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A theoretical model for uni-directional ant trails

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ABSTRACT

A theoretical model of uni-directional ant traffic, motivated by the motion of ants in trail is proposed. Two different type of ants, one of which smells very well and the other does not, are considered. The flux of ants in this model is investigated as functions of the probability of evaporation rate of pheromone. The obtained results indicate that the mean velocity of the ants varies non-monotonically with their density. In addition, it is observed that phase transition in the flux and the mean velocity vs. density occurs at certain density for a fixed evaporation rate. The effective hopping probability is investigated as well depending on the evaporation rate of pheromone. It is worth to note that the proposed model can be generalized for vehicular traffic on freeways.

1. Introduction

In recent years, particle-hopping models have attracted a great deal of attention and have been used to investigate the physical systems of interacting particles far from equilibrium [1–4], including vehicular traffic [5,6] where the vehicles are represented by particles. In general, the interparticle interactions tend to inhibit their motions and therefore the mean speed decreases monotonically as the density of the particles increases. Such models are formulated usually in terms of cellular automata [7]. On the other hand, it is shown in a recent study [8] which is motivated by the flux of ants in a trail [9] that the mean speed of the particles varies non-monotonically with their density because of the coupling of their dynamics with another dynamical variable. The basic principles which govern the formation of the ant trails are of fundamental importance to understand the population biology of social insect colonies [10]. These fundamental studies have shed light on new insights and have found applications in computer science [11], communication engineering [12], artificial swarm intelligence [13] and microrobotics [14].

The study of diffusion laws in disordered systems has attracted a great deal of attention because of the physical importance of the problem [15] in which a method for the study of random walks on disordered systems is presented and applied to the problems of diffusion on percolation clusters. The authors describe the method by using two different types of ants: a blind ant and a myopic ant [16]. The myopic ant is not literally blind: it is capable of choosing among the possible sites with an allowed probability. A similar consideration applies to the blind ant with a smaller allowed possibility. As for the ants in trail, on the other hand, the ants communicate with each other by dropping a chemical called pheromone on the substrate as they crawl forward [10,17]. The trail pheromone adheres to the substrate long enough for following ants to smell it and follow the trail. In this study, we develop a cellular automata model which is based on uni-directional flow in an ant trail. Each site of our one-dimensional ant trail represents a cell that can occupied by only one ant at a time. The lattice sites are labelled by the index i, $i = 1, 2, \ldots, L$. Here L denotes the length of the lattice. Each site assumes two binary variables A_i and p_i; A_i takes 0 or 1 depending on whether the site is empty or occupied by an ant, and p_i takes 0, 0.25, 0.5, 0.75 and 1 depending on the evaporation rate of pheromone. The details of evaporation of pheromone are given below. Furthermore we assume that ants do not move backwards but do forwards and the hopping probability is higher if there is a pheromone in front of an ant.

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2. The model

The state of the ant colony is updated at each time in two stages [8,18]. In first stage, ants are allowed to move and the set of ants, $\{A(t+1)\}$, are obtained at the time $t+1$ using the full set of $\{A(t), p(t)\}$. In second stage, the set of $\{p(t)\}$ is updated so that at the end of second stage, the new configuration $\{A(t+1), p(t+1)\}$ at time $t+1$ is obtained. Since a uni-directional motion is assumed, ants do not move backward. We consider two different cases; in our first case, smelling of ants is good and in the second it is poor. These cases are very similar to those of blind and myopic ants in the study of random walks on disordered systems [15,16].

In these two cases, we follow the rules given below.

In first stage, the position of ants $\{A(t)\}$ is updated in parallel by following the rules;

If the site is occupied by an ant at time t, i.e. $A_i(t) = 1$ and $A_{i+1}(t) = 0$ then the ant moves to the next site $i+1$ with the probability

$$prob. = \left\{ \begin{array}{l} q_1,\ \text{if } A_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 1 \\ q_2,\ \text{if } A_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 0.75 \\ q_3,\ \text{if } A_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 0.5 \\ q_4,\ \text{if } A_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 0.25 \\ q_5,\ \text{if } A_{i+1}(t) = 0 \text{ and } p_{i+1}(t) = 0.125 \\ 0,\ \text{if } A_{i+1}(t) = 1 \end{array} \right\}. \tag{1}$$

It is worth noting that we choose $q_1 > q_2 > q_3 > q_4 > q_5$ to be consistent with real ant trails.

In the second stage, the evaporation of pheromone is determined as follows:

At each site i occupied by an ant after the first stage a pheromone is dropped:

$$p_i(t+1) = 1, \quad \text{if } A_i(t+1) = 1. \tag{2}$$

However, any free pheromone at a site i not occupied by an ant evaporates with the probability f per unit time:

$$probability = \left\{ \begin{array}{l} 1,\ \text{if } A_i(t+1) = 1 \\ 1 \text{ with probability } 1-f, \\ \ \text{if } A_i(t+1) = 0 \text{ and } p_i(t) = 1; \\ \text{otherwise } p_i(t+1) = 0.75 \\ 0.75 \text{ with probability } 1-f, \\ \ \text{if } A_i(t+1) = 0 \text{ and } p_i(t) = 0.75; \\ \ \text{otherwise } p_i(t+1) = 0.5 \\ 0.5 \text{ with probability } 1-f, \\ \ \text{if } A_i(t+1) = 0 \text{ and } p_i(t) = 0.5; \\ \ \text{otherwise } p_i(t+1) = 0.25 \\ 0.25 \text{ with probability } 1-f, \\ \ \text{if } A_i(t+1) = 0 \text{ and } p_i(t) = 0.25; \\ \ \text{otherwise } p_i(t+1) = 0 \end{array} \right\} \tag{3}$$

where f is the pheromone evaporation probability per unit time. Please note that if the acception criterion is not satisfied when $A_i(t+1) = 0$, the value of pheromone at time $t+1$ reduces by -0.25. But whenever site i is occupied by an ant, the pheromone value at site i is set $p_i(t+1) = 1$. In all simulations, we apply periodic boundary conditions so that the number of ants is conserved but the number of pheromones is not. As mentioned previously, computer simulations are performed for two different cases: (I) $q_1 = 1,\ q_2 = 0.75,\ q_3 = 0.5,\ q_4 = 0.25,\ q_5 = 0.125$; (II) $q_1 = 1,\ q_2 = 0.25,\ q_3 = 0.125,\ q_4 = 0.062,\ q_5 = 0.031$. Case (I) corresponds to the ants who smell very well, and Case (II) corresponds to the ants whose smelling is poor. In certain limits, we believe that our model could be applied to the vehicular traffic on freeways [19].

In all simulations performed in this study, the lattice size is chosen $L = 1000$ and we begin with a random initial configuration. The system of ants reaches the equilibrium after typically 10^5 time steps, so we begin to calculate the observables, i.e. flux and mean velocity, over the next 10^5 time steps.

3. Results and discussion

The flux as a function of density is the most important quantity in flow properties of traffic models. Flux is just the product of density and the mean velocity, $F = \rho V$; here F is the flux, ρ is the density and V is the mean velocity. In Fig. 1, the flux vs. density and the mean velocity vs. density for the case (I) are illustrated for several values of f. The density dependence of the flux for case (I) is shown in Fig. 1(a). In Fig. 1(a), for some f values, sharp crossovers are observed at some densities, which indicate a transition. Sharp crossovers are also seen in the density dependence of the mean velocity in our ant trail model, (Fig. 1(b)). There is a sharp increase in flux and mean velocity at $\rho = 0.248, 0.483, 0.507, 0.76, 0.811$ for $f = 0.001$,