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Social field model to simulate bidirectional pedestrian flow using cellular automata

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Abstract

A collective phenomenon appearing in the simulation of bidirectional pedestrian flow in corridors is dynamic multi-lane (DML) flow. We present a cellular automata model that reproduces this behavior. We propose to incorporate a social distance emulating a territorial effect through a social field, similar to the dynamic floor field of Burstedde et al [1]. This model also considers a vision field that allows a pedestrian to collect information from cells in front of him/her and also to get the weighted social parameter; the importance of this parameter in the formation of dynamic lanes is that it helps a pedestrian to choose the lane that contains the highest concentration of persons walking in the same direction. We present numerical simulations in corridors with bidirectional flow and the fundamental diagram for unidirectional flow.

Keywords: cellular automata, bidirectional pedestrian flow, social field model, fundamental diagram, dynamic parameters

1 Introduction

In recent decades the study of the dynamics of pedestrians has witnessed a great development, mainly through cellular automata (CA) modeling due to its efficiency in describing model complex systems.

Different models have been developed to simulate pedestrian traffic based on cellular automata [1, 2, 3, 4, 5, 6, 7, 8, 9]. In order to model the change of walking lane, these

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models have used different types of probabilities or parameters: either prefixed or dynamical. The latter are calculated according to the conditions that exist around the pedestrians. An important factor to determine the dynamic parameters is to define properly the shape of the area that influences the behavior of pedestrians.

Few cellular automata models take into account social distance between pedestrians [1, 10]. We introduce the idea of social distance through a social field, according to the dynamic floor field of Burstedde et al [1], which resembles the territorial effect [11].

Our goal is to combine a dynamic parameter with the overlapping of different fields of influence in order to obtain numerical simulations that generate dynamic lanes and to avoid body contacts. As will be shown, with the addition of the social field, we were able to reproduce Weidmann's fundamental diagram [12].

This paper presents the modeling of bidirectional pedestrian flow in a corridor, where in order to change the walking lane we define a vision field for each pedestrian and a weighted social parameter. In section 2 the proposed model is described and in sections 3 and 4 the numerical simulations and conclusions are presented, respectively.

2 Description of the model

Our microscopic model based on CA is intended to simulate bidirectional pedestrian traffic along a corridor. The CA is defined on a rectangular grid of size $I_1 \times I_2$ contained in $\mathbb{R}^2$. Each cell is a square of 40×40 cm^2. Pedestrian enter and exit through (lateral) left and right boundaries of the corridor. Impenetrable boundary conditions are imposed at the top and bottom borders of the corridor, and two types of boundary conditions on the lateral boundaries are considered: open and periodic.

There are three basic elements that a microscopic pedestrian model must take into account: to mitigate conflicts, forward and lateral motions (as in change of lane) [3]. For this reason a pedestrian is only allowed to move as shown in Figure 1.

A collective phenomenon, the dynamic multi-lane (DML) flow is formed by groups of pedestrian moving along directional lanes. Pedestrians generate a lane by avoiding others coming from the opposite direction and by following the one just ahead of him/her and going in the same direction [3]. A factor enabling self-organization of collective phenomena in pedestrian behavior is the social distance or social field [1, 10, 11].

Formation of dynamical lanes can be understood as follows: a typical pedestrian chooses to minimize its energy by walking along currents of people in its own direction. Thus when he/she walks along he/she has to worry about keeping its own distance from the pedestrian

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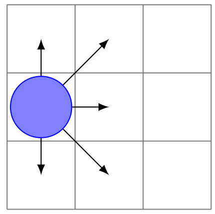
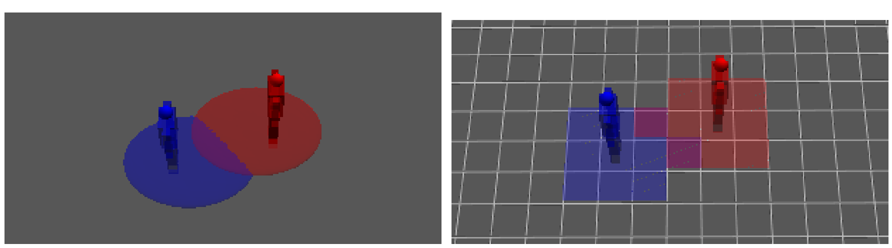


Figure 1: Movements allowed in the model.

in front of him/her. Without forming lanes pedestrians will confront each other frequently and would have to deviate from its own route avoiding physical contact, thus expending more energy.

2.1 Social field

Territorial trends affect changes in pedestrian behavior which are guided by social fields. Helbing [11] takes this ideas to model territorial behavior by means of repulsion forces, in such a way that persons tend to move away from others or objects to avoid collisions or hurting. Social field resembles an individual space where each person feels comfortable. Thus he social field acts in a similar manner as the repulsive force of the social force model.



(a) (b)

Figure 2: Social fields: (a) continuum y (b) discrete.

Whenever a person invades the social space of another, the last tries to move in a direction that diminishes the discomfort, acting as a repulsive force among persons. In this way the social distance is kept among individuals. Social field also augments the presence of the individual in such a way that he/her is perceived among others. Figure 2 shows two kinds of social fields: continuous and discrete. The shape of a discrete field is similar to the continuous field due to the fact that it is elliptical. To each cell a discrete value of the social field is assigned. In the case that the fields intersect, the values at the intersected cells are summed up as shown, so the intensity or presence of the individual is increased.

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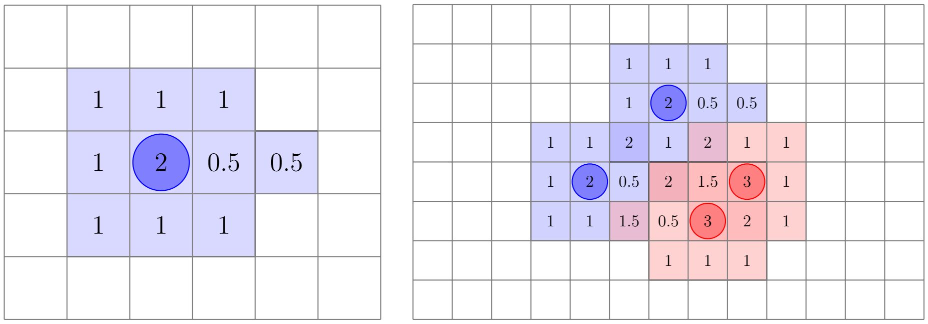
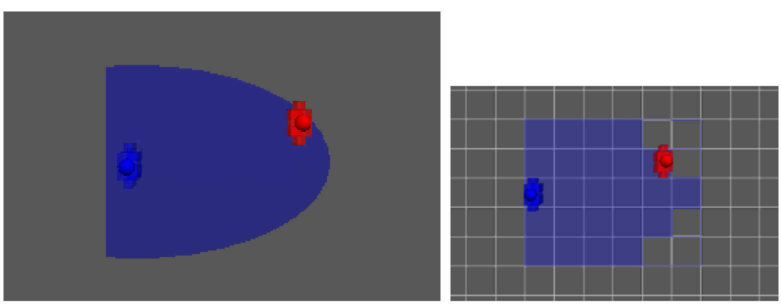


(a) (b)

Figure 3: (a) Social field configuration and (b) intersections of social fields.

2.2 Vision field

The majority of pedestrians look at all what happens in front of them, as they walk by. In this way they can avoid collisions with objects or another persons. The vision field reflects the attention that a pedestrian pays to situations that happens in front of him/her, giving them more attention than those which happen besides or back of him/her. On the other hand, pedestrian's vision scope becomes important from certain distance on, where he/her can change direction to avoid collision with obstacles. This characteristic permits the pedestrian to take a decision, to continue walking straight ahead or deflect.



(a) (b)

Figure 4: Vision fields: (a) continuum y (b) discrete.

Figure 4 shows two types of vision fields: continuous and discrete. The vision scope of a pedestrian will be equal to its individual velocity, thus he/her will have a vision of the route along time. Figure 5 shows different scopes of vision field.

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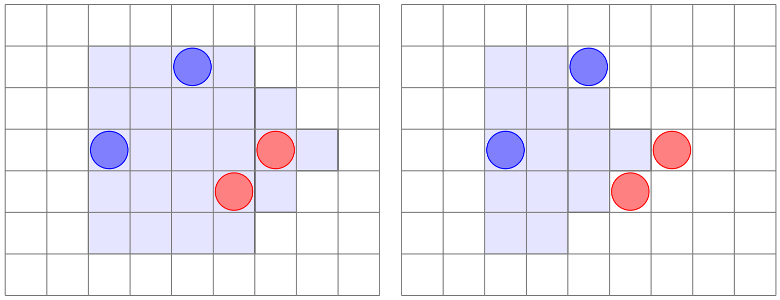

(a) (b)

Figure 5: Different scopes of vision field: (a) $v^i = 5$ y (b) $v^i = 3$.

2.3 Weighted social parameter

Hao Yue et al [4] introduce dynamical parameters in order to control pedestrian motion. Similarly we introduce the so called weighted social parameter. The idea of this parameter is to help pedestrian decide on the lane with the highest pedestrian concentration walking in the same direction. In this way formation of dynamical lines is more likely. Let us introduce two intermediary parameters: the weight and the social value per lane.

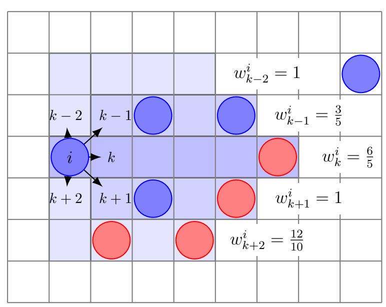

Figure 6: Weights per lane for each walking lane.

The weight per lane for lane i is defined by

$$w^i_k = 1 + \sum_{j=1}^{np_k} \frac{d_j}{l_k \times v^i} \tag{1}$$

where np_k is the number of persons in lane k, v^i is the number of cells within the vision scope of a pedestrian, $l = 1$ for walking lanes $k-1$, k and $k+1$, and $l = 2$ for walking lanes $k-2$ and $k+2$; $d_j = +1$ if pedestrian j walks in the opposite direction as pedestrian i and

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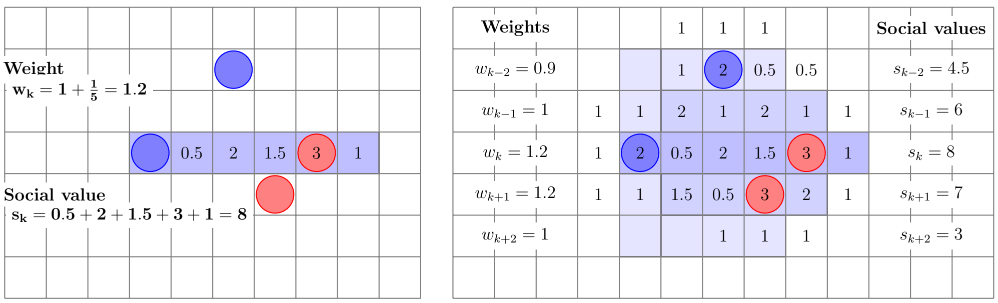
$d_j = -1$ for those walking in the same direction. The composition of walking lanes is shown in Figure 6; cells of the same color belong to the same walking lane.

The social value of lane k is obtained by summing the social field of cells that form the walking lane, see Figure 7 for an example. The weighted social parameter for each lane is computed by taking the weight times the social value per lane. See the example in Figure 7.



(a) (b)

Figure 7: Computation of weights and social values per lane.

2.4 No crossing paths

The restriction of "no crossing paths" applies to models that use maximum speeds greater than 1 per cell in each time-step.

The pedestrian moves ahead as long as there is no other pedestrian blocking his/her path, see Figure 8. We have incorporated this restriction since it was shown to worked well [13].

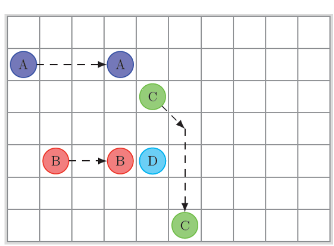


Figure 8: Restriction of no crossing paths.

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2.5 Pedestrian motion

Pedestrian motion is achieved in two stages: first the whole path of each pedestrian is computed, then each pedestrian position is updated. Each time step is sectioned in time sub-steps. Pedestrian motion applies to each time sub-step until completing the whole time step or the individual velocity is attained. The updating of pedestrian positions is made in parallel, that is, in each time step a pedestrian moves to the last cell of the computed path.

Following is the sequence of pedestrian motion:

I. Computation of pedestrian path

1. Compute the weighted social parameter of walking lane k.
2. If the weighted social value is less than 1, then go to step 5. Otherwise repeat steps 3-5 until sweeping all five possible pedestrian motions.
3. Compute the weighted social parameter for adjacent walking lanes as shown in Figure 7.
4. Compare and choose the cell with the least weighted social value.
5. Verify if cell is free, otherwise choose another free cell with the least weighted social value.
6. In case there is no free cell, pedestrian stays in the same cell.

3 Numerical simulations

We consider two types of boundary conditions in a corridor of size 10 m $\times$ 50 m for bidirectional pedestrian flow: (a) open and (b) periodic. For both boundary conditions the common parameters are: time step $\Delta t = 1$ s which is divided in five subintervals of equal length. Each pedestrian is assigned a velocity taken from a normal distribution with mean 1.34 m/s and variance 0.26 m/s. In the following figures, pedestrians in blue move from left to right, those in red move in the opposite direction.

For open boundary conditions, 0 to 5 pedestrians are introduced at the left and right boundaries every two time steps. Figure 9 shows the numerical simulation in this case for 167 pedestrians. Dynamical multi-lane flow is clearly apparent in our simulation.

For periodic boundary conditions, 125 pedestrians were uniformly distributed along the corridor as shown in Figure 10. The same pattern of dynamical lanes is also evident in this situation.

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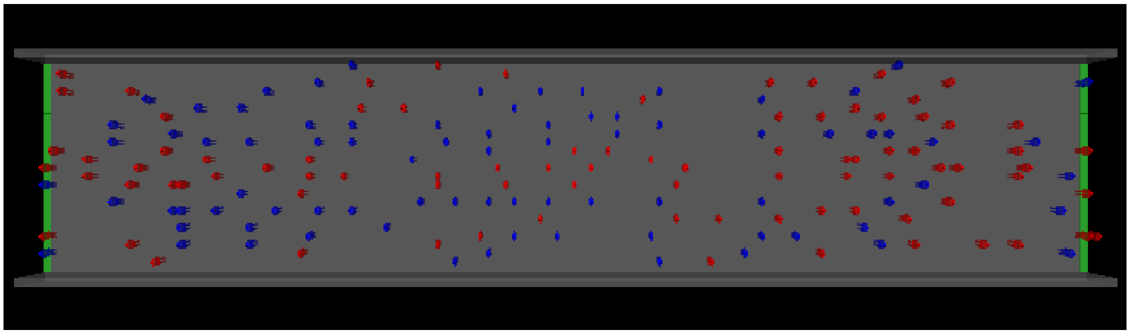

Figure 9: Numerical simulation with open boundary conditions.

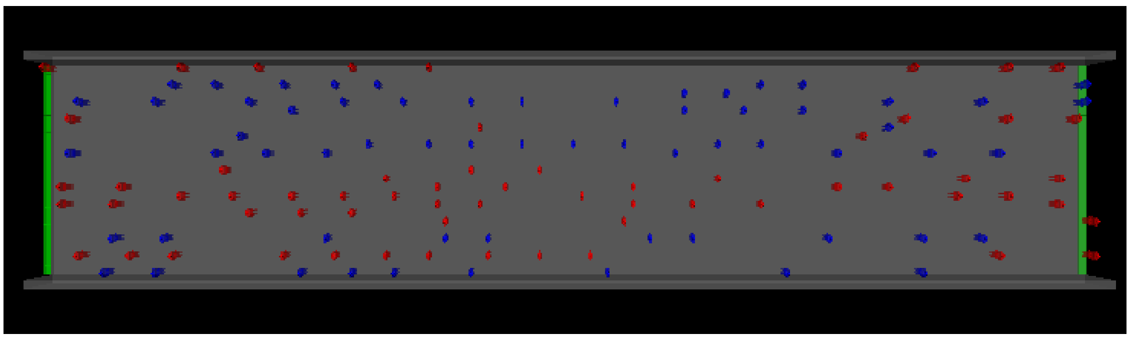

Figure 10: Numerical simulation with periodic boundary conditions.

3.1 Fundamental diagram

We compute a fundamental diagram of velocity vs. density from our CA model. Data were generated as follows: A corridor of 3.6 m $\times$ 40 m size was simulated. Each simulation was run for 500 s. After a transient period of 60 seconds when the flow has been stabilized, data (mean velocity and density) were computed in a sub-region of the corridor of size 3.6 m $\times$ 5.6 m. Figure 11 shows: (a) Weidmann's empirical curve (continuous), (b) computed data with social field model (red dots) and (c) computed data with modified social force model (blue asterisks) [14]. Remarkably, social field model reproduces Weidmann's curve to such high densities as 4.8 p/m^2.

4 Conclusions

We have proposed a CA model that incorporates three main features: a social field, a vision field and a weighted social parameter. Our results reproduce dynamical multi-lanes

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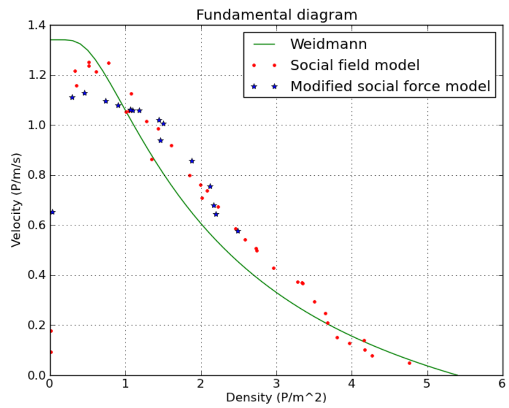

Figure 11: Fundamental diagram.

as observed empirical data published elsewhere.

Our social field model fits quite well to Weidmann's empirical curve up to high densities such as 4.8 P/m^2.

The advantages of a CA modeling are its simplicity and its computational speed which are very convenient for real time simulation.

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