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Perception of Realistic Flocking Behavior in the Boid Algorithm

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Abstract

Context. Simulation of nature is something that is used to immerse the player into the world of games. By adding details in the world such as birds circling in the sky or small fishes swimming in a flock, developers can improve the gaming experience for the user. More precise simulations are something that should be aspired for. This thesis will explore the boid flocking algorithm and evaluate what settings users perceive as realistic behavior for simulating schools of fish.
Objectives. This thesis proposes that there should be a set of variables that reflect a more realistic behavior and through gathering data from volunteers and mapping their answers, conclude if that statement is true.

Methods. A boid simulation will be run in a number of different scenarios, each differing in variables that are vCohesion, vSeparation and vAmount that make changes to the overall behavior. This behavior is then recorded and compared next to each other in a perceptual experiment with the objective of finding out the preferred settings in terms of realism.
Results. The experiment showed that the preferred value of vSeperation was around 50 to 60 world units. The value of vCohesion and vAmount was random to what was perceived, so their impact on realism was not significant enough.
Conclusions. After running the experiment it was apparent that there was a preferred value on some of the variables that were examined. The larger impact on realism was in the distance each boid wanted to keep from its neighbor, the vision range of each boid defined what was considered a neighborhood. The range on this variable was not of much importance and did not impact what the user perceived as realistic.

Keywords: Flocking behavior, Boids, Realism, Perceptual Experiment

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Chapter 1

Introduction

The boid algorithm [1] is used to simulate flocking of various animals, most commonly school of fish and flocks of birds. It has been expanded on throughout the years to include more extended behavior [3] and increased its performance [2], but at the boid algorithm's core, the flocking behavior has remained the same. The same rules and variables are still present even today.

This paper examines separation, alignment and cohesion, the three rules that make up the boid algorithm, and do a perceptual experiment to find out a visually appealing representation of a fish flock. A deeper explanation how separation, alignment and cohesion work can be found in Chapter 2.2.

1.1 Background

The term realism is hard to define and since the definition is of a very subjective nature, this paper defines realism as follows, a given simulation that acts as the user would expect in its given context in regards.

In 1986 Reynolds wrote an algorithm to simulate a coordinated flocking behavior such as bird flocks and fish schools, which is called boids. During the years his work has been refined and improved by additional behavior rules, such as the work by Chen and Yen-Wei [3].

During the lifespan of the algorithm it has been improved to increase performance [2][6] and some additional rules [3] have been done on the algorithm to create additional behavior for attraction to a feed, following a leader, evasion, and dodging enemies. Evasion will make the boids avoid certain obstacles in the environment and feed will attract the boids to a specific object, such as a breadcrumb.

In games an economy regarding memory and performance is preferred since the behavior of wildlife is not often crucial for gameplay. Since flocking behavior is an immersive feature that often strives to add realism to the game, the authors believe that it is important to explore what users find most interesting in flocking behavior so that the boid algorithm can be used with satisfying results.

In this paper, only movement will be of interest, textures and models will not be taken into consideration regarding realism since it will demand a study by itself. The simulation will be run in a 2D environment.

1.2 Aim and Objectives

In this paper, the authors will evaluate people's preferred configuration of the boid algorithm in regards of realism, by making changes to Separation, Alignment, Cohesion and Amount.

- Implementing a user interactive flocking algorithm.
- Mathematically describe the constants and its relationship to the behavior.
- Perform a perceptual experiment where different values in Seperaion are compared, followed up with different values of Cohesion and alignment being compared and lastly different values of Amount being compared. The comparison will be done in regards to what the user perceive as the most realistic behavior.
- Evaluate the gathered data and analyze the result.

1.3 Research Questions

This paper will aim to answer the following question:

- How does changing the rules of separation, cohesion and number of boids relate to what users perceive as realistic behavior for simulating schools of fish?

1.4 Related Works

In this field, there are many studies focusing on optimizing and performance [2], other studies describe the boid algorithm or extend the rules [3]. Nevertheless, the authors found no studies regarding what users find most enjoyable or realistic when using the Boid algorithm, which is why the authors of this paper do not have extensive related works.

Chapter 2

Theory

2.1 Dictionary

Before going into the details of the steering rules that are being used in this application, some words will be covered that will be used in this paper.

- Boid: Refers to an individual fish that react and interact with other boids in the world.
- Flock: Refers to a group of boids.
- Active boid: Refers to the boid that the algorithm is currently working on.
- Neighborhood: Refers to the boids that the active boid sees.
- vSeparation: Is the value that indicate how far apart boids wants to keep from each other.
- vCohesion: Is the cohesion value that dictates the range that a boid can see. vCohesion is in direct correlation with the neighborhood size, since the neighborhoods radius is the vCohesion value.
- vAmount: Refers to the amount of boids that are active in the simulation.
- Set: A set is a combination of the three variables vCohesion, vSeparation and vAmount. For example, the set =20,30,40 refers to when vCohesion is 20, vSeparation is 30 and vAmount is 40.
- WorldUnit: is a unit that describes length, discussed in section 2.2.5.

2.2 The Boid Algorithm

Is commonly used to create a flock or swarm behavior for large groups of animals, such as fishes and birds. It works by creating a series of entities also known as boids that are normally given three sets of rules [1][3] that determine how they behave around the surrounding neighbors. They are as follows:

- Separation: Is the rule that makes the boids keep a certain distance from each other.
- Alignment: Is the rule that makes the boids steer towards a common direction.
- Cohesion: Is the rule that makes the boids want to move towards the center of a group.

The vision range determine how far the active boid sees, which is used in all rules in Boids. In order to be able to change one individual rule, all rules got their own vision variable, that is named vSeparation, vAlignent and vCohesion. However, when studying and changing these variables, the authors decided to keep the vision range for vAligmnent and vCohesion shared, since they have little impact on the behavior of the flock. In short, vSeperation is the vision range variable for the rule of seperation, while vCohesion is the vision range shared for the rules of alignment and cohesion.

- vSeparation, determine the size of the neighborhood for the rule separation.
- vCohesion, determine the size of the neighborhood for the rules of alignment and cohesion.
- vAmount, simply holds the number of individuals in the scene.

Changing these constants may change the boid's behavior drastically. Doing different changes to the constants can prove to make the behavior more like that of a school of fish whilst another change will make it more like the pattern of a flock of birds.

2.2.1 Separation

The first rule that applies to Reynold's boid algorithm is collision avoidance. In order to create a realistic flocking behavior, it is important to make sure that the boids avoid colliding with each other. This applies the moment any flock member is within vSeparation range of any other boid, as show in Fig: 2.1. A vector between the active boid and the boid within range is calculated, this vector is refered to as BoidVec.

For the separation, it is calculated by taking the length of the vector boidVec and divide it by the vSeparation. The scalar is then multiplied with the normalized vector from boidVec. The formula is described below in eq: 2.1[3].

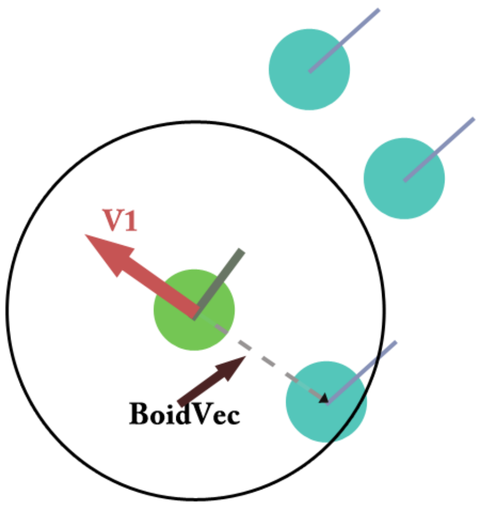


Figure 2.1: Separation

$$V1 = \begin{cases} \left(\frac{|boidVec|}{vSeparation} - 1\right) \cdot \frac{boidVec}{|boidVec|} & ,(|\text{boidVec}| \leq vSeparation) \\ 0 & ,(|\text{boidVec}| \geq vSeparation) \end{cases} \tag{2.1}$$

2.2.2 Alignment

The second rule is to apply direction alignment for every boid in the neighborhood. This is done by calculating the average of all the neighbor's directions, as shown in fig: 2.2. The calculated vector V2 is then used to steer the next direction. The direction calculated is described by eq: 2.2 [3], were n are the number of boids in the neighborhood.

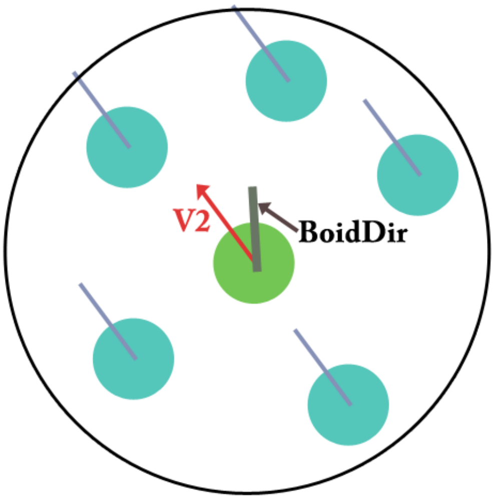


Figure 2.2: Alignment

$$V2 = \frac{1}{n}\sum_{i=2}^{n} Direction_i \tag{2.2}$$

2.2.3 Cohesion

The third rule is about gathering together, keeping the flock intact. This is done by finding the vector V3 from the active boid to the average position of the neighborhood and moving the boid towards that position. The radius of the neighborhood is defined as the vCohesion value. fig: 2.3. In eq: 2.3 [3], centerVec represents the average position of all the boids in a neighbourhood.

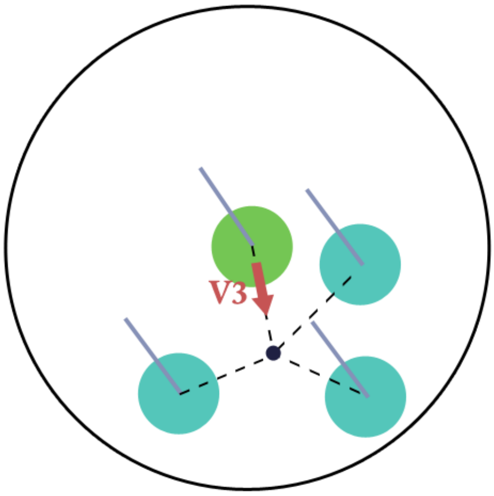


Figure 2.3: Cohesion

$$V3 = \begin{cases} \frac{centerVec}{|centerVec|} & ,(|\text{centerVec}| \leq vCohesion) \\ 0 & ,(|\text{centerVec}| \geq vCohesion|) \end{cases} \tag{2.3}$$

2.2.4 Avoiding Danger

When an animal tries to get away from danger the animal usually try to run away in the opposite direction, fig: 2.4. To achieve this the speed of the boids was amplified the closer they were to danger. The avoid danger rule was included in this thesis work because it made the boid algorithm easier to evaluate. In the conducted test this rule was used to put more tension on the flock. The formula can be found in eq: 2.4 [3].

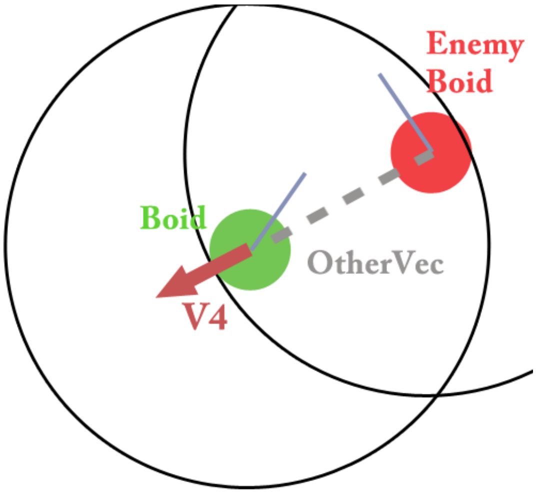


Figure 2.4: AvoidDanger

$$V4 = \begin{cases} \left(\frac{|OtherVec|}{vCohesion} - 1\right) \cdot \frac{Othervec}{|OtherVec|} & ,(|\text{OtherVec}| \leq vCohesion) \\ 0 & ,(|\text{OtherVec}| \geq vCohesion) \end{cases} \tag{2.4}$$

2.2.5 Scale

In order to understand the numbers that are being used in vSeparation and vCohesion, it is important to understand the scale that it is all being presented in. The boids in this thesis are spheres with a radius of 16 pixels, therefore are all the constants based on that scale. To recreate the values of this thesis one would have to scale it accordingly. In the following equations, the constant is 16 and boidDia is the diameter of the boid. To use this in another application, vSeperation and vCohesion has to be multiplied with the worldUnit. The formula is described in eq: 2.5.

$$worldUnit = \frac{boidDia}{16} \tag{2.5}$$

Chapter 3

Method

There are methods for statistics analysis that plot user's preferred setting in a visual context. In this project, "goodness of fit" was chosen in order to evaluate if users prefer a setting over another. There are several "goodness of fit" techniques and in this paper, chi-square is used. Chi-square was chosen for this particular analysis as it gives a clear view of the preferred data.

The chi-square statistic is sometimes also referred to as a test of independence, which suits the needs to find out if the values of vSeparation, vCohesion and vAmount can indeed impact what participant perceive as realistic behavior. For this project, a significant level of 5 percent is used, since it is common for researchers to use [7].

When conducting an experiment it is important that the participant can perform the test without outer disturbances such as noise, movement or other things that can interfere with the test results. In order to reduce these risks, it was made sure that the test was performed in a remote room with as little disturbance as possible.

3.1 Experimental Design

For this experiment it was best to secure that the participants were over 18 years old, to make sure that ethics regulation was followed. The participants' experience in games are not taken into consideration, but since the test will be conducted at a technology institute, it is expected that a strong majority are experienced in using digital media.

To reduce the chance of distraction for the participant, a secluded room was used, booked in Blekinge Institute of Technology. The room will include a computer with the test application installed.

To indicate what variable that are tested in the program, the test is split into two parts, the first part only dealing with vSeparation and the other part only dealing with vCohesion. To do this, several prerecorded videos displaying several instances of the simulation using different values of the variables vSeparation and vCohesion was displayed all together fig: 3.1.

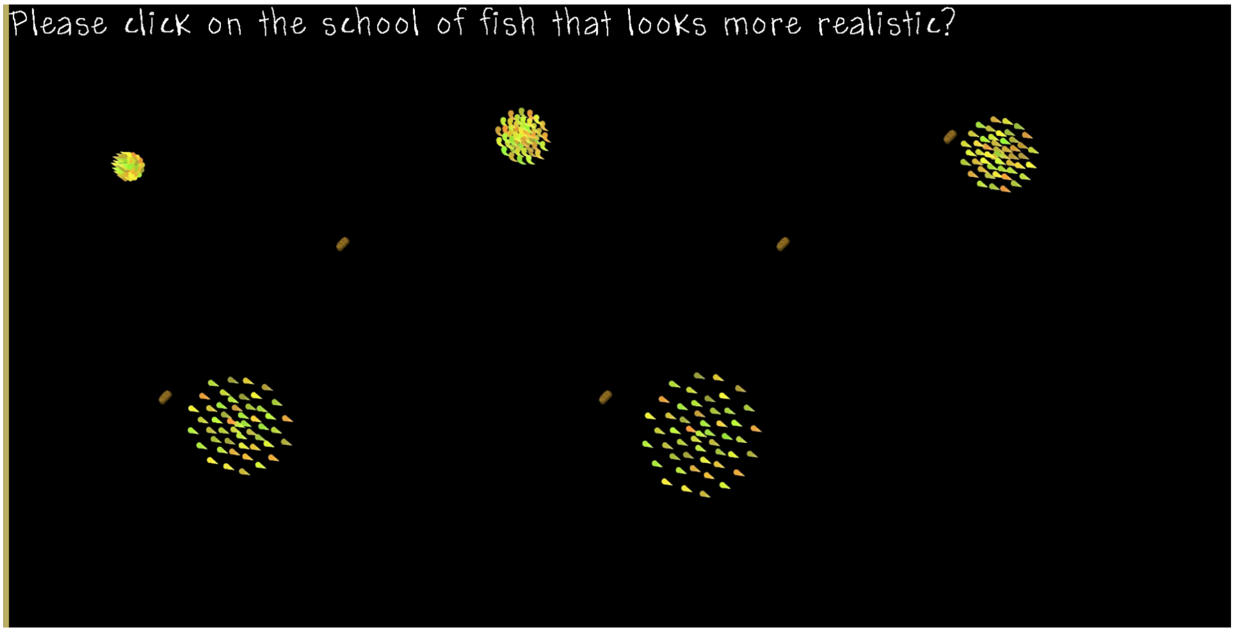


Figure 3.1: The user had to choose between vSeperation 20 (top left), 40 (top middle), 60 (top right), 80 (bottom left), 100 (bottom right)

3.2 The Hypothesis

In this test, the goal is to find out if there is a more preferred setting in the boid algorithm in terms of realism. To achieve this some assumptions must first be set up about the boid algorithm and how it relates to realism.

There are many species of fish in the world, and many of these species have optimized their flocking behavior to improve the chance for survival when predators are looking for a meal. This results in users having different references to how the fish should behave in a flock, even though this is true this paper assumes that there should still exist a general perception of what users perceive as realistic behavior. If the chi-square results show a low p-value the alternative hypothesis must be rejected and the conclusion that these constants have little to no influence on the flocking behavior must be accepted. This is true for both vCohesion and vSeperation.

3.2.1 Alternative hypothesis

There are settings in vSeparation or vCohestion that users generally prefer in regards to realism in the boid algorithm.

3.2.2 Null hypothesis

The constants vSeparation and vCohesion does not have a significant influence in the realism in a flocking behavior using boids.

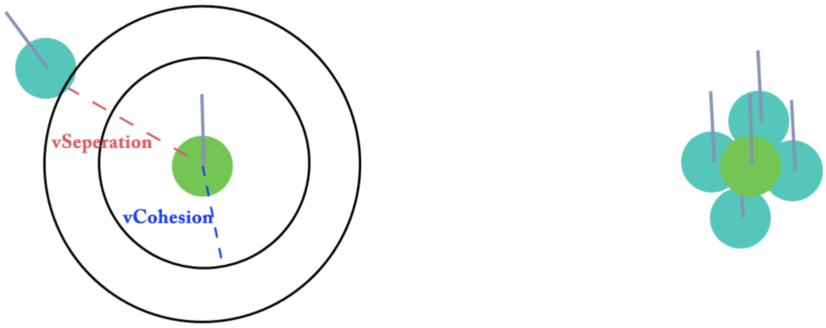
3.3 The Variables

For the sake of clarity and making the experiment simple to analyze, it will be a series of questions with multiple choices with a single answer. Comparing different setting against each other. The comparison is being done on the vCohesion, vSeparation and vAmount constants, and to not have too many choices to choose from per question, each constant was limited to be within a certain range.

The range was 20, 40, 60, 80 and 100 for vSeparation. The motivation for this is that smaller spans than this will result in many choices looking the same for the users, and a higher span might result in loss of precision in the experiment. The motivation is the same for vCohesion, except the span here are 50, 70, 100.

The simulation has some values of these constants that can be exclude from the range since it would break the flocking behavior. The range was defined as follows:

- vSeparation can not be higher than vCohesion since that would make the boids stop acting like a flock and swim as an individual instead. fig: 3.2 a
- vSeparation can not be too low of a value since that would make the boids swim on top of each other. fig: 3.2 b



(a) vSeparation exceeds vCohesion (b) vSeparation can't be too small

Figure 3.2: limitations to the variables

The sets that were chosen were the preferences that were described earlier in this chapter. As explained before, if vSeparation exceeds the value of vCohesion, the boid will swim away from their neighbors and lose sight of their friend, which results in the boids actively swimming from each other, see fig: 3.2 a. If vSeparation are below 20 (pixels), the group will overlap on each other which will make the flock look more like one boid rather than a flock.

Each question in the experiment aims to answer one question about one of the constants, the videos displayed all have the same values except the corresponding constant that is being studied. Each combination of the variables were divided into what was called "sets", each set differentiating as described earlier in this section.

3.3.1 vSeparation

Making changes to the vSeparation variable made very drastic changes to the flocking behavior, even when incrementing it at small intervals. As very little change was required to make the differentiating result, five different sets would be preferred, each with an increment of 20 on the vSeparation variable between each set.

Because of the limitations in a number of sets to compare, it would be preferable to start with values from the lowest, without the algorithm breaking the behavior. When the vSeparation has reached the point of acting as an individual instead of a flock, it is pointless to increase the value since the behavior of a flock is broken. The table below fig: 3.3 illustrates the values on the constants that are used to test vSeparation and its influence on realism according to the participants.

vSeparation	20	40	60	80	100
vCohesion	200	200	200	200	200
vAmount	5/50/100	5/50/100	5/50/100	5/50/100	5/50/100

Figure 3.3: vSepatation values tested

3.3.2 vCohesion

The vCohesion variable changed the range that determined how far a boid could see. This made changes to how large each neighborhood would be. Changes to this variable weren't apparent until the boids tried to regroup or merge into a larger flock.

It was difficult choosing the sets for this variable as it was hard to compare the differences. It wasn't until the avoid enemy rule had been implemented that it was apparent that the vCohesion variable determined how easy it was to split up a flock. With a higher vCohesion the flock would be harder to separate, whilst with a low vCohesion, the boids would have a harder time finding each other again after separation. At low incrementation, changes to the behavior was not apparent. Because of this it was not necessary to create a huge amount of sets that had to be compared. Earlier a value was decided that was considered too high for the simulation, beyond this value the changes was not really noticeable on the behavior. The lowest value vCohesion can be is just a bit higher than vSeparation since vCohesion can not be lower than vSeparation. Starting out with having vSeparation at the lowest value that did not cause over plotting. This range is what this paper has based the experiment on.

Since low increments did not make enough visible changes to the behavior, it would be enough with three sets. The three different sets represented the lowest, middle and highest value of the range that had previously been defined. In the figure 3.4 is the sets defining the test.

vSeparation	40	40	40
vCohesion	50	70	100
vAmount	5/50/100	5/50/100	5/50/100

Figure 3.4: vCohesion values tested

3.3.3 vAmount

The vAmount variable has a very strong visual feedback as it adds additional boids to the simulation, besides that it does not effect the behavior of the boids. The change in the amount of boids swimming around can make a difference in the user perception of what they consider to be realistic behavior. The application supports around 700 boids to be run in real time, but for the sake of narrowing the scope down, 100 boids were decided as the largest amount as more boids cluttered up the application. The lowest amount was 5 boids. This was because everything below that did not make for a very good representation of what the boid behavior was doing.

3.4 Execution

Before participating in the experiment the participant will be asked to read an introduction in order to get an understanding of the purpose of the experiment and what is requested of them. If the participant is still interested in participating, he or she will be asked to fill in an informed consent, including the remainder of their right of leaving the experiment without leaving any motivation.

When the participant is done with their test, their preferred settings will be stored in a text file on the computer. This file will be copied to both Google drive and a physical hard drive if a loss of data should occur due to damage of hardware.

The experiment will take place at Blekinge Institute of Technology during the day, using one of the school's computer to run the experiment. The room itself is remote with no distraction in terms of social interruptions.

The interior is very simple, providing as little external distractions as possible. This will be a suitable testing environment to make sure the participant can focus on the application and the boids behavior.

3.5 Processing Data

After the experiment the results will be saved in a text file, all the data will then be transferred by hand to an Excel document. Since this is done by hand there might be a risk of input mistakes. To reduce this risk it's planned that every time a new test result is transferred, the number of subjects that has been stored will be counted and compared to the total number of participants.

Chapter 4

Results

A total of 31 people participated in the study, most participants was males between the age 18 to 30. The data collected was then analyzed using the chi-square statistics analyzing method. In each diagram there is a included expected outcome which is based on the goodness of fit provided by the chi-square analysis. This chapter will cover a series of graphs that show what the participants voted on during the experiment. The graphs will present two values, a observed value and a expected value. The expected value is based of off the null hypothesis, so it represents a even distribution of votes. The observed value is the actual distribution of votes.

4.1 vAmount 5

fig: 4.1 shows the result of the preferred amount in vSeparation when vAmount was 5 and fig: 4.2 shows the result for vCohesion.

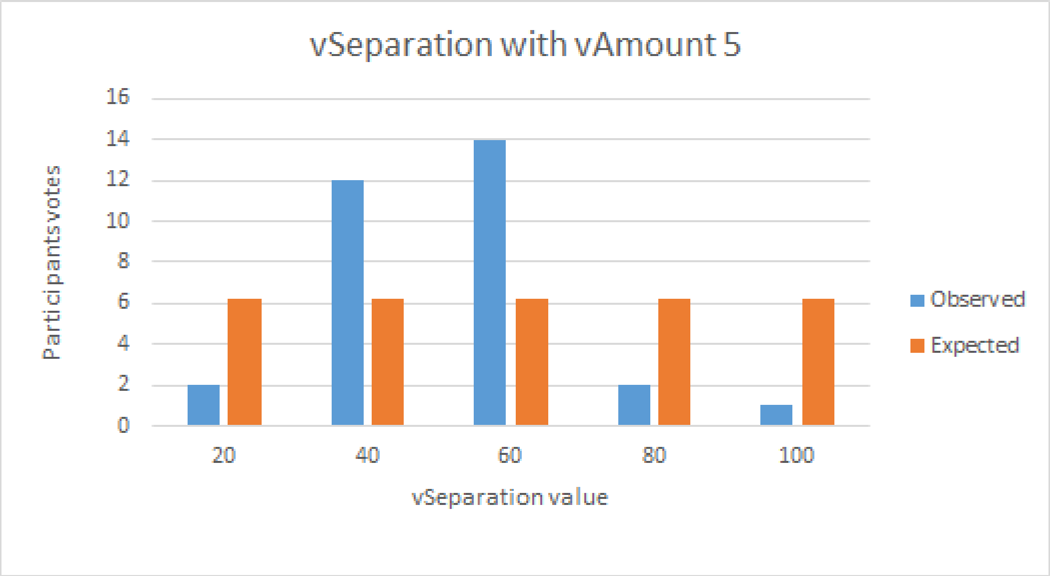


Figure 4.1: Participants preferred value in vSeparation, vAmount 5

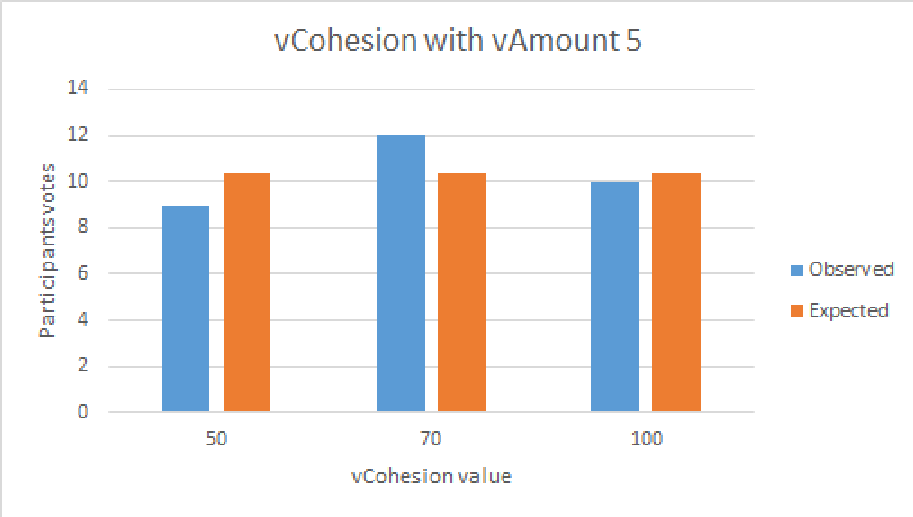


Figure 4.2: Participants preferred value in vCohesion, vAmount 5

4.2 vAmount 50

fig: 4.3 shows the result of the preferred amount in vSeparation when vAmount was 50 and fig: 4.4 shows the result for vCohesion.

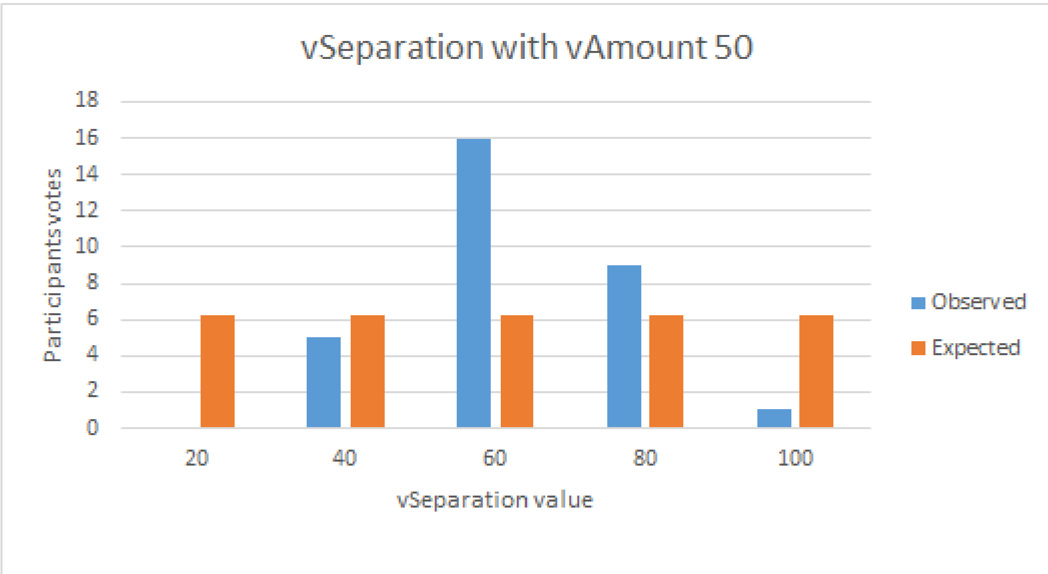


Figure 4.3: Participants preferred value in vSeparation, vAmount 50

Figure 4.4: Participants preferred value in vCohesion, vAmount 50

4.3 vAmount 100

fig: 4.5 shows the result of the preferred amount in vSeparation when vAmount was 100 and fig: 4.6 shows the result for vCohesion.

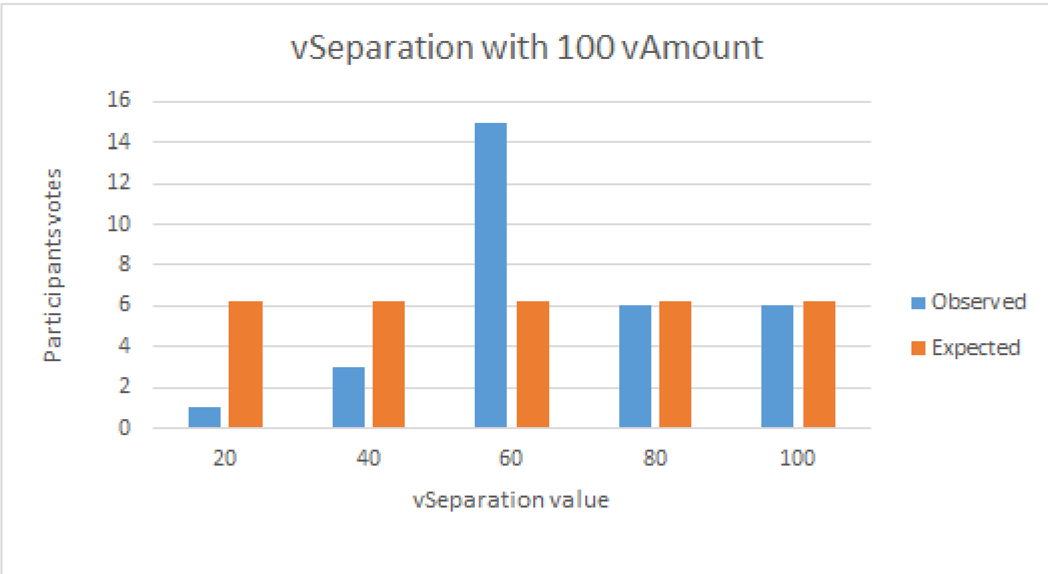


Figure 4.5: Participants preferred value in vSeparation, vAmount 100

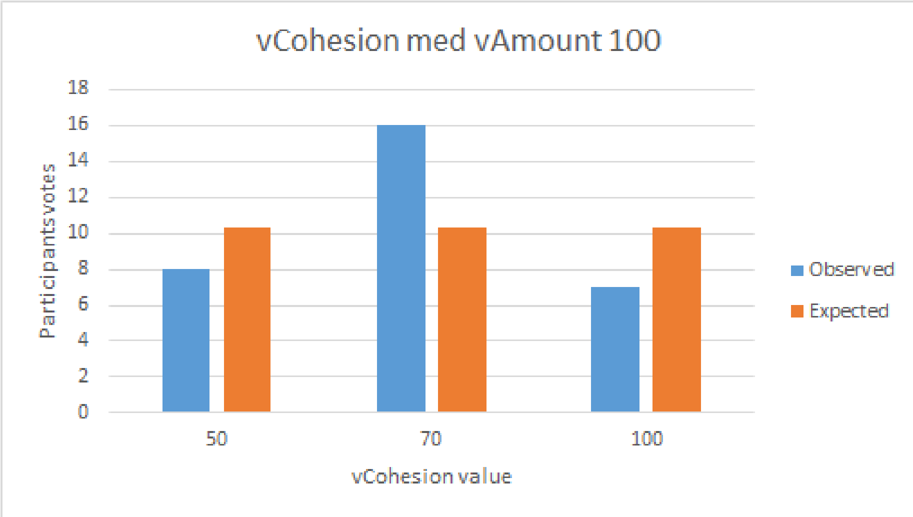


Figure 4.6: Participants preferred value in vCohesion, vAmount 100

4.4 Overall Results of the Study

fig: 4.7 shows the total preferred amount for vSeparation and fig: 4.8 shows the same total result for vCohesion.

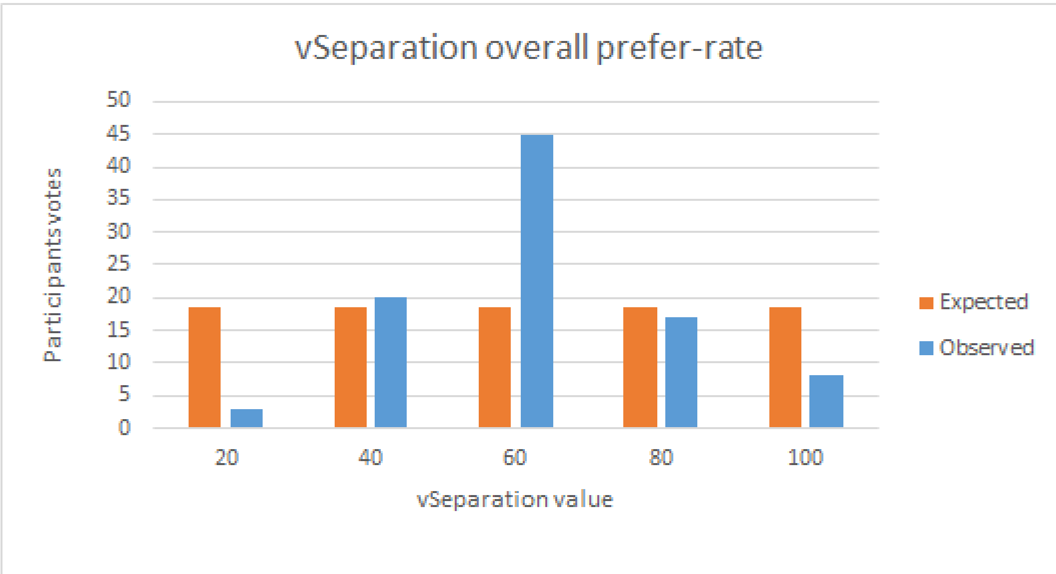


Figure 4.7: The overall best preferred value for vSeparation

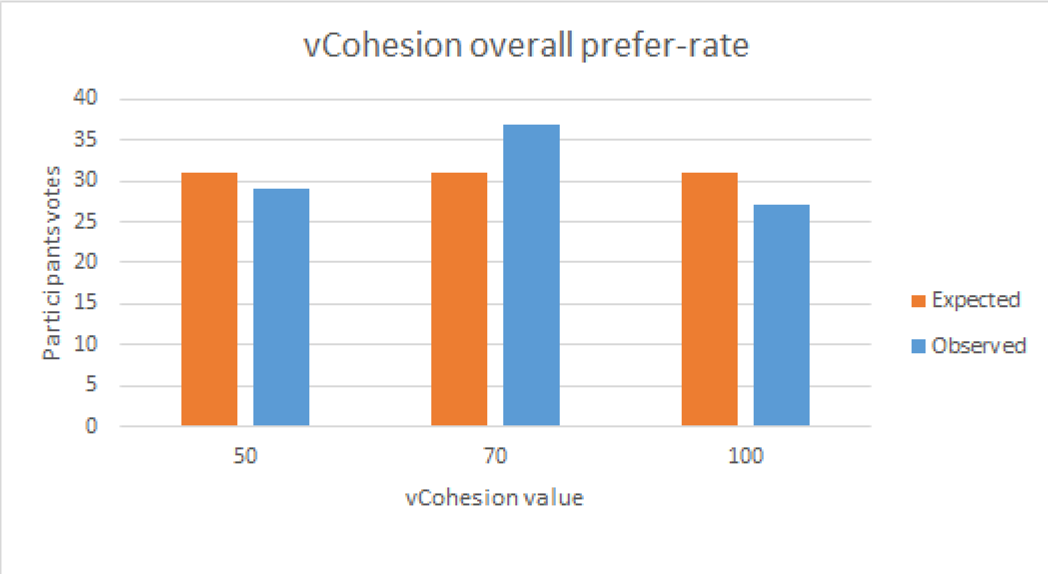


Figure 4.8: The overall best preferred value for vCohesion

Chapter 5

Analysis

5.1 vAmount 5

vSeparation was the constant that was expected to have the most impact on the visible algorithm and overall impact. When studying the chart in the fig: 4.1 it iss apparent that the preferred vSeparation value lies in the middle of the range that was previously defined, with a slight preference towards a lower value. As expected there was a little preference towards the two extreme values of the range and the p-value of the chi-test are according to Table: 7.1.

Looking at the results of the observation of the vCohesion variable fig: 4.2, no value has a major visual impact on the behavior of the boids as the result are very close the expected outcome, as seen in Table: 7.4 in appendix A.

5.2 vAmount 50

With the amount of boids changed, the result of vSeparation still correlates towards the same preference as before. The middle value is once again the most preferred but interestingly enough a shift of preference has occurred as it seems that the higher values had got an influx in preference, fig: 4.3. The p-value on the chi test was 0.0000154 which is lower than the significant value Table: 7.2 in appendix A.

Another observation being done on the cohesion value fig: 4.4, once again no value really deviates too much from the rest. Looking at the chi-square analysis of this value there was the p-value of 0.80, Table: 7.5 in appendix A.

5.3 vAmount 100

The last vSeparation comparison of 100 once again shows us that the preferred value is around 60, see fig 4.5. It can also be observed that the shift has once again started to lean even more towards the higher values, as even the extreme value of the range has started to get some preference. The observed p-value of

0.000978 for the vSeparation test was far lower than the significant value of 0.05 Table: 7.3 in appendix A.

Unlike the previous cohesion tests, a setting was found that was considerably higher than the alternatives. The results show that a pattern is taking form here, with a large amount preferring 70 as their preferred value in vCohesion fig: 4.6. Still, the p-value lands at 0.09 and according to the chi-square the p-value is larger than the significant value Table: 7.6 appendix A.

5.4 Overall Analysis of the Study

In this section, the results of the study and the hypothesis will be discussed. In all flock sizes the vSeperation p-value is far lower than the significant value, which means that there is some preferred value that the users perceive as more realistic than the other iterations, Table: 7.7 appendix A.

In regards of the vCohesion the p-value is far above the significant value which means that the preferred setting in this constant is random, which means that there is no value that the users find more realistic than the other, Table: 7.8 appendix A.

Since one of these constants, vSeparation, has values that the users find more realistic, the null hypothesis can be rejected. There are some values in the constants of the boid algorithm that are more preferred than others.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

Lets return the research question of this paper and discuss the outcome.

How does changing the rules of separation, cohesion and number of boids relate to what users perceive as realistic behavior for simulating schools of fish?

Regarding the separation and cohesion, it can be observed that the constant vSeparation has the most impact on flock behavior. According to the experiment, it was concluded that the most preferred value of vSeparation is around 60. When considering a small flock of boids, vSeparation should be around 50 to 60, since there is a considerable amount that preferred 40 when the flock was smaller in size. On larger flocks, the authors recommend using the value of 60 to 70 when taking the result of 100 fishes, since there was a considerable amount that preferred 80.

There seems to be little to no importance on what value the vCohesion are by looking at the result of the experiment. According to the chi-square, the preferred value is too random to have some preferred pattern here. The study shows us that it does not matter much of what you as a developer choose here.

6.2 Future Work

In this paper the vAlignment and vCohesion share the same value, it would be interesting to see if the outcome of the study would differ if vAlignment and vCohesion got separate variables.

A suggestion for further studies would be to do the experiment on a larger audience groups with different background and digital experience, would the results show the same or does the background in digital media have a greater impact on what humans perceive realistic.

There is a high probability that the outcome of this paper would be much different if it the simulation would be rendered in 3D. It would also be interesting to conduct a perception test using other platforms, such as Virtual Reality.

A issue of this paper was that there was no test to actually evaluate how realistic the boid algorithm was. During the testing phase participant would choose the boid algorithm settings that they perceived as realistic, that does not equate that the chosen setting was realistic, it only means that the chosen setting looked more realistic than the rest. For future work the authors suggest some way of evaluation to conclude if the actual chosen algorithm setting looks realisitc.

References

[1] "Boids (Flocks, Herds, and Schools: a Distributed BehavioralModel)", Red3d.com, 2017. [Online]. Available: http://www.red3d.com/cwr/boids/. [Accessed: 17-Jun- 2017].

[2] C. Reynolds, ”Big Fast Crowds on PS3”, in Proceedings of the 2006 ACM SIGGRAPH Symposium on Videogames, New York, NY, USA, 2006, s. 113–121.

[3] Y.-W. Chen, K. Kobayashi, H. Kawabayashi, och X. Huang, ”Application of Interactive Genetic Algorithms to Boid Model Based Artificial Fish Schools”, in Knowledge-Based Intelligent Information and Engineering Systems, 2008, s. 141–148.

[4] A. S Udd, “Flocking of birds: A comparison between two boid algorithms,” Ph.D, dissertation, dept NADA. Swe., KTH Royal Institute of Technology., Stockholm, 2010.

[5] C. O Erneholm, “Simulation of the Flocking Behavior of Birds With the Boids algorithm,” Ph.D. dissertation, dept NADA. Swe., KTH Royal Institute of Technology., Stockholm, 2011.

[6] S. Alaliyat, H. Yndestad, och F. Sanfilippo, ”Optimisation Of Boids Swarm Model Based On Genetic Algorithm And Particle Swarm Optimisation Algorithm (Comparative Study)”, ECMS 2014 Proceedings edited by: Flaminio Squazzoni, Fabio Baronio, Claudia Archetti, Marco Castellani.

[7] "Chi-Square Statistic: How to Calculate It / Distribution", Statistics How To, 2017. [Online]. Available: http://www.statisticshowto.com/probability-and-statistics/chi-square/. [Accessed: 29- May- 2017].

[8] Y. Chen, K. Kobayashi, X. Huang and Z. Nakao, "Genetic Algorithms for Optimization of Boids Model", Lecture Notes in Computer Science, pp. 55-62, 2006.

Chapter 7

Appendix A

	Observed	Expected			
				p-value	4.4E-05
20	2	6.2		significant value	0.05
40	12	6.2			
60	14	6.2			
80	2	6.2			
100	1	6.2			

Figure 7.1: vSeparation with vAmount 5

	Observed	Expected			
				p-value	1.54E-05
20	0	6.2		significant value	0.05
40	5	6.2			
60	16	6.2			
80	9	6.2			
100	1	6.2			

Figure 7.2: vSeparation with vAmount 50

	Observed	Expected			
				p-value	0.000978
20	1	6.2		significant value	0.05
40	3	6.2			
60	15	6.2			
80	6	6.2			
100	6	6.2			

Figure 7.3: vSeparation with vAmount 100

	Observed	Expected		p-value	0.797873
50	9	10.33333		significant val	0.05
70	12	10.33333			
100	10	10.33333			

Figure 7.4: vCohesion with vAmount 5

	Observed	Expected		p-value	0.797873
50	12	10.33333		significant val	0.05
70	9	10.33333			
100	10	10.33333			

Figure 7.5: vCohesion with vAmount 50

	Observed	Expected		p-value	0.094909
50	8	10.33333		significant val	0.05
70	16	10.33333			
100	7	10.33333			

Figure 7.6: vCohesion with vAmount 100

	Observed	Expected		p-value	1.33741E-11
20	3	18.6		significant val	0.05
40	20	18.6			
60	45	18.6			
80	17	18.6			
100	8	18.6			

Figure 7.7: Overall result for vSeparation

vCoh	Observed	Expected		p-value	0.40526
50	29	31		Significant val	0.05
70	37	31			
100	27	31			

Figure 7.8: Overall result for vCohesion