MODULE 10.4

Movement of Ants—Taking the Right Steps

Prerequisite: Module 10.2, "Diffusion—Overcoming Differences"

Downloads

For several computational tools, the text's website has an *Ants* file, which contains the simulation this module develops, and a *10_4QRQ.pdf* file, which contains system-dependent Quick Review Questions and answers, available for download.

Introduction

> *Everyone says stay away from ants. They have no lessons for us; they are crazy little instruments, inhuman, incapable of controlling themselves, lacking manners, lacking souls. When they are massed together, all touching, exchanging bits of information held in their jaws like memoranda, they become a single animal. Look out for that. It is a debasement, a loss of individuality, a violation of human nature, an unnatural act.*
>
> —Thomas (1979)

Ants are extremely successful constituents of the earth's fauna, but they seem so different from human beings and are generally regarded as pests. So, what can human beings learn from such lowly creatures?

Ants have occupied a variety of ecological niches for millions of years. They are the epitome of social insects, living in colonies of varying size. These colonies are generally made up of one or more queens, many workers, and various immature stages (egg, larvae, pupae). During most of the year, all the adults are female, and all but the queen are sterile. Seasonally, a few winged males and females (fertile) are produced, but normally most of the adults are sister workers.

The queen's responsibilities are fairly uncomplicated: she mates and lays eggs. Workers have a variety of chores: tending to young, nest construction, foraging, and protecting the nest. Their entire life is dedicated to sustaining the colony.

A nest of ants typically begins with only one individual, the queen. New, mature queens fly from the nest and search for mates from groups of males that have been produced during the same time. In selected meeting places, the queen mates with one or a few males, storing the sperm in special sacs until needed. Then she flies off to find suitable nest sites. Few of these queens successfully establish a new colony, and the males die right after their big moment.

Besides keeping herself alive, a queen must find a suitable site for the new colony, excavate the site, lay the eggs, and care for the developing young. She may also have to forage for food. A queen lives off of stored food reserves and some of her laid eggs until her young grow up. Once the first workers are produced, they take over all the queen's chores except laying eggs. The queen can now concentrate on her major role, although she also has some control over the sex ratios and new-queen production in the colony. The workers take care of everything else.

Gradually the colony grows as more and more young mature into workers. In many species, worker ants themselves become specialized for all the roles necessary to sustain the queen and the colony. Some remain in the nest, caring for the queen or the young. Others guard the nest, and still others forage for food.

There is quite a bit of variability in feeding strategies and food sources used by different species of ants, and many employ more than one type of feeding behavior. Ants may prey on small insects or eat dead insects. Others rely on seeds or raid other ant nests. One of the most interesting strategies is used by the leafcutter ants, which farm nutritious fungus.

Analysis of Problem

Most species of ants communicate their movements when carrying food by leaving trails with a chemical **pheromone**. Also, an ant can reinforce a trail by secreting additional pheromone. Thus, by following a scent, other ants can locate a food source. As expected, the pheromone dissipates and diffuses with time. In this module, we simulate the movements of such ants in the presence of a chemical trail, which spreads and evaporates over time. We do not include an ant carrying food, although the projects consider such an extension.

For the simulation, we use a model that incorporates aspects of cellular automaton simulations from Module 10.3, "Spreading of Fire," and Module 10.2, "Diffusion—Overcoming Differences." We hope to observe over time that the simulated ants tend to follow a chemical trail. Thus, the simulation should help us reflect on how behavior on the local level can lead to global behavior, which we can observe in some ants. Through the interactions of many separate individuals, a group of ants as a whole can exhibit **self-organizing** behavior that makes the group appear to have a single consciousness.

Formulating a Model: Gather Data

For the model we develop in this module, we employ empirical observations of ant species that leave pheromone trails. With each step, such an ant tends to turn to and move in the direction of the greatest amount of chemical. As time passes, the chemical diffuses away from an initial deposit; and with no ant in a location, the amount of pheromone diminishes there. For a professional model, we should obtain more exact data, such as the average amount of pheromone an ant deposits and the rates at which the chemical diffuses and decreases.

Formulating a Model: Make Simplifying Assumptions

In formulating a model, suppose that the ants are contained in a square area enclosed by glass. Moreover, we assume that an ant does not turn around completely in one time step, returning immediately to the location from which it just came, but otherwise tends to move toward an unoccupied neighboring location with the greatest amount of chemical. If no such move is available, we assume the ant waits in its current location. Thus, we employ an **avoidance-or-wait strategy** to prevent collision. With movement from a site that has a certain threshold of chemical, the ant deposits additional pheromone for reinforcement. However, the chemical diffuses and dissipates with time. For this problem, we start with a straight trail of increasing amounts of pheromone, perhaps laid by ants heading for food. We do not consider food or a nest, although various projects do.

Formulating a Model: Determine Variables

In Module 10.3, "Spreading of Fire," each cell of a grid contains an integer indicating the state of the cell—empty, tree, or burning tree; and in Module 10.2, "Diffusion—Overcoming Differences," we employ a grid of diffusing temperatures. In the current model, we have one grid to hold ant information, similar to the former, and another to store pheromone amounts, comparable to the later. To simulate a closed container, we assume absorbing boundary conditions. In the ant grid, each element of the first and last rows and columns has a constant value, ***BORDER*** = 6; and an empty cell has the value ***EMPTY*** = 0. A cell with an ant contains a constant—***NORTH*** (1), ***EAST*** (2), ***SOUTH*** (3), ***WEST*** (4), or ***STAY*** (5)—indicating direc-

Table 10.4.1
Cell Values with Associated Constants and Their Meanings

Value	*Constant*	*Cell Meaning*
0	*EMPTY*	Empty ground containing no ant
1	*NORTH*	Ant about to move to or just moved from the north
2	*EAST*	Ant about to move to or just moved from the east
3	*SOUTH*	Ant about to move to or just moved from the south
4	*WEST*	Ant about to move to or just moved from the west
5	*STAY*	Ant about to stay in or did not move from the current site
6	*BORDER*	Border

tional information. Before movement, such a constant indicates the von Neumann neighborhood cell where the ant intends to go; and after movement, the constant points back to the direction from which the ant just came. *STAY* denotes that the ant is staying in its current location for a time step. Table 10.4.1 enumerates the ant constants, their meanings, and suggested values.

For the initialization of this grid, we have a function, ***initAntGrid***, with parameters for the size, ***n***, of the internal part of the grid and the probability, ***probAnt***, that an ant initially occupies a cell. Thus, the function returns an $(n + 2) \times (n + 2)$ matrix of integers from Table 10.4.1. With probability *probAnt* a site contains an ant; should an ant be at a location, we assign a random integer—1, 2, 3, or 4—representing a direction—*NORTH*, *EAST*, *SOUTH*, or *WEST*, respectively.

Quick Review Question 1

From the text's website, download your computational tool's *10_4QRQ.pdf* file for this system-dependent question defines *initAntGrid*.

In the pheromone grid, a floating-point number represents the amount of chemical at a site. Because an ant is to move to a neighboring available cell with the maximum amount of chemical and because we are employing absorbing boundary conditions, in the pheromone grid, we have a border of slightly negative values, such as –0.01. Thus, an ant will never be tempted to step outside the grid. Moreover, these border values tend to diffuse inward, encouraging the ants to stay away from borders, which represent the walls. A function, ***initPherGrid***, initializes most of the interior cells as 0. However, for the pheromone trail, in the middle of the grid, we have a horizontal row of increasing pheromone values. With ***MAXPHER*** (say, 50.0) being the maximum initial chemical value, i starting at 1 and being a function of an internal column number, and n being the size (number of rows and number of columns) of the internal part of the grid (omitting the border), the amount of chemical in the trail is $MAXPHER \cdot i/n$. Thus, initially, the amount of pheromone gradually increases from left to right in the trail's row. If *MAXPHER* is 50.0 and n is 10, then in internal column 1 of the trail, the amount is $50.0 \cdot 1/10 = 5.0$; in column 5, the value is $50.0 \cdot 5/10 = 25.0$; and in column 10, we have the maximum pheromone amount of $50.0 \cdot 10/10 = 50.0$.

Quick Review Question 2

From the text's website, download your computational tool's *10_4QRQ.pdf* file for this system-dependent question that defines *initPherGrid*.

Formulating a Model: Establish Relationships and Submodels

Ant movement for one time step consists of two actions, sensing and walking. First, the ant tests the empty neighboring sites and turns to the one with the greatest amount of pheromone or decides to stay in its current location if no such site is available. Then, if possible to do so without colliding with another ant, the ant moves to the preferred location. After the reaction (sensing and walking) of the ants, a diffusion of the pheromone occurs. Thus, we have a **reaction-diffusion**-type simulation. As with diffusion in Module 10.2, "Diffusion: Overcoming Differences," we employ Moore neighborhoods with eight neighbors of a site and define a function, ***diffusion***, with parameters for a diffusion rate constant (*diffusionRate*) and pheromone values for the site and its neighbors. Because absorbing boundary conditions employ constant boundary values, all matrices are of the same size, $(n + 2) \times (n + 2)$. Thus, a function, ***applyDiffusionExtended***, applies *diffusion* to each internal cell and returns an $(n + 2) \times (n + 2)$ pheromone grid, keeping the border intact. The next two sections develop the *sense* and *walk* functions.

Quick Review Question 3

From the text's website, download your computational tool's *10_4QRQ.pdf* file for this system-dependent question that defines *applyDiffusionExtended*.

Formulating a Model: Determine Functions—Sensing

As with the fire simulation, for sensing we consider the neighbors to be the cells to the north, east, south, and west, that is, those neighbors in the von Neumann neighborhood. The rules for the function ***sense***, which points the ant towards its new location, are as follows:

1. An empty cell does not point toward any direction.
2. An ant does not turn to a cell from which the creature just came.
3. An ant does not turn to a location that is a border site.
4. An ant does not turn to a location that currently contains an ant.
5. Otherwise, an ant turns in the direction of the neighboring available (not the previous, an occupied, or a border cell) with the greatest amount of chemical. In the case of more than one neighbor having the maximum amount, the ant turns at random towards one of these cells.
6. If no neighboring cell is available, the ant will not move.

In the list, *lst*, of neighboring pheromone values of an ant that just moved, we assign an artificially small value, say –2, to the one corresponding to the direction from which it moved. Similarly, if another ant is in a neighboring site, we change *lst*'s corresponding value to –2. Such changes help to enforce Rules 2 and 4. To model Rule 5, we first form list, *posList*, of indices for maximum *lst* values. We randomly pick an index, *rndPos*, that has a maximum pheromone value in *lst*. For example, suppose *lst* contains adjusted pheromone values 9, –2, 9, and 8. With the maximum being 9 and assuming indexing begins with 1, *rndPos* could be 1 or 3 because the indices of 9 in *lst* are 1 and 3, which correspond to the directions north and south, respectively. The algorithm for *sense* follows.

sense*(site, na, ea, sa, wa, np, ep, sp, wp)*

Function to return the direction in which an ant is to turn (*NORTH* (1), *EAST* (2), *SOUTH* (3), or *WEST* (4)) or *STAY* (5) should the ant be planning to remain in its current location

Pre: *site*, *na*, *ea*, *sa*, and *wa* are the ant grid values for the current site and its neighbors to the north, east, south, and west, respectively. If a cell contains an ant, then its value represents the direction from which the ant came in the last time step. *site* is not *EMPTY* or *BORDER*.
np, *ep*, *sp*, *wp* are the pheromone grid values for the current site's neighbors to the north, east, south, and west, respectively.

Post: The function has returned *STAY* or the direction to which the ant turns.

Algorithm:

```
lst ← list with np, ep, sp, and wp
if site is not STAY, lst(site) ← –2         // Rule 2
if a neighboring cell contains an ant       // Rule 4
    assign –2 to the corresponding lst element
mx ← maximum value in lst                  // Rule 3 (pheromone < 0 on border)
if mx < 0                                   // Rule 6
    return STAY
else                                        // Rule 5
    posList ← list of positions in lst containing mx
    lng ← length of posList
    rndPos ← random integer between 1 and lng, inclusive
    return posList(rndPos)
```

Quick Review Question 4

From the text's website, download your computational tool's *10_4QRQ.pdf* file for this system-dependent question to define *sense*.

Similar to the models for diffusion and spreading of fire in earlier modules, we have a function, in this case ***applySenseExtended***, to process every cell of the internal grid. Unlike the application functions in those earlier modules but like *applyDiffusionExtended*, *applySenseExtended* returns $(n + 2) \times (n + 2)$ ant grid with the borders unchanged. In the function's definition, we first copy a parameter *antGrid* to a *newAntGrid* that the function returns after possible changes. Should an *antGrid* cell contain *EMPTY*, no further processing needs to be done on that location (Rule 1). Otherwise, *applySenseExtended* applies *sense* to that site, sending *sense* the ant grid value for the site and the ant and pheromone grid values for its four von Neumann neighbors.

Quick Review Question 5

From the text's website, download your computational tool's *10_4QRQ.pdf* file for this system-dependent question to define *applySenseExtended*.

Formulating a Model: Determine Functions—Walking

After applying the function *sense* to each cell of the grid, we call a function, ***walk***, which computes updated ant and pheromone grids for the next time step. The following additional rules relate to walking:

7. For a cell that remains empty, the amount of chemical decrements by a constant amount, ***EVAPORATE***, but does not fall below 0. Thus, the new amount is the maximum of 0 and the current amount minus *EVAPORATE*.
8. An ant facing in a certain direction will move into that neighboring cell as long as no other ant has already moved there.
9. Otherwise, the ant will stay in its current cell.
10. If an ant leaves a cell that has pheromone above a certain threshold, ***THRESHOLD***, the amount of chemical increments by a set amount, ***DEPOSIT***, to reinforce the trail.
11. If an ant stays in a cell, the amount of chemical remains the same.
12. After moving to a new location, the ant faces towards the cell from which the animal just came.

The design of the *walk* function follows, with details for one sense direction (*NORTH*). Behavior of the ant when facing another direction is comparable.

walk(antGrid, pherGrid)

Function to return a new ant and pheromone grids after each ant has moved or decided to remain in its current location

Pre: *antGrid* is an ant grid after application of *applySenseExtended* in a time step.
pherGrid is the corresponding pheromone grid.
Post: New ant and pheromone grids have been returned after application of the walk rules.

Algorithm:

```
n ← number of rows/columns in ant/pheromone grid minus 2
newAntGrid ← antGrid
newPherGrid ← pherGrid
for i going through each internal row index, do the following:
   for j going through each internal column index, do the following:
      if antGrid(i, j) is EMPTY                              // Rule 7
         newPherGrid(i, j) ← maximum of 0 and
            (newPherGrid(i, j) – EVAPORATE)
      // Corresponding segments to the following occur for each direction:
      if antGrid(i, j) is NORTH
         if newAntGrid(i – 1, j) is EMPTY
            if newPherGrid(i, j) > THRESHOLD                 // Rule 10
               newPherGrid(i, j) ← newPherGrid(i, j) + DEPOSIT
            newAntGrid(i, j) ← EMPTY                         // Rule 8
```

```
            newAntGrid(i - 1, j) ← SOUTH                    // Rule 12
          else
            newAntGrid(i, j) ← STAY                         // Rules 9 and 11
        // Corresponding segments for directions EAST, SOUTH, WEST go
        // here
    return newAntGrid and newPherGrid
```

Quick Review Question 6

From the text's website, download your computational tool's *10_4QRQ.pdf* file for this system-dependent question to define *walk*.

Solving the Model—A Simulation

The simulation function, ***ants***, initializes the ant and pheromone grids and stores each in lists of grids, *antGrids* and *pherGrids*. After initialization, for each of the *t* time steps, reaction and diffusion occur. All the ants sense pheromone and walk toward the scent; and then, the pheromone diffuses. At each iteration, *antGrids* and *pherGrids* store the new grids. As the following algorithm reveals, the function finally returns these lists of grids.

***ants*(*n*, *probAnt*, *diffusionRate*, *t*)**

Function to return a list of ant and pheromone grids in a simulation of ant movement, where ant cell values are as in Table 10.4.1 and pheromone cell values represent the levels of pheromone

Pre: *n* is the size (number of rows/columns) of the internal ant and pheromone grids.
probAnt is the probability that an ant initially occupies a cell.
diffusionRate is the diffusion rate.
t is the number of time steps.

Post: A list of the initial and subsequent ant grids at each time step of the simulation and a list of the initial and subsequent pheromone grids were returned.

Algorithm:

```
antGrid ← initAntGrid(n, probAnt)
pherGrid ← initPherGrid(n)
antGrids ← a list containing antGrid
pherGrids ← a list containing pherGrid
do the following t times:
    antGrid ← applySenseExtended(antGrid, pherGrid)
    antGrid and pherGrid ← walk(antGrid, pherGrid)
```

```
    pherGrid ← applyDiffusionExtended(pherGrid, diffusionRate)
    antGrids ← antGrids with antGrid appended
    pherGrids ← pherGrids with pherGrid appended
return antGrids and pherGrids
```

Quick Review Question 7

From the text's website, download your computational tool's *10_4QRQ.pdf* file for this system-dependent question to define *ants*.

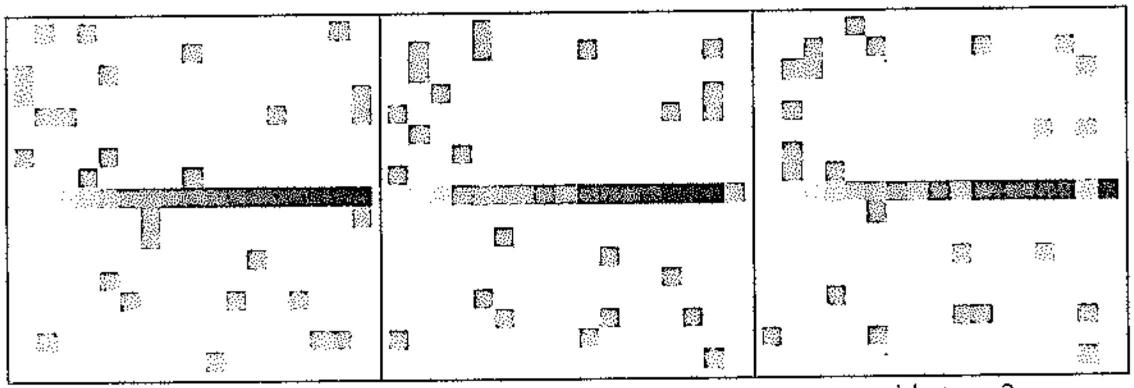
Verifying and Interpreting the Model's Solution—Visualizing the Simulation

We have a number of choices of how to communicate the information in an ant simulation for verification and interpretation of the model's solution. With constants *MAXPHER* = 50.0, *EVAPORATE* = 1, *DEPOSIT* = 2, and *THRESHOLD* = 0 and parameters $n = 17$, *probAnt* = 0.1, *diffusionRate* = 0.01, and $t = 11$ for the call to *ants*, Figure 10.4.1 presents a sequence of frames, with color representing ants and the level of gray indicating the strength of the chemical at a site with no ant. As the sequence shows, most ants have moved closer to the initial pheromone trail, while ants in contact with the a chemical trail have traveled along the path to levels of greater chemical strength. Initially, none of the 28 ants were on the trail. However, by time step 11, 8 of the 28 ants, or 29%, are on the trail, and 15 (54%) are within one unit of the path. Moreover, darkening near the path indicates the impact of pheromone reinforcement and diffusion. The simulation represents how this social insect can communicate chemically with its sisters for the common good.

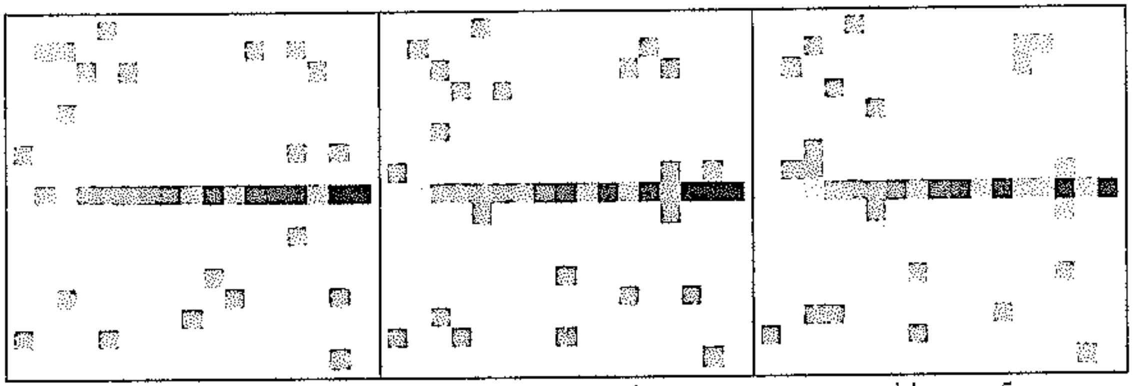
For indicating the appropriate level of gray, whose values range from 0.0 to 1.0, we calculate the maximum amount of pheromone, *maxp*, throughout the list of pheromone grids, *pherGrids*. For each cell without an ant, we divide each pheromone value by *maxp* to obtain a normalized value from 0.0 to 1.0. The larger the pheromone amount, the closer this quotient is to 1.0. However, because a grayscale value of 0.0 represents black and 1.0 corresponds to white, we subtract this quotient from 1.0, 1.0 – pheromone/*maxp*, to obtain the appropriate grayscale number. Thus, the minimum amount of chemical, 0, yields RGB components of 1.0 – 0.0 = 1.0, while the maximum amount of chemical has grayscale value of 0.0. For example, if *maxp* is 50.0, the grayscale value is 1.0 – (50/50) = 0.0. A scientific visualization should impart information clearly while not misleading the viewer or suggesting more than is available.

Quick Review Question 8

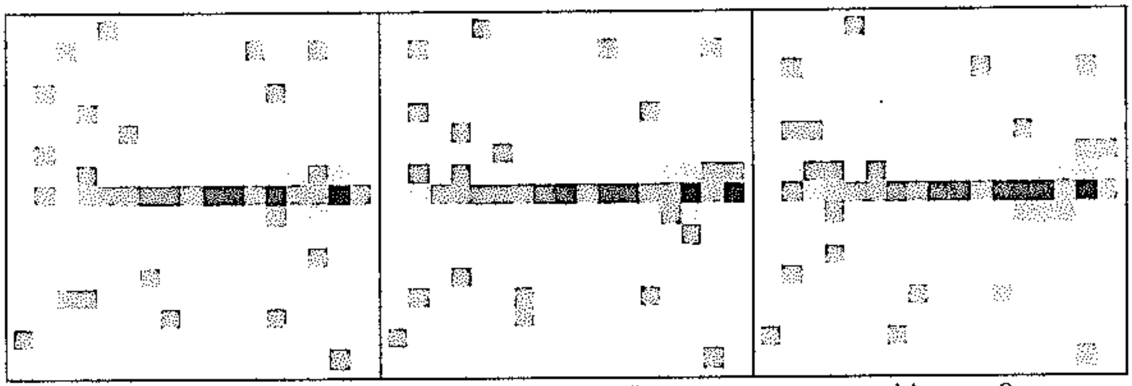
From the text's website, download your computational tool's *10_4QRQ.pdf* file for this system-dependent question that develops a visualization for the simulation.



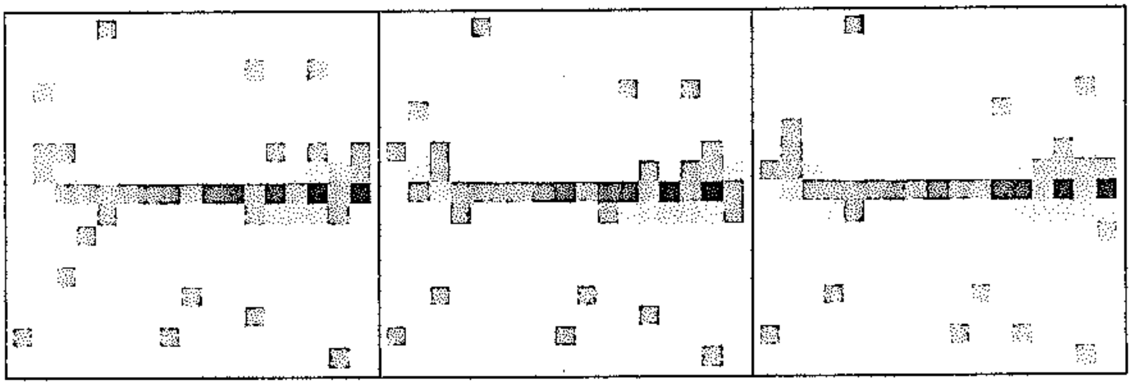
initial grid grid at $t = 1$ grid at $t = 2$



grid at $t = 3$ grid at $t = 4$ grid at $t = 5$



grid at $t = 6$ grid at $t = 7$ grid at $t = 8$



grid at $t = 9$ grid at $t = 10$ grid at $t = 11$

Figure 10.4.1 Several frames in an animation of ant simulation

Exercises

On the text's website, Ants *files for several computational tools contain the code for the simulation of the module. Complete the exercises below using your computational tool.*

1. Suppose the size of an internal grid is $n = 100$ and *MAXPHER* is 20. Using the initialization of the pheromone path in "Formulating a Model: Determine Variables," do the following.
   - **a.** Give the number of cells that will be initialized with pheromone in the path.

   Give the pheromone amount in each column of the internal grid:

   b. 2 **c.** 10 **d.** 50 **e.** 80 **f.** 100
2. In the simulation of this module, an ant cannot return immediately to a cell from which it just came. Without this rule, describe the movement of an ant in an area where no other ants are near and, initially, the ant is far from chemical deposits.

Projects

On the text's website, Ants *files for several computational tools contain the code for the simulation of the module. Complete the following projects using your computational tool.*

For additional projects, see Module 14.3, "Foraging—Finding a Way to Eat"; Module 14.4, "Pit Vipers—Hot Bodies, Dead Meat"; Module 14.5, "Mushroom Fairy Rings—Growing in Circles"; Module 14.6, "Spread of Disease—Sharing Bad News"; Module 14.7, "HIV—The Enemy Within"; Module 14.8, "Predator-Prey—'Catch Me If You Can'"; Module 14.9, "Clouds—Bringing It All Together"; Module 14.10, "Fish Schooling—Hanging Together, Not Separately"; Module 14.11, "Spaced Out—Native Plants Lose to Exotic Invasives"; and Module 14.12, "Re-Solving the Problems with Cellular Automaton Simulations."

1. For the ant simulation in the file *Ants* of this module, investigate the ant behavior in the following situations, keeping all parameters fixed, perhaps as in the section "Verifying and Interpreting the Model's Solution—Visualizing the Simulation," except as noted. Run each simulation at least 10 times, calculate the mean number of ants that are within two units of the chemical for each time step over a period of time, describe the results, and discuss the implications.
   - **a.** Use the original *Ants* file.
   - **b.** Have varying numbers, m, of areas of chemical concentrations with $m = 1$, 2, 3, 4, and 5.
   - **c.** Vary *probAnt* from 0.06 to 0.14 in increments of 0.02.
   - **d.** Vary n from 10 to 50 in increments of 10.
   - **e.** Vary *diffusionRate* from 0.01 to 0.10 in increments of 0.01.
   - **f.** Vary *MAXPHER* from 10 to 80 in increments of 10.
   - **g.** Vary *EVAPORATE* from 0.5 to 3.0 in increments of 0.5.

   h. Vary *DEPOSIT* from 0.5 to 3.0 in increments of 0.5.
   i. Vary *THRESHOLD* from 0 to 20 in increments of 2.

2. Consider an *Ants* model with a **decrease strategy for collision.** That is, two ants could go to the same cell, but after movement, that cell records only one ant, so that we have one less ant. Revise the simulation rules and implement the strategy. Running the simulation at least 10 times, plot the mean number of ants over time. Discuss the results.
3. Develop a simulation in which a single ant leaves the nest searching for a food source that is unknown to the ant and that is due north of the nest. Initially, the grid does not contain pheromones. With food, she returns directly to the nest in a straight-line fashion, leaving a chemical trail. As soon as one ant returns to the nest, another ant leaves, following the pheromone trail in the search for food. An ant following a pheromone trail emits a smaller chemical signal than one carrying food. Perform the process for a sequence of 10 ants, saving the points of each ant's path to the food. Plot each ant's path to the food. Discuss the results.
4. Develop a simulation with a nest, a food source, and ants that should not collide on a 20 × 20 grid. A sequence of 10 numbered ants leave the nest in search of food. Once an ant finds food, she returns to the nest carrying a morsel and depositing pheromones, with greater amounts closer to the food source. An ant seeking food, usually travels in the direction of maximum pheromone, but occasionally moves in a random direction. Have a large reinforcement threshold (e.g., 0.8 for pheromone values in the range 0 to 1), a small diffusion rate constant (e.g., 0.005), and a small evaporation constant (e.g., 0.001 or less). Besides ants and pheromone grids, have a nest grid, where the strength of a nest signal is related to the distance from the nest and is greatest close to the nest. Run the simulation 10 times, and plot the mean length of time for each ant to find the food. Do ants that leave the nest later find the food faster?
5. Develop a simulation with a nest, two food sources, and ants at random initial positions. Once an ant finds food, the amount of food at that location decreases by one unit and she returns to the nest with morsel. Besides ants and pheromone grids, have a nest grid, where the strength of a nest signal is proportional to the distance from the nest. Do ants exhaust one food source before focusing on the other?
6. An army ant raid can be 20 m wide and 200 m long and involve hundreds of thousands of ants. The raid is self-organizing, evolving from interactions on the local level into a global pattern. The pattern appears treelike with the forward part of the raid being branchlike. Develop a simulation with no food present that has the following rules, which are based on those of (Franks 2001):

   - Every ant deposits pheromone unless the cell is saturated, containing the maximum amount of chemical.
   - In new territory, where pheromones are not present, an ant goes randomly to the northeast or to the northwest.
   - When pheromone exists, with a certain probability an ant is more likely to follow the peromone trail.

- More than one ant can be in a cell, up to some maximum number of ants.
- Each time step, a constant number of ants leaves the nest, which is one cell.

7. Augment Project 6 to include the following rule: ants move faster in the presence of more pheromone. For example, you could consider that based on the amount of chemical, an ant makes a move per every one, two, or three time steps. Discuss the effects of varying the speed of the ants.
8. Augment Project 6 to include food and the following rule: once an ant finds food, she returns to the nest using the same rules as those of Project 6, except she goes to the southeast or southwest (Franks 2001). Discuss the difference in the self-organizing pattern between this simulation and that of Project 6.

For Projects 9–11, repeat the indicated project with the direction being relative to an ant's heading, front right and front left, instead of northeast and northwest, respectively. Have the nest be in one corner of the grid.

9. Project 6
10. Project 7
11. Project 8
12. Usually, trail following is not completely accurate. Introduce an additional stochastic element in the choice of direction in any of the earlier projects. For example, you might have an ant picking a random direction 25% of the time and face an available neighbor with the most chemical 75% of the time. Discuss the advantages and disadvantages of this lack of precision.
13. Adjust the grid on any of the earlier projects to contain obstacles.
14. Develop a cellular automaton simulation to illustate the exploitive competition of Argentine ants versus native ants, as described in Project 2 of Module 4.1, "Competition." Illustrate the competitive factor of discovery time. See Project 12 for an idea on simulating discovery time (Holway 1999).
15. Develop a cellular automaton simulation to illustrate the exploitive competition of Argentine ants versus native ants, as described in Project 2 of Module 4.1, "Competition." Illustrate the competitive factor of recruitment rate. See Project 7 for an idea on simulating rate of recruitment.
16. Develop a cellular automaton simulation to illustate the interference competition of Argentine ants versus native ants, as described in Project 2 of Module 4.1, "Competition."

Answers to Quick Review Questions

From the text's website, download your computational tool's *10_4QRQ.pdf* file for answers to these system-dependent questions.

References

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