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Abstract

We study the motion of pedestrians through obscure corridors where the lack of visibility hides the precise position of the exits. Using a lattice model, we explore the effects of cooperation on the overall exit flux (evacuation rate). More precisely, we study the effect of the buddying threshold (of no–exclusion per site) on the dynamics of the crowd. In some cases, we note that if the evacuees tend to cooperate and act altruistically, then their collective action tends to favor the occurrence of disasters.

Résumé

Nous étudions la dynamique des movements de foules dans des corridors dont la visibilité est trés reduite. Tout en particulier, nous nous intéréssons á des corridors dont les sorties ne sont pas visibles. Á l'aide de notre modèlle – un automate cellullaire – nous éxploitons les éffects que la cooperation parmis les piétons produit sur le flux macroscopique d'évacuation. Dans des certains cas, nous observons que si les piétons se comportent altruistiquement, alors des phénomènes macroscopiques catastrophiques émergent de la combinaison de ces interactions locales.

Key words: Dynamics of crowd motions ; lattice model ; evacuation scenario

Mots-clés : La dynamique des mouvements de foules ; des automates cellulaire ; un scénario d'évacuation

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1 Introduction

This Note studies the following evacuation scenario: A large group of people needs to evacuate a subway station or a tunnel system [with complicated geometry] without visibility. The lack of visibility, or say, the heavily reduced visibility, can be imagined to be due to the breakdown of the electricity network, or due to the presence of a very dense smoke. We assume also that the evacuation audio signaling is not activated and that, in spite of all these difficulties, all pedestrians need to travel through this dark region and must find as soon as possible their way out towards the hidden exit. Additionally, we assume that all the persons are *equally fit* (i.e. they are indistinguishable) and that none of them has *a priori* knowledge on the location of the exit. To keep things simple, we consider that there are not spatial heterogeneities inside the region in question.

There are studies done [especially for fire evacuation scenarios] on how information and way finding systems are perceived by individuals. One of the main questions in fire safety research is whether green flashing lights can influence the evacuation (particularly, the exit choice); see e.g. [11,14,10] (and the fire engineering references cited therein) and [16] (partial visibility due to a non–uniform smoke concentration) [5] (partial visibility as a function of smoke's temperature), [17] (flow heterogeneity due to fire spreading). If exits are visible, then an impressive amount of literature provide proper working methodologies and efficient simulation tools. Preliminary assessment tests (cf. [6,2,15], e.g,) and many modeling approaches (deterministic or stochastic) succeed to capture qualitatively basic behaviors of humans (here referred to as pedestrians) walking within a given geometry towards *a priori* prescribed exits; see, for instance, social force/social velocity crowd dynamics models (cf. e.g. [8], [12], [4], [3]), simple asymmetric exclusion models (see chapters 3 and 4 from [13] as well as references cited therein), cellular automaton-type models [9,7], etc.

But, as far as we are aware, nothing seem to be known on evacuating people through regions without visibility, therefore our interest.

By means of a minimal model, we wish to describe how a bunch of people located inside a dark (smoky, foggy, etc.) corridor exits through an invisible door open in one of the four walls. We decide on this way (cf. section 2) on a possible mechanism regarding how do pedestrians choose their path and speed when they are about to move through regions with no visibility. The question that triggers our attention here is the following:

Is cooperation/group formation the right strategy to choose to ensure the crowd evacuation within a reasonable time?

2 A lattice model

We use a minimal lattice model, which we name the *reverse mosca cieca game*, where we incorporate a few basic rules for the pedestrians motion in dark.

2.1 Basic assumptions on the pedestrians motion

We take into consideration the following four mechanisms:

(A1) In the core of the corridor, people move freely without constraints;

(A2) The boundary is reflecting, possibly attracting;

(A3) People are attracted by bunches of other people up to a threshold;

(A4) People are blind in the sense that there is no drift (desired velocity) leading them towards the exit.

(A1)–(A4) intend to describe the following situation:

Since, in this framework, neighbors (both individuals or groups) can not be visually identified by the individuals in motion, basic mechanisms like attraction to a group, tendency to align, or social repulsion are negligible and individuals have to live with "preferences". Essentially, their motion is more *behavioral* than *rational*. We assume that the individuals move freely inside the corridor but they like to buddy to people they accidentally meet at a certain point (site). The more people are localized at a certain site, the stronger the preference to attach to it. However if the number of people at a site reaches a threshold, then such site becomes not attracting for eventually new incomers. (A3), referred here as the *buddying mechanism*, is the central aspect of our research.

Once an individual touches a wall, he/she simply felts the need to stick to it at least for a while, i.e. until he/she can attach to an interesting site (having conveniently many hosts) or to a group of unevenly occupied sites or the exact location of the door is detected.

Since people have no desired velocity, their diffusion (random walk) together with the buddying are the only transport mechanisms. Can these eventually lead to evacuation? How efficient is such combination?

In the following, we study the effect of the threshold (of no–exclusion per site) on the overall dynamics of the crowd. Here we describe our results in terms of the averaged outgoing flux; see Fig. 1 and Fig. 2. In a forthcoming publication, we will investigate also other macroscopic quantities like the stationary occupation numbers and stationary correlations.

2.2 The lattice model

We start off with the construction of the lattice. Let $e_1 := (1,0)$ and $e_2 = (0,1)$ denote the coordinate vectors in $\mathbb{R}^2$. Let $\Lambda \subset \mathbb{Z}^2$ be a finite square with odd side length L. We refer to this as the *corridor*. Each element x of Λ will be called a *cell* or *site*. The external boundary of the corridor is made of four segments made of L cells each; the point at the center of one of these four sides is called *exit*.

Let N be positive integer denoting the (total) *number of individuals* inside the corridor Λ. We consider the state space $X := \{0, \ldots, N\}^\Lambda$. For any state $n \in X$, we let $n(x)$ be the *number of individuals* at cell x.

We define a Markov chain n_t on the finite state space X with discrete time $t = 0, 1, \ldots$. The parameters of the process will be the integers (possibly equal to zero). We finally define the function $S : \mathbb{N} \to \mathbb{N}$ such that

$$
S(k) := \begin{cases} 1 & \text{if } k > T \\ k+1 & \text{if } k \leq T \end{cases}
$$

for any $k \in \mathbb{N}$. Note that for $k = 0$ we have $S(0) = 1$.

At each time t, the N individuals move simultaneously within the corridor according to the following rule:

For any cell x situated in the interior of the corridor Λ, and all y nearest neighbor of x, with $n \in X$, we define the weights

$$
w(x,x) := S(n(x)) \quad \text{and} \quad w(x,y) := S(n(y)).
$$

Also, we obtain the associated probabilities

$$
p(x,x) \text{ and } p(x,y)
$$

by dividing the weight by the normalization

$$
w(x,x) + \sum_{i=1}^{2} w(x, x + e_i) + \sum_{i=1}^{2} w(x, x - e_i).
$$

Let now x be in one of the four corners of the corridor Λ, and take y as one of the two nearest neighbors of x inside Λ. For $n \in X$, we define the weights

$$
w(x,x) := S(n(x)) \text{ and } w(x,y) := S(n(y))
$$

and the associated probabilities $p(x, x)$ and $p(x, y)$ obtained by dividing the weight by the suitable normalization.

It is worth stressing here that T is not a threshold in $n(x)$ – the number of individuals per cell. It is a threshold in the probability that such a cell is likely to be occupied or not.

For $x \in \Lambda$ neighboring the boundary (but neither in the corners, nor neighboring the exit), y one of the two nearest neighbor of x inside Λ and neighboring the boundary, z the nearest neighbor of x in the interior of Λ, and $n \in X$, we define the weights

$$w(x, x) := S(n(x))$$
$$w(x, y) := S(n(y)) \ w(x, z) := S(n(y)).$$

The associated probabilities $p(x, x)$, $p(x, y)$, and $p(x, z)$ are obtained by dividing the weight by the suitable normalization.

Finally, if x is the cell in Λ neighboring the exit and y is one of the two nearest neighbor of x inside Λ and neighboring the boundary, z being the nearest neighbor of x in the interior of Λ, and $n \in X$, we define the weights

$$w(x, x) := S(n(x))$$
$$w(x, y) := S(n(y))$$
$$w(x, z) := S(n(y))$$
$$w(x, \text{exit}) := T + 1.$$

The associated probabilities $p(x, x)$, $p(x, y)$, $p(x, z)$, and $p(x, \text{exit})$ are obtained by dividing the weight by the suitable normalization.

The dynamics is then defined as follows: At each time t, the position of all the individuals on each cell is updated according to the probabilities defined above. If one of the individuals jumps on the exit cell a new individual is put on a cell of Λ chosen randomly with the uniform probability $1/L^2$.

It is worth mentioning that the approach we take here is very much influenced by a basic scenario described in [1] for randomly moving sodium ions willing to pass through a switching on–off membrane gate. The major difference here is twofold: the gate is permanently open and the buddying principle is activated.

3 Comments on cooperation effects – the buddying threshold T

The possible choices for the parameter T correspond to two different physical situations. The first one, for $T = 0$, the function $S(k)$ is equal to q (the minimal quantum) whatever the occupation numbers are. This means that each individual has the same probability to jump to one of its nearest neighbors or to stay on his site. This is resembling the independent symmetric random walk case; the only difference is that with the same probability the individuals can decide not to move. We expect that this "rest probability" just changes a little bit the time scale.

The second physical case is $T > 0$. For instance, $T = 1$ means *mild buddying*, while $T = 100$ would express an *extreme buddying*. No simple exclusion is included in this model: on each site one can cluster as many particles (pedestrians) as one wants. The basic role of the threshold is the following: The weight associated to the jump towards the site x increases from 1 to $1 + T$ proportionally to the occupation number $n(x)$ until $n(x) = T$, after that level it drops back to 1. Note that this rule is given on weights and not on probabilities. Therefore, if one has T particles at y and T at each of its nearest neighbors, then at the very end one will have that the probability to stay or to jump to any of the nearest neighbors is the same. Differences in probability are seen only if one of the five (sitting in the core) sites involved in the jump (or some of them) has an occupation number large (but smaller than the threshold).
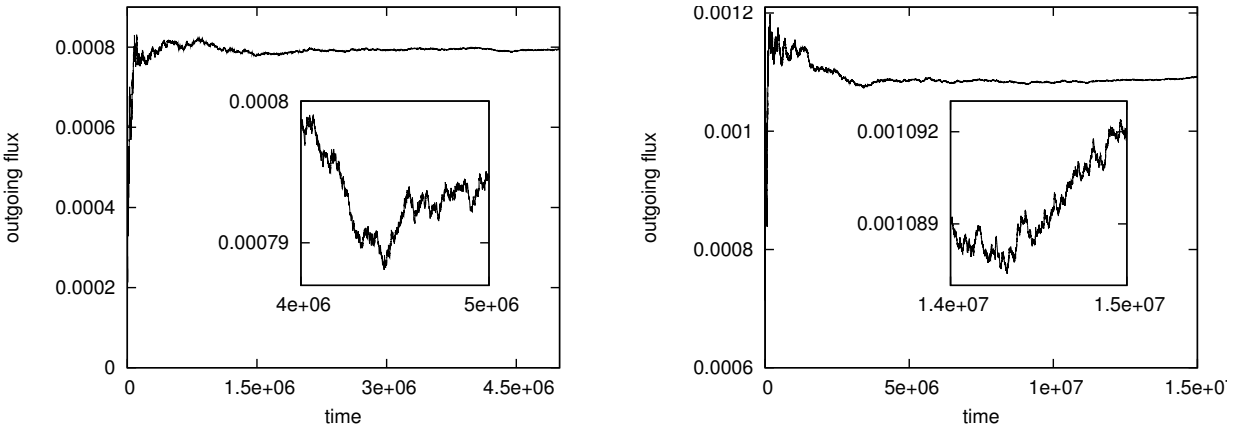

Figure 1. Averaged outgoing flux vs. time in the case $T = 0$ and $N = 100$ on the left and $T = 100$ and $N = 100$ on the right. The inset is a zoom in the time interval $[4 \times 10^6, 5 \times 10^6]$ on the left and $[1.4 \times 10^7, 1.5 \times 10^7]$ on the right.

In Fig. 2, we see that the overall dynamics very much depends on both the number N of individuals and their ability to cooperate (the threshold T). In
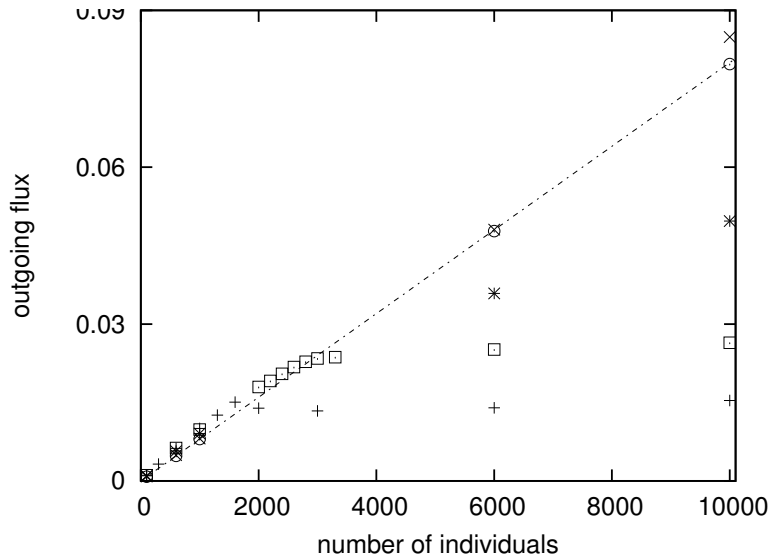
6

Figure 2. Averaged outgoing flux vs. number of pedestrians. The symbols $\circ$, $\times$, $*$, $\square$, and $+$ refer respectively to the cases $T = 0, 1, 5, 30, 100$. The straight line has slope 8×10^{-6} and has been obtained by fitting the Monte Carlo data corresponding to the case $T = 0$.

particular, this figure indicates that if N is sufficiently large, then cooperation does not seem to be the best option. Otherwise, for N sufficiently small, cooperation seems to be able to ensure a timely evacuation. This counter intuitive effect leaves us with the open questions: *How cooperation can slow emergency evacuations?* Why this effect überhaupt happens?

Acknowledgments

References

[1] D. Andreucci, D. Bellaveglia, E. N. M. Cirillo, and S. Marconi. Monte Carlo study of gating and selection in potassium channels. *Phys. Rev. E*, 84:021920, 2011.

[2] J. L. Bryan. Behavioral response to fire and smoke. In P. P. DiNenno and M. A. Quincy, editors, *Chapter 12 in SFPE Handbook of Fire Protection Engineering*, pages 3–315 – 3–341. National Fire Protection, 2002.

[3] P. Degond, L. Navoret, R. Bon, and D. Sanchez. Congestion in a macroscopic model of self-driven particles modeling gregariousness. *Journal of Statistical Physics*, 138:85–125., 2010.

[4] J. H. M. Evers and A. Muntean. Modeling micro-macro pedestrian counterflow in heterogeneous domains. *Nonlinear Phenomena in Complex Systems*, 14(1):27–37, 2011.

[5] Z.-M. Fang, W.-G. Song, J. Zhang, and H. Wu. A multi-grid model for evacuation coupling with the effects of fire products. *Fire Technology*, 48:91–104, 2012.

[6] S. Grimaz and E. Tosolini. PASS: a test-based method for a preliminary assessment of the egress system safety. In A. Cuesta, V. Alonso, and J. Cuesta, editors, *Evacuation and Human Behavior in Emergency Situations*, pages 193–207. Universidad de Cantabria, Santander, 2011.

[7] X. Guo, J. Chen, Y. Zheng, and J. Wei. A heterogeneous lattice gas model for simulating pedestrian evacuation. *Physica A: Statistical Mechanics and its Applications*, 391(3):582 – 592, 2012.

[8] D. Helbing and P. Molnar. Social force model for pedestrian dynamics. *Physical Review E*, 51(5):4282–4286, 1995.

[9] A. Kirchner and A. Schadschneider. Simulation of evacuation processes using a bionics-inspired cellular automaton model for pedestrian dynamics. *Physica A: Statistical Mechanics and its Applications*, 312(12):260 – 276, 2002.

[10] M. Kobes, I. Helsloot, B. de Vries, and J. G. Post. Building safety and human behaviour in fire: A literature review. *Fire Safety Journal*, 45(1):1 – 11, 2010.

[11] D. Nilsson, M. Johansson, and H. Frantzich. Evacuation experiment in a road tunnel: A study of human behaviour and technical installations. *Fire Safety Journal*, 44(4):458 – 468, 2009.

[12] B. Piccoli and A. Tosin. Time-evolving measures and macroscopic modeling of pedestrian flow. *Arch. Ration. Mech. Anal.*, 199(3):707–738, 2011.

[13] A. Schadschneider, D. Chowdhury, and K. Nishinari. *Stochastic Transport in Complex Systems*. Elsevier, 2011.

[14] T.J Shields and K.E Boyce. A study of evacuation from large retail stores. *Fire Safety Journal*, 35(1):25 – 49, 2000.

[15] F. Venuti and L. Bruno. An interpretative model of the pedestrian fundamental relation. *Comptes Rendus Mécanique*, 335:194–200, 2007.

[16] W. Yuan and K. H.Tan. A model for simulation of crowd behaviour in the evacuation from a smoke-filled compartment. *Physica A: Statistical Mechanics and its Applications*, 390:4210 – 4218, 2011.

[17] Y. Zheng, B. Jia, X.-Gang Li, and N. Zhu. Evacuation dynamics with fire spreading based on cellular automaton. *Physica A: Statistical Mechanics and its Applications*, 390:3147–3156, 2011.

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