Sheep Flocking with a Single Sheepdog Predator using Boids Model

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Abstract

The boids model, created by Craig Reynolds in 1986, is an agent-based method for modeling animal behavior. It was originally used to coordinate realistic animal motions such as bird flocks and fish schools.[1] Since then, the model's use has expanded to many areas such as flocking animations[†] and robotics experiments.[2] The goal of this experiment is to use the boids model to create complex global behavior from interaction between individual agents in a continuous world. More specifically, the boids model will be used to create rational sheep behavior in the presence of a single controlled predator, the sheepdog, whose objective is to group and direct the sheep. Upon model completion, we would like to discover the effects of barking frequency on flocking, the maximum number of sheep a single sheepdog can flock, and capture the art of steering behavior parameter specification.

1 Introduction

In order to model interaction between sheep and sheepdog, it is essential to have a basic understanding of each animal's behavior. Sheep are the prey species while the sheepdog is the predator species.

Sheep Behavior

Sheep have unique behavioral characteristics that have contributed to their survival and proliferation in their environments. Dr. R. Kilgour, one of the world's foremost

† The Lion King (1994) movie stampede scene <http://www.lionking.org/movies/Stampede.mov>

sheep ethologists, defines sheep as a "defenseless, wary, tight-flocking, visual, wool-covered ruminant…displaying a 'follower-type' dam precocial offspring relationship with strong imitation between young and old…." The sheep behavior is mostly attributed to its feeding and survival needs. Sheep only need to graze for food, but must protect themselves from carnivorous predators by flocking. Additionally, sheep are passive creatures that would never hunt another animal.

The senses are used to interact with the environment. The placement of the sheep's eyes on the side of the head allow for a wider visual field when compared to predator species such as the sheepdog. With only slight head movement, sheep can scan their environment. The biological structure of the eye also provides enhanced peripheral vision. Furthermore, sheep have very acute hearing, and can pinpoint sound with its ears. Research shows that sudden loud noise raises stress-related hormones.[3] Sheep also have a "flight zone" that is defined as the space around the sheep which, if entered by a perceived threat, will cause the sheep to react.[4] All of the above mentioned behaviors were implemented into the simulation with exception to offspring relationships.

Sheepdog Behavior

Sheep are natural prey to sheepdogs. However, training by man has allowed these domestic dogs to assist with herding sheep. Their primary role is to move the sheep. In the real world, different breeds specialize in different aspects of flocking. Headers are in charge of keeping the livestock in a group, while heelers are responsible for pushing the animals forward. Moderate types work more independently, and some breeds can be adapted through training to play any role. Furthermore, some sheepdogs can work well herding any type of animal, whereas others have developed physical characteristics or techniques that improve their ability to handle particular animals.[5,6,7] This implies that some sheepdogs are better suited for a herding sheep than others.

Sheepdogs have traits that assist them with outmaneuvering sheep. Sheepdogs have a more concentrated field of view, because the eyes are placed towards the front of their head which gives them better depth perception.[3] Additionally, they have better speed and endurance compared to the sheep.[6]

The primary objective for the sheepdog in this simulation is to group the sheep, but it can also direct the movement of the flock given commands from the owner or user. The sheepdog in the simulation is assumed to be perfectly trained and responds perfectly to user commands. A list of the implemented commands can be found below:

Come-bye – move clockwise around the sheep
Away – move counterclockwise around the sheep
Stand – stop
Steady – slow down
Bark – bark at sheep

Walk up – move in closer to the stock
That'll do – stop working and return home

2 Boids Model and Algorithm

The boids model is an agent-based framework for simulating coordinated animal behavior. Three simple steering behaviors drive the simulation – cohesion, alignment, and separation. Each behavior can be scaled with a parameter to vary the effect of each behavior on the velocity at each time step. However, the balancing of the parameters takes insight or rigorous trial and error to reach the desired effect.

Algorithmically, the boids model loops over drawing the boids, updating velocity to next time step based on the steering behavior, and updating position to next time step. The velocity is updated by summing the effects of cohesion, alignment, and separation with the velocity at the previous time step. Figure 1 shows the overall flow for the boids model.

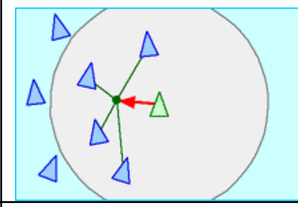
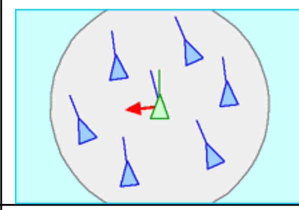
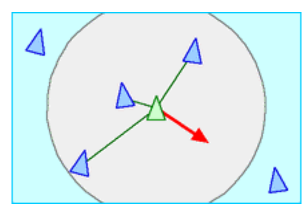
Boids Program:

```
initialize_positions()
loop
  draw_boids()
  update_boids_velocity_and_position()

function update_boids_velocity_and_position()
  vector v1,v2,v3
  boid b
  for each boid b
    v1 = cohesion(b)
    v2 = alignment(b)
    v3 = separation(b)

    b.velocity = b.velocity + v1 + v2 + v3
    b.position = b.position + b.velocity * timestep
```

Figure 1 – Pseudocode for the boids model. initialize_positions() would set original position for the boids, and then the program loops over drawing the boids and updating the velocity and position to create an animation. The timestep for the simulation was 0.15. The cohesion, alignment, and separation functions are explained in more detail Table 1.

The steering behaviors define how one boid interacts with other boids. In this experiment, there are three types of reactions – sheep to sheep, sheep to sheepdog, and sheepdog to sheep. Generally, sheep are drawn to other sheep, sheep run away from the sheepdog, and the sheepdog is drawn towards the sheep. Each of these behaviors can be produced by simply varying the parameters for cohesion, alignment, and separation. For example, a positive cohesion modifier would result in moving closer to a target, while a negative modifier would cause the boid to move away from a target. A comprehensive list of the parameters for the sheep and sheepdog can be found in Table 2,3, and 4. Table 1 explains the effect of each behavior separately and the basic algorithm.

Table 1 – Cohesion, Alignment, and Separation Explanation and Implementation

<table>
<tr><th>Behavior</th><th>Algorithm (N is # of boids)</th><th>Graphic Representation</th></tr>
<tr><td>Cohesion:
Steer towards center of mass of flockmates in sight</td><td>function cohesion(boid b1)
vector center
for each boid b
if b != b1 then
center = center + b.position
center = center / N-1
return (center – b.position)*c_param</td><td></td></tr>
<tr><td>Alignment:
Steer towards average velocity of local flockmates</td><td>function alignment(boid b1)
vector vel
for each boid b
if b != b1 then
vel = vel + b.velocity
vel = vel / N-1
return (vel-b.velocity)*c_param</td><td></td></tr>
<tr><td>Separation:
Steer away from local flockmates to avoid overcrowding and/or collision
Note: only effective when neighboring boid is within the alignment parameter</td><td>function alignment(boid b1)
vector vec
for each boid b
if b != b1 then
if |b.position – b1.position| < a_param then
vec = vec – (b.position – b1.position)
return vec</td><td></td></tr>
</table>

In order to make the simulation more realistic, several other factors are necessary. Parameters for these factors can be found in Table 4.

Max Speed

Max speed is essential for realistic movement. Since the cohesion, alignment, and separation velocities are added to the velocity of the boid in the previous iteration, the velocity quickly becomes unreasonable after a succession of velocities pointing towards the same direction. In this model, the sheepdog's maximum speed is 1/8th more than the sheep's. The speed cap is implemented by scaling down the velocity vector before the new position is calculated. The pseudo code can be found below:

```
function limitVelocity(boid b)
  if magnitude(b.velocity) > boid.max_velocity
      b.velocity = (b.velocity / magnitude(b.velocity)) *
b.max_velocity
```

Vision

Sheep and sheepdog have limited knowledge of their surrounds. Sheep have a wider range of vision than the sheepdog, but the sheepdog can see further than sheep. In this model, the world is a small 2D plane, so the sheepdog and sheep can see everything within their angle of view. Sight is implemented by adding an if statement within each steering behavior function to check whether or not the current target boid can be seen.

Boundaries

An extra velocity component is necessary to keep the boids within boundaries of the 2D world. This one is simple to implement. If the boid's position is beyond a certain point, then add a velocity pointing back into the world. This allows the boids to turn back into the boundaries rather than hit a hard wall. The model boundaries are at ±200 pixels on the x and z axis.

Sheep States

Sheep have two different states. They are usually grazing unless agitated into a "flight zone." The sheep attempt to escape from the dog who enters their "flight zone." To model this behavior, a check is made each time step to see if a dog has entered the sheep's flight zone. If so, the sheep goes into an agitated state, and an agitated_count is used to keep track of how long the sheep has been agitated. After a certain number of time steps, the sheep returns to a grazing state. The implementation uses modifiers for the steering behavior parameters. Table 2 shows the overall behavioral parameters for the graze and agitated states.

Table 2 – Behavioral Parameters for Sheep

	Sheep to Sheep Relationship			Sheep to Sheepdog Relationship			All
Behavior Parameters	Cohesion	Alignment	Separation	Cohesion	Alignment	Separation	Max Speed
Graze State	0%	0%	10 pixels	0%	0%	10 pixels	3 pixels
Agitated State	2%	30%	10 pixels	-3%	0%	10 pixels	4 pixels

Note: these are values relative to the simulation and are not associated with the real world

Sheepdog States

The sheepdog has different states depending on the command given to it by its owner or user. Just like the sheep, the implementation uses modifiers for the steering behavior parameters. Table 3 shows the overall behavioral parameters for the sheepdog when given various commands.

Table 3 – Behavior Parameters for Sheepdog to Sheep Relationship

Behavior Parameters	Cohesion	Alignment	Separation	Max Speed (per step)	Other
Default State	3%	1%	10 pixels	3 pixels	
Stop Command	0%	0%	0 pixels	0 pixels	
Slow Down Command	NC	NC	NC	90% from previous	
Move In Closer Command	4.5%	0.5%	10 pixels	4.5 pixels	
Stop Working, Return Home Command	0%	0%	10 pixels	3 pixels	Set flag for return home
Bark Command	NC	NC	NC	NC	Agitate all sheep
Rotate Left Command	NC	NC	NC	NC	Add a velocity perpendicular to the vector from the sheepdog to the center of the sheep in clockwise direction
Rotate Right Command	NC	NC	NC	NC	Add a velocity perpendicular to the vector from the sheepdog to the center of the sheep in counter-clockwise

					direction

Note: NC = No Change

Note: these are values relative to the simulation and are not associated with the real world

Randomization

Randomization is implemented throughout the model. A small random velocity is added to each sheep and sheepdog during each time step. This does not significantly affect the movement of the sheep and sheepdog. However, when the sheep are grazing, they will random walk instead of standing still. This is representative of how sheep act during grazing, because they frequently turn their head to examine their surroundings.[3] Additionally, many other factors are randomized by taking a normal distribution of the value with 90% confidence the value will be within 10% of the original value. Randomized values include agitated_count, steering behavior parameters, and maximum speed for sheep and sheepdog.

Table 4 – Constants and Parameters for the Sheep and Sheepdog

Parameter	Current Boid	Value
Maximum Velocity	Sheep	4 pixels
Angle of View[†]	Sheep	145°
Range of Sight	Sheep	Whole Field
Flight Zone	Sheep	4 grids
Agitation Duration	Sheep	200 time steps
Random Velocity	Sheep	0.5 pixels
Maximum Velocity	Sheepdog	6 pixels
Angle of View[†]	Sheepdog	110°
Range of Sight	Sheepdog	Whole Field
Random Velocity	Sheepdog	0.75 pixels

Note: these are values relative to the simulation and are not associated with the real world

[†] Angle on left and right from current velocity

3 Procedure

Several experiments were performed with our simulation model. In each experiment, the standard deviation of the sheep positions were computed to measure the magnitudes of their flocking behavior. Below are the performed experiments. Each experiments were repeated 10 times and average was taken to reduce the factors of random initial positions of sheep:

1. Frequency of barking, number of sheep, and speed of flocking

We varied frequency of barking in range of every 100 steps to every 1000 steps, while varying the number of sheep varying from 5 to 50. This experiment is done with sheep-sheep alignment constant 0.15.

2. Sheep-sheep and wolf-sheep alignment constants, and speed of flocking

We varied the alignment factors of sheep-sheep and wolf-sheep relationships to see how they affect the flockings. These constants were varied from 0 (do not try to align at all) to 1 (always align to velocity vectors of other sheep).

4 Results and Discussion

The Figure 1 below shows one sample run of sheep separation vs barking intervals. There are 20 sheep and the sheep-sheep alignment constant is set to 0.15.

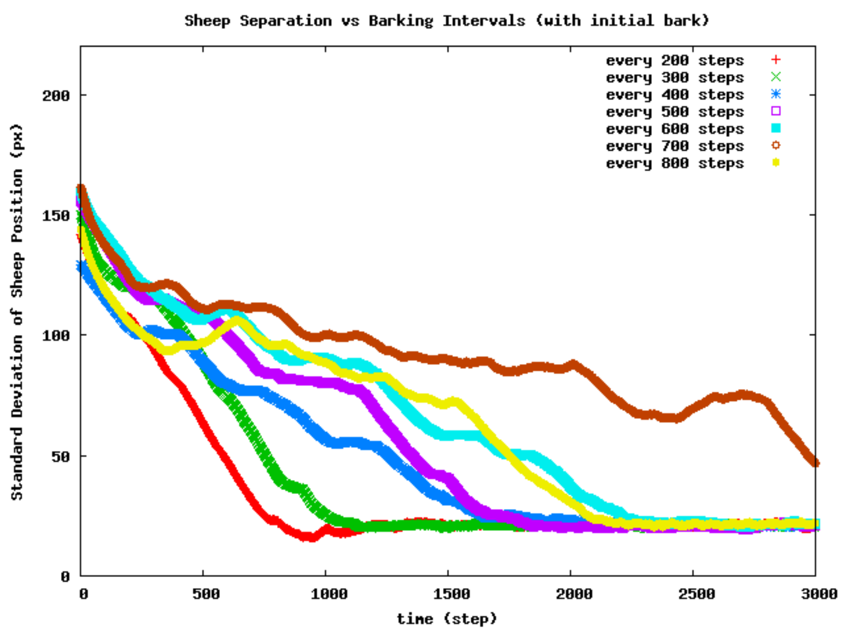


Figure 1: Sample result of SD of sheep position , varying barking intervals. (one run, not averaged)

This plot above shows clear relationship between the barking interval and the flocking behavior of sheep. This satisfies the expected sheep behavior discussed in [3].

The figures 2 to 5 shows standard deviation of sheep positions versus step. Each plot consists various barking rates with constant number of sheep. Number of sheep increases from Figure 1 to 4 as 5, 15, 25 and 35.

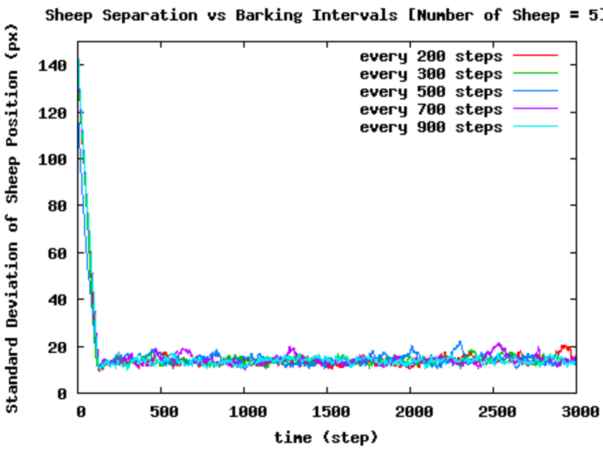


Figure 2: SD of sheep position of 5 sheep, varying barking frequency of sheepdog.

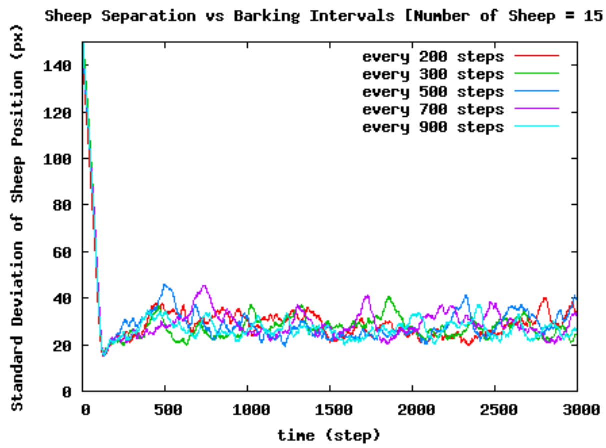


Figure 3: SD of sheep position of 15 sheep, varying barking frequency of sheepdog.

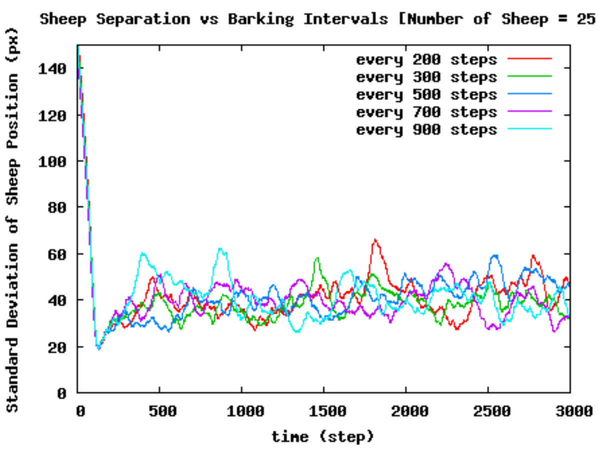


Figure 4: SD of sheep position of 25 sheep, varying barking frequency of sheepdog.

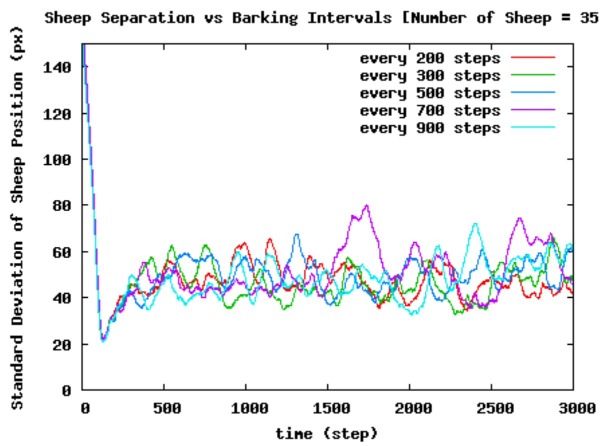


Figure 5: SD of sheep position of 35 sheep, varying barking frequency of sheepdog.

Plots 2 to 5 show the sheepdog having more difficulty maintaining a larger flock of sheep. The barking interval does not significantly effect sheep flocking. For a set number of sheep, the standard deviation mean and variance are similar visually at all barking intervals between 200 and 900, inclusive. The flocking ability (standard deviation of sheep position) of a single sheepdog is effected by the number of sheep. At higher numbers of sheep, the mean and variance of the standard deviation increases visually. There is the issue with the number of sheep that can fit in a certain area, since there is a separation (anti-collision) behavior. However, for all values of the number of sheep, the standard deviation minimizes at a similar value of 20 px at approximately time = 100. The increase in the mean of the standard deviation as number of sheep increases is significantly larger than the change in volume required to hold the number of sheep.

Plots 6 to 11 show the results of experiment 2. Each plot contains various sheepdog-sheep (ws) alignment constants with constant sheep-sheep (ss) alignment value. The ss alignment value increases from figure 6 to 11 as 0, .2, .4 ... 1.0. The zero alignment constant in the Boids model shows there are no properties of alignment between these agents.

These plots show very interesting properties of the Boids model. The first obvious feature is the strong oscillation of the flock size for any run except with ws alignment=0. Tracking only zero ws alignment (red lines), it is clearly shown that the sheepdog more successfully groups sheep with higher alignment of the sheep-sheep relationship. At ss=0, the sheep almost always fail to form a flock.

The oscillations in the standard deviation of the sheep position are attributed to the barking in intervals. When the sheepdog barks and it is aligned with the sheep, the sheep are initially drawn together. However, due to the small world size, the sheep soon hit the boundaries of the world, and they turn back. Because of the strong alignment of the sheepdog to the sheep, the sheepdog turns as well and never gets close enough to the sheep to agitate the sheep into a continuous flock. This kind of behavior is unreasonable in the real world.

Thus, the only part that can analyzed is the effect of variations on sheep-sheep alignment while the wolf-sheep alignment is zero. The results are clear in this case, as the alignment of the sheep increases, the sheep flock more as indicated by the visually lower standard deviation mean and variance.

However, even if the world size was infinite, similar behavior may be observed. Very interestingly, these oscillations are visible in nature in fish schoolings[11], as well as in simulation of fish schoolings[8,9,10]. At alignment factors larger than certain values, the fish school tightens and loosens becoming more and less dense alternatively.

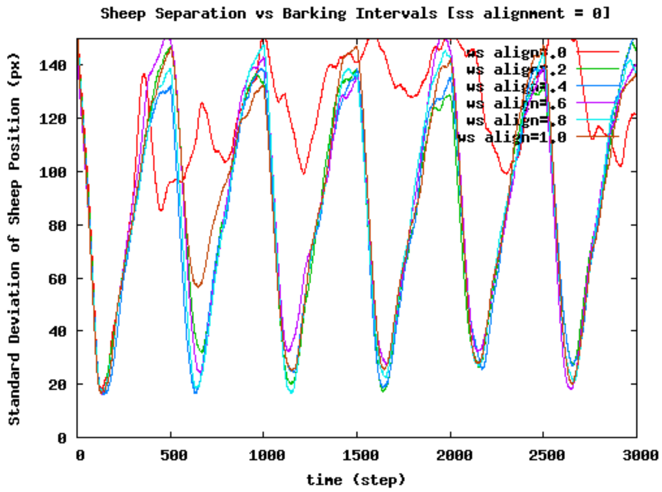


Figure 6: SD of sheep position with ss=0
Varying sheepdog-sheep alignment.

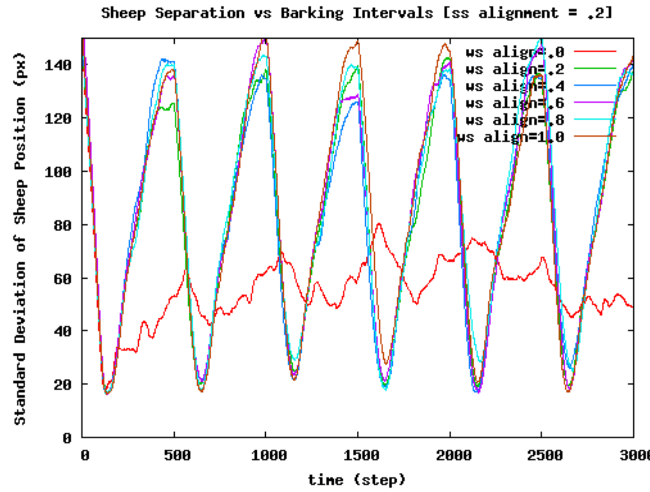


Figure 7: SD of sheep position with ss=0.2
Varying sheepdog-sheep alignment.

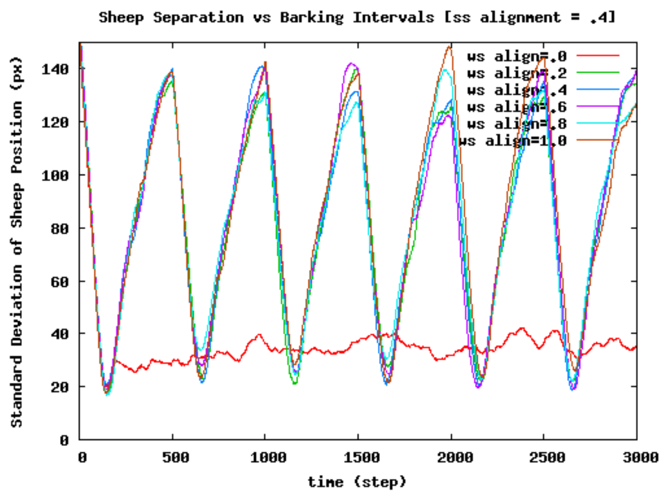


Figure 8: SD of sheep position with ss=.4
Varying sheepdog-sheep alignment.

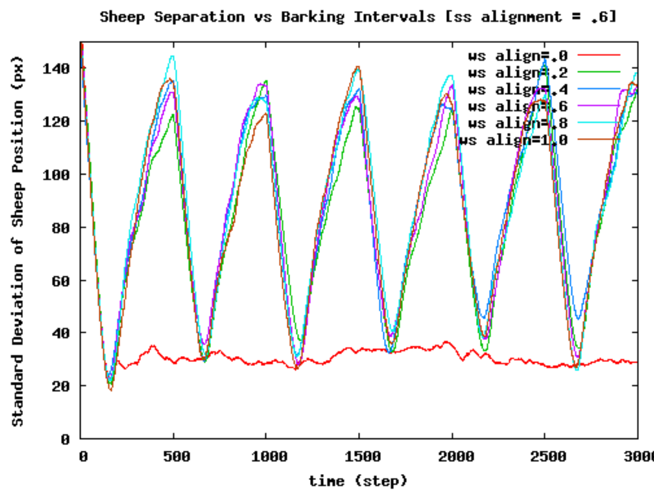


Figure 9: SD of sheep position with ss=.6
Varying sheepdog-sheep alignment.

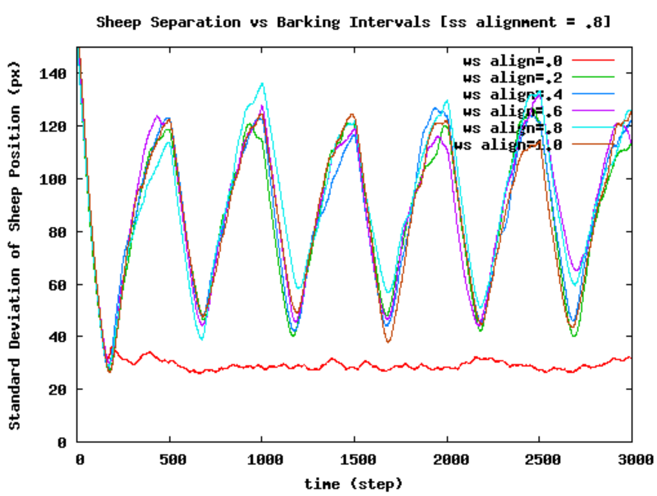


Figure 10: SD of sheep position with ss=.8
Varying sheepdog-sheep alignment.

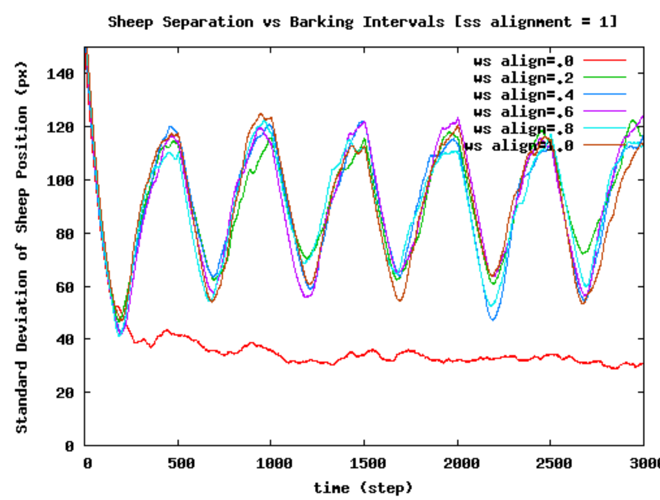


Figure 11: SD of sheep position with ss=1
Varying sheepdog-sheep alignment.

5 Conclusion

In this project, sheep and sheepdog behavior was modeled and simulated using Boids model and agent based simulation. We could successfully observe sheepdog flocking sheep on any initial position or number of sheep. The alignment factor of sheep-sheep and sheepdog-sheep relationship had core factor on Boids model. At higher than 20% (0.2) of alignment factor, sheep showed clear oscillation on the size of flock with frequency of barking. The sheepdog had difficulties forming a flock of sheep with no alignment factor.

One of the applications of this project is to determine best sheepdog traits (implement learning for sheep and sheepdog) through the simulation states and constants, train sheepdog owners on how to best control dog, and determine limit of sheep that a certain number of sheepdog can flock.

Possible further works include to capture intuition for Boids constants, add more realistic movement (turning and forward/backward movement), real world experiments to validate Boids constants, add obstacles and agent reaction to obstacles, keep at least 4-5 sheep in sight of each other during grazing[3], and to add learning to the dogs so they become better at herding over many iterations.

6 References

1. Boids - Reynolds, C. W. (1987) Flocks, Herds, and Schools: A Distributed Behavioral Model, in Computer Graphics, 21(4) (SIGGRAPH '87 Conference Proceedings) pages 25-34.
2. Vaughan, R. Robot Sheepdog Project achieves automatic flock control. in Proceedings of the International Conference on Simulation of Adaptive Behaviour, Zurich, Switzerland (1998).
3. Sheep behavior – Gill, W. Applied Sheep Behavior. Animal Science Department of The University of Tennessee. <http://animalscience.ag.utk.edu/sheep/pdf/AppliedSheepBehavior-WWG-2-04.pdf>
4. Grandin, T, and M. J. Deesing. 1998. Genetics and Behavior during handling and restrain. In Genetics and Behavior of Domestic Animals. Academic Press. San Diego, CA.
5. Renna, Christine Hartnagle. *Herding Dogs: Selection and Training the Working Farm Dog*. Kennel Club Books (KCB). ISBN #978-1-59378-737-5.
6. Hartnagle, Jeanne Joy. *Herding I, II, III*. Canine Training Systems (CTS).
7. Hartnagle-Taylor, Jeanne Joy. *All About Aussies*. Alpine Publications. ISBN # 1-57779-074-X.
8. Reynolds, Craig W., Flocks, Herds, and Schools: A Distributed Behavioral Model, *Computer Graphics*, **21**(4), July 1987, pp. 25-34.
9. Huse, Geir, Steve Railsback, Anders Ferno, Modelling Changes in Migration Patterns of Herring by Numerical Domination, <http://www.humboldt.edu/~ecomodel/clupeoids.htm>
10. Kurtus, Ron. Simulation of Flocking Behavior <http://www.school-for-champions.com/behavior/floys/simulation.htm>

11. Suzuki, Katsuya., Tsutomu Takagi, Tomonori Hiraishi, Video analysis of fish schooling behavior in finite space using a mathematical model, Fisheries Research, **60**, 1, 2003, 3-10.