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Does communication enhance pedestrians transport in the dark?

La communication facilite-t-elle le déplacement des piétons dans l'obscurité ?

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ABSTRACT

We study the motion of pedestrians through an obscure tunnel where the lack of visibility hides the exits. Using a lattice model, we explore the effects of communication on the effective transport properties of the crowd of pedestrians. More precisely, we study the effect of two thresholds on the structure of the effective nonlinear diffusion coefficient. One threshold models pedestrian communication efficiency in the dark, while the other one describes the tunnel capacity. Essentially, we note that if the evacuees show a maximum trust (leading to a fast communication), they tend to quickly find the exit and hence the collective action tends to prevent the occurrence of disasters.

RÉSUMÉ

Nous étudions la dynamique des mouvements de foules dans un tunnel dans lequel la visibilité est très réduite. Nous nous intéressons tout particulièrement à des tunnels dont les sorties ne sont pas visibles. À l'aide de notre modèle – un automate cellulaire – nous exploitons les effets de la communication interpersonnelle parmi les piétons sur la structure de la non-linearité du coefficient de diffusion. Nous modélisons l'efficacité de la communication interpersonnelle ainsi que la capacité des sorties à l'aide de deux barrières.

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1. Introduction

This Note deals with the following evacuation scenario: a possibly large group of pedestrians needs to evacuate a long and obscure tunnel. The lack of visibility is due to either an electricity breakdown or to a dense smoke. The basic modeling assumption is that the pedestrians are equally fit, do not know each other, and also, are unaware of the precise geometry of

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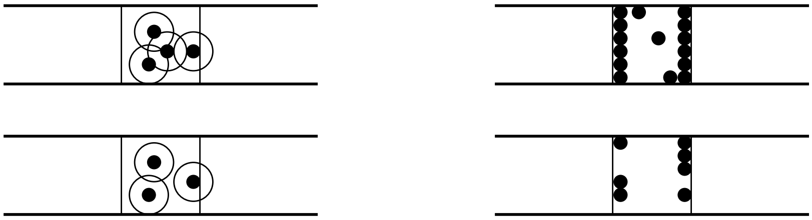

Fig. 1. Sketch of pedestrians moving through a cell of the obscure tunnel driven by a two-threshold biased dynamics.

the tunnel. We wish to build a lattice model to explore the effects of communication on the effective transport properties of these pedestrians. As a modeling tool, we use a particular type of particle system, known as zero-range process (abbreviated here ZRP), whose dynamics is affected by two thresholds. One threshold – called *activation threshold* – models pedestrian communication efficiency in the dark, while the other one – the *saturation threshold* – describes the tunnel's capacity. From the modeling point of view, the activation threshold is open to many interpretations. In this Note, we associate the size of this threshold not only with the geometric level of the possibility of communication, but also with the willingness and ability of the pedestrians to process the transmitted information to make a decision towards orientation to a potential exit or choice of speed in the dark. We refer to this as the *level of trust*. Essentially, a small activation threshold implies in this context a high level of trust.

In Fig. 1, we sketch the meaning of the two thresholds, whose precise mathematical definition is given in Section 2. Each solid circle represents a pedestrian, whereas the associated open (bigger) circle represents his/her communication domain and level of trust. On the left bottom, the number of pedestrians in the cell is so small that their typical distance is larger than the radius of the communication domain. On the left top, we see that if the number of pedestrians is large enough, information can propagate throughout the cell. In other words, we assume that information can be efficiently transmitted among the different pedestrians as soon as any single communication domain (the open circles) intersects at least one other pedestrian. Essentially, we need here a minimal degree of packing of the open circles, which is guaranteed in our scenario by the activation threshold. When the number of pedestrians in a cell is smaller than the activation threshold, the rate at which people leave the cell is equal to a minimal quantum; on the other hand, above the activation threshold, such a rate increases proportionally to the number of people in the cell.

On the right of Fig. 1, we show how the bounded capacity of the tunnel naturally leads to the introduction of a saturation threshold. In the bottom part, we indicate that, provided the number of pedestrians in the cell is smaller than the number of people that can occupy positions on the boundaries of the cell, the rate at which a pedestrian leaves the cell increases proportionally to the number of people in the cell. On the other hand, if the number of pedestrians in the cell is too high (see right top), then the number of them exiting the cell per unit time saturates.

It is worth mentioning that thresholds-biased dynamics have been discussed also for other transportation scenarios; compare, e.g., [1–3] (group formation and cooperation in the dark) and [4,5] (collective dynamics of molecular motors). This Note focusses on communication efficiency and is organized as follows: our transport model is described in Section 2, while Section 3 contains the hydrodynamic limit of the model as well as numerical illustrations exploring the effects of communication on the effective transport properties of the crowd of pedestrians traveling the obscure tunnel.

2. The model

The situation described in the Introduction will be modelled by means of a one-dimensional zero-range process (ZRP). We imagine to partition the tunnel into cells and associate each cell with a variable counting the number of people in that cell. We assume that, due to darkness and (possibly) panic, pedestrians move at random and, when they decide to leave a cell, they move either forward or backward with the same probability.

The key point in the definition of the model is choosing the rate at which people leave cells: due to darkness, no information is available about the number of people in neighboring cells, hence we assume that the rate at which one pedestrian leaves a cell depends only on the number of people in the cell itself. The effects of the two thresholds described in the introduction will then come into the game in the definition of such a rate function. We shall assume it to be constantly equal to a minimal value up to the activation threshold and then to increase linearly up to the saturation one.

The remarks above leads to the formulation of the following model. We consider a positive integer L and define a zero-range process [6,7] on the finite torus (periodic boundary conditions) $\Lambda := \{1, \dots, L\} \subset \mathbb{Z}$. Fix $N \in \mathbb{Z}_+$ and consider the finite *state* or *configuration space* $\Omega := \{0, \dots, N\}^\Lambda$. Given $\omega = (\omega_1, \dots, \omega_L) \in \Omega$, the integer ω_x is called *number of particles* at site $x \in \Lambda$ in the *state* or *configuration* ω. We pick $A, S \in \{1, \dots, N\}$ with $S \geq A$, the *activation* and *saturation thresholds*, respectively. We define the *intensity function*

$$g(k) = \begin{cases} 0 & \text{if } k = 0 \\ 1 & \text{if } 1 \leq k \leq A \\ k - A + 1 & \text{if } A < k \leq S \\ S - A + 1 & \text{if } k > S \end{cases} \tag{1}$$