Agent-based simulation of building evacuation using a grid graph-based model

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Abstract. Shifting from macroscope models to microscope models, the agent-based approach has been widely used to model crowd evacuation as more attentions are paid on individualized behaviour. Since indoor evacuation behaviour is closely related to spatial features of the building, effective representation of indoor space is essential for the simulation of building evacuation. The traditional cell-based representation has limitations in reflecting spatial structure and is not suitable for topology analysis. Aiming at incorporating powerful topology analysis functions of GIS to facilitate agent-based simulation of building evacuation, we used a grid graph-based model in this study to represent the indoor space. Such model allows us to establish an evacuation network at a micro level. Potential escape routes from each node thus could be analysed through GIS functions of network analysis considering both the spatial structure and route capacity. This would better support agent-based modelling of evacuees′ behaviour including route choice and local movements. As a case study, we conducted a simulation of emergency evacuation from the second floor of an official building using Agent Analyst as the simulation platform. The results demonstrate the feasibility of the proposed method, as well as the potential of GIS in visualizing and analysing simulation results.

1. Introduction

Computational simulation of emergent evacuation is a powerful tool for evacuation planning and evaluating building safety. Considering differences in individuals' characteristic features, agent-based simulation has been used to study crowd evacuation in various situations for its ability to model individualized behaviours [1, 2]. Since evacuation behaviour is closely relative to the spatial features of the environment [3], effective representation of the space is essential for agent-based modelling of indoor evacuation behaviour. In the meanwhile, the powerful spatial functions of GIS, which have shown a great potential in evacuation planning, are expected to facilitate the modelling of evacuee's route choice and local movement. In consideration of these, we used a grid graph-based model in this study to represent the inner space of the building for agent-based simulation of building evacuation. The grid graph-based model allows us to integrate GIS based route analysis into agent-based modelling of evacuation behaviour. As case study, the evacuation simulation of the second floor of an official building has been conducted.

The remainder of the paper is organized as follows. Section 2 introduces related work in the field of evacuation simulation. Section 3 describes the proposed agent-based evacuation simulation using grid graph-based model. Section 4 provides the evacuation simulation of a case study. Section 5 concludes the paper and proposes future works.

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2. Related work

The structure of a typical agent-based model is composed of agents that are capable of interacting with each other and with their environment. For the simulation of building evacuation, each evacuee is modelled as an agent complying with a series of behaviour rules. The evacuation behaviour could be modelled at two levels, the high level of global way-finding and the low level of local motion [4]. Considering the complex interactions among people in emergent situation, Pan et al. proposed a multi-agent based framework for simulating human and social behaviour during emergency [5].

As for the representation of the indoor space, discrete space especially the regular cell model is widely used for reducing computational cost in comparison to continues space [2]. However, such cell-based representation has limitations in handling structural properties such as topological relationship of the indoor units. Li et al. proposed a grid graph-based model that takes into account the structural and spatial properties of the indoor space and shows advantages for indoor route analysis [6]. In the meanwhile, considering the impact of spatial accessibility on evacuation behaviour, researchers start to incorporate various spatial functions of GIS into the simulation of building evacuation [7, 8]. It is noticed that GIS has a potential link with agent-based simulation of indoor evacuation for input data and output visualization and analysis.

3. Evacuation modelling

In this study, we consider each evacuee as an agent that is capable to make decisions regarding the escape route choice and move along the route while interacting with the surrounding people. The indoor space is represented by a grid graph-based model that encapsulates the movement probability derived from GIS based route analysis.

3.1. Agent-based modelling of evacuation behaviors

The agents' evacuation behaviour model consists of two modules, as shown in figure 1. The route planning module decides the exit to evacuate from and generates the corresponding escape route which consists of a series of goals to move to (e.g. room door, stair, exit, etc.). Movements to reach the goals are carried out through the movement module. When block is detected in the movement module, the route planning module is called to modify the escape route.

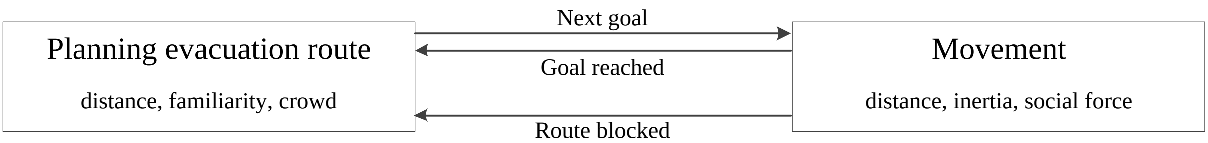


Figure 1. Agent-based behaviour modelling of evacuees.

When modelling the process of route planning, following factors are taken into account according to previous studies and observations [3, 5, 9]:

- In emergent situation, people tend to choose the nearest exit to evacuate.
- In a state of panic, people subconsciously choose their most familiar exit to evacuate.
- If the distances are similar, people are willing to choose the path that is not crowded.
- People won't change their route unless there is an alternative route that is clearly better than the current choice in terms of route length and estimate time of waiting.

The movement module is developed based on the theory of social force [10]. On the one hand, people move to the next goal along the shortest path given time pressure. On the other hand, people try to keep a distance from others and obstructions when moving on. Besides, people tend to keep its previous moving direction because of inertia force.

3.2. GIS-based analysis of evacuation environment

In this paper, a grid graph-based model proposed by Li, et al. [6] is employed to represent the indoor space, where nodes and edges are labelled with membership values according to the underlying cellular units for indoor space analysis. We set the granularity of the grid graph to 50cm ×50cm, which is approximately the typical space occupied by a pedestrian [11]. At each time step, the agent moves from a node to one of the neighbouring nodes. According to the evacuation behaviour model discussed in the previous section, the probability of moving to a neighbouring node is calculated in the following way.

First of all, the agent tends to move along the shortest path to exit which would be calculated through edge impedances. To reflect the spatial accessibility and the travelling time from one node to another, edge impedances are defined according to table 1. Generally, edge impedance is equal to edge length to indicate the time cost in free space, and is set to a very high value meaning not accessible in occupied space. Besides, since people try to keep a distance from obstructions when moving on, edges touching the boundary of occupied space are assigned with larger impedance values to indicate lower spatial accessibility. Figure 2(b) illustrates the grid graph-based representation of the indoor space shown in figure 2(a), where edges are classified according to its impedance value.

However, because of the interactions among agents, especially collision avoidance, agents are not likely to move strictly along the shortest path. In order to model the repulsion force among agents, impedances are assigned to each node according to its available capacity. We assume that each node may accommodate at most two people at once. Then, the node impedance is set to *i/2*, where *i* is the number of agents on the node.

In addition, there should be an enhancement on the agent's previous moving direction because of inertia force. In summary, the probability to move to a neighbouring node is as following:

$$P_i = (W_{I_e} \sum I_e + W_{I_n} I_n + W_I I) / \sum P_i$$

$\sum I_e$ is the total edge impedances along the shortest path from a neighbouring node to the next goal. I_n is node impedance of the neighbouring node. I is an enhancement on the neighbouring node in the previous moving direction. W_{I_e}, W_{I_n} and W_I are the weights of the corresponding factors. Figure 3 illustrates a comparison between the ideally shortest path to the exit and the agent's moving trajectory considering the impact of repulsion force to avoid occupied space and other agents, as well as the impact of inertia force.

Table 1. Edge impedance for shortest path analysis in an indoor space.

Description	Edge length	Impedance
Edges are completely within free space: room, corridor, stairs, opened door, opened exit, etc.	g[a] $\sqrt{2}$g	G $\sqrt{2}$g
Edges touch the boundary of occupied space: wall, closed door, closed exit	g $\sqrt{2}$g	2g 2$\sqrt{2}$g
Edges are completely within or intersect with occupied space: wall, closed door, closed exit	g $\sqrt{2}$g	Infinity[b] Infinity

[a] Granularity of the model.

[b] Infinity could be a very high value and indicates that the edge is not accessible.

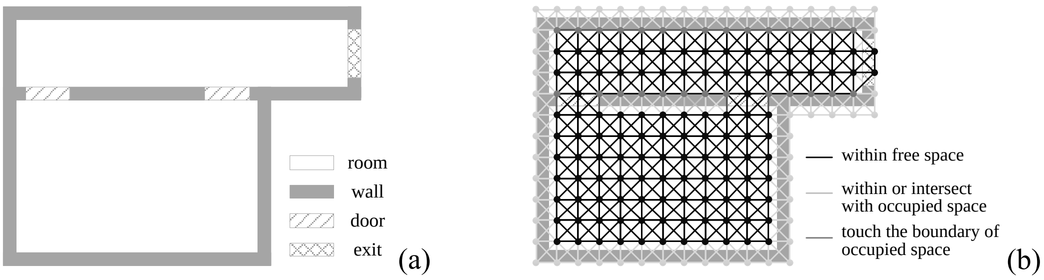


Figure 2. Using grid graph-based model (b) to represent an indoor space (a).

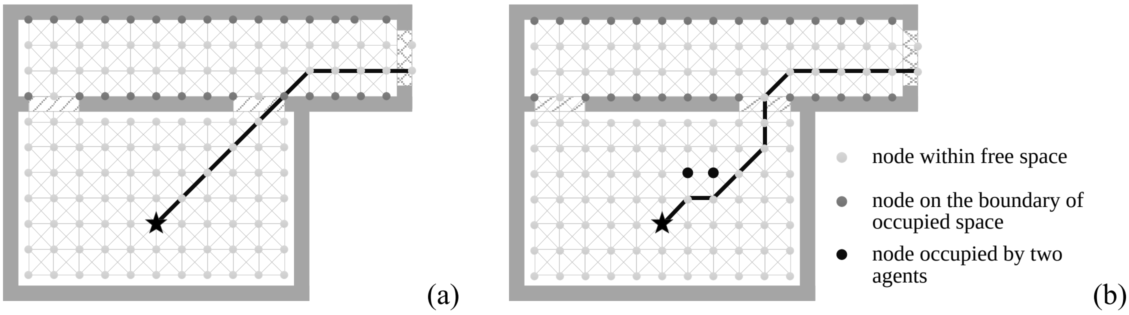


Figure 3. The shortest path (a) and moving trajectory affected by obstructions, other agents and inertia force (b).

4. Case study

Using the model discussed above, we conduct a preliminary simulation of emergency evacuation from the second floor of an official building. The floor plan includes 4 rooms, 2 stairwells, a corridor and an elevator, as show in figure 4. We do not consider evacuees' movement on stairs at this stage and simulate only the process of moving towards the exits. We use Agent Analyst [12] as the simulation platform, which is an open-source software compatible with the widely used ArcGIS software.

4.1. Analysis of potential escape route

We first created the grid graph of the floor plan. Figure 5 shows the grid graph excluding edges completely within or cross the occupied space which are not accessible and have very high impedance values. Considering that the elevator cannot be used for evacuation during fire emergency, we treat the elevator as occupied space in the simulation. One hundred evacuees which are simulated as agents are randomly distributed in rooms and corridor. Black circles in figure 5 illustrate their locations at the beginning of evacuation.

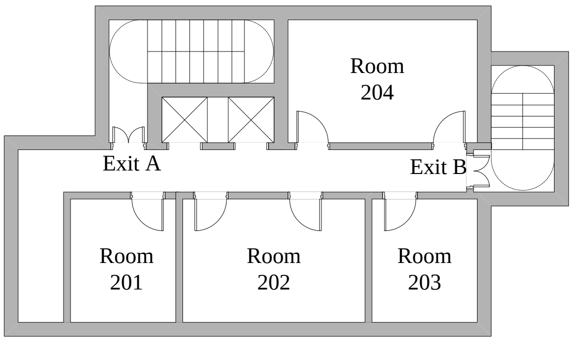


Figure 4. The second floor plan of an official building.

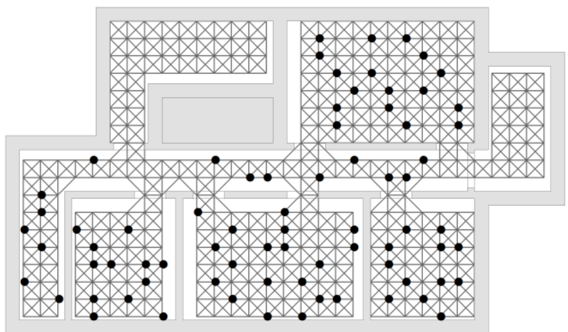


Figure 5. Grid graph-based representation and initial distribution of evacuees.

To simplify the evacuation simulation, we assume that evacuees have completely spatial knowledge of the indoor space and are familiar with both escape routes to the two exits. Generally, people tend to move to the nearest exit along the shortest path. Using the grid graph, shortest paths from each node to the nearest exit are generated through network analysis based on the edge impedance values, taking into account both time consumption and collision avoidance from the obstructions (figure 6).

However, human's perception of distance would be affected by psychic stress in emergent situation [13]. Therefore, we set a threshold for agents' awareness of the shortest path in the following way. When the agent's in a room, it will clearly identify the nearest exit only if the shortest route to the nearest exit is at least 10 meters shorter than the shortest route to any other exit. Otherwise the agent feels difficult to justify the nearest exit and will move towards the nearest door or less crowded door to get out of the room in first time. Similarly, when the agent's in the corridor or in a room with two doors, it may not tell the nearest exit or the nearest door if the difference between the shortest path lengths is less than 2 meters, and will choose the next goal according to crowd density. Therefore, when block occurs and the current route is not the clearly shortest route, the agent would try to change to an alternative route.

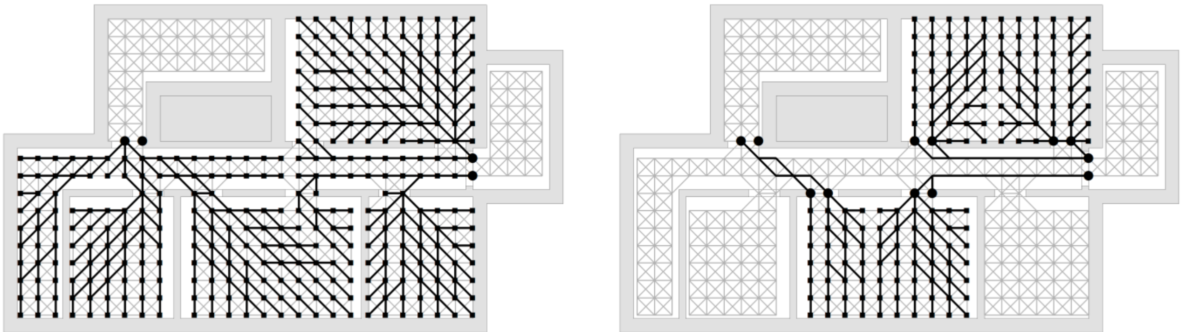
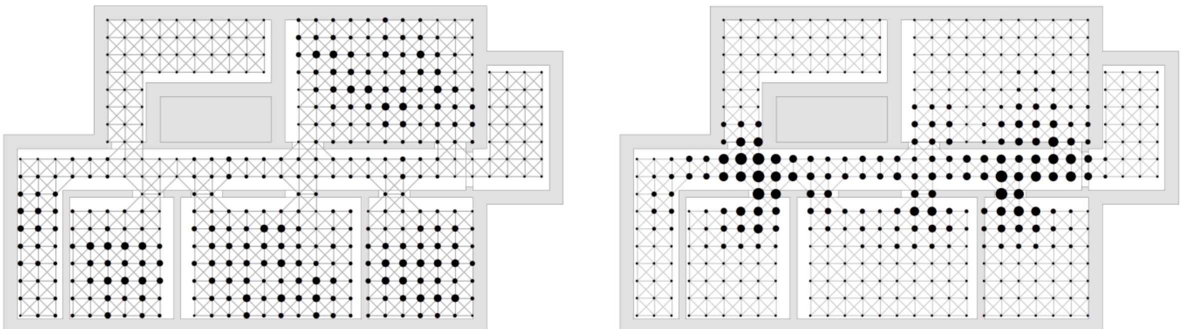


Figure 6. The shortest paths to the closest exit (a) and the shortest paths to the closest room door (b).

4.2. Simulation results

We simulated the evacuation process of one hundred evacuees from the floor. Figure 7(a) illustrates the distribution of crowd density at the initial time. When evacuation starts, the agents evaluate the potential escape routes from their current location and decide the next goal to move to. Figure 7(b) illustrates the distribution of crowd density at tick 10. Most agents have arrived at the corridor and crowding can be observed near doors and exits.

Figure 8 is a visualization of the agents' escape trajectories according to the frequencies the edges have been passed by. Because of interactions with the surrounding population, agents did not move exactly along the shortest path during evacuation. This is especially obvious in the corridor where the crowd density is relatively high. Referring to the escape trajectories and the statistics on the usage of the two exits (figure 9), it is observed that most agents in Room 204 move towards the right door and evacuate from Exit B although the left door is less crowded. The reason is that the route to Exit B via the right door is clearly shorter than any other escape route from the room and the agents would insist on it in spite of the crowding. In contrast, usage of the two doors of Room 202 is relatively balanced, since the route length to Exit A via the left door and the route length to Exit B via the right door are quite similar and the agents would try to avoid crowding.



(a) tick = 0 (b) tick = 10

Figure 7. Crowd distributions at certain time ticks. Black circle magnitudes reflect the number of agent at the node and its neighbours.

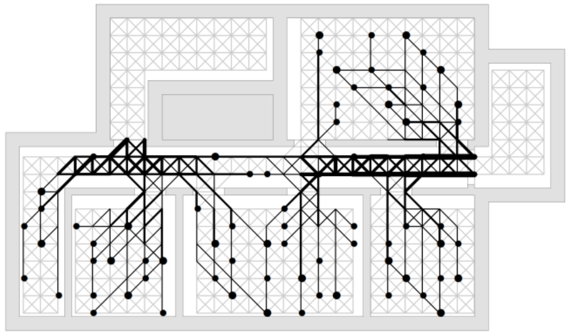


Figure 8. Escaping trajectories during evacuation. Black line widths reflect the frequency the edge is passed by.

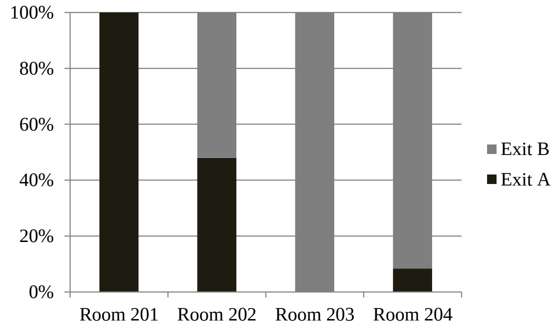


Figure 9. Statistics on usage of the two exits

5. Conclusions and future work

In this study, we explored the way to integrate GIS based route analysis with agent-based simulation of building evacuation. Instead of regular cells, we used a grid graph to represent the indoor place. The grid graph takes into account the structural and spatial properties of the indoor space and allows us to take advantage of the powerful topology analysis functions of GIS. Therefore, the agent's movement probability is calculated through GIS based route analysis considering both the spatial structure and route capacity, which are the two main factors impacting evacuation behaviour. In addition, GIS technology also shows an important role in visualization and analysis of the simulation results, such as the distribution of crowd density and the evacuees' moving trajectories. This would be helpful to identify the potential bottleneck and evaluate the evacuation plan. However, the evacuation behaviour model adopted in this study is a preliminary model mainly focusing on the spatial aspect of evacuation behaviour, while complex psychological and sociological impacts are not taken into account. Future works come to develop more sophisticated evacuation behaviour model for a more realistic simulation.

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