Assignment 0
Flocking Phenomena

Project Collective intelligence

Problem description

Flocking is the phenomena observed when a flock of birds fly together forming different simple to complex, often irregular, patterns. The collective behaviour involves no collisions while the entire flock is constantly moving, and most importantly, in a self-organizing fashion, thus, highlighting the complexity of the collective (Figure 1). Consequently, modelling this complex behavior has been a research focus for many swarm intelligence and swarm robotics projects throughout the end of 20th century and even nowadays. In this assignment we will examine in more depth the seminal implementation by Craig Reynolds [1].

Figure 1: Flocking

Problem Definition According to Reynolds

In his work Reynolds introduced an individual-based model where each agent acts autonomously only based on information from its neighbors and without centralized control. An agent, known as 'boid', could execute some simple individual behaviours, and by having many of these boids together, it is possible to create something similar to a bird's flocking behavior. The three individual behaviours were the following:

- **Alignment:** Steer towards the average direction of local boids

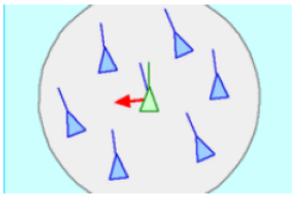

Figure 2: Alignment

- **Separation:** Steer away to avoid being in too close proximity to local boids

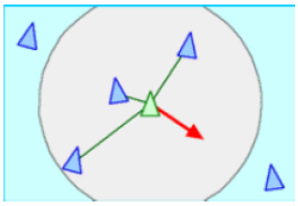

Figure 3: Separation

- **Cohesion:** Steer towards the average position (center of mass) of local boids

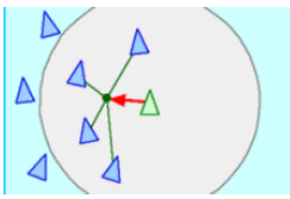

Figure 4: Cohesion

Implementation

All three individual behaviours assume an interaction range R denoted by the grey circle in the figures. As the figures already allude, the individual behaviours consist in vector contributions to the adjustments of the boid's velocity vector. Another individual behaviour of a boid that does not take place in the figures is a small and random steering which interestingly required in some cases. In particular, the four actions can be expressed by the following vector updates (see first equation below), where each action creates a steering force that updates a given boid's velocity, which subsequently updates the boid's position via the following equations:

$$f_{total} = \frac{\alpha s + \beta c + \gamma a + \varepsilon w}{M_{boid}}$$

$$V_{boid} = V_{boid} + f_{total}$$

$$X_{boid} = X_{boid} + V_{boid} \cdot \Delta t$$

where s, c, a and w are the vectors denoting the individual steering forces of the separation,cohesion, alignment and random steering components, which all are adjusted by a given weight α, β, and γ (respectively), and subsequently combined in one steering vector and divided by M_{Boid}, the mass of the boid into f_{total}, V_{boid} is the velocity vector, Δt is the duration of the movement, and X_{boid} is the updated position vector of the boid, according to the calculated velocity vector. Note that for a basic flocking algorithm, the implementation of random steering movements is not strictly necessary.

- **Alignment** (Figure 2):

$$V_N = \frac{1}{|N|} \sum_{i \in N} V_i$$
$$a = V_N - V_{boid}$$

  where V_N is the average of the velocities V_i of the boids that are within the neighborhood N. The neighborhood N contains all the boids that are within the range R with respect of the position of the focal boid (the range is indicated by the grey circle in the figure).

- **Separation** (Figure 3):

$$s = \frac{1}{|N|} \sum_{i \in N} (X_{boid} - X_i)$$

  where X_{boid} is boid's position, X is neighbor boid's position, and N denotes the set of neighbors of the boid, containing the neighbors that are within range R.

- **Cohesion** (Figure 4):

$$\overline{X}_N = \frac{1}{|N|} \sum_{i \in N} X_i$$

$$f_c = \overline{X}_N - X_{boid}$$

$$c = f_C - V_{boid}$$

where $\overline{X}_N$ is the average position of neighboring boids (green dot in the figure), fc is the cohesion force.

Pseudocode

Algorithm 1 Flocking Algorithm

procedure CHANGE POSITION
  Check neighbours in radius R
  $Alignment \leftarrow V_N - V_{boid}$
  $Separation \leftarrow \frac{1}{|N|} \sum_{i \in N} (X_{boid} - X_i)$
  $Cohesion \leftarrow f_C - V_{boid}$
  $f_{total} \leftarrow \frac{\alpha Alignment + \beta Separation + \gamma Cohesion}{M_{boid}}$
  $Move \leftarrow Move + f_{total}$
  $Move \leftarrow \min(Move, MaxVelocity) * Move.Normalize()$
  $Position \leftarrow Position + Move * \Delta t$
end procedure

Assignment Description

This assignment aims to help you gain familiarity with the code.You will be provided with a python based simulator called Violet. The assignment contains two stages. For more detailed information about the specification of the functions to implement, refer to the *'Code Tutorial - Assignment 0'* document. .

Stage 1

You will be asked to implement the simulation of flocking behaviour. In particular, you will need to implement the behaviour in the file flocking.py. In this file you will find `class FlockingAgent(Agent)`. This class will control the agents' behaviour during the simulation. Within this class you will find the function `def change_position()`. Here you will implement the flocking behaviour; Alignment, Separation and Cohesion. Do not change the other settings; these are just meant for the general functionality of the code. You can find the general structure of the code and documentation for the simulator in the supplementary documents. Note that if the expected behavior is not observable in 6-10k time-steps, then adjustments to the parameters should be made. While there is no maximum amount of time-steps imposed for the simulations anything above 10k time-steps is generally useless for this and the following assignment. It remains your responsibility to devise and research criteria and metrics to assess the quality of the flocking behavior, as well as properly referencing the academic sources.

Stage 2

After implementing a functioning flocking, you will find a particular idea that you want to explore further involving flocking. (e.g., how does the flock behave when we add obstacles, what happens if we suppress one of the forces, what if we add an extra force to the mix, etc). Do some experiments and add your findings and the possible explanation for it. Try to be as scientific as possible in your conclusions and hypothesis.

By the end of the week, you are expected to present a video of the simulation with the flocking behavior implemented, plus the extra idea that you decided to explore. An example video can be found on canvas

Mock Presentation

You will have a short presentation of your work by the end of the first week. Important to note that this presentation´s mark does not count towards the final grade, but is rather a practice round so you can learn from it for the next ones. The presentation should last max 15 min (including showcasing the created simulation and excluding 5 minutes for questions), and the structure should be as follows:

For a more detailed description of what is expected from you, check the grading rubrics in Canvas.

Introduction	Briefly introduce the report: the purpose of the simulation, type of analysis being done, questions that will be answered with the simulation.
Methodology	Present how agents are modeled. How is their interaction implemented? Try to explain the main idea without showing the actual code (e.g. use finite state machines, formulas, or pseudo-code if everything else fails).
Results	Present the result, in the form of images and videos of the simulations, trajectories of the agents, and simple plots.
Conclusion	Conclude stating what you have learned. How do different choices concerning the embodiment affect the collective behavior/intelligence of the population?

Table 1: Presentation Sections

Deadlines

Presentation/Demo	Friday 06-06-2025 (during class)
Hand in slides on canvas	Friday 06-06-2025 (before class)

References

[1] C. Reynolds, “Boids, 1986,” Homepage: https://www. red3d. com/cwr/boids, vol. 2, 2018.

[2] R. Zandie, “Simulating bird flock behavior in python using boids,” May 2019.