Cellular Automata Based Modeling of Competitive Evacuation

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Abstract. In the paper we present a model using Cellular Automata dedicated for competitive evacuation. Floor field models of pedestrian dynamics are the starting point. We have observed that during competitive evacuation, the dynamics of particular pedestrians is similar to the dynamics of particles in granular flow when viscosity is taken into account. In order to address this issue we have prepared real experiments and have proposed and implemented a Cellular Automata model using an idea of viscosity.

Keywords: CA-based models · Pedestrian dynamics
Competitive evacuation · Crowd dynamics · Evacuation · Viscosity

1 Introduction

The rules of behavior of people in different situations are of interest to architects, engineers and security managers. Competitive evacuation is one of the greatest challenges, in particular when it occurs in a situation of high density of pedestrians [7]. Generally, simulation of such situations is not a trivial task, especially if we take into account a discrete framework. However, discrete models are generally much more efficient and useful for simulations of large scenarios. It should be stressed that in classical CA-based models like [2,10] different physical analogies, namely: floor fields, bosons, transition functions, etc. are applied. There are no direct calculations of superposition of forces for particular pedestrians like in molecular dynamics models of granular flow [6,9], however, one can point out hybrid algorithms [3,15] when some forces influence the movement of pedestrians in terms of CA lattices.

The main concept in many CA based models is the static floor field [2,5,16], which points out attractors – pedestrians' aims [13], and dynamic floor field which provide mechanisms analogous to chemo-taxis. Sample mechanisms regulating pedestrians' speeds in CA models, are discussed in [1,8].

In this paper our starting point is a classical CA-based model of floor field and we propose additional rules which mimic movement in high densities when pedestrians become competitive. Idea of friction in pedestrian dynamics was proposed in [11,12]. We propose extension of this idea taking into account analysis

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of viscosity in high densities. In our approach friction is dependent on the pressure force (precisely - crowd pressure) and we take into consideration pressure from different directions. In order to address this issue we performed some real experiments which illustrate viscosity in high densities.

2 Motivation and Observations

When a group of people relocates in the conditions of high density, apart from social forces, additional direct physical forces caused by mutual pressure appear. These forces result in jams in narrow passages, that is the speed of movement of particular persons decreases. In case of pressure, people from the back pass the narrow passage much more slowly than in a situation when there is no crowd. While describing human traffic, most discrete models based on Cellular Automata do not take into account physical effects between people in high density, which happen e.g. during competitive evacuations. It might considerably influence the accuracy of simulation results, e.g. while setting the time required for the evacuation of a building.

In one of Cracow's universities we have carried out a set of experiments with competitive (Fig. 1) and non-competitive evacuation (Fig. 2).

Fig. 1. Experiments with competitive evacuation. Blockages are visible.

A group of 68 students took part in the experiments and their task was to pass the door following two scenarios. We have divided experiments for two parts: during the first one they had to obtain the best individual time and during the second one they had to obtain the best time for the whole group [14]). The door width was 1 m.

During competitive evacuation we observed high local densities and congestions. We also observed stopping of particular participants (Fig. 1).

During non-competitive evacuation we observed no rivalry between pedestrians and lower densities of pedestrians. Due to much less pressure between

Fig. 2. Experiments with non-competitive evacuation.

students in this situation blockades in the narrow passage were not observed (Fig. 2).

One can distinguish different flow characteristics during the experiments. In Fig. 3 we present pedestrians' flow through the door per second.

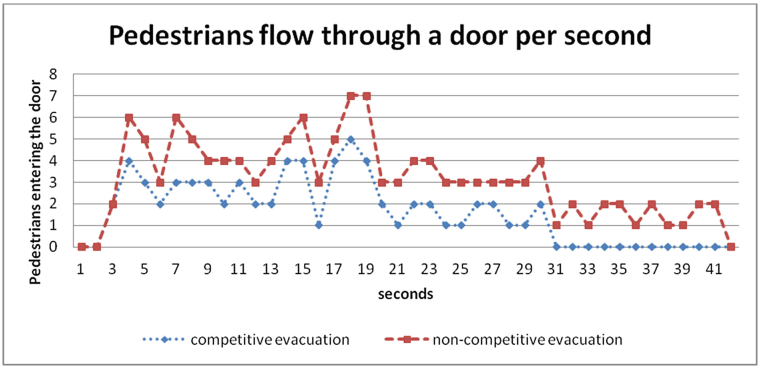

Fig. 3. Flow per second in various experiment scenarios per 1 m of door width. As we can see competitive evacuation has lower maximum flow, but it takes shorter for entire group.

Analogously, we present density of participants (students) in the analyzed scene (Fig. 4).

3 Proposed Model

3.1 Basic Issues

In order to map the dependence between the speed of moving through narrow passages and the crowd's pressure, the movement of a group of people will be

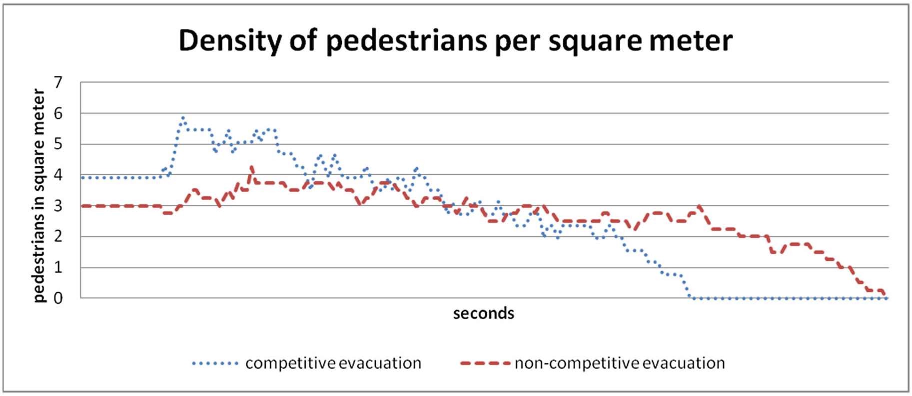

Fig. 4. Density of pedestrians per 1 square meter during competitive evacuation.

compared to fluid flow. In describing fluid flow with the use of equations of motion, viscosity is an important factor. Adopting the approach from classic physics textbooks (e.g. [4]), the impact of viscosity on the fluid motion can be illustrated with the following experiment (see Fig. 5). Let us assume that we have two flat plates and liquid (e.g. water) between them. The bottom plate is fixed, and the top plate is moving horizontally with speed v_0, as a result of applied force F. The force which needs to be applied in order to keep speed v_0 is proportional to the area of the plates (A) and to the proportion v_0/d, where d is the distance between the plates. So, shear stress (F/A) is proportional to v_0/d:

$$\frac{F}{A} = \mu \frac{v_0}{d} \tag{1}$$

Viscosity is the proportionality factor μ in this formula. If force F, area A and the distance d between the plates are the same, when viscosity increases, the speed with which the top plate moves decreases. Analogously, if we treat a group of people as fluid, the decrease in the speed of motion which happens in narrow passages for high densities (in case of the crowd pressure) can be explained as the increase of liquid viscosity. So, for high densities the crowds behave as non-Newtonian fluid, for which - when the pressure grows (caused by the increase of the forces operating between persons) - viscosity grows (shear thickening fluid).

3.2 The Details of the Model

The model presented in this paper is an extended version of standard models of Cellular Automata, which are based on static and dynamic fields. The extension is achieved by introducing additional interactions between persons representing physical forces occurring in situation with high density of crowds (e.g. in case of competitive evacuation). These interactions can increase the pressure affecting particular persons and, by doing this, increase viscosity in a given area. A classic

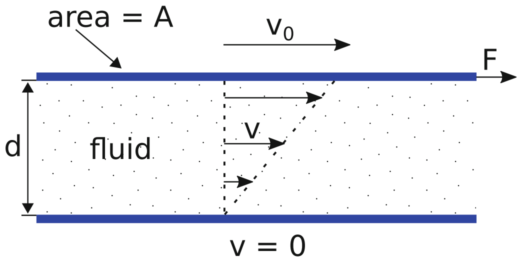

Fig. 5. Velocity of fluid layers between two plates. Based on [4].

CA model [2] has been applied in the study as the base model. Following this model, physical interactions have been introduced as additional bosons transferred between cells occupied by individuals - we call them 'p-bosons' (physical forces bosons). These bosons propagate between consecutive time steps of the simulation (we assume that the speed of propagation of interactions is much higher that the speed with which these individuals move). Individuals whose preferred direction of movement is directed at the cell occupied by another individual (one person presses another) are the source of p-bosons creation. A p-boson also carries information about the direction of this interaction (it is the same as the direction of pressure exerted by one person on another) - it can assume one of 8 values (consistent with the Moore neighborhood). Bosons are propagated along the direction of the impact till the moment when cells are occupied by other individuals; at the moment when an empty cell appears, a boson cascade is no longer propagated. It corresponds to a situation occurring in real life: physical interactions between persons are propagated only for a crowd with high density; when density is low, the interaction is no longer propagated. When p-bosons reach a person who faces an obstacle (a wall or people pressing him from this direction) on his other side (looking from the direction of a given boson), they increase viscosity in the cell occupied by this person. In case of a wall, i.e. a fixed obstacle, all p-bosons coming from the opposite direction increase viscosity - let us call them compensated bosons. When bosons reach a person pressed by other people from the opposite direction (bosons have an opposite direction), the number of compensated bosons is the smaller value of the number of bosons coming from two opposite directions.

3.3 The Impact of Viscosity on People's Movement

As it was shown above, the consequence of the increase of viscosity is the decrease of the maximum speed $v0$ with which a layer of liquid moves. Analogously, when people move, the increase of viscosity should lead to the decrease of the speed with which they move. Because in the base model [2] the speed of moving is constant and equals 40 cm (the length of the side of the cell) divided by 1 time step (that is 1/3 of a second), the introduction of slowing down must be expressed as the lack of movement (remaining in the same cell) in a given time step. In the proposed model it was assumed that the probability of a blockade (lack of movement of a given person) is proportional to viscosity in a given cell:

$$P_{blockade} \sim \mu \tag{2}$$

where:

- $P_{blockade}$ is probability of a blockade in a given cell
- μ is viscosity in a given cell

The proportionality factor can be introduced to the equation above:

$$P_{blockade} = c \cdot \mu \tag{3}$$

where:

- c is proportionality factor

The higher physical pressure is exerted on a person by other people (the number of compensated p-bosons), the more slowed down the person will be, and the greater viscosity will appear in the cell occupied by this person. The c factor's value can be estimated empirically by comparing with data from real life experiments.

4 Implementation and Results

We have implemented the above mentioned floor field model using $C++$ programming language. Our starting point was a classical floor field model [2].

In order to compare the results of the simulation with experimental data, we prepared a simulation with analogous geometry and allocation of pedestrians. The initial allocation of pedestrians visualised as 3D figures is visible in Fig. 6:

Fig. 6. Initial allocation of participants (before opening the door).

Next we compared two versions of the application. Firstly, we implemented a traditional floor field model without the viscosity mechanism. A sample screenshot from the simulation is visible in Fig. 7.

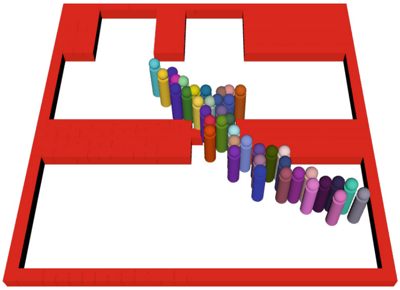

Fig. 7. Simulation of the competitive scenario without viscosity after 4.7 s since the simulation started.

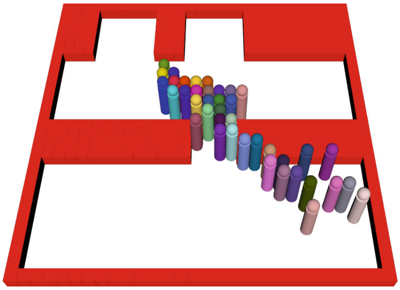

Fig. 8. Simulation of the competitive scenario with viscosity after 4.7 s since the simulation started.

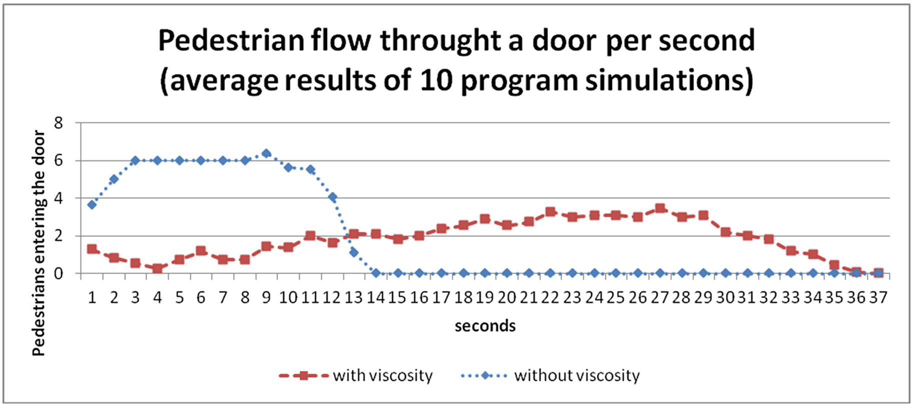

Fig. 9. Flow per second in our program with and without considering viscosity (flow through 1 m of door width).

Next we implemented a floor field model with the viscosity mechanisms. As we can see, it reflects a situation of local congestions caused by a competitive behavior of pedestrians.

As can be seen in Fig. 9, the total time of evacuation in case of a traditional floor field model without the viscosity mechanism is over two times shorter then when this mechanism is present. Such fast movement of people is possible when density is low, that is there are no narrow passages or other obstacles which slow the crowd down and make people exert physical pressure on one another. In case of high density such fast movement is impossible due to a frequent occurrence of blockades. The proposed viscosity mechanism can improve the model in such situations - as can bee seen in Figs. 9 and 3 the total time of evacuation (that is a time step during which flow through the door continues) estimated by the model with the viscosity mechanism and time obtained in real life experiments are similar (Fig. 8).

5 Conclusions

We have performed a set of simulations as well as experiments regarding non-competitive and competitive evacuation. We have noticed that the great pressure between participants particularly influences flow in the bottleneck. The pressure is more clearly visible in blockages between participants in the door. Thus, competitive behavior of pedestrians, when the exit is narrow (1 m) makes the evacuation process inefficient - we observe the faster-is-slower effect.

In the simulation part of our study we have proposed applying the concept of viscosity, which is responsible for the transition function in high densities, to competitive behavior of pedestrians. We compared classical floor field models with a model including the viscosity mechanism. We have confirmed that such a mechanism can reflect the faster-is-slower effect [17] during competitive evacuation.

We believe that the application of idea of viscosity for pedestrian flow is a convenient mechanism of presenting different levels of competitive evacuation or even panic. Discrete modes like CA are efficient, thus such an implementations can be profitable.

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