

Mathematical Modeling of Ant Pheromones: Determination of Optimum Pheromone Evaporation Rate and Simulation of Pheromone Tracking Abilities

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Introduction

Communication between individuals is essential for the efficient function of insect colonies such as ants. There is a wide variety of mechanisms used by ants to communicate as well as a variety of reasons for communication. Some of these forms of communication involve stroking, gasping, antenna movements, and streaking of chemicals.¹

Chemicals known as pheromones are a major form of communication and are known to aid in the foraging ability of the colony, as sexual communication, and act as an alarm system. More than ten glands have been associated with the production of chemicals although the endocrine system varies between ant species. The pheromones are often mixtures of more than one organic compound. It is thought that this mixing allows species to identify their own pheromones and for the transmission of more complicated messages.¹

When foraging for food, worker ants will choose to lay pheromones depending on the quality and volume of food found at a source. If they do lay a pheromone trail, they adjust the quantity based on how profitable the food source is². Experiments have shown that the pheromone trail left by a single worker will evaporate within a few minutes (Figure 1)¹. Therefore, a strong pheromone path is created when a profitable food source

is found and large amounts of pheromones are laid by returning workers in order to recruit more ants from the nest.

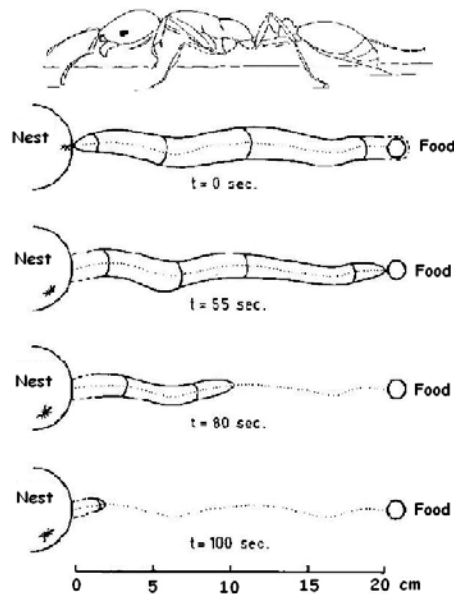


Figure 1. The evaporation of ant pheromones over time.

When a specific food source is present in unlimited quantities, it would be advantageous for the pheromone to evaporate very slowly or perhaps not at all. However, in a case where the food source is limited, it is to the advantage of the colony for the pheromones to evaporate over time. This eliminates the possibility of ants following a strong pheromone trail to a food source that has already been diminished and thus wasting energy. It follows then, that in a situation where there is a certain probability of food randomly appearing, it could be advantageous for the trails to evaporate and so the colony could find the new food sources. With a fixed probability of food appearing, it is proposed that there is an optimum rate at which the pheromone should evaporate allowing the colony to bring the most food back to the nest. In this part of the project, an agent based model will be used (NetLogo) as well as a differential equation based model

to explore the factors which determine the optimal rate of evaporation. This work has implications beyond simple foraging strategies and sheds light on the optimal flexibility for an organism in a constantly changing and unpredictable environment.

The second project deals with models for pheromone tracking. An experiment by Hangartner showed that ants track a pheromone trail by detecting varying concentrations of the pheromone in chemical form (Figure 2).¹

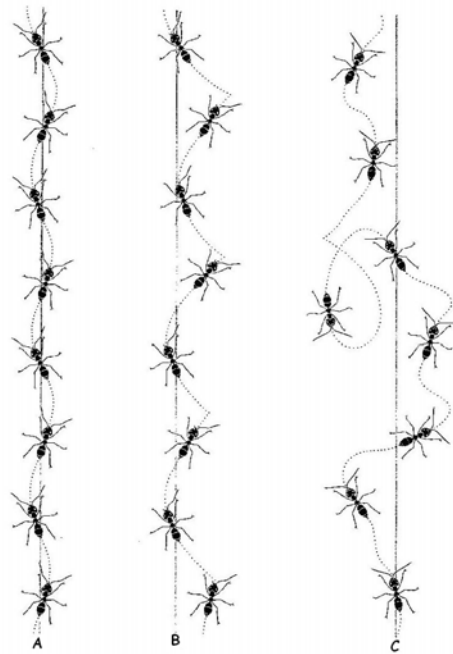


Figure 2. Pheromone tracking abilities of ant's with a) two functional antennae b) the left antenna removed c) antennae glued in the crossed position

The pheromone laid by the ant is presented by the straight line in the diagram. In case a, the ant orients itself by sweeping back and forth, measuring the pheromone vapor concentration with both antennae, and constantly returning to the point of highest vapor concentration. However, when one antenna is removed, as shown in case b, the ant constantly over corrects on the side opposite the missing antenna. In this case, the left antenna is missing so the ant can not properly assess the change in vapor concentration

on the right side of the idealized route. The most interesting case arises when the ant's antennas are crossed and glued in this position, as shown in case c. As the figure shows, the ants with crossed antennas do manage to follow the pheromone trail in the correct direction; however it is very difficult for the ant to keep track of the tail and a sporadic behavior is observed.¹ A system of ordinary differential equations will be derived to represent and describe the observed behavior for all three cases.

Questions to be Answered

Optimum value

1. Is there an optimum rate of pheromone evaporation when there is a certain probability of food randomly appearing in the foraging area?
2. What is the value of the optimum evaporation rate?
3. How does this optimum value change with the certain parameters of the experiment, such as population size and amount of food per pile?

Tracking

1. Is it possible to simulate the "mixed antenna behavior" (described above) with the use of ordinary differential equations?
2. What factors contribute to the observed behavior?
3. How does this behavior change as the strength of the pheromone trail is altered?

Methodology

The analysis of these questions will be done with the help of two computer programs. To simulate ants foraging for food, a program called NetLogo will be used. This is a programmable agent based program that easily allows the user to simulate social colonies. The behavior of an ant colony over time can be observed since directions can

be given to thousands of agents that operate independently. Useful functions such as pheromone evaporation and diffusion have already been defined and can be called in a new program specifically designed to investigate the evaporation questions proposed above.³

NetLogo will be programmed to make food piles randomly appear while the amount of food brought back to the nest is measured and recorded. The amount of time to forage will be held constant and the experiment will be repeated for a number of pheromone evaporation rates. The optimum rate will be determined by the rate of evaporation that allows for the ants to bring the most pieces of food back to the nest.

The pheromone tracking will be modeled with ordinary differential equations. The behavior of these equations can be easily and quickly determined with the help of a program called XPP. It offers several advantages over other mathematical programs and will provide aid in determining an appropriate differential equation model.⁴

References

1. Holldobler, Bert, and Edward Wilson. The Ants. 1st. Cambridge: Harvard University Press, 1990.
2. Sumpter, David, and Madeleine Beekman. "From nonlinearity to optimality: pheromone trail foraging by ants." Animal Behavior 66(2003): 273-280.
3. <http://ccl.northwestern.edu/netlogo/docs/>
4. Bard Ermentrout. Simulating, Analyzing, and Animating Dynamical Systems. 1st. Philadelphia: Siam, 2002.