Conflicts and Friction in Pedestrian Dynamics

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Abstract. "Conflicts" occur generically in particle-hopping models with parallel dynamics when multiple occupation of sites is forbidden. For cellular automata models of pedestrian dynamics we argue that such conflicts represent an important aspect of the real dynamics. Clogging at bottlenecks is described more realistically if one introduces "friction", i.e. conflicts in which none of the involved agents is allowed to move.

Keywords: cellular automata, evacuation simulation, floor field model.

1 Introduction

Usually, cellular automata (CA) models are based on discrete time dynamics which is realized in computer simulations through a synchronous (parallel) updating scheme. In models with moving particles (*particle-hopping models*) [1,2], this causes inherent problems if an *exclusion principle* has to be satisfied, i.e. if a site can not be occupied by more than one particle. This leads to *conflicts* when two or more particles try to move to the same destination cell within the same timestep (Fig. 1). Since multiple occupations are not allowed a procedure to resolve these conflicts has to be defined. Obviously this is a complication of the dynamics which has a direct influence on the efficiency of simulations. Therefore it is often tried to avoid conflicts by modifying the dynamics. However, such modifications might cause problems in identifying timescales needed for the calibration of the models.

Here we investigate the problem of conflicts in more detail in the context of the *floor field model* [3,4,5] of pedestrian dynamics which provides a rather realistic description of crowd motion and the related collective effects [6,7,8].

2 The Floor Field Model

In CA models of pedestrian dynamics space is discretized into cells which can be occupied by at most one pedestrian which leads to a typical cell size of $40 * 40\,\mathrm{cm}^2$ [3]. The timestep is identified with the reaction time of a pedestrian. Models that yield realistic crowd behaviour are based on stochastic rules where the motion of particles is determined by transition probabilities to neighbour cells.

The dynamics of the floor field model [3,4,5] takes inspiration from the process of *chemotaxis* used by ants for communication [9]. This translates effects of

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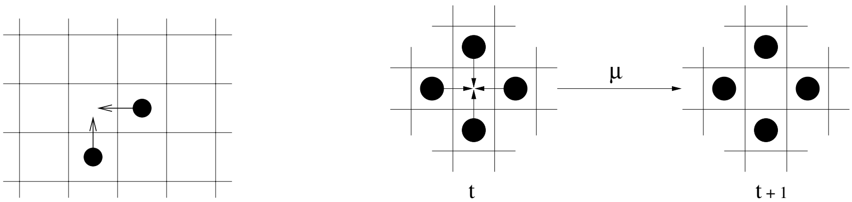

Fig. 1. Left: Typical conflict in a particle-hopping model: Two or more particles try to move to the same destination cell within the same timestep. Right: Refused movement due to the friction parameter μ for a conflict involving four particles.

longer-ranged interactions into purely local ones by introducing a kind of memory. The transition probabilities are determined by three contributions: (i) the preferred walking direction of each pedestrian, (ii) interactions with other pedestrians, and (iii) interactions with the infrastructure (walls, doors etc.). The last two contributions are incorporated via floor fields. These act like virtual chemotaxis by enhancing transitions in the direction of stronger fields.

The *dynamic floor field* $D_{ij} = 0, 1, 2, \ldots$ at site (i, j) represents a virtual trace left by moving pedestrians. Similar to chemotaxis this trace has its own dynamics (diffusion and decay), leading to its broadening and dilution. The *static floor field* $S_{ij} = 0, 1, 2, \ldots$ does not change in time. It reflects the surrounding infrastructure. For evacuation processes, S_{ij} describes the shortest distance to an exit door and increases in the direction of the exit. The relative influence of the two fields is determined by sensitivity parameters k_s and k_d. k_d controls the tendency to follow in the footsteps of others, sometimes called *herding*, and k_s determines the effective velocity of a single agent in the direction of its destination.

3 Conflicts and Friction

In the original model variant [3] conflicts are resolved by chosing one particle randomly which is allowed to move whereas the others stay at their positions. The details of this choice have only weak influence on the overall dynamics [3].

Conflicts might appear to be undesirable effects that should be avoided by using a different update scheme. However, it turns out that they are important for a correct description of crowd dynamics [5]. Although conflicts are local phenomena they can have a strong influence on global quantities like evacuation times, especially in clogging situations near intersections and bottlenecks. In real life this often leads to dangerous situations and injuries. We will show that the inclusion of conflicts in the model is important for a correct reproduction of the dynamics observed empirically.

For a more realistic description of clogging effects the resolution of conflicts has to be considered in more detail [5]. In real life, conflict situations often lead to a moment of hesitation before a conflict is resolved which reduces the effective velocities of all involved pedestrians. This can be incorporated in the model in a simple way: With some probability μ the movement of all involved pedestrians is denied, i.e. all remain at their site (Fig. 1). Thus with probability $1 - \mu$ one of the individuals moves to the desired cell. Usually the moving pedestrian is chosen randomly. We call this effect *friction* and μ *friction parameter* since it has similar consequences as contact friction, e.g. in granular materials.

The use of a parallel update is essential as any sequential update will disguise the number of conflicts in the system. In any model with continuous time these effects have to be implemented in a different way, e.g. through contact friction.

4 Evacuation Simulations

The influence of friction effects has been tested in simple evacuation scenarios [4,5]. Generically evacuation times will increase with increasing μ due to the conflicts near the exit which have a direct influence on the outflow [5,10]. Even at high densities the outflow shows an intermittent behaviour which is well-known from granular flow and is typical for clogging situations [11].

However, friction also leads to counterintuitive effects. Fig. 2 shows the influence of the coupling strength k_S for fixed μ. For $k_S \to 0$ pedestrians perform random walks and evacuation times are almost independent of μ since conflicts are not very important for the dynamics. In contrast, for $k_S \to \infty$ the shortest way to the exit is chosen. Then evacuation times should decrease with increasing k_S since also the effective velocity in the direction of the door is increased. This is only true for small friction μ, but for $\mu \to 1$ the number of unsolved conflicts increases due to strong jamming at the exit. Then one finds a minimal evacuation time for an intermediate coupling ($k_S \approx 1$) ($\mu = 0.9$ in Fig. 2). This means that a larger k_S, which implies a larger average velocity of freely moving pedestrians, leads to larger evacuation times. This collective phenomenon is known as *faster-is-slower effect* [7,12].

Experiments have shown [13] that the motivation level of passengers has a significant influence on the egress time from an aircraft. Egress times were measured

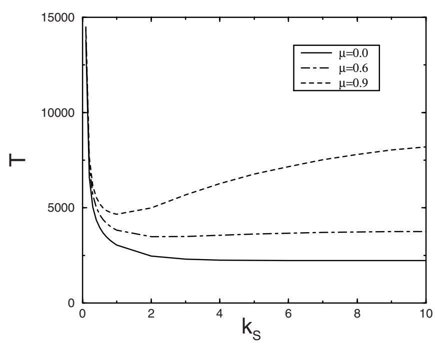

Fig. 2. Evacuation time as function of k_S for different values of μ and $k_D = 0$, $\rho = 0.3$

for various exit widths w in two different situations: (i) competitive, and (ii) cooperative (non-competitive). In the competitive case a bonus was paid for the first passengers to reach the exit. The main result is that $t_{\text{comp}} > t_{\text{non-comp}}$ for $w < w_c$, whereas $t_{\text{comp}} < t_{\text{non-comp}}$ for $w > w_c$, where $w_c \approx 70$ cm. Thus competition is beneficial for wide exits, but harmful for narrow ones.

This surprising result is reproduced by the floor field model. Competition is described by increased assertiveness (large k_S) and strong hindrance in conflicts (large μ) whereas cooperation is represented by small k_S and $\mu = 0$ [14].

5 Conclusions

We have shown that conflicts in particle-hopping models with discrete time update and particles obeying an exclusion principle be considered as an essential part of the dynamics. Their occurance is important for an accurate description of several aspects, e.g. for clogging at bottlenecks. Close to exits, conflicts are most harmful because they have a direct influence on evacuation times.

To further improve the realism of CA models of pedestrian dynamics the concept of "friction" has been introduced, i.e. with probability μ none of the particles involved in a conflict is allowed to move. This leads to effects like formation of arches near exits and has an important influence on quantities like the evacuation time. It also leads to counterintuitive phenomena like the faster-is-slower effect and an unusual dependence of egress times on the exit width and motivation level.

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