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Research Article

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The solution of Louvre evacuation problem based on cellular automaton

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Abstract At this stage, the situation in France is chaotic. In order to ensure the safety of visitors to the Louvre, it is very important to formulate a reasonable evacuation strategy. This question is based on the evacuation of people in the Louvre scene. The cellular automata theory should be combined with the ant colony algorithm to consider the construction of evacuation models by considering various potential safety factors, planning the optimal path, calculating the minimum evacuation time, and determining the evacuation plan.

We use the cellular automata theory to construct the cell space using the Louvre plan. To enhance the adaptability, randomly assign the location and state of the cell representing the visitor. To the psychological influence and group effect of tourists, the particle swarm optimization algorithm is used to optimize the local movement rules of the cell, and the optimal path is planned. The fitness value of the particle swarm algorithm is used to reflect the competitiveness of the cell, and a conflict resolution mechanism is formed. Internal and inter-layer connections form a pseudo-three-dimensional structure, construct an idealized evacuation model, use Anylogic to simulate and simulate the time when visitors arrive at the main exit, and combine with the time provided by Afflence to find the evacuation time.

Keywords personnel evacuation; cellular automaton; particle swarm optimization

1. Problem Background

The Louvre is one of the oldest, largest and most visited museums in the world. As a world-famous attraction, the Louvre hosted more than 8.1 million visitors in 2017, with huge daily traffic and complex composition. The Louvre is a large-scale and complex structure. It is divided into six columns: the Ancient Greek and Ancient Roman Pavilions, the Ancient Egyptian Pavilion, the Ancient Oriental Pavilion, the Oil Painting Sketch Museum, the Sculpture Hall, and the Arts and Crafts Museum. There are five floors above and below, two of which are located, underground. The Louvre has a large number of entrances and exits, including four main entrances and exits, VIP entrances, employee entrances, and historical entrances. These factors make the Louvre a well-established evacuation plan for tourists.

At present, the political situation in France is turbulent, and there have been many terrorist attacks in various places, posing a serious threat to tourists. In the specific environment of the Louvre, accidents such as fires, earthquakes, and explosions may occur. In the process of evacuation, there may be unexpected situations such as crowded trampling and partial export closure. These will seriously threaten the safety of life and property of tourists. Therefore, it is very important to establish relevant mathematical models to understand the evacuation of tourists in the Louvre under the existing scheme and to develop a reasonable evacuation plan.

Our goal is to establish a model of evacuation of tourists in large-scale building structures by means of cellular automata, particle swarm optimization, queuing theory and other theories and algorithms, simulate evacuation processes, and develop evacuation plans.

2. Problem Analysis

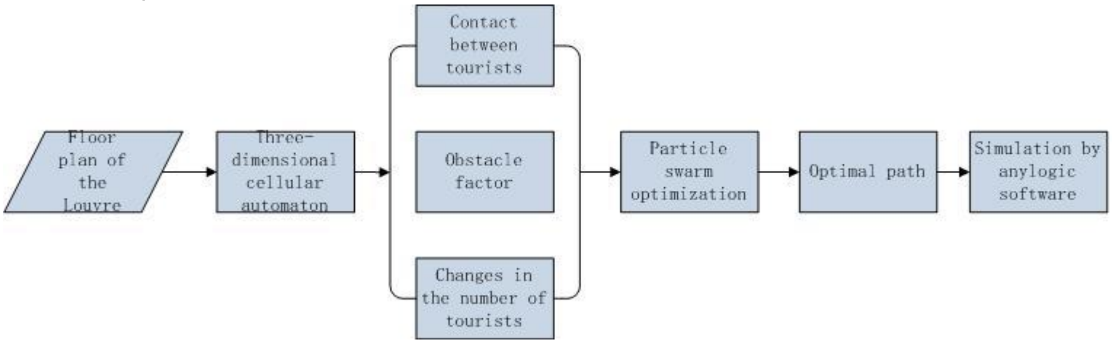

Figure 1: Model establishment process

First of all, we can determine that this is a problem of personnel evacuation, and to solve this problem requires the use of cellular automata, particle swarm algorithm and queuing theory and other related theories and knowledge, we obtained through the access to information. The data of the Louvre Museum was given a plan of the Louvre Museum. The Louvre is a three-dimensional building, and only the layers are related, and the floors are connected only by stairs, so a pseudo three-dimensional cellular automaton is considered here.

Considering the actual situation, the number of tourists in the museum changes with time, so the number of tourists is a dynamic parameter that changes in real time, not a constant state. When the tourists flee, it is inevitable that various emergencies may happen such as the trampling accident, the terrorists in the exit, and the dumping of the objects, etc., which will make the state of each exit different. When establishing the model, we consider randomly setting obstacles as the interference factor, and assign various possible states as obstructing cells and assign these in the cellular automata to deal with all kinds of risks. Considering the psychological state of the herd mentality, the connection between the tourists also affects the movement of the tourists. It is the relationships between the cells and cells when reflected in the cellular automata theory [1].

After the cellular automata theory is constructed, the corresponding rules are defined so that the cells move according to certain rules, and the anylogic software is used to simulate the running process under different states.

3. Symbol Description

V	Tourist speed collection
V_1	Self-operating passenger speed
V_2	Speed of visitors who are not self-motivated
k	Cell direction
w	Inertia weight
c_i	Acceleration constant
r_i	a random function with a value of [0,1]
$pbest_i$	Optimal solution to an individual
$gbest_i$	Optimal solution to a group
x_i	The current location of the cell

4. Model Establishment and Solution

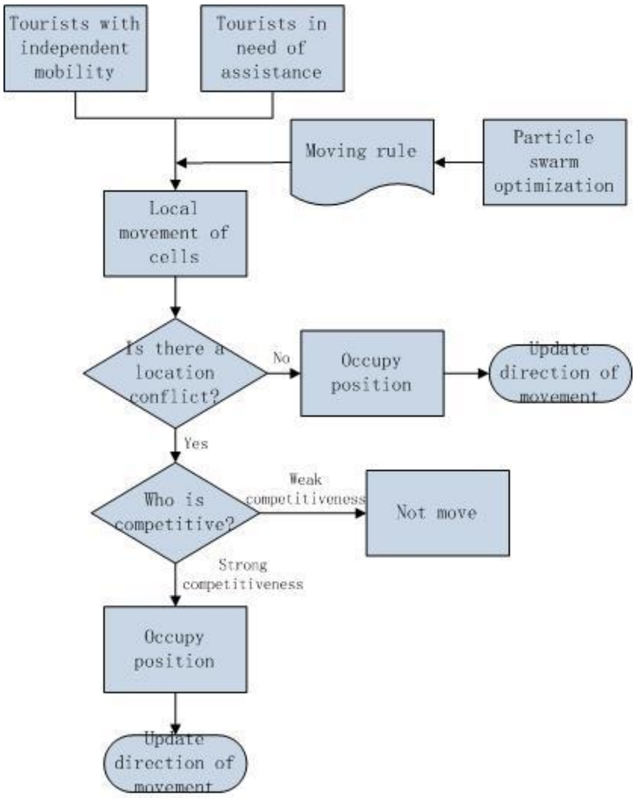

Figure 2: The basic process of establishing an idealized evacuation model

For the first question, we construct the cell space according to the Louvre plan, use the particle swarm algorithm to determine the local cell movement rule, establish the conflict resolution mechanism through the fitness value, and let the cell reach the designated exit through the optimal path.

4.1. Establishment of an ideal evacuation model

First, based on the problem analysis, we need to build an evacuation model and use simulation to determine the optimal path and calculate the shortest time. To solve this problem and establish a related model, we use the concept of cellular automata proposed by Von Neumann in 1966.

The two cell neighbors commonly used in CA are Von Neumann type and Moore type. We use the Moore type shown in Figure 3 to construct the model. The moving direction of the cell is shown in Figure 4 [2].

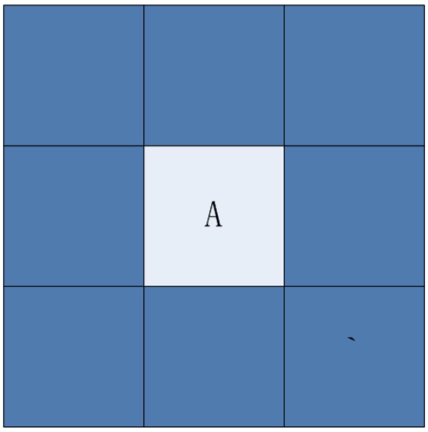

Figure 3: MOORE type cell neighbors

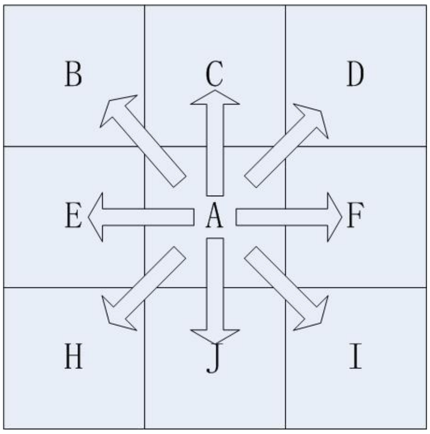

Figure 4: Cell movement direction

We use the plane structure diagram of the Louvre to build an infrastructure map. According to the analysis of the topic, there are many types of tourists in the Louvre. We divide them into tourists with independent mobility and tourists who need assistance from others, and give them different speeds.

$$V = \begin{cases} V_1 = 0.667m/s \\ V_2 = 0.334m/s \end{cases} \quad (4.1)$$

Among them, V is the collection of two tourist speeds, V_1 is the speed of normal visitors, and V_2 is the speed of walking for tourists who need assistance from others.
After determining the walking speed of the visitor, in order to achieve local movement of the cell, it is necessary to determine the local movement rule of the cell. To achieve the transition of cells from static to dynamic, we use particle swarm optimization.
Based on the actual conditions, we need the cell to determine the direction based on the personnel density, obstacle position and exit position in the forward direction. Therefore, the fitness function is constructed as follows [3]:

$$fitness = \varphi(k)\omega(k)[k_1 p_1(k) + k_2 p_2(k)] \quad (4.2)$$

Wherein, $\varphi(k)$ is the adjustment coefficient. When the direction k exists, we take 1, otherwise take 0. $\omega(k)$ is the exit direction influence factor, k_1 is the attraction weight of the direction k, $p_1(k)$ is the probability of the direction k, k_2 is the density weight of the direction, k and $p_2(k)$ is the density probability of the direction k.
Based on the actual conditions, we use the idea of particle swarm optimization to construct a local movement rule and transform the original speed updating into a speed direction updating, as follows:

$$D_{i+1} = wD_i + c_1 r_1(pbest_i - x_i) + c_2 r_2(gbest_i - x_i) \quad (4.3)$$

Among this, D_{i+1} is the direction in which the cell $i+1$ moves; w is the inertia weight used to adjust the search range; c_1 c_2 is the acceleration constant used to adjust the learning step; and r_1 r_2 is a random function with a value of [0, 1] to increase the search randomness. $pbest_i$ is the optimal solution considered by the individual $gbest_i$ is the optimal solution considered by the group and x_i is the current location.
When the cell obtains the direction of the next motion, it is necessary to determine whether other cells collide with it at the predetermined location. Therefore, a competitive mechanism is introduced to determine the competitiveness of the cell by calculating the fitness value of the cell.
Let the competitiveness of the cell α be $fitness_\alpha$, the competitiveness of the cell β is $fitness_\beta$.
If $fitness_\alpha > fitness_\beta$, the cell α reaches this position, the cell β seeks a suboptimal solution by the particle swarm algorithm.
If $fitness_\alpha < fitness_{\beta\beta}$,the cell β reaches this position, the cell α obtains a suboptimal solution by the particle swarm algorithm.
When there is no suboptimal solution, the cell stops in place.
Since the Louvre is a multi-layer structure, it is necessary to extend the model from a planar structure to a multi-layer structure. Since the interior of the floor can communicate with each other in this question, the floor and the floor are only communicated by stairs. Therefore, only the cell at the stairway is designed to communicate with the rest of the cell space, and the cell can only pass through the location to achieve the purpose of communicating the layers. Based on the above conditions, the two-dimensional planar structure can be expanded into a pseudo three-dimensional structure.
Finally, the evacuation time can be obtained by summing the time obtained by the simulation and the waiting time obtained by Affluences.

4.1.1. Solution of ideal evacuation model

In order to fully demonstrate the application of the evacuation model to the Louvre, we use Anylogic for simulation. The following are the model simulation steps.

Step 1: to construct a cellular automaton based on the Louvre plan by Anylogic

Step 2: to initialize the process, adjust the viewpoint to the appropriate viewing position, the initial position of the cell, the context of the mesh, and the distribution of obstacles in the grid.

The Louvre has a large number of tourists each year, and there are large differences in the number of tourists in different seasons. Therefore, in order to ensure that the model can be applied to the Louvre in different periods, and can be extended to other large buildings, the model's universality and self-expression are embodied. Adaptability, when designing the location and quantity of visitors, adopt random placement method, and the position and quantity of personnel obey the Poisson distribution. The specific allocation is shown in Figure 5.

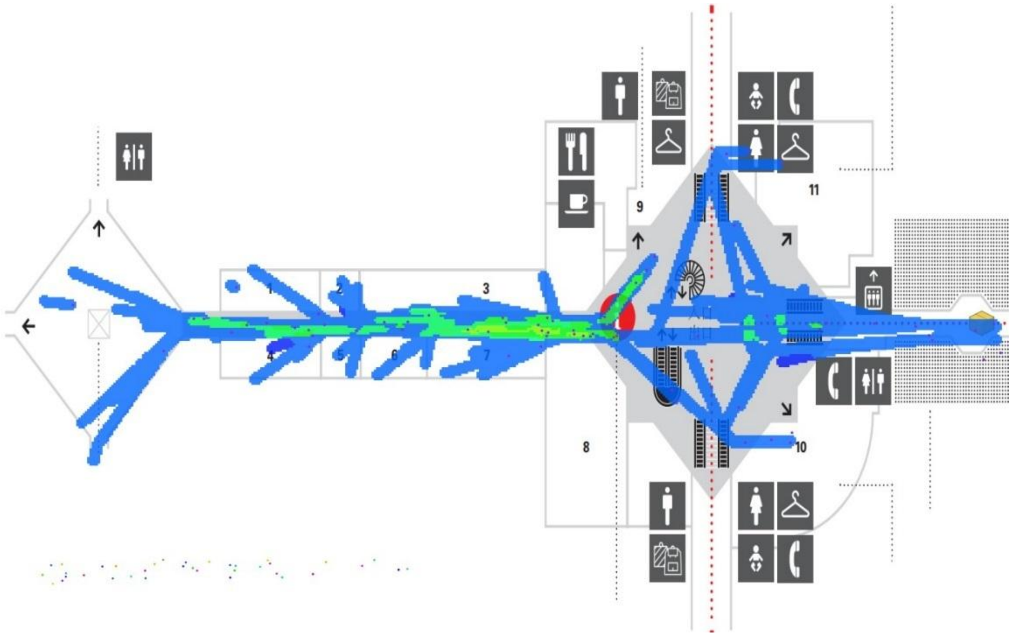

Figure 5: Visitor initial location allocation

Step 3: to perform computer simulation according to the established movement rule (as shown in Figure 6)

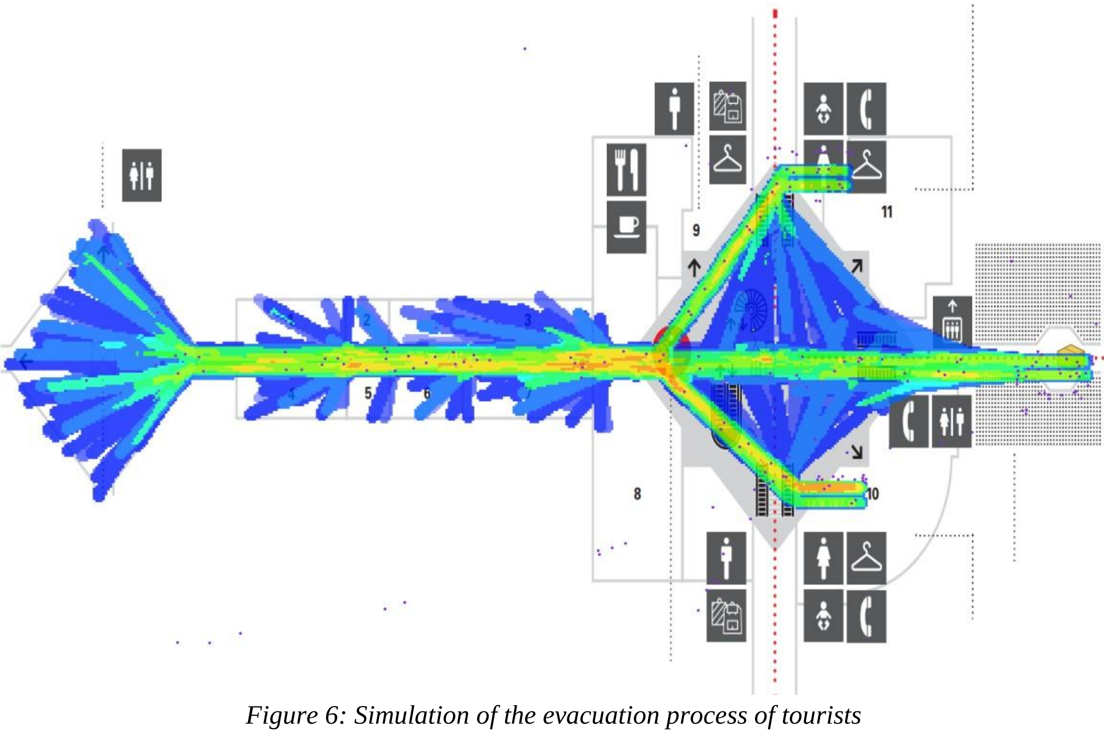

Figure 6: Simulation of the evacuation process of tourists

Step 4: to determine whether the evacuation is completed, if not completed, go to step 3;

Step 5: evacuation is completed and the process is finished (as shown in Figure 7).

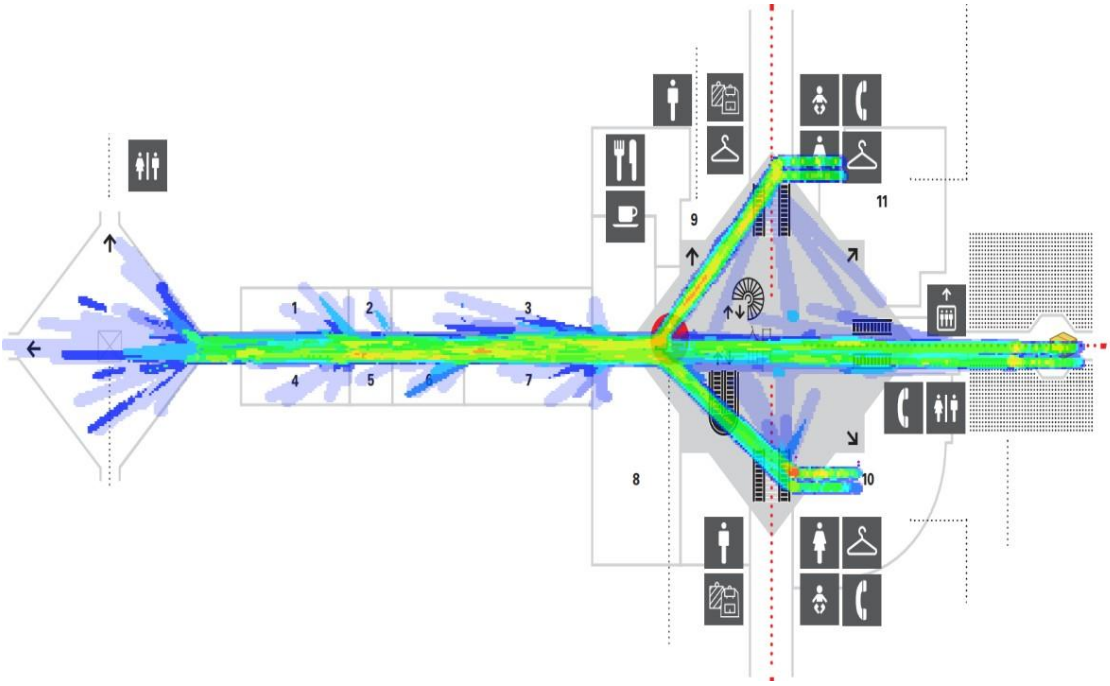

Figure 7: Evacuation results

Through simulation, we can see that under relatively ideal conditions, the time for randomly simulated visitors moving from their location to the main exit is shown in the figure below.

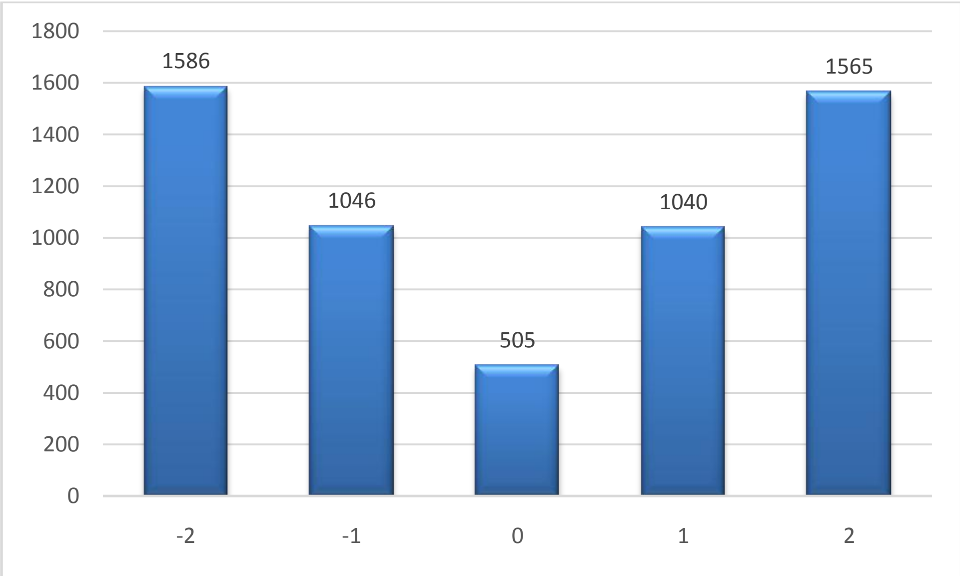

Figure 8: Simulation results of ideal evacuation model

According to the analysis of Fig. 8, as the distance from the 0 layer of the main exit increases, the time required for evacuation increases, and the evacuation time of the -2 and 2 layers is about 3 times of the evacuation time of the 0 layer, and at the same time, with the evacuation As the process progresses, the queue length of the exit will increase, which will lead to further increase of evacuation time, posing a great threat to the safety of tourists.

5 Model Evaluation

5.1. Advantages of the model

- Using the theory of cellular automata, construct an evacuation model in space, clearly reflect the interaction between the various components of the system, and describe complex, global, continuous systems with simple, locally regular, discrete methods. , through a few simple rules to evolve highly complex results.

- Using the particle swarm optimization algorithm to optimize the local movement principle of the cell, reflecting the influence of human psychological behavior on the evacuation movement, and also showing the interaction between people, at the same time, planning the optimal path and improving the evacuation efficiency.

5.2. Shortcomings of the model

- The internal plan of the Louvre is not clear enough, and the data is insufficient, resulting in the incomplete construction of the cell space.
- The speed setting of the visitor and the setting of the necessary safe evacuation time lack the actual experimental data verification.

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