Annular Structures in NetLogo Inspired by Brood Sorting in Ant Colonies

Aniello Panariello 140195

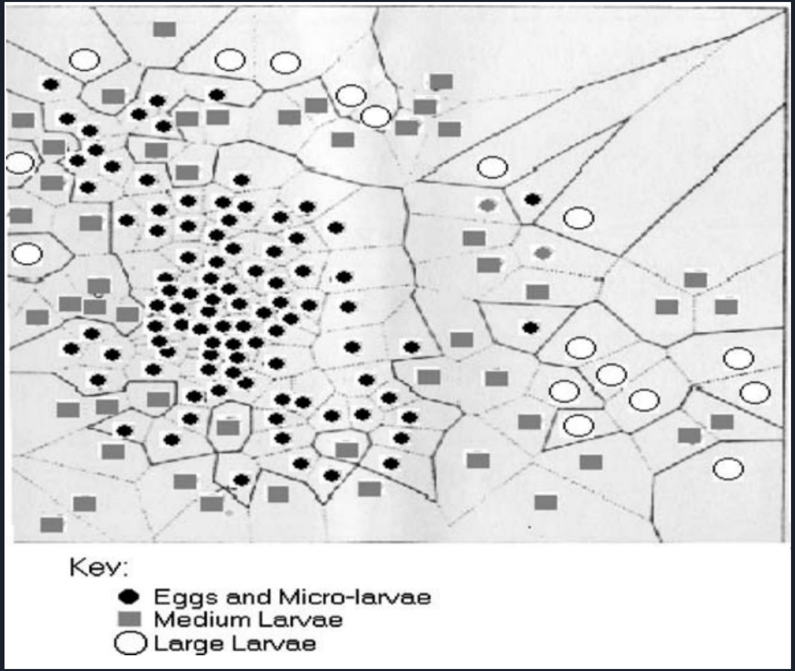
Swarm Intelligence

- Swarm intelligence is a **collective behaviour** seen in self-organized systems, both natural and artificial.
- We have a population of simple agents which interact locally with each other and with the environment. These agents follow very simple rules, and while there is no centralized structure that impose a certain behavior, the interactions between agents lead to the emergence of “intelligent” global behavior, unknown to the single agent.
- One of the most famous example of swarm intelligence is the ant colony.
- It is important to study such behaviors since it let us build simple agents to achieve something more complex.

Ant-like Annular Sorting

Some type of ants, like *Leptothorax* ants, sort their larvae in an annular structure. This is because they evolved to live in the narrow cracks in rocks, thus having almost a two dimensional environment.

Different brood stages are arranged in concentric rings, in a single cluster around the eggs and micro-larvae.



Ant-like Annular Sorting

Wilson et. al (2004) were the first to study and implement such mechanisms. They followed two different theories.

- **Theory 1:** brood structures form simply because objects are of different size. This is called "muesli effect" where the small particles percolate to the bottom of the packet (Barker and Grimson, 1990).
- **Theory 2:** ants deliberately introduce spacing between brood items with the amount of spacing influenced by the size of the brood, detected by the amount of waste gas the brood produces.

Wilson at al Setup

- Robots able to move in an approximately straight lines in an arena and with sensor to detect walls, objects and other robots. They can discriminate between objects exploiting the reflectivity of the objects.
- Arena is a regular octagon
- Experiments involved:
  - Six robots
  - 15 objects per type
  - 500.000 iterations (~ 4 hours of real time)

NetLogo Setup

- Robots are turtles which move in approximately straight lines, turning around when hitting a wall or another turtle.
- Arena is square without warping.
- Number of robots and objects is the same as Wilson et al.

Performance Metrics

- **Separation**: computed by calculating the radial distance from the centre of the structure for each object. Sorting these according to the type provides a lower and upper quartile for each type. The distance between an object type lower and upper quartile defines the type's "home zone".
- **Compactness**: the ideal structure should be perfectly compact so that it fits into the smallest possible circular area. Finding the dimension of the circle is a complex geometrical problem, but the values for few object is known, so we take these to compare with our structure.
- **Shape**: we compute a clustering performance component that describes the central cluster and then we add the sum of the performances for each band.

Mechanism 1: Object Clustering using Objects of Different Size

The first mechanism is based on the hypothesis that the brood of Leptothorax ants is organized in concentric annuli as a result of the the size of the brood items.

In order to simulate this behaviour we consider the article “The Physics of Muesli”, by Baker and Grimson (1990), in which the central theme is the idea that under gravity, particles separate according to their size. Considering the scenario in which we shake a packet of muesli, we observe two simultaneous mechanisms:

- Small particles filter down through the pores created by larger particles.
- The shaking process allows small particles to move into these voids.

Mechanism 1: Object Clustering using Objects of Different Size Algorithm

Rule 1: If *(carrying object and obstacle ahead)* **then**

- *Make random turn away from obstacle.*

Rule 2: If *(carrying object and hit another object)* **then**

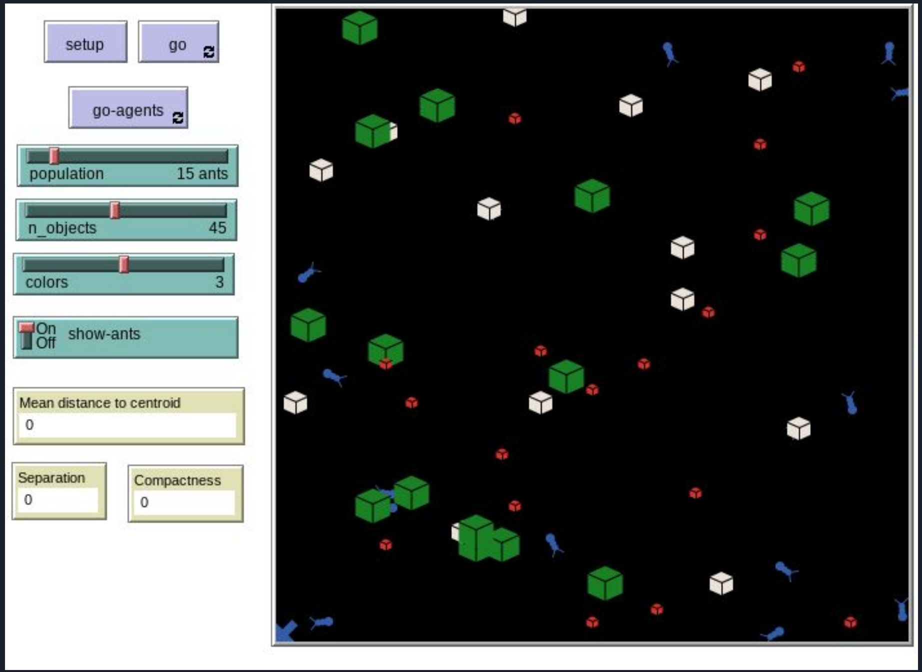
- *Reverse a small set distance which causes the object to be dropped.*
- *Make random turn left or right.*

Rule 3: If *(Not carrying any object)* **then**

- *Go forward*

Mechanism 1: Simulation Starting Position

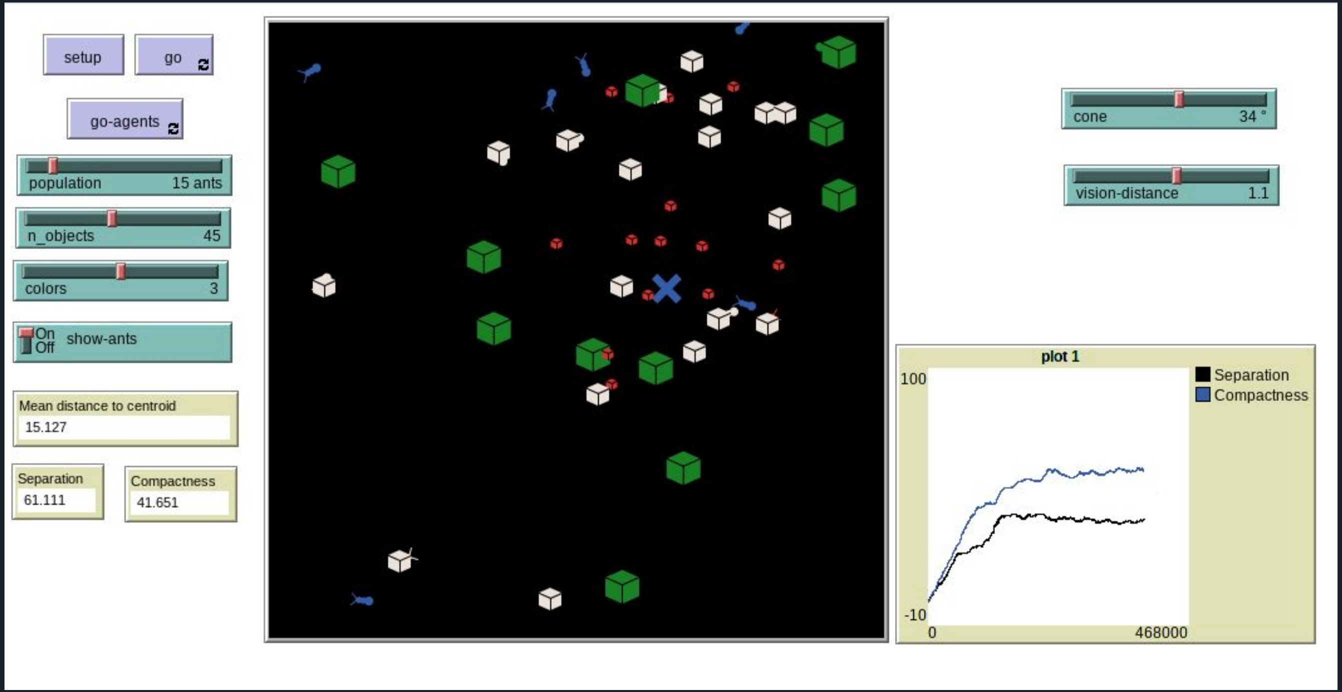
When the simulation starts, objects and agents are scattered around the environment.



Mechanism 1: Simulation after 500.000 iterations

We can see that after about 500k iterations we reach a good result, but not extremely satisfying.

This first simulation show us that is indeed possible to have an annular like sorting using ants algorithms.

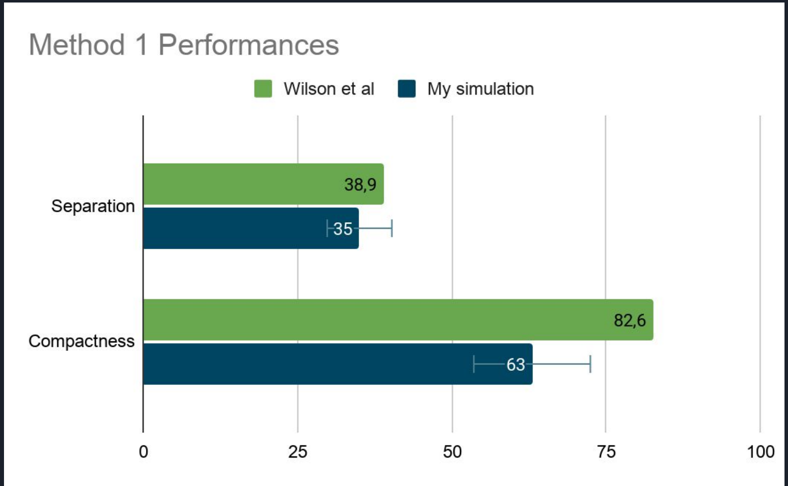


Mechanism 1: Differences with Wilson et al

Separation is almost the same, while the compactness is lower.

This is due to the fact that the arena is **squared** and not octagonal thus letting the ants go to the “bottom” of the packet and moving around the objects. (Camazine, 1991)

This also leads to less consistent simulations, that not always reach convergence.



Mechanism 2: Extended Differential Pullback

To improve upon the first mechanism we need to make some assumptions and then formulate another mechanism.

1. The brood items (objects) have a constant metabolic rate, meaning that smaller items produce fewer “waste products” than the larger one.

2. The ants (agents) are able to sense the volume of metabolic by-product that has been produced by a brood item.

This two assumptions are then used to model a new mechanism which exploits the stimulant concentration, which in this case is the by-product of brood items.

Mechanism 2: Extended Differential Pullback

We know that animals sensory apparatuses tend to work in a range between a lowest and a highest detection threshold.

Since what is under the low threshold is not even detected, and what is above the high threshold does not make a difference, animals usually recalibrate their “sensors” when a high concentration of stimulant is present. This creates a problem, that is that the sensor operating range can shift toward higher stimulant concentrations.

It is possible that Leptothorax ants try to modify the environment to keep the metabolic by-product sensors in an optimal range. This means that small brood items are clustered together to produce the same volume of gas as large brood items that are spaced out.

Mechanism 2: Extended Differential Pullback Algorithm

Rule 1: If *(carrying object and obstacle ahead)* **then**

- *Make random turn away from obstacle and drop the object.*

Rule 2: If *(carrying object and hit another object)* **then**

If *(carrying Type 1 object)* **then**

- *Drop the object.*

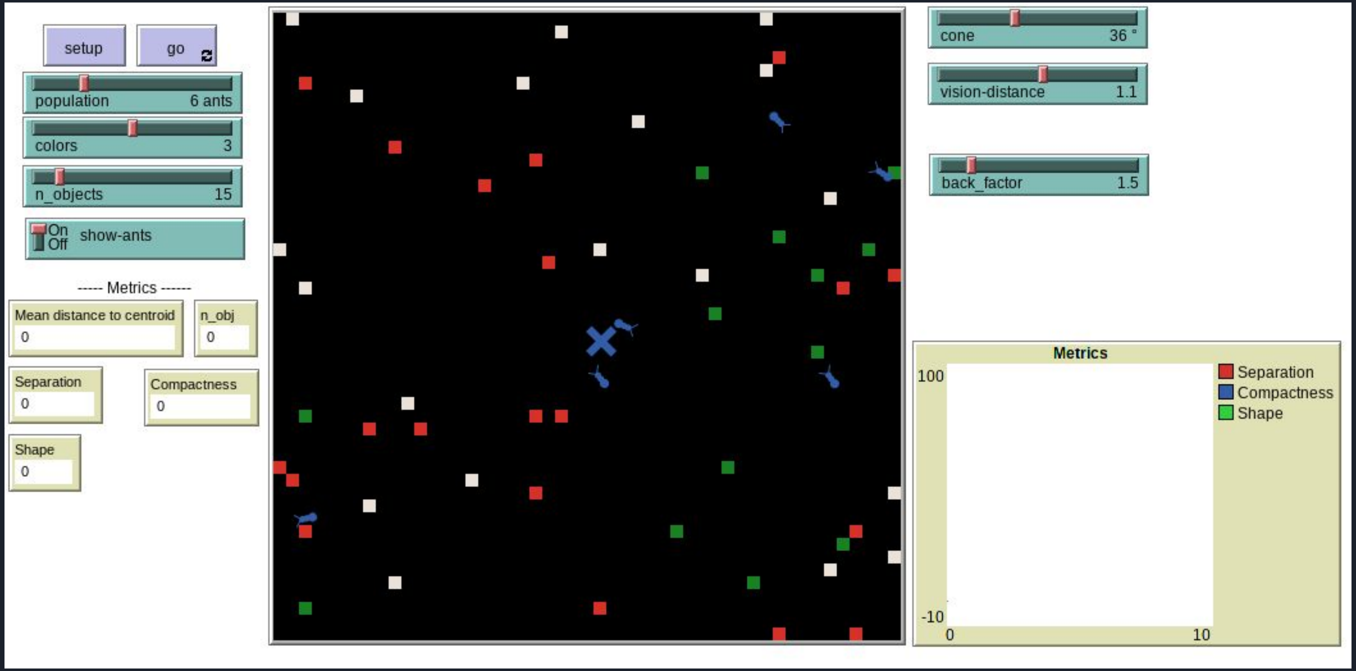
Else

- *Pullback a distance relative to the object type and drop the object.*

Rule 3: If *(Not carrying any object)* **then**

- *Go forward*

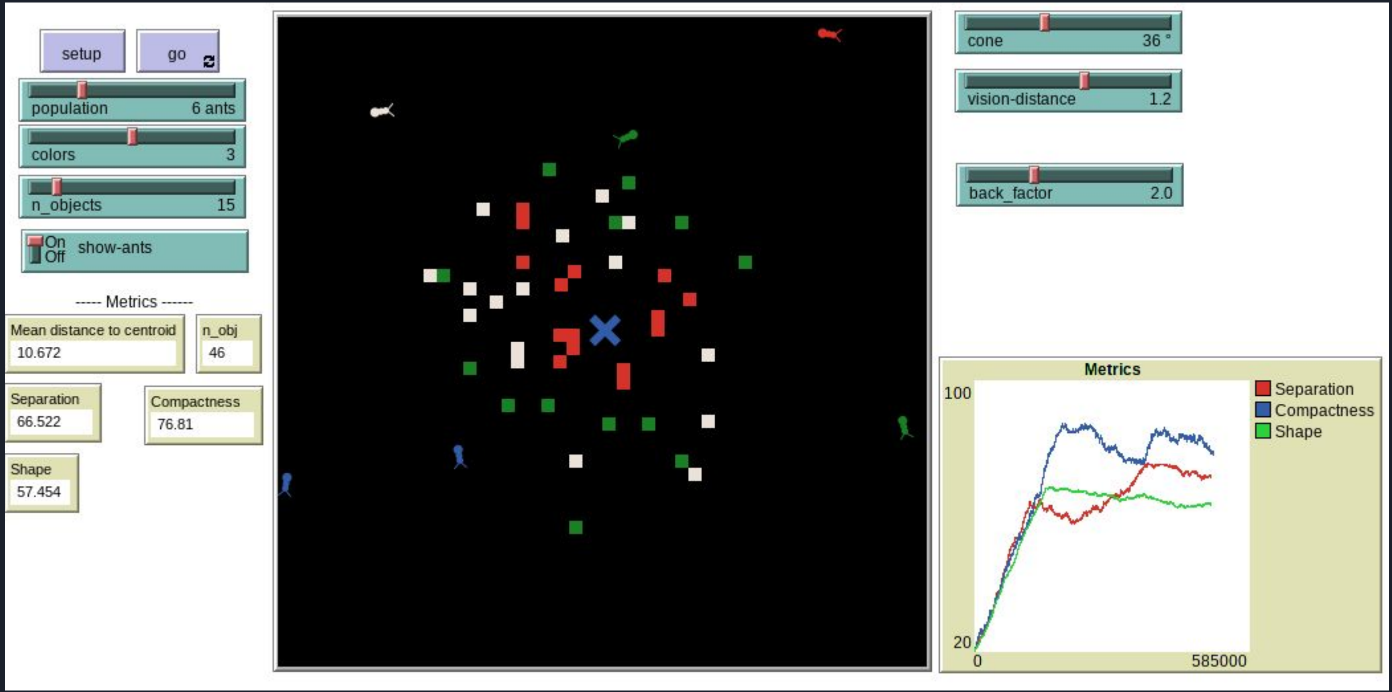
Mechanism 2: Simulation Starting Position



Mechanism 2: Simulation after 500.000 iterations

We can see that with the second mechanism we reach a much better result.

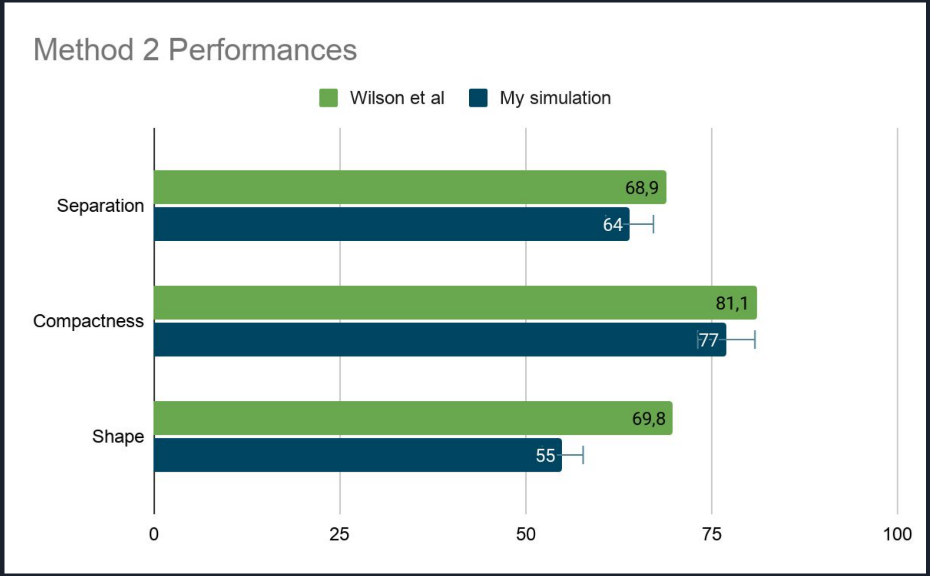
This algorithm reaches convergence a bit easier but still not always.



Mechanism 2: Differences with Wilson et al

Performances are almost the same, with the shape being a little lower.

This is still due to the shape of the arena.



Mechanism 3: Combined Leaky Integrator

The second mechanism works well but we have lower performances, especially with respect to the compactness, when the number of objects and object types increases. The combined leaky integrator attempts to fix this problem.

We have a differential pullback mechanism, just like the second mechanism, but this time the pullback distances change dynamically.

Integrators will rapidly “forget” and will only take into account recent information. We will keep a counter for each type of object which are analogous to containers for liquid. Each time an agent drops the object, an amount of liquid is added to the corresponding container. To avoid saturation the volume of each container slowly drains away.

Mechanism 3: Integrators

$$Integrator_1 = (\rho_1 h_1)\, g$$

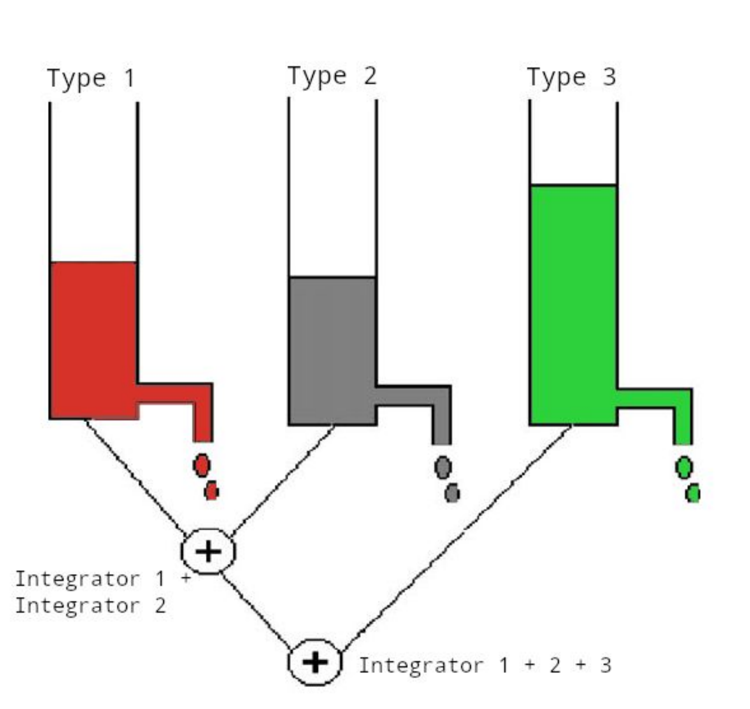
$$Integrator_2 = (\rho_1 h_1 + \rho_2 h_2)\, g$$

$$Integrator_3 = (\rho_1 h_1 + \rho_2 h_2 + \rho_3 h_3)\, g$$

Where:

- ρ is the density of the fluid
- h is the height of the fluid
- g is the gravity

All of these defaults to 1



Mechanism 3: Combined Leaky Integrator Algorithm

Rule 1: If *(carrying object and obstacle ahead)* **then**

- *Make random turn away from obstacle.*

Rule 2: If *(carrying object and hit another object)* **then**

If *(carrying Type 1 object)* **then**

- *Drop the object and add 15 units to Type 1 integrator.*

Else If *(carrying Type f object)* **then**

- *Pullback a distance relative to the sum of integrators 1 to f.*
- *Add 15 units to the Type f integrator.*

Rule 3: If *(Not carrying any object)* **then**

- *Go forward*

Rule 4: If *(Time counter reaches threshold)* **then**

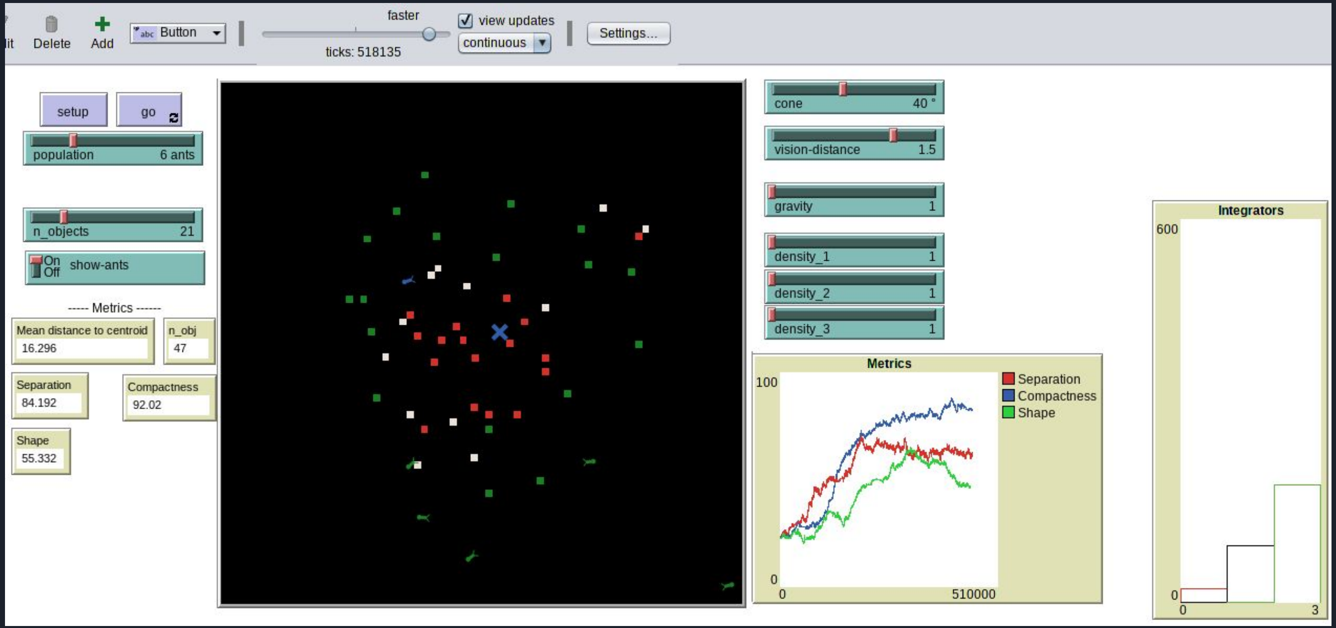
- *Deduct 1 unit from all integrators and reset time counter.*

Mechanism 3: Simulation after 500.000 iterations

Much better compactness and separation.

Shape still low.

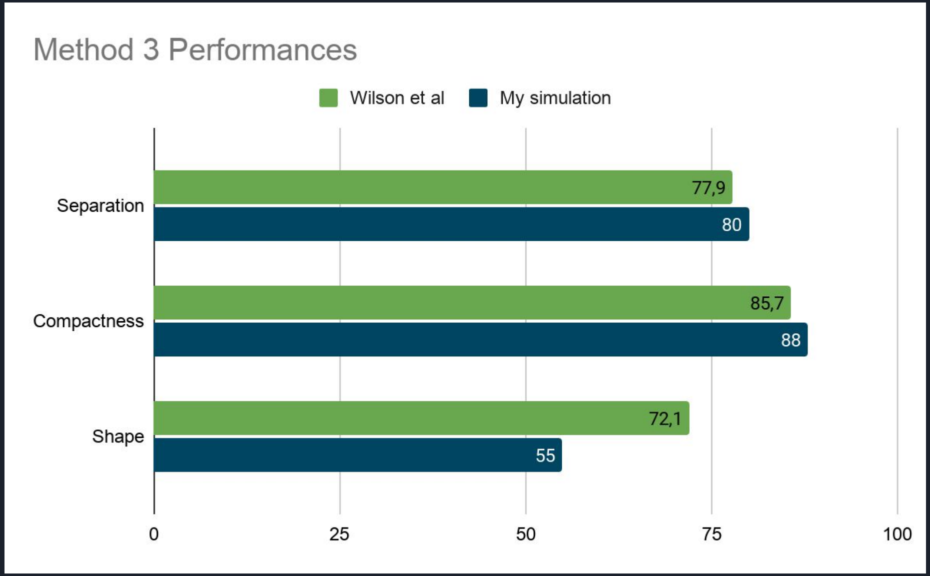
Overall a good mechanism but still not always consistent.



Mechanism 3: Differences with Wilson et al

We have slightly better performances in separation and compactness but a lot less in shape.

This is a correct result since performances are almost “complementary”, thus we cannot reach 100% simultaneously on all metrics and when one increase, another one should decrease.



Conclusion

The Wilson et al study and my simulation, show that is indeed possible to have some sort of annular like sorting exploiting the behaviors of *Leptothorax* ants. We have seen that with simple algorithms, inspired by these ants, it is possible to reach good performances in the metrics that have been defined.

We have also found that the shape of the structure is influenced by the shape of the arena, thus it would be interesting to analyze this algorithm with different arena types.

In the future a probabilistic *placement score*, based on size and on the number of neighbors, for each object could be introduced, in order to let the agents to understand if it is beneficial to pick up or put down the objects.

References

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