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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).

Seyfried et al. [2] have revisited the fundamental diagram (FD), which is a diagram that describes the relationship between the velocity and density of individual humans.

Baglietto et al. [3] 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 an FD.

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. [3] 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.

We chose to model the same dimensions as Baglietto et al. [3] used in their circular racetrack, but for visibility, we scaled everything up such that one meter in the paper is $m = 70$ pixels in the code. This means that the measurements are scaled, e.g. a boid moving at 70 m/s means that it is moving at 70 pixels per second.

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

- The way the boids are kept on the racetrack (and in the counter-clockwise direction) is done by adjusting the steering direction when the future position of the boid (in this case, 25 pixels ahead) is outside the racetrack boundaries. The steering angle is computed by computing the difference between the desired angle and the velocity (as described in the paper by Reynolds [1]).
- Separation is implemented by adjusting the steering relative to the number of close neighbours a boid has. The direction vector is greater in the 'away' direction when more neighbours are close.

- Cohesion is implemented very similarly, but the steering is directed towards the average position of the neighbours.

- Alignment is implemented as adjusting the steering angle towards the average heading of the local neighbours.

The magnitude of these forces acting on the boids was adjusted by trial and error. The multipliers we use are: `3 path, 0.1 cohesion, 1 separation, 1 alignment`.

The way we generate the racetrack, and process velocity and density, are coded in `sketch.js`. We added a 0.2m 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 do not hard-code the boundaries 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. Using the 0.4m extra makes sure that this does not happen (in our tests).

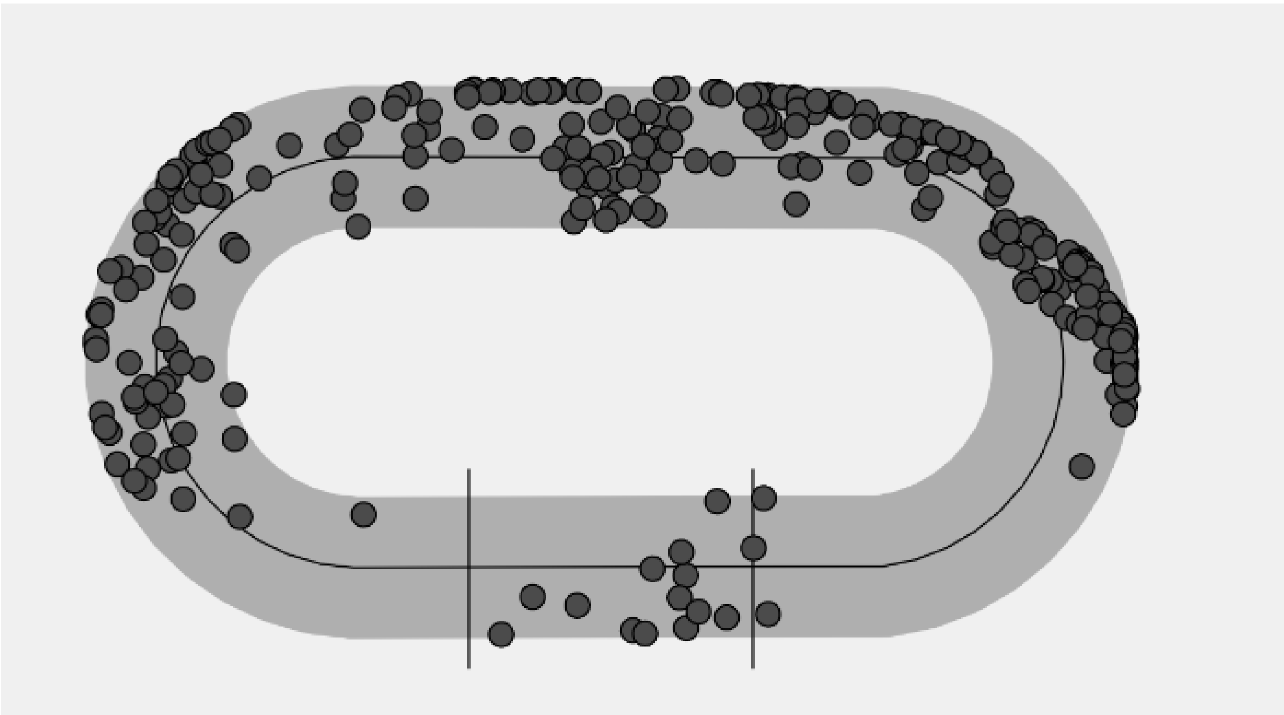

Figure 1: The racetrack on which the boids move. Their speed and density are tracked between the bottom two lines.

The start and end times are clocked using the p5.js timesteps since the p5.js `millis()` function is inaccurate and differs per frame. This means that our speed is measured in m/timesteps. We report it in 1000 m/t, i.e. 1000 meters per timestep.

For each measurement, i.e. a boid passing both the start and end lines of the measurement in that order, we save the velocity and density of that measurement. They are computed using the equations provided in the assignment. After 1000 measurements, we save the data.

2.1 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.

3 Results

The structure of the subplots in figure 2 is shown in table 1. For post-processing, we have removed outliers. We identified outliers as being more than 2 standard deviations away from the mean. These outliers could have been generated by edge cases regarding the start of the simulation.

`baseline`	`-a`	`-ca`	`-sa`	`-sca`
`baseline`	`-s`	`-sc`	`-sa`	`-sca`
`baseline`	`-c`	`-ca`	`-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 are inactive. Combinations of the letters indicate that those forces are inactive.

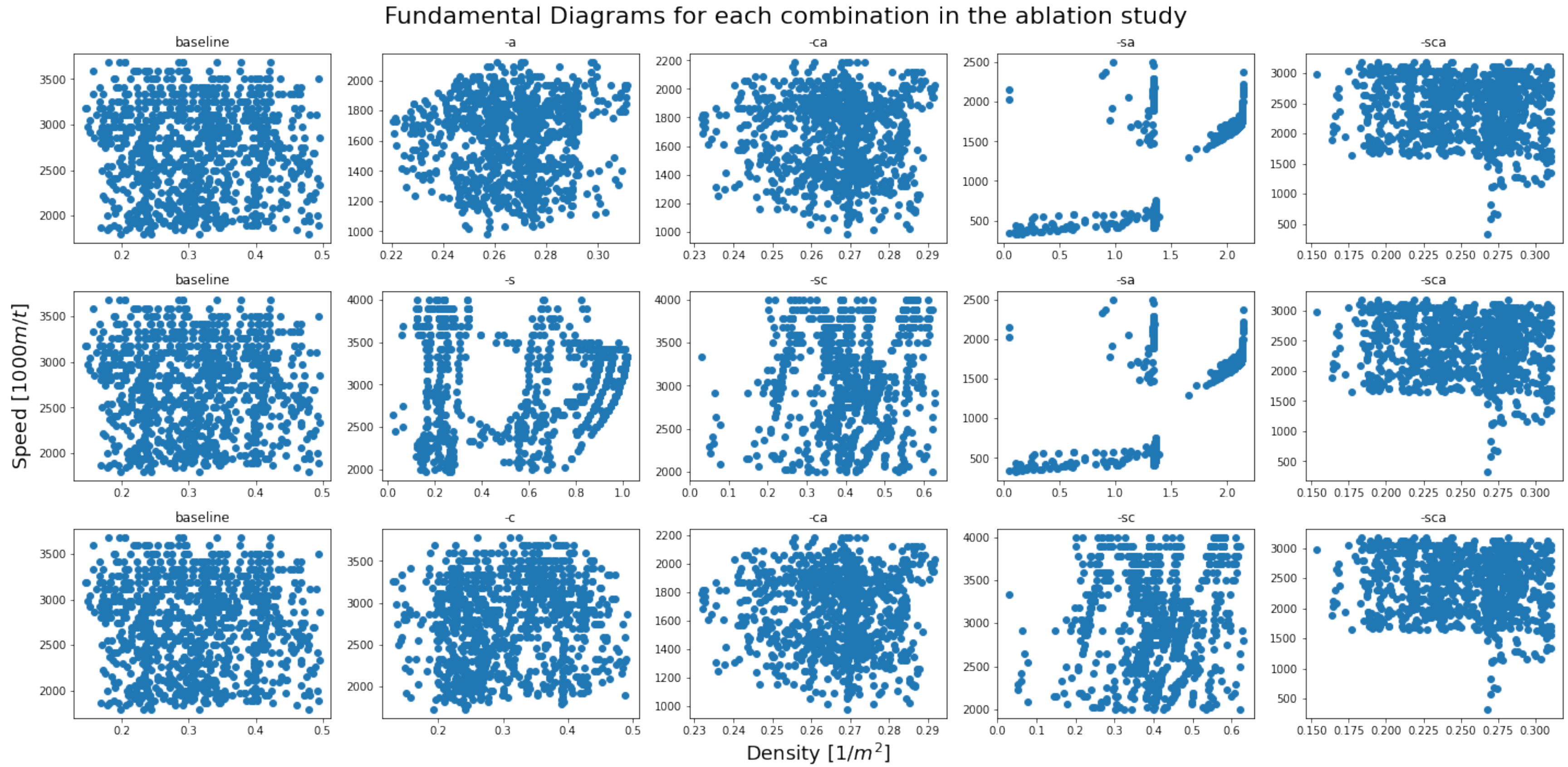

Figure 2: Fundamental Diagrams for each combination in the ablation study. On the y-axis is the speed in 1000 meters per timestep. On the x-axis is the density in $1/\mathrm{m}^2$ The titles `-a, -ca, -sa, -sca` indicate that the boids were simulated without alignment, cohesion and alignment, separation and alignment, separation, cohesion and alignment, respectively. The subplots are structured such that in each row, a different force is removed, and in each column an extra force is removed. Further explanations in table 1.

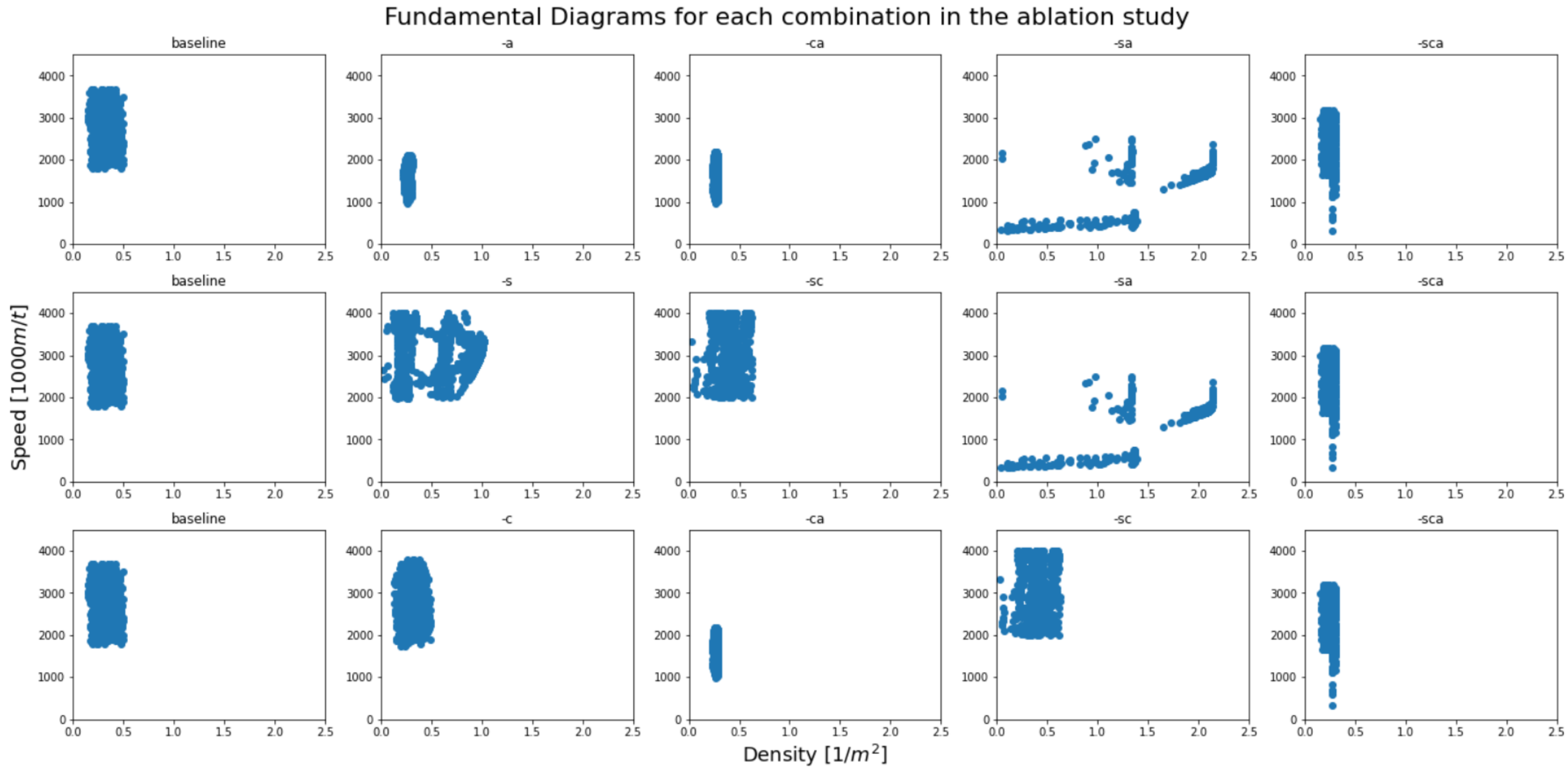

Figure 3: Fundamental Diagrams for each combination in the ablation study. On the y-axis is the speed in 1000 meters per timestep. On the x-axis is the density in $1/m^2$ The titles `-a`, `-ca`, `-sa`, `-sca` indicate that the boids were simulated without alignment, cohesion and alignment, separation and alignment, separation, cohesion and alignment, respectively. The subplots are structured such that in each row, a different force is removed, and in each column an extra force is removed. Further explanations in table 1.

3.1 Ablation results

The FDs of our ablation study are shown in figures 2 and 3. Based on these figures and the observations made during testing, the following can be concluded. The baseline condition leads to a well-spread-out group, with a high speed. Removing adherence decreases the speed compared to the baseline condition and an even better spreading out. Removing separation seems to lead to a situation in which there is no transfer of high-energy (faster) boids to low-energy (slower) boids. This makes the density more spread out and the fastest boids faster compared to the baseline. Removing coherence does seem to impact neither the speed nor the spreading of the boids.

Removing both coherence and alignment does not seem to change the results much compared to just removing alignment, with the range of speeds being very similar and the density only shrinking very slightly. Removing both coherence and separation seems to generate 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 leads to cluster forming, although these clusters are not very stable. This means that there is a large variety of speeds within a cluster, and they tear themselves apart from time to time, only to reform a few rounds later. This instability is captured in 3, as without this instability there would be two main vertical lines, but now these vertical lines are quite warped. Removing all three forces, we can see the effect that the implementation of standard steering and velocity has on the boids. It is clear that there are quite large differences in speed and the spread is quite good.

4 Discussion

Based on the result above, we can conclude that the movement of our boids is not similar to humans, regardless of which forces are used. None display the characteristic negative correlation between density and speed that is present in the study on humans.

5 Future work (before Tuesday)

To keep statistical variability into account, we could do multiple runs and comment on the variability we find between runs.

We also intend to simulate these runs with different amounts of boids. Additionally, we also want to do runs with different size boids. Lastly, we might (depending on the time) give the optional exercise, in which we are asked to implement “vision”, a shot.