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Modelling the Foraging Patterns of a Colony of Co-operating Army Ant Agents using NetLogo*

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ABSTRACT

An attempt is made to model the foraging behaviour of army ants through the development of a NetLogo simulation. The simulation is interactively interrogated and systematically explored via the use of NetLogo's interface and *BehaviourSpace* utilities.

Keywords

swarm intelligence, stigmergy, emergent behaviour

1. INTRODUCTION

Modeling may help to uncover what actually happens in a natural system – here an insect colony – that should [1]:

- i)* reproduce some features of the natural system it is supposed to describe (be a simplified view of reality),
- ii)* be consistent with what is known: parameters cannot take arbitrary values, and the mechanisms and structures of the model must have biological plausibility,
- iii)* make testable predictions, and
- iv)* enable all variables and parameters to be accessible to experimentation.

The swarm-based approach is potentially powerful due to (p.8 [1]) randomness, decentralization, indirect interactions among agents (called stigmergy), and self-organization. It

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is adaptive, flexible, and robust. The pathways to solutions are usually not predefined but emergent, and solving a problem amounts to finding a trajectory for the system and its environment so that the states of both the system and the environment constitute the solution to the problem: although appealing, this formulation does not lend itself to easy programming.

2. THE ARMY ANT MODEL

The self-organization model of army ant raid patterns due to Deneubourg et al. as reported on pages 36-9 of [1] is:

1. The environment is represented as a bidimensional grid. Each node of the grid is called a site. The system is updated at discrete time steps.
2. The ants lay pheromone trails both on the way out to the raid front and when returning to the nest. Ants deposit one unit of pheromone per unit area (that is, per visited site) on their way out to the raid front; if the amount of pheromone at the site exceeds 1,000 units, no additional pheromone is laid. Returning ants deposit ten units of pheromone per visited site; if the amount exceeds 300 units, no additional pheromone is laid. A fixed fraction $e = \frac{1}{30}$ of the pheromone at each site evaporates at each time step.
3. Ants return to the nest after finding prey; an ant that returns to the nest is laden with a prey item.
4. At each time step, an ant decides whether to advance or stay at its current site. Let ρ_l and ρ_r be the amounts of pheromone on the left and right sites, respectively. The probability of moving an ant is given by:

$$p_m = \frac{1}{2} \left[1 + \tanh \left(\frac{\rho_l + \rho_r}{100} - 1 \right) \right] \quad (1)$$

Therefore, the more pheromone on the sites the ant is facing, the more likely the ant is to move. This corresponds to the empirical observation that the ants move more and more quickly as the pheromone concentration increases, and move more slowly in unmarked areas.

5. When an ant chooses to move, it selects the left or right site according to its absolute and relative pheromone

concentrations. More precisely, the ant selects the left site with probability:

$$p_l = \frac{(k + \rho_l)^n}{(k + \rho_l)^n + (k + \rho_r)^n} \quad (2)$$

With $n = 2$ and $k = 5$, while the right site is selected with probability:

$$p_r = 1 - p_l \quad (3)$$

6. Ten ants leave the nest per time step. There cannot be more than 20 ants per site. If the ant has decided to move, and selected a site that is full, it moves to the other site; if both sites are full, the ant stays where it is.
7. The food distribution is represented by a probability of finding a food source per site. The food source can be small or large. Each ant that finds a food source returns to the nest with one unit of food.

2.1 Additional Model Assumptions

The following assumptions are also made for the simulation:

1. When an ant is born at the nest, it has an infinite lifespan and faces north.
2. If an ant goes off the screen, then we kill it.
3. In general, an ant could move in any direction, which would mean that it is possible that an ant does not move off the site that it started on. For simplicity, this is ignored in the model because ants can only move to adjacent sites.
4. The amount of food on a site is fixed at setup time.
5. The amount of food decreases over time as the ants take it back to the nest. This implies that at some point in the future, there will be no food in the ant-world that is obtainable by the ants adhering to the model constraints. For example, food at greater than 45° off North w.r.t. the nest, is not reachable.
6. The simulation will terminate when all of the ants die or if it is started with no ants leaving the nest.
7. Ants are selected at random and instructed to move. This increases latency of each time step of the simulation, but reduces bias due to possible ordering effects.

2.2 Discussion of Ant Model

A model of the behaviour of (1) w.r.t. a where $a = \frac{\rho_l + \rho_r}{100}$ and varies from 0 to 100 is shown in Fig-1. Setting $a = 0$ implies there is no pheromone to the left or right of an ant, and hence implies that ρ_m , the probability of movement, is at a constant level of about 0.1. As a increases, the characteristic $\tanh()$ shape appears, until the limit, when ρ_m approaches a drastic step function, modelling the fact that if there is a lot of food in front, the ant will certainly move.

Fig-2 presents a view of $\tanh()$ w.r.t. the actual equation (1), rather than a model of (1). The figure shows the relationship between ρ_l and ρ_r . In particular, if *i*) $\rho_l = \rho_r = 0$ then $p_m \approx 0.11$, *ii*) $\rho_l = \rho_r = 25$ then $p_m \approx 0.26$, *iii*)

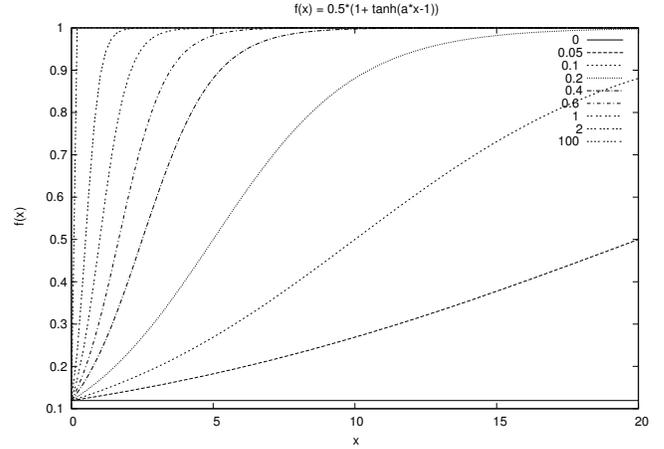


Figure 1: Model of equation (1). Increases of pheromone produce corresponding increases in the probability of movement (ρ_m).

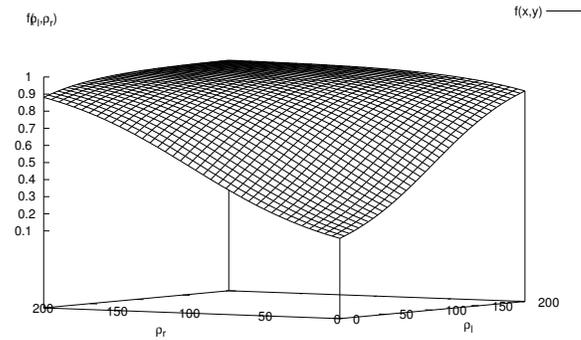


Figure 2: More explicit model of equation (1) showing interaction between ρ_l and ρ_r .

$\rho_l = \rho_r = 50$ then $p_m = 0.5$ and, *iv*) $\rho_l = \rho_r = 75$ then $p_m \approx 0.73$. Nicely agreeing with a linear intuition, of how an ant might behave when confronted with more and more pheromone in front of it.

Fig-3 shows the complex nature of an ant deciding to move left based on equation (2). If there isn't any pheromone in front, then the ant model does not state what the ant should decide to do, when $k = 0$. There are other undecidability (singularity) points.

3. EXPERIMENTAL SETUP

NetLogo 2.0 [2] is used to model the Army Ant system, as described in the course lectures and on pages 36-39 of [1]. The simulation is able to display the time evolution of army ants *i*) foraging for food (ant and food are displayed), *ii*) returning to the nest with food, and *iii*) depositing pheromone (through the display of pheromone concentrations).

In addition, BehaviorSpace, a tool within the NetLogo en-

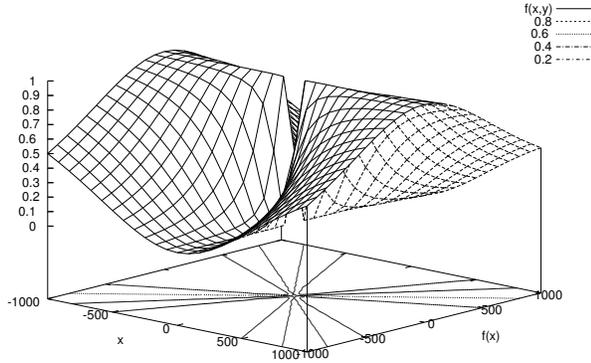


Figure 3: Probability surface for an ant deciding to move left, based on equation (2) where $n = 2$ and $k = 5$. A contour plot is beneath.

environment, is used to investigate, via 240 experiments of 3 trials each, an ant foraging model. It was executed for 1000 ticks, for a total of 720 distinct trials, by varying the parameters listed in Table-1. For the swarm-based emergent behaviour to emerge, a good random number generator is important. NetLogo 2.0 uses a *Mersenne Twister* pseudo-random number generator [1]. NetLogo has an $\arctan(z)$ primitive (i.e. $\tan^{-1}(z)$) but not $\tanh(z) \equiv \frac{\sinh(z)}{\cosh(z)} = \frac{e^{2z}-1}{e^{2z}+1}$, which needed to be implemented.

Table 1: Experimental Parameters investigated using NetLogo’s BehaviourSpace Tool

No. ants leaving the nest	{1, 5, 10}
Maximum number of ants on a site	{10}
n	{2, 5}
k	{5, 100}
Probability of food at a site	$\{\frac{1}{2}, \frac{1}{100}\}$
Number of units of food at a site	{1, 400}
Pheromone amount when foraging	{1}
Pheromone amount when returning	{10}
Pheromone evaporation rate	{1, 7, 15, 30, 60}

4. RESULTS

The 720 BehaviourSpace experiments required approximately 17 hours of CPU time and 252MB of RAM to complete on a single Intel Pentium 1.9GHz computer running the Windows 2000 operating system.

Fig-4 shows both *i*) pheromone being deposited by army ants, and *ii*) evaporation of the pheromone trail after the ant has left a site. This evaporation model is divisive (not by design, but by accident), rather than the fractional subtractive model already described.

Fig-5 demonstrates a fully formed foraging front. When the

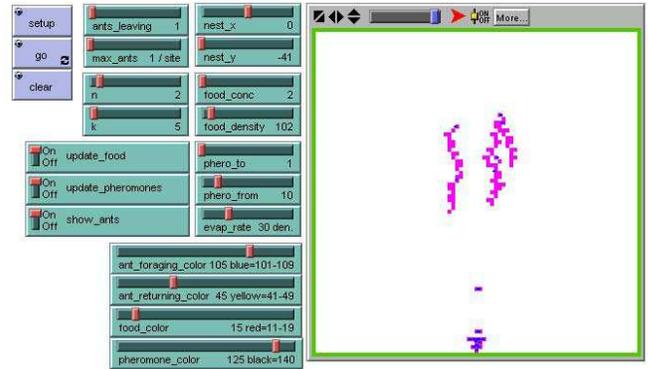


Figure 4: Screen shot demonstrating evaporation of pheromone (Ants=blue, Pheromone=pink)

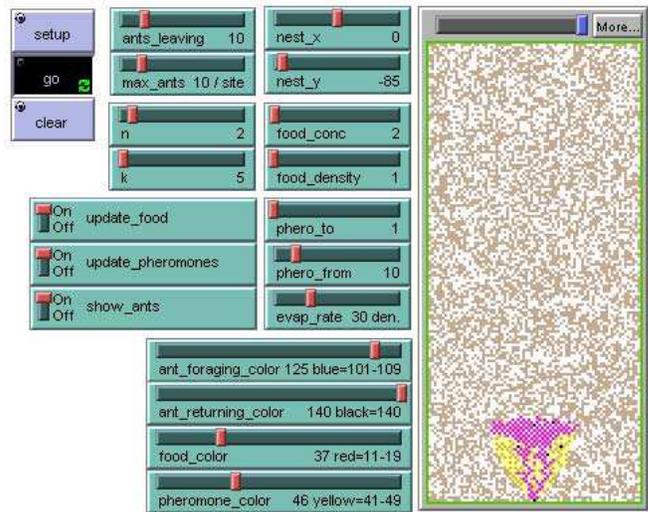


Figure 5: Ants forming a foraging front to search for and retrieve food.

evaporation rate changes so that it is almost immediate, the characteristic front breaks down Fig-6. But when the original evaporation rate is restored, then the foraging front is able to reform Fig-7.

When a unit of food is distributed with a probability such as $p = \frac{1}{2}$, then foraging patterns emerge like in Fig-5 and Fig-7. The food distribution could be changed so that $p = \frac{1}{100}$ with 400 units of food are placed at a site. This leads to more *wispy* or *stringy* type patterns as also shown in [1].

The global (macro) behaviour of how the total number of ants varies during the course of a simulation is shown in Fig-8. It is interesting to observe that *i*) some lines, where a line represents the average of 3 experiments over the course of the 1000 time steps, tend to group together, and that *ii*) there is a very sudden decline in the number of ants for some experiments at the 500-th tick¹.

¹No pun intended between the blood sucking kind of tick and the simulation kind of tick while modelling ants.

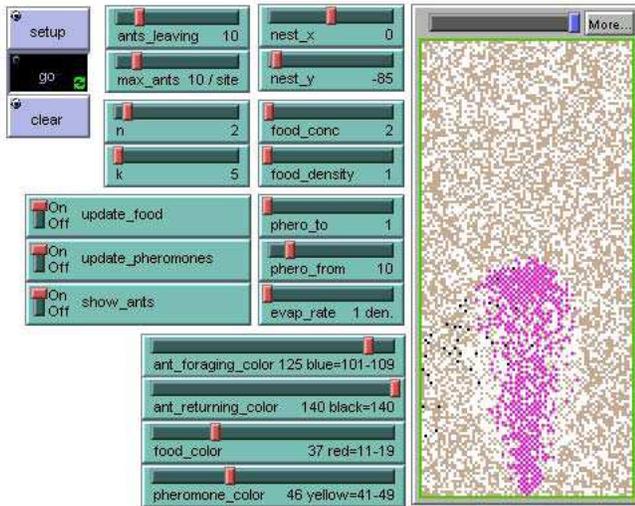


Figure 6: When the evaporation rate of pheromone increases dramatically, the foraging front disappears.

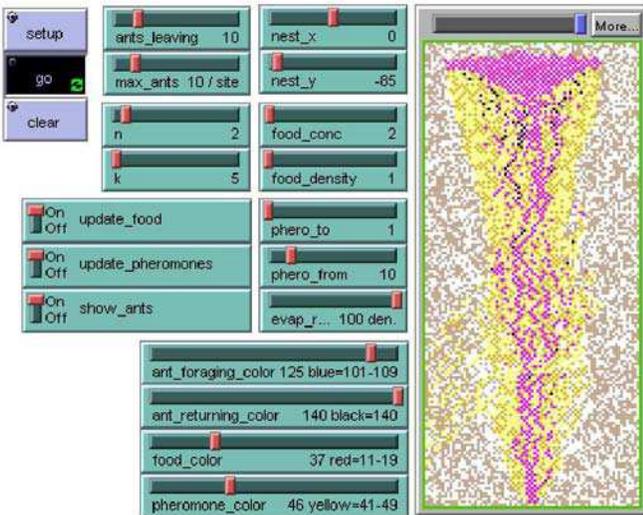


Figure 7: Restoration of evaporation rate enables the emergent foraging front to form once again.

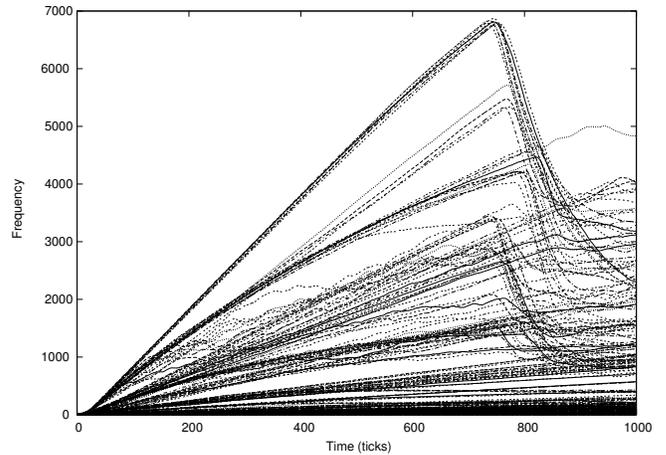


Figure 8: Total number of living army ants, averaged over 3 trials, at each of the 1000 ticks of a simulation for each of the 240 experiments.

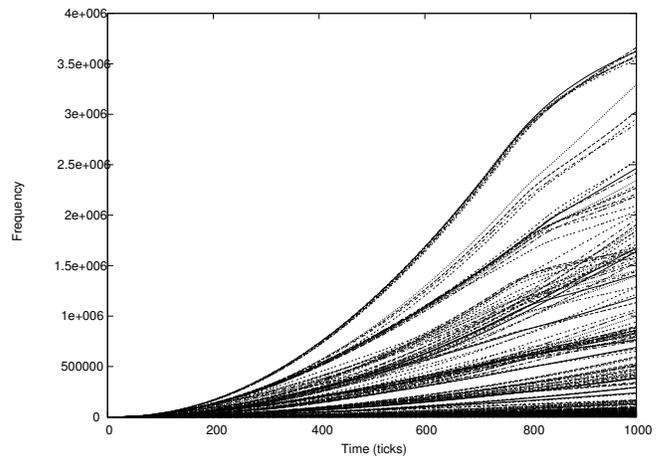


Figure 9: Total number of living ants who are foraging at simulation tick $i = [0..1000]$ averaged over 3 trials of 240 experiments.

The relationship between food density and ant foraging efficiency was investigated through the use of BehaviourSpace. In particular, the total number of ants (at tick i) who are foraging (Fig-9) and the total number of ants returning to the nest (Fig-10) is reported. The shapes of these time-series are roughly the same, with the exception of *i*) y-axis scale, and *ii*) a slight levelling of the slope of the curve for the number of returning ants at about tick 850 in Fig-10. This could be interpreted to mean that quite a lot more ants are foraging than compared to the number of ants returning to the nest, and with the observed levelling of the returning ants, it may be possible that this difference will get larger and larger with time. This may not accurately reflect what happens in the real-world for ants, because they may be likely to turn around and head back to the nest after not finding food for a long time, or they might die of starvation.

4.1 Utility as a problem solving tool

Speculations about the use of modelling army ants are:

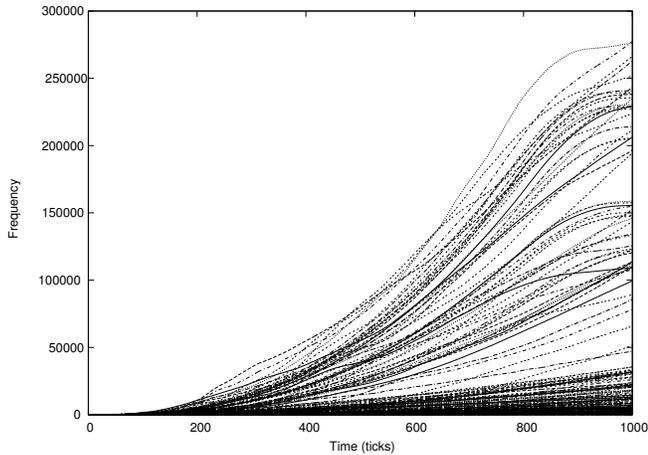


Figure 10: Total number of living ants who have picked up a food unit and are returning to the nest.

1. The nest needs to be placed somewhere in space, but what is the *best* location?
2. The ant algorithm walks on a graph implying that the problem to be solved should be discrete. What about continuous input spaces? There is at least one algorithm that exists that lays a grid over the input space and forages like the continuous space, but this grid laying is very similar to the *equal-width interval discretization problem*. In particular, what width should be the grid/intervals? Is this something that the ants could learn? Or is it not a problem, if the ants can also walk around inside the grid?
3. As stated, the algorithm requires a preprocessing discretization step in order to rerepresent the data so that the algorithm may deal with it. But there are many ways to discretize. How know the best way? I.e. treat attributes as being independent? What if they are not? What if there are subtle simultaneous effects between attributes? Is this something that the algorithm could discover?
4. With so many ants foraging, and possibly relatively few returning, an implementation would need to properly take into account the pheromone depositing strategy along with the pheromone evaporation rate. This seems like a difficult problem.

If optimality w.r.t. a fixed food distribution is wanted, then the least amount of food left at the completion of an experiment may be one way to measure optimality. But:

1. How much food left (or difference between how much food started with and how much left) at experiment completion?
2. How much pheromone deposited in total during course of experiment, or how much pheromone exists at experiment completion? The former could indicate cumulative effort by the colony, w.r.t. energy exerted by movement (i.e. walking with or without food).

The following enhancements could be considered for a more advanced simulation:

1. Ants leave the nest at a fixed rate that is changeable by the user. The model could be made more detailed in that the colony could start from a queen and some ants, and then depending on the amount of food that comes back to the nest by the foraging activities, the ants could reproduce and/or die.
2. The model could be enhanced to allow food to grow and/or die over time.
3. Ants could spontaneously leave the nest to form a new nest that also begins foraging activities. Ants would have to know to which nest they belonged.
4. A nest could be modeled as a set of distributed and linked nests, where ants can forage from nest i and then at some later point move to nest j and start foraging from there.

5. CONCLUSIONS

An army ant model was successfully implemented in the language constructs provided by NetLogo 2.0. This model was put into the simulation environment and investigated in both an interactive and an automatic manner. The characteristic foraging patterns of army ants were observed as well as the deep dependence of this emergent behaviour on pheromone evaporation rate. More detailed analysis of the results of the 720 experiments (22MB of data) are necessary in future investigations.

6. REFERENCES

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