

Swarm Dynamics and the Evolution of Antipredator Tactics

Independent Study in Mathematics

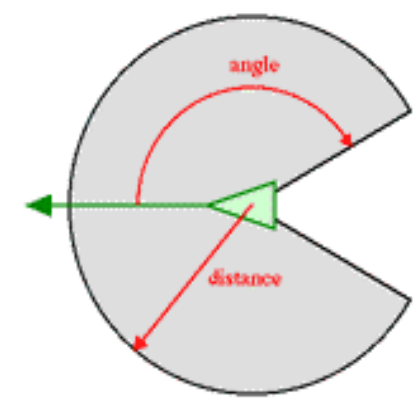
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Introduction

•My work makes use of the **Boids** concept devised by Craig Reynolds in 1986. Boids is an artificial life algorithm that simulates the **flocking** or **swarming** behavior of certain species.

•In Boids, each individual “boid” is modeled as an independent agent responding only to the boids within their immediate “neighborhood”.

•The boids each separately obey **3 simple rules**:



•**Separation**: Steer away from boids that are too near.

•**Cohesion**: Steer towards the average center of mass of the boids within your neighborhood.

•**Alignment**: Steer in the average direction of the boids in your neighborhood.

•Reynolds demonstrated that a population of boids that follow these rules display behavior analogous to a flock of birds or school of fish. In essence, swarm behavior is an “**emergent property**” of this simple system.

•One explication of swarming as found in nature is that it offers an evolutionary advantage as an **antipredator tactic**.

•For my independent study in mathematics, I applied Reynolds’ Boids algorithm to a two dimensional simulation of predator-prey dynamics in an effort to numerically investigate the validity of the previous claim.

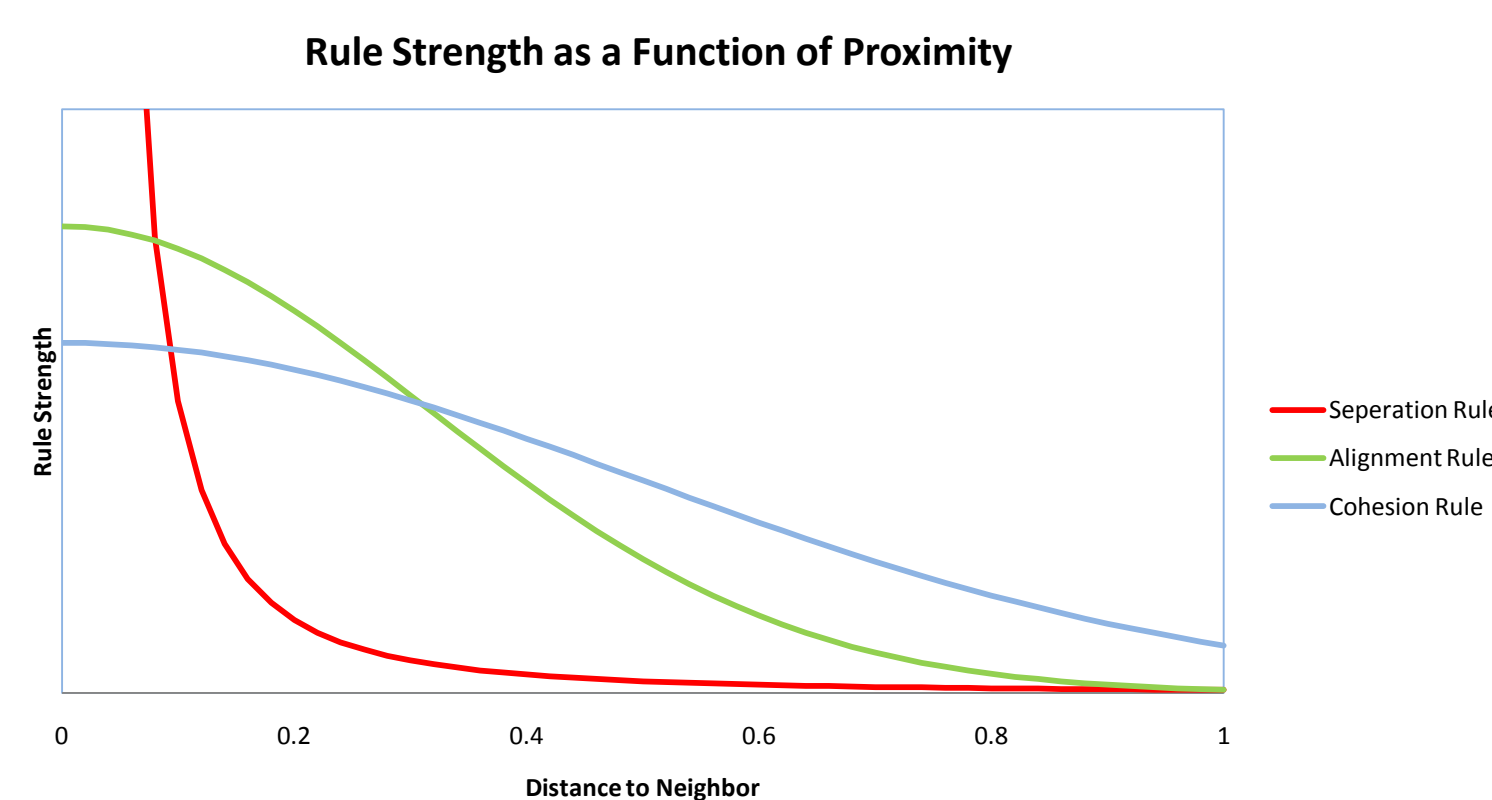
•In addition, I implement a **genetic algorithm** in order to model the long-scale evolution of flocking tactics in response to the pressure of predatory forces.

Principles of Motion

•In my program, each boid is represented by a black oval characterized by a **location, orientation** and **angular velocity**.

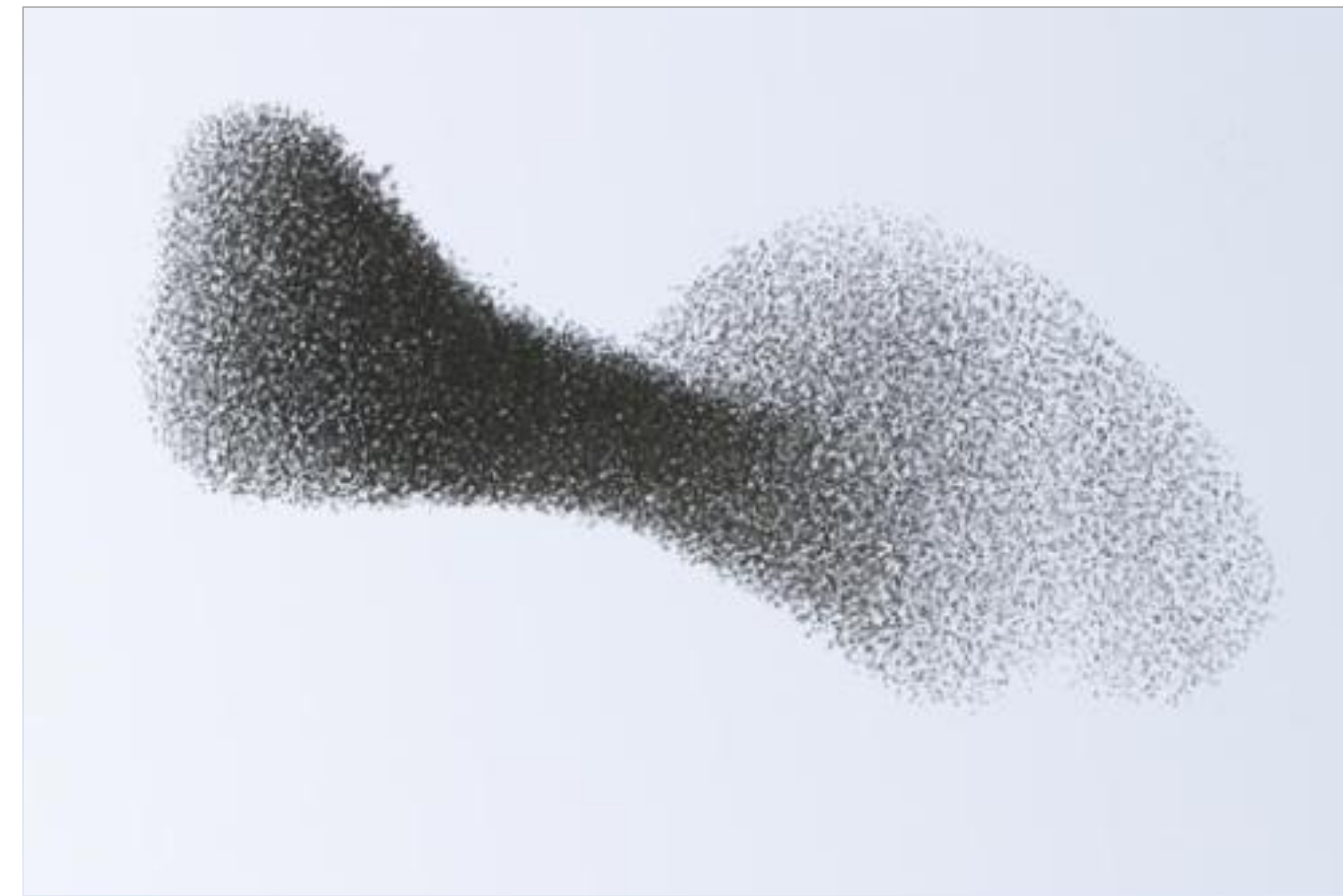
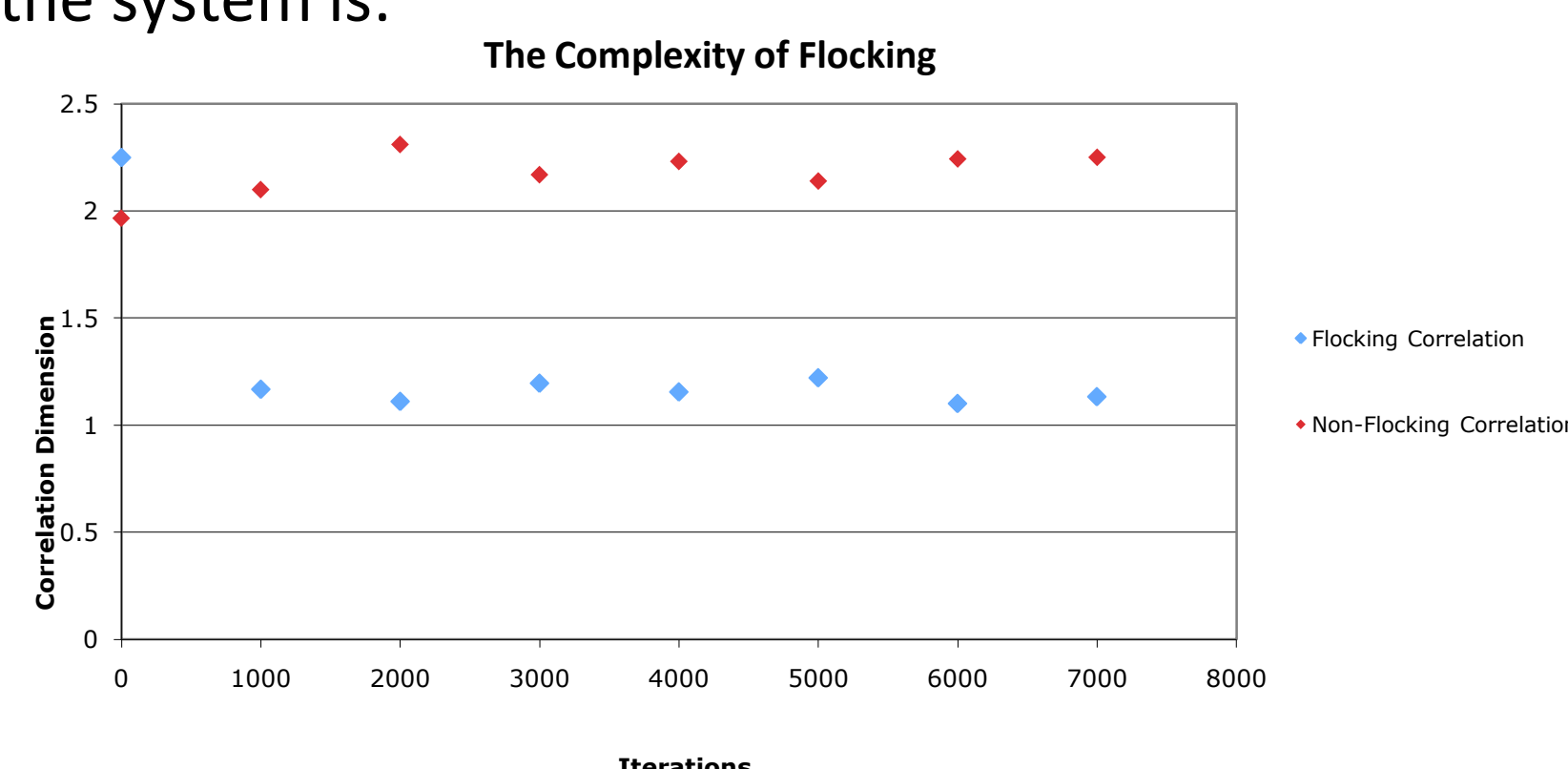
•Every iteration, each boid’s location is updated using Euler’s method in accordance with its orientation and a constant, common speed. The boid’s orientation is also updated using Euler’s method with respect to its angular velocity and a constant, common angular speed.

•The angular velocity is determined by taking a **weighted average** of the three rules for each neighbor. The weighting is determined by the distance between the boid and the neighbor in question. The following is a graph of the relative weightings as a function of distance for the three rules:



The Order of Complexity

•The emergence of apparent complexity from a simple system can be analyzed through an application of **the correlation function** which yields the **correlation dimension** of the system. The correlation dimension quantifies the order or the degree of patterns in the system. The lower the correlation dimension, the more patterned the system is:



Predator-Prey Rules

•With respect to their own type, the prey in my predator-prey simulation obey the rules of separation, alignment and cohesion.

•Predators do not align or cohere with each other but they do separate. The predators have the same line of sight restrictions as the prey, however they move somewhat more quickly.

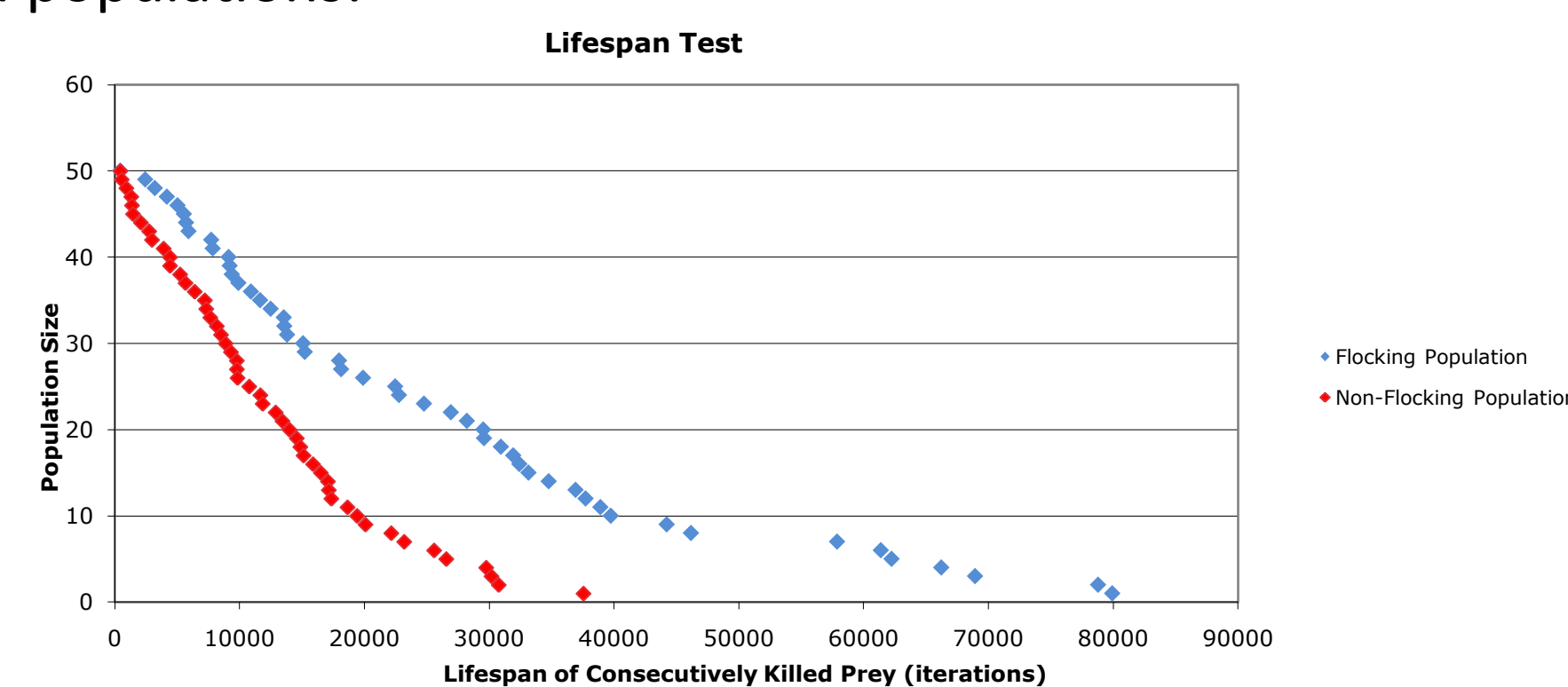
•Prey flee any predators in their line of sight and predators pursue any prey in their line of sight. The pursue and flee rules obey the same weighting principles with respect to proximity as the coherence or alignment rules.

•When a predator has pursued a prey to within a minimal “kill” distance, the prey is removed from the simulation and the predator takes a short break before pursuing further prey.

Swarming vs. Non-Swarming Populations

•In order to quantify the potential evolutionary advantage offered by flocking behavior I have run predator-prey simulations that compares flocking populations to non-flocking populations.

•Non-flocking populations do not obey the rules of coherence or alignment.
•The following displays the **lifespan** (in iterations) of successively “killed” prey for two such populations:



•As is seen above, the flocking population outlasted the non-flocking population by a factor of about 2. There are also considerable gaps in time where the predators simply could not find any flocking prey.

•I ran the above simulation 50 times and found that, for flocking populations, the average lifespan was about 40,000 iterations with a standard deviation of 6000 iterations.

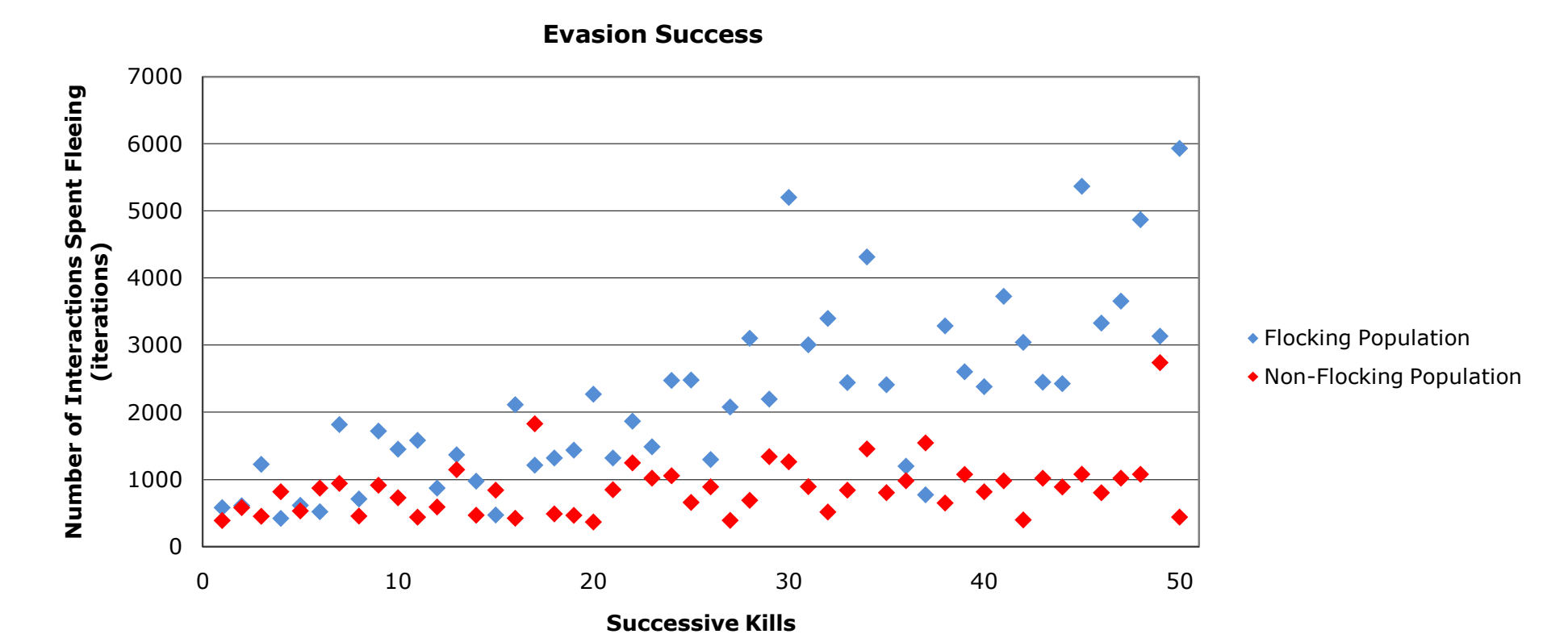
•Non-flocking populations had an average lifespan of 21,000 iterations and a standard deviation of 1000 iterations.

•Another yardstick by which to measure the advantage offered by flocking as an antipredator tactic is what I have coined “**evasion success**.”

•**Evasion success** seeks to remove the advantages offered by the “**dilution effect**” and thus to quantify the how successful the prey are at escaping a predator once in pursuit. Evasion success thus measures the number of

iterations a prey spent “fleeing” before it is finally killed.

•The following presents the evasion success of successively killed prey in both flocking and non-flocking populations:



•As is apparent above, the evasion success of prey that obeyed flocking rules is remarkably increased over those that simply avoid collisions. The evasion success also increases for successively killed prey as the prey that survive the longest have had more interactions with predators on average.

•Similarly to the Lifespan tests, I repeated the above simulation 50 times for flocking and non-flocking populations.

•I found that the average evasion success for flocking populations was 2000 iterations with a standard deviation of 230 iterations.

•The average evasion success for non-flocking populations was 770 iterations with a standard deviation of 80 iterations.

The Evolution of Antipredator Tactics

•Given that an entire population that flocks is more successful than one that does not, the next step is to show how a population might arise wherein all members obey the flocking rules.

•I thus implemented a genetic algorithm into my predator-prey simulation.

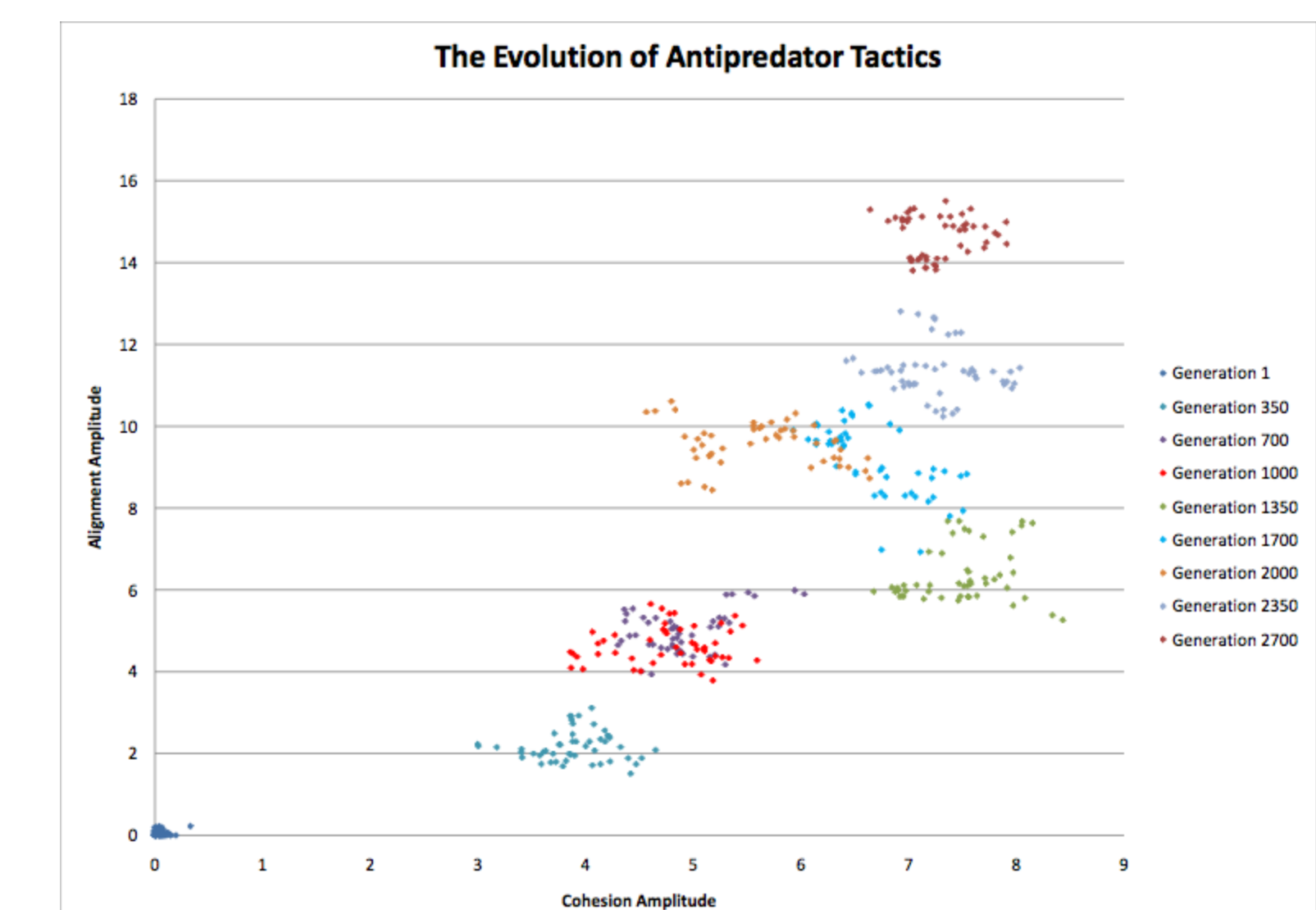
•The rules of separation, alignment and cohesion are each multiplied by a different scaling amplitude in addition to being weighted according to the proximity of the neighbor in question.

•I commenced my evolution test with alignment and cohesion amplitudes of zero, which simulates a non-flocking population.

•The simulation runs until the predators have halved the population of prey at which point the next generation begins.

•The cohesion and alignment characteristics of each successive generation are modeled with slight deviations upon the amplitudes of those rules for the surviving half of the generation before.

•The following illustrates the cohesion and alignment amplitudes of the prey at discrete generations over a 2700 generation test that I ran:



•This test successfully shows that a flocking population can evolve from a population wherein no members flock.

Acknowledgments:

•Reynolds, C. W. (1987) Flocks, Herds, and Schools: A Distributed Behavioral Model, in Computer Graphics, 21(4) (SIGGRAPH '87 Conference Proceedings) pages 25-34.

•Critical Mass by Philip Ball

•Photograph by Manuel Presti