Social Distances Model of Pedestrian Dynamics

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Abstract. The knowledge of phenomena connected with pedestrian dynamics is desired in the process of developing public facilities. Nowadays, there is a necessity of creating various models which take into consideration the microscopic scale of simulation. The presented model describes pedestrian dynamics in a certain limited area in the framework of inhomogeneous, asynchronous Cellular Automata. The pedestrians are represented by ellipses on a square lattice, which implies the necessity of taking into account some geometrical constraints for each cell. An innovative idea of social distances is introduced into the model — dynamics in the model is influenced by the rules of proxemics. As an example, the authors present a simulation of pedestrian behavior in a tram.

1 Introduction

The modeling of pedestrian behavior has been very popular over the last years. Scientists and engineers have become interested in methods, which give more and more realistic results of simulation. As a result of wide research, Cellular Automata have become one of the most useful approaches to pedestrian dynamics. Let us mention some interesting recent works.

In the model by Burstedde et al. [2], a concept of static and dynamic floor fields is proposed. Dynamic floor field makes it possible to track and indicate the most attractive cells on the basis of selected criteria. Thus, simulated pedestrians can follow each other in the evacuation process.

Dijkstra et al. [3] present a model, which combines Cellular Automata and Multi-Agent Systems. Agents in the model have the possibility of perceiving their local neighborhood and affecting their environment. It makes it possible to simulate pedestrian traffic in streets or commercial centers.

A model of tourist activity in the Alps is presented in the work by Gloor et al. [6]. Tourists are understood as agents. Each agent makes certain decisions such as: excursion destination, route choice etc. In the model, an additional lattice of nodes (graphs) is added to the basic Cellular Automata lattice. The shortest way in the network is calculated for all Alpine paths simulated in the model.

Another problem is presented by Narimatsu et al. [11]. In their works, authors present an algorithm of collision avoidance for bi-directional pedestrian

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movement. Pedestrians walk along a corridor in two opposite directions and they learn some patterns to avoid collisions.

In this paper, the authors present a Cellular Automata model of pedestrian dynamics applying the sociological theory of *Social Distances* introduced by E. T. Hall [8,9]. As an example a passenger movement in a tram is discussed.

2 Social Distances Theory

The issues of the space requirements of people and optimal distances among them became a subject of research of sociologists and anthropologists long time ago. In 1959, Edward Hall popularized spatial research on human beings. In his book: "The Silent Language" [8], he introduced the term *proxemics*. He formulated the basic law of proxemics as follows: *We may not go everywhere as we please. There are cultural rules and biological boundaries.* Hall mentioned some interesting facts concerning *personal space* among people [8,9]. In proxemics, one can differentiate four sorts of distances:

Intimate distance ranges from body contact to approximately 40–50 cm. It can appear between couples, parents and children, friends etc. Intimate distance is different in various cultures. The infringement of intimate distance zone by another person causes discomfort and could be perceived as painful. Already 3 seconds of eye contact in closer distance is perceived as an intrusion or expression of pressurization [5].

Personal distance ranges approximately from 40–50 cm to 150 cm. Hall identifies a close and a far phase [9]. The close phase: 50 to 90 cm permits one person to touch the other, while the far phase of personal distance: 90 cm to 150 cm "an arm's length" does not permit this [1]. The close phase is typical, for instance, for people, who know each other very well. It is sometimes called "a shaking hand distance". The wider personal distance is the limit of the personal area of domination. This is the distance which people usually accept when they meet each other unexpectedly (i.e. in the street). Such distancing expresses the message that someone is prepared for an open and neutral conversation [5].

Social distance ranges approximately from 150 cm to 3 m. It is the casual interaction-distance between acquaintances and strangers. It is common for business meetings, classrooms and impersonal social affairs [1].

Public distance (above 300 cm) is observed between strangers and in audiences. This distance is also called a public speaking distance.

It is important to emphasize that these distances could vary according to *personality* and *environmental factors* since an abnormal situation could bring people closer than they usually are [8].

3 General Assumptions

The presented model is based on 2-dimensional Cellular Automata. In the model, space is represented as a lattice with square cells. The size of each cell

d_g equals 0.25 cm. A formalization for this type of inhomogeneous CA could be found in [4].

3.1 Pedestrian Representation

Each person in the model is represented by an ellipse, whose center concides with the center of the cell occupied by that person. The size of each ellipsis equals $a = 0.225$ cm (semimajor axis) and $b = 0.135$ cm (semiminor axis) which is assumed the average size of a person (WHO data). A pedestrian can transfer to another cell in Moore neighborhood of radius 1. A person occupying the cell can take one out of four allowed positions: H, R, V and L which correspond to the action of turning the ellipsis around by: ± 0, ± 45, ± 90 and ± 135 degrees respectively. Thus, in each time-step-slice, we determine a combination of allowed positions for each cell on the basis of the neighborhood configuration.

The crucial issue is to establish the set of forbidden and allowed positions for all cells in Moore neighborhood of radius 1, each cell being occupied by one person. The calculation of the allowed/forbiden positions is based upon simple geometrical dependencies. It takes into account: the orientations of two ellipses occupying two adjacent cells and the size of their crossection. It is assumed that the position is allowed, if the ratio of the calculated crossection (for this position) to the size of the ellipsis is smaller than imposed tolerance $\epsilon_N \in [0, 1]$. For a square lattice, with eight neighbor cells and four possible positions in each cell one has to investigate only 14 combinations (Fig. 1). The remaining combinations can be obtained on the basis of the mentioned ones due to the existing symmetries.

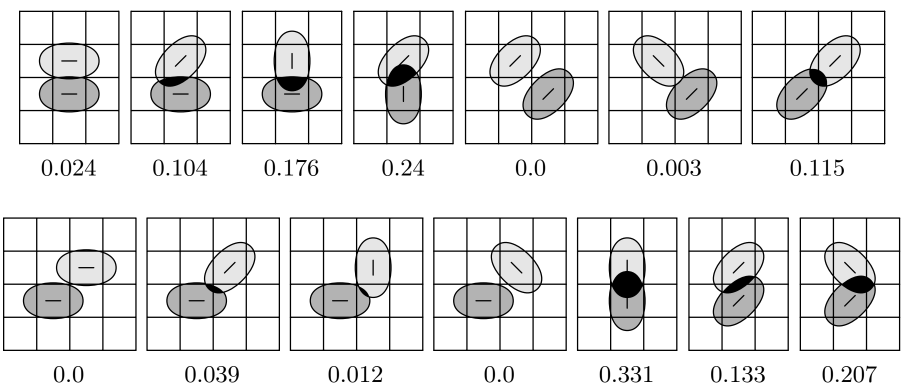

Fig. 1. Reciprocal orientations of two persons (represented by grey ellipses) and calculated ratios of crossections (black) and ellipse size for cell size $d_g = 0.25$ cm

As an example, Fig. 2 presents allowed states for neighbor-cells for different tolerance parameters.

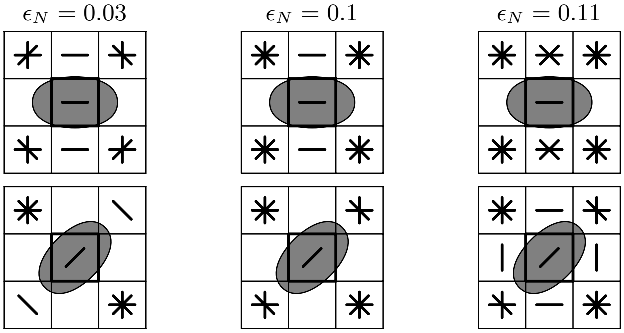

Fig. 2. Allowed neighborhood configurations for different tolerance parameters

3.2 Social Distances Representation

People in the model are represented by ellipses, thus social areas are represented similarly. However the eccentricities of both ellipses can differ. The authors suggest that social distances are asymmetric due to the fact that "social configuration" in front of the person has much more influence on them behavior than the configuration behind them. Therefore geometrical centers of both the ellipses are not identical: usually ellipse representing the social area is shifted forward along line of vision of the considered pedestrian by some distance t (see Fig. 3). Due to

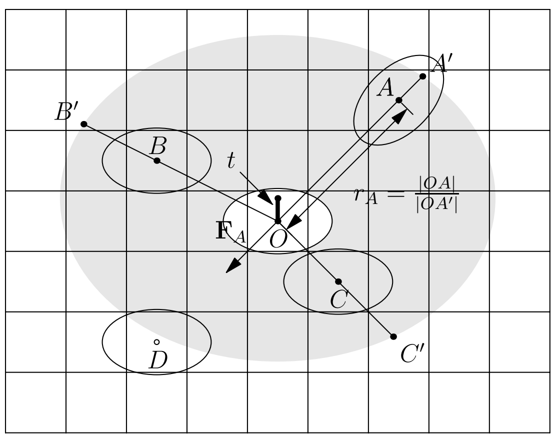

Fig. 3. Social area ellipse: semimajor axis equals $4a$ and semiminor axis equals $5b$. Shift t equals $0.7b$. Parameters a and b defined in subsection 3.1.

the mentioned asymmetry, the model has to distinguish the front and the back of the person which results in 8 possible orientations: N, NE, E, SE, S, SW, W and NW. Fig. 3 presents the method of calculating the distance between the "observer" O and "intruders" (A, B, C and D). If the intruder enters the social area of the observer (on Fig. 3 only A, B and C) the normalized distance r within the social area is calculated as a ratio of the distance between the centers of persons (e.g. $|OA|$) to the distance between the observer and the point of projection of the intruder's center on the boundary of the social area (respectively $|OA'|$). The normalized distance belongs to the interval $[0, 1]$.

The interaction between the observer and a single intruder is described by "social distance force" $\mathbf{F}_s$. The absolute value of $\mathbf{F}_s$ depends only on the normalized distance between them, $\mathbf{F}_s = F_i(r)$ where F_i is one of some assumed models for social distance force (presented in Fig. 4). $\mathbf{F}_s$ has reverse sense than the vector observer-intruder. Total social force affecting the observer is calculated simply as a vector sum of social forces calculated for each intruder (in the presented case: $\mathbf{F}_s = \mathbf{F}_A + \mathbf{F}_B + \mathbf{F}_C$).

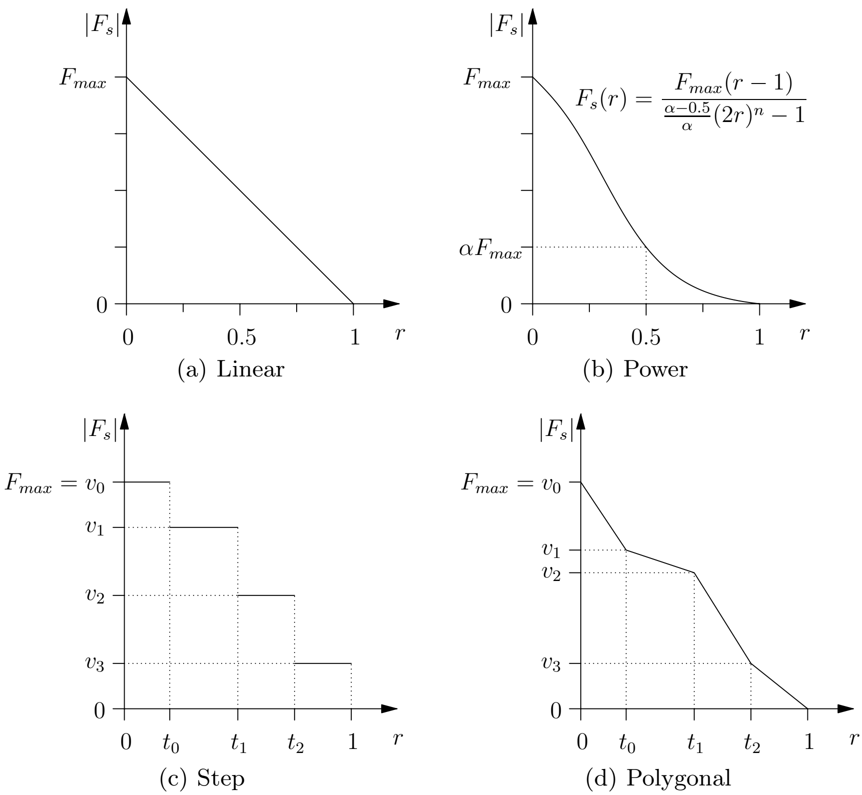

Fig. 4. Applied social distance force models

3.3 Movement Algorithm

The presented model proposes three possible pedestrians states: *Go to*, *Wait in intermediate aim* (*tarpit*) and *Wait*. The general movement algorithm is shown in Fig. 5.

A pedestrian's orientation can be changed only during movement to the next cell. The new orientation is determined according to the following rules: firstly, the pedestrian tries to adjust his/her orientation to the movement direction (face directed forward), otherwise the pedestrian takes one out of the allowed positions randomly. Social forces do not affect changing the orientation directly.

Depending on their state, pedestrians proceed according to different movement algorithms. Passengers having particular aims (tarpits) in "mind" try to move towards descending values of potential field. It is possible that in an actual time-step a passenger has more than one neighbor cell to choose. In this case a passenger selects the next cell randomly from among them. If a passenger is blocked, that is in their radius 1 Moore neighborhood there is no cell with a potential field value better than the potential value of the field occupied by the passenger, they try to move randomly to one of the cells with equal potential value.

Sitting passengers only wait for their tramstop. When the tram reaches their desired destination they run to the exits using movement algorithm described above.

The only state, when social distances have a direct influence on pedestrians is the *Wait* state. Every pedestrian in this state is under the influence of all other pedestrians. If the value of social force influencing the pedestrian exceeds the assumed threshold, he/she calculates the new target cell on the basis of resultant social force vector and changes his/her state to *Go to*.

4 Model Application in a Tram Simulation

As an example of the model described above, the authors consider passenger dynamics in a tram NGT–6 used by Public Transport Company in Kraków, Poland [7]. We take into account a movement algorithm from the previous section (Fig. 5). Let us analyze some important elements of this algorithm.

Resources and intermediate aims in the model like: seats, validators, exits etc. are understood as ”tarpits” [7,14]. These tarpit cells are aims of *Go to* action and simultaneously they are objects of *Wait in intermediate aim*. Pedestrians, behaving according to social distances rules, try to get to intermediate aims. If their trip is short or if they have not defined any intermediate aims, they are in the third state: *Wait*. This state causes pedestrian's behavior to be passive, that is if she/he does not violate any strangers' territory but if her/his social area is violated, pedestrian recedes the others with greater priority.

5 Implementation

The model has been implemented with the use of C++ programming language. All features of the model are enclosed into several C++ classes, which represent: grid, grid cells, passengers, a set of allowed configurations, the geometric model of social areas and considered variants of social distance forces. The application has two main parts: the part representing the model and Graphical User Interface.

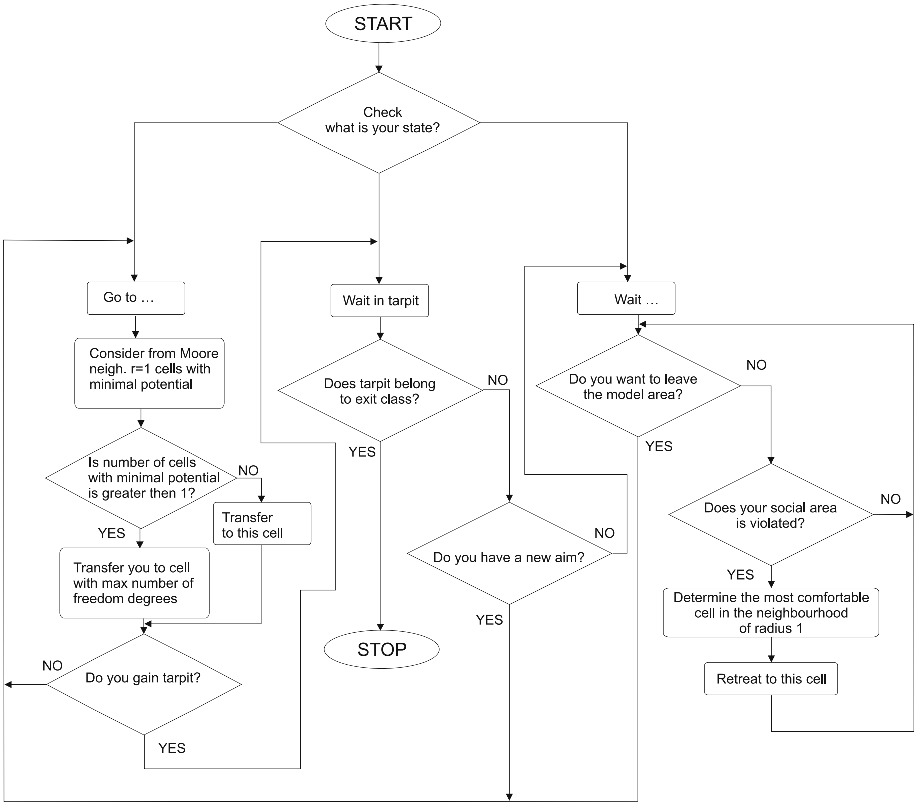

Fig. 5. Movement algorithm for each pedestrian for single time step

The most important module of the simulation part of the program is the *executive* [12], which controls the simulation progress. The *executive* has to control time flow in the model and has to ensure that every passenger is handled in every time-step-slice. Each passenger is enqueued in one of the three lists: the list of passengers getting off, the list of boarding passengers and the list of passengers who are standing inside the vehicle. Every list has assigned priority. The *executive* examines the lists of passengers in a descending order of priority. In every time-step-slice all lists are examined. Passengers getting off are handled first, then boarding passengers or passengers moving towards their intermediate aims, and finally — passengers standing inside the vehicle. Moving passengers do not care about the violation of their social distance areas. However, standing passengers try to find the most comfortable place inside the vehicle. Therefore the executive examines lists in the described order.

It is worth noting supplementary classes performing key computations. *FieldPattern* class is used to determine the templates of allowed configurations inside a passenger's neighborhood, depending on his orientation in the space and his geometric dimensions. *SocialField* class computes vector of the "repulse" force coming from the intruder who violates the passenger's social distance area.

Simulation program is an application working under Windows 2000/XP operating system. Therefore the Microsoft Visual C++ 6.0 compiler was used. GUI implementation uses classes of standard MFC library.

6 Simulation Results

In the presented simulation we can observe how the social distance force idea works. First, let us consider situation with two pedestrians: the first one is in the state *Go to* (Action: *Go to* exit) and the second one is in the state *Wait*. The second pedestrian stand on the way of the first one. In this situation the first one is the "intruder" for the second one.

In Fig. 6 one can observe a situation in which the pedestrian marked grey goes to the exit (cells also marked grey). The "grey" pedestrian (in the state *Go to*) influences two others, marked black (in the state *Wait*). The third, pedestrian marked black (in the bottom right-hand corner of Fig. 6) is too far from the grey "intruder" to experience any influence.

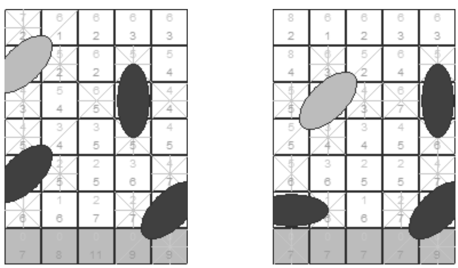

Fig. 6. Two consecutive phases of the simulation. Pedestrian marked grey, which get off the vehicle, violates the social distances of two other pedestrians marked black. Pedestrians marked black recede and make get off possible.

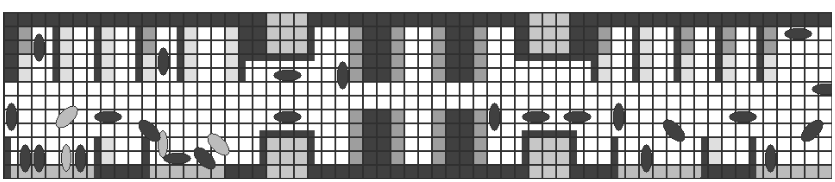

Fig. 7. Pedestrian proxemics across a vehicle

In Fig. 7 the pedestrian allocation in a part of vehicle is shown. It presents a typical situation at the tram stop. Some passengers (marked grey) get off the vehicle, while the majority (marked black) stay inside. Dark grey cells represent unoccupied seats and light grey cells represent occupied seats. In the population of travelling passengers (marked black) one can see a tendency towards regular, equilibrated allocation. Proposed wall representation is connected with pedestrian movement possibilities.

7 Conclusions

An innovative idea of introducing social distances to the CA pedestrian dynamics model, contributes to a significant growth of realism of the simulation. Social distances mechanisms make simulated interactions among passengers more realistic. The authors propose several models of social distances forces. One of the presented models was called *Step* (Fig. 4) and it corresponds directly to E.T. Hall theory. The remaining models of social distance forces seem to be more precise in interactions simulation.

The second profit resulting from the application of social distances theory is the explanation of passenger distribution inside a considered area (vehicle). It is a practical application of proxemics.

To illustrate practical application of the theory of social distances, the authors have created CA modeling pedestrian behavior inside a tram. Space in the model is represented as square, regular lattice. Pedestrians are represented by ellipses. A center of an ellipse coincides with the cell center. In one time-step-slice, pedestrian can transfer into another cell in Moore neighborhood of radius $r = 1$.

In one of the previous models [7] the authors presented another pedestrian representation, where each pedestrian was similarly represented by an ellipse. The difference is that the ellipse occupied two or four adjacent cells of the lattice. In such case, the movement algorithm was much more complicated.

The main limitation of the current model is lack of strategical abilities of pedestrians. Actually, pedestrians always approach the closest aim (in the sense of potential), while such choice is not necessarily globally optimal (e.g. one could faster reach another equivalent aim).

Instead of the necessity of computing social distances, discrete character of simulation allows its to be effective. Simulations based on Molecular Dynamics (e.g. Social Forces by Helbing and Molnar [10]) gives possibilities of more detailed simulation, but computational effectiveness of this method is probably lower.

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