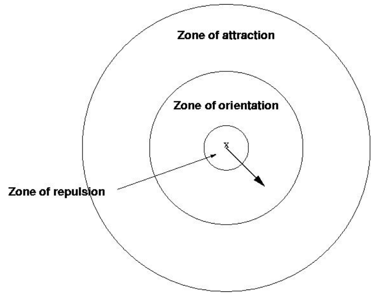
Artificial swarms: Biologically inspired organization



Background and motivation

Many species of animals self-organize into coherent groups called swarms, flocks, schools, etc. These coherent groups enhance to the fitness of the individuals within it in a variety of ways including moving toward desirable goals or avoiding threats. Remarkably, the group forms without any sort of central control. Local interactions with a simple set of rules can lead to remarkably complex behavior.

Typical approaches to controlling artificial systems typically relies upon a *top-down* control theoretic approach where one describes desired qualities and finds solutions that optimize these qualities. Unfortunately, these approaches seldom scale well, so that controlling large numbers of artificial objects can be rather challenging.

The alternative is to seek biologically inspired solutions. Even simple animals can form societies that yield a collective organism. Ants are a good example though there are many successful social insects. Individual ants are inept by almost any measure but through local interactions can solve a variety of difficult problems including finding the shortest path from their nest to the cookie crumbs on your kitchen counter without any sort of central leadership. However, the connection between the local interactions and the globally complex behavior can be elusive.

Central issues

1. Given a system of simple local rules, can one predict all possible coherent configurations? For instance, can you predict the phase diagram in [7]?

2. Given a desired configuration, can one generate a system of local rules to produce the configuration?

3. How can one insert effective leadership in a swarm? In other words, if one individual is driven in a particular direction, will the others follow?

Experiments

All of the experiments in this project will be computational using Matlab. I will furnish a simulator that will permit you to simulate your ideas. Each artificial organism is a function definition that maps the locations of the animals in the swarm to vector of derivatives.

Challenges

- Milestone #1: Find the most relevant and informative reference for your project and defend your determination.
- Milestone #2: Design a simple system of artificial animals that organizes itself into a circle.
- Milestone #3: Design a simple system of artificial animals that organizes itself into a swarm with a minimum number of leaders that move to a location I specify. All animals must be the same except for those (the leaders) which some knowledge of the location I specify. All animals must appear identically to one another. In other words, your algorithm cannot use information such as "Animal #1 is the leader. Follow it." The only dynamic behavior inputs permitted are the relative positions of the other animals.
- Milestone #4: Design a simple system of artificial animals that organizes itself into a swarm with a minimum number of leaders that move to a location I specify while avoiding a predator. All animals must appear identically to one another. The only dynamic behavior inputs permitted are the relative positions of the other animals, and the possible the position of the predator.
- Milestone #5: I will give you a function describing a scalar field $-1 \leq f(x, y, z) \leq 1$. You design an algorithm for identifying the $f(x, y, z) = 0$ contour. The isosurface will be continuous and compactly supported. All animals must appear identically to one another. The only dynamic behavior inputs permitted are the relative positions of the other animals. You can assume that your artificial animals can read the gradient of $f(x, y, z)$.

Literature

There is a wide range of literature on self-organization and patterns in biological systems. Often ideas in one discipline do not move easily into another. For instance, ideas can be drawn from the control-theoretic community in the engineering disciplines, nematic phase theorists in physics or from ecologists in biology. A very readable review appeared recently which highlights many of the relevent biological and therefore technological challenges and questions [11].

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