Modeling Nature's Emergent Patterns with Multi-agent Languages

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https://ccl.northwestern.edu/papers/MEE/

Summarized by Leen-Kiat Soh

Introduction: the emergence of pattern 1

- Everywhere we look, we see regularities, patterns, order
  - the growth of a snowflake crystal, the perimeter pattern of a maple leaf, the dynamics of the Dow Jones, etc.
  - The characteristic shape can unfold in space or in time, sometimes striking and unmistakable and sometimes more hidden, needing probing observation or ingenious experiment to uncover it

Introduction: the emergence of pattern 2

- Why is there so much pattern in the world?

Introduction: the emergence of pattern 3

- Large scale patterns in the world are usually the result of the interactions of large numbers of smaller pieces that somehow combine in surprising ways to create the large-scale pattern.
- Such large-scale (macro-) patterns that arise out of the interactions of numerous interacting (micro-) "agents" are called "emergent phenomena" — that is, ***phenomena that emerge from interactions at a lower level or scale***

Introduction: the emergence of pattern 4

- The study of emergent phenomena is the principal occupation of a developing field of science, the study of complex dynamic systems (Gleick, 1987; Waldrop, 1992; Gell-Mann, 1994; Kelly, 1994; Holland, 1995; Kauffman, 1995)
- This broad new field seeks to **understand how systems of interacting components evolve over time**
- In the minds of many, however, **complex systems theory** is *not* a new branch of science, but rather a new framework, a new perspective that allows us to see old scientific content in new ways

Introduction: the emergence of pattern 5

- This new perspective and the methods it brings to bear have been adopted across a wide array of natural and social sciences
- An understanding of complex systems is becoming an essential part of every scientist’s knowledge and skills
- The time has come for these ideas and methods to become a central part of *every* student’s learning.

Some models: Predator, Prey, (and Poison!) 1

http://ccl.northwestern.edu/netlogo/models/community/Predator,%20Prey,%20Poison

- Predator, Prey, Poison is a model of the interactions of predators, prey, and food eaten by the prey
- The predator is represented by coyotes, the prey by rabbits, and the prey's food by grass, although the model can apply to any three species in an ecological food chain
- The model simulates the population dynamics of coyotes and rabbits as they move around a grassy meadow feeding, reproducing, and dying
- During part of a simulation, some patches of the meadow are treated with a poison that kills any rabbits or coyotes that move to those patches

Some models: Predator, Prey, (and Poison!) 2

http://ccl.northwestern.edu/netlogo/models/community/Predator,%20Prey,%20Poison

- Using this model, you can ask how a generalized source of mortality on both predators and prey (poisoning) influences the relative abundances of the predators and prey
- This question was first investigated by the Italian mathematician Vito Volterra in the 1920s in response to a question from a fisheries biologist named Umberto D'Ancona
  - During World War I, commercial fishing decreased in the Adriatic Sea, presumably because it was a war zone
  - D'Ancona noticed that numbers of predatory sharks increased relative to numbers of cod and other prey species during World War I, while the pattern was reversed after the war ended and fishing increased to pre-war levels
  - Volterra built an abstract mathematical model to do so; Predator, Prey, Poison is an individually based and spatially-explicit computer simulation with the same goal
  - In the fishing example, humans are a generalized source of mortality on both sharks and cod, so humans act like the poison in this model of coyotes, rabbits, and grass

Some models: Gas in a Box

https://ccl.northwestern.edu/netlogo/models/GasLabGasinaBox

- This model simulates the behavior of gas particles in a closed box, or a container with a fixed volume. The basic principle of the models is that gas particles are assumed to have two elementary actions: they move and they collide --- either with other particles or with any other objects such as walls.
- The particles are modeled as hard balls with no internal energy except that which is due to their motion
- The basic principle of all GasLab models, including this one, is the following algorithm:
  - A particle moves in a straight line without changing its speed, unless it collides with another particle or bounces off the wall
  - Two particles "collide" if they find themselves on the same patch
    - A random axis is chosen, as if they are two balls that hit each other and this axis is the line connecting their centers
    - They exchange momentum and energy along that axis, according to the conservation of momentum and energy. This calculation is done in the center of mass system
    - Each particle is assigned its new velocity, energy, and heading
  - If a particle finds itself on or very close to a wall of the container, it "bounces”—that is, reflects its direction and keeps its same speed

Why simulation of complex systems? 1

- We live in an increasingly interconnected world
    - Rainforest destruction in South America leads to Greenhouse effects and weather pattern changes in Africa
    - Market collapses in the Far East can wreak great consequences on economies in the West
- Traditional science which studies phenomena in isolation is not equipped to analyze and understand such systemic effects
- One strength of the complex systems theory perspective is that it enables us to see common patterns across traditionally separate fields:
    - physical matter is the emergent result of molecular interactions; ecologies and biological niches are emergent results of interacting organisms; economies and markets are emergent results of the interactions of buyers and sellers.

Why simulation of complex systems? 2

- Many everyday phenomena and experiences arise from the interactions of many different factors, thus an understanding of patterns as emergent phenomena, rather than as results of equations, is both a more accurate picture of nature AND easier for most people to understand