Proxemics in Discrete Simulation of Evacuation

Jarosław Wąs, Robert Lubaś, and Wojciech Myśliwiec

AGH University of Science and Technology
al. Mickiewicza 30, 30-059 Kraków, Poland
jarek@agh.edu.pl

Abstract. The article deals with a proxemic approach to evacuation modeling. Proxemics is interpreted as a process of acquisition of space. The authors propose a new, discrete model, based on a more detailed representation of space (taken from the Social Distances Model) and the idea of floor fields. The presented model allows for efficient, real time simulation of evacuation from large facilities using more detailed representation of spatial relations.

1 Introduction

The term *proxemics* was introduced by an American anthropologist Edward T. Hall in 1959 to describe *a set of measurable distances among people as they interact.*

According to [7],the etymology of the word refers to as a combination of two elements: prox(imity) + -emics (as in phonemics). The term *proxemics* is defined as: *the study of the cultural, behavioral, and sociological aspects of spatial distances between individuals.*

Recently, the application of the theory of proxemics is becoming an important issue in crowd dynamics modeling. In [5] the idea of space acquisition process in inflow process using proxemic floor field is proposed. Whilst [4] deals with the influence of groups in crowd in the context of spatial relations (proxemics).

One of the possible keys to the understanding of pedestrian behavior and dynamics in different situational contexts is using the theory of proxemics. It is worth noting that the idea of the optimal use of space and pedestrian comfort is described in the Fruin's work [1]. Fruin introduces the term *Level of service* (dedication of a given area of public space to a statistical pedestrian). The originally reffered to a free movement of pedestrians on the streets, but it is also useful for other scenarios.

It should be stressed, that problems related to space acquisition are valid in free movement and also in evacuation situations (resources include time and space). Thus the authors suggested that the concept of *proxemics* in crowds modeling should be interpreted both in normal and emergency situations.

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2 Adaptation of Social Distances Model for Emergency Evacuation

The starting point is Social Distances model described in [10], but actually we do not take into account a force component in pedestrian algorithm movement, because the aim is to create an effective model for large facilities.

2.1 Geometrical Representation of Pedestrian

In the simplest case, a pedestrian in the model is represented by an ellipse, whose center coincides with the center of the cell occupied by that person. The size of each ellipse equals $a = 0.225$ m (semi-major axis) and $b = 0.135$ m (semi-minor axis) which is assumed to be the average size of a person (according to WHO data), while cell size is equal $0.25m$ [10]. A pedestrian can transfer to another cell in Moore neighborhood of radius 1. Each ellipse can be rotated around by: ± 0, ± 45, ± 90 and ± 135 degrees.

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/forbidden positions is based upon simple geometrical dependencies [10]. It takes into account the following: the orientations of two ellipses occupying two adjacent cells and the size of their cross-section. 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 $\epsilon_N \in [0, 1]$.

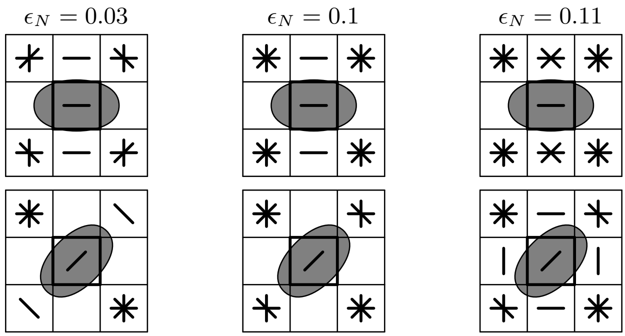

Fig. 1. Allowed neighborhood configurations for different tolerance parameters

Fig. 1 presents allowed states for neighbor-cells for different tolerance parameters. Lines represents allowed configurations of different agents in an agent neighborhood.

With this approach, we can consider the fluctuations of density and crowd compressibility more accurately, than in classical CA based models (where a pedestrian is represented as a special state of square-shaped cell sized $0.4m$).

It should be stressed, that elliptic representation of pedestrians, taking into account forbidden/allowed states in the neighborhood, make the modeling of proxemics rules during evacuation possible.

2.2 Movement Rules

Applied movement algorithms are based on three ideas known from other CA based models [2,3]: static floor field, dynamic floor field and a cost function. The implementation of ideas were modified to apply in the Social Distances Model environment.

The execution of a single-step of the simulation includes choosing the next destination cell by pedestrians. The following steps are realized:

Calculation of *Visibility Fields* (VF). Visibility field is determined by head position Fig 2. It is calculated on the base of a static field S in Moore neighborhood.

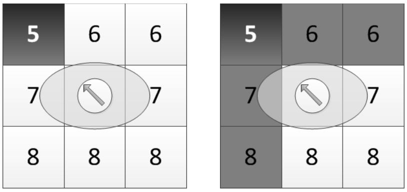

Fig. 2. (a) The head is directed toward the field with the smallest value of static field S. (b) Viewing angle is 180 degrees. Visibility field are marked in gray.

Calculation of Cost Function. For each field f_{ij} in VF (Visibility Field) the following cost function eq. 1 is calculated:

$$cost(f_{ij}) = S_{ij} + (dens(f_{ij}) + \alpha * dist(s, f_{ij})) * W * I \tag{1}$$

The values of the cost function for each cell $c_{ij} \in VF$ are stored in VF_{cost}.

Afterwards, it is necessery to take into account a component described in equation (2) It will give rise of number of parallel lanes in moving crowd (Fig. 3). Different colors of pedestrians in Fig. 3 represent different maximal velocities of pedestrians.

$$dens(f_{ij}) = e^{\delta * D_{ij}} \tag{2}$$

where:

D_{ij} - value of dynamic field,
$\delta \in [0, \infty)$ – chosen empirically.

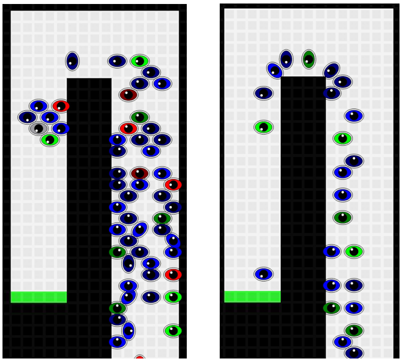

Fig. 3. Simulation with parameters $\delta = 3.5$, $\alpha = 1.3$, $diag = 3.0$, $straight = 0$, $rad_1 = 0.14$, $rad_2 = 0.07$, $I = 0.55$ - overtaking is possible (a) and in (b) are the same parameters except $\delta = 0$, thus $dens(f_{ij}) = 1$ - the shortest path is preferred

Next, we have to take into consideration the distance component [12] to improve obstacle avoidance.

$$\alpha * dist(s, f_{ij}) = \begin{cases} diag & \text{for diagonal movement direction} \\ straight & \text{for straight movement direction} \end{cases} \tag{3}$$

where:

$\alpha \in [0, \infty)$,
s - is the cell occupied by a pedestrian.

Wall force - avoiding wall component is simalar to [2].

$$W = 1.0 + \sigma_W \tag{4}$$

$$\sigma_W = \begin{cases} rad_1 + rad_2 \in (0, 1] & \text{if an obstacle is located in the von Neumann} \\ & \text{neighborhood of radius 1} \\ rad_2 \in (0, 1] & \text{if an obstacle is located in the von Neumann} \\ & \text{neighborhood of radius 2} \\ 0 & \text{otherwise} \end{cases}$$

Inertia component - we use inertia factor I, thanks to which pedestrians keep their direction as long as possible.

Selection of the most attractive field (new destination) f_{best} from VF_{cost}

$$f_{best} = min(VF_{cost}) \tag{5}$$

In the end, when two or more pedestrians want to chose the same cell a mechanism of conflicts resolving is applied by random function or by the selection

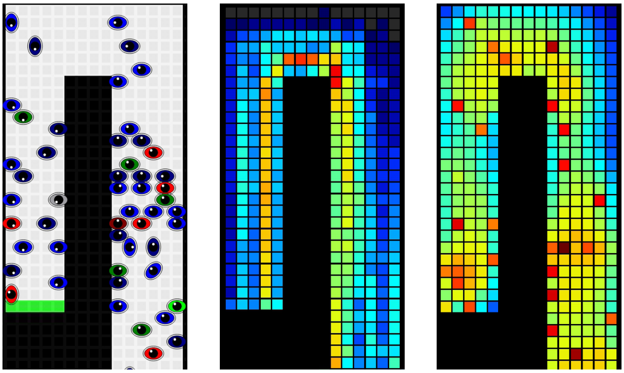

Fig. 4. View of pedestrians represented by ellipses (a), view of frequency matrix (b), view of dynamic fields

of a pedestrian who is waiting the longest to adjust the allowed neighborhood configuration Fig.1.

Fig. 4 presents different views from simulation based on the described model: simulation, frequency matrix and dynamics field. While a view on evacuation of a stadium tribune is presented in Fig 5

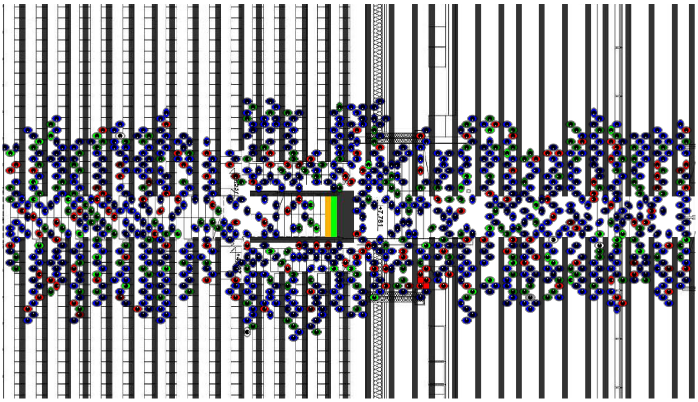

Fig. 5. Simulation of a stadium tribune

The presented model is actually validated. Exemplary fundamental diagram (flow/density relation) is presented in Fig. 6.

2.3 Performance

A performance test was executed on a unit with the following specification: Intel CPU q6600 3.2GHz, 4GB RAM and Microsoft Windows 7 Pro 64-bit. Test object

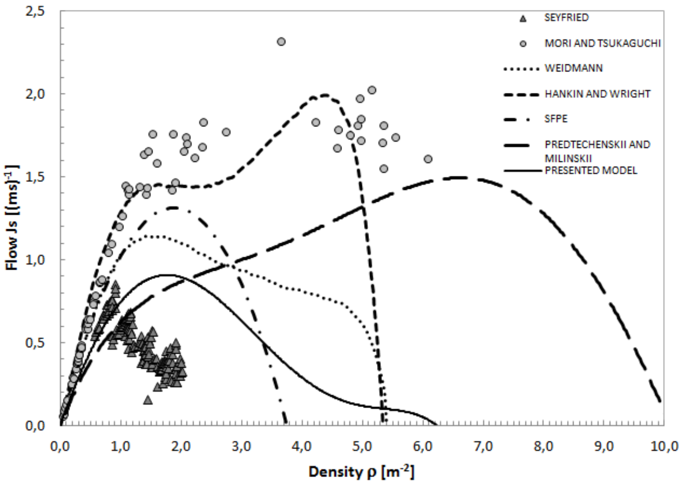

Fig. 6. Fundamental diagram of presented model compared with fundamental diagrams by SFPE Handbook [13], Predtechenskii & Milinskii [14], Weidmann [16], Hankin & Wright, Seyfried [9], Mori i Tskukaguchi

is defined as an empty space with dimensions of $176.5m$ x $176.5m$ ($31152.25m^2$). The number of pedestrians in the simulation were $100, 1000, 10000, 25000, 50000$. The graph 7 shows the dynamics of memory usage and the average execution time of one iteration of the algorithm.

Execution time of a single iteration is the average of 500 trials.[1]

The run-time complexity for the avarage-case scenario of presented algorithm is quasilinear: $O(n \log n + m)$, where n – number of pedestrians in simulation and m – number of emergency exits. The reason for that class of complexity is the sorting algorithm used to sort list of agents. It is worth mentioning, that the time complexity is not dependent on the size of grid, but only on the number of agents.

Memory complexity is directly related to the size of grid in the model. If we denote in this case n as the grid size (m - is still number of emergency exits), the memory complexity will be estimated as $O(n^2m)$ class. One can observe increasing of memory usage in dependence on the number of emergency exits in the grid. This is due to the structure of static fields.

3 Concluding Remarks

The issue of proxemics, understood as the process of acquisition space by individuals, requires a different approach to normal and emergency situations in the modeling of crowd behavior.

[1] SysInternals Process Explorer was used to measure the memory consumption. The value refers to the Private Working Set.

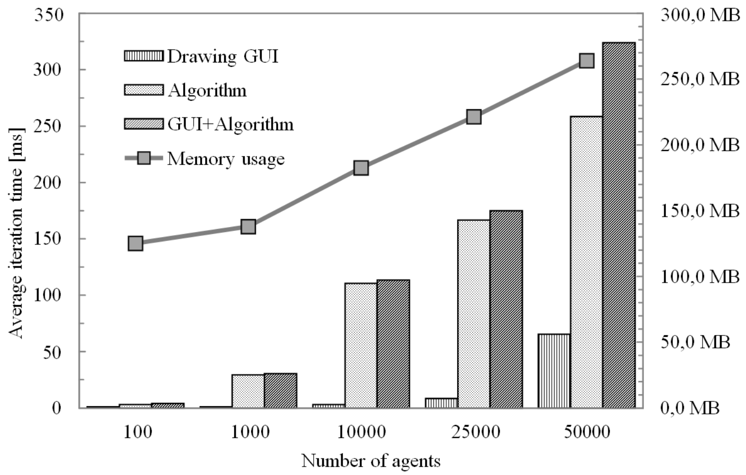

Fig. 7. Results of performance tests.

In a normal situation, we can observe *territoriality* and *classical social zone* around individuals or groups of people. On the other hand in evacuation situation, pedestrians want to leave the occupied facility. In this case, the process of achieving the aims (like exits or safe places) is realized dynamically using different strategies such as: fastest path, shortest path, etc depending on specific conditions.

The proposed model allows for more accurate modeling of spatial relations than models based on classical cellular automaton. We do not consider the zones around an individual, but we take into account different configurations in neighborhood, that allow for more precise modeling of the occupation of space.

The model was tested for large facilities and we obtained encouraging results. The proposed model works in real time, but it is a necessity to carry out further, comprehensive performance tests. The model is being validated. Some procedures and scenarios are successfully finished like the scenario described in [9,8,15], but the validation process is in progress.

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