Swarms and Consensus from Couzin's Equations

What parameters produce a swarm, torus, highly parallel group, and dynamic parallel group?

Most tests were performed with between 30 and 80 agents.

Swarm:
The two keys to creating a swarm are:
- Small radius of orientation: this way the primary mechanism acting on agents is their attraction, which causes more random-looking patterns.
- Large field of perception: to prevent agents from getting lost from the swarm.

Number of individuals	N	Value
Zone of repulsion	r_r	1
Zone of orientation	r_o	1.1
Zone of attraction	r_a	12
Field of perception	α	$3/2\pi$
Turning rate	θ	$5/9\pi$
Speed	s	3
Time step increment	τ	0.1
Error (S.D.)	σ	0

Torus:
To create a torus, the most important parameters were 1) a small radius of orientation (relative to the radius of attraction) and 2) a smallish field of perception. The Torus was by far the hardest pattern for us to get. The closest torus-like behavior we observed was with the following parameters:

Number of individuals	Symbol	Value
Zone of repulsion	r_r	1
Zone of orientation	r_o	1.6
Zone of attraction	r_a	18
Field of perception	α	π
Turning rate	θ	$1/6\pi$
Speed	s	6
Time step increment	τ	0.1
Error (S.D.)	σ	0

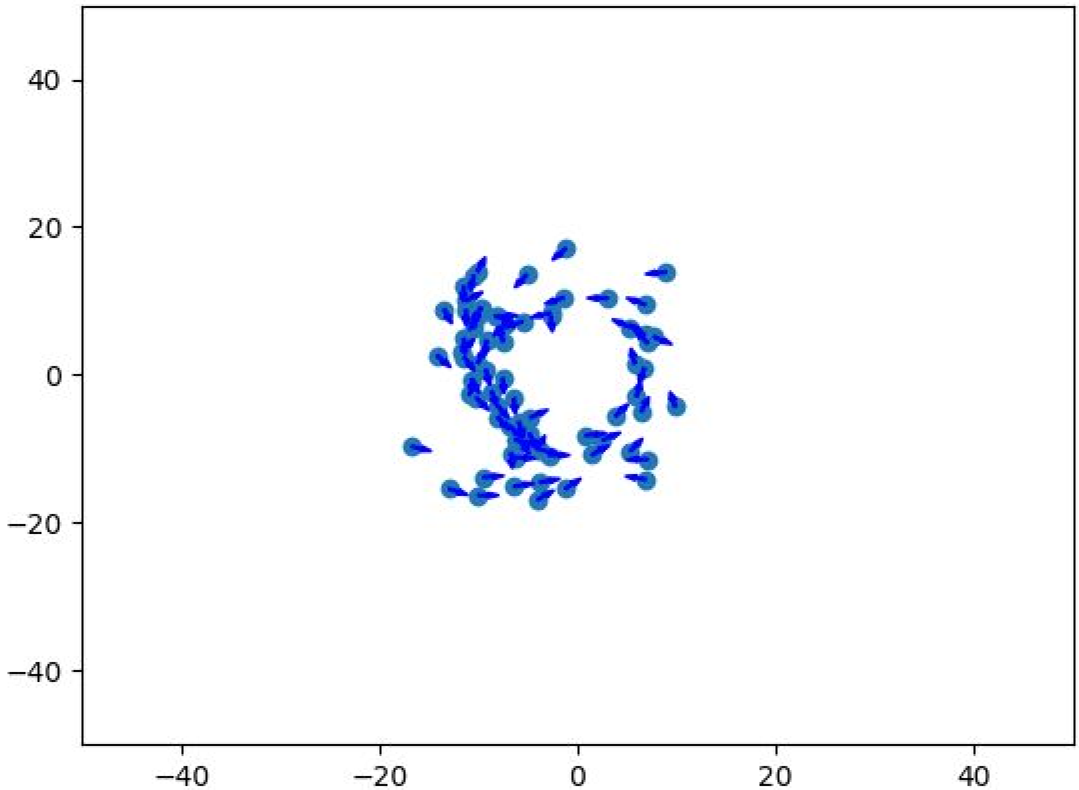
When a torus-like shape was observed with random initialization, it often did not last very long. We spent a tremendous amount of time trying to get it to form consistently. One method we employed to encourage torus like behavior was to create a central agent that repulsed all other agents. While more torus-like patterns were observed, again, they usually did not persist indefinitely. However, if we initiated the system in a circular-ish pattern, a torus could be maintained.

Several difficulties included:

- Agents would follow each other in a curved line, that eventually straightened out and went out to infinity. Presumably, the lead agent couldn't see the agent on the other end, or the field of perception was too narrow. Making the field of perception too broad however, caused other problems.
  - Increasing the number of agents occasionally mitigated this, which helped the "lead" agent to find a "tail" agent.
- Agents would achieve a torus that continually shrank until it collapsed on itself. Subsequently, lines of agents would diverge in different directions. This probably had to do with balancing velocity and turning rate.[1]
- Another issue may have been, for most of our tests, agents were permitted to "wrap around" within the world (as in the 1979 Atari classic "Asteroids"). Sometimes stray agents and stray groups instigated chaos when a torus was forming.

That it was difficult to get the system to converge may have been implied in the paper, as the authors suggested dynamically changing parameters can impact the formation of toruses; that is, the parameter and path history plays a role in what formations are possible in the future.

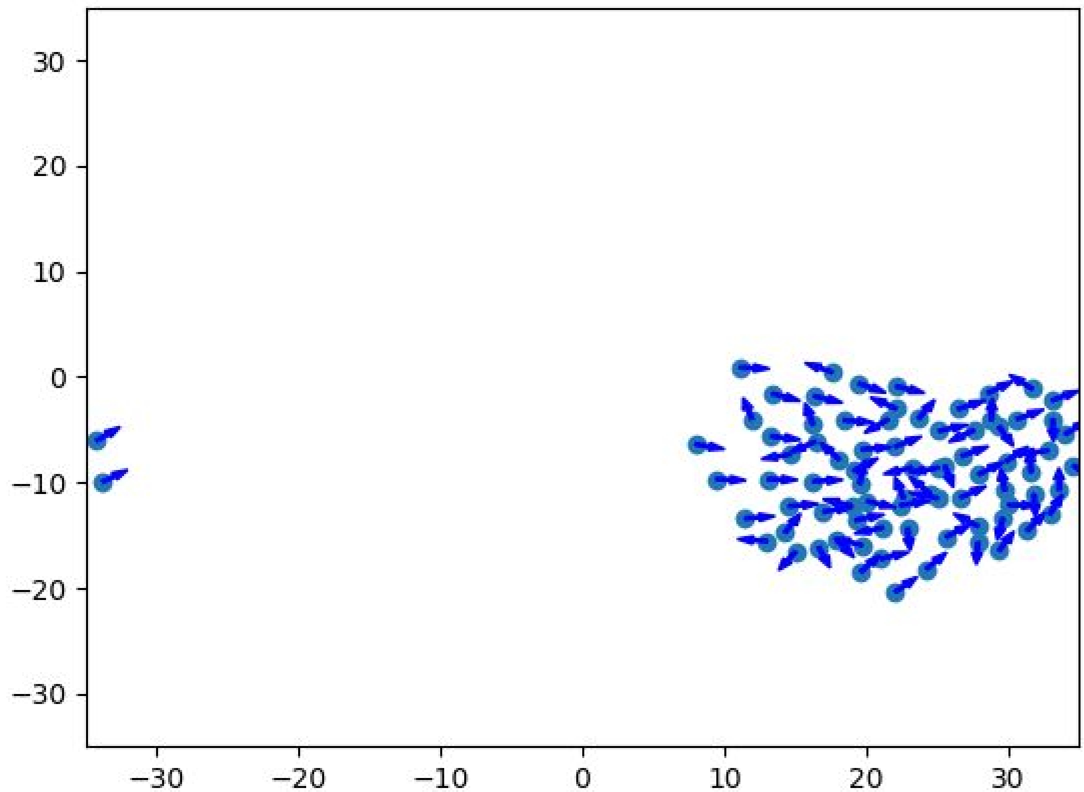
[1] We effectively needed to achieve a stable "orbit", where an agent's interia needed to be matched to the attraction and orientation forces.



Dynamically Parallel Group:
The key here was a medium sized radius of orientation, and an even larger radius of attraction. If the radius of orientation was too small, agents would form queues rather than groups. Additionally, increasing the error standard deviation (from non-zero) and the repulsion radius further facilitated this arrangement.[2]

Number of individuals	N	Value
Zone of repulsion	r_r	2
Zone of orientation	r_o	7
Zone of attraction	r_a	10
Field of perception	α	3/2π
Turning rate	θ	1/3π
Speed	s	3
Time step increment	τ	0.1
Error (S.D.)	σ	0.2

[2] Increasing repulsion radius may have primarily served to magnify the dynamics so we could more easily observe them.

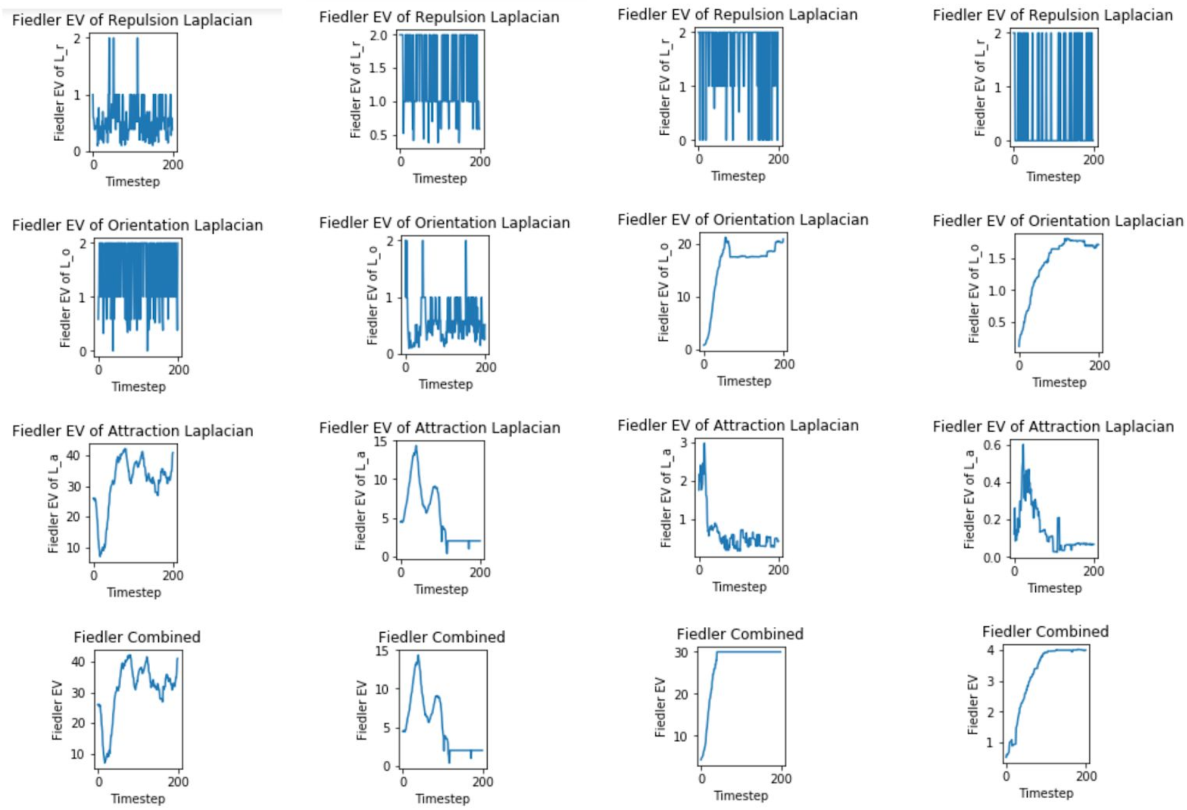


Highly Parallel Group:

For the highly parallel group, the radius of orientation was the critical parameter; making the radius very large appeared to be sufficient, while giving agents larger fields of perception and fast turing rates helped.

Number of individuals	N	Value
Zone of repulsion	r_r	1
Zone of orientation	r_o	10
Zone of attraction	r_a	15
Field of perception	α	1.2π
Turning rate	θ	$4/9\pi$
Speed	s	3
Time step increment	τ	0.1
Error (S.D.)	σ	0

What are the average Fiedler eigenvalues for each of the groups above?



Swarm Torus Dynamically Parallel Highly Parallel

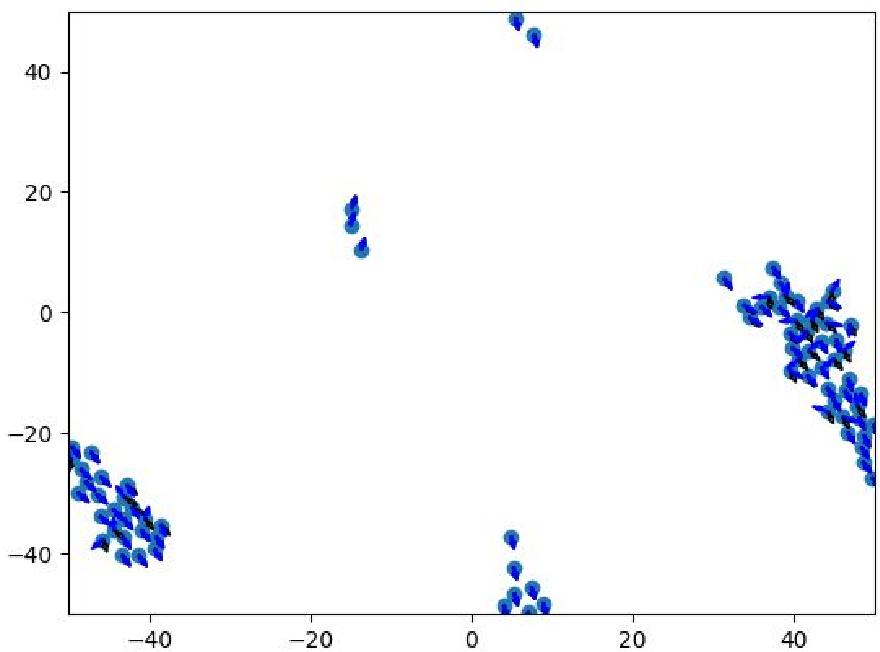
We thought it would be informative to breakout Fiedler eigenvalues by zone.

- Swarm: We see that the attraction Fiedler matrix dominates. It oscillates back and forth depending whether the swarm is generally converging or diverging.
- Torus: Again, the attraction matrix dominates. On average, agents are farther apart, so the magnitude of the pull toward their neighbors is smaller than it was for the swarm. Again, the effect of orientation is small.
- Dynamically Parallel: Orientation plays a much bigger role. Most of the agents end up in the same orientation radius; this dense connection yields a higher Fiedler eigenvalue. Attraction is initially strong, but wanes after the group is formed.
- Highly Parallel: Very similar to dynamically parallel. Notably, the orientation Fiedler eigenvalue is much smaller. However, with the dynamically parallel group, we increased the repulsion radius from 1 to 2; consequently, all zones are connected to more agents in the dynamically parallel version.

What happens if you change the organization above from one that interacts with only five nearest neighbors rather than all neighbors within the repulsion, alignment, or attraction radius? Can you produce a swarm? torus? highly parallel group? dynamic parallel group?

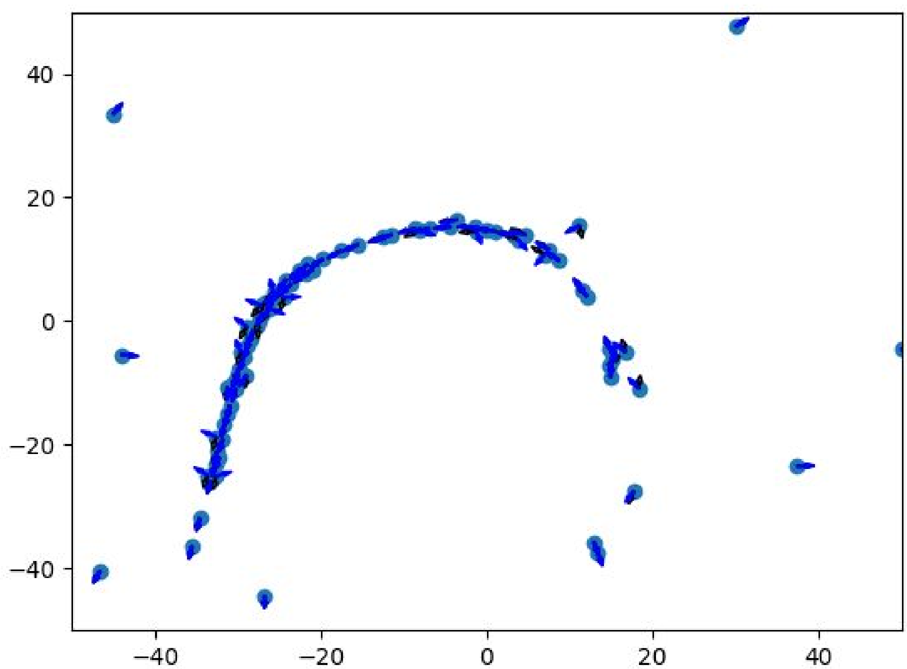
The agents’ movement was altered to only be influenced by their five nearest neighbors. We hypothesized that agents would be more influenced by agents in their orientation zone than before. If there are any agents in the field of repulsion, all agents outside it will be ignored. So we expected little change when agents are too close. Likewise we expected little change when nearby agents are only within the radius of orientation. However, when there are neighbors in both the fields of orientation and attraction, the farther agents in the radius of attraction may be ignored. This is because if an agent is surrounded by many others, the closest five are most likely within the radius of orientation. This made us hypothesize that parallel groups would be more likely.

We were able to recreate all four desired formations (swarm, torus, dynamic parallel group, and highly parallel group). We did so with the same initializations. Swarms and the parallel groups were about as easy to obtain in this model as in their standard-model counterparts. Toruses were more difficult to create, which will be discussed below. The agents sometimes formed longer strings instead of clumps. This is because they are only oriented toward or attracted to a few neighbors, so they aren’t drawn to each other en masse as they are in the standard model. Below is an example of a dynamic parallel group formed with the nearest neighbors algorithm. The agents are less of a “mass” than in the image above, and more of an elongated group.



We found that the torus was even harder to form than it was with the standard model. There were initializations that formed a torus using the standard model, that formed parallel groups with the five neighbors model. One such initialization is shown in the table and graph below. When run using five nearest neighbors, the agents begin forming a torus but then break out and create a long dynamic parallel group instead. This is in line with our hypothesis, the attraction field is ignored in favor of closer neighbors in the orientation field. Because the agents ignore all but their 5 nearest neighbors, they aren't attracted to others in the torus. Instead, they focus mainly on orientation, and follow their closest neighbors, leading all to begin orienting toward the same direction.

Number of individuals	Symbol	Value
Zone of repulsion	r_r	1
Zone of orientation	r_o	1.8
Zone of attraction	r_a	12
Field of perception	α	π
Turning rate	θ	$2/9\pi$
Speed	s	6
Time step increment	τ	0.1
Error (S.D.)	σ	0

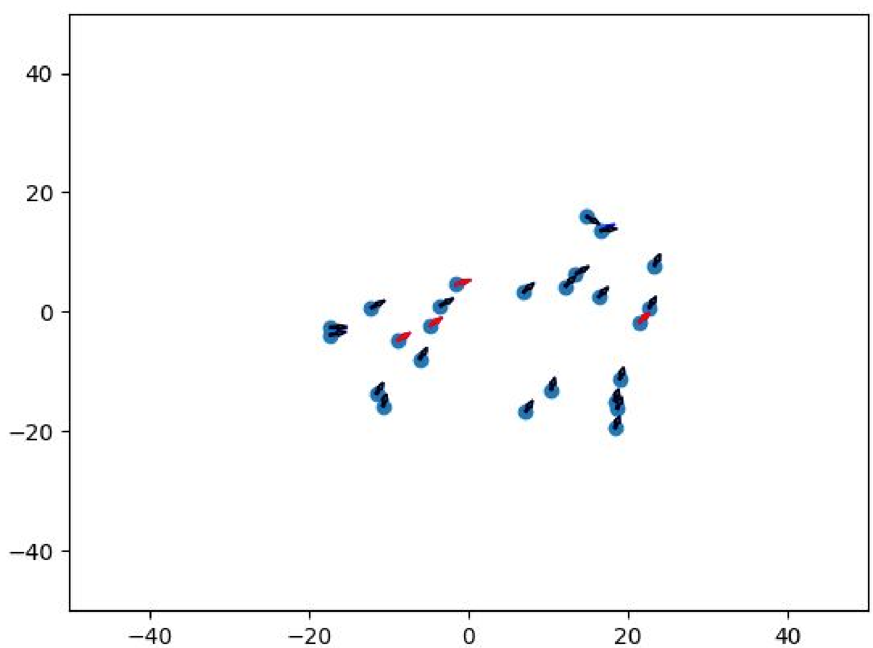


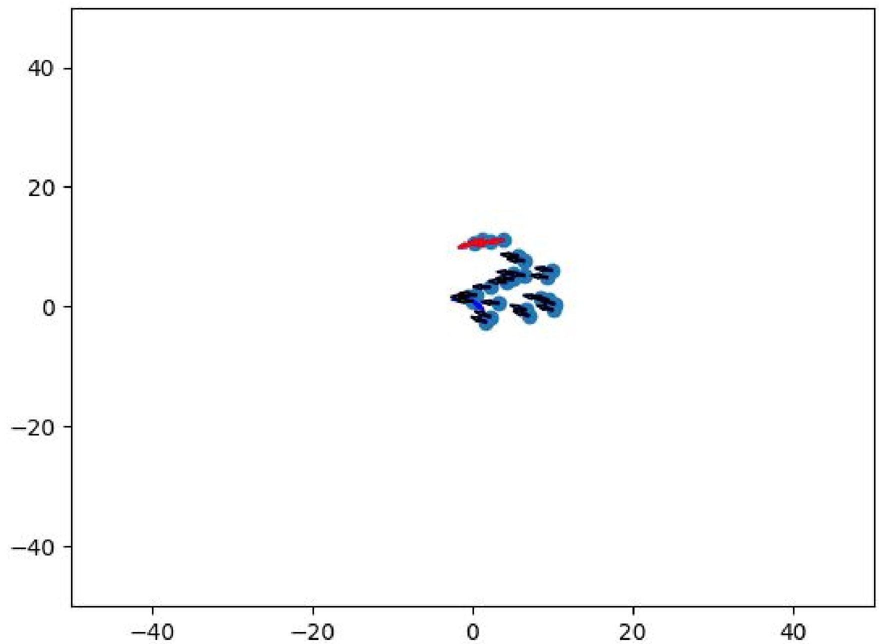
In summation, we found that moving agents based on their 5 nearest neighbors generally performed similarly to Couzin's standard model. We were able to create all the same formations, though they were sometimes more elongated rather than clumps. Changing the model this way didn't change agents' behavior as much as we expected, but the effects were similar--though smaller scale--to what we predicted.

Modify something less than 50% of the agents so that they don't behave according to the equations, and tell me what cool thing you were able to get them to do.
Write a report on the experiments that you performed. The rubric from the first lab will be used on this lab too.

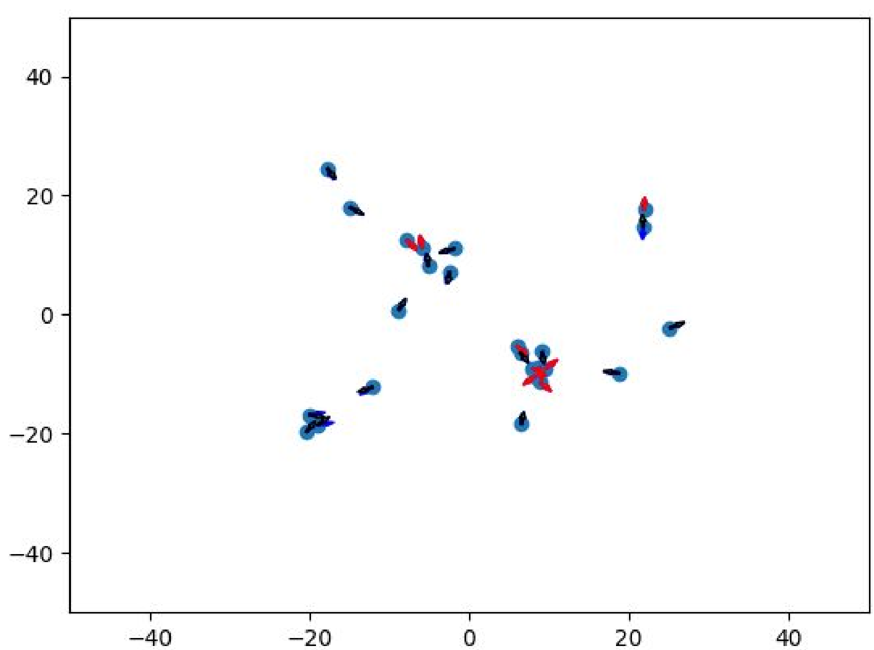
We created agents that move four times faster than the regular agents, have a turning rate and field of perception of 360 degrees. We experimented with different modifications, but these provided the most interesting results. Under the right conditions, these agents will circle or “herd” the other agents, so we call them “sheepdog” agents. The modified behaviors of the sheepdog agents allow them to overtake the other agents, always have them in view, and turn instantly in whichever direction they need to. We randomly select agents to be sheepdog agents, each having some probability of being selected. For most of our tests, we set this probability to 25%.

When the orientation radius and the attraction radius are both relatively large, the sheepdog agents pull together and “herd” the other agents. It effectively creates a parallel group within a torus. The sheepdog agents create a torus orbiting the other agents, who are always directed toward the sheepdogs. This is because the slower agents begin to form a parallel group, and the sheepdogs are able to use their velocity to get ahead of the group. Then, they are attracted back toward the other agents when they get too far away. They begin to orbit the mass of normal agents indefinitely. The two figures below are an example case of the sheepdog agents (red arrow) surrounding and orbiting the normal agents.

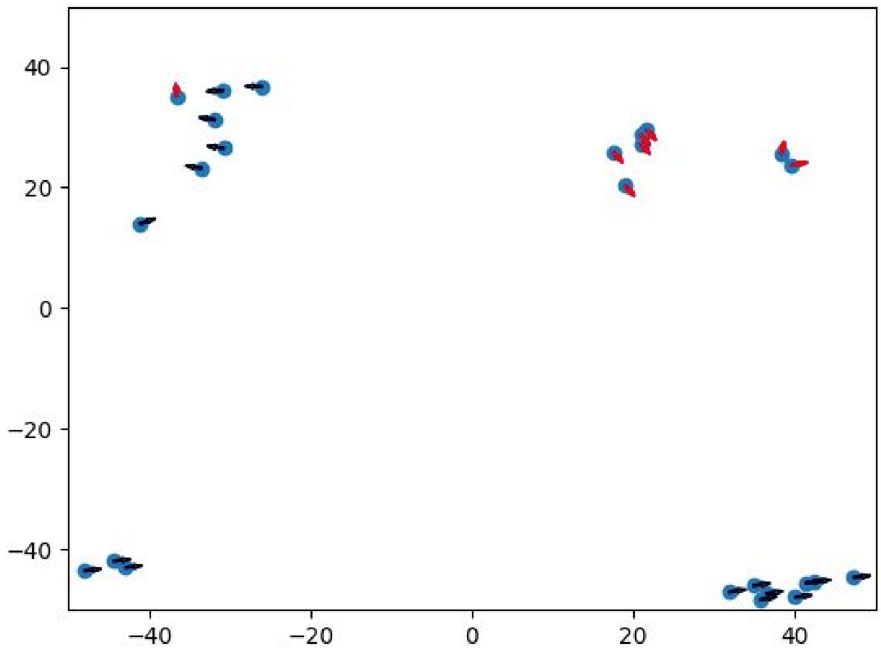




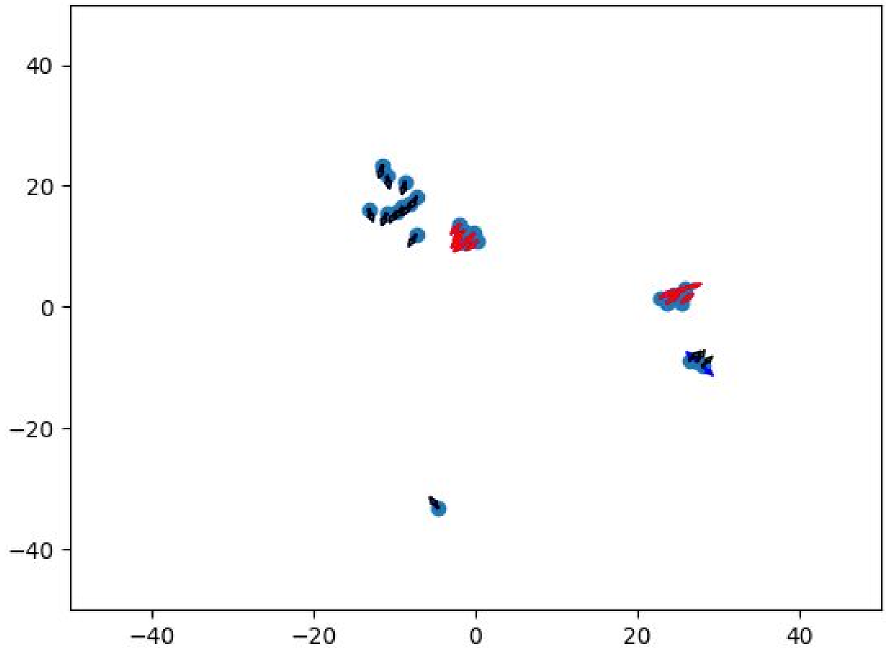
With a relatively small radius of orientation, and a large radius of attraction, the sheepdog agents are unable to get away from the swarm of normal agents. Since their attraction fields take up much more space, they are attracted to the normal agents instead of oriented by them. As such, swarms are created instead. This is in line with Couzin et al's results, where a small orientation field and a large attraction field created swarms. The figure below shows this behavior, with sheepdog agents at the center of several different swarms.



We also experimented with a relatively small orientation and attraction radii. We found that sheepdog agents and normal agents each formed their own parallel groups. This is probably because a small attraction radius (7 in most experiments we tried) meant that the sheepdogs could use their large velocity to quickly escape any pull from the slower agents. The figure below shows the agents' parallel groups, separated naturally by agent type.



We experimented with smaller and larger probabilities of sheepdog agents, different amounts of agents, different normal agent turning rates and fields of perception. We found that, in general, changing these parameters had no effect on the end result of the system. However, with a large enough probability of sheepdog agents, the possibility for multiple toruses increases. Below is an example of this. Because there were near 50% sheepdog agents, but not all of them met up with each other, they "herded" different groups of agents and created separate communities.



We also experimented with agents that could take steps in a random direction sporadically, and agents that could “teleport” (move a medium distance instantly), but didn’t find any particularly interesting formations that were created from these behaviors.