Team-06: Checkpoint 1

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GitHub Repo: https://github.gatech.edu/zhao48/CSE6730-Project

Abstract

In the face of unpredictable situations such as fires, disasters, and toxic gas leaks, emergency evacuation in public areas has received attention from society. This study represents a mathematical model based on pedestrians' movement factors for emergency evacuation. In this study, we employ the model of pedestrian evacuation built on the social force model with modified settings on driving forces and interaction forces between human beings and between individuals and obstacles. The goal of the study is to find the optimal routes to reduce evacuation time. We plan to demonstrate the effectiveness of the model through agent-based simulation by changing the forces between agents and the simulation of evacuation process under real-world evacuation network settings.

1 Description of the system being studied

There are two main models for crowd evacuation research: macroscopic and microscopic. Macroscopic models consider the crowd as a single entity and focus on its overall attributes. The behavior of individual members does not affect the movement of the crowd. These models are mostly based on fluid dynamics and include the hydrodynamic model [GCK+09], potential field model [PVDBC+10], continuum model [GVDBL+12], and N-S equation model [HG08]. Microscopic models, on the other hand, focus on the behavior and features of individual members and how they interact with each other and obstacles. These models include the Cellular Automata model [CL16], Boids model [Rey87], Force-based model [HFV00], Velocity-based model [AA14], Vicsek model [VCBJ+95], and Agent-based model [HXDD10]. The interaction behavior between individuals is a key area of research in microscopic models.

In our project, we will use the social force model [HM95]. In this model, when an organism receives a stimulus through its senses, it responds by selecting a behavior that aligns with its personal goals and preferences, based on a range of possible behaviors. The ultimate goal of this behavior selection is to maximize utility or benefits to the organism. Due to pedestrians' familiarity with their typical situations, their responses are often instinctive and based on their past experiences of which reaction will be the most effective. As a result, it is feasible to formulate the regulations of pedestrian conduct in the form of a motion equation. The equation describes how the preferred velocity $\vec{\omega_\alpha}(t)$ of a pedestrian α changes over time, and this change is determined by a vectorial quantity called the social force, denoted by $\vec{F_\alpha}(t)$. This social force accounts for the effects of social interactions and external factors on the pedestrian's movement. In summary, a pedestrian behaves in a way that appears to be influenced by external forces acting upon them.

2 Literature review

In the field of emergency preparedness, the study of how people can quickly and securely leave a structure or an area during an emergency is known as evacuation modeling. Evacuation modeling uses mathematical models to analyze and optimize the evacuation process during emergencies. There are various types of models have been developed, including agent-based models [CLQ96], Cellular Automata (CA) models [PM08], and fluid dynamic models [BG12].

The agent-based strategy, which treats each person as an agent and simulates their behavior during evacuation, is a well-liked technique. Roan and Haklay carried out one of the initial studies [RHE11] that employed the agent-based approach for evacuation simulation, suggesting a model that represented how a building would be evacuated in the event of a fire. The model took into account elements, including the structure's architecture, inhabitant behavior, and the existence of impediments. The agent-based technique is an effective way of simulating evacuation that takes into account the actions of individual agents. This research shows how the agent-based technique may be used to simulate the evacuation process and assess the efficacy of various evacuation tactics. To increase the agent-based models' precision in foretelling occupant behavior in an emergency, more study in this area is required.

Another widely-used model, Cellular Automata (CA), can be applied to simulate how people move across a physical location over time to depict evacuations. A grid of cells is used to represent the actual space in this context, and each cell might be in one of the multiple states (e.g., occupied by an individual, empty, obstructed by an obstacle, etc.). One example is the work of Bandini [BCGV14] in 2014, who created a CA-based model for pedestrian dynamics, which serves as one illustration.

They created rules that controlled how people moved based on their environment and utilized a two-dimensional grid to simulate a pedestrian area. A variety of pedestrian behaviors, such as congestion, lane creation, and evacuation, may be accurately simulated by the model.

The movement of people may be modeled as a fluid flow in an evacuation scenario, with people acting as particles in the flow. The model examines parameters such as the density of people in various regions, the pace of movement, the accessible departure routes, and the features of the building or surroundings. Therefore, fluid dynamic models could provide an analysis of the efficiency of various evacuation plans and point up any possible dangers or bottlenecks. These models have been used to study various aspects of evacuation, such as exit capacity, congestion, and the impact of social norms and communication.

3 The conceptional model of based pedestrian evacuation

Our model is a social force-based pedestrian model. In detail, The individuals in the positions follow the rule through the social force model in moving to the location provided by the navigation agent. The entire process is repeated until the exit is reached. We have considered many factors in this experiment and designed a working frame as follows. Individuals move according to the obtained personal and global best positions. Historical knowledge is the path record and running time after each evacuation and is adopted in the update operator to update the historical knowledge. The goal of dynamic path planning is to help evacuees find optimal routes to reach safe exits. Therefore, the path selection criteria aim to ensure that evacuees avoid passing through congested zones/barriers and minimize the evacuation time.

3.1 Our modified social forces settings

The social forces model was firstly established by Helbing [HM95]. the social force model (SFM) based on Newtonian mechanics from characteristics of collective behaviors. The social force refers to the force that one individual obtains from the environment (including humans and objects), whereas the physical force is the force that is directly applied to the individual. Based on the different motivations of pedestrians and impacts from the environment, SFM has four forces: (1) the driving force, (2) the interaction force between human beings, (3) the interaction force between individuals and obstacles, and (4) the disturbing force.

Our modified model considered first three forces. The resultant force of the three forces impacts pedestrians and contributes to the acceleration. The internal driving force guides the individual to move toward the target. However, before body contact, the exclusive force becomes involved in preventing individuals from colliding with one another. Specifically, to prevent individuals from colliding with obstacles we considered the smart strategy: if the agent meet the lines, the driving force will change to the best verticle of obstacles then recover to initial settings (referring Section 3.2 for details). We define the resultant force of three forces as following:

$$m_i \frac{\overrightarrow{dv_i(t)}}{dt} = \overrightarrow{f_i^0} + \sum_{j \neq i} \overrightarrow{f_{ij}} + \sum_{w} \overrightarrow{f_{iw}} \tag{1}$$

where m_i is the mass of pedestrian i, and $v_i \rightarrow (t)$ is the actual walking velocity. Eq.(1) shows that the motion of pedestrian i is affected by four types of forces, which include the pedestrian's driving force $\overrightarrow{f_i^0}$, the interaction force between pedestrian i and the other pedestrians $\sum_{j(\neq i)} \overrightarrow{f_{ij}}$, the interaction force between pedestrian i and obstacles $\sum_w \overrightarrow{f_{iw}}$ when meeting the obstacle the driving force become 0 and modified interaction between pedestrian and obstacles appears. The position of pedestrian i changes under the interactions of the four forces. The pedestrian's driving force $\overrightarrow{f_i^0}$ is defined as

$$\overrightarrow{f_i^0} = m_i \frac{v_i^0(t) e_i^0(t) - \overrightarrow{v_i}(t)}{\tau_i} \tag{2}$$

where m_i is the mass, and $v_i \rightarrow$ is the actual velocity of pedestrian i. Moreover, the velocities were controlled by the velocities and the acceleration equations can be expressed as follows: $\overrightarrow{a_{il}^0} = \frac{v_{il}^0(t)\overrightarrow{e_{il}^0} - \overrightarrow{v_i}(t)}{\tau_i}$ and $\overrightarrow{v_i}(t) = \frac{\overrightarrow{dr_i}}{dt}$.

3.2 The shortest path of our model

The problem of Multi-Agent Path Finding (MAPF) is an instance of multi-agent planning and consists in the computation of collision-free paths for a group of agents from their location to an assigned target [SSF+19]. The elements of a classical MAPF problem are the following:

- a set $A = \{1, 2, \ldots, k\}$ of k agents;
- an undirected graph $G = (V, E)$, where V is the node set, and E is the edge set. The nodes represent the possible locations of the agents, while the arcs are the possible connections between such positions;
- a map $s : A \to V$ that associates each agent with its starting point;
- a map $t : A \to V$ that associates each agent with its target point.

For our model, all agents should move in every second, which allows the agent to move to an adjacent node. An action is formalized as a function $a : V \to V$, meaning that $a(v) = v'$ represents the action of moving from v to v' if v' is adjacent to v which is different than v'.

4 Platform(s) of development

Our simulation models were developed with Python 3.11, and the simulation visualization was created with `pygame` library.

5 Current state of the project

5.1 Progress

Since the last submission, "literature review", we chose one of the topics, evacuation, and have been proceeding with our research, modeling, and simulation.

Besides this report, we have programmed a general framework for agent-based simulation and added the basic force and interaction between agents. For more details, please refer to the GitHub repository.

Figure 1 are some screenshots of a run of a simple simulation.

5.2 Division of labor

- Zihong Hao: Code and visualization.
- Qilin Li: Experiment and analysis.
- Chen Lin: Model, simulation settings, report.
- Hanzhang Liu: Experiment and analysis.
- Mian Wu: Code, model and simulation settings.

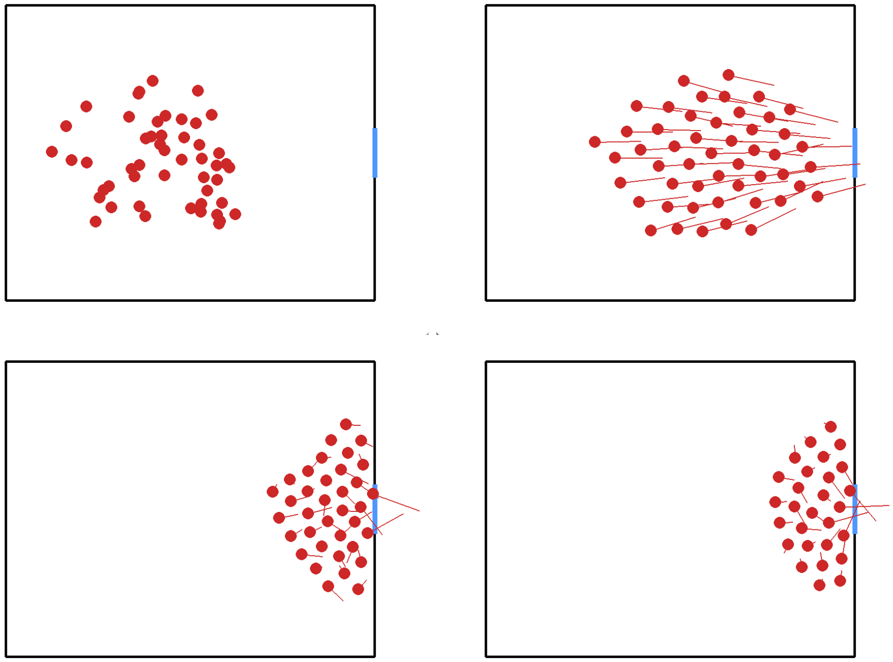

Figure 1: Simulation Program in Progress

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