Flocking Behaviour: Agent-Based Simulation and Hierarchical Leadership

Abstract

This work aims to implement the model 'Emergence of a Leader in a Group' based on the study of Flocking Behaviour: Agent-Based Simulation and Hierarchical Leadership by Vicenç Queraa, Francesc S. Beltrana and Ruth Doladob in 2010.

Introduction

The study of the emergence of a leader in groups is quite interesting because it can be supplemented by various factors, such as political and personal preferences, the extent to which a person is influenced by others, and the level of independence in decision-making. This can be useful for creating evacuation plans and modelling people's behaviour during emergencies.

We will implement a model that works on this principle: agents move in a two-dimensional open(toroidal) world consisting of cells (or patches), where one cell can be occupied by only one agent at a time (i.e., there is no layering of agents). Each agent is identified by its coordinates and direction at time t. The direction of an agent at time t is defined as the vector connecting its location at time t-1 and its current location, and is expressed as the counterclockwise angle between this vector and the oX axis.

$a_i(t) = \tan^{-1} [(y_i(t) - y_i(t-1)) / (x_i(t) - x_i(t-1))]$.

Agents have a perceptual field, defined as a circular sector centred on the agent's current location and intersected by the vector of its current course; the radius r_i and angle θ_i of the circular sector are the depth and volume of agent i's perceptual field, respectively, and are model parameters that can be changed. The Ideal Distance matrix is also defined, where the distances from agent i to agent j are recorded, i.e., at what distance Dij agent i wants to be from agent j at a given time. The ideal distance is not necessarily symmetrical. The distance is Euclidean.

At time t, the agent also calculates her ideal or possible future dissatisfaction at the future time t+1 for all candidate positions p in her current environment by calculating the distances to them. Then the agent decides to move to the position with the lowest level of dissatisfaction. If several positions have the same minimum level of dissatisfaction, the agent chooses the one that requires the least change in its current course. This agent may have conflicts with other agents, so it is possible that its minimum dissatisfaction is not achieved. The decision to move within their neighbourhoods is made independently by the agents. At each time point, if there is an overlap between agents' areas, their priority to move to minimum dissatisfaction is sorted in a random order. Agents with lower priorities will only be able to move to cells that have not been selected by agents with higher priorities and that provide less than minimum dissatisfaction.

$$U'_{ip}(t+1) = \frac{\sum_{j \in Z_i(t)} \left| d_{ijp}(t) - D_{ij}(t) \right|}{m \cdot |Z_i(t)|}$$

The minimum dissatisfaction is calculated as the sum of all absolute differences between the predicted distance after moving to cell C and the ideal Distance that the agent *i* wants to achieve in regards with agent *j*, divided by the maximum possible distance and the cardinal number of all the agents perceived by agent *i* at the moment of time *t*.

After the agent chooses the cells which will provide them minimum dissatisfaction, all the agents move and the ideal distance is updated for all the agents, based on if they were to achieve their goals.

FSR - Flocking Synthesis Rules - the rules by which an agent should act when it is in a flock.
- 0 - the agent is far from other agents, there is no principle
- 1 - you need to coordinate your actions with the actions of the pack
- 2 - the agent falls into “stagnation” as the change in its ideal distance was cyclic for some period of time that exceeds the Stagnation tolerance (either unchanged for a long time or was periodically decreased/increased) and so abruptly changes it’s ideal distance regarding the other agent. The distance remains unchanged for an “Exile tolerance” period of time.

If the agent i didn't perceive agent j at time or the critical distance between them wasn't achieved, the FSR rule "off" will be applied and the distance for the pair won't change.
If the agent_i reaches the requirements above, the FSR "smooth" rule will be applied.

After moving, agent i evaluated the difference between $d'_{ij}(t)$, and its previous real distance from agent j, $d_{ij}(t\text{-}1)$.

$$u_{ij}(t) = |d_{ij}(t) - D_{ij}(t\text{-}1)| - |d'_{ij}(t) - D_{ij}(t\text{-}1)|$$

Which, in fact, would be the same as calculating the differences of the expected and real dissatisfaction. If $u = 0$, the agent i momentarily adapted to agent j, similarly if $u < 0$ it overadapted, and if $u > 0$ it underadapted.

If $c < 0$ and $u > 0$, or $c > 0$ and $u < 0$, the ideal distance is increased, as the agent "wishes" to be further from the other agent (it either wished to approach and didn't achieve its goals to full extent, or wished to move away, and overachieved its goals)

On the other hand, the ideal distance is decreased if $c < 0$ and $u < 0$ or $c > 0$ and $u > 0$. (Agent attempted to approach and overadapted or agent attempted to move away and under adapted)

If the agent is temporarily adapted, there will be no change in the ideal distance.

If the agent didn't attempt to move, but either adapted or underadapted, there will be a random increase or decrease of the ideal distance between the agents.

	Underadapted $u_{ij}(t) > 0$	Adapted $u_{ij}(t) = 0$	Overadapted $u_{ij}(t) < 0$
Attempt to approach $c_{ij}(t) < 0$	Increase ($k = 1$) Penalty	No change ($k = 0$)	Decrease ($k = -1$) Reward
No attempted move $c_{ij}(t) = 0$	Random Increase or Decrease	No change ($k = 0$)	Random Increase or Decrease
Attempt to move away $c_{ij}(t) > 0$	Decrease ($k = -1$) Penalty	No change ($k = 0$)	Increase ($k = 1$) Reward

If an agent experienced cyclic decrease or increase (or his ideal distance remained unchanged) for a period of time greater than stagnation tolerance time, an agent enters an “abrupt” mode of the FSR.

His ideal distance is greatly increased by a factor of P_c * S [i, j], where P_c is the change rate and S[i,j] is the stagnation tolerance between pairs of agents i and j.
The ideal distance then remains unchanged for a period of time equal to Exile tolerance time (P_e).

Simultaneously, his Stagnation tolerance time increases by a factor of (1+P_c), and the Exile tolerance time decreases by a factor of (1 - P_c), as the agent adapts to the presence and movements of the other agent.

Flocking index

Whether or not agents are forming a flock is determined by two factors: the distance between them and the difference between their headings.

For each individual agent their flocking index is defined by two functions:

$$f_{ij}(t) = H(\Delta\alpha_{ij}(t))\, Z(d_{ij}(t))$$

where $\Delta\alpha_{ij}(t)$ is the difference in radians between their headings,

$$\Delta\alpha_{ij}(t) = \min(|\alpha_i(t) - \alpha_j(t)|, 2\pi - |\alpha_i(t) - \alpha_j(t)|)$$

and $d_{ij}(t)$ is the real distance between their locations at t. Functions H and Z are defined as:

$$H(\Delta\alpha_{ij}(t)) = 1 - \Delta\alpha_{ij}(t)/\pi$$

$$Z(d_{ij}(t)) = 1 - 1/[1 + \exp(-g(d_{ij}(t) - rm)/m)]$$

For function Z, g, r and m are some variables where $g > 0$, $0 < r < 1$, m is the maximum distance in the world. The values are assigned experimentally, in our model $g = 2.0$, $r = 0.5$

H approaches 1 as the difference between angles is closer to 0, and approaches 0 otherwise

Similarly Z approaches 1, if distance between agents is close to 0, and 1 if the distance is great.

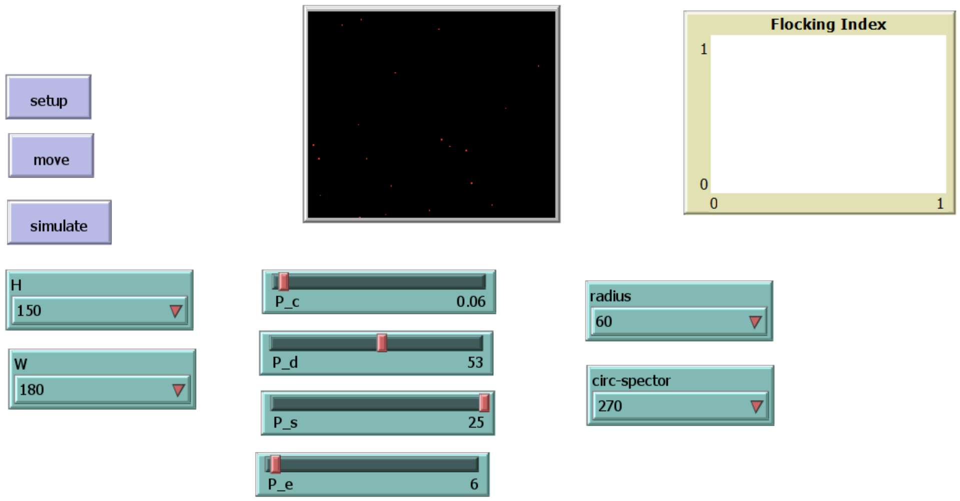
The global flocking index is calculated as the sum of all flocking indexes between all unique pairs of agents divided by N * (N-1) /2, which is the number of unique pairs and therefore the maximum possible sum of their flocking indexes.

$$F(t) = [\Sigma_{i<j} f_{ij}(t)] / [N(N-1)/2]$$

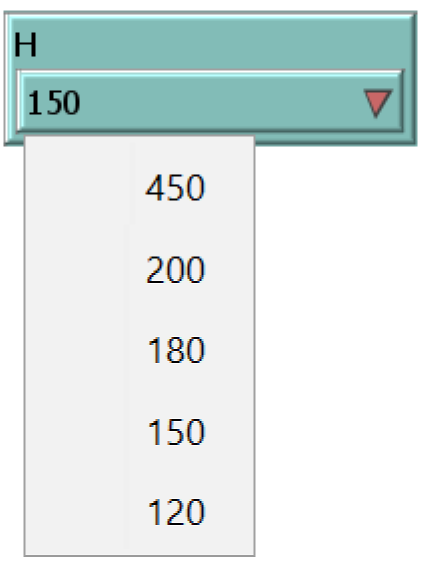
Values of $F(t)$ range from 0 to 1; when $F(t) = 1$, the group of agents move in a coordinated, compact fashion in the same direction, and when $F(t) = 0$, they are scattered and move in a disorderly fashion.

Setup

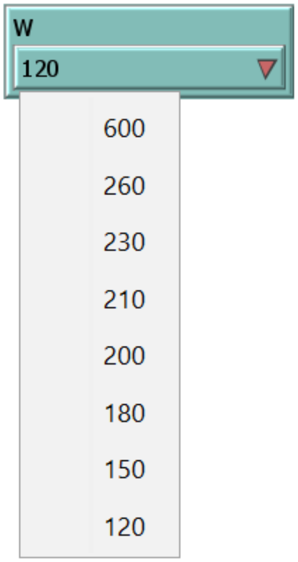
This implementation consists of many components:



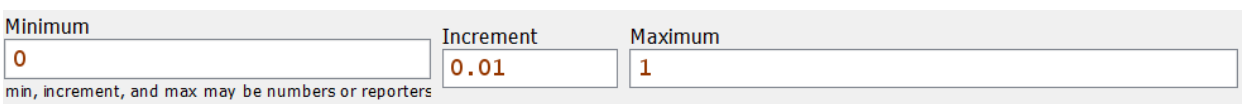
Button “Setup” - scatters 20 agents randomly on the field, each agent has a different direction in which they are pointed at the initial position (random value from 0 to 2pi).
Button “Move” - the movement of an agent.
Button “Simulate” - repeat the move 100 times.
Chooser “H” - world height.



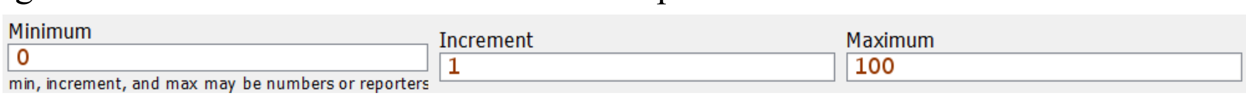
Chooser “W” is the width of the world.



Slider “P_c” is the rate of change of the ideal distance and of the stagnation time of tolerance to the leader before leaving the group. (the modifier which influences how fast these variables will change_

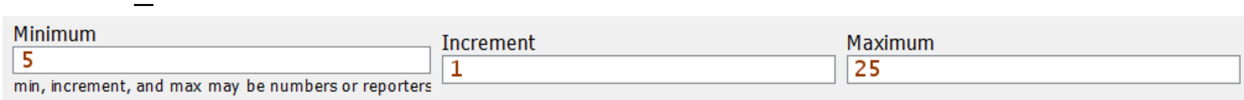


Slider “P_d” is the critical distance at which we begin to take into account the agent's behaviour in relation to ours and adapt our ideal distance to it

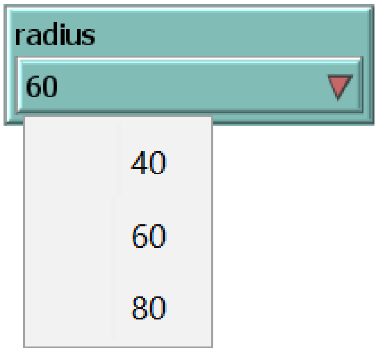


Slider “P_s” is the initial value of stagnation tolerance time, how long agents can stay in the group before leaving it. P_s = P_e.

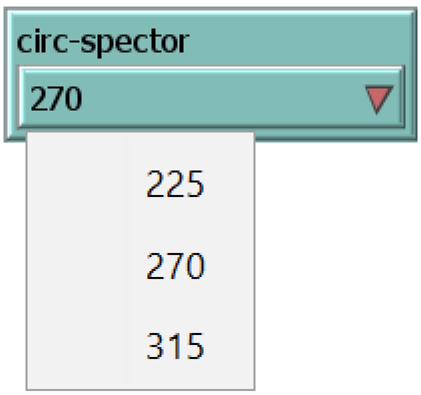
Slider “P_e” is the initial value of exile tolerance time.



Radius - how far an agent can see other agents.



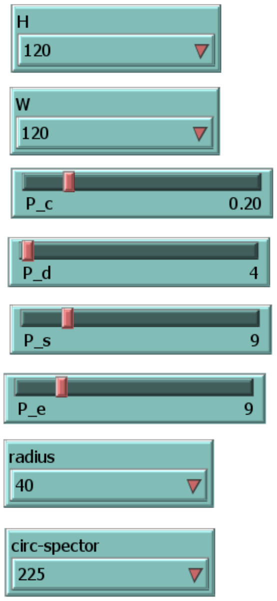
circ-spector - the angle that an agent can see.

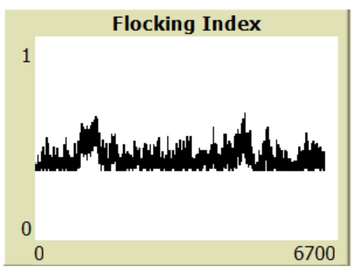


Stagnation Tolerance Time can increase, and simultaneously Exile Tolerance Time decreases, so each time after encountering the group with a certain agent as its leader, we can stay near it for a longer period of time the next time.

Results

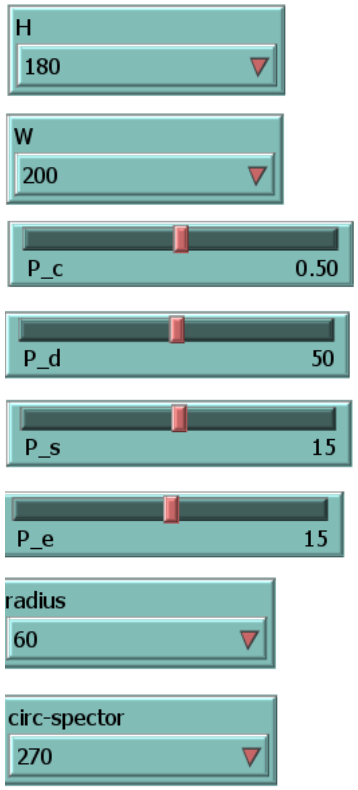
1) Close to the minimum settings

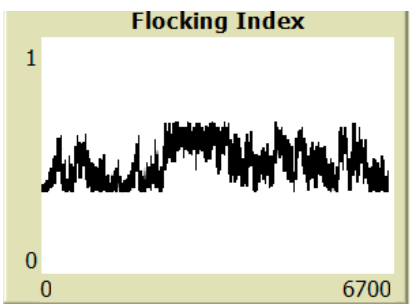




As we can see from the graph of the flocking index (the index of ‘flocking’ behaviour of agents), when the settings are close to the minimum, group behaviour is almost not observed, we have only two increases in this index on the graph, and then it stays at the usual value.

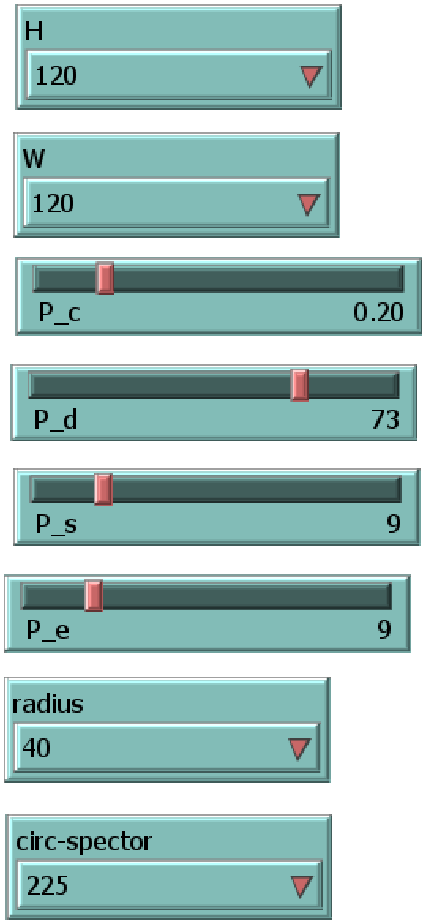
2) Medium settings

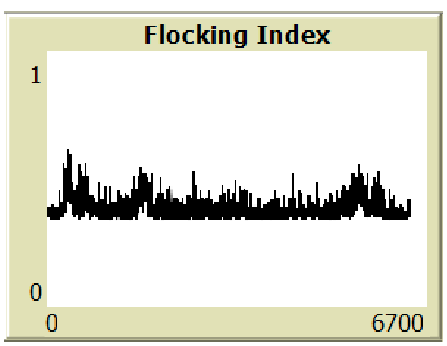




At higher values of the variables, we see that the flocking behaviour started to appear more often and last longer than in case 1. This is due to the increase in the values responsible for the agent's patience (P_s and P_e) and also to the increase in the distance at which we take into account the behaviour of other agents (P_d) and the viewing angle, which leads to taking into account the behaviour of more agents (circ-spector).

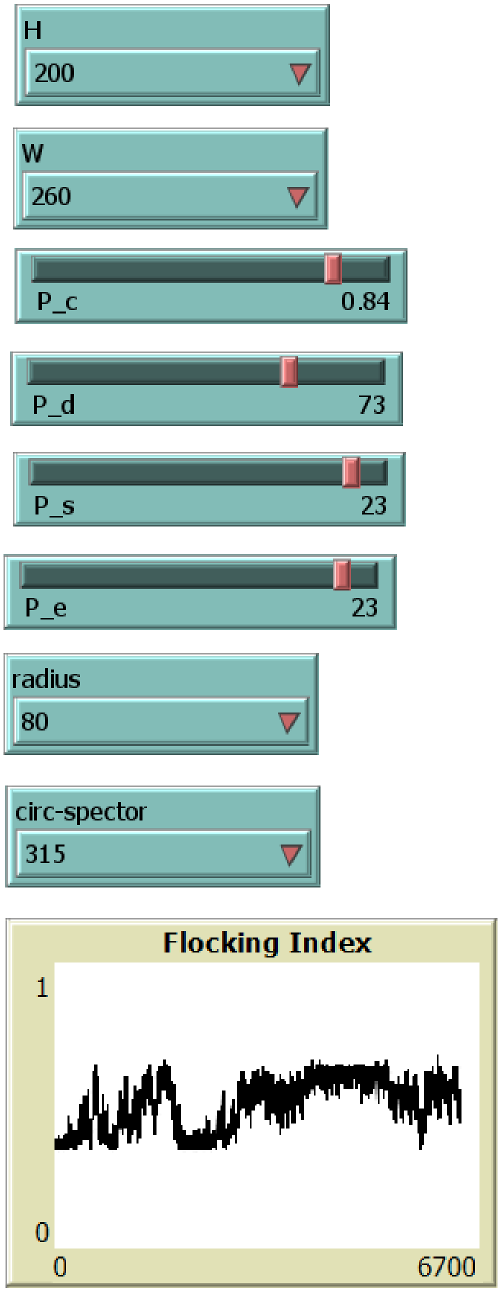
3) The distance at which we pay attention to the behaviour of other agents is important, and the distance for everything else is small.





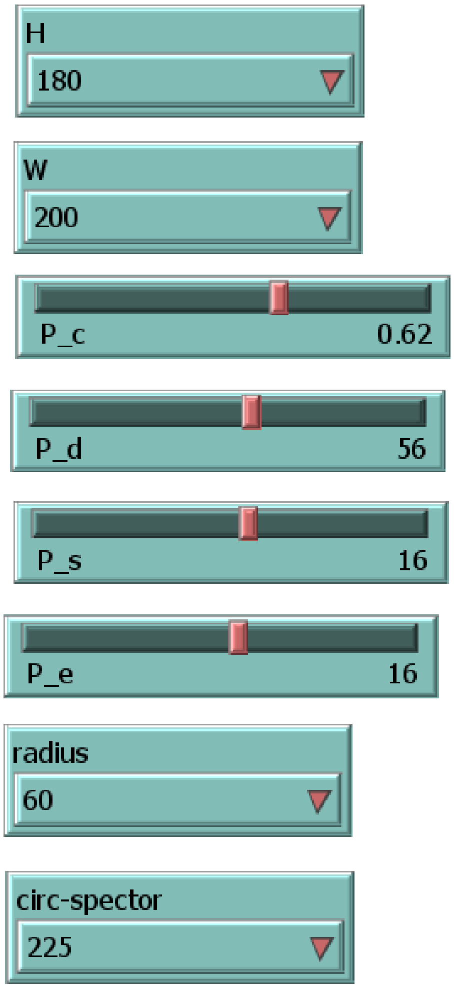
As we can see, with these settings, there is no pack behaviour at all.
Even though P_s and P_e is relatively average, this can be caused by the high P_c, meaning that values like P_s and P_e, change at a quicker rate, but so does the ideal distance, which means it’s harder for the agent to adapt to its new preferences at each tick. (As he still can move only by one patch and the difference between his ideal distance and his real distance to the other agent is bigger)

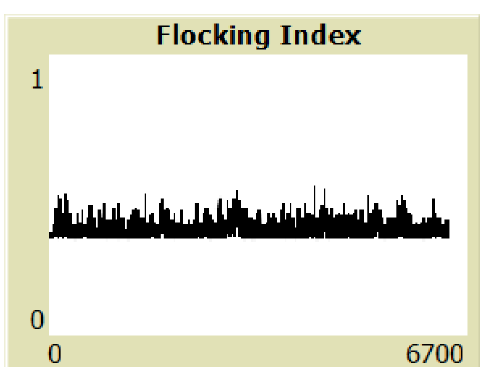
4) Almost maximum settings



At near-maximum settings, our agents can stay in a group for a long time and take into account the behaviour of many agents around them due to their large view, so pack behaviour is established quite quickly, but it can also break up just as quickly if many agents simultaneously decide not to tolerate the leader, and also due to the high P_c value.

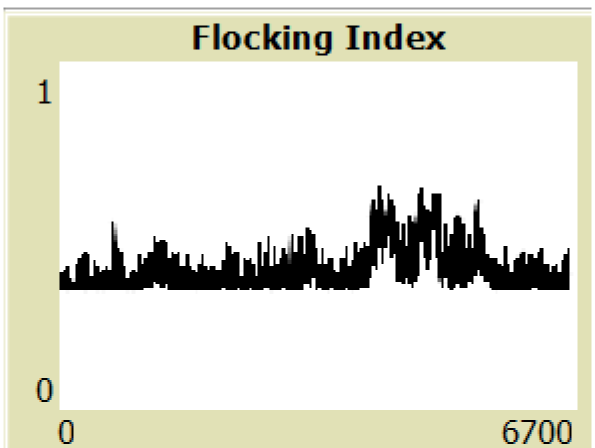
5) Average settings with a minimum viewing angle for agents





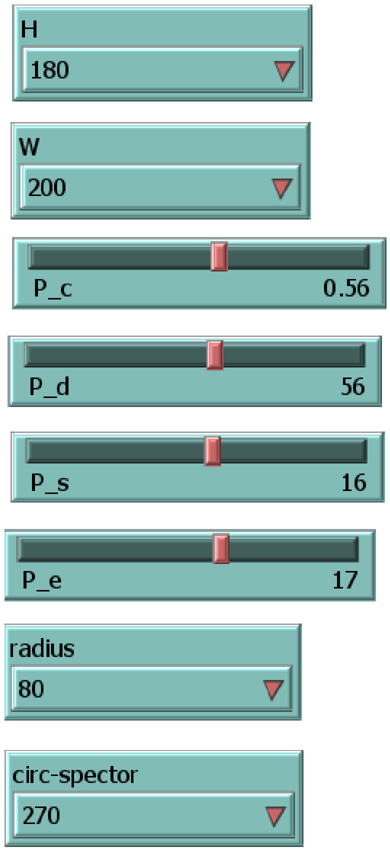
As we could see in case 2 (Average settings), if we reduce the viewing angle of agents, they will pay even less attention to the behaviour of others and no pack behaviour will be observed.

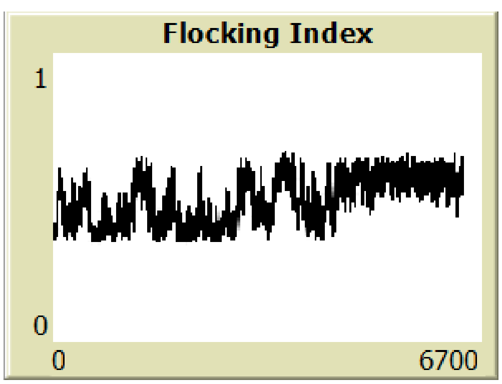
6) Changing P_s and P_e while maintaining all other preceding conditions from case 6 (Average settings with a minimum viewing angle for agents).



Changing P_s and P_e while maintaining all other preliminary conditions leads to minimal occurrence of flocking behaviour, i.e. increasing these two parameters leads to partial compensation of the agents' viewing angle.

7) Averaged settings with a wide viewing angle for agents





As we can see, increasing the viewing angle of agents has a positive effect on the level of agent flocking.

Conclusion

From all of the above graphs, we can conclude that the larger the agent's field of view, the more likely pack behaviour is, and the more likely it is that agents will gather to follow someone in the same direction. At the same time, the distance at which agents pay attention to other agents also has a significant impact on their pack behaviour, the greater the distance, the faster the coordinated movement of the entire pack is formed. We can also see that the smaller the field size, the faster the flock gathers together.

High P_c (change rate) will allow quicker changes in the general state of the world - be it in forming flocks, or unforming them. At higher values of the r - radius of vision and circ-spector - the angle of vision, the packs will last longer as the remote agents can still observe and be observed by others, and it takes longer for them to leave the area of visibility. While at lower settings for these variables, the groups would be disbanded quicker. Meaning, that the faster the agents / humans change their preferences, the more frequently can groups / flocks be formed.

High P_s and P_e allow for agents to stay longer near other agents, but it also means that if suddenly all the agents in the group were to undergo an abrupt change in their ideal distance, and disband the group, it would take them longer to come back together.

Sources

[1] Vicenç Quera, Francesca S. Beltran and Ruth Dolado (2010) *Flocking Behaviour: Agent-Based Simulation and Hierarchical Leadership*
https://www.jasss.org/13/2/8.html