Course: CS30A1570 Complex Systems

Assignment 1 (updated version 2): What is Complexity?

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Versioning History			
Version	Description	Reviewer Note	Date
1	First submission	3.1 It is not reasonable to show so many digits after the decimal point 4.1 You may not include the results of each specific measurement, but only the average values that play a role in confirming/refusing the hypothesis. 6.1 No captions!	10.03.2024
2	Made changes to the report after reviewer comments. Update the report format by adding abstract, introduction, research objective and question, results, discussion and conclusion section.		20.03.2024

Exploring Complexity in Ant Foraging Behavior through Agent-Based Modeling

Abstract: This report investigates the impact of various factors on the efficiency of food gathering in an ant colony simulation model. The study utilizes the NetLogo platform and explores how population size, movement parameters (such as step size and turn angle of ants), and pheromone communication mechanisms influence the time taken by ants to deplete all available food sources. The results suggest that optimal foraging efficiency depends on all these factors, and further exploration is needed to fully understand the underlying complexities.

Introduction: Ant colonies exhibit remarkable efficiency in foraging for food despite lacking a centralized control system. This phenomenon is attributed to self-organization and emergent behavior arising from simple individual ant actions. Agent-based modeling provides a valuable tool to investigate these complex systems. This study uses the NetLogo platform to simulate ant foraging behavior and analyze the impact of different factors on their foraging efficiency.

Research Objective and Questions:

This research aims to understand how complexity arises in ant foraging behavior through an agent-based modelling approach. The specific questions addressed are:

1. How do variations in population size, maximum step size, and maximum turn angle affect the average time taken by ants to consume all food in the MultipleAnts.nlogo model?

2. How does the introduction of a pheromone mechanism, where ants leave and follow trails, influence foraging efficiency compared to a model without pheromones?

3. What are the optimal values for pheromone diffusion and evaporation rates in the Ants Simple model for a fixed population size, and how do these parameters impact foraging efficiency?

Results:

Task 1: Based on the data (Appendix- Table 1) obtained from running the modified MultipleAnts.nlogo model (Appendix- Image 1 & Attachment 1) 5 times per configuration and taking the average time taken (as ticks), it is evident that the average time taken for the ants to consume all available food varies depending on the population size, maximum step size, and maximum turn angle.

Population Size: Increasing the population size from 50 to 100 decreases the average time (ticks) taken for ants to consume all available food.

Maximum Step Size: Increasing the maximum step size from 4 to 8 increases the average time for a population of 50 but decreases the average time for a population of 100.

Maximum Turn Angle: Increasing the maximum turn angle from 60 to 120 degrees decreases the average time for a population of 100 but increases the average time for a population of 50.

The observations suggest that the average time taken for the ants to deplete the food sources depends on all the parameters. However, further testing is needed to identify and understand the proper causes and the effects of each parameter. Moreover, the results vary due to the stochastic nature of the simulation.

Task 2: The introduction of a pheromone mechanism in the ant simulation model appears to have some effect on the ant colony. Based on the data (Appendix – Table 2) obtained from running the modified MultipleAntsWithPheromone.nlogo model (Attachment 2) with incorporating the concept of pheromones (Appendix- Image 2) 5 times per configuration and taking the average time taken (as ticks), it is evident that the average time taken for the ants to consume all available food varies depending on the population size, maximum step size, and maximum turn angle. For this experiment, the diffusion rate and the evaporation rate of the pheromones were kept fixed in all the experiments.

Population Size: Increasing the population size from 50 to 100 decreases the average time (ticks) taken for ants to consume all available food (Appendix- Plot 4).

Maximum Step Size: Increasing the maximum step size from 4 to 8 increases the average time for a population of 50 but decreases the average time for a population of 100 (Appendix- Plot 5).

Maximum Turn Angle: Increasing the maximum turn angle from 60 to 120 degrees decreases the average time for a population of 100 but increases the average time for a population of 50 (Appendix- Plot 6).

When comparing the model without the concept of pheromone (Appendix- Table 3), the average time taken generally increases. It is observed that the incorporation of pheromones usually increases the average time taken with the exception of 2 cases where the (population, max-step-size, max-turn-angle) is (50, 8, 60) and (100, 8, 60). This demonstrates that the optimal value for max-step-size is 8 and for the max-turn-angle is 60.

This data suggests that while the introduction of a pheromone mechanism has an effect on the efficiency of foraging on the ant colony, the impact can vary depending on the factors such as population size, maximum step size, maximum turn angle, pheromone diffusion and evaporation rate. Further investigations are required to observe how these factors interact with each other to affect the efficiency of the model in terms of time taken. Genetic Algorithm can be the best method to figure out the optimum values of the parameters.

Task 3: For this task, the AntsSimpleModel.nlogo model was modified (Attachment 3) so that the experiment population remained constant at 100 and before stopping the ticks were stored in a global variable named experiment-result. Then, the tool "*Behavior Search*" was used (Appendix- Image 3 and Image 4). The "*Behavior Search*" experiment was setup with the following configurations:

- o Population: 100 fixed
- o Diffusion rate: initiated at 10 with increment 10, and maximum value was 100.
- o Evaporation rate: initiated at 10 with increment 10, and maximum value was 100.
- o Repetitions: 5

The total experimentation yielded 500 sets of data. From the data, it was evident that the minimum time achieved for a population of 100 was 980 ticks where the evaporation-rate was 40 and diffusion-rate was 70 (Attachment 4- ants-behavior-space-data.xlsx). Running a python script (Attachment 5: ants.py) gives the following result:

- o Correlation between experiment result and evaporation rate: 0.032
- o Correlation between experiment result and diffusion rate: -0.067

For a fixed population of 100, the optimal combination of diffusion and evaporation rates for fastest foraging was identified as 70 and 40, respectively. Correlation analysis suggests a weak negative influence of diffusion rate and a negligible influence of evaporation rate on foraging time.

Discussion:

The findings highlight the interplay between various factors in determining foraging efficiency. While increasing population size intuitively improves efficiency, the impact of movement parameters (step size and turn angle) is less straightforward. The introduction of pheromones demonstrates a trade-off between exploration and exploitation: pheromones guide ants towards known food sources but might also limit exploration of new areas. The optimal values for pheromone parameters in Task 3 suggest a sweet spot where diffusion allows exploration while evaporation prevents trails from persisting indefinitely. However, the weak correlations require further investigation and may indicate the influence of additional factors not considered in this study.

Conclusion:

This study demonstrates the effectiveness of agent based modelling in exploring complex phenomena like ant foraging. The results highlight the dependence of foraging efficiency on numerous factors and the need for further exploration to fully understand their interaction. Future studies could investigate the impact of environmental complexity, the influence of different pheromone decay mechanisms, and the potential for learning and adaptation within the ant colony model.
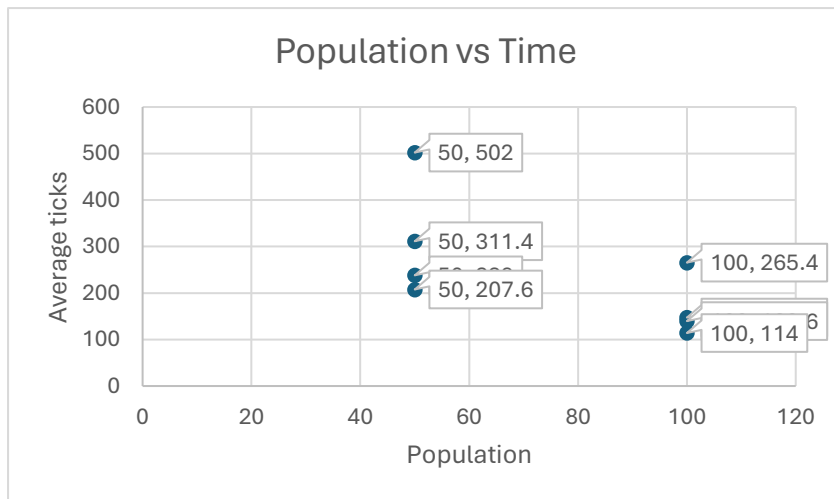
Appendix:

Table 1: Average time (ticks) required to deplete all the food sources (without pheromones).

Population	Maximum Step Size	Maximum Turn Angle	Average Ticks
50	4	60	311.40
100	4	60	147.20
50	8	60	502.00
100	8	60	265.40
50	4	120	238.00
100	4	120	139.60
50	8	120	207.60
100	8	120	114.00

Table 2: Average time (ticks) required to deplete all the food sources (with pheromones).

Population	Maximum Step Size	Maximum Turn Angle	Average Ticks
50	4	60	347.80
100	4	60	182.20
50	8	60	276.20
100	8	60	156.60
50	4	120	361.20
100	4	120	225.40
50	8	120	363.40
100	8	120	200.40

Table 3: Comparison of the average time (ticks) required to deplete all the food sources (without pheromones and with pheromones).

Population	Maximum Step Size	Maximum Turn Angle	Average Time without Pheromones	Average Time with Pheromones
50	4	60	311.4	347.8
100	4	60	147.2	182.2
50	8	60	502	276.2
100	8	60	265.4	156.6
50	4	120	238	361.2
100	4	120	139.6	225.4
50	8	120	207.6	363.4
100	8	120	114	200.4

Plot 1: Varying population (50 and 100) vs Average ticks required.

Population vs Time

Average ticks (y-axis): 0, 100, 200, 300, 400, 500, 600
Population (x-axis): 0, 20, 40, 60, 80, 100, 120

Data labels:
- 50, 502
- 50, 311.4
- 50, 207.6
- 100, 265.4
- 100, 114

Plot 2: Varying maximum step size (4 and 8) vs Average ticks required.

Maximum Step Size vs Time

Average ticks (y-axis): 0, 100, 200, 300, 400, 500, 600
Maximum Step Size (x-axis): 0, 2, 4, 6, 8, 10

Data labels:
- 8, 502
- 4, 311.4
- 4, 238
- 4, 139.6
- 8, 265.4
- 8, 207.6
- 8, 114

Plot 3: Varying maximum turn angle (60 and 120) vs Average ticks required.

Maximum Turn Angle vs Time

Average ticks (y-axis): 0, 100, 200, 300, 400, 500, 600
Maximum Turn Angle (x-axis): 0, 20, 40, 60, 80, 100, 120, 140

Data labels:
- 60, 502
- 60, 311.4
- 60, 265.4
- 60, 147.2
- 120, 207.6
- 120, 114

Plot 4: Varying population (50 and 100) vs Average ticks required.

Population vs Time

- 50, 363.4
- 50, 276.2
- 100, 200.4
- 100, 156.6

Plot 5: Varying maximum step size (4 and 8) vs Average ticks required.

Step Size vs Time

- 4, 361.2
- 8, 363.4
- 8, 276.2
- 4, 225.4
- 4, 182.2
- 8, 200.4
- 8, 156.6

Plot 6: Varying maximum turn angle (60 and 120) vs Average ticks required.

Turn Angle vs Time

- 60, 347.8
- 120, 363.4
- 60, 276.2
- 120, 225.4
- 120, 200.4
- 60, 182.2
- 60, 156.6
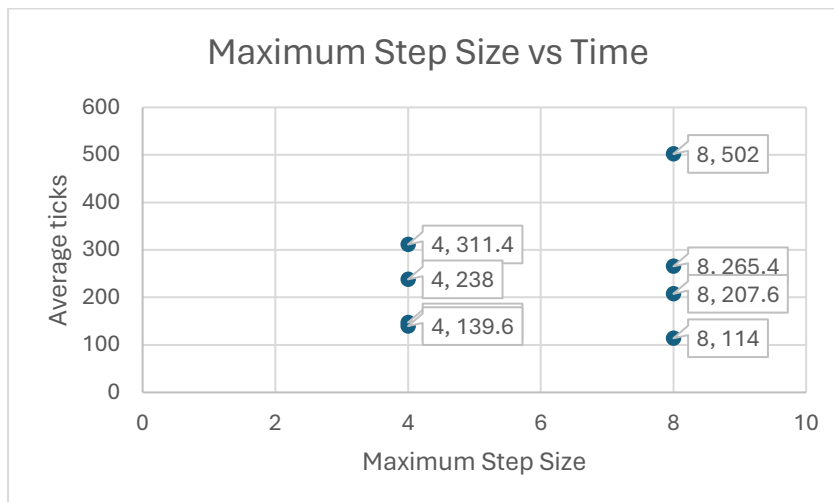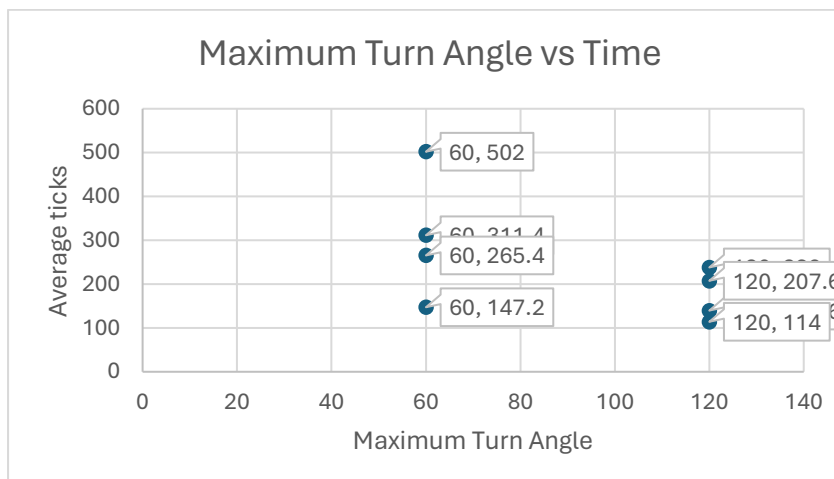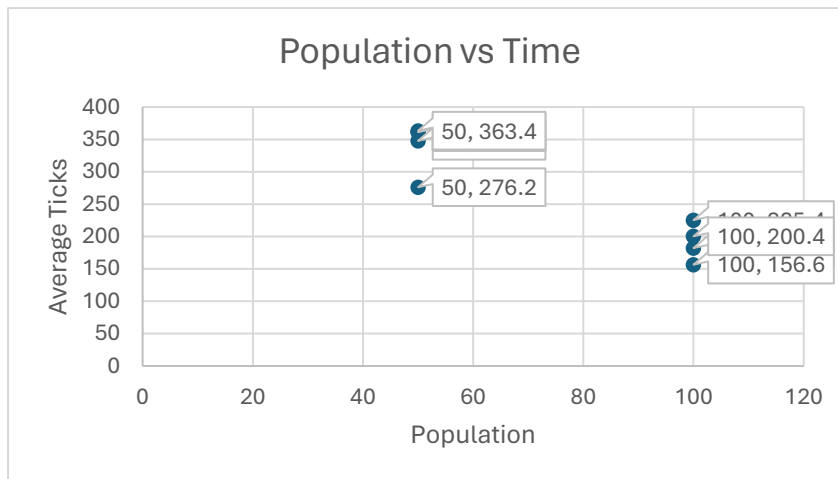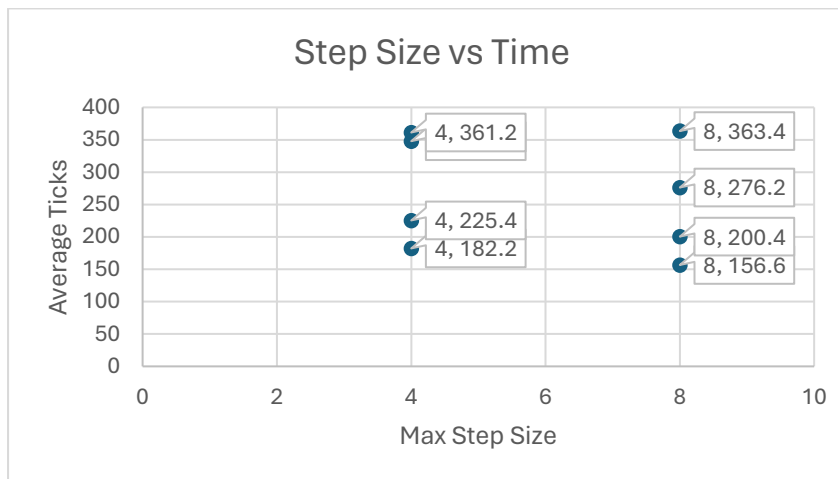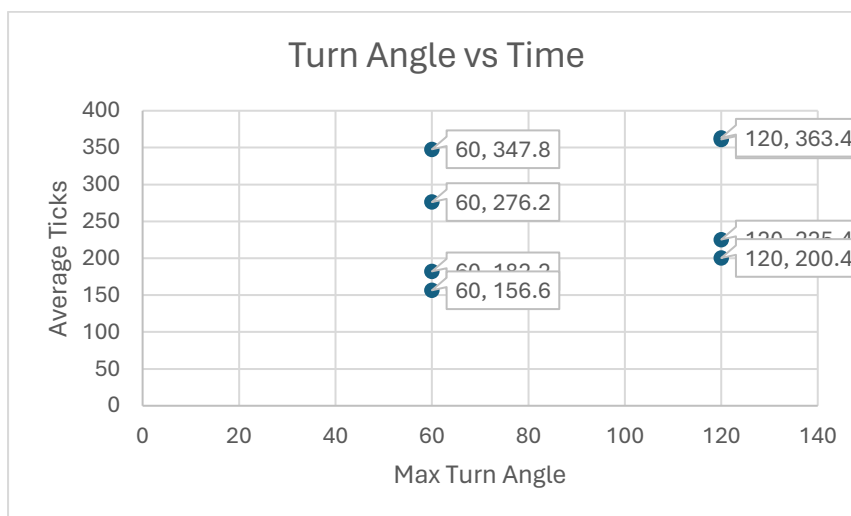
Plot 7: Heatmap of behavior-space data

Heatmap of Ticks (Min: 102, Max: 724)
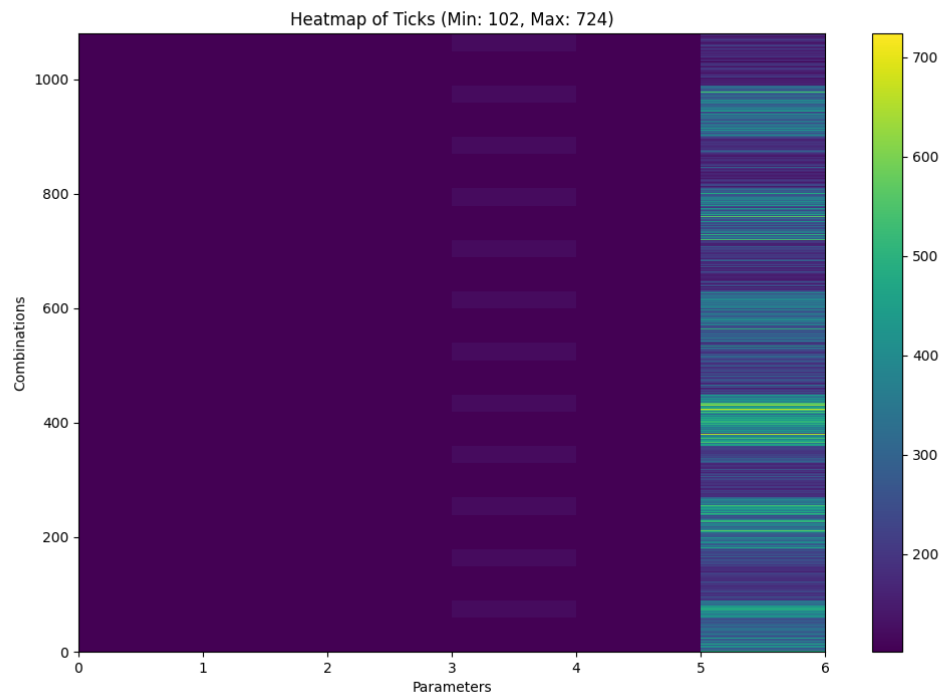
Plot 8: Pair-plot of behavior-space data
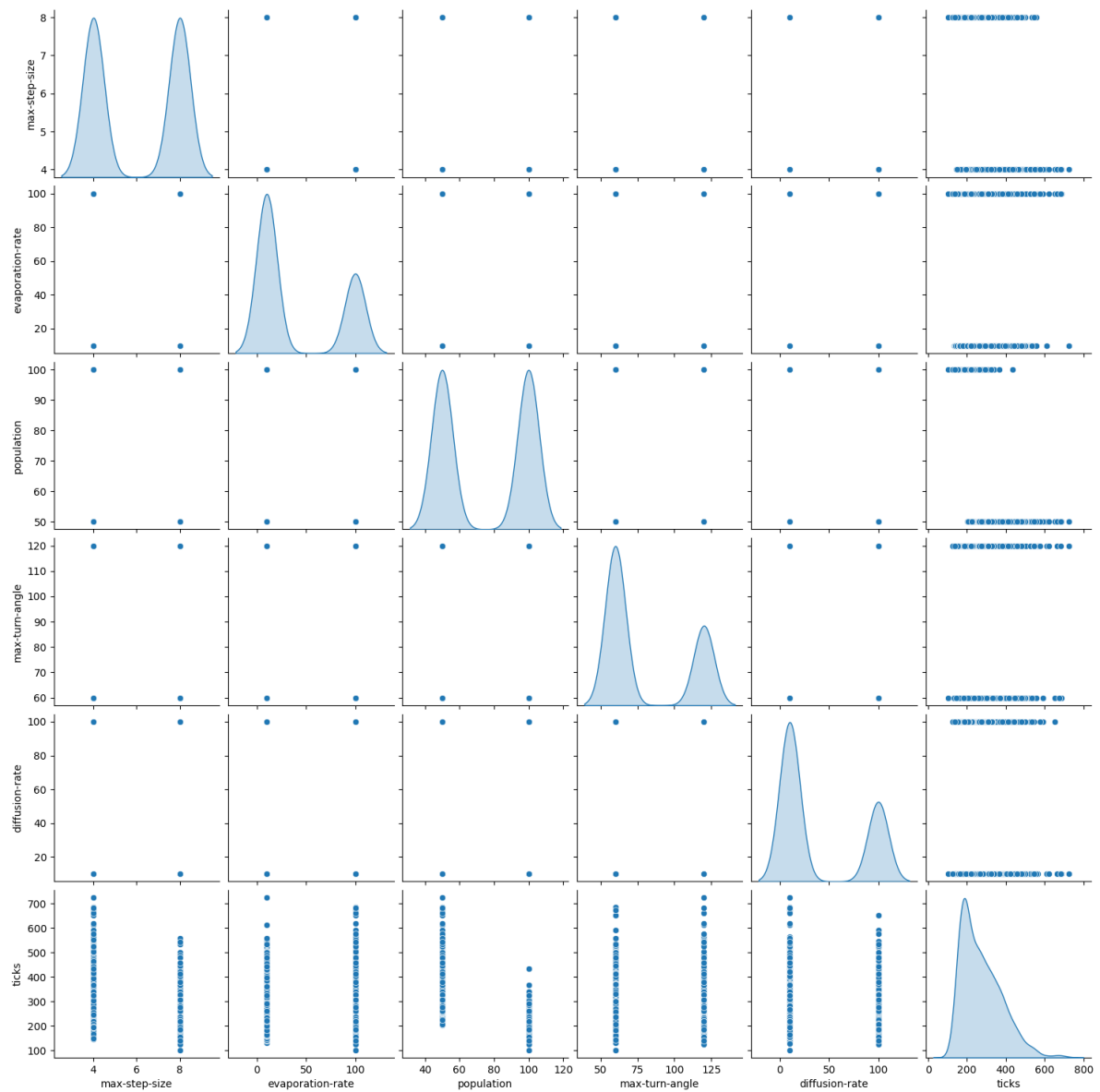
Image 1: Multiple Ants Model
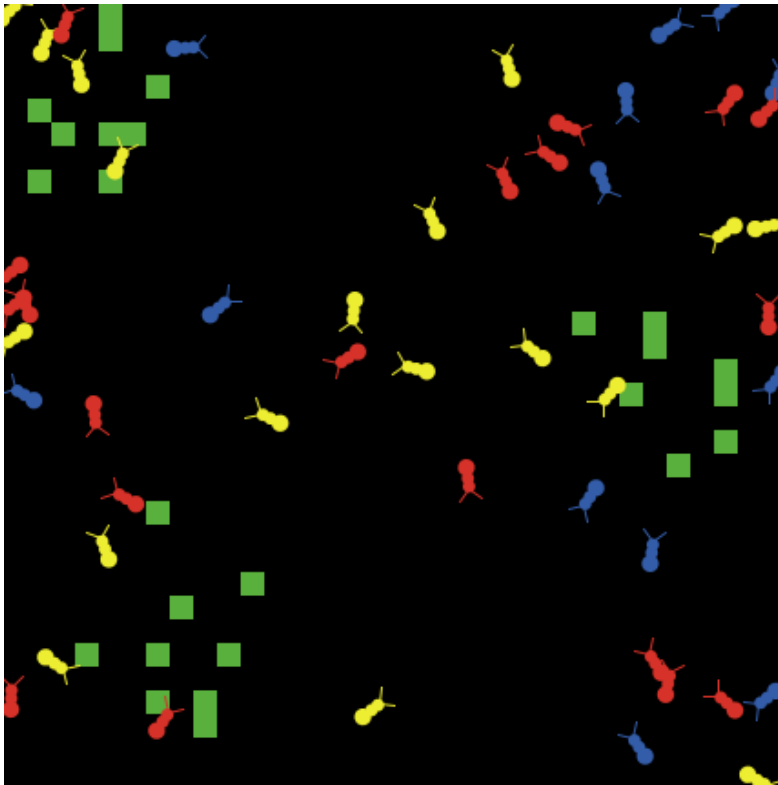
Image 2: Multiple Ants Model with pheromones
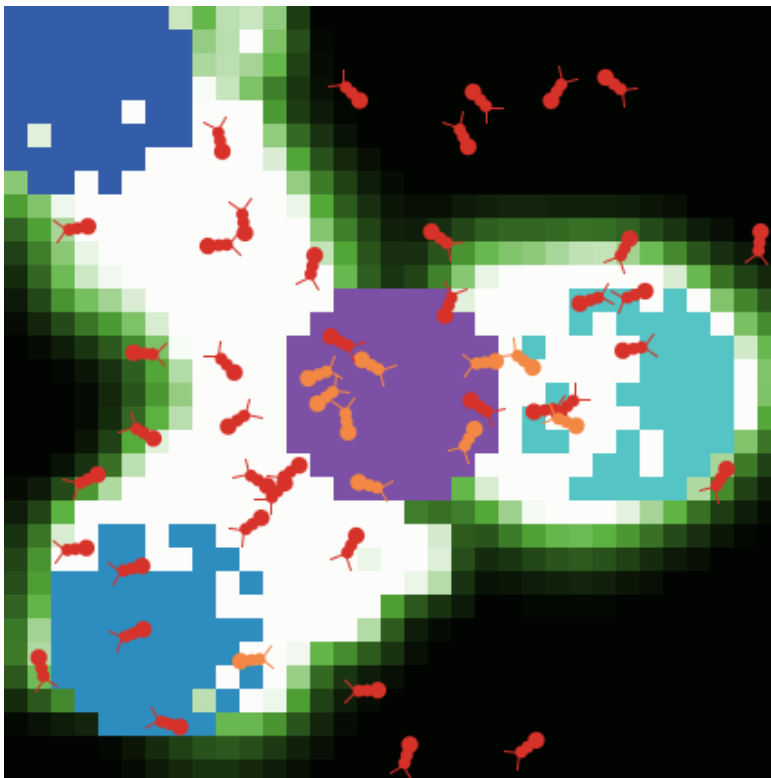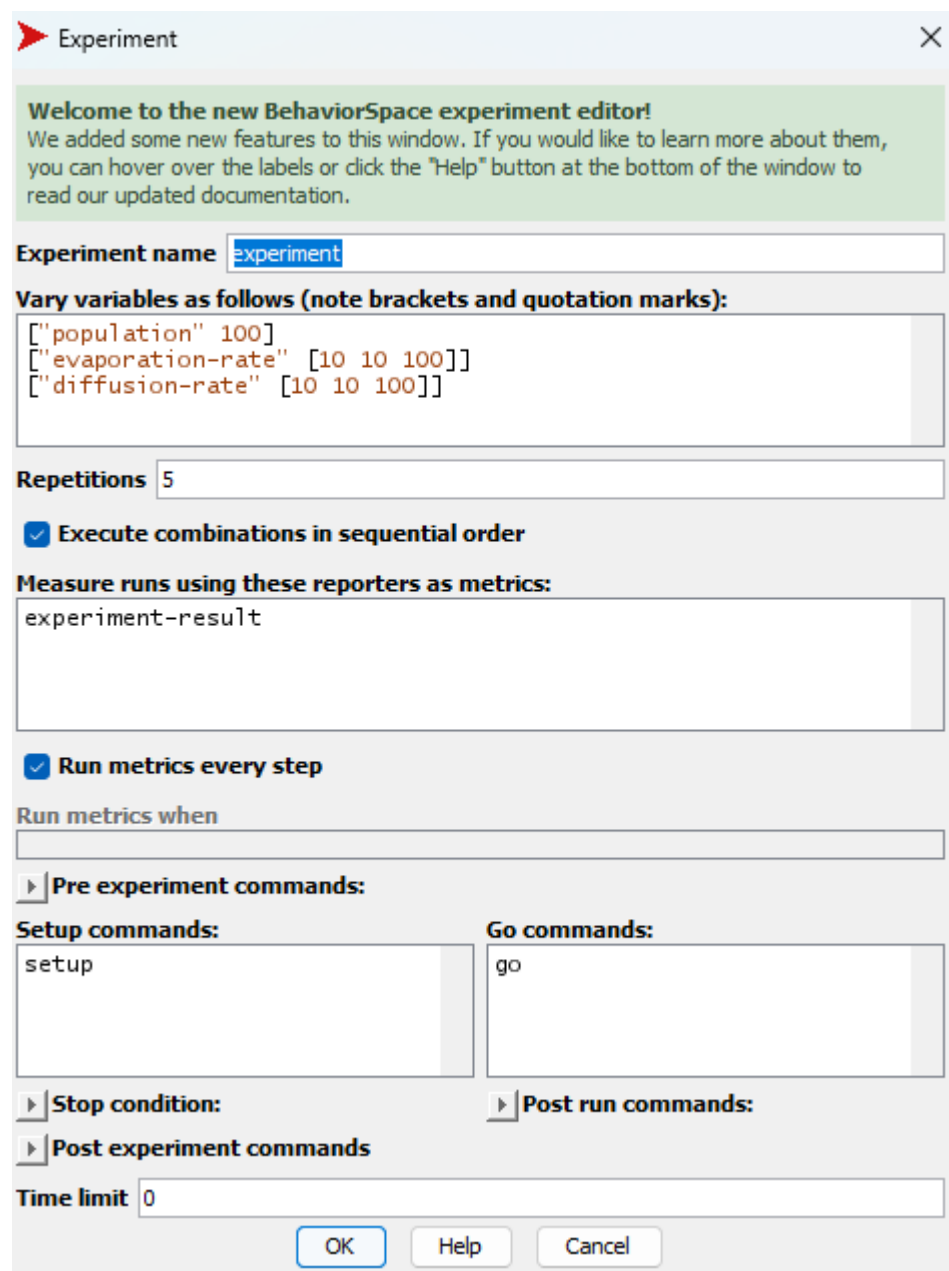
Image 3: The "Behavior Space" experiment configuration

Experiment   ✕

Welcome to the new BehaviorSpace experiment editor!
We added some new features to this window. If you would like to learn more about them, you can hover over the labels or click the "Help" button at the bottom of the window to read our updated documentation.

Experiment name | experiment |

Vary variables as follows (note brackets and quotation marks):

```
["population" 100]
["evaporation-rate" [10 10 100]]
["diffusion-rate" [10 10 100]]
```

Repetitions | 5 |

☑ **Execute combinations in sequential order**

Measure runs using these reporters as metrics:

```
experiment-result
```

☑ **Run metrics every step**

Run metrics when
| |

▸ **Pre experiment commands:**

Setup commands: **Go commands:**

```
setup
```                                     ```
go
```

▸ **Stop condition:**                    ▸ **Post run commands:**

▸ **Post experiment commands**

**Time limit** | 0 |

[ OK ]   [ Help ]   [ Cancel ]

Image 4: Multiple ants with pheromones mechanism
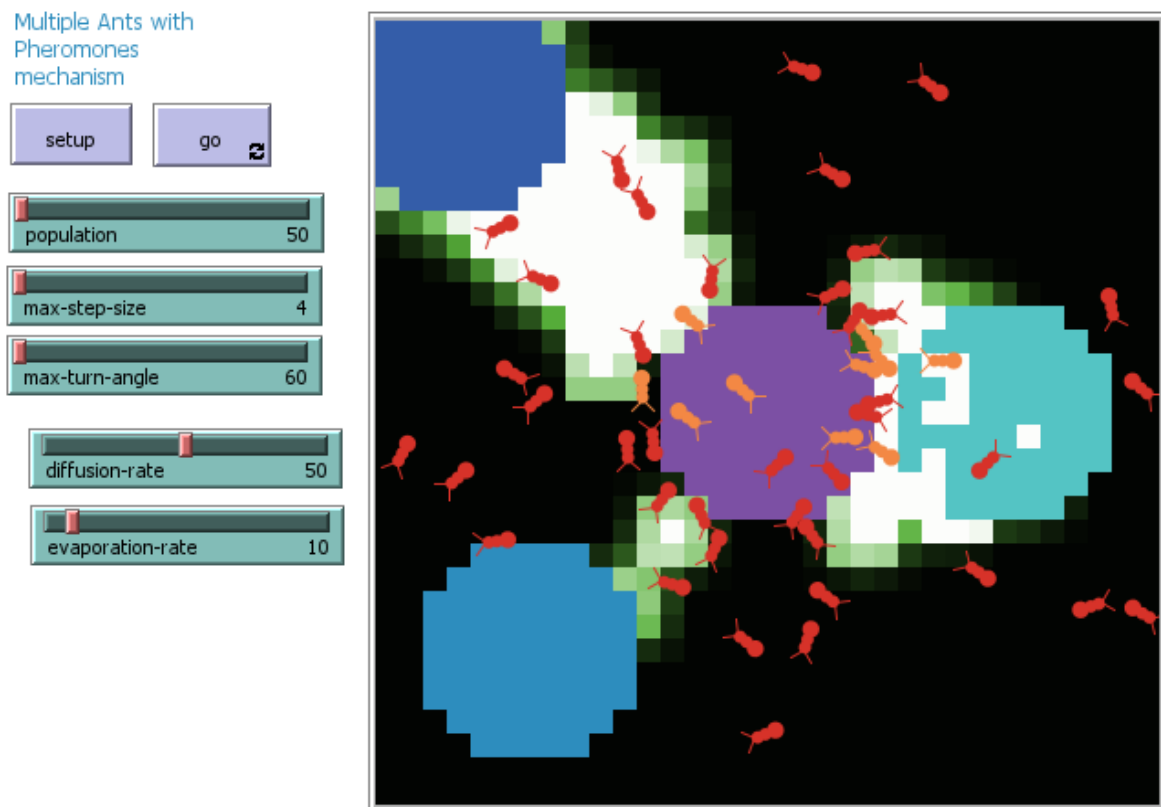


**Attachments:**

1. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_1/MultipleAnts.nlogo
2. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_1/MultipleAntsWithPheromones.nlogo
3. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_1/AntsSimpleModel.nlogo
4. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_1/ants-behavior-space-data.xlsx
5. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_1/ants.py
6. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_1/data-analysis.py
7. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_1/ants-with-pheromones-behavior-space-data.xlsx