2.6 Balancing feedback, swarms and emergent behavior

Feedback processes lead to the emergence of new behaviors that exist collectively but not individually. The interaction of individual elements reacting to feedback often using simple local rules can give rise to more complex global behaviors. This is called “emergence”. Emergence is where the whole does indeed becomes greater than the sum of its parts.

We are surrounded by examples of emergent behavior. Your ability of sight, for example is an emergent property of your visual system. By itself, your eyeball cannot see, nor can your optic nerves or the visual cortex in your brain. Individually, no-one element has this ability. Together they interact and create a new or “emergent” behavior, the miracle of sight.

We can see why it is so important to study systems as a whole: if we take a system apart, we break the interconnections and we can no longer observe the system’s fascinating, emergent properties.

A famous example of emergent behavior in social systems was demonstrated by the economist Thomas Schelling in the early 1970s in his work on neighborhood racial segregation. Using a checkerboard to represent a neighborhood, and coins the inhabitants, Schelling showed how individual preferences for similar neighbors could lead to segregated communities. Rational local, micro behaviors can lead to unacceptable global behaviors. This happens through balancing feedback.

You can experiment this yourselves. Make yourself a checkerboard with 64 squares: 8 columns and 8 rows. Randomly place 24 white tokens and 24 black tokens. The checkerboard represents a city and each token represents an inhabitant. A neighborhood is the eight surrounding squares. Now you need to apply the local preference rule. Each inhabitant wants to live in a neighborhood where one half of neighbors are like themselves. When an inhabitant feels out-numbered, he or she moves to an empty square where their preference is satisfied. Can you see the segregation emerging on the checkerboard?

While Shelling’s model is a simplified one, it does illustrate how rational individual behaviors and feedback can lead to unexpected and sometimes unwanted global behaviors at a systems level.

Balancing feedback is behind a large number of adaptive behaviors that we observe in groups and that allow them to self-organize and work together. Fish school, birds flock, insects swarm and cattle herd using balancing feedback. Have you ever seen a manager in a flock of birds telling them where to go and how to group? Of course not! Organization emerges from each bird using simple local rules, communication and feedback. This emergent behavior is called “self-organization”. Self-organization has often been compared to improvisation in jazz and jam sessions where musicians adapt to the notes and rhythms of others.

There are many fascinating examples of self-organization in the natural world. Insects such as ants rely on feedback mechanisms to collectively carry large prey that are many times their individual weight. Scientists for example have found that the “crazy ant” paves its path on a moment-to-moment basis, adapting its behavior to the pheromone deposits communicated by the other ants.

Crowds of people also sometimes flock like sheep and birds. Researchers at the University of Leeds found that in large crowds of 200 or more, five per cent of the group is enough to influence the direction in which it travels and the other 95 per cent follow without even realizing it.

We can see how self-organization emerges from simple local interactions in groups using computer modeling. Thirty years ago, a software engineer by the name of Craig Reynolds programmed a flock of birds using three simple feedback rules for each individual bird based on the positions and velocities of its nearby flock-mates:

Rule 1, separation : birds steer to avoid crowding local flock-mates

Rule 2, alignment : birds steer towards the average heading of local flock-mates

Rule 3, cohesion : birds steer to move toward the average position of local flock-mates

The simulation is so realistic that it has been adapted and used in seven motion pictures, including Batman and TRON and today is being tested in the military to build swarms of drones. Most importantly though it shows how complex global behavior can arise from the interaction of simple local rules and balancing feedback.

When we look around the world we live in, we can see many examples of systems that are made up of multiple elements that adapt and learn from their interactions with one another. The stock market, our brain, a national economy, a company or an ant colony. These are all “complex adaptive systems”, and complex adaptive systems are everywhere.