHARMACY AND PHARMACEUT | theory                 | Maria Oudman       | E 524 | Tuesday   | 2025-05-20 | 2:00 PM    | 5:00 PM  |
| PPSP56    | Programme secondary pricing structure                                     | Healthcare Information  | practical              | Brian Nelson       | L 231 | Tuesday   | 2025-05-20 | 11:00 AM   | 12:00 PM |
| HSLB102   | Statistics for Law Science  | LOW SCIENCE             | theory                 | Barbara Parker     | E 524 | Tuesday   | 2025-05-20 | 11:00 AM   | 2:00 PM  |
| HNTHCS316 | DECISION THEORY   | Engineering             | theory                 | Herman Mafoni      | E 524 | Tuesday   | 2025-05-20 | 11:00 AM   | 2:00 PM  |
| HNTHCS231 | ANALYSIS 3  | MATHEMATICS AND COMPUTA | theory                 | Maria Oudman       | B 267 | Tuesday   | 2025-05-20 | 2:00 PM    | 5:00 PM  |
| HNTHCS232 | FOURIER SERIES AND PDES   | MATHEMATICS AND COMPUTA | theory                 | Josiah Clayton     | E 524 | Tuesday   | 2025-05-20 | 9:00 AM    | 12:00 PM |
| ISCE101   | INFORMATION DIGITAL SKILLS  | CENTER FOR COMPUTER TEC | theory                 | William Gombani    | B 267 | Tuesday   | 2025-05-20 | 11:00 AM   | 1:00 PM  |
| HCS113    | WEB DESIGN AND MOBILE COMPUTING   | COMPUTER SCIENCE        | theory                 | Mary Jordan        | A 305 | Tuesday   | 2025-05-20 | 9:00 AM    | 10:00 AM |
| HNTHCS324 | MATHEMATICAL MODELLING  | Engineering             | theory                 | Kyle Mordaga       | E 524 | Wednesday | 2025-05-21 | 9:00 AM    | 1:00 PM  |
| SD700     | Springboard secondary throughout  | Healthcare Information  | practical              | Frederick Marika   | L 231 | Wednesday | 2025-05-21 | 2:00 PM    | 3:00 PM  |
| HNTHCS212 | NUMERICAL METHODS   | MATHEMATICS AND COMPUTA | theory                 | Christian Hall     | E 524 | Wednesday | 2025-05-21 | 2:00 PM    | 4:00 PM  |
| SELBSC401 | STUDENT DEVELOPMENT AND LIFE SKILLS                                       | ANALYTICS AND INFORMAT  | theory                 | Ernest Lewis       | B 267 | Wednesday | 2025-05-21 | 2:00 PM    | 4:00 PM  |
| SELBSC301 | STUDENT DEVELOPMENT AND LIFE SKILLS FOR SCIENCE                           | BIOCHEMISTRY AND BIOTEC | theory                 | Karen Mafoni       | E 524 | Thursday  | 2025-05-22 | 2:00 PM    | 5:00 PM  |
| VLA101    | Vocabulary language alliance  | Engineering             | practical              | Brian Nelson       | L 231 | Thursday  | 2025-05-22 | 9:00 AM    | 1:00 PM  |
| LACND101  | LANGUAGE ACQUISITION AND INTERCULTURAL COMMUNICATION: NOBLE FOR BEGINNERS | LANGUAGES               | LITERATURE AND CULTURE | Unknown Instructor | E 524 | Wednesday | 2025-05-21 | 9:00 AM    | 9:00 PM  |

Figure 20 Calendar Page Testing

Designed by the author

#### 4.3.2.2 Current Timetable Testing

Generate the optimized timetable using genetic algorithm and hill climbing local search algorithm. The page shows the timetable and allow the user save it to the database and to save a csv file in the local machine file and to print the whole timetable in a csv file. It entertain the user during the optimization time.

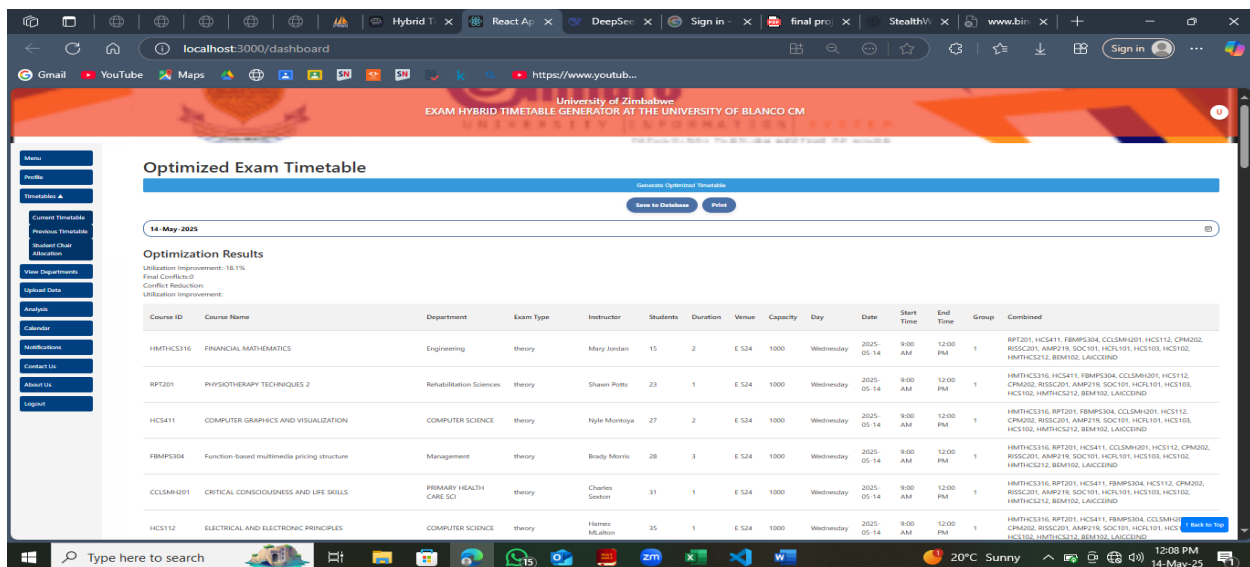


Figure 21 Current Timetable Testing

Designed by the author

#### 4.3.2.3 View Department Timetable

This page it allows the user to view the timetable of every department that offered courses in that block and it also send the timetable to all lecturers which one teaches trough email. It allows the user to print the department timetable.

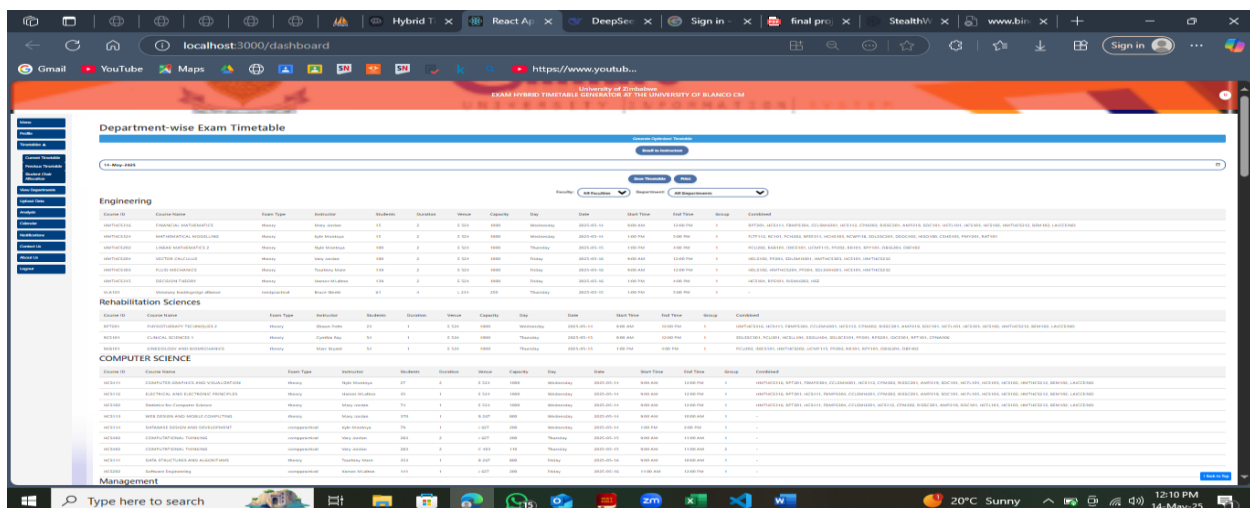


Figure 22 View Department Timetable

Designed by the author

#### 4.3.2.4 Student Allocation Page

The module shows all students that have registered the course that the department offered that block. It shows student timetable based on the scheduled courses the student enrolled. The user can send student timetable through email. The student timetable shows the Course, Type, Date & Time, Venue, Seat(chair number).

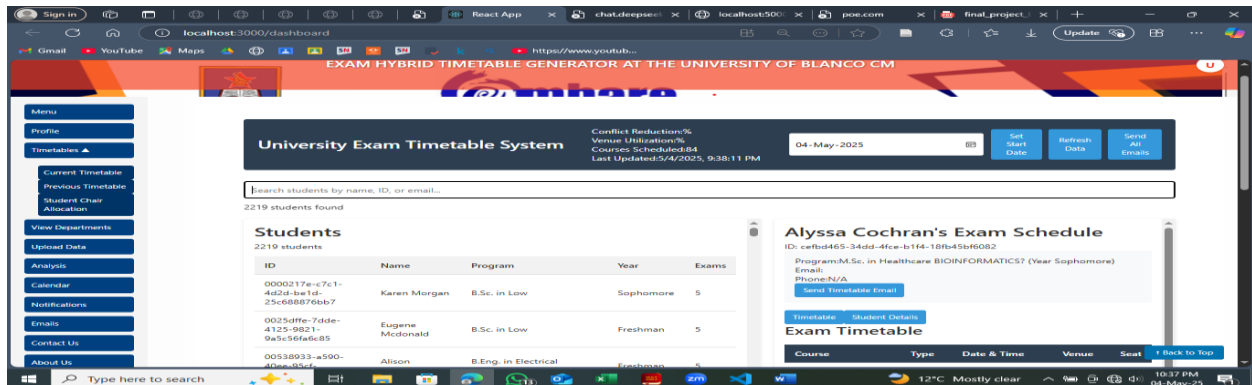


Figure 23 Student Allocation Page

Designed by the author

#### 4.3.2.5 Upload

Upload the data of courses, instructors, venues, students of that exam block. This module allows the user to clear data in the database and upload new data needed to be scheduled. It allows the user to edit data before uploading to the database.

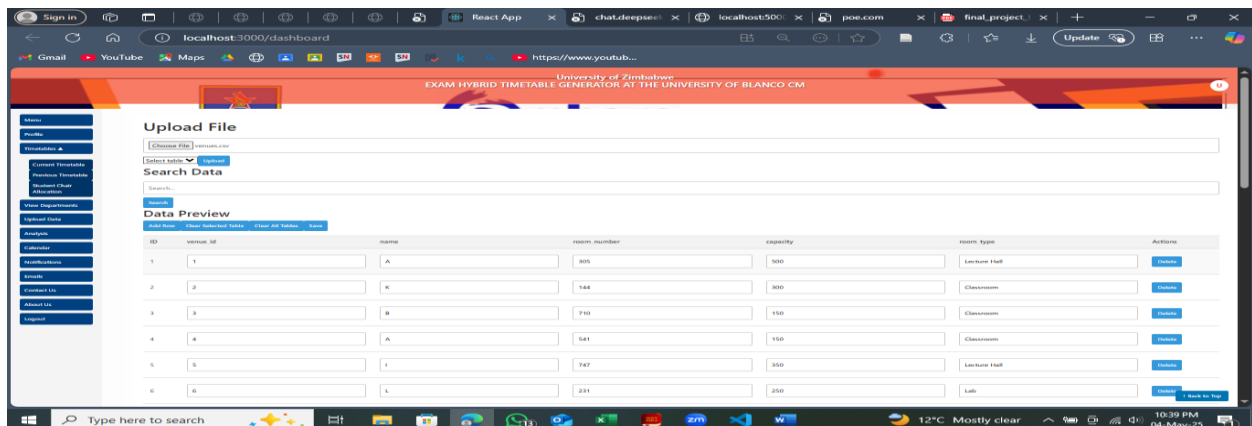
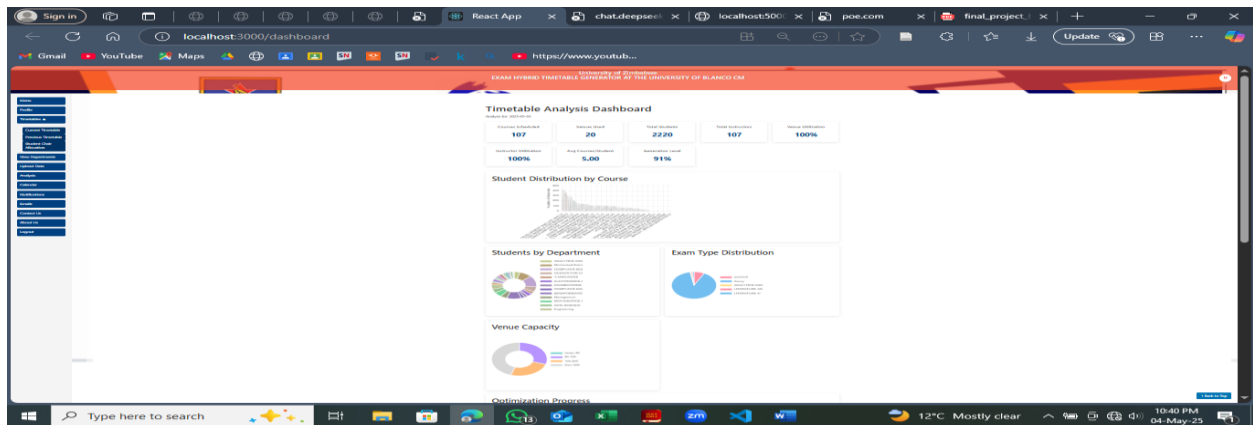


Figure 24 Upload

*Designed by the author*

#### 4.3.2.6 Analyses

At this module called analysis it shows the number courses scheduled number of venues number of instructors average course per child venue utilization generation level. It also shows the student distribution by course, student by department, exam type distribution, venue capacity (in range), optimization progress.

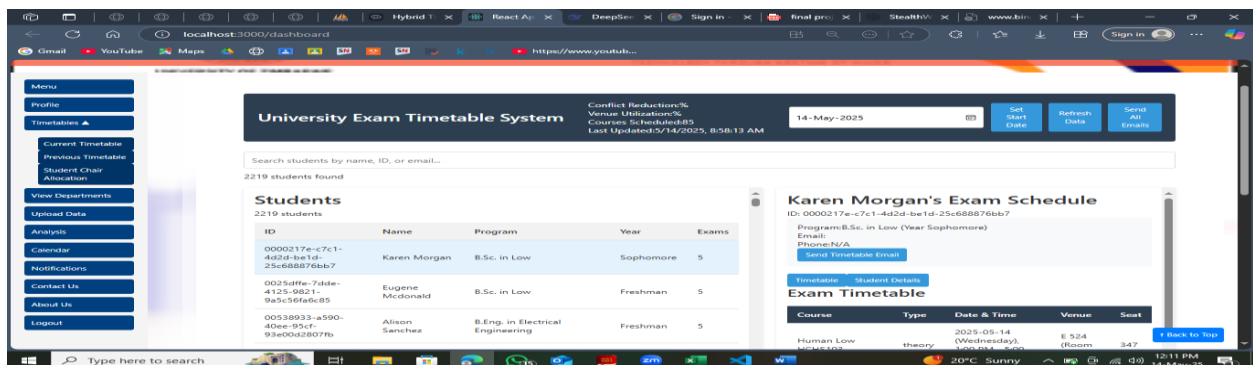


*Figure 25 Analyses*

*Designed by the author*

#### 4.3.2.7 Today Exams

On this module it show the notifications that the university have how many exams and the exam course details, venue, and time slots.

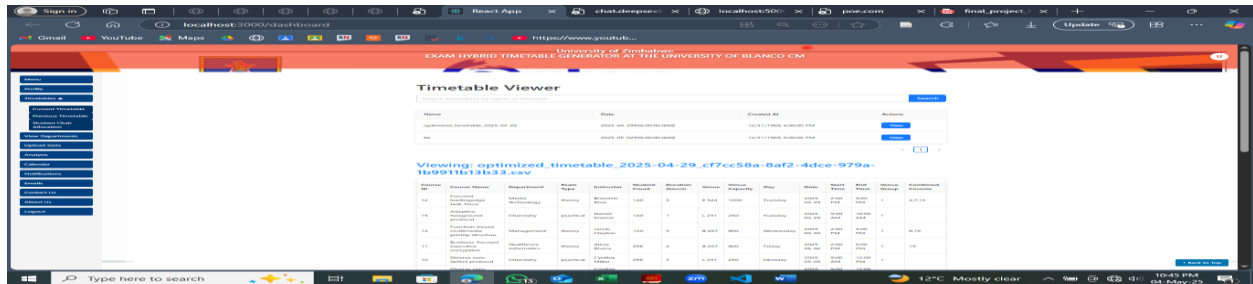


*Figure 26 Today Exams*

*Designed by the author*

#### 4.3.2.7 View Saved

In this module, the user will view the saved data from the data base.



The screenshot shows a web application titled "EXAM HYBRID TIMETABLE GENERATOR AT THE UNIVERSITY OF BLANCO CM". The "Timetable Viewer" section displays a table of saved timetables. The table has columns for Name, Date, Created At, and Actions. Below the table, there is a link to view a specific timetable: "Viewing: optimized\_timetable\_2025-04-29\_cf7cc58a-8af2-4dce-979a-1b9911b13b33.csv".

| Name                           | Date                | Created At          | Actions              |
|--------------------------------|---------------------|---------------------|----------------------|
| Optimized Timetable 2025-04-29 | 2025-04-29 10:00:00 | 2025-04-29 10:00:00 | <a href="#">View</a> |

Viewing: [optimized\\_timetable\\_2025-04-29\\_cf7cc58a-8af2-4dce-979a-1b9911b13b33.csv](#)

*Figure 27 View Saved*

*Designed by the author*

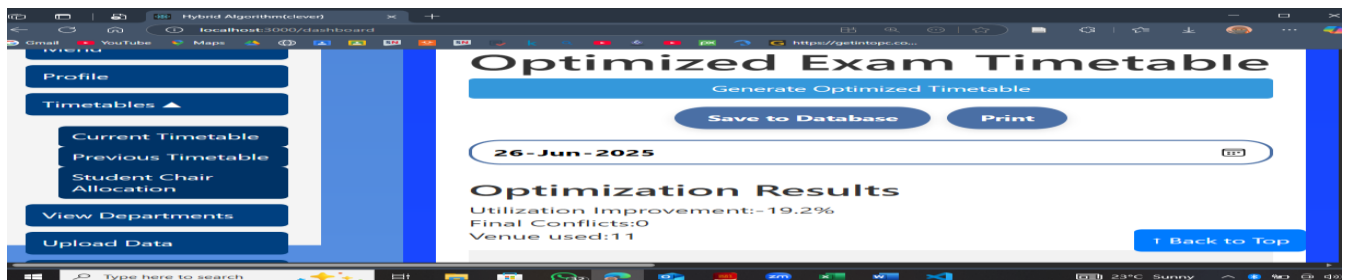
#### 4.3.3 Performance Evaluation

Using; performance metrics were judged upon either of:

- Timetable generation time
- Conflict rates between scheduled courses
- Frontend interaction, the rate at which a user responds.

Results showed that the system manages very many courses and students, with little conflicts.

##### 4.3.3.1 Performance Metrics Table and Result



The screenshot shows a web application titled "Optimized Exam Timetable". The "Generate Optimized Timetable" section displays a date selector set to "26-Jun-2025". Below this, the "Optimization Results" section shows the following metrics: Utilization Improvement: 19.2%, Final Conflicts: 0, and Venue used: 11. A "Back to Top" button is located at the bottom right.

| Metric                  | Value |
|-------------------------|-------|
| Utilization Improvement | 19.2% |
| Final Conflicts         | 0     |
| Venue used              | 11    |

*Figure 28 Performance Metrics Result*

*Designed by the author*



Table 2 Performance Metrics Table

| Matrics  | Value      |
|--|------------|
| Average optimization with genetic and hill climb algorithm of initial timetable Time | 20 seconds |
| <b>optimization_metrics</b>  |            |
| Average Utilization Improvement of reasoses :  | 19.8%      |
| final_conflicts:   | 0          |
| unscheduled_courses  | 0          |

#### 4.3.4 URLS

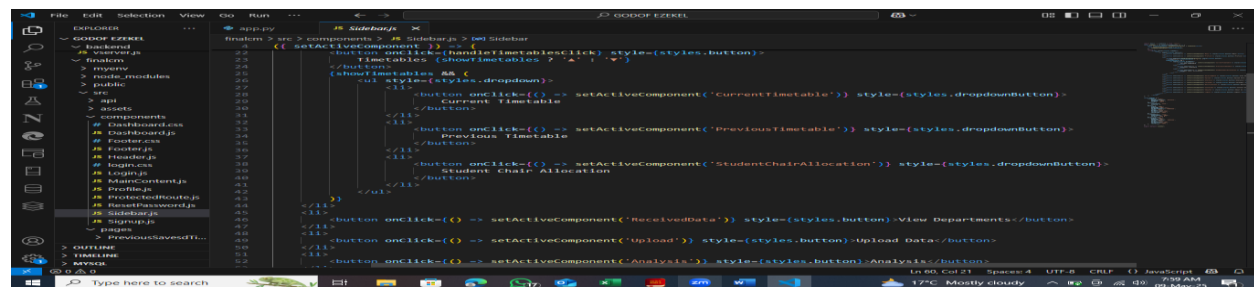


Figure 29 URLS

Designed by the author

#### 4.3.5 User Feedback

User test has been attained among a group of students and instructors. Feedback was related to usability, and functionality. Among the changes that were implemented after getting the feedback the following were these:

- Better error messages when time table is being generated.
- Improved user navigations in the frontend.

#### 4.3.6 Challenges Faced

Several challenges arose during implementation:

Database connection issues: Resolved by proper error handling.

Complexity of conflict detection: And for efficient scheduling, optimized algorithms were developed.

#### References

- Documentation for Flask and React.
- MySQL documentation for database management.
- Relevant literature on optimization algorithms.

## CHAPTER FIVE: DISCUSSION AND CONCLUSION

### 5.1 Final Discussion

Through the development of the hybrid timetable generator based on genetic algorithms and hill climbing local search, many insights into exam scheduling have been observed. Not only the practical use of state-of-the-art computational methods is shown by this project but the necessity of adaptability and efficiency in educational settings is made evident as well.

By introducing genetic algorithms into it, the system is capable of testing multiple possibilities, navigating the restraints and itineraries that are fundamental to exam timing. This approach allows us to find such timetables that would be optimal for the maximal use of resources among all students while being fair for everybody. The incorporation of hill climbing local search further tunes these solutions to the point that they can be subject to continuous incremental improvements via local optimization.

The results demonstrate that this hybrid approach can greatly reduce scheduling conflicts and reduce the burdens of administration, and therefore improve the overall scheduling. Moreover, the system's flexibility to adjust to real-time data and people preferences guarantees that it will always be up to date and have practical relevance to the needs of the academic population.

Involvement of the stakeholders in designing scheduling system is also highlighted by this project. Involving students, faculty and administrative staff during this process is more than a gesture of belonging, it also means that the system will serve the interests and desires of its users.

In other words, the hybrid timetable generator is a good example that the usage of advanced algorithms can be properly transferred to the educational fields. Outcomes of this project open the way for further work and development, making it possible to encourage schools to implement innovative solutions leading to efficiency and equity, as well as an improved academic environment. Further work should involve further improvement of such algorithms, their extension ability, and their dissection for other uses within the educational landscape.

## 5.2 Impact of hybrid algorithm

The implication of a hybrid timetable generator for exam scheduling might significantly benefit as well as challenge in a number of ways. One of the key benefits is optimal resource while minimizing conflicting and maximizing utilization; basically, efficient utilization of classrooms and examiners amongst other resources. Furthermore, the patience of such systems provides for different needs and tastes of students and it is especially useful for part-time or special students. A hybrid timetable can also reduce (stress levels) on students, exam loads would also be balanced from day to day thus eventually improving performance and well-being of students. Moreover, these systems foster fairness because of equal distribution of the exam time thus eliminating biasness with regard to some groups.

One of the main advantages of the hybrid timetable generator is the effective avoidance of scheduling clashes and overall simplification of the procedure, which results in minimising the quantity of work for the administrative personnel. Automating much of the process of timetable creation, the system eliminates time and reduces errors inherent to manual scheduling. Nevertheless, there are implementation difficulties of the kind of technology. The complexity of such systems may prove challenging because they need sophisticated algorithms, and consume large amounts of computational resources. Also, change in faculty and students who are used to traditional scheduling practices may be resisted calling for effective change management strategies. Technical problems, software bugs or system integration with existing systems, can throw the process of scheduling off the mark. Moreover, the currently existing staff might need training, to be able to use and control the new system and time and budget need to be allocated for it. Notably, continuous assistance by the development team will be essential, particularly following the manual scheduling, for resolving arisen problems and improving this system according to users' feedback. Finally, as institutions expand the scale-ability of the system can be problematic with the increase in complexity. All in all, although some dissemination of an hybrid timetable generator might improve exam scheduling as it relates to efficiency and fairness, considerate proceeding and help are required to mitigate such On balance, while some spread of an hybrid timetable generator could enhance planning of examinations in respect to efficiency and fairness, sensible conduct and aid are needed to avoid such issues.

### 5.3 Recommendation (Future Directions)

Hybrid timetable generators' future is promising as education establishment continues to grow. One important direction is the introduction of integration of artificial intelligence and machine learning for improving algorithm used for scheduling. These technologies can process enormous amounts of data in order to enable even more accurate predictions and optimizations contingent on student performance and taste, as well as their statistics' history.

The other significant direction is integration of real-time updates of the data. When hybrid generators include systems that give immediate feedback on resource availability and student attendance, it can allow adjustment of schedules dynamically in order to maximize efficiency of last minute changes. Such a flexibility can severely minimise the amount of disruptions and overall accuracy in scheduling.

In addition, there is a possibility of additional customization possibilities of the users. Creating helpful user interfaces that will enable the faculty and students to adjust their preferences and constraints, can bring more personalized scheduling solutions. This may range from choices on the time and place to take an exam, accommodating various forms of learning.

There will also be cooperation with stakeholders. Involving students, faculty and administrative personnel in the construction and perfecting of such systems would go a long way to ensure that the solutions address the real needs of the community and consequently that they become actively owned by it.

Lasting but not least, research on the combination of hybrid timetable generators with other institutional systems, like learning management systems (LMS) and student information systems (SIS), may develop a more integrated eco-system of education. This holistic attitude can simplify processes even further and increase the general experience of both students and educators.

In conclusion, the future of hybrid timetable generators is based on the application of advanced technologies, the cooperation, and support of customer-centered development for creating more efficient, responsive, and user-friendly schedule providers.

## 5.5 Conclusion

The creation of a hybrid timetable generator, based on genetic algorithms and hill climbing local search techniques, is a big leap towards timetabling for educational institutions. Through using genetic algorithms, the system searches efficaciously through a large solution space for optimal or near optimal timetables which consider complex constraints and preferences. The presence of hill climbing local search augments this capability, so the system can tune solutions while it refines them in an iterative process that makes minimal modifications using local adaptation.

This two-pronged approach not only maximizes resource allocation but also addresses varied student's needs to end up promoting fairness in exam distribution. The automation of the scheduling process using these modern techniques lessens the administrative staff load and eliminates human error leading to a smoother and ultimately more successful scheduling process.

Further, the flexibility of the system to serve in real-time data, user-friendly systems guarantees its responsiveness to evolving conditions. Involving stakeholders in the development process allows the generator to provide a better fit to the needs of students and faculty resulting in acceptance and usability.

With this in mind, the hybrid timetable generator using genetic algorithms and hill climbing local search not only automates the scheduling process but also helps to create a more level playing field and improve disciplinary productivity in school. With this unique approach, it becomes an important instrument for institutions wishing to improve their scheduling effectiveness and educational experience.

## 1.10 References

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