Agent Evacuation Simulation Using a Hybrid Network and Free Space Models

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Abstract. The simulation of a large number of people's evacuation behaviors is assumed to support the decision of rescue operations or prompt planning for disaster mitigation. Simulations of agents at wide areas with fine resolutions require a lot of computational resources and computer powers. We propose a hybrid traffic simulation combining network and area models to simulate agents' behaviors. This paper presents that a hybrid traffic simulator had same results that have used all free space models. This indicates that our system can simulate behaviors a huge number of agents at wide areas with high resolutions by reasonable computational resources.

1 Introduction

It is difficult to make models for human behaviors in complex situations. Disaster and rescue simulation is one of the issues, and involves a very large numbers of heterogeneous agents in a hostile environment. Agent based simulations (ABS) have been providing a paradigm to simulate it [1]. The ABS presents humans as agents and simulates their behaviors in environments created by data from real worlds and disaster simulators.

The simulation of a large number of people's evacuation behaviors is assumed to support the decision of rescue operations or prompt planning for disaster mitigation. The movement of people happens at disasters are escape from a smoke-filled room, evacuating from buildings or underground malls, moving outside to refuges. Various systems of simulating human movements have been presented. One of them is pedestrian simulation and crowd simulations [4] [7]. They simulate human movements in open spaces. The other simulation is traffic of cars in downtown [2].

In a case of disaster and rescue simulations in cities, it is required to simulate human movements inside buildings and outside of them, and the traffics of cars including emergency vehicles. The modeling of space where agents move is different from the purposes of simulation or the available resources of computation. For example, three dimensional geographical data and free space model are used in indoor simulations [6] [3]. Outside wide area simulations use two dimensional data and network model of roads [5]. In a case of simulations for outside area,

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the size of area is wide and the number of objects in the map is large, so it takes a lot of computational resources for simulations.

We propose a hybrid simulator that enables to simulate the behavior of agents on maps that are represented in a network model, free space model and combined one . By presenting crowded areas as free spaces and the places that human move smoothly by the network, the simulation of evacuation behaviors at wide area becomes possible. Section 2 describes traffic simulation in disaster and rescue simulations. Our proposed hybrid simulator is presented in Section 3, and the results of experiments are discussed in Section 4. Summary and discussions are in Section 5.

2 Human Movements in Disaster and Rescue Simulations

2.1 Rescue Scenarios

When earthquakes occur in urban areas, various types of causalities and accidents occur. These are related to one another. Collapsed buildings injure civilians and block roads with debris. The rescuers must rush the victims to hospitals, help civilians evacuate to safe areas, and prevent fires, if any, from spreading.

We consider following rescue scenarios, if disasters occur when students attend their lectures.(Figure 1)

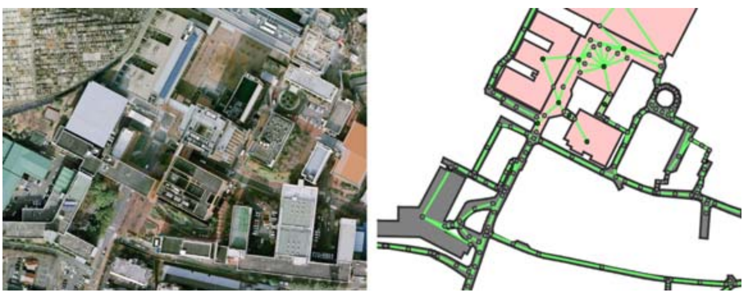


Fig. 1. Students evacuation task. (left: An image of our university by Google Map, right: A model used by our traffic simulator. Buildings and roads inside campus are modeled by free space and roads outside are represented by a network model.)

- **A.** At outside buildings: Students evacuate from buildings. On the other hand, rescue teams rush to the buildings to rescue injured students. The students move to refuges and injured ones are transported to hospitals.
- **B.** At inside buildings: Students go to the exits of classes, look for the emergency exit, and take the stairs to the ground floor. The rescue teams enter the buildings, go to rooms, and check whether there are some left there.
- **C.** At outside and inside buildings: Around entrances of the buildings, there are many students and rescue teams. The crowded situations are to be simulated.

Simulation of scenario A corresponds to movements from a building inside campus to refuges outside campus. Scenario B is handled by house size simulations with three dimensional graphical models. Scenario C requires simulation at both inside and outside.

2.2 Related Works and Problems

ABS provides the paradigm that implement agents behaviors as results of their wills. The wills are for example, they want to go home, go to refuges, or search for their family. One of methods that involve the agent's will in a multi agent simulation system (MABS) is that MAS has a function of calculating their positions at every simulation step. A traffic simulation is a typical one. Most of traffic simulations are using a network model. The network model is consisted of edges and nodes, and the edges have lanes along that cars run. Methods for simulating behaviors using a free space model are used to simulate the movements of human in an open space, One crowd simulation is based on a force model by defining objects as points, lines and polygons. Other crowd simulation presents objects as arrays of cells, express the occupant agents as a cell, and simulate the behavior as Cellular Automata [8].

Casti showed that MABS traffic planners, TRANSIMS, simulated traffic patterns in Albuquerque, New Mexico, and was used to assess the impact of new road construction [2]. For pedestrian simulations, FreeWalk provides a social interaction platform [3]. Human participants and autonomous characters can socially interact with one another in a virtual city space. There are also commercial products [9].

The above systems can simulate the behaviors of agents, but they cannot take into eternal factors such as earthquakes, fires, and floods. There are systems that simulate the behaviors of agents under dynamically changing environments combined with disaster simulations. RoboCup Rescue Simulation (RCRS) was designed to simulate the behaviors of civilians, the operations of rescue teams, and disasters situations simultaneously at the Hanshin-Awaji earthquake disaster [5]. USARSim is a robot simulator developed based on the 3D game environment [6].

3 A Hybrid Model of Network and Free Space

Simulating evacuation behaviors at disaster situations requires follows:

1. Several types of agents such as persons and cars, are involved in the simulation. And they have different wills and their behaviors are not represented by one model. As a result, their movements are not similar ones when they are at the same situations.
2. When a huge number of agents move in area with limited space, traffic jam may occur there.
3. When the area of simulation is wide, the required resolution or dimension of the area varies according to the situations.

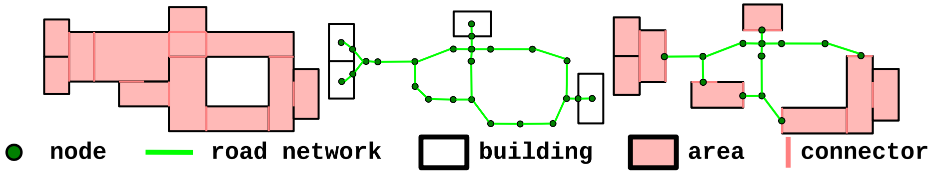


Fig. 2. Map representation in different models (top: a free space model, center: a network model, bottom: area & network models)

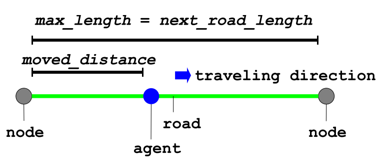
We propose a hybrid traffic simulator that can simulate agents' behavior in wither a network model or a free space model. Using a free space model, it takes computational resources to simulate the behaviors of agents, while using a network model costs less computational resources. The hybrid traffic simulator can meet the above requirements by switching the models to present maps.

3.1 Specifications of Maps

Figure 2 shows maps represented by three models. The top one shows a free space model. The center one displays a network model and four builds are represented as nodes. The bottom one is a hybrid of network & free space models and some roads are represented as a form of free space models in addition to the buildings.

3.2 Simulations of the Behavior of Agents

Behavior simulation using network model: Under a network model, agents move along lanes that are components of edges. Collisions between different lanes are not taken into considerations in simulations. The destination that agents want to go and the route to it are represented as a node and a path of edges to the node. The position in an edge is calculated as following codes at every simulation step (Figure 3).




```
if (next_road == true) {
    moved_distance <- 0;
    max_length <- next_road_length;
    next_road <- false;}
moved_distance <- moved_distance + v * dt;
if (moved_distance >= max_length) {
    next_road <- true;}
```

Fig. 3. The position of agents in a network model. A wide road (edge) is consisted of several lanes. Agents are on one lane, if their positions (*moved_distance*) are different.

Behavior free space model: The movements of agents in free spaces are calculated with Helbing's physical force model [4]. The destinations of agents are given as $\mathbf{e}_i^0(t)$ in the following.

$$m_i \frac{\mathrm{d}\mathbf{v}_i}{\mathrm{d}t} = m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_{W} \mathbf{f}_{iW} \tag{1}$$

where m_i represents a pedestrian i of mass, v_i^0 represents a certain desired speed, $\mathbf{e}_i^0$ represents a certain direction, $\mathbf{v}_i$ represents a actual velocity, τ_i represents a certain characteristic time, j and W represent other pedestrians and walls, $\mathbf{f}_{ij}$ and $\mathbf{f}_{iW}$ represent interaction forces, and t is simulation time.

3.3 Results of Implementation

Figure 4 shows snapshots of agents' behaviors. The left figure is the movements of 300 agents from a right room (free space) to the left up position through the other space. Two spaces are connected via an access aisle presented as an edge of a network model. The connector node in Figure 2 between a free space and an edge works as ingress and egress points of agents. Each agent is displayed by a cycle with two arrows. The dark arrow shows the movement and the other light arrow is the force applied to them. The right figure shows the collisions of two groups of agents at the narrow aisle. The groups move to opposite directions.

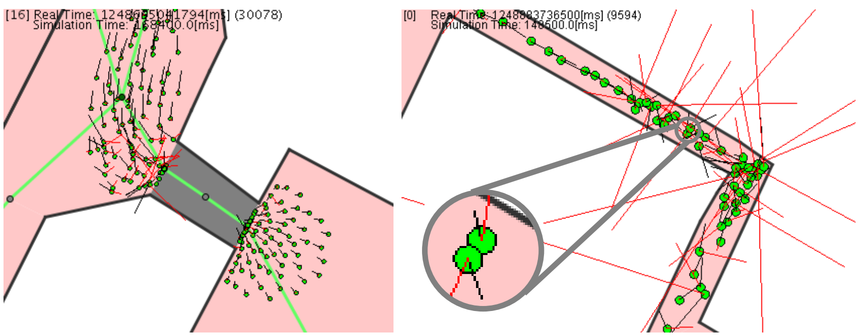


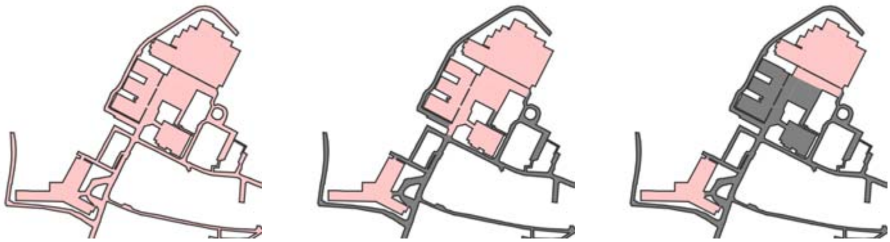
Fig. 4. Snapshots of simulations (light gray (pink) area: using free space model, gray area: using network model, white (green) line: road network used network model) left: agent movements from a free space to the other space via a road present in a network model. right: collisions of agents at narrow space.

4 Evacuation Simulations

4.1 Rescue Scenarios and Experiment Environments

Rescue scenarios: Followings are experiment rescue scenarios described in section 2.1.

- A large number ($n = \{100, 300, 600, 900\}$) of students move from a right up building to a left bottom building in Figure 5.
- A number (30) of rescue teams move in the opposite direction, from the left bottom building to the right up building.



(a) all free space (b) network & free space (c) all network

Fig. 5. Experiment maps of three models (light gray (pink) area: simulation is done by free space model. gray area: network model is used in the simulation.)

The times of agents of student group and rescue team group to move are measured in simulation time and wallclock time.

Experiment environments: The simulations are executed at three models of maps (Figure 5).

(a) All objects in a map are represented by free space models.
(b) Some objects are represented by free space mode, others are by a network model.
(c) All except buildings are represented by a network model.

4.2 Experimental Results

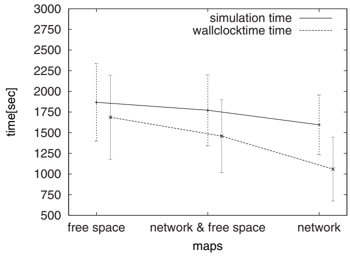
One PC (CPU: Core2Duo, 3.0GHz, RAM: 3.2GB) is used for simulations. Figure 6 shows simulation results.

(a), (b) show times simulation taken that all agents come to the destinations, respectively in simulation time and wall clock time. The times become less as the portions that are represented in the network model are increased. It is interesting that rescue team takes more time than students in the case of free space than in the case of network model.

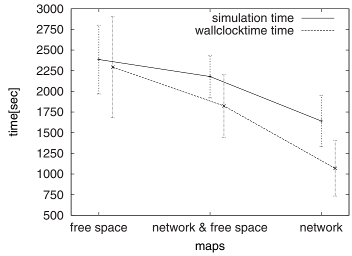
It makes sense to take longer time to get through against large oppositely-directed flow of a pedestrian than usual. This feature can be found in free space model and hybrid model. It shows that hybrid model can simulate fine resolution as free space model one.

(c), (d) show the average times needed for student agents and rescue team agents to move, respectively. When the number of students agents the simulation time to move increased. The increases show the collisions among agents causes traffic jams.

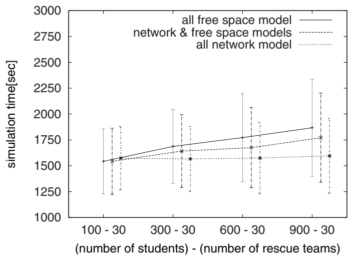
(e), (f) show histograms of arrival times for 300 and 900 students, respectively. The arrival times among three models correlate each other. The peak times between the 300 student case and 900 student case are almost the same. The late ones of 900 student case take more time than the 300 student case.



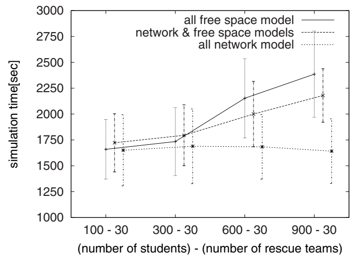
A) Simulation and wallclock times for 900 students.



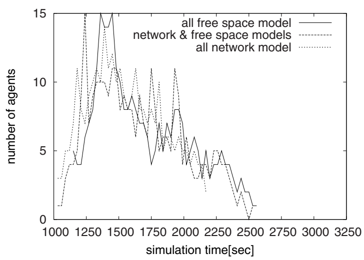
B) Simulation and wallclock times for 30 rescue teams.



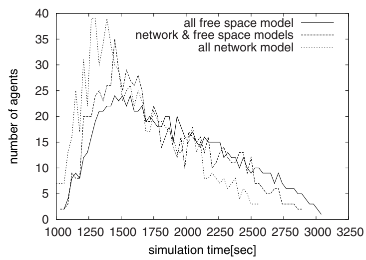
C) the average of arrival time of students.



D) the average of arrival time of rescue teams.



E) histogram of arrival times for 300 students.



F) histogram of arrival times for 900 students.

Fig. 6. Results of experiments

These show that (1) our hybrid evacuation simulation model presents similar results of free space model ones, , and (2) crowd situations are presented in space model. And these show possibility that setting parameters of them will give reasonable results with less computational resources.

5 Discussion and Summary

The simulation of a large number of people's evacuation behaviors is assumed to support the decision of rescue operations or prompt planning for disaster mitigation. Agent based simulations (ABS) have been providing a paradigm to simulate situations that are difficult to model. Simulations of many agents at wide areas with fine resolutions require a lot of computational resources and computer powers.

We propose an idea of a traffic simulator combining network and free space models. The traffic simulator simulates the movement of a large number of agents at wide areas with high resolutions by reasonable computational resources. The experiments show that our method can simulate behaviors of a huge number of agents, the behavior causes crowded situations, and similar outputs are simulated for different models.

This indicates that our system can simulate behaviors a huge number of agents at wide areas with high resolutions by reasonable computational resources.

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