Modeling Collective Behavior in Ants
BioComputing, CSE 598
Assignment 3, Spring Semester 2024
Due: May 2, 2024 (11:59 pm)

1 Introduction

In this assignment you will implement a spatial agent-based model to study decision making and allocation of resources in ants.

Late Policy: You are allowed three "free" late days during the semester. Once you have used up those late days, 10% of your grade will be deducted for each day that it is late.

2 The Model

The model is based on the lecture given by Prof. Stephen Pratt in which he described the following ordinary differential equation (ODE) model:

$$\frac{dX_A}{dt} = \alpha(N - X_A - X_B) + \beta_A X_A(N - X_A - X_B) - \lambda_A X_A$$

$$\frac{dX_b}{dt} = \alpha(N - X_A - X_B) + \beta_B X_B(N - X_A - X_B) - \lambda_B X_B$$

where A and B refer to two different feeders and the ants choose between the two feeders, N refers to the total number of foragers (ants), X_A to the number of foragers at feeder A, X_B to the total number of foragers at feeder B, α_A and α_B are the rates of independent feeder discovery for each feeder, β_A and β_B are the recruitment rates to each feeder, and λ_A and λ_B are the attrition rates for each feeder. Ants can be in one of three possible behavioral states: uncommitted, committed to feeder A, or committed to feeder B. Figure 2. The model is described in the paper "Linear recruitment leads to allocation and flexibility in collective foraging by ants" Z. Shaffer*, T. Sasaki, and S. C. Pratt. *Animal Behavior* (2013).

The parameters represent the quality of the food at each feeder, but they affect different ant behaviors. α captures how attractive a food source is. It determines the likelihood of an ant committing to the food on its own, if it stumbles upon it. β represents how persuasive an ant is about its selected food source once it is committed to it, and λ represents how forgettable a food source is, once committed to. For now, we will assume that α is the same for both feeders.

Your assignment is to translate the ODE model into an agent-based model (ABM). You will implement the model, run experiments, and compare your results to those from the ODE model. ABMs are used to simulate many actors, or "agents," and their actions and interactions. These models differ from ODE models in that rather than averaging the behaviors across actors in the model, each actor is a distinct part of the model and acts accordingly to a specified set of rules. These actors respond to both the environment and other actors within the system. In this assignment, the actors will be ants that move randomly but are influenced by recruitment via tandem running.

Figure 1 illustrates the basic setup for your model.

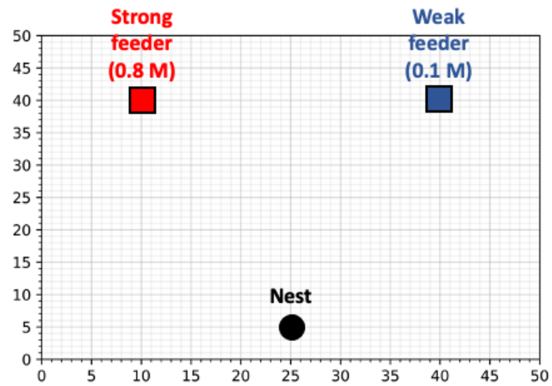

Figure 1: Illustration of the simulation setup (you will use different parameter values for your default runs).

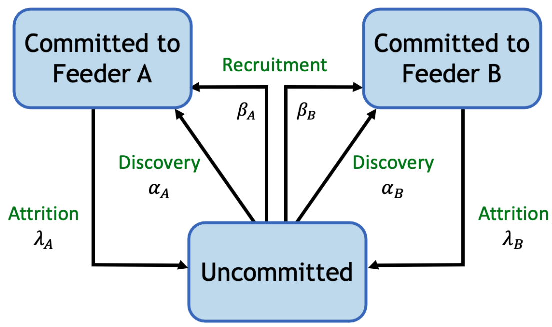

Figure 2: State transition diagram for the ants.

3 Details

Figure 2 shows the state transition diagram for the ants. Every ant must be in one of these three states on each time step. To describe how ants transition between states, the model introduces β, α and λ parameters, which are coefficients in the ODE model. The parameters α_A and α_B describe the rate at which the uncommitted ants commit to feeder A and feeder B respectively (once they have discovered it), which will be interpreted as a probability in the ABM. In addition to independent discovery, ants can also be recruited by interacting with those ants who have committed to either feeder. In the ABM, recruitment is only possible when two ants are immediately adjacent to one another or on the same square. This recruitment happens at the rate β_A for feeder A and β_B for feeder B. Finally, ants are not necessarily committed to a single feeder for the duration of the experiment and may return to the uncommitted state at an attrition rate of λ_A for feeder A and λ_B for feeder B.

The first step in converting an ODE model into an agent-based model is to establish an environment for the agents to exist in. For this assignment you can define a a 50×50 grid, with the origin located at the bottom left. The nest is located at the location (25,5), and the strong and weak feeder are at locations (10,40) and (40,40) respectively.

Next you will need to establish the feeders: A and B. Each feeder contains an integer amount of food, which is initialized to 100 units. A strong feeder has higher quality food (think seeds which are discrete) than a weaker feeder. This difference is reflected in the recruitment and attrition rates.

The third step is to define the ant agents for the simulation. As mentioned earlier, ants can be in one of three states: Uncommitted, Committed to Feeder A, Committed to Feeder B. Uncommitted ants move randomly until they encounter a food source at which point they commit to that feeder with probabity α. When an ant encounters a food source, it collects one unit of food and then travels directly (following Manhattan Distance) back to the nest, depositing the food at the nest. It then travels directly back to the preferred feeder following shortest path if it is committed to that feeder (Manhattan distance). When a committed ant encounters an uncommitted ant, it recruits one ant to become committed to its preferred feeder (tandem running). Note that the model assumes that all ants are explorers and have the ability to recruit other ants. Each ant moves only one position at a time, and the simulation is initialized with all ants at the nest.

Simulation details: Your ABM will implement what is called a *discrete time model*, which means that on every time step, each ant moves one grid position. Thus, we will allow multiple ants to occupy the same grid position and not consider collision avoidance in our model.

4 Experiments

4.1 Default parameters

Initialize your simulation with 100 ants and run it with the following parameters: $\alpha_A = 0.75$, $\alpha_B = 0.75$, $\beta_A = 0.9$, $\beta_B = 0.36$, $\lambda_A = 0.009$, $\lambda_B = 0.038$.

Make a plot that shows how many ants are feeding from each feeder over time, and report the number of time steps it takes for one feeder to be depleted (whichever one gets to zero seeds first). Compare your plot to the ODE model by plotting the ODE population over time.

4.2 Variations

Change the location of the weak feeder to be at least 10% closer to the nest than the strong feeder. What happens? How much closer does the weak feeder need to be to the nest than the strong feeder to overcome the advantage of the higher-quality food? Once you establish that distance, try adjusting the discovery, recruitment, and attrition parameters to see what it takes to overcome the distance advantage.

What happens if different feeders are initialized with different amounts of food? What happens if your simulation has three feeders (note: you may need a larger grid and more ants to study this case).

4.3 Extra credit

Use an Evolutionary Computation algorithm to find a set of discovery, recuritment, and attrition parameters that optimize the total amount of food in the three-feeder model collected in given period of time. Make a plot showing these totals over time and another plot that shows how much the overall fitness increases throughout an EC run.

4.4 Reporting results

Please hand in a 4-5 page report using the ACM format, written in appropriate academic style with proper citations. Please print a copy of your assignment paper and bring it to class on March 21 and submit a .pdf of the writeup and a .zip file with your code, instructions for running it through Canvas. Your Canvas submission time will document when you completed the assignment. If you miss class on the due date, then bring a printed copy the next time you come to class. Your paper should describe the following:

1. The problem you are trying to solve (in your own words) and a **brief** description of the model;
2. A short description of how you designed and implemented your simulation, e.g., what software you used and the basic architecture of your simulation.
3. Experimental results, as detailed above;
4. Discussion of your results, how well your project worked, and what you learned.