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Pedestrian flows: from individuals to crowds

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Abstract

Interactions between pedestrians give rise to various dynamical structures such as stop-and-go waves in one-dimensional flows, lane formation in bidirectional flows in corridors, and diagonal patterns at crossings of perpendicular flows. How does the macroscopic behavior emerge from the microscopic interactions? Here we explain the diagonal pattern emerging at the crossing of perpendicular flows in terms of an effective interaction between pedestrians, and show that the pattern actually has the form of chevrons rather than diagonals. Secondly, we outline the derivation from a microscopic vision-based model of a two-dimensional macroscopic model, which can handle pedestrians having different targets.

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1. Introduction

The behavior of crowds, though it results from individual behaviors, may lead to pattern formation at a much larger scale. These patterns have a strong influence on the efficiency of the flow. It is thus interesting to understand how they emerge spontaneously in a crowd. More generally, even in a more homogeneous flow, it is of interest to be able to predict the global behavior of the crowd from the local interactions of individuals.

In a first part (section 2) we shall review several types of patterns that are formed in different geometrical configurations of the pedestrian flows. Then, in section 3, we shall focus on one of these patterns, namely the diagonals that form at the crossing of two perpendicular flows, and explain the pattern formation in terms of an effective interaction between pedestrians. Eventually, in section 4, starting from one particular agent based model, we shall illustrate the main steps to derive from it a macroscopic model for crowds.

2. Pattern formation in pedestrian flows

Though pedestrians react only to the local configuration around them, they may spontaneously form structures at larger scales. The most well-known example is the spontaneous lane formation in bidirectional flows inside corridors

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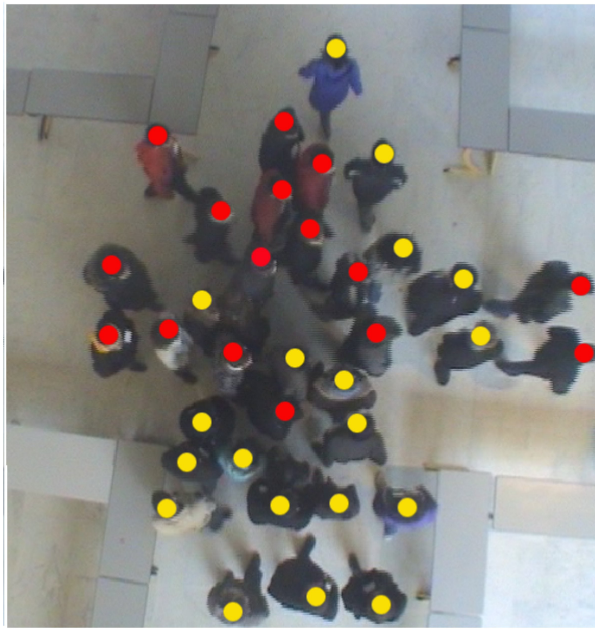

Fig. 1. Snapshot of an experimental realization of an intersection of two perpendicular pedestrian flows (d'Alessandro et al., 2010). Some red (yellow) dots have been added on eastward (northward) pedestrians (modified by J. Cividini).

or in crowded streets (Zhang and Seyfried, 2014; Kretz et al., 2006). This phenomenon has been widely observed in real pedestrian flows, and it is a criterion for the validity of models to be able to reproduce this spontaneous lane formation (Schadschneider et al., 2009). The number of lanes may range from two (one in each direction) to a larger number of lanes, depending in particular on the width of the corridor. It can also depend on the destination of pedestrians once they exit the corridor (Zhang et al., 2012). The number of lanes is not necessarily stable in time. Some controlled experiments obtained in the framework of the Project PEDIGREE (2009-2011) in a ring corridor have shown transitions occurring between 2-lane, 3-lane, or even 4-lane states (Moussaïd et al., 2012).

Another collective effect observed in pedestrian flows is the formation of stop-and-go waves (Seyfried et al., 2010). These waves can be seen even in pedestrian lines, if the density is high enough (Lemercier et al., 2011).

A pattern can appear at the crossing of two perpendicular pedestrian flows: Hoogendoorn and Daamen (2005) observed experimentally that diagonal stripes are formed in the intersection region. Fig. 1 shows another example of experimental realization performed by d'Alessandro et al. (2010), in which a tendency to form diagonals can be noticed. This diagonal pattern was observed also in various types of numerical simulations, either agent-based (Hoogendoorn and Bovy, 2003; Yamamoto and Okada, 2011) or based on PDEs (Yamamoto and Okada, 2011). It was also observed in a cellular automaton called BML (Biham et al., 1992) (this model was first meant to model road traffic in Manhattan like cities but can also be seen more generally as a model of intersecting perpendicular flows). A more thorough observation of this pattern in the simplified model of Fig. 2 revealed that actually the diagonals are not exactly straight lines, but rather have the shape of chevrons (Cividini et al., 2013a). This phenomenon was called the "chevron effect". We shall present in the next section some explanations for these phenomena.

3. Instabilities at the intersection of two perpendicular flows

The aforementioned diagonal instability at the intersection of two perpendicular pedestrian flows was observed in different settings - real or numerical - and seems quite robust. Thanks to this robustness, it was also possible to observe it in the simplified model of Fig. 2, for which some mathematical analysis could be performed. Only two parameters are needed to explore the dynamics of the system: the size M of the intersection square, and the rate α with which pedestrians arrive in the corridors, which determines the density in the intersection square.