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Study of influence of groups on evacuation dynamics using a cellular automaton model

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Abstract

We study evacuation processes of pedestrian crowds with differently interacting groups using an extended floor field cellular automaton model. For homogeneous crowds floor field automaton models introduce a mutual dynamic floor field and apply an equal set of update rules. We use an extended model with group-specific floor fields inducing attraction and herding behaviour within respective groups only. As another approach we introduce group-related update rules to form couples with one pedestrian leading the other. We use these approaches to model groups with symmetric and asymmetric group interactions and study the impact of such groups on evacuation dynamics.

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Keywords: evacuation dynamics; pedestrian dynamics; floor field cellular automaton model; groups; nonequilibrium physics; statistical physics

1. Introduction

In the last two decades interdisciplinary research has led to a better understanding of pedestrian traffic and evacuation dynamics. As statistical physics deals with many body systems it is a promising approach to apply methods from this field to pedestrian crowds. In fact these methods have been successfully used to create efficient computer simulations which can reproduce several characteristic collective effects and self-organization phenomena occurring during regular pedestrian traffic and evacuation scenarios (Schadschneider et al. (2009)).

However, most models assume that pedestrian crowds are homogeneous in the sense that crowds are composed of individuals interacting with each other with the same set of rules. In reality pedestrian crowds are not homogeneous, but most individuals move in groups e.g. with family members or friends (Moussaïd et al. (2010)). Especially when it comes to emergency situations and evacuation scenarios it is important that this fact is not overlooked. Therefore it is of high interest to understand how evacuation dynamics change when a pedestrian crowd contains groups whose dynamics are governed by group-specific subsets of rules. We define groups as pedestrian sub-crowds whose members share specific properties which create a group-specific interaction. Individuals of a different group distinguish in these properties. In our study the group-specific interactions are attractions between group members which create the

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tendency that the group stays together. We will call such groups distinctive groups in the following to differentiate them from groups which form spontaneously, e.g. because of a general herding behaviour.

Distinctive groups can always be characterized by a spatial coherence which is the result of the attraction between the group members. Distinctive groups can be very diverse. For example a mother who takes her child by the hand forms a very stable group of two individuals with a strong bond between the group members. Their interaction is asymmetric as the mother guides her child. It is likely that the bond persists unless it comes to very high densities. Another example is a family of several members. The family can move as a whole without an identifiable leader of motion or one family member can play the role of the group leader who is followed by the other members. In physical terms the first case would translate into a symmetric interaction the second into an asymmetric. Groups like families have a strong tendency to persist, but still can break up in high densities e.g. during emergency situations. In this case group members can get separated from the group. A third example is a loose formation of friends which tends to persist during normal situations, but may break up in smaller sub-groups during emergency situations when it comes to highly congested states.

Studies which incorporate distinctive groups from a physical perspective are comparably rare. Moussaïd et al. (2010) examined pedestrian groups outside of emergency situations. Here the pedestrians' interactions and the resulting walking patterns mainly arise from the desire for comfortable communication. Pedestrians tend to walk abreast in low densities or - depending on the number of group members - in V-like or U-like shapes in higher densities. However, in evacuation scenarios the demand for comfortable communication is of low importance compared to the desire to leave the room (Koester et al. (2011)). In our study we concentrate on evacuation dynamics and therefore anticipate that the herding behaviour which arises in emergency situations will be dominant (Kirchner and Schadschneider (2002)). We do not consider model parameters which achieve special shapes of groups here.

The diversity of groups and the multiplicity of scenarios such groups can be exposed to show that it is difficult to find a general model which allows efficient computer simulations of pedestrian dynamics for all cases. It is necessary to examine different models and their applicability to specific groups and situations. We therefore develop different models for computer simulations of evacuation processes in the presence of groups and study the underlying mechanisms which create the respective group interaction. In a next step these models have to be validated against real life scenarios. We currently evaluate experiments which could be used to conduct the validation.

Our computer simulations are based on floor field cellular automata (FFCA) models which have been successfully used to simulate collective phenomena of homogenous pedestrian crowds in the past (Burstedde et al. (2001), Kirchner and Schadschneider (2002), Kirchner et al. (2003)). We introduce additional properties to the FFCA creating the desired group interactions. In our paper we first give an introduction to the general model using FFCA for simulations of pedestrian movement in the absence of distinctive groups. We then extend the FFCA model for group interaction and examine the impact on evacuation dynamics. We first extend the notion of dynamic floor fields by introducing group-specific dynamic floor fields which create attraction between members of the same group only. We then introduce a new floor field, the moving target floor field, that creates a permanent attraction between group members. As a third approach we define new update rules to create a fixed bond between couples of leaders and followers. Finally we compare the results.

2. Modeling groups with group floor fields

The FFCA model as introduced by Kirchner and Schadschneider (2002) is defined on a two-dimensional lattice with discrete time evolution. Each cell of the lattice can be occupied by one particle which represents a pedestrian. A set of N particles interacts with the static floor field and the bionics-inspired dynamic floor field which translates long-range interactions between particles into local interactions with the occupied and neighboring cells of each particle. For a thorough discussion of the FFCA model we refer to Kirchner and Schadschneider (2002). For computer simulations the model has the advantage that the number of interactions which need to be calculated in each time step can be reduced to $O(N)$ instead of $O(N^2)$ like in social-force models which take their inspiration from classical mechanics. This considerably reduces calculation efforts and allows real time simulations of large crowds. However, the standard model assumes that all pedestrians have the same interaction with the floor fields. This means that all pedestrians have the same level of orientation towards the exits and the same tendency to get attracted by other pedestrians via the dynamic floor field. The standard FFCA model represents a homogeneous crowd and does not allow to distinguish between different groups. Following our definition of distinctive groups it is our aim to enhance the FFCA model in a way that it considers attractive interactions between group members. This will ensure the tendency to reproduce the spatial coherence of groups.

We use an object-oriented software-design to implement the properties of cells, particles and bosons mediating the interaction between particles. The flexibility of objects allows an efficient implementation of changes to the model. For example boson objects can be easily extended by additional information, e.g. the time step at it was dropped. This information could then be used for models which incorporate temporal aspects of interaction.

2.1. Modeling large groups with the dynamic group floor field $D^{(s)}$

Our first approach to model distinctive groups extends the notion of the dynamic floor field within FFCA models. We introduce n different species of particles (pedestrians) and assign a specific dynamic group floor field $D^{(s)}$ to each species s. When moving from one cell to another each particle drops m "bosons" which increase the dynamic group floor field of the respective species by m. The bosons play the role of trace markers which locally increase the transition probability of associated particles. Hence they mediate the interaction between particles. In contrary to the particles the trace markers do not obey an exclusion principle. Therefore the particles have fermionic characteristics while the trace markers feature bosonic characteristics, which explains the choice of terminology. The bosons decay with probability δ and diffuse to a neighboring cell with probability α. Each particle interacts only with bosons which have been dropped by particles of the same species. In addition each boson carries the information from which individual it was dropped. This way we can ensure that individuals do not interact with bosons they dropped themselves to avoid self-interaction. Self-interaction would add noise to the system and would not contribute to the desired attractive effects between group members. This is particularly important when particles drop a high numbers of bosons m. Due to the resulting high and long-lived nonvanishing field values self-interaction can occur over several time steps and lead to resonance effects with long-lasting oscillations around cells with highly increased field values. Due to the oscillatory motion the field is locally self-perpetuating and can persist for a long time. This effect can lead to highly increased evacuation times. Such oscillations cannot be observed in real evacuation scenarios and would counteract realistic simulation results.

In the following we use the concept of dynamic group floor fields to simulate a crowd of pedestrians consisting of large distinctive groups of same size and study the impact on evacuation times. In all simulations we will use a quadratic grid. The outer cells of this grid are inaccessible wall cells apart from a defined set of door cells which form one door through which the pedestrians can exit the room. Pedestrians of each group drop one boson when moving from their cell to a neighboring cell. These bosons will only be sensed by members of the same group. For positive values of the coupling constant k_D the transition probability $p_{ij}^{(s)}$ to an accessible cell at (i, j) increases for a pedestrian of species s with higher values of the associated group floor field $D_{ij}^{(s)}$.

With increasing coupling parameter k_D the simulations show that the pedestrians tend to form clusters of the same group with progressing time evolution. Like in simulations of homogeneous crowds herding behaviour can be observed, but here it is limited to pedestrians of the same group. The dynamic group floor field induces selective herding behaviour which creates the desired attraction between group members.

It is an interesting question how the separation in groups changes evacuation times. We therefore simulate pedestrian evacuation on a grid of 63×63 cells with one door cell in the middle of a wall and randomly distributed pedestrians with density $\rho = 0.3$. The evacuation times T are measured in update time steps and are averaged over 100 runs. We will regard the evacuation as completed when 95% of all pedestrians have left the room. It can be observed that single remaining pedestrians sometimes take much longer to leave the room than the majority of the crowd. With the quota we eliminate such cases.

Fig. 1 shows the dependence of the evacuation time T on the coupling parameter of the group floor field k_D for a crowd consisting of large distinctive groups. The case of one group coincides with the case of a homogeneous crowd. For all four cases it can be seen that evacuation times show a non-trivial dependence on k_D with a minimum for values $k_D < 1$. This means that moderate herding behaviour can lead to decreased evacuation times as pedestrians follow others on their way to the exit. This behaviour has already been observed by Kirchner and Schadschneider (2002) for homogeneous crowds. Fig. 1 shows that the cooperative effect of the dynamic floor field persists in the presence of distinctive groups. However, in the cooperative regime overall evacuation times increase with the number of groups and the characteristic minimum becomes less distinctive. This can be understood in the sense that the cooperative effect between pedestrians is limited once the crowd does no longer interact as a whole. Due to the separation in groups the dynamic floor field is diluted as a smaller number of pedestrians drop bosons which contribute to the field others can sense. The fact that graphs cross indicates that for strong coupling to the field (disordered regime) the dilution turns into an advantage. In homogeneous crowds strong coupling to the dynamic floor field leads to increased evacuation times since the dominating herding behavior impairs orientation towards the exits. The dilution of the field mitigates this effects which results in decreasing evacuation times for an increasing numbers of groups.

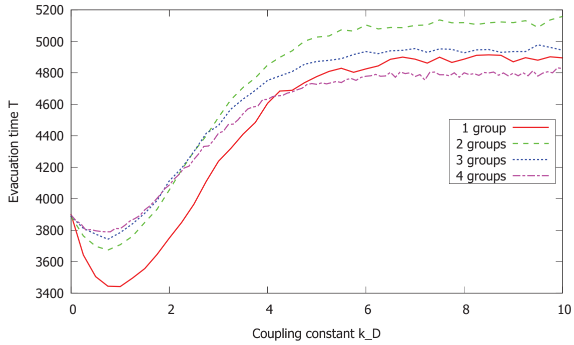

Fig. 1. Averaged evacuation times for a crowd consisting of one, two, three and four large groups of same size with a total initial particle density $\rho = 0.3$ (1116 pedestrians), coupling constant for static floor field $k_S = 0.4$, decay parameter $\delta = 0.2$ and diffusion parameter $\alpha = 0$.

2.2. Modeling asymmetric pair-coupling with the dynamic group floor field $D^{(s)}$

For another application of dynamic group floor fields we move from large groups to minimum groups of two pedestrians. While the interaction of large groups was symmetric between group members the interaction of interest is asymmetric here. The crowd is solely composed of couples which consist of a leader and a follower. One could think of such a couple as a mother leading her child through the room. Both leaders and followers have an orientation towards the exit which can be different. The respective orientation is represented by two coupling constants for the static floor field k_{SL} for the leader and k_{SF} for the follower. Leaders drop one public and m group-specific bosons in each time step. Leaders can sense only the public bosons, which allows them to interact with the other leaders analogous to the standard FFCA model. The new approach in this model is that each follower can only sense bosons which have been dropped by his leader. In contrary to the standard FFCA model as introduced by Kirchner and Schadschneider (2002) leaders can drop more than only one boson at each time step. This property is important as the pedestrian crowd is highly fragmented into two-pedestrian-groups and therefore the dynamic floor field the followers can sense is highly diluted. In order to allow followers to continuously follow the trace of their leaders it is required to enrich the field by a higher number of bosons which are dropped at each time step. In addition decay and diffusion of bosons have to be fine-tuned. While diffusion adds noise and will not lead to improved evacuation times in the standard FFCA model by Kirchner and Schadschneider (2002), it has positive effects on the orientation of followers since it broadens the trace of a leader. A high number of bosons per time step creates a trace of dynamic floor field values with enhanced spatio-temporal information via decay and diffusion. Within the trace field values increase with decreasing distance to the leader on average. This results in a field gradient which points to the position of the leader and allows the follower to orientate towards his leader.

We simulate evacuation of such couples on the grid we used before for two different densities. The evacuation times T are again measured in update time steps and are averaged over 100 runs. The pairs are randomly distributed over the field however the followers are set next to the leaders and do not move in the first time step since no dynamic floor field is present before first movement. This prevents followers from losing the trace of their leaders, e.g. by moving in the opposite direction. Instead of only one boson leaders drop 40 bosons which can be sensed by their follower. Only one boson per time step can be sensed by other leaders. This way it can be avoided that leaders confuse other leaders with their trace while still a cooperative mechanism between leaders can be maintained. As we know from previous simulations by Kirchner and Schadschneider (2002) with homogeneous crowds a strong influence of the dynamic floor field between the leaders would increase evacuation times and we want to avoid this additional effect.

The left diagram of Fig. 2 shows the dependence of evacuation times T on the coupling parameter k_D of the group floor field for different values of k_{SL} in low density of $\rho = 0.02$, which equals 74 pedestrians. k_{SF} is set at $k_{SF} = 0.2$. This means that the orientation of followers towards the door is low. The right diagram shows the same setting for high densities ($\rho = 0.3$). It can be seen that the guidance of the leaders results in reduced evacuation times for low densities, but in high densities there is only little effect visible. This can be understood as follows.

In areas with free flow it can be observed that the model produces a mutual movement of followers and leaders for sufficiently high values of k_D. Pairs stay together while approaching the door cells. This can be verified by the reduced evacuation times for low densities ρ (see Fig. 2). If the orientation of leaders towards the door is better than the orientation of the followers ($k_{SL} > k_{SF}$) sufficiently high values of k_D clearly reduce evacuation times. Followers sense the dynamic group floor field produced by their respective leader and follow him on his oriented way towards the exit. Interestingly, the evacuation times do not monotonically decrease with increasing orientation k_{SL} of the leaders (see inset graph of Fig. 2). Evacuation times take on a minimum for moderate values of k_{SL}. Here followers can follow their leaders best. In higher densities the behaviour is completely different. At some point the couples enter the typical half-circle jamming configuration in front of the door (Kirchner and Schadschneider (2002)) and movement of the leaders is highly reduced. Like the standard dynamic floor field the group dynamic floor field is not related to position but to the flow of particles. Due to the low flow of particles in congested situations leaders rarely drop new bosons and the group dynamic floor field decays and eventually reaches low values or zero. This causes that within the jam there is a high probability that followers lose the trace of their leaders. When this happens they need a much longer time to find the doors as k_{SF} is small and thus their orientation is low. In case a follower loses the trace of his leader the cooperative effect vanishes completely for this couple. Therefore in high density situations the dynamic group floor field is of little effect for the overall evacuation time.

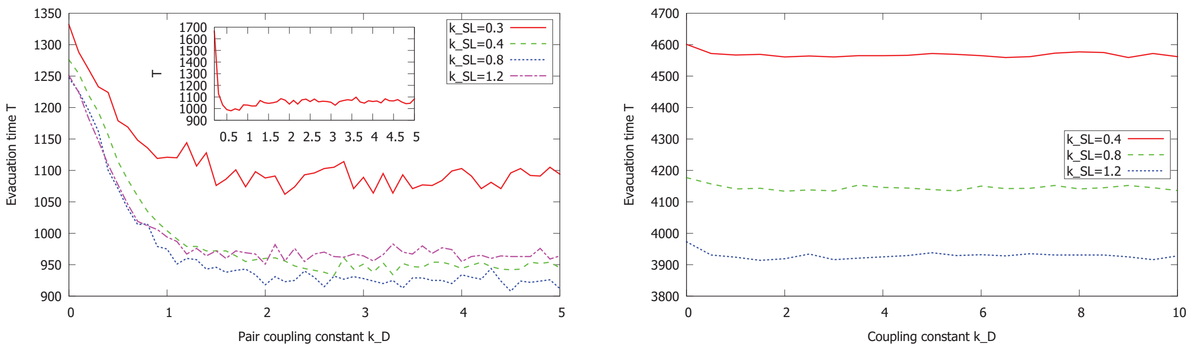

Fig. 2. Evacuation times against the strength of pair-coupling k_D and different levels of orientation of the leader (k_{SL}). The orientation of the follower is at a low level of $k_{SF} = 0.2$. Left: Low densitiy situation ($\rho = 0.02$).The inset graph shows the non-monotonic dependency of T on the leader's orientation (k_{SL}) for fixed $k_D = 3$. Right: High densitiy situation ($\rho = 0.3$).

2.3. Modeling asymmetric pair-coupling using the moving target floor field $M^{(s)}$

By construction the dynamic group floor field carries temporal information about recent movement of group members and creates a tendency to move to cells which have been recently left by a group member. In congested situations it is likely that the field decays and no trace is available anymore. We therefore study another mechanism which can build up a continuous interaction between a leader and his follower.

The moving target floor field $M^{(s)}$ is associated to the leader of group s and permanently carries full information about the direction to the leader. It can only be sensed by followers of the same group and does not affect pedestrians outside of the group. Here the interaction of leader and follower is asymmetric, permanent and of unlimited reach. Followers can get separated from the group, but in contrary to the dynamic group floor field the attraction to the leader will persist. The persistence of bonds ranges between the dynamic group floor field and the leader-follower model with fixed bonds, which we will study in the next section. Though the moving target floor field is not static, but evolving with time, a snapshot of the moving target floor field has similarities to the static floor field. $M^{(s)}(T)$ is calculated in each time step T for each cell which is occupied by a follower and the four neighboring cells using a distance metric:

$$M_{ij}^{(s)}(T) = \max_{(\tilde{i},\tilde{j})}\left\{ \sqrt{(i_L(T)-\tilde{i})^2 + (j_L(T)-\tilde{j})^2} \right\} - \sqrt{(i_L(T)-i)^2 + (j_L(T)-j)^2} \quad (1)$$

The strength of $M^{(s)}$ in each cell depends on the distance of the cell to the leader of the group s. $(i_L(T), j_L(T))$ denotes the position of the leader at time step T. $\max_{(\tilde{i},\tilde{j})}\left\{ \sqrt{(i_L(T)-\tilde{i})^2 + (j_L(T)-\tilde{j})^2} \right\}$ is a normalization term where $(\tilde{i}, \tilde{j})$ runs over the cells occupied by the follower and all neighboring cells (von Neuman neighborhood). This ensures that field values of $M_{ij}^{(s)}$ increase with decreasing distance to the leader. For efficiency reasons $M_{ij}^{(s)}$ is only calculated for each set of five cells relevant for the movement of each follower. Fig. 3 shows an example of the construction of $M_{ij}^{(s)}$ at a given time step. The total transition probability of a follower of group s is:

$$p_{ij} = N \exp(k_{SF} S_{ij} + k_M M_{ij}^{(s)})(1-\eta_{ij})\xi_{ij} \quad (2)$$

with occupation number $\eta_{ij} = 0, 1$ and obstacle number $\xi_{ij} = 0, 1$ depending on the accessibility of the cell. N is the normalisation of probabilities which is the inverse of the sum of all relevant transition probabilities.

In the moving target floor field model a leader can have an arbitrary number of followers, but we will restrict our studies to pairs of leaders and followers to maintain comparability to the two other models of asymmetrically coupled two-pedestrian-systems studied here. To understand the influence of the model on evacuation dynamics we measure the evacuation times for increasing values of the coupling constant k_M. We conduct all simulations on a 63×63 grid with one exit formed by three door cells in the middle of a wall and a high density of $\rho = 0.3$. We study three different system configurations which reflect different properties of the coupled pedestrians. In config. 1 we equip leaders and followers with the same moderate level of orientation towards the exit ($k_{SL} = k_{SF} = 0.4$). In config. 2 followers have a moderate level of orientation ($k_{SF} = 0.4$) while the leaders have a better orientation ($k_{SL} = 0.8$). In config. 3 followers have a low level of orientation ($k_{SF} = 0.2$) while their leaders have much better orientation ($k_{SL} = 1.2$). Fig. 3 shows the result for the three different situations. In contrary to the dynamic group floor field we can clearly see effects in high density situations. The moving target floor field mediates a permanent interaction which does not depend on flow. The case of $k_{SF} = k_{SL} = 0.4$ shows increased evacuation times for increasing values of k_M. The coupling in pairs is disadvantageous for the orientation towards the exit. This is due to the increasing herding behaviour of the followers which results in a lower orientation to the exit. This behaviour culminates in the occurrence of long-term gridlocks. These can be observed for high values of k_M and low door width. Gridlocks also occur for couples with fixed bonds. We will study such systems in the next section. The phenomenon arises when followers are positioned next to door cells, but block the exit because they are oriented towards their leader instead of moving to the door cell to exit the room. In config. 3 the less oriented followers profit from their orientation towards their better oriented leaders. With increasing coupling strength k_M the evacuation times clearly decrease. Since the moving target floor field only depends on position this effect persists in high density situations. In config. 2 the two opposing effects of config. 1 and 3 mix and nearly compensate.

3. Asymmetric fixed-bond leader-follower floor field model

In the following we will consider modifications to the update rules of the floor field model to address the evacuation dynamics of pedestrians in distinctive, fixedly joined groups of two. This leader-follower model is motivated by asymmetric two-person-dynamics with a designated leading pedestrian and a decision-free follower such as the scenario of a mother with her trailing child. In this setup we assume all pedestrians to be part of such a two-person-group. Besides that this model is a simple form to introduce the aspect of distinctive group dynamics into pedestrian evacuations, it realizes its application in evacuations of strongly bonded couples. The approach taken leaves the fields of the FFCA model as introduced in Sec. 2 unchanged. Instead the setup and update rules are modified. At time step $T = 0$ fixed bonded couples will be randomly distributed on the lattice. The agents of a pair are connected via a virtual bond and cannot be separated throughout the process. Additionally one pedestrian in each pair is named the 'leader' while

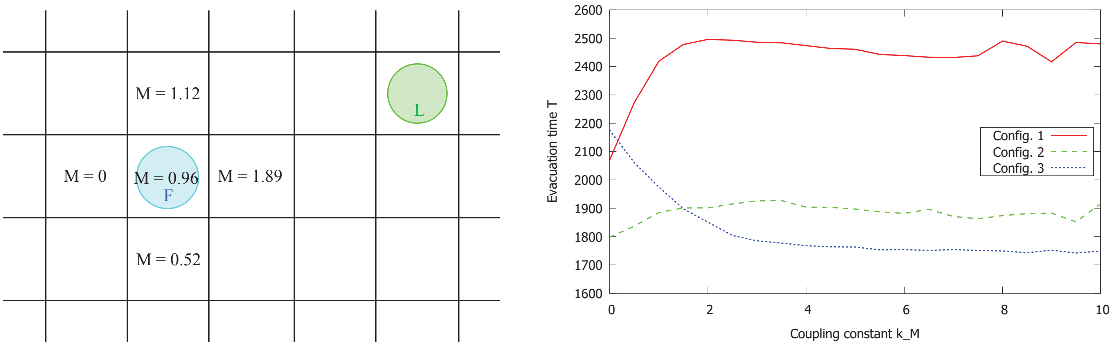

Fig. 3. Left: Construction of the moving target floor field. At each time step T the leader ("L") induces a moving target floor field around each follower ("F"). M denotes the field values. Right: Averaged evacuation times T against coupling constant k_M for three configurations. Config. 1: $k_{SL} = k_{SF} = 0.4$, config. 2: $k_{SL} = 0.8$ and $k_{SF} = 0.4$, config. 3: $k_{SL} = 1.2$ and $k_{SF} = 0.2$.

the other will be the 'follower'. During each update step (parallel-update), the corresponding transition probability calculations and conflict resolutions are done only for the leader according to the rules of the simple floor field model of Kirchner and Schadschneider (2002). This reduces the maximum number of transition directions from four to three, as one previously available direction is now blocked by the trailing agent (see Fig. 5). All resulting movements are then done by the leaders who are immediately (same time step) trailed by the followers, as they occupy the site previously held by their leader. The produced dynamics can, in other words, be understood as the motion of a reduced number of particles (half) with twice the previous size (two cells instead of one).

In the following quantitative and qualitative results will be discussed to achieve a better understanding of the impact of the fixed-bond leader-follower model. In particular it is of interest whether this model reduces evacuation times, and whether the motion can be compared to those of individual dynamics at half density. In all simulations a quadratic 63×63 lattice is used with one exit with the width of three lattice sites (unless stated otherwise) on one side. The density ρ for the standard processes is chosen to be $\rho = 0.3$ (corresponding to 1116 pedestrians). Accordingly, all processes done for half-sized densities contain 558 walkers. Given that the pedestrian motion is determined by the underlying dynamical and static fields of the floor field model, a first approach is to analyse their effect on the group dynamics (see Kirchner and Schadschneider (2002) for basic floor field results). In Fig. 4 the static parameter k_S is varied for a constant dynamic parameter k_D=0, while k_D is varied for $k_S = 0.4$.

The static parameter is used as a control measure of how strong the attraction of the exit is felt by the pedestrians at each cell. Hence, a small value of $k_S \ll 1$ indicates little knowledge of the surroundings and can thus be used to simulate dark or smoke filled locations. In particular, for $k_S \to 0$ the pedestrians perform a random walk throughout the lattice and the evacuation time is bounded by some maximum value depending on the lattice size. On the other hand, $k_S \to \infty$ suggests full knowledge of the surroundings at every point and induces a trajectory along the fastest possible path for each pedestrian. The evacuation times thus also have some lower bound to which they converge. It can be seen in Fig. 4 that this is indeed the case. Interestingly, the evacuation times for the group dynamics lie in between those for the individual agent processes for $k_S \ll 1$ and $k_S > 1$, effectively moving closer to the times for the half-density data for increasing k_S. Additionally we see that for a small interval there seems to be a disturbance in the dynamics of the leader-follower process causing the evacuation times to rise whilst also fluctuating strongly. Both observations can be explained when considering that this model introduced positive and negative effects on the evacuation times. It appears that reducing the particle number by combining pedestrians to fixed bonded pairs also reduces the evacuation times. Besides the fact that less effective agents need to find the exit, random backward transition probabilities are forbidden which correspondingly favor a more direct exit route. Opposingly, there seem to be two different effects of clogging occurring, which delay the evacuation times. These can be separated into inner clogging which is always present, but varies in strength depending on the field parameters and exit clogging which only occurs for k_S values in a critical interval depending on the choice of k_D. The former can simply be explained by considering that straying particles (particles that are deviating left or right) are harder to pass due to the greater size. This effect is reduced for larger k_S where the dynamics of the leader-follower model are related more and more to half-density dynamics of individual agents. The latter effect describes clogging through which the exit doors are being blocked. This can be understood when considering the scenario of a leader-follower particle sitting in front of the right most exit cell at time step T to transition right (away from the door; possible in the floor field model) so that the follower now blocks one of the exit possibilities. It has previously been shown that the floor field model realistically reproduces a cluster of all pedestrians surrounding the exit doors leaving few empty cells and thus reducing the probabilities for transitions (Burstedde et al. (2001)). This implies that the leader-follower pair blocking one exit cell might not be able to move further for quite some time, thus clogging the exit motion. This exit clogging effect causes the evacuation time fluctuations in the critical interval and will be now discussed in more detail.

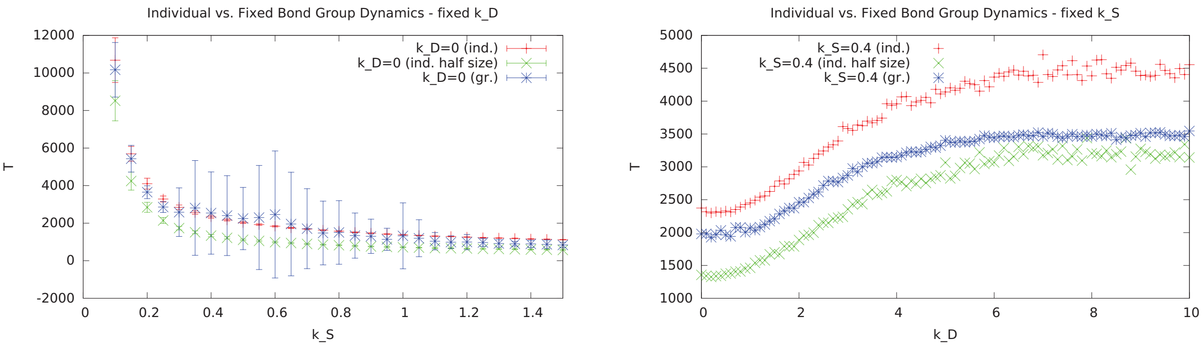

Fig. 4. The evacuation time is plotted against each of the sensitivity parameters k_D and k_S, while the respective other parameter is held constant. Both plots contain three different data sets, one for each of the individual evacuation processes at ρ=0.3 and ρ=0.15, and one for the group dynamics for ρ = 0.3.

In Fig. 5 the effect of clogging for a setup with exit doors of width two is presented. For the plots, clogging in % against k_S, an upper time cut off was implemented in the simulations as an indicator to when a process results in a fully clogged exit scenario in which further evacuation becomes impossible on relevant time scales. For each parameter configuration 100 runs were done. The clogging percentage indicates how many of those runs resulted in unsuccessful evacuations and can be understood as a probability value. For $k_S \ll 1$ this probability is equal to zero. This is the case because the pedestrians start out uniformly distributed and have such an undirected motion towards the exit that no relevant cluster forms in front of the door cells. Increasing the static parameter causes the system to be in a phase where clogging at exit doors becomes more and more relevant, before dying off again. Here the overall evacuation time averages fluctuate because now clogging which exists on relevant time scales (i.e. disappears again) causes a deviation of these times from their optimal value. The averages were always only taken with the results from successful evacuations.

The effect of inner clogging can also be seen in the k_D-against-T plot in Fig. 4. Here the fluctuating clogging effects at the exit were filtered to allow an analysis of the optimal evacuation times of the different setups. A larger k_D value corresponds to a larger urge for particles to follow a virtual trace left by previously transitioning particles, thus the formation of pedestrian clusters throughout the automaton occurs. Again for smaller values of k_D the inner clogging plays more of a role than for larger values where the evacuation times of the group dynamics and those of individual walkers at half-density approach a closer difference. For larger k_D it becomes more likely for particles to follow one another and reduce congestion through particles running into one another.

Concludingly it can be said that the asymmetric fixed-bond leader-follower model introduces different interesting phenomena of clogging. On the one hand, due to the limitations of the model, severe clogging can occur at the exits resulting in the possible evacuations only on time scales much larger than relevant. On the other hand, non fluctuating inner clogging due to larger particle size is constantly influencing the processes but decreases for greater knowledge of the surroundings (k_S, k_D value).

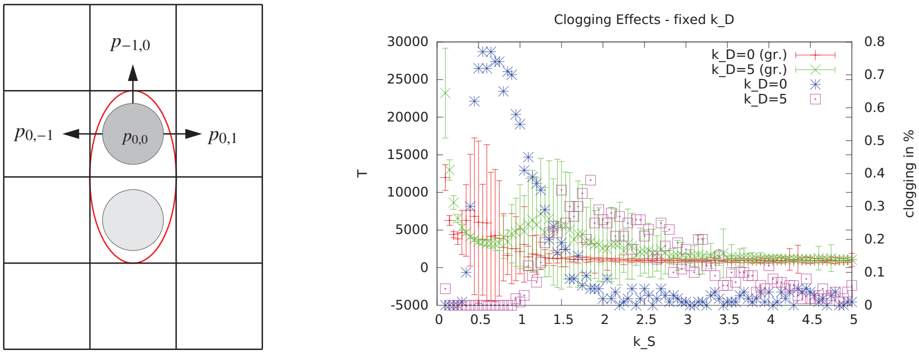

Fig. 5. On the left hand side the setup of the asymmetric fixed-bond particle in a cellular automaton, including possible transition probabilities, is presented. The 'leader' is identified via the darker shaded circle and defines the motion. The effect of clogging which is produced by these distinctive two-person-groups, is visualized by plotting the evacuation times against k_S for $k_D = 0, 5$ (right hand side). The fluctuations occurring due to the clogging can be seen directly, as well as through the plots: clogging in % against k_S.

4. Conclusions

We have studied different models using floor field cellular automata to incorporate distinctive groups into evacuation dynamics. We have shown that the concept of dynamic group floor fields is able to reproduce symmetric group formation of large groups. It can also reproduce asymmetric group formation for leader-follower-groups in low densities with the tendency to break up in higher densities. The moving target floor field can be used to model leader-follower-groups in all densities. It creates permanent interactions which persist even in high densities, however, groups can still break up. The asymmetric fixed bond leader-follower model creates a permanent bond. Here coupled particles act like one larger particle which leads to decreased evacuation times compared to models for individual particles. The increased particle size and the restricted directions of motion can cause clogging effects which do not occur in this form in homogeneous models.

We want to emphasize that further research has to validate the different models. In addition more mechanisms of group formation have to be taken into account and compared to reality. The diversity of groups suggests that no general model will suit all scenarios, but a well-understood portfolio of models can provide the basis to apporach the various evacuation scenarios containing distinctive groups.

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