Optimal boid flocking with a genetic algorithm

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Abstract

A genetic evolution-based approach is used to determine the coefficients of a boids model for optimal flocking. The model is inspired by the original Reynolds model, and adds predators. The results show that ...

1. Introduction

What are boids?

Applications of boids framework: - Helped understand animal flocking (e.g. how do birds determine where to fly when) - CGI (movies, games) - Collective motion of drone/vehicle swarms. Very feasible, because each agent measures and reacts to surroundings on its own, without the need of a central controller that controls all boids. In simulations, this allows parallelization.

2. Background

Reynolds (Reynolds, 1987).

Optimization of boids (Alaliyat et al., 2014).

3. Approach

3.1. Boids system

Prey boids have the three original steering forces; cohesion, separation and alignment (Reynolds, 1987). These are depicted in Figure 1.

The cohesion force F_c on boid b_j is given by

$$F_c = c_c \frac{1}{n-1} \sum_{i \neq j}^{n} x_i - x_j \tag{1}$$

where c_c is a corresponding coefficient on the force, and x_i is the position of b_i. It draws boids closer to the general position of neighboring boids.

Similarly, the separation force is given by

$$F_s = c_s \frac{1}{n-1} \sum_{i \neq j}^{n} \frac{x_i - x_j}{\|x_i - x_j\|_2} \tag{2}$$

This force only considers boids that are very close, and ensures boids do not fly too close to each other. In some sense this simulates that the boids have some size and avoid crashing.

Finally, the alignment force is

$$F_a = c_a \frac{1}{n-1} \sum_{i \neq j}^{n} v_i - v_j \tag{3}$$

where v_i is the velocity vector of b_i. Boids steer towards the average heading of neighboring boids.

The forces are combined to produce a total force, which is clipped, simulating how animals only can turn at certain rates. The total force is therefore given by

$$F = \max(F_c + F_s + F_a, F_{\text{max}})$$

The boid masses are normalized, so the force is the acceleration. We also have a time step $\Delta t = 1$. Therefore, the velocity and position updates are

$$v^{(k+1)} = v^{(k)} + F$$
$$x^{(k+1)} = x^{(k)} + \frac{v^{(k+1)}}{\left\|v^{(k+1)}\right\|_2}$$

Note that the velocity is normalized. This paper assumes that all boids fly at their max speed v_{max} at all times.

3.2. Genetic algorithm

Genetic algorithm approaches commonly have three components; selection, crossover and mutation (Kochenderfer & Wheeler, 2019). The fashion in which these are performed commonly differs based on the particular application and the way the chromosomes are encoded.

3.3. Computational considerations

For performance reasons, the implementation of the boids framework and genetic algorithm was done in C++.

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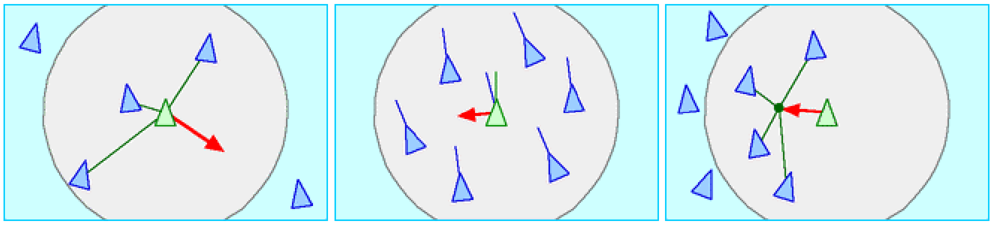

Figure 1. Steering forces on prey boids. From the left: Separation, alignment and cohesion (Reynolds, 1987).

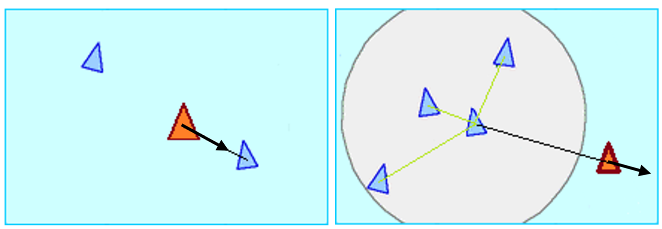

Figure 2. Hunt and flee steering forces on predator boids. Modified versions of images from (Reynolds, 1987).

Table 1. Parameters used for the genetic algorithm and boids simulation

Name	*Symbol*	*Value*
Separation range		
Prey force ranges		
Kill range		
Hunting coefficient	c_h	
Flee coefficient	c_f	
Predator v_{max}		1.1
Prey v_{max}		1.0

With a naive implementation the computation of the steering forces is $\mathcal{O}(n^2)$. For each boid, the positions of all other boids are required. This is clearly not feasible for simulations with many boids and many generations of evolution.

To reduce the computational load, each boid locally keeps track of it's nearest neighbors and only use these to compute steering. This is updated with some frequency.

4. Results

5. Conclusion

6. Future directions

More realistic physics simulation -¿ interesting applications. E.g. drone swarms. Applications in e.g. defense systems.

Also optimize predator behaviour (this could in turn further optimize prey behaviour. Turns into a min-max problem.)

Add obstacles and potentially add some goal area to get to.

References

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Kochenderfer, M. J. and Wheeler, T. A. *Algorithms for Optimization*. The MIT Press, 2019. ISBN 0262039427.

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