The Evacuation Process Study with the Cellular Automaton Floor Field on Fine Grid

Tomasz M. Gwizdałła(✉)

Department of Solid State Physics, University of Łódź,
Pomorska 149/153, 90-236 Łódź, Poland
tomgwizd@uni.lodz.pl

Abstract. The modification of Cellular Automaton Floor Field based simulation of evacuation is presented. The typical approach, where the pedestrian occupies single cell, usually of size $0.4 \times 0.4\,\mathrm{m}^2$. is modified by assumption that the single person can occupy 2 cells. The rules of motion are presented and the basic characteristics as well as comparison with the one-cell model are shown.

1 Introduction

There is a large number of approaches which are devoted to study the process of motion or even evacuation of people under different conditions (see e.g. [1,2]). Also Cellular Automata were extensively studied as a tool for analyzing the evacuation process. It can be suggested that the initial attempts follow the experience of their authors coming from other areas of CA interest, like traffic analysis [3] or collective processes [4].

From our point of view those papers are of much interest where the unconventional approach to the problem of pedestrian's size is presented. We can enlist here e.g. [5], where the model of two cells occupying person is used to show the people flow in public transportation. From the same group it comes the paper [6] where the elliptic-like shape of person corresponds to the interpretation of social distance. Here however, the persons are localized in the centers of cells. The choice of the size of individual, exceeding the typical one cell and going beyond the circular or four-fold symmetry, comes from real observations and practice [7–9]. It was shown that the axes of the personal space (PS) connected with the single individual was as great as approximately $2.5\mathrm{m} \times 0.5\mathrm{m}$. In our paper we are not going to deal with the psychological notion of PS but we want to follow the observation about the asymmetric shape of person. We should point out that the definition of the size appropriate for single person (as expressed in cells) is the crucial problem of fine-grid approaches since we have to strictly distinguish the models where we can use the CA definition and rules and models which are close to macroscopic, dynamical analysis. It seems that the upper limit can be found in [10].

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2 Model

The system under consideration follows a lot of earlier attempts. We especially want to refer here to papers [11,12]. The room is presented as a two-dimensional array of $n_x \times n_y$ cells. The size of edge of every cell is typically assumed as 0.4 m. The value assigned to every cell has to somehow describe the distance to the closest exit. Such an array of numbers is called the Floor-Field (FF). In the paper we use generally two schemes of creating FF, but several properties characterizes both methods. The room is bounded with the wall and the FF values are for the wall's cells significantly higher than for all other positions. The number of doors is arbitrary fixed and all cells corresponding to the doors are assigned the value $FF_{door} = 1$. Subsequently one of the enlisted methods can be used.

– The one following the Varas' scheme - According to this algorithm we start from the location of doors and try to assign values for the adjacent cells. They can be either incremented by 1 ($FF_{new,proposed} = FF_{neighbor,set} + 1$) when they adjoin vertically or horizontally, or by some predefined value λ ($FF_{new,proposed} = FF_{neighbor,set} + \lambda$) when they adjoin diagonally. The value of λ can be understood as a parameter of procedure and for the cases studied in this paper, which are limited to the empty spaces we should mention $\lambda = 2$ as the critical value. Above this value, the Varas' procedure produces the Manhattan metric what can be observed in Fig. 1. Certainly, approaching the cell from different directions we can obtain different values, so finally we choose the lowest one.
– The Euclidean scheme - According to this scheme the FF for a particular cell is calculated from the formula

$$FF_{i,j} = min\{k : 1 + \sqrt{(i - door_i^k)^2 + (j - door_j^k)^2}\} \tag{1}$$

where k enumerates the positions of doors i and j are the coordinates of cell and simultaneously describe the corresponding coordinates of doors. Like in the previous case, having more doors we can obtain different values of FF and always the lowest one is chosen.

In further parts of paper we consider only the presented above static Floor Fields and all results are the effects of this static description and some procedures implemented for the individuals' motion. In our calculations we used three different models of Floor Field: the Varas model with $\lambda = 1.5$, the Varas model with $\lambda = 2.5$ and the Euclidean model. The comparison of models for reduced sizes of rooms are shown in Fig. 1.

The crucial point of this paper is the proposition of enlargement of individuals' silhouette. Typically one assumes that one cell of dimensions $0.4 \times 0.4\,\mathrm{m}^2$ can be occupied by one person. Such an assumption can lead to un unrealistic estimations for people density. It can be easily shown that we can assemble up to $2.5 \times 2.5 = 6.25$ person per square meter. Although the values close to the

	6.5	7.0	7.5	8.0	
	5.5	6.0	6.5	7.0	
	4.5	5.0	5.5	6.5	
	3.5	4.0	5.0	6.0	
	2.5	3.5	4.5	5.5	
1	2.0	3.0	4.0	5.0	
1	2.0	3.0	4.0	5.0	
	2.5	3.5	4.5	5.5	
	3.5	4.0	5.0	6.0	
	4.5	5.0	5.5	6.5	
	5.5	6.0	6.5	7.0	
	6.5	7.0	7.5	8.0	

	7.0	8.0	9.0	10	
	6.0	7.0	8.0	9.0	
	5.0	6.0	7.0	8.0	
	4.0	5.0	6.0	7.0	
	3.0	4.0	5.0	6.0	
1	2.0	3.0	4.0	5.0	
1	2.0	3.0	4.0	5.0	
	3.0	4.0	5.0	6.0	
	4.0	5.0	6.0	7.0	
	5.0	6.0	7.0	8.0	
	6.0	7.0	8.0	9.0	
	7.0	8.0	9.0	10	

	6.1	6.4	6.8	7.4	
	5.1	5.5	6.0	6.7	
	4.2	4.6	5.2	6.0	
	3.2	3.8	4.6	5.5	
	2.4	3.2	4.2	5.1	
1	2.0	3.0	4.0	5.0	
1	2.0	3.0	4.0	5.0	
	2.4	3.2	4.2	5.1	
	3.2	3.8	4.6	5.5	
	4.2	4.6	5.2	6.0	
	5.1	5.5	6.0	6.7	
	6.1	6.4	6.8	7.4	

Fig. 1. Three models of Floor Field: left - Varas $\lambda = 1.5$, center - Varas $\lambda = 2.5$, right - euclidean.

presented one were presented for example for so-called "One Million March" by El-Baz ([13]: $5\,persons/\mathrm{m}^2$, $2.15\,ft^2/person$) we think that such values may be appropriate for static situations. When we assume the possibility of motion the above value seems to be visibly exaggerated. On the other hand we should point out that the size of the contour of person's silhouette projection usually exceeds the value of 0.4 m as well as 0.56 m, the value of diagonal of single cell.

The motion of individual is performed in the same way as it was presented in our earlier paper [12]. The pedestrian chooses always the direction of the lowest possible Floor Field value what, generally, corresponds to the path to the closest exit. Among those empty cells in the neighbourhood of analyzed one which have the same FF value we choose one randomly. With the probability 0.05 the possible move is not performed what corresponds to the random panic effect. The main properties of our model can be presented as follows (the visualization of the discussed situations is shown in Fig. 2).

– Since we consider two-cell sized individual we have to redefine slightly the determination of the direction of motion. Usually we consider the value assigned to the potentially next cell. Now we take into account the sum of values in the cells which could be occupied by the individual after the move.
– The pedestrian has either 4 or 8 possibilities of motion. The choice of particular number depends on the parameters of simulation. In the case presented as (a) where only 4 directions parallel to the axes are allowed we, due to similarities, say about von Neumann update while the case (c) we present as Moore update.
– The usual motion of the person is performed front-facing. We distinguish two possible versions of motion. With the first one we accept the arbitrary direction

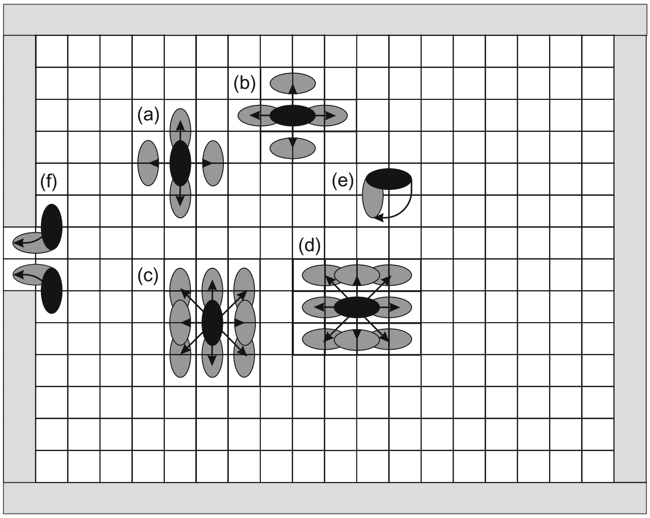

Fig. 2. The acceptable moves of pedestrian according to the two-cell approach. For details, see text.

of person. In the further part we call it "arbitrary motion" (but with different updates or neighbourhoods). This situation is shown in situations (b) and (d) where pedestrians moves sideways in the direction of door. The typical motion, called "front set" is shown in mentioned earlier cases (a) and (c).

– If we want to disable the sideways moves we have to force the individual to change his/her direction. The appropriate move is shown as situation as (e). In order to determine the correct direction we define, except of FF array, the array of gradients. The pedestrian, who has to move front-facing, changes his direction in compliance with the direction of gradient. The gradient is calculated as a direction parallel to the axis and leading into the cell with the lowest possible value of FF. In the ambiguous situations, like for Varas' model with $\lambda = 2.5$ we choose such direction of gradient which distinguishes it from the $\lambda = 1.5$ case. The comparison of gradient array is shown in Fig. 3.
– We include also some specific procedure of avoiding the deadlock near doors. When two pedestrians block themselves, like in situation (f) we allow both of them to slide through the door sideways.
– The follow generally the rules constructed for the one-cell model in our previous paper [12]. It corresponds especially to the situations of conflict between two or more individuals. In the situation when two persons try to move into the same final cell, the random selection between these two persons is performed. It concerns the typical steps as well as the rotation described as the case (e).

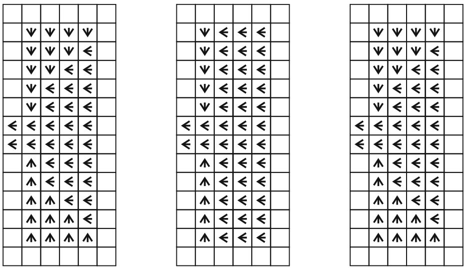

Fig. 3. Three models of Floor Field - gradient directions: left - Varas $\lambda = 1.5$, center - Varas $\lambda = 2.5$, right - euclidean.

3 Results

All calculations were made for empty room 14×18 cells. It corresponds to the room size $5.6\,\text{m} \times 7.2\,\text{m}$. According to this notation, Figs. 1 and 3, shown earlier, correspond to the size 12×4 and Fig. 2 presents correctly the considered room. For simplicity we will define the horizontal axis in the figures as the X-axis and the vertical one as the Y-axis. It means that in our simulations the length of the room along the X-axis is always greater than that along the Y one. In the majority of presented results the location of door is the same as in the Varas' paper, i.e., they are located in the middle of shorter wall. In some further calculations, the positions of doors are changed.

The short view at the Figs. 1 and 3 makes it possible to say that two FF configurations: Varas' with $\lambda = 1.5$ and the Euclidean one are similar one to another. Only the small sections of room are shown in Fig. 3 but those presented ones are the most important for creating deadlocks and, finally, for the overall evacuation time.

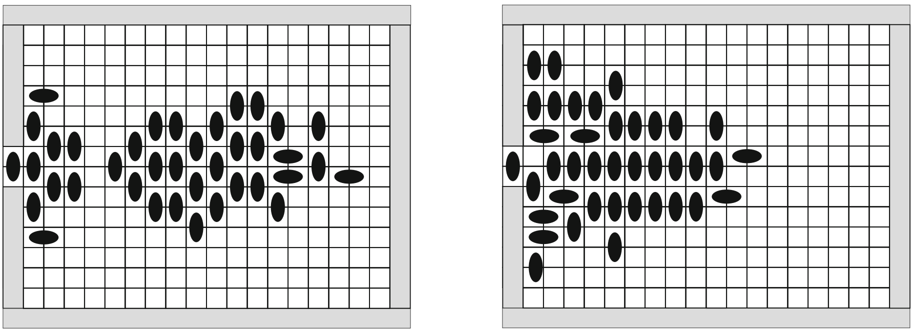

Fig. 4. The snapshot of simulation of about 40 individuals for two FF models. On the left $\lambda = 2.5$, on the right the Euclidean one.

In the Fig. 4 we show the snapshot of two simulations for two different Floor Field definitions. On both pictures there are visible about 40 pedestrians among 50, which were initially distributed randomly in the room. The pattern formed by the individuals is explicitly different. Some unexpected effect is that the accumulation of people at the wall containing the door is observed rather for Euclidean FF. For this model we could expect the earlier convergence into the middle of the room. Very interesting observation can be made when we compare Fig. 4 with the Fig. 4 of original paper by Varas et al. [11]. The authors show there an artificial configuration of pedestrians sampled along the diagonals heading to the exit. Both our configurations are much more realistic.

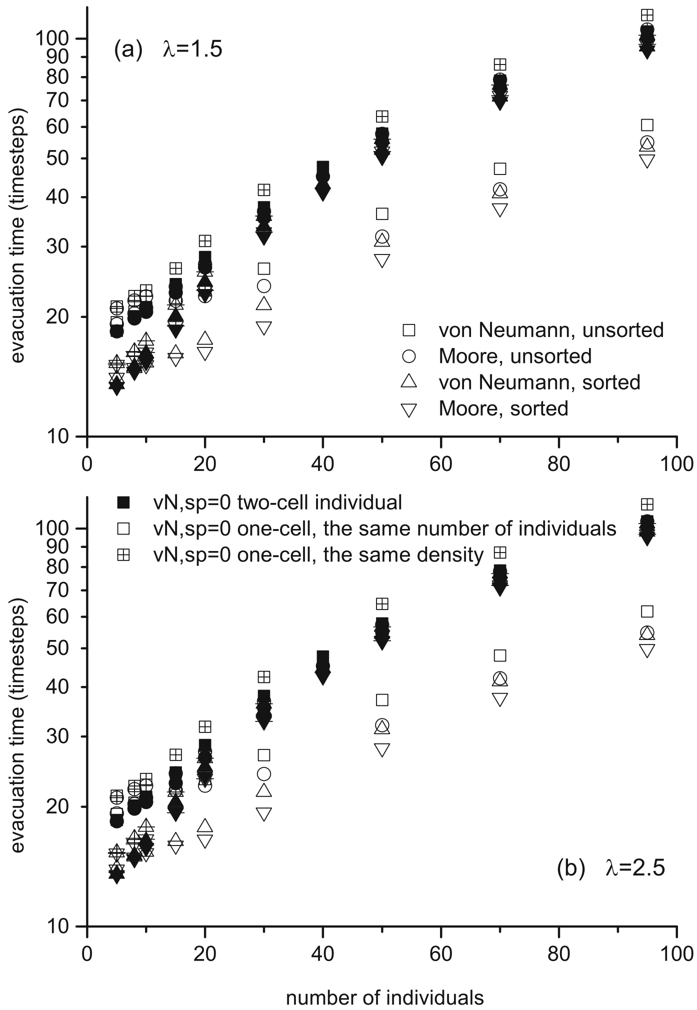

Fig. 5. The comparison of simulation results between the one-cell and two-cell models.

Figure 5 is prepared in such a way that it enables to compare the results obtained with the proposed two-cell model with the ones obtained within the one-cell model described in our former paper [12]. Taking into account the parameters of simulation we choose here 4 combinations of von Neumann and Moore update as well as sorted and unsorted pedestrian management. The sorting of persons is in more detail described in [12] (see especially Fig. 4) and is dedicated to prevent the rising of unreal gaps between the people. It is expected that sorting should lead to shortening of evacuation time. The plots are prepared for the initial number of pedestrians from 5 to 95. The highest number may seem unrealistic but we intentionally choose it since it corresponds to the higher value of density ($\rho = 0.75$) considered in our earlier paper [12]. We should also emphasize that the proximity of results for both updates and high densities is the expected effect since in this case the final result is mainly influenced by the jam at the exit. Similarly, the lower density ($\rho = 0.079$) corresponds to the initial presence of 10 persons. Every plot for two-cell model is compared with the two plots for one-cell model, the first one is calculated for the same number of people (so the initial density is two times smaller) and the second one is prepared for the same initial density (so the number of people is doubled). Here as well as for other simulations every point is the average over 10000 independent runs.

Figure 5 shows that for both FF models used the effects are similar, the differences are almost invisible. The results for the two-cell model are close to those for the same density except of two cases. The first one is the von Neumann, unsorted update (one-cell) and the second one is the behavior for lower densities. When the number of persons is lower the plots for two-cell model start to group into two distinctly visible sets. They are distinguished by a fact of sorting of the individuals. The process of sorting plays visibly more important role in our model as compared with the one-cell one but it can be considered as more typical for higher densities. We expect also that the difference between von Neumann and Morse update vanish with increasing density and this effect can be observed for two-cell model better than for a one-cell.

In the Fig. 6 we want to check, which of the steering parameters has an influence on the results obtained for our model. Since the former figure show some effect of dependency on sorting process, the first two plots are prepared in order to distinguish both cases. It can be seen that, except of some quantitative differences, the qualitative behavior does not change. The way of update, here the number of positions considered is more important than the need to preserve the correct orientation in the direction of exit. The third plot shows that the selection of particular Floor Field model is almost unimportant when taking into account the evacuation time. It can be considered unexpected since Fig. 4 shows visibly different patterns produced by different FFs. Finally, it turns out that for one configuration the pedestrians are huddled and have to wait for the possibility to move, for the other one they move quite freely and the effects of both tactics are similar.

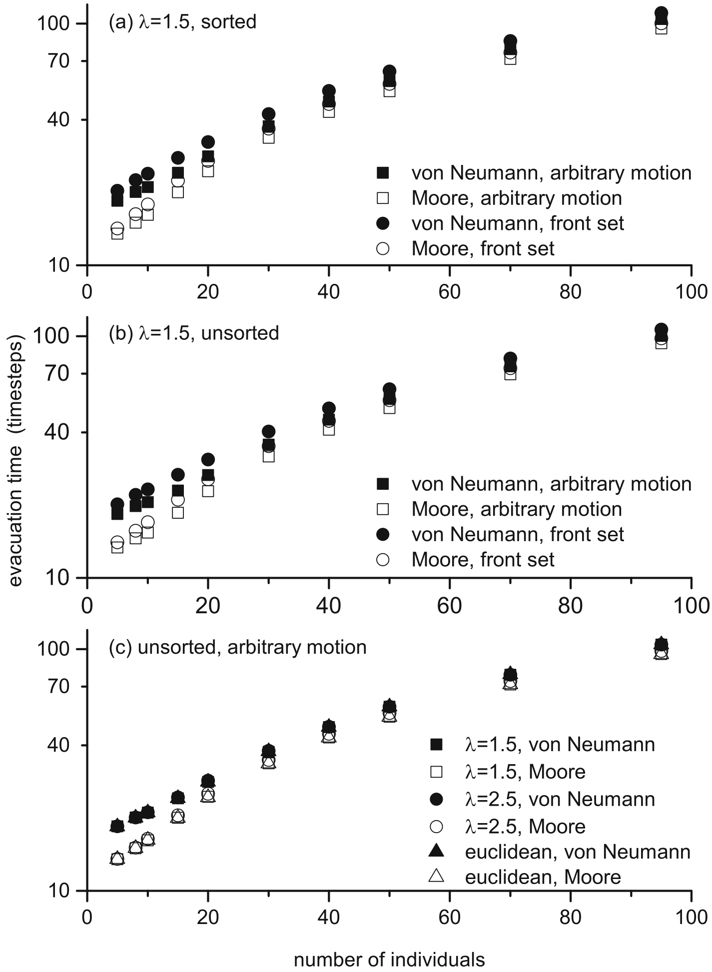

Fig. 6. Two-cell model. Dependence of results on different simulation parameters.

In the Fig. 7 we show whether the effects observed for the one location of door is reproduced for other orderings. We consider three other configurations, in more detail described in paper [12] (see e.g. Fig. 7). Generally: in the configuration (b) the door is in the middle of longer wall (X), (c) - two doors are located in the corners of shorter wall (Y), (d) - two doors are located in the corners of longer wall (X). Once more it turns out that the size of neighbourhood considered is the crucial factor. An interesting observation is that the configuration (d) produces result significantly different from all others. Firstly, the value of evacuation time is almost two times lower that for other cases. Usually we explain such differences with the increase of the width of exit and the decrease of distance between the exit and the farthest point in the room. Here, in order to observe the effect, we

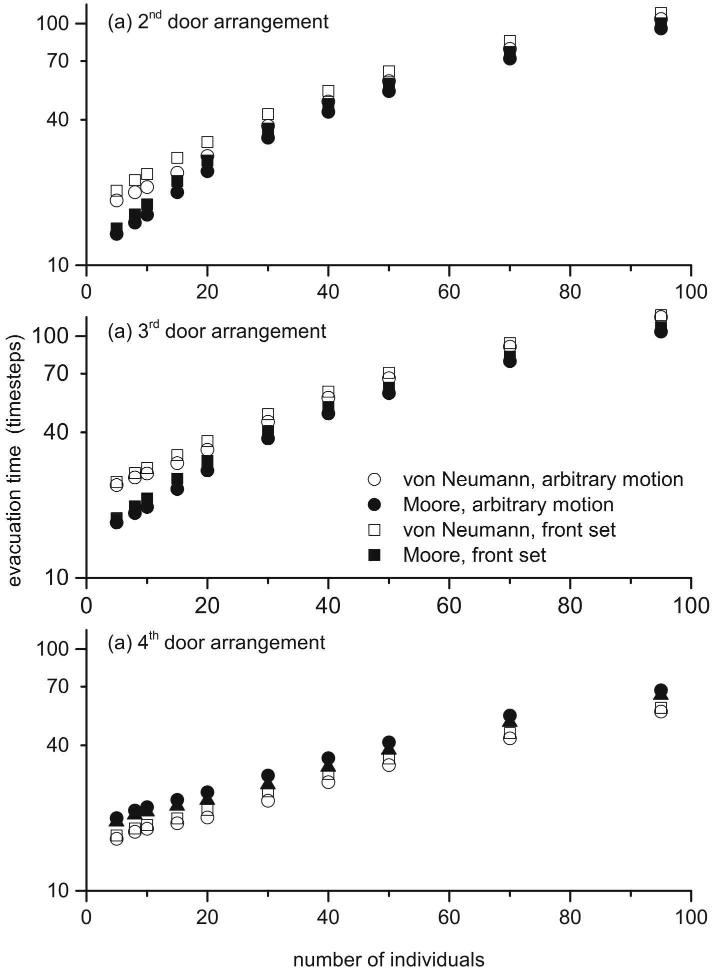

Fig. 7. Two cell model. Results for different doors configurations.

have to combine both these features while every single feature does not produce any result what can be observed in plots (a) and (b) when compared to earlier figures.

An interesting information about the evacuation process is that about the possible scaling of the result. In our model almost all lines can be scaled with the linear dependence with the slope similar to that one for one-cell model which corresponds to a higher density case. Only for the last configuration of exits (d) the better approximation is the Euclidean one. We can also remark on the patterns presented in the Fig. 4. We performed some undocumented observations concerning people leaving the building with similar door arrangement and proportionally greater size.

We observed that the choice of pattern in the figure mentioned above depends strongly on the dynamics of the process. Although we are unable to present now the snapshots from these observations we noticed that for the quiet motion, the left pattern can be observed, while for rapid evacuation it resembles the right one. This makes it possible to ask question whether the typical Manhattan metric with the two-cell pedestrian model does nicely conform to some customs of people.

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