Study of the classroom arrangement problem based on ant colony algorithm

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Abstract. In this paper, the ant colony algorithm is presented to optimize the university classroom arrangement and solve the corridor congestion problem. Firstly, the classroom capacity, the course time periods and the distance between classrooms are considered, and then the ant colony algorithm is applied to the corridor congestion problem by minimizing the distance between the students' classroom of the courses. The experimental results show that the ant colony algorithm is able to construct feasible solutions and solve the classroom arrangement problem.

1. Introduction
Ant Colony Algorithm (ACA) is a metaheuristic for solving hard combinatorial optimization problems\[1\] and is proposed by the Italian scholar M. Dorigo et al. in the early 1990s\[2\]. It simulates the foraging behavior of the natural ant colony and uses pheromones as a communication medium. It adopts a positive feedback mechanism, which makes the search process converge continuously, and finally approaches the optimal solution. It is more robust than the exact search algorithm and is easy to be combined with other algorithms. This paper uses the ant colony algorithm to optimize the classroom arrangement of university courses.

In recent years, the enrollment scale of universities has gradually expanded, which has brought about a shortage of classroom resources and led to a series of problems such as overcrowded classroom and long moving distance between classes. The problem of classroom arrangement has been proven to be an NP problem. In 1963, C. C. Gotlieb firstly proposed a mathematical model for the scheduling problem\[3\], and many researchers then began exploring the problems of the curriculum. In the arrangement of the curriculum, Yuehua Feng proposed a dynamic adjustment strategy of pheromone to improve the sensitivity and convergence speed of the shortest path and was completely feasible in the scheduling system\[4\]; Patrick Kenekayoro proposed a greedy ants colony optimization strategy to solve the university timetabling problem\[5\]. However, the above literature only optimizes the time setting of the course to optimize the use of teaching resources but does not consider the classroom arrangement of the corresponding course.

Based on the curriculum design and the completion of the curriculum timetable, this paper uses the ant colony algorithm to arrange the appropriate classroom for each course. The solution is evaluated by the objective function and then through multiple iterations, the optimal solution or relative optimal solution is gained for the classroom arrangement problem.
2. Problem description
The problem of classroom arrangement to be dealt with in this paper is to reduce the distance generated by students changing classrooms between courses, and then alleviate the congestion of the corridor. Time periods, courses, classes and classrooms are the four entities considered in this problem.

2.1. Model establishment
The basic information of the classroom arrangement model is set as follows:

$\text{Model} = \{R, S, T, M, C\}$, and $R = \{r_1, r_2, \ldots, r_n\}$ is a set of courses, where $r_i = f(rk_i)$ and $rk_i$ denotes the number the classes in course $r_i$. $S = \{s_1, s_2, \ldots, s_n\}$ is a set of classes. $T = \{t_1, t_2, \ldots, t_n\}$ is a set of time periods. Also, $M = \{m_1, m_2, \ldots, m_{nk}\}$ is a set of classrooms, where $m_i = f(nl_i, gl_i)$, and $nl_i, gl_i$ denote the number, the floor and the capacity of the classroom $m_i$ respectively. $C = \{c_1, c_2, \ldots, c_n\}$ is a set of constraints.

The classroom arrangement problem considered in this paper is carried out under the conditions that the time and the class number of the courses, the classroom capacity has been arranged previously. An example of timetable schedule and classroom capacity are shown in Table 1 and Table 2 respectively.

| Course | Time period | Class |
|--------|-------------|-------|
| $r_1$  | $t_1$       | $s_1, s_5, s_7$ |
| $r_2$  | $t_2$       | $s_2, s_4$     |
| $r_3$  | $t_3$       | $s_5$          |
| ...    | ...         | ...            |

Table 1 Example of initial timetable schedule.

| Classroom | $m_1$ | $m_2$ | $m_3$ | $m_4$ | $m_5$ |
|-----------|-------|-------|-------|-------|-------|
| Capacity  | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ |

Table 2 Classroom capacity.

2.2. Constraints
The constraints of the classroom arrangement model are as follows:

$c_1$: Each course can only be scheduled in one classroom at the same time period.
$c_2$: Each classroom can accommodate no more classes than its capacity.
$c_3$: Each class can’t be arranged in different courses and classrooms at the same time period.

2.3. Assumption:
To simplify the problem, the model is based on the following assumptions:

$a_1$: The number of students in each class is exactly the same, and the students in the same class have the same course.
$a_2$: The basic information like the time of the course and the classroom capacity is determined and cannot be changed.
$a_3$: A course can contain multiple classes in a single time period.
$a_4$: If there is no course for a class at a time period, the classroom floor is marked as 0.
$a_5$: Only two time periods are considered, namely, $T = \{t_1, t_2\}$.

3. Ant colony algorithm
The basic idea of using the ant colony algorithm to solve the optimization problem is to use the walking path of the ant to represent the feasible solution of the problem. All the paths of the whole ant colony constitute the solution space of the problem. Therefore, it is necessary to establish a related ant colony path model so that the classroom allocation scheme can be represented by the ant walking path.

Since the courses at different time periods do not interfere with each other’s classroom arrangements, we can first arrange them in the time period $t_1$ and then the time period $t_2$, and vice versa.

First, create three collections here, the course collection for $t_1$, the course collection for $t_2$, and the
classroom collection, which is shown in Figure 1.

The basic idea: there is a path between each course and the classroom, and the ant selects a course as the starting point in the course collection of the time period \( t_1 \), such as course \( r_5 \). Then select a classroom with appropriate capacity from the classroom collection as the next target point, such as classroom \( m_1 \). At this point, the ants move from the course collection along the path to the classroom collection, and the course \( r_5 \) establishes contact with the classroom \( m_1 \), indicating that \( r_5 \) is in the \( m_1 \). Then the ants go back to the course collection and select the next course as a starting point in a certain order, repeating the above operation. Until, every element in the set of course of time period \( t_1 \) has a connection with an element in the classroom collection. Then repeat this operation in the course collection of time period \( t_2 \). At this point, the complete walking path of the ant can be expressed as a kind of classroom arrangement.

The parameter of ACA is shown in Table 3.

| Parameter                               | Symbol |
|-----------------------------------------|--------|
| Number of ants                          | \( m \) |
| Pheromone importance factor             | \( \alpha \) |
| Heuristic function importance factor    | \( \beta \) |
| Objective function importance factor    | \( e \) |
| Volatility of pheromones                | \( \rho \) |
| Total pheromone                         | \( Q \) |

3.1. Objective function
The objective function is used to measure the merits of the classroom arrangement, it’s defined as:

\[
f = \sum_{i=m}^{m_u} |l_{ij} - l_{ji}|
\]  

(1)

It represents the sum of the floors that all students move between classrooms during the breaks. And, the smaller its value, the better the classroom arrangement.

3.2. Ant colony movement principle
Let \( d_{ij} \) denotes the distance between course \( i \) and classroom \( j \) and in the time period \( t \), the pheromone concentration on the path between course \( i \) and classroom \( j \) is denoted as \( \tau_{ij}(t) \). When \( t=0 \), the pheromone concentration on each path is:

\[
\tau_{ij}(0) = \begin{cases} \tau_0 & g_j \geq r_{kj} \\ 0 & g_j < r_{kj} \end{cases}
\]  

(2)

When the initial concentration is set in this way, there is no case where the capacity of the arranged
classroom is not appropriate.

The ant \( k \) \((k=1, 2, 3...m)\) determines the next classroom to be visited based on the pheromone concentration on each path. Let \( P_{ij}^k(t) \) denotes the probability that ant \( k \) will transfer from course \( i \) to classroom \( j \) at time \( t \), and its calculation formula is:

\[
P_{ij}^k(t) = \begin{cases} \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}(t)]^\beta}{\sum_{s \in \text{allow}_k} [\tau_{is}(t)]^\alpha [\eta_{is}(t)]^\beta} & s \in \text{allow} \\ 0 & s \notin \text{allow} \end{cases}
\]

(3)

Where \( \eta_{ij}(t) \) is the heuristic function, \( \text{allow}_k \) is the collection of classrooms where ants \( k \) is to visit.

When all ants complete a cycle, the pheromone concentration on each path needs to be updated in real time:

\[
\tau_{ij}(t+1) = (1 - \rho) \cdot \tau_{ij}(t) + \Delta \tau_{ij}
\]

\[
\Delta \tau_{ij} = \sum_{k=1}^{m} \Delta \tau_{ij}^k \quad \text{while} \quad 0 < \rho < 1
\]

(4)

Where \( \Delta \tau_{ij}^k \) represents the pheromone concentration released by the ant \( k \) on the path connecting the course \( i \) and the classroom \( j \); \( \Delta \tau_{ij} \) represents the pheromone concentration released by all ants on the path connecting the course \( i \) and the classroom \( j \).

For the pheromone release problem of ants, the model given here is:

\[
\Delta \tau_{ij}^k = \begin{cases} \frac{Q}{f_{kj}} & \text{Ant } k \text{ passes the road between classroom } i \text{ and course } j \\ 0 & \text{otherwise} \end{cases}
\]

(5)

3.3. Heuristic function

Suppose you first schedule the course of the time period \( t_1 \), and the heuristic function is set to a fixed value \( 1 \) when you schedule the course, \( \eta_{ij}(t) = 1 \). When scheduling the course of the time period \( t_2 \), the heuristic function is defined as the reciprocal of the total number of floor movements added after the classroom of course \( i \) is arranged. Do the same when scheduling the course of the time period \( t_2 \) first and then scheduling the course of time period \( t_1 \).

3.4. Course order

When the ants move between the course and the classroom, they are selected according to the pheromone concentration between the paths, but the order of arrangement between the courses cannot be determined. Now make the following provisions:

a. Because the courses at different time periods do not interfere with each other's classroom arrangements, when the ant \( i \) travels, if \( i \) is an odd number, we first arrange the courses in the time period \( t_1 \) and then the time period \( t_2 \); When \( i \) is an even number, we first arrange the courses in the time period \( t_2 \) and then the time period \( t_1 \).

b. Classify each course with its minimum required classroom capacity as its rating. And the course with a high capacity level is then arranged in front of the course with a low capacity level when deciding the course schedule.

c. Every time an ant is replaced, the order of the courses should be changed once. In addition to the exchanges between courses at different time periods, courses of the same capacity level in the same time period should be randomly exchanged, too.

4. Experiment

Matlab language is used to implement the ant colony algorithm and observe the influence of parameters on the results. The initial course information is presented in Table 4:
Table 4 Initial course information.

| No. of courses | No. of classes | No. of floors | No. of classrooms | Classroom capacity |
|----------------|----------------|---------------|-------------------|-------------------|
| 40             | 100            | 5             | 35                | 2, 4, 6           |

Change only one parameter at a time, and perform 10 repeated tests on one data by observing the change of the average value of the results. The default value of the parameter is in Table 5:

Table 5 The default value of the parameter.

| m   | α  | β  | e  | ρ   | Q  |
|-----|----|----|----|-----|----|
| 30  | 1  | 2  | 3  | 0.1 | 1  |

4.1. Initial value experiment result

As shown in Figure 2, moving distance significantly reduces as the number of iterations increases. It can also be seen from the figure that the distance will not change after the 600th generation or so, and it can be approximated as the best solution. And the total number of moving floors in the class decreased to 145 from 186, which greatly reduce the moving distance between classes.

4.2. Influence of parameters

Table 6 Average distance change due to parameter variation.

| ø   | 0    | 0.5  | 1    | 1.5  | 2    | 3    | 4    | 5    |
|-----|------|------|------|------|------|------|------|------|
| α   | 0    | 5    | 1    | 1.5  | 2    | 3    | 4    | 5    |
| β   | 145.8| 162.1| 146.5| 149.9| 151.8| 153.5| 153.6| 153.2|
| e   | 146.4| 147.4| 146.6| 146.2| 146.4| 146.8| 146.6| 146.5|
| m   | 148.2| 147.1| 147.3| 146.9| 145.7| 147.2| 146.7| 146.3|
| ρ   | 0.1  | 0.2  | 0.3  | 0.4  | 0.5  | 0.6  | 0.7  | 0.8  |
| Q   | 1    | 10   | 20   | 30   | 40   | 50   | 60   | 70   |
| average | 146.9| 147.1| 147.7| 146.2| 145.8| 147.3| 147.6| 148.2|

The two parameters α and β together determine the probability of the ant selecting the path. The total distance decreases first and then increases with the increase of the two of them. When one of α or β is too large, the ant colony algorithm converges prematurely and eventually falls into local optimum, and we can't get good experimental results.

The total distance first decreases and then tends to remain unchanged with the increase of e. But when the data size is larger, increasing the value of e can often lead to better results. The total distance fluctuates with the increase of parameters m and Q, but the larger m means longer calculating time. The total distance increases as ρ increases. When ρ = 0.1, we can get a relatively good result.
5. Conclusion and future work
This paper uses the ant colony algorithm to optimize the arrangement of college classrooms. We establish an ant colony model for the arrangement of college classroom, construct a heuristic function consistent with this model, design the transfer rules of ant colony between the courses and the classrooms, and analyze the influence of various parameters in the algorithm on the experimental results. And the experimental results verify the feasibility and effectiveness of the ant colony algorithm proposed.

However, only two time periods and total moving distance are involved in the paper. The degree of congestion in the corridor depends not only on the distance of movement but also on the direction of movement, the position of movement, etc. And more time periods need to be considered. These factors will be researching directions in the future.

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