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A cellular automata model for ant trails

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Abstract. In this study, the unidirectional ant traffic flow with U-turn in an ant trail was investigated using one-dimensional cellular automata model. It is known that ants communicate with each other by dropping a chemical, called pheromone, on the substrate. Apart from the studies in the literature, it was considered in the model that (i) ant colony consists of two kinds of ants, good- and poor-smelling ants, (ii) ants might make U-turn for some special reasons. For some values of densities of good- and poor-smelling ants, the flux and mean velocity of the colony were studied as a function of density and evaporation rate of pheromone.

Keywords. Ant trail; cellular automata; computer simulation.

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1. Introduction

For the last few years, statistical physicists have focussed on the particle-hopping models and applied them as an approach to the physical systems of interacting particles far from equilibrium [1–4]. These models include vehicular traffic [5,6] where particles represent the vehicles. Mostly, because of the interparticle interactions, particles decelarate and in this case the mean speed decreases monotonically while the density of the particles increases. Cellular automata models are commonly used in studying such systems [7]. Cellular automata, being an idealized version of a complex system, are composed of a number of cells, which communicate with one another via a small fraction of other components without a central controller [8]. Besides, a recent study [9] that is inspired from the behaviour of ants in a trail [10] indicates that the mean speed of the particles changes non-monotonically with their density in as much as their dynamics couple with another dynamical variable. It is easy to comprehend the population biology of social insect colonies [11] using the basic principles which affect the formation of the ant trails. Thanks to these fundamental studies, new understandings have emerged and recent developments in computer science [12], communication engineering [13], microrobotics [14] and artificial swarm intelligence [15] have occurred.

The problem [16] in which a method for studying random walks on disordered systems is presented is important and therefore the study of diffusion laws in disordered systems has attracted a great deal of attention. In ref. [17], two different types of ants, blind ants and myopic ants, were proposed. According to this model, myopic ants are capable of choosing the possible sites with an allowed probability and a similar consideration applies to blind ants with a smaller permitted possibility. The communication of ants in the trail is provided by a chemical, called pheromone, in such a way that as ants crawl forward [11,18], they drop pheromones on the substrate and this serves as a stimulus for the following ants to smell it and follow the trail. Classification like good- and poor-smelling ants has been observed in nature [19] where it is reported that Azteca and Maculatus move fast (i.e. good-smelling) and slow (i.e. poor-smelling) respectively. Such a classification of ants is very similar to that in ref. [16] where random walks on disordered systems were studied by using myopic and blind ant classification. In this paper, we propose a cellular automata model based on such a classification. At a given time, a cell must be occupied by only one ant. The lattice sites are labelled by the index i, $i = 1, 2, \ldots, L$. Here L is the length of the lattice and is taken as $L = 1000$. For each site, we assume two binary variables, Q_i and p_i. Q_i is 0 or 1 depending on whether the site is empty or occupied by an ant. If the cell is not occupied, then $Q_i = 0$. p_i represents the amount of pheromone and it is assumed to be 0, 0.25, 0.5, 0.75 and 1 depending on f, the evaporation probability of pheromone per unit time. Details of evaporation rules of pheromones are given in Stage II in §2. Additionally, we propose that ants can move forwards and backwards (U-turn) when some special conditions are satisfied.

The paper is organized as follows: In §2, the description of the model is given. Then the density dependence of the flux and mean velocity for some f values are discussed in §3. Finally a summary of the study is given in §4.

2. Model

In the model, the trail is assumed to be one-dimensional consisting of cells for the ants that are allowed to move forward and backward (U-turn). All ants aim to move forward. But if there is an ant in front, then the ant checks if there is an ant behind and U-turn can occur only if acceptance criterion is satisfied. The state of the ant system is updated at each time step in two stages [9,20]. In the first stage, ants are allowed to move and the positions $\{Q(t+1)\}$ are obtained at time $t+1$ by using the old configuration $\{Q(t), p(t)\}$. In the second stage, the pheromone is allowed to evaporate and the set of $p(t)$ is updated so that at the end of the second stage, the set of $p(t+1)$ is obtained. Finally, the new configuration $\{Q(t+1), p(t+1)\}$ at time $t+1$ is obtained. Now we would like to give details of Stage I and Stage II respectively.

Stage I. If the site is occupied by an ant at time t $\{Q_i = 1\}$, then the ant moves to the next site $i+1$ $\{Q_i = 0$ and $Q_{i+1} = 1\}$ with the probability

$$\text{Probability} = \begin{pmatrix} q_1, & \text{if } Q_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 1 \\ q_2, & \text{if } Q_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 0.75 \\ q_3, & \text{if } Q_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 0.5 \\ q_4, & \text{if } Q_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 0.25 \\ q_5, & \text{if } Q_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 0.125 \\ q_1, & \text{if } Q_{i+1}(t) = 1,\ Q_{i-1}(t) = 0 \text{ and } p_{i+1}(t) = 1 \\ 0, & \text{if } Q_{i+1}(t) = 1 \text{ and } Q_{i-1}(t) = 1 \end{pmatrix}.$$

To be consistent with real ant trails, we choose $q_1 > q_2 > q_3 > q_4 > q_5$. Computer simulations are performed for Case I (ants smelling good) by taking $q_1 = 1$, $q_2 = 0.75$, $q_3 = 0.5$, $q_4 = 0.25$, $q_5 = 0.125$; and for Case II (ants smelling poor) by taking $q_1 = 0.25$, $q_2 = 0.125$, $q_3 = 0.06$, $q_4 = 0.03$, $q_5 = 0.01$. Note that for both forward and backward moves, the hopping probability depends on the amount of pheromone in front.

Stage II. Pheromone is evaporative. That is why the dropped amount of pheromone will gradually decrease according to the following rules: at each site that is occupied by an ant after the first stage a pheromone is dropped; if $Q_i(t+1) = 1$, then $p_i(t+1) = 1$. However, if $Q_i(t+1) = 0$, the pheromone evaporates with the probability f:

$$\text{Probability} \\ = \begin{pmatrix} 1, & \text{if } Q_i(t+1) = 1 \\ 1 \text{ with probability } 1-f, & \text{if } Q_i(t+1) = 0 \text{ and } p_i(t) = 1; \\ & \text{or else } p_i(t+1) = 0.75 \\ 0.75 \text{ with probability } 1-f, & \text{if } Q_i(t+1) = 0 \text{ and } p_i(t) = 0.75; \\ & \text{or else } p_i(t+1) = 0.5 \\ 0.5 \text{ with probability } 1-f, & \text{if } Q_i(t+1) = 0 \text{ and } p_i(t) = 0.5; \\ & \text{or else } p_i(t+1) = 0.25 \\ 0.25 \text{ with probability } 1-f, & \text{if } Q_i(t+1) = 0 \text{ and } p_i(t) = 0.25; \\ & \text{or else } p_i(t+1) = 0 \end{pmatrix}.$$

According to the model, when a site is not occupied by an ant and the acceptance criterion is not satisfied, the amount of pheromone at time $t+1$ decreases by -0.25. On the other hand, whenever a site is occupied by an ant, the amount of pheromone at this site is $p_i(t+1) + 1$. In the simulations, periodic boundary conditions are applied and hence the number of ants is conserved. However, the amount of pheromones is not conserved. We believe that the proposed model can be applied to the vehicular traffic on freeways [21].

3. Results and discussion

The most significant quantity in the flow properties of traffic models is the flux. Flux depends on density and mean velocity, and is given by $F = \rho V$, where F is the flux, ρ is the density and V is the mean velocity. In figures 1 and 2, the fundamental diagrams obtained by computer simulations of forward and backward motions in the trail are plotted for several values of f. Red and green lines represent forward and backward moves respectively for Case I. On the other hand, blue and pink lines stand for forward and backward moves respectively for Case II.

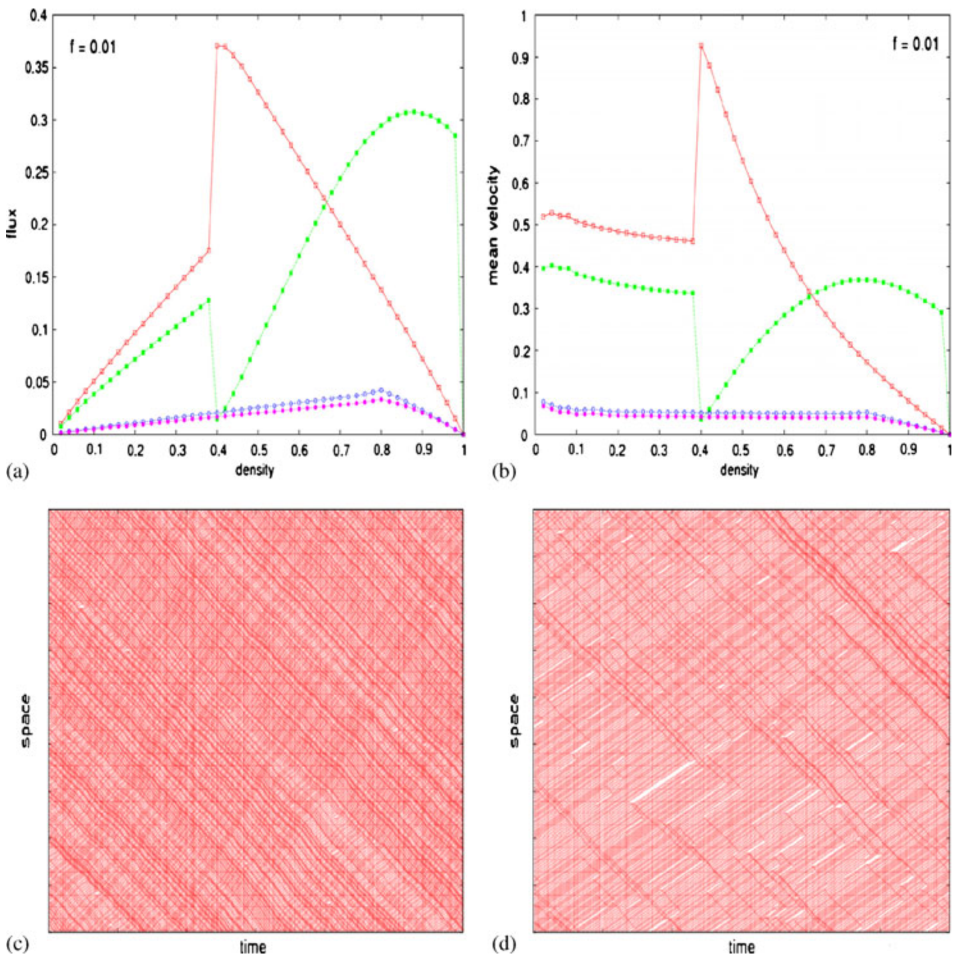

Figure 1. Simulation results for $f = 0.01$: (**a**) flux vs. density, (**b**) mean velocity vs. density (red and green lines represent the forward and backward moves for Case I, blue and pink lines stand for the forward and backward moves for Case II respectively). (**c**) and (**d**) are space-time diagrams for good-smelling ants only. For figure 1c, $\rho = 0.38$ and for figure 1d, $\rho = 0.42$.

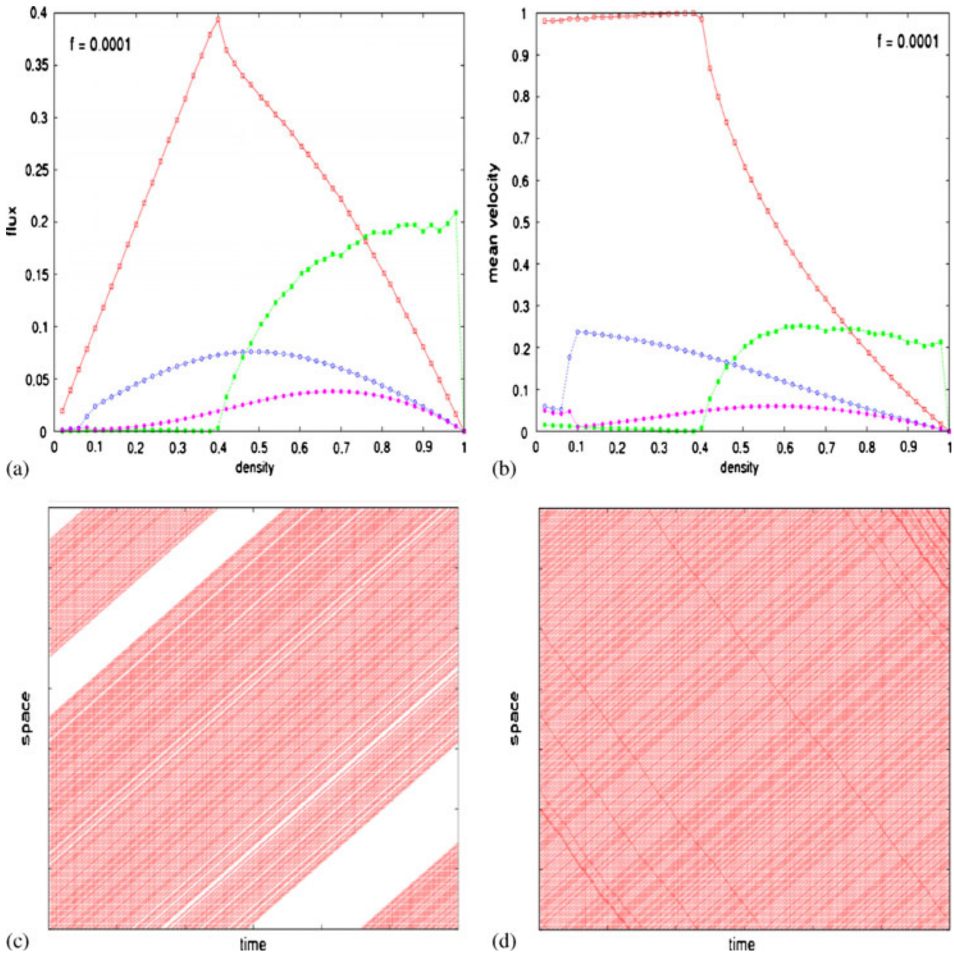

Figure 2. Simulation results for $f = 0.0001$: (**a**) flux vs. density, (**b**) mean velocity vs. density (red and green lines represent the forward and backward moves for Case I, blue and pink lines represent the forward and backward moves for Case II respectively). (**c**) and (**d**) are space-time diagrams for good-smelling ants only. For figure 1c, $\rho = 0.3$ and for figure 1d, $\rho = 0.42$.

For Cases I and II, the density dependence of the flux for forward and backward moves is illusrated in figures 1a and 2a, and the mean velocity for forward and backward moves as a function of density is illustared in figures 1b and 2b. The curves in figures 1 and 2 are plotted for $f = 0.01$ and $f = 0.0001$ respectively. In figure 1, for Case I it is seen that the flux curves of forward and backward motions first increase up to $\rho = 0.381$, while the mean velocity curves assume an almost constant value. At this density, there is a sharp increase in forward motion and a sharp decrease in backward motion. The reason for the increase in forward motion is that the pheromone dropped by an ant evaporates rapidly before the ant following it comes close enough to smell it. On the other hand, in sufficiently high densities, ants are getting closer to each other and smell the pheromone dropped by the leading ant. The increase in flux for forward moves naturally causes a decrease in the number of backward moves in the trail. After the sudden increase in the flux for the forward moves, a monotonic decrease is observed in both mean velocity and flux. It is also seen that after this sudden decrease, a monotonic increase in flux and mean velocity takes place with increasing density upto $\rho \sim 0.9$. For Case II, we find that flux and mean velocity increase with increasing density until $\rho = 0.80$ is reached and then they both decrease. In order to see what is going on in the ant trail, space-time plot for Case I is shown in figures 1c and d; figure 1c stands for $\rho = 0.38$ and figure 1d for $\rho = 0.42$. From figure 1a it is seen that fluxes for forward and backward moves for $\rho = 0.38$ are almost equal. On the other hand, for $\rho = 0.42$ it is seen from the flux diagram that flux for the forward move assumes a value much higher than that for backward move. Consistent with these observations, amounts of forward and backward moves seem to be equal in figure 1c, and amounts of forward moves are more than that of backward ones, as seen in figure 1d. In figure 2, the obtained results for $f = 0.0001$ are illustrated. The flux for forward moves for Case I first increases to a maximum value and then starts decreasing. It is also seen that there is no backward motion up to $\rho = 0.40$. After $\rho = 0.40$, the flux for forward moves begins to decrease, but that of backward moves starts to increase. This case is clearly seen in figures 2c and d. Figures 2c and d are space-time diagrams plotted for $\rho = 0.3$ and 0.42 respectively. Note that in figure 2c, only forward moves occur, but in figure 2d the backward moves also exist. For Case II, a minor increase in flux is occurring at $\rho = 0.3$. At this density, a clear increase in the mean velocity is observed. After this increase, mean velocity is seen to decrease monotonically.

4. Summary

In conclusion, it was considered that an ant colony consists of two kinds of ants, good and poor smelling ones, and each ant might make U-turn for some special cases. In this respect, for some values of densities of good- and poor-smelling ants, the density dependence of flux and mean velocity of the colony were studied as a function of evaporation rate of pheromone. It was shown that there might be a sudden increase in flux at a certain density, from jammed to free phase, for some values of evaporation rate of pheromone.

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