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Swarm Intelligence

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1 Introduction

A boid is a fictional entity created by Reynolds to simulate flocking behaviour in computers [1]. Reynolds modelled it by using three forces: cohesion, alignment, and separation. Cohesion makes the boids stick together, alignment aligns each boid's direction to the average direction of the group, and separation pushes the boids apart (such that they do not collide).

Baglietto et al. [2] have researched the relationship between the density of humans on a racetrack and the velocity of the humans. They did this on a circular racetrack. They found a negative relation between the speed (in m/s) and the density (in humans/m^2), which can be nicely shown in a fundamental diagram (FD) [3].

In this assignment, we will research whether boids behave as humans do on a similar circular racetrack. We will do so by conducting an ablation study on simulated boids on a similar racetrack to Baglietto et al. [2] and comparing the FDs.

We hypothesize that boids will not share a similar FD to humans on a circular racetrack, since humans on a racetrack do not experience each of the three forces that Reynolds [1] describes for the boids.

2 Methods

We built our code on the foundations of The Coding Train YouTube channel, more specifically a complex path following example using the p5.js library. Our code is available on Github [1].

We chose to model the same dimensions as Baglietto et al. [2] used in their circular racetrack, but for visibility, we scaled everything up such that one meter in the paper is 70 pixels in our simulation. A boid moving at 1 m/t is moving at 70 pixels per time step.

The boids move by reacting to forces that act upon their `steer` direction. In the current case, there are four forces: the path, separation, cohesion, and alignment (all coded in `vehicle.js`).

- To keep the boids on the racetrack and moving in the counter-clockwise direction, their steering direction is adjusted when their future position (i.e., 25 pixels ahead) falls outside the racetrack boundaries. This adjustment is done by calculating the steering angle, which is obtained by computing the difference between the desired angle and the velocity of the boid. This technique is described in the paper by Reynolds [1].
- The separation behaviour is achieved by adjusting the steering of a boid based on the number of its nearby neighbours. When there are several close neighbours, the steering direction of the boid is biased towards moving "away" from its neighbours. This is

[1] Code available at `https://github.com/freek1/naco-si`

achieved by increasing the magnitude of the steering direction vector pointing in the opposite direction of the neighbours.

- Cohesion is implemented very similarly to separation. Instead of steering away from nearby neighbours, the boid is directed towards the average position of its neighbours.
- Alignment is implemented as adjusting the steering angle towards the average heading of local neighbours.

The magnitude of these forces acting on the boids was adjusted by trial and error. The multipliers we use are: `3 path, 0.3 cohesion, 3 separation, 1 alignment`. Additionally, the radius of the default boids is set to `12`. The radius of the big boid is `24`.

The racetrack and the velocity and density calculations are coded in `sketch.js`. We added a 0.2 m slack vertically on each side (up and down) to the start and end markers of the measuring space (visible in figure 1). This is done because we did not implement a hard boundary of the racetrack (which improves the similarity to the experiment on humans [3]), but unfortunately allows for some boids occasionally moving around the start- or end lines of the measuring spaces. The additional band and outlier removal in post-processing make sure that this does not happen (in our tests).

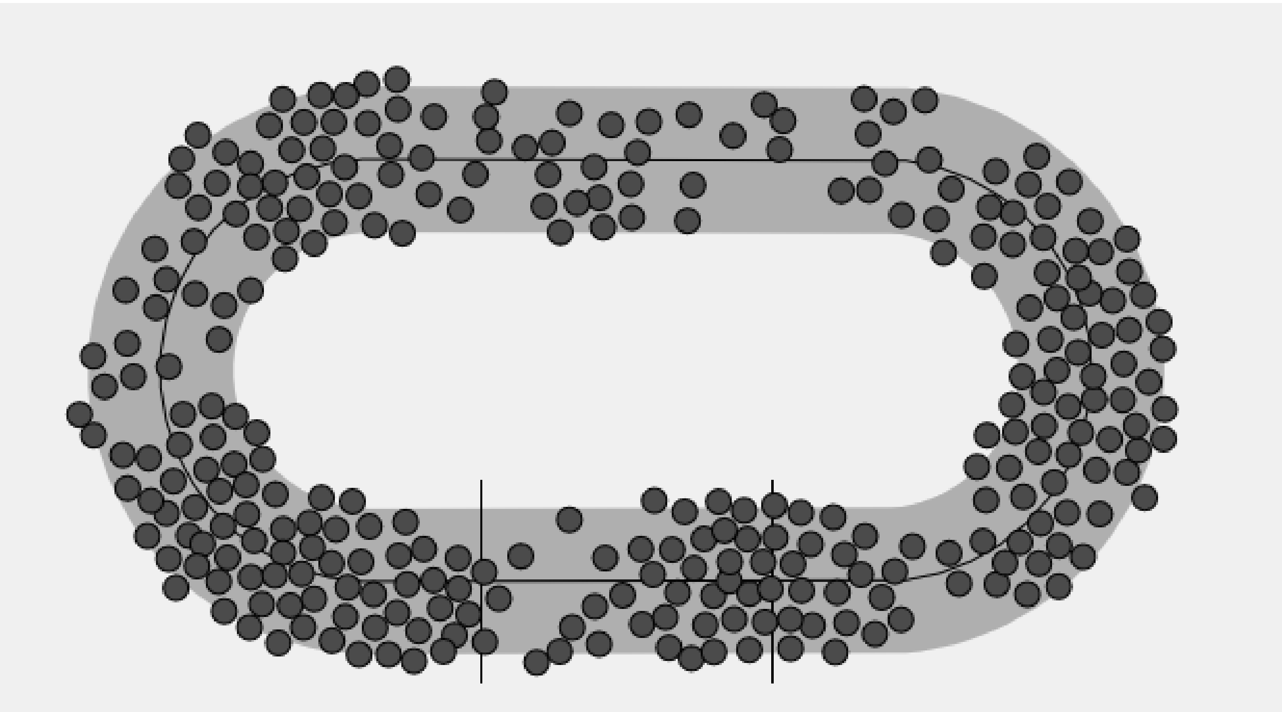

Figure 1: The racetrack on which the (300) boids move. Their speed and density are tracked between the bottom two lines.

For each measurement, i.e. a boid passing first the start and then the end lines of the measurement space, we save the average velocity and density of the boid in this segment. They are computed using the equations provided in the assignment. After 1000 measurements, we save the data.

2.1 Other parameters

Besides the ablation study, we are also interested in the effects that the size of the boids and the number of boids on the racetrack has on the FD. Therefore, we also did one simulation with a larger boid (radius of 24 instead of 12). Additionally, one run is done for 100 to 500 (with a step-size of 100) default sized boids.

2.2 Ablation study

We conduct an ablation study where we turn off each of the three fundamental forces of the boid algorithm individually and combined in groups of two, and finally all three, and look at how this affects the FD. We simulate 300 boids each run, and we save the results when we have 1000 measurements. To account for variability, we run each situation of the ablation study 5 times.

3 Results

Figure 2 presents the fundamental diagrams obtained for each situation in the ablation study. The figure's structure is outlined in Table 1. To improve the data's readability and reliability, we eliminated outliers located more than two standard deviations from the mean. Such outliers might have been caused by edge cases that almost exclusively could occur at the beginning of the simulation.

`baseline`	`-a`	`-ac`	`-as`	`-sca`
`baseline`	`-s`	`-sc`	`-as`	`-sca`
`baseline`	`-c`	`-ac`	`-sc`	`-sca`

Table 1: The structure of figure 2. Baseline means a run with all three forces acting on the boids. `-a` means the force alignment is inactive. Similarly, `-c` and `-s` mean that cohesion and separation respectively are inactive. Combinations of the letters indicate that those forces are inactive.

3.1 Ablation results

Figure 2 shows the fundamental diagrams obtained from our ablation study. Based on these figures and our observations during testing, the following conclusions can be drawn.

Firstly, the variability between runs is negligible, as the distributions largely overlap. Secondly, removing adherence decreases the speed compared to the baseline condition, but results in a more even spread of the boids on the racetrack. Removing separation leads to the formation of high-density clumps of boids, which are not eliminated and therefore allows for a larger range of density values. Removing coherence seems to have little impact on either the speed or densities of the boids.

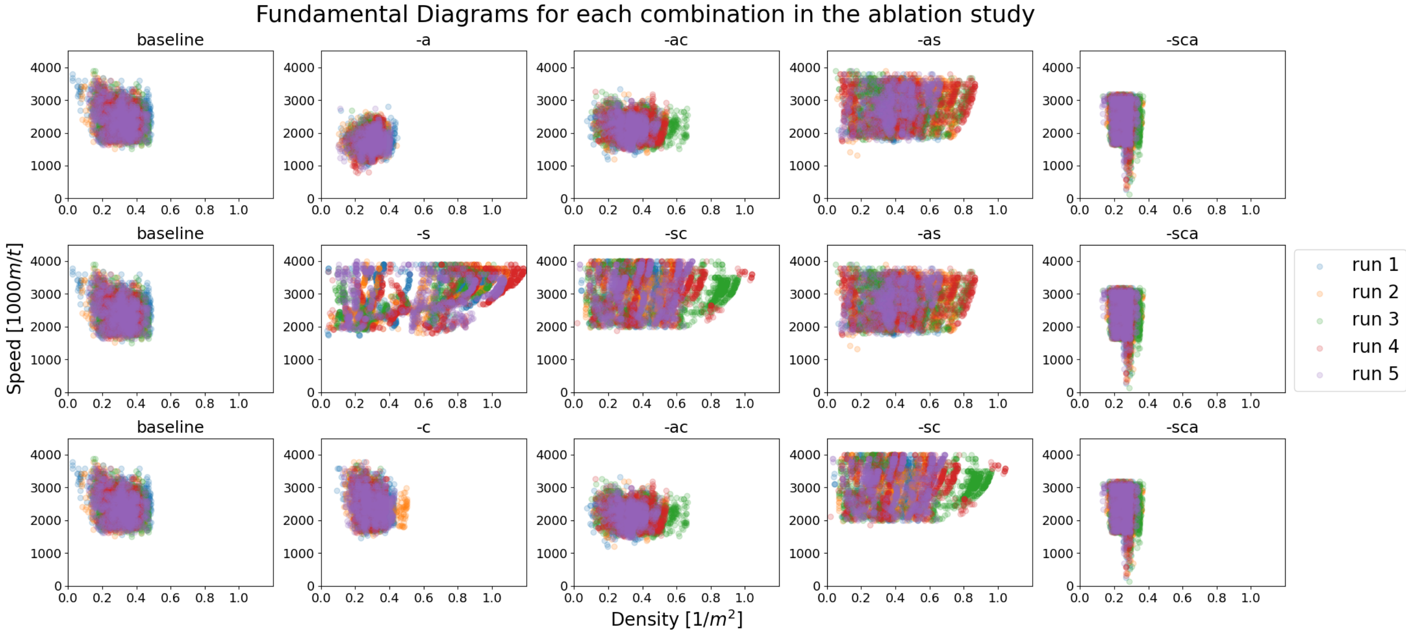

Figure 2: Ablation study results for all 5 runs we did to account for variability. The unit of speed is 1000m per time step. It shows little variability between runs. Run with 300 default sized boids. Explanations for the structure of the subplots are in table 1.

Removing both coherence and alignment results in a larger range of density values compared to the baseline. Removing both coherence and separation generates some weak clusters, indicated by the higher values and clustering on the density axis compared to the baseline where the points are spread out quite evenly. Removing both separation and alignment also leads to cluster formation, although these clusters are not very stable. This means that there is a large variety of speeds within a cluster, as they tear themselves apart from time to time. This instability is captured in Figure 2, as without this instability there would be two main vertical lines, but now these vertical lines are quite warped.

In the situation where all additional forces are removed, we can see the effect that the implementation of standard steering and velocity has on the boids in isolation. It is clear that the spatial spreading is very even compared to the other simulations, as indicated by the narrow range of density measurements. The velocities show the same spreading as in the other simulations where alignment is removed, which indicates that the alignment force provides an additional boost to the boid velocities.

3.2 Other parameters

Since we did not find the expected negative correlation in the FDs, we experimented with the number of boids and the boid size. The results of these experiments can be seen in Figure 3 and Figure 4, respectively.

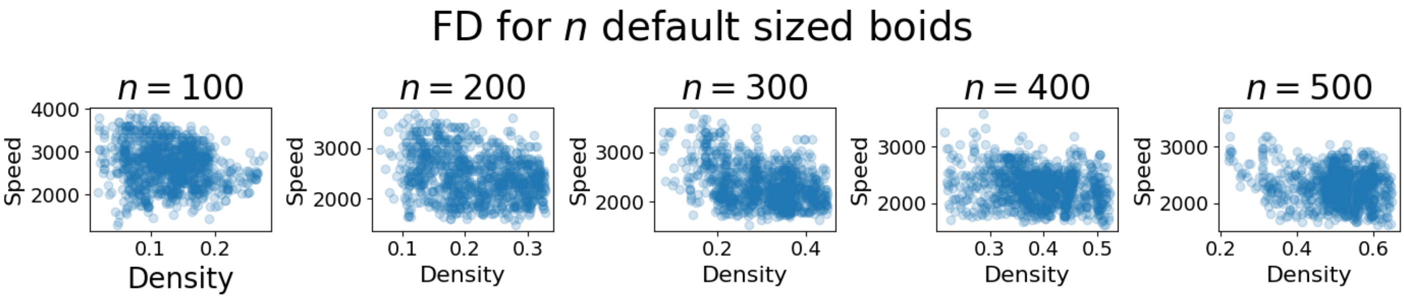

Figure 3: FDs for n boids, from 100 to 500 default size boids, run with all forces enabled, i.e. baseline. Speed is in 1000m per time step and density is in $1/\mathrm{m}^2$.

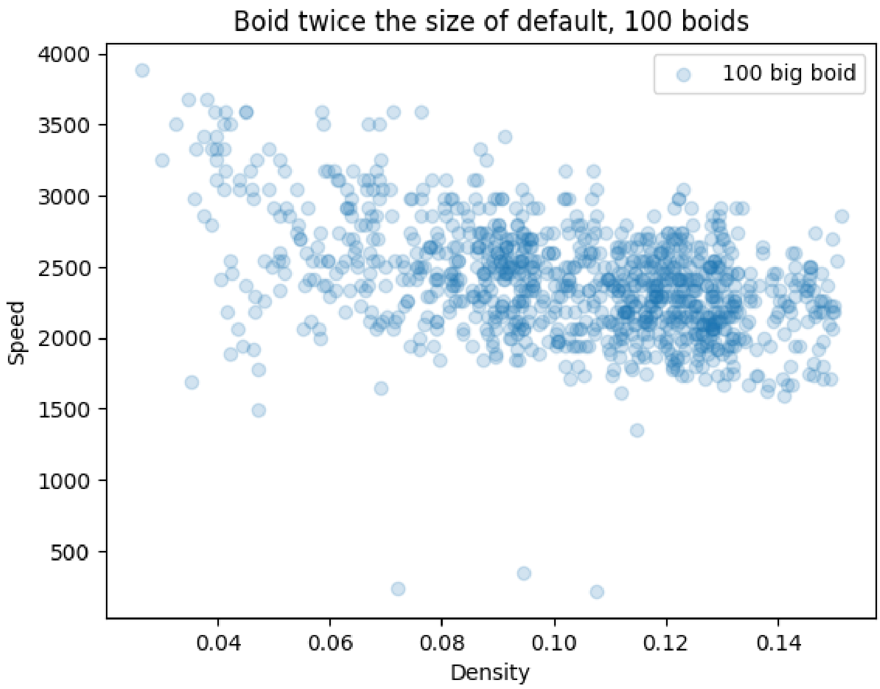

Figure 4: FD for 100 boids with a radius twice the size of the default boid.

The experiments with 500 default boids and 100 big boids show a clearer relation between density and velocity compared to the other experiments.

4 Discussion

Based on the results shown in Figure 2, it can be concluded that the movement of 300 default-sized boids does not exhibit a negative correlation between density and speed, which is a characteristic observed in human studies. This observation is independent of the type of force used. However, when 500 default-sized boids (Figure 3) or 100 large-sized boids (Figure 4) are used, a negative correlation between density and speed can be observed. This finding suggests that the size and number of boids play a crucial role in the emergence of the negative correlation between density and speed.

The high-density areas of 300 regular-sized boids did not appear to be affected much by the limited space, as they had ample room to spread out. However, in high-density areas with a larger number of regular-sized boids or larger boids but fewer boids, the boids were observed to slow down. This is evident in Figure 3, which depicts the FDs of the baseline boids for an increasing number of boids, showing that the correlation between speed and density becomes apparent at $n = 500$.

It is important to note that removing the separation force leads to boids stacking on top of each other, as this force is the only factor preventing this behavior. While we did not prevent this from happening regardless of preferred boid behavior, it makes the measurements where the separation force is turned off unsuitable for the comparison between boids and humans on a racetrack. Based on feedback, we have increased the separation force significantly to reduce the likelihood of boid overlap. However, it is still possible for the boids to overlap when other forces, especially the path force, are stronger than the separating force. However, decreasing the path force would cause the boids to go off the track too often, so we decided against doing so.

References

[1] Craig W Reynolds. "Flocks, herds and schools: A distributed behavioral model". In: *Proceedings of the 14th annual conference on Computer graphics and interactive techniques.* 1987, pp. 25–34.

[2] Gabriel Baglietto and Daniel R Parisi. "Continuous-space automaton model for pedestrian dynamics". In: *Physical Review E* 83.5 (2011), p. 056117.

[3] Armin Seyfried et al. "The fundamental diagram of pedestrian movement revisited". In: *Journal of Statistical Mechanics: Theory and Experiment* 2005.10 (2005), P10002.