

Experiments in Path Optimization via Pheromone Trails by Simulated Robots*

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September 17, 1996

Abstract

Ants lay pheromone trails to lead other individuals to a destination. Due to stochastic variations in path following, these paths become optimized. Aspects of this behavior were considered using a simulation modeled on a physical robot colony. Milling and path optimization were observed. This led to the conclusion that, though simplistic, the model captures several interesting features of ant trail following including circular milling in several *Eciton* species.

1 Introduction

Multi-agent foraging is the underlying mechanism for accomplishing many tasks, such as recovery of accident survivors, coordination of battlefield units, harvesting, removal of land mines, and planetary exploration. These applications require that many distributed objects be located quickly and efficiently by a team of agents. Similarly, ants must accomplish this task every day in order to survive. Ants manage this task robustly (Franks & Fletcher, 1983) with the meager allotment of roughly 500,000 neurons per individual.

2 Purpose of Experiment

The goal in this work has been to model the behavior of ants in order to gain insight into models of simplified foraging tasks for robots. This paper analyzes a sub-task of the foraging problem, the optimization of simulated pheromone trails by the robots following them.

*Indiana University Computer Science Dept. Technical Report 466, 1996

[†]Supported in part by NSF GER-9354898

3 Experimental Setup

The robots were tested under two experimental conditions. In the first condition, a robot was allowed to roam freely while emitting pheromone and turning up the pheromone gradient, if any. The intention was to verify that a simple ‘turn towards pheromone’ rule would produce path following. The second ‘task’ was to optimize paths during an idealized foraging task. The robot(s) start at randomly chosen locations. They roam around the colony, ignoring any pheromones, until they reach one of two distinguished corners in the colony. On entering one of the special corners (“home”), a robot begins emitting and following a characteristic pheromone. The robot follows this pheromone until it reaches the other special corner (“food”) where it switches to emitting and following the other pheromone. This behavior simplifies the data logging for the experiment by creating clearly defined end points for the paths. The biological footing is more tenuous: ants do use multiple signaling pheromones (Hölldobler & Wilson, 1990), but most ants generally only lay trails when returning to the nest with food. Anthropomorphizing the resulting behavior, the robot initially roams around looking for “home” or “food”, on finding one it starts looking for the other.

3.1 Colony

The simulator which was used to conduct the experiments is based on a robot colony under development at IU. The robot performance parameters were set by measuring a Stiquito robot. Briefly, Stiquito is a 15cm long hexapod robot which derives its motive power from wires of shape-memory alloy. Descriptions of previous versions of Stiquito robots are available in (Mills, 1992; Mills, 1993; Mills, 1994). The low level controllers are implemented with offline reprogrammable FPGAs. This allows the robots to be easily used for different purposes by different experimenters. The high level robot controllers are currently implemented offboard on a central workstation. The robot bodies receive motion commands via an IR transmitter connected to a serial port of the workstation. The control loop is closed by a vision system which tracks the locations of the robots. This information is used to inform each of the individual robot controllers of the inputs it receives from its sensors. While ‘global’ position information is used within the simulated pheromone system, these coordinates are *not* available to the robot controllers. Instead, the robots detect the “scent” of their peers when they are too close and move away from them.

3.2 Robot

The robots have very simple behavioral controllers vaguely reminiscent of the subsumption architecture (Brooks, 1986). The most basic response of the robots is to avoid the walls of their arena and other robots. When they are too close

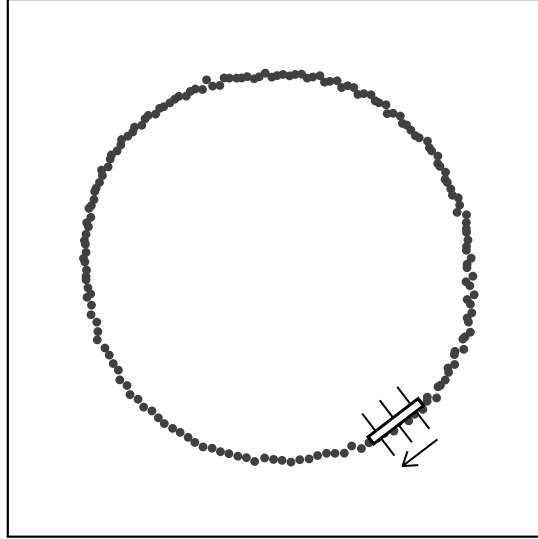


Figure 2: Previous robot some time later ($t=57600s$)

(A)fter Ecitons have formed a column around a glass jar on a glass substratum, removal of the jar leaves a regular circular procession which usually is able to maintain its formation for a considerable time. The chemical trail which is formed as the ants follow the surface becomes sufficient alone to canalize the column. Thus in a number of instances, Ecitons ceased trekking around the outside edge in running around the top surface of a square wooden block, gradually shifting to a course that cut the corners more and more, until finally they followed a circular course which neared the edge only at the center of each side (Schneirla, 1944, pg. 10).

A tripartite mechanism was identified in the case of the Ecitons. The ants turn towards a weak tactile stimulation, away from a strong tactile stimulation, and up the pheromone gradient (Schneirla, 1944). The primary differences between the resulting behavior appear to be in the number of agents needed for path optimization to occur and in the robots' tendency to lose the wall. In the former case, a single robot has been seen to be sufficient for path optimization. However, a single ant follows a trail without optimization. The latter difference is not surprising since the robots have no rules for turning towards any object.

4.2 Path Optimization

To further study the optimization effects, we extended the simulation to include an abstraction of a foraging task. Two opposing corners of the colony

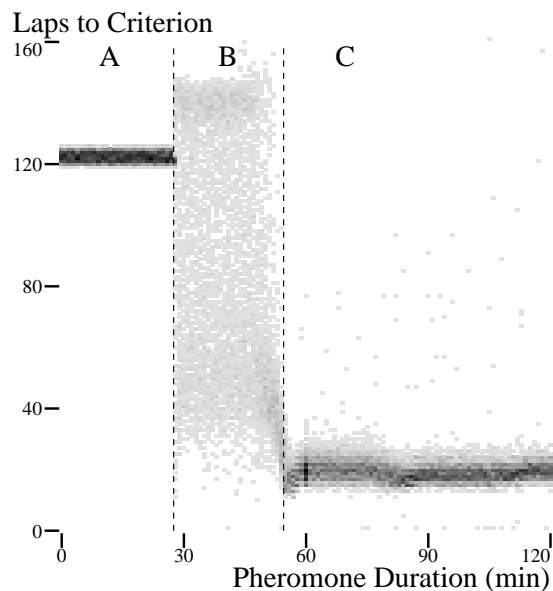


Figure 3: Laps to Criterion (13 min. half-lap) vs. Pheromone Duration Histogram

are distinguished. On entering a corner, a robot changes its behavior mode and begins following and marking a trail with the pheromone associated with that corner. This was done for ease of computing statistics, not for biological realism. Figure 3 is a histogram of the raw data for one robot with step decay of pheromones. Pheromone duration is varied from zero to 120 minutes in steps of one minute with 128 runs per step for a total of 256 half-lap trials per step. We will examine four interesting features of these data.

Region A of the plot (durations from zero to 27 minutes) corresponds to trails which are not long enough for the robot to catch before they evaporate. In this case they walk along the edge of the colony, much like Schneirla's ants (Schneirla, 1944). The robots are not actually attracted to the walls, but since they are only repelled by the walls while pointed at them the effect is similar for the straight walls of the current colony.

In region B (durations from 27 to 54 minutes), the trails are long enough for the robot to catch up to and form a cycle that is then optimized. However, the trails are weak enough that they can be lost at the corners. This is caused by the geometry of the receptive fields, pheromone deposition, and the turn mode of the robot. The change from one behavioral mode to the other tends to cause a kink in the pheromone trail. Because the receptive fields are in front of the pheromone emitter, there is a region near the distinguished corners where the robots are still following the previous trail but the trail has ended. After walking forward, the robot enters the corner and begins following the other pheromone.

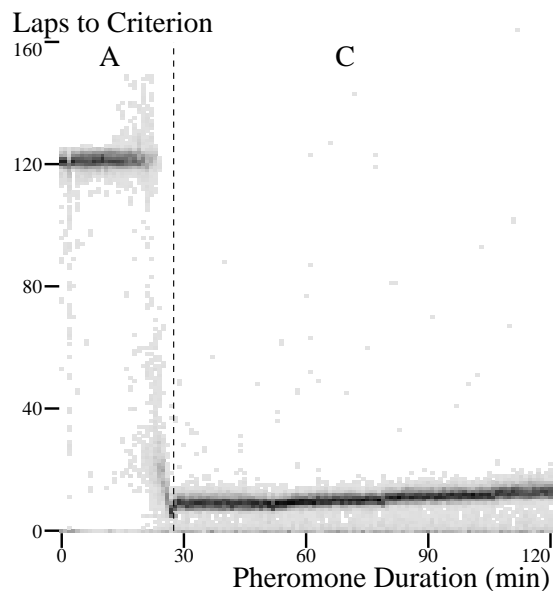


Figure 4: Laps to Criterion (13 min. half-lap) vs. Pheromone Duration Histogram for Two Robots

The optimization of this new trail requires the robot to make a hard turn which it occasionally cannot manage. This causes the broad spread of data points as the robots fall in and out of the cycles at various times during the trial.

Pheromone durations from 54 minutes onward (region C) create trails that are strong enough for the robots to follow fairly robustly. As indicated above, there are occasional outliers that indicate that a robot has lost a trail, but they are uncommon.

Next, we ran the same experiment with two robots (Figure 4 is a 3D histogram of the raw data for two robots collected under the same conditions as the one robot case.) Here we notice that the transition region B between the no optimization region and the optimization region has disappeared. Examining several individual trials led to the unexpected observation that the robots tended to clump together instead of spreading evenly. The conclusion we drew was that the effective length of the trail did not lead to more robust trail following behavior, but rather the doubled strength of the trail was responsible.

We tested this hypothesis by running a single robot with double the usual pheromone deposition rate (data in Figure 5.) This experiment supports the trail strength theory. Close inspection of optimized pheromone durations suggests that after the point of robustness is reached path optimization slows down due to the ‘mass’ of the trail that must evaporate before a new, optimized region can predominate.

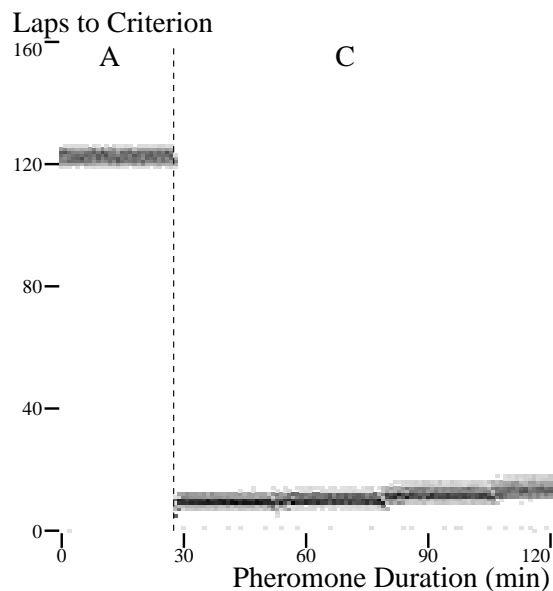


Figure 5: Laps to Criterion (13 min. half-lap) vs. Pheromone Duration Histogram for One Robot with Double Pheromone Deposition Rate

5 Perspectives

The current version of the model, while producing some interesting and unexpected behavior, is still too simple to model realistic foraging tasks. Future work will extend the model so that further learning questions can be addressed. When presented with a choice between two trails of differing lengths (Goss et al., 1989; Deneubourg & Goss, 1989) or a choice between two food sources (Pasteels et al., 1987), the reinforcement of the selection can be seen as a form of Hebbian learning (Millonas, 1992). If an ant at a fork F with a choice between branches A and B chooses A and leaves pheromone, then future ants will be more likely to choose A . Future work with this system should examine the effect of not just the choices between forks, but also the effect of the evolution of the trails between the forks and the creation of new trails.

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