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Optimisation of Students' Examination Seating Arrangements Using Simulated Annealing

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***Abstract*: Exam seating arrangements must be carefully designed to reduce academic dishonesty. Many institutions make deliberate seat assignments to minimise the possibility of proximity-based collusion. However, typical methods frequently fail in large student populations, stressing the importance of optimisation strategies. This work investigates the use of Simulated Annealing (SA) to generate near-optimal seating arrangements, considering limitations such as students' courses, departments, and academic levels. The SA algorithm is constructed and assessed using synthetic data for a 40-student examination hall. The results indicate that SA effectively reduces adjacency violations and has practical applications in institutional exam seating arrangement planning.**

***Keywords*: Constraint Satisfaction, Examination, Simulated Annealing, Seating Arrangement.**

1. Introduction

Arranging students' seats during exams is crucial for ensuring fairness and ensuring that available spaces are used efficiently. In many institutions, students are seated based on factors such as the course they are taking, their academic level, and the department to which they belong. While this may seem straightforward, the process becomes more complicated with many departments and overlapping courses. At that point, traditional seating methods, often based on simple rules, struggle to handle the complexity. The result is frequently poorly organised seating plans that waste space and make it easier for academic misconduct to occur.

Numerous heuristic techniques have been developed to overcome these issues, including the greedy approach [1] and the round-robin policy [2], which iteratively makes local judgments based on immediate restrictions.

In contrast, this paper investigates the feasibility of using Simulated Annealing (SA), a metaheuristic optimisation technique inspired by the annealing process in metallurgy, to generate near-optimal examination seating arrangements. Unlike greedy algorithms trapped in local optima, SA enables a more global exploration of the solution space by periodically accepting inferior solutions, particularly in the early phases of the search. This feature allows the algorithm to escape local minima and explore alternative configurations.

Furthermore, SA is computationally cheap and scalable, making it appropriate for larger, constraint-laden situations that would be computationally prohibitive for exhaustive approaches like backtracking [3]. This research evaluates the effectiveness of Simulated Annealing in generating exam seating configurations that minimise adjacency violations while adhering to various constraints. The approach is tested on synthetic data that simulates a typical examination hall environment, and the findings show that it is feasible in academic institutions.

2. Review of Related Works

The work in [1] proposes a web-based application that utilises a greedy graph colouring algorithm to automate examination seating arrangements based on conflict constraints, such as shared courses. While it provides a simple and fast solution, it often fails to find globally optimal configurations and does not consider multi-level constraints such as student levels or departmental groupings. [2] introduced a Python-based GUI application utilising a round-robin policy to automate seating arrangements, ensuring that no two students taking the same exam are seated on the same bench. This approach aimed to prevent cheating by systematically distributing students across available seating. However, its poor scalability and lack of adaptability to overlapping courses or shared departmental structures make it inadequate for more complex institutional setups. [4] explored robustness approaches for the examination timetabling problem under data uncertainty. They discussed various robust optimisation techniques and analysed their impact on real-world instances, emphasising the importance of accounting for uncertainties in scheduling. Although it improves reliability in dynamic environments, it is computationally intensive and less focused on fine-grained seating-level constraints such as adjacency avoidance. [5] proposed an optimised approach using Weighted Constraint Satisfaction Problem (WCSP) techniques to enhance timetabling, hall distribution, and seating arrangements. Their method incorporated dynamic algorithms capable of adapting to varying institutional needs, demonstrating significant improvements in reducing scheduling conflicts and optimising space utilisation. However, it struggles with runtime performance in very large-scale datasets, and accuracy heavily depends on well-tuned weights for constraints. [6] Applied a simulated annealing algorithm to the faculty-level university course timetabling problem, considering complex constraints

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such as double majors and shared classrooms. Their approach yielded optimal solutions within reasonable computational times, underscoring the efficacy of simulated annealing in addressing complex scheduling scenarios. However, their model was applied at the faculty level, rather than being tailored to examination seating, where adjacency and fairness metrics play a more critical role. [7] Introduced a fuzzy logic-based software package, "CUB", for developing classroom seating arrangements to reduce student distraction. Their approach combined fuzzy inference systems and clustering techniques to generate seating plans that minimise classroom distractions, suggesting potential applicability in examination settings. The solution is not optimised for high-density examination settings, where the primary goal is to prevent collusion rather than a behavioural distraction.

This paper contributes to the existing body of knowledge by proposing a simulated annealing-based approach that addresses these limitations, offering a scalable and efficient solution for optimising examination seating arrangements in academic institutions.

3. Problem Formulation

The examination seating arrangement problem is modelled as a combinatorial optimisation problem, where the objective is to assign students to seats in a way that minimises the likelihood of academic dishonesty while satisfying several institutional constraints.

The problem involves mapping a set of students.

$$D = \{D_1, D_2, \dots\dots\dots\dots\dots\dots..D_n\}$$

to a set of seats

$$S = \{S_1, S_2, \dots\dots\dots\dots\dots\dots..S_n\}$$

In the examination venues, the constraints are met, and the cost function is minimised.

A. Objectives

1. Minimise adjacency violations: ensure that students writing the same course are not seated beside each other.
2. Maximise distribution across departments and levels: reduce the possibility of collusion by distributing students from the same department and level apart.
3. Ensure seat utilisation efficiency: all seats should be assigned with minimal wastage.

B. Constraints

1) Hard Constraints (Must be Satisfied)

a. Each student is assigned exactly one seat.
b. No two students share the same seat.
c. Students taking the same course must not be seated in adjacent seats.

2) Soft Constraints (Preferably to Satisfy)

a. Students from the same department or level should not be seated adjacent to each other.
b. Students should be evenly distributed across rows and columns to discourage collaboration.

Mathematical Representation:

Let,

$A_{ij} = 1$ If the student i and student j j are taking the same course.

$B_{ij} = 1$ If the student i and the student j are from the same department.

$C_{ij} = 1$ If student i and student j are from the same academic level

$adj(S_i, S_j) = 1$ if S_i is adjacent to S_j

Equation 1 minimises the cost function.

$$Cost = \sum_{i,j}(\alpha\, A_{ij} + \beta B_{ij} + \gamma C_{ij}) * adj(S_i, S_j) \qquad (1)$$

Where α, β, and γ can be tuned based on institutional priorities or empirically optimised to reflect the severity of constraint violations.

4. Implementation

The examination seating optimisation model was developed in Python, chosen for its simplicity, flexibility, and rich ecosystem of libraries supporting data processing and visualisation. Key libraries included *random* for generating student attributes and sampling, *math* for computing the Simulated Annealing acceptance function, *NumPy* for efficient array operations, and *matplotlib.pyplot* for visualising cost convergence, penalty heatmaps, annotated seating grids, and final arrangements. Development was conducted in Jupyter Notebook, offering an interactive environment ideal for testing and visualisation. Outputs such as graphs and seating layouts were saved as images for documentation. The Simulated Annealing algorithm operated with an initial temperature of 1000, a final temperature of 1, a cooling rate of 0.95, and up to 1000 iterations, parameters tuned to balance exploration and convergence efficiency.

5. Result Evaluation

Figure 1 shows how the total penalty (or “cost”) evolves over iterations. The algorithm begins with a high penalty (above 300) due to poor initial random seating, where many students from the same course, department, or level are seated adjacent to each other. As iterations progress, the penalty steadily drops, reaching a stable minimum of around 160; the cost function penalises adjacent students with:

i. Same course: +5 points
ii. Same department: +3 points
iii. Same level: +1 point

The stepwise drops in the plot highlight where the algorithm discovers better configurations; eventually, improvements diminish, and the temperature reduces, leading to convergence. In conclusion, the algorithm successfully minimised conflicts over time, demonstrating the effectiveness of simulated annealing in solving this combinatorial optimisation problem.

Figure 2: The heatmap visualises per-seat penalty scores based on the number of same-course, same-department, or same-level students seated adjacent (top, bottom, left, right).

i. White/yellow zones = high local penalties (more conflicts).
ii. Red/black zones = optimised areas with fewer conflicts.

A. *Penalty Calculation Per Seat*

i. Check the 4-neighbour seats (N, S, E, W).
ii. Increments penalty based on similarities (course/department/level).

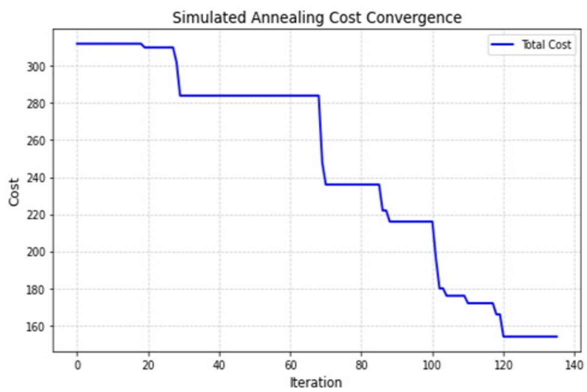

Fig. 1. Convergence plot of the simulated annealing algorithm

In contrast, most of the seating layout is dark (optimised), with one or two lighter spots, suggesting minor clustering of similar students still within acceptable limits. This confirms that the overall seating has been effectively optimised, but some high-penalty zones remain.

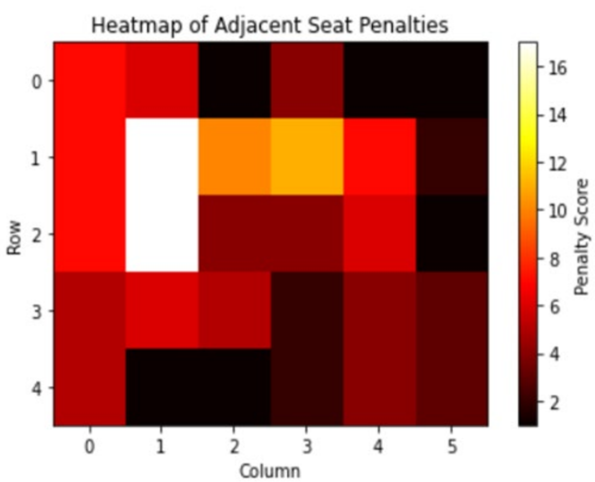

Fig. 2. Penalty intensity heatmap of the seating grid

The layout of the examination venue and how each student is seated based on the optimised results is presented in Figure 3.

Each seat is labelled with the student's ID and their respective course. The grid shows a well-distributed arrangement of students across various courses and levels. This annotated grid provides a clear layout of the optimised seating arrangement:

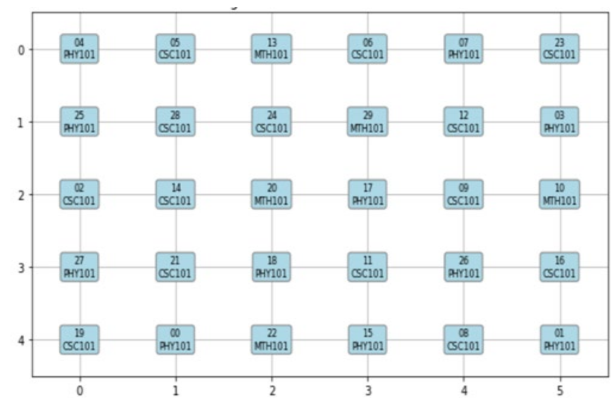

Fig. 3. Final seating arrangement: Student ID with course

a. Each box represents a seat.
b. *Labels show*: Student ID (2-digit), Course code (e.g., CSC101, MTH101, PHY101)

Key observations made are that there is no clear clustering of students taking the same course, each row and column show a fairly diversified mix of courses, and the algorithm successfully interleaves students to reduce cheating risk and maintain fairness. This grid validates that the seating is well-distributed, satisfying the optimisation goals.

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Final Seating Arrangement (Student IDs):
04  05  13  06  07  23
25  28  24  29  12  03
02  14  20  17  09  10
27  21  18  11  26  16
19  00  22  15  08  01
```

Fig. 4. Final seating arrangement (Student IDs)

The final seating arrangement in Figure 4 is represented in a 5x6 grid (5 rows and 6 columns), where each cell contains the Student ID assigned to that seat after optimisation using Simulated Annealing. The goal was to ensure minimal conflicts by avoiding adjacent students from the same course, department, or level, which means each value represents a Final Seating Arrangement: Student ID with Course. The seating grid is optimised such that students sitting next to each other are less likely to share the same:

Table 1
Summary of results

Metric	Result
Initial Cost	> 300
Final Cost	~160
Penalty Rules	+5 (course), +3 (department), +1 (level)
Iterations	Up to 1000 (stopped earlier due to convergence)
Seating Optimisation	High — most conflicts avoided
Visualisation Tools	Cost graph, heatmap, annotated grid, final seating grid

i. Course (high penalty)
ii. Department (moderate penalty)
iii. Level (low penalty)

This arrangement reduces the total conflict cost significantly compared to a random distribution.

The summary of the optimisation result is shown in Table 1.

6. Conclusion

This paper demonstrates the application of Simulated Annealing to optimise students' examination seating arrangements, thereby reducing the risk of academic dishonesty. By defining a cost function that penalises adjacent seating of students from the same course, department, or educational level, the algorithm efficiently searched for a near-optimal configuration that minimises these conflicts. Through iterative seat swapping and probabilistic acceptance of worse solutions, the system could avoid local minima and converge on a better solution over time. Visual tools such as the cost convergence graph, penalty heatmap, and annotated seating grid provided valuable insights into the performance and effectiveness of the optimisation process. The final results confirm that Simulated Annealing is a practical and scalable approach for tackling real-world scheduling and arrangement problems, particularly in academic settings. This method can be further extended for larger seating arrangements, multiple exam halls, or integration with automated examination management systems.

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