# Cellular automaton models for humans and ants

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## I. INTRODUCTION

Particle-hopping models have been used widely in the recent years to study the spatio-temporal organization in systems of interacting particles driven far from equilibrium. Often such models are formulated in terms of cellular automata (CA). Examples of such systems include vehicular traffic and pedestrian flow [1, 2] where their mutual influence is captured by the inter-particle interactions. Usually, these inter-particle interactions tend to hinder their motions so that the *average speed* decreases *monotonically* with the increasing density of the particles. In a recent letter [3] we have reported a counter-example, motivated by the flux of ants in a trail [4], where, the average speed of the particles varies *non-monotonically* with their density because of the coupling of their dynamics with another dynamical variable. In this paper, we show some recent developements on cellular automaton models of pedestrian flow and ant trail.

## II. PEDESTRIAN MODEL

Recent progress in modelling pedestrian dynamics [5] is remarkable and many valuable results are obtained by using different models, such as the social force model [6] and the floor field model [7, 8]. In this paper, we will propose a method to construct the static floor field for complex rooms of *arbitrary* geometry. The static floor field is an important ingredient of the model and has to be specified before the simulations. Basic rule of the model is seen in the previous papers [7, 8], thus we will omit the explanation of this model and concentrate only on the construction of the static floor filed. We propose a combination of the visibility

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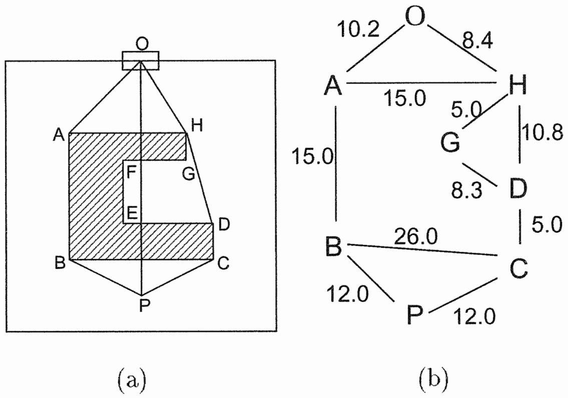



FIG. 1: Example for the calculation of the static floor field using the Dijkstra method. (a) A room with one obstacle. The door is at $O$ and the obstacle is represented by lines $A-H$. (b) The visibility graph for this room. The real number on each bond represents the distance between them as an illustration.

graph and Dijkstra's algorithm to calculate the static floor field. These methods enable us to determine the minimum Euclidian ($L^2$) distance of any cell to a door with arbitrary obstacles between them.

Let us explain the main idea of this method by using the configuration given in Fig. 1(a) where there is an obstacle in the middle of the room. We will calculate the minimum distance between a cell $P$ and the door $O$ by avoiding the obstacle. If the line $PO$ does not cross the obstacle $A-H$, then the length of the line, of course, gives the minimum. If, however, as in the example given in Fig. 1(a), the line $PO$ crosses the obstacle, one has to make a detour around it. Then we obtain two candidates for the minimum distance, i.e., lines $PBAO$ and $PCDHO$. The shorter one finally gives the minimum distance between $P$ and $O$. If there are more than one obstacle in the room, then we apply the same procedure to each of them repeatedly. Here it is important to note that all the lines pass only the obstacle's edges with an acute angle. It is apparent that the obtuse edges like $E$ and $F$ can never be passed by the minimum lines. To incorporate this idea into the computer program, we first need the concept of the *visibility graph* in which only the nodes that are visible to each other are bonded [9] ("visible" means here that there are no obstacles between them). The set of nodes consists of a cell point $P$, a door $O$ and all the acute edges in the room. In the case of Fig. 1(a), the node set is $\{P, O, A, B, C, D, G, H\}$ and the bonds are connected between

$A - B$, $A - H$, and so on (Fig. 1(b)). Each bond has its own weight which corresponds to the Euclidian distance between them.

Once we have the visibility graph, we can calculate the distance between $P$ and $O$ by tracing and adding the weight of the bonds between them. There are several possible paths between $P$ and $O$, and the one with minimum total weight represents the shortest route between them. The optimization task is easily performed by using the Dijkstra method [9] which enables us to obtain the minimum path on a weighted graph. Performing this procedure for each cell in the room, the method allows us to determine the static floor field for arbitrary geometries. We can make use of this static floor field to simulate evacuating processes under realistic situations.

## III. ANT TRAIL MODEL

The ants communicate with each other by dropping a chemical (generically called *pheromone*) on the substrate as they crawl forward [10, 11]. In [3] we developed a particle-hopping model, formulated in terms of stochastic CA, which may be interpreted as a model of unidirectional flow in an ant-trail. The effects of counterflow, which are important for some species, will be investigated in the future.

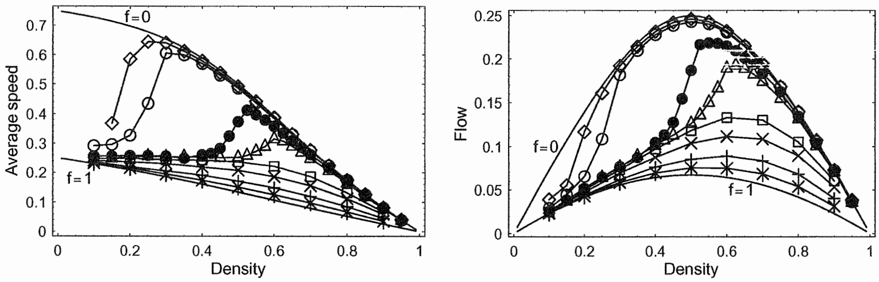
The model can be written as the coupled equations[12]

$$S_j(t+1) = S_j(t) + \min(\eta_{j-1}(t), S_{j-1}(t), 1 - S_j(t)) - \min(\eta_j(t), S_j(t), 1 - S_{j+1}(t)), \quad (1)$$

$$\sigma_j(t+1) = \max(S_j(t+1), \min(\sigma_j(t), \xi_j(t))), \quad (2)$$

where $\xi$ and $\eta$ are stochastic variables defined by $\xi_j(t) = 0$ with the probability $f$ and $\xi_j(t) = 1$ with $1 - f$, and $\eta_j(t) = 1$ with the probability $p = q + (Q - q)\sigma_{j+1}(t)$ and $\eta_j(t) = 0$ with $1 - p$.

The fundamental diagram, which is the density-dependence of the average speed in our ant-trail model is shown in Fig. 2(a). Over a range of small values of $f$, it exhibits an anomalous behaviour in the sense that, unlike common vehicular traffic, the average velocity is not a monotonically decreasing function of the density $\rho$. Instead we have found that a relatively sharp crossover can be observed where the speed *increases* with the density.




(a) (b)

FIG. 2: The average speed (a) and flux (b) of the ants, extracted from computer simulation data, are plotted against their densities for the parameters $Q = 0.75, q = 0.25$. The discrete data points corresponding to $f$ = 0.0005($\Diamond$), 0.001($\circ$), 0.005($\bullet$), 0.01($\triangle$), 0.05($\square$), 0.10($\times$), 0.25($+$), 0.50($*$) have been obtained from computer simulations.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