Course: CS30A1570 Complex Systems

Assignment 7: Models of Biological Self-Organization

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Submitted by: Turzo Ahsan Sami

Title: Analysis of Biological Self-Organization in Fireflies Synchronization and Flocking Behavior

Introduction

This report presents an analysis of two models of biological self-organization: Fireflies Synchronization and Flocking Behavior. The study aims to understand the underlying mechanisms that lead to emergent behaviors in biological systems. The models are simulated using NetLogo, a multi-agent programmable modeling environment.

Research Objective and Questions

The objective of this research is to investigate how different parameters affect the time it takes for all fireflies to synchronize their flashing in the Fireflies model and to understand the flocking behavior in the Flocking model. The research questions are:

- R1: How do the number of fireflies, flash length, and cycle length affect the time to synchronization in the Fireflies model?
- R2: How do the vision and maximum turn angle of birds affect the flocking behavior in the Flocking model?

Experiment Design:

The experiment design involves running simulations on the Fireflies and Flocking models with varying parameter values. For the Fireflies model, the parameters varied are the number of fireflies, flash length, and cycle length. For the Flocking model, the parameters varied are the vision and maximum turn angle of the birds. The time steps required for all fireflies to synchronize, and the circular mean of bird headings are recorded for each simulation run.

Task 1: R1: Fireflies Synchronization in Netlogo

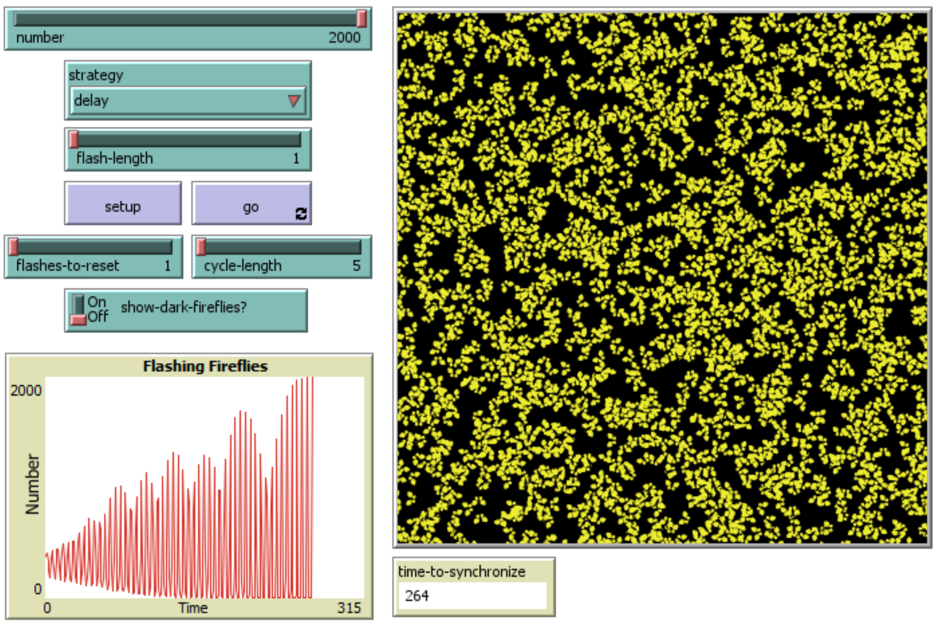
This analysis investigates how different parameters affect the time it takes for all fireflies in the modified Fireflies.nlogo model to synchronize their flashing. The following three parameters influence the time to synchronize all fireflies to flash at the same time:

- Number of Fireflies (number): This variable controls the population density of fireflies in the environment.
- Flash Length (flash-length): This variable determines the duration of a firefly's flash.
- Cycle Length (cycle-length): This variable sets the internal cycle a firefly goes through before flashing again.

Model Modification:

The original code for the Fireflies.nlogo model was modified (Appendix: Attachment 1). The key aspect to consider for analyzing synchronization time is the look procedure, where fireflies check their neighbors and potentially adjust their clocks. The go procedure was modified so that the simulation stops when all fireflies are flashing (color = yellow). A time to synchronize monitor was added that displayed total time (ticks) taken for all fireflies to flash. Randomized testing of the model with showed that a certain set of parameter runs the model indefinitely. To mitigate that infinite running problem of the behavior space tool, the model was modified so that after 9000 ticks, the simulation would stop.

Image 1: Fireflies model simulation in netlogo



Hypotheses:

- H1: Increased Number will increase time: As the number of fireflies increases, the time to synchronization will likely increase. With more fireflies, there are more interactions needed for all individuals to become aligned.
- H2: Increased Flash Length will decrease time: A longer flash length might provide a clearer signal for neighboring fireflies. This could lead to faster synchronization times as fireflies have a larger window to adjust their cycles based on neighbors.
- H3: Shorter Cycle Length will decrease time: Shorter cycle lengths could lead to faster interactions and adjustments between fireflies. This might decrease the time needed for all fireflies to synchronize. However, extremely short cycles might create noise and hinder coordination.

Experiments Design:

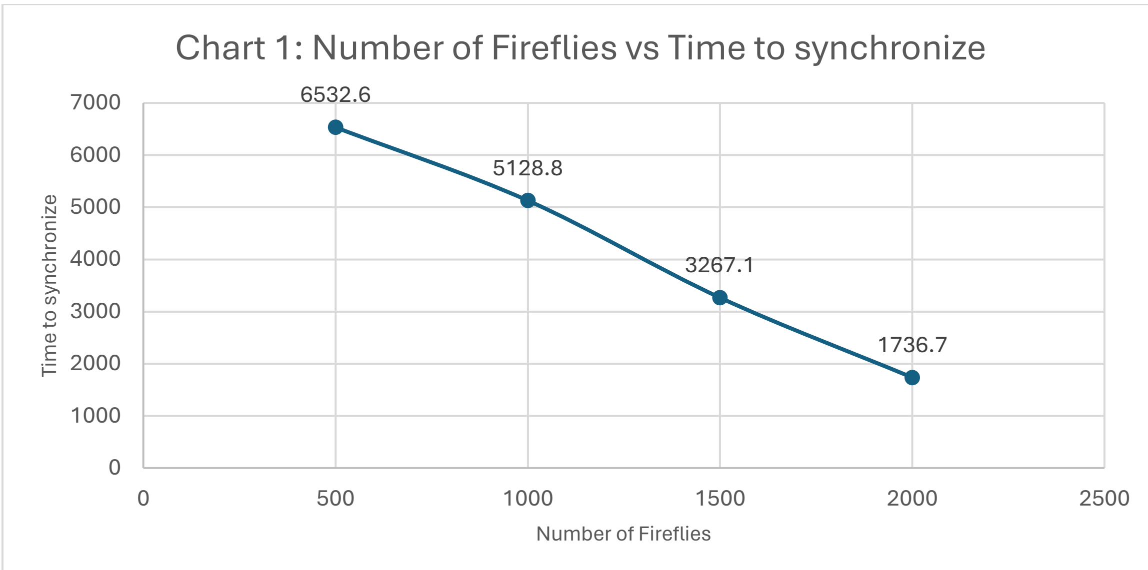
The model simulation was run multiple times using the Behavior Space tool. The following three parameter values were varied:

- Number of Fireflies (number): The parameter values were (500, 1000, 1500, and 2000).
- Flash Length (flash-length): The parameter values were (5, 10, 15, and 20).
- Cycle Length (cycle-length): The parameter values were (1, 3, 5, 7, and 9).

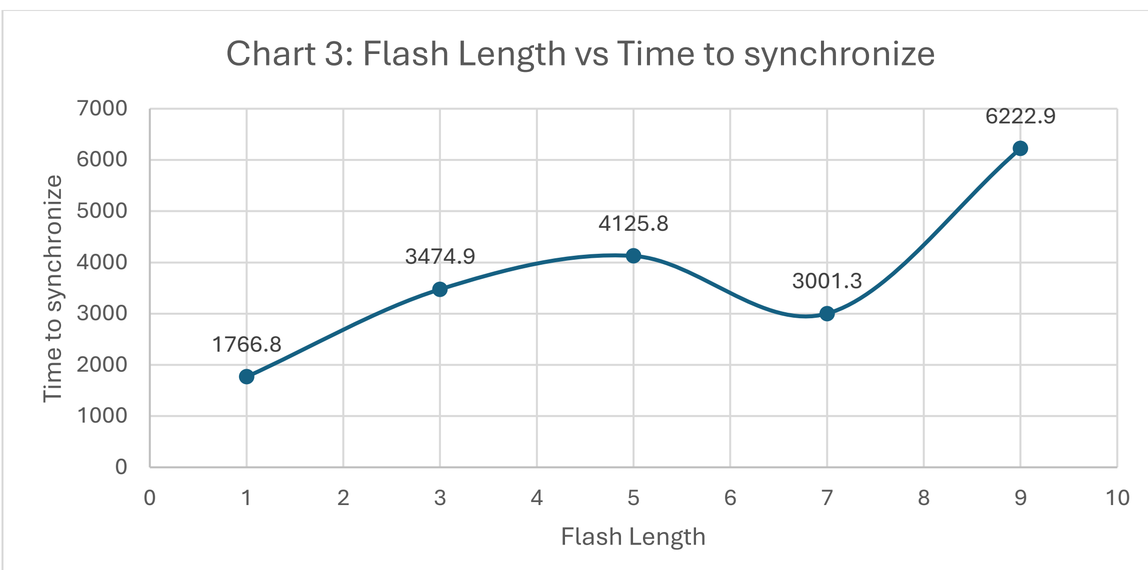
The time steps required (time-to-synchronize) for all fireflies to synchronize under each parameter combination were recorded (Appendix: Attachment 2).

Findings:

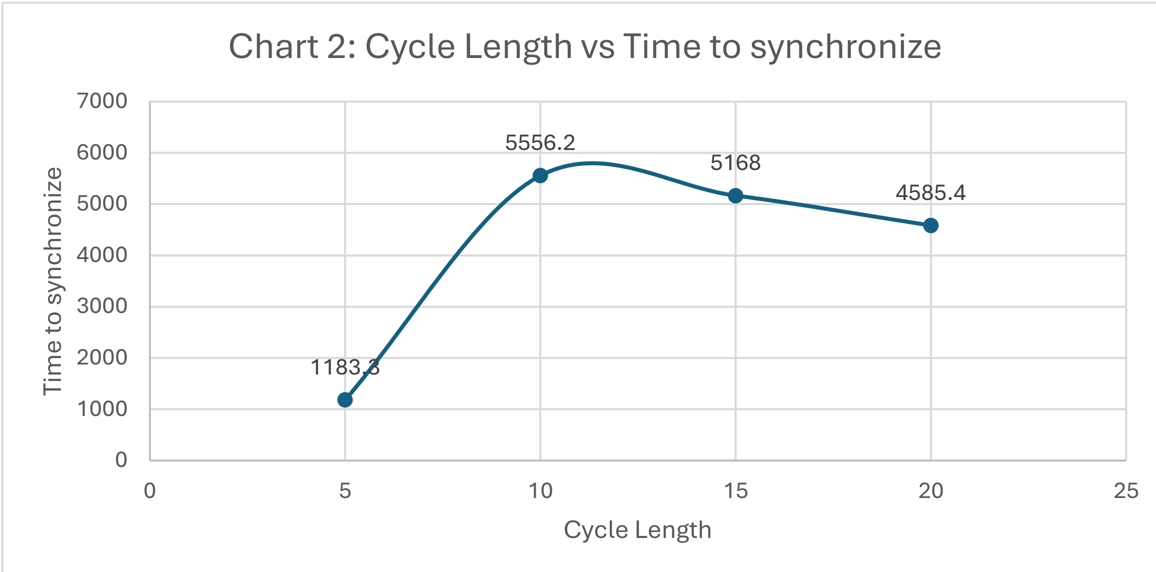
H1: The time to synchronization shows a positive correlation with the number of fireflies. A greater number of fireflies decreases the synchronization time as evident from the data (Chart 1).



H2: There is an optimal flash length for faster synchronization. Lower flash-lengths decrease the time to synchronize as opposed to the hypothesis, as evident from the data (Chart 2).



H3: Shorter cycle lengths lead to faster synchronization as evident from the data (Chart 3). However, in most cases when cycle length is more than 10 the fireflies did not synchronize.



Analysis:

Number of fireflies vs. Time to synchronize: It appears that regardless of the number of fireflies, when the cycle length is 5, the fireflies synchronize instantly (time to synchronize = 0). As the cycle length increases, the time to synchronize generally increases as well, especially noticeable when the cycle length is 10 or higher.

Cycle length and Flash length: For each combination of cycle length and flash length, the time to synchronize varies. However, for certain combinations, such as cycle length 5 and flash length 1, synchronization is achieved almost instantly (time to synchronize = 0).

When the flash length is higher (e.g., 5, 7, or 9), it seems to take longer for the fireflies to synchronize, especially evident with higher cycle lengths. In most cases when flash length was higher than 5, the fireflies did not synchronize. However, in some cases when the flash-length was higher than 5, the fireflies synchronized which dictates that the cycle-length may have caused that deviation.

General trends: A trend was observed where longer cycle lengths and flash lengths lead to longer synchronization times. Some combinations of parameters seem to result in synchronization happening almost instantly, while others require more time. There seems to be a threshold effect, where certain combinations of parameters lead to synchronization happening almost instantly, while others lead to synchronization taking a longer time, potentially even exceeding the measurement. There could be an optimal flash length for faster synchronization. Excessively long flashes might overlap and create confusion. Long cycles might introduce too much noise and hinder the fireflies' ability to adjust their flashing patterns effectively.

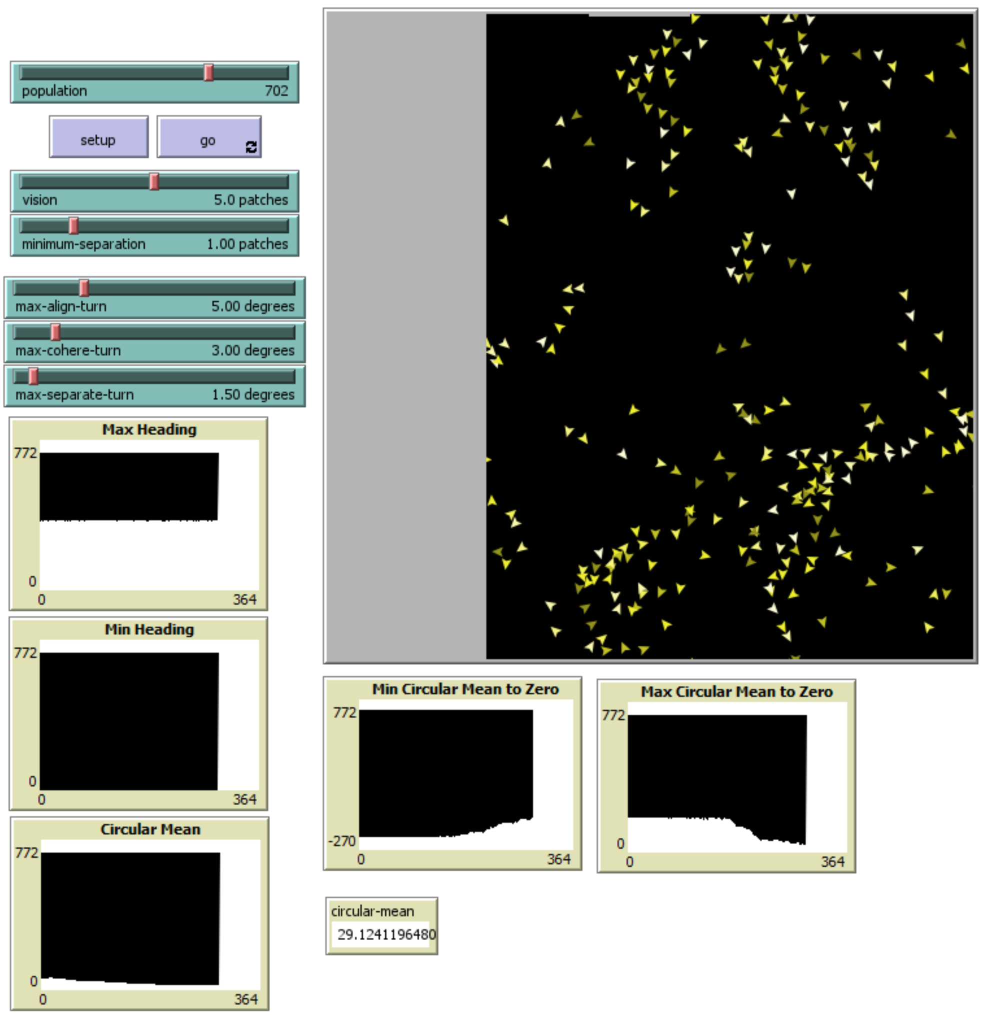
Task 2: R2: Analysis of Flocking in Netlogo

The model aims to explore how seemingly simple individual behavioral rules can lead to complex collective motion patterns like flocking. The Flocking.nlogo model (Appendix: Attachment 3) simulates the emergent behavior of flocking birds. Individual birds (turtles) move around a toroidal world (edges wrap around) following three simple rules:

- Alignment: Each bird tends to move in the same direction as its nearby peers
- Separation: Each bird avoids others that get too close
- Cohesion: Each bird moves towards other nearby birds, unless another bird is too close

These rules, when applied to each bird at every time step, lead to the flocking behavior observed in the model. The problem is to understand how these simple rules lead to the complex behavior observed in flocks of birds. Specifically, how different parameters (like the number of birds, their vision, and the maximum angle they can turn) affect the flocking behavior.

Image 2: Flocking simulation in netlogo



Hypotheses

- H1: Increasing the vision of the birds will lead to larger, more cohesive flocks.
- H2: Increasing the maximum turn angle will lead to larger, more cohesive flocks.

Experiment Design:

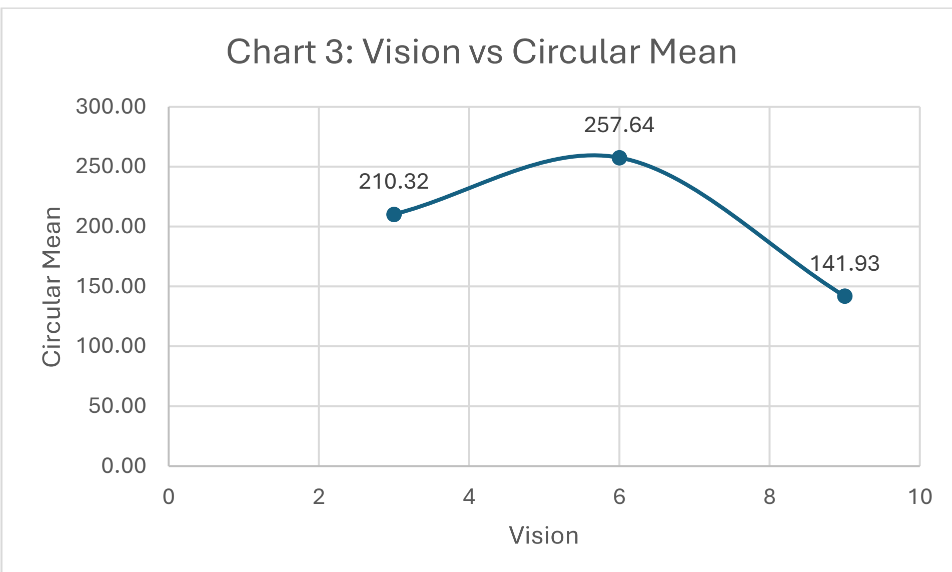
Experiments are conducted using the Behavior Space tool to investigate how different parameter values affect flocking behavior. The following parameters were varied:

- Vision: The parameter values were (3, 6, and 9)
- Maximum Turn Angle: The parameter values were (4, 8, 12, and 16)

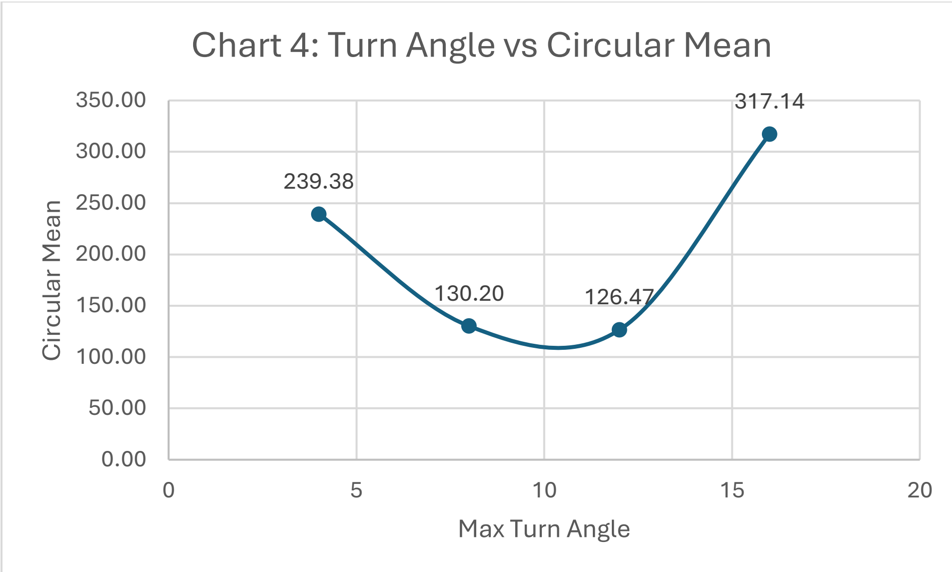
The circular mean of bird headings is calculated at each time step to quantify how aligned the flock is. A higher circular mean indicates a more unified flock direction (Appendix: Attachment 4).

Findings:

H1: Increasing the vision range might lead to tighter flocks and a higher circular mean of bird headings was hypothesized, however the data from the experiment shows that there the cohesion is strongest when Vision is somewhere in the middle (Chart 3).



H2: The data from the experiments (Chart 4) present an interesting scenario where the cohesion is stronger when turn angle is lower and then the cohesion gradually decreases. However, the cohesion increases rapidly as the turn angle is higher. This shows that there might be a threshold value after which there is more cohesion amongst the birds of the flock.



Analysis:

There are 12 combinations of vision and max-align-turn in the Behavior space experiment setup. The circular-mean values vary across these combinations. There is a variability in circular-mean values across different vision and max-align-turn combinations. For instance, when vision is 3 and max-align-turn is 4, the circular mean is approximately 305.71. Similarly, when vision is 3 and max-align-turn is 16, the circular mean is around 236.45. The result indicates a correlation amongst the vision and maximum turn angle parameters for the birds to have a cohesive flocking. However, to obtain the more optimum parameter values, genetic algorithm can be used.

Discussion:

The findings from the experiments provide valuable insights into the factors influencing the time to synchronization in the Fireflies model and the flocking behavior in the Flocking model. The results indicate that there is a correlation between the vision and maximum turn angle parameters for the birds to have a cohesive flocking in the Flocking model. In the Fireflies model, the time to synchronization shows a positive correlation with the number of fireflies. However, there are certain threshold effects observed in both models, indicating the complex nature of these biological systems.

Conclusion:

This study demonstrates the power of simple rules in driving complex behaviors in biological systems. While the models used in this study are simplifications of real-world phenomena, they provide a useful framework for understanding the fundamental mechanisms underlying biological self-organization. Future work could extend these models to incorporate more realistic parameters and behaviors, providing even deeper insights into the phenomena of fireflies synchronization and flocking behavior.

Attachment:

1. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_7/Fireflies.nlogo
2. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_7/Fireflies-experiment-spreadsheet.csv
3. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_7/Flocking.nlogo
4. https://github.com/ahsan-sami-turzo/complex-system-code/blob/main/CS_Assignment_7/Flocking-experiment-spreadsheet.csv