Density Avoidance in Pedestrian Crowds

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ABSTRACT
Traffic jam caused by self-propelled particles is a research topic of broad interest. Cellular automata models are used for the simulation and analysis. One of the popular models is the floor field model. We add the rule of avoiding high density among particles to the model and show that it enables simulating a more realistic situation.

Keywords
Jamology, Floor field model, Human behavior, Cellular automata

1. INTRODUCTION
There is an academic study called Jamology. It is to reproduce and resolve congestion in general. Several models including self-propelled particles (SPP) and a variant of cellular automata are used to model cars and humans. In this study, a floor field (FF) model [1][2], which is a type of cellular automata (CA), is adopted for simulating jams and mass evacuation. One of the merits of the FF model is that it can be easily extended, so many variants of the FF model have been introduced.

In this study, we model pedestrians with a FF model. We add a property of avoiding high density. Assume that there are two paths from the current position to the destination. On one route, the distance is shorter but is crowded with many people. On the other route, the distance is longer but not crowded. In this case, we often choose the longer, not crowded route, even if we know that the shorter but crowded route let us get to the destination earlier. In this study, we call this characteristic as high-density avoidance (HDA) behavior. We examine the result of simulations with a FF model with HDA.

2. THE FLOOR FIELD MODEL
One of the most representative models for pedestrians and mass evacuation is a CA model called the floor field (FF) model. CA are discrete computational models consisting of a lattice-shaped space with a state update rule globally applied. In a CA model, time, space and state are all discrete. State of each cell at time $t+1$ is defined by the state of the cell and its neighboring cells at time t. The discrete unit of space is called cell. In a FF model, each cell can have a state called floor field. Floor field can be static (SFF) like a fixed quantity or dynamic (DFF), variant state.

2.1 Static Floor Field Model
SFF model is designed to have a static state quantity (SFF) in each cell. SFF of a cell is the shortest distance to the destination from the cell and it can be computed using Dijkstra's algorithm. To model evacuation of an agent, the agent is designed to move to a neighboring cell with a smaller SFF.

2.2 Dynamic Floor Field Model
DFF model is designed to have a DFF in each cell.

DFF is typically footprints. As the agents move around in the floor, they leave volatile footprints on each visited cell. So, DFF is similar to pheromone in ant colony optimization. Because with only DFF, it is not easy to model evacuation, DFF is usually used in conjunction with SFF.

3. DENSITY-REFERENCE TYPE FLOOR FIELD MODEL
In this study, we designed a FF model named density-reference type FF model (DRT-FF), in which agents have HDA. In order to implement the HDA, the agents are defined to move around as follows.

- If there are few other agents on the shortest route to the destination, an agent tries to go along the route.
- If there are many other agents on the shortest route, an agent tries to avoid it.

In the model each cell has SFF. An agent calculates the density of the number of agents around for each cell. Finally, the agent moves to a neighboring cell, according to the rules above. Figure 1 and 2 illustrate the difference between an ordinary SFF model and our model.

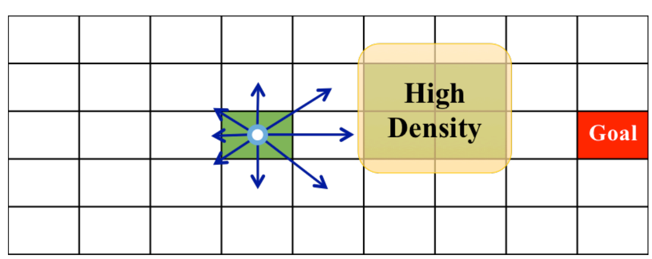

Figure 1: SFF model

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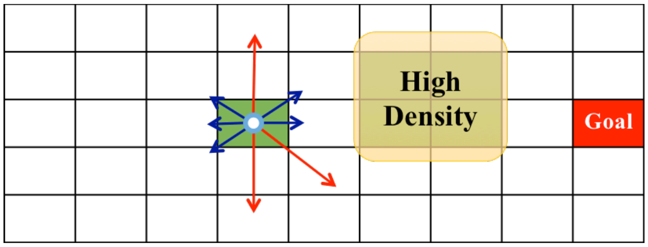

Figure 2: DRT-FF model

4. SIMULATION 1

We simulated an oncoming traffic of pedestrians with SFF and HDA models. The map is shown in Fig. 2. Blue cells represent impassable areas and white cells represent passable areas. Pedestrians of one kind (orange) appear at Start 1 on top and try to go to Goal 1 on bottom. Pedestrians of the other kind (green) appear at Start 2 on bottom and try to go to Goal 2 on top. There are two routes, Route 1 and Route 2. Route 1 is shorter but tend to be crowded. Route 2 is longer but it can be less crowded. We executed two simulations on this map.

4.1 Simulation 1.1

4.1.1 Setting

In Simulation 1.1, we tested how agents in the SFF and DRT-FF models move. To show how many agents passed each cell in the map, the more passers a cell has had, the redder the color is, as in Figure 4. The parameters are set as follows. The total number of agents is $N = 1000$. The entry parameter e, which is the spawning probability of agents for each start cell is 0.5. For DRT-FF, the radius of the neighborhoods for which the density is calculated is 2. DFF and SFF are given equal weights.

4.1.2 Result

The result of the SFF and HDA models are in Fig. 5 and Fig. 6, respectively. In SFF, most of footprints are in Route 1, and Route 2 was little used. The flow of the agents tended to stop with this entry parameter, even when Route 2 is vacant. In contrast, in HDA, a footprint of Route 2 is almost as much as Route 1. In addition, the flow of the agent did not get congested very much, even though the entry parameter was high.

4.1.3 Discussion

In SFF, most of agents did not take advantage of Route 2 and go along Route 1. In spite of a lot of cells the agents could pass, there was a jam on Route 1. In contrast, in DRT-FF, we see that many of the agents took Route 2. The diagonal lines form a V-shaped path. We find many agents took the path, first from a start to the vertex in the right, and then from the vertex to a goal. We see that HDA is well represented by DRT-FF, and the result was more realistic than the plain SFF model.

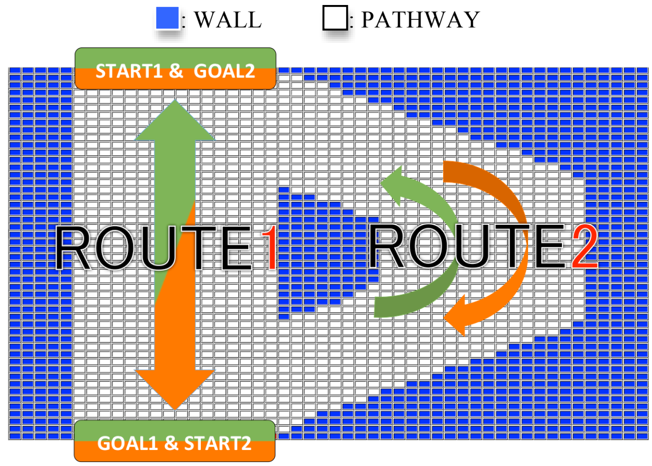

Figure 3: The map for Simulation 1

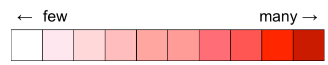

Figure 4: The spectrum of the number of footprints

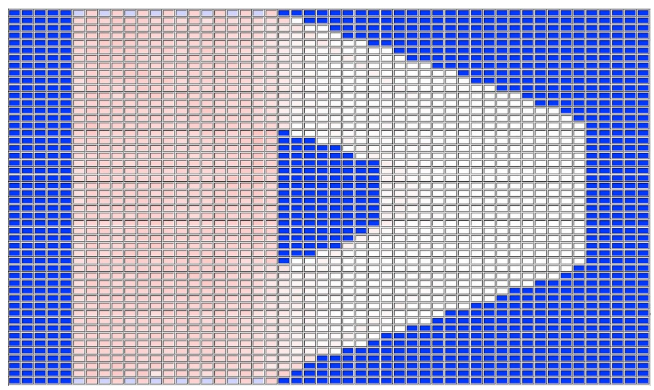

Figure 5: The footprint map of SFF model in Simulation 1.1

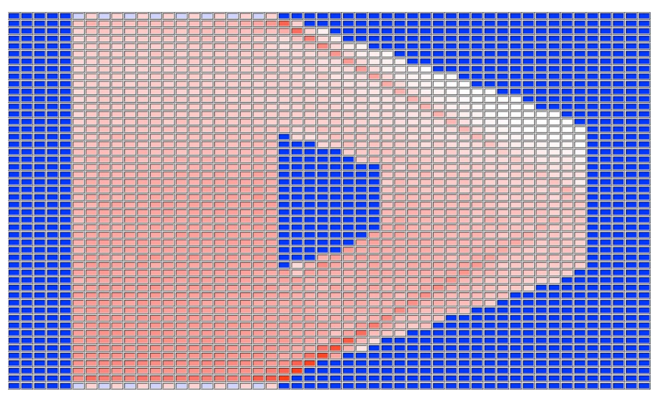

Figure 6: The footprint map of DRT-FF model in Simulation 1.1

4.2 Simulation 1.2

4.2.1 Setting

In Simulation 1.2, we examined how many turns it takes for all the agents to reach the goal. We also measured the number of times the agents' flow stopped. The settings of this simulation are the same as in Simulation 1.1 except that the entry parameter is varied to $e \in \{0.01, 0.02, \ldots, 1\}$. The simulations are stopped at 7,000 turns.

4.2.2 RESULTS

The turns when the agents finished reaching their goals, as a function of entry parameter, is shown in Fig. 7. Figure 8 shows the magnitude of the jams in the simulations, the number of agents that stopped while migrating.

4.2.3 DISCUSSION

We can see that for small values of entry parameter e, SFF very quickly finishes the migration. However, when e is bigger than some threshold around 0.25, the agents in the model consume very many turns to finish the migration. In contrast, in DRT-FF, the migration takes quite constant turns to finish, irrelevant to e.

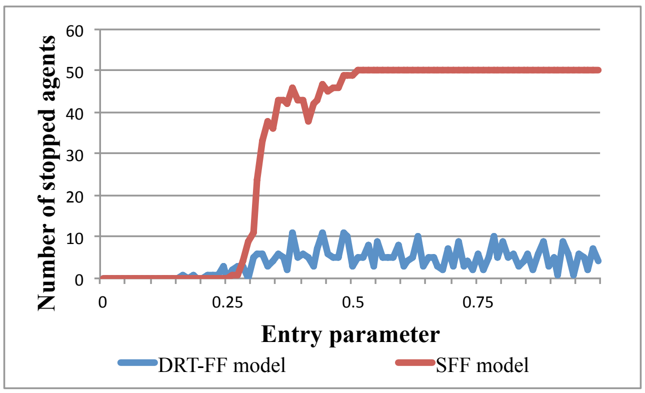

Figure 7: The turn of migration finished in Simulation 1.2

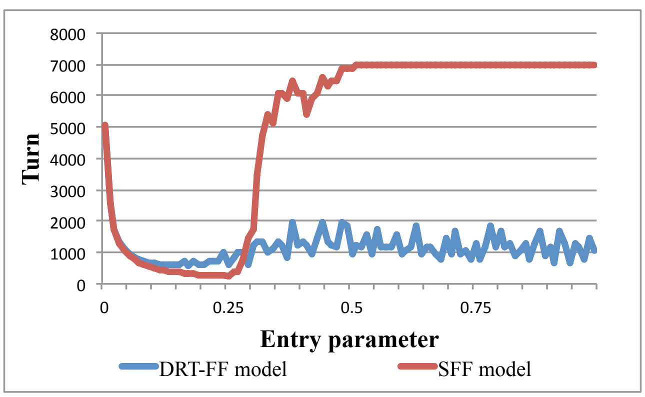

Figure 8: The number of stopped agents

5. SIMULATION 2

In this simulation, we try to reproduce a real accident happened on July 21, 2001. The 100×100 map is shown in Fig. 9, representing the pedestrian bridge near JR Asagiri station in Akashi, Hyogo, Japan. There are two types of agents. Agents of one type appear at the top part of the map and migrate to the lower left part. Agents of the other type follow the opposite direction. We observe the density of agents when the flow gets stuck. It is said that when the tragedies happened, the density was 13 people per one square meter.

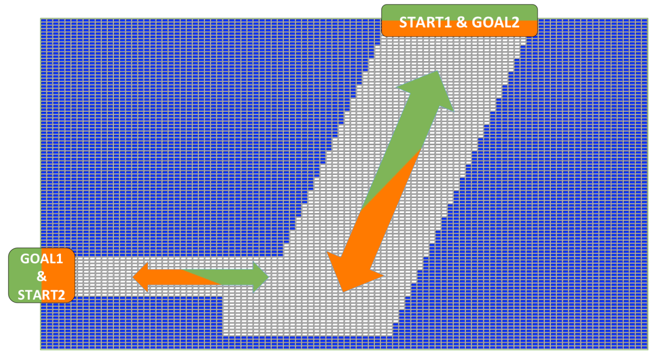

Figure 9: Map of Simulation2

5.1 Setting

The map is prepared so that each cell represents an area of 25cm×25cm, We define the index, the highest density in a simulation, MAX_DENSITY as follows:

$$\text{MAX\_DENSITY} = \frac{\text{no. of all agents in the map}}{\text{no. of all passable cells}} * 16.$$

The number of agent is $N = 1800$, entry parameter e is varied from 0.01 to 0.15. The other settings are the same as in Simulation 1.

5.2 Results

In SFF, the agents of two types stop around the corner in the map. Then the following agents start to concentrate and stuck in a narrow line of stick-like shape. The agents stop moving with relatively lower entry parameter e. In contrast, in DRT-FF, the area around the corner gets crowded more and more, but because the agents avoid high density, they spread out to the broader, actually whole areas in the map. Figure 10 shows MAX_DENSITY as a function of entry parameter e. In SFF, the agents' movement stopped first time when e is bigger than 0.04. MAX_DENSITY at $e = 0.04$ was 9.98, while when $e = 0.03$ and the agents did not get stagnated, MAX_DENSITY was 5.59. In DRT-FF, MAX_DENSITY at $e = 0.13$, the threshold of agents stopping, was 12.79. For $e = 0.12$, it was 12.23.

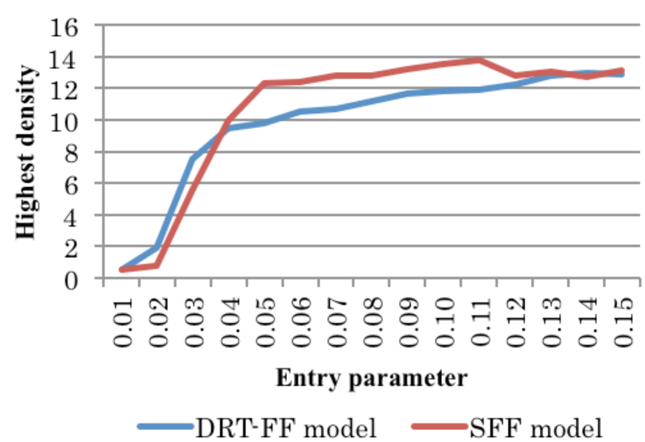

Figure 10: Result of Simulation 2

5.3 Discussion

We could think the real accident happened at a point in the process of the number of entering people gradually increasing. So, the highest density at the lowest entry parameter with which the flow stops is the quantity to be compared with the density at the accident. It was 9.98 in SFF and 12.79 in DRT-FF.

6. CONCLUSION

In order to represent high density avoidance, we designed the DRT-FF model. Adding high density avoidance enabled simulations more realistic than an ordinary model in that the agents showed use of a detour when the main, shorter route is crowded. We could reproduce a situation of a real accident with a density value close to the actual one.

8. REFERENCES

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7. ACKNOWLEDGMENTS

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