Complex Adaptive Systems

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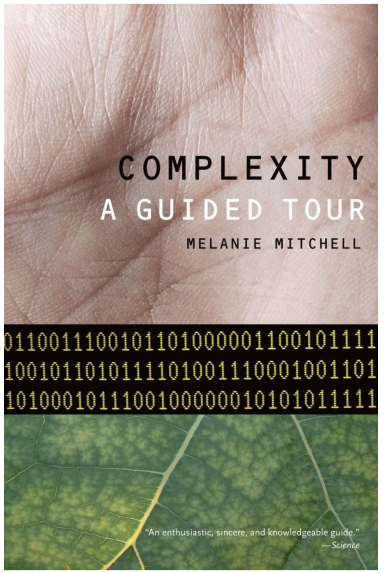
Complexity: A Guided Tour

Complex system: a system in which large networks of components with **no central control** and simple rules of operation give rise to **complex collective behavior, sophisticated information processing, and adaptation** via learning or evolution.

Systems in which organized behavior arises without an internal or external controller or leader are sometimes called self-organizing. Since simple rules produce complex behavior in hard-to-predict ways, the macroscopic behavior of such systems is sometimes called **emergent**.

A system that exhibits nontrivial emergent and self-organizing behaviors. The central question of the sciences of complexity is how this emergent self-organized behavior comes about.



Complex Adaptive Systems

Interactions
Systems composed of interacting components

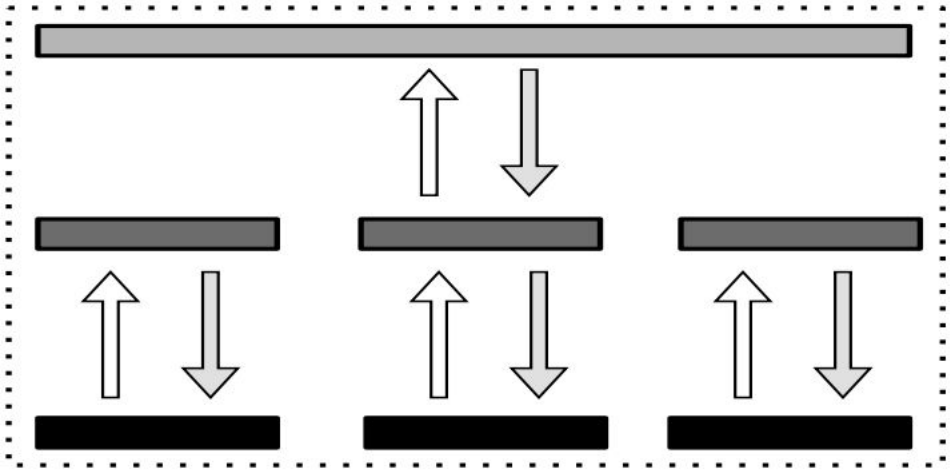
Emergence
Structure emerges from interactions among components and between components and their environment

Scale
Systems are nested and structure emerges at different scales

Evolution
Systems are dynamic and adapt to internal and external conditions

Brian Arthur, Complexity Economics

Economies are organic and evolutionary…
actions and strategies constantly evolve,
structures constantly form and re-form
…individual behaviors react to the pattern they together create



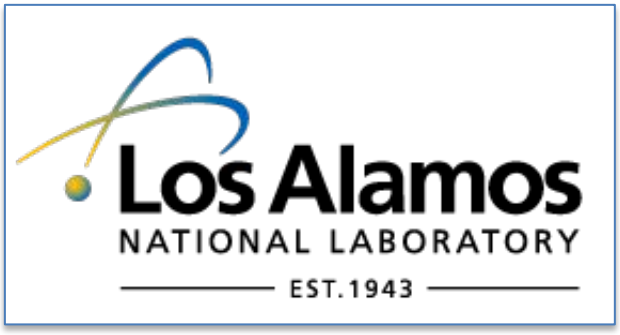
What are examples of CAS?

Team up with a couple of neighbors

List some CAS and explain why they are CAS.

Describe:

- Interactions
- Emergence
- Relevant scales
- Evolution/adaptation
- Nested reactions



New Mexico is the birthplace of the interdisciplinary study of Complex Systems

Henri Poincare
1903 “Science and Method”

Sensitive dependence on initial conditions

It may happen that small differences in the initial conditions produce very great ones in the final phenomena. A small error on the former will produce an enormous error on the latter. Prediction becomes impossible…

It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us.

Charles Darwin
Origin of Species 1859

Andreas Wagner
Arrival of the Fittest

- a phenotype like that of a human body is not just a string of DNA. It is a hierarchy of being that descends from the visible organism, its tissues and cells, to the molecular webs formed by metabolic molecules, signaling molecules, and many others, extending down to the level of individual proteins.
- computers are the microscopes of the twenty-first century. They help us understand molecular webs that Darwin did not even know existed. …

Stuart Kauffmann

http://edge.org/conversation/the-adjacent-possible

If a random mutation happens by which some organism can detect and utilize some new source of free energy, and it's advantageous for the organism, natural selection will select it.

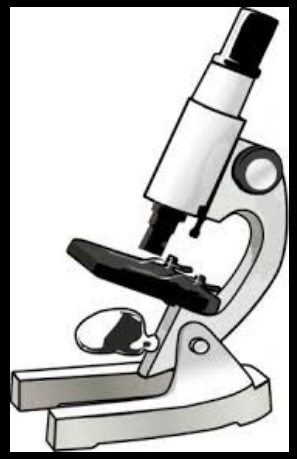
The whole biosphere is a vast, linked web of work done to build things so that, stunningly enough, sunlight falls and redwood trees get built and become the homes of things that live in their bark.

The complex web of the biosphere is a linked set of work tasks, constraint construction, and so on. … necessitating a theory of organization that describes what the biosphere is busy doing…Currently we have no theory of it—none at all.

Traditional Science

Reductionism: zoom in

Learn more & more about less & less



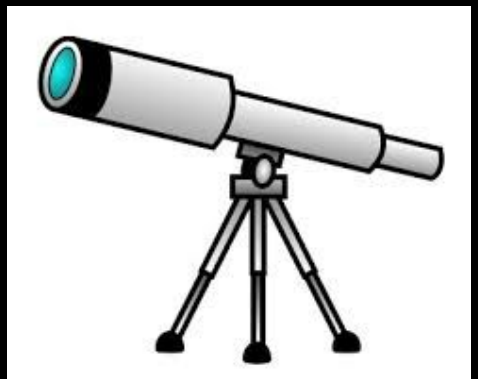
Complexity Science

Look across scales: zoom in & zoom out

Use multiple perspectives

Understand how structure emerges

from interactions within & across levels



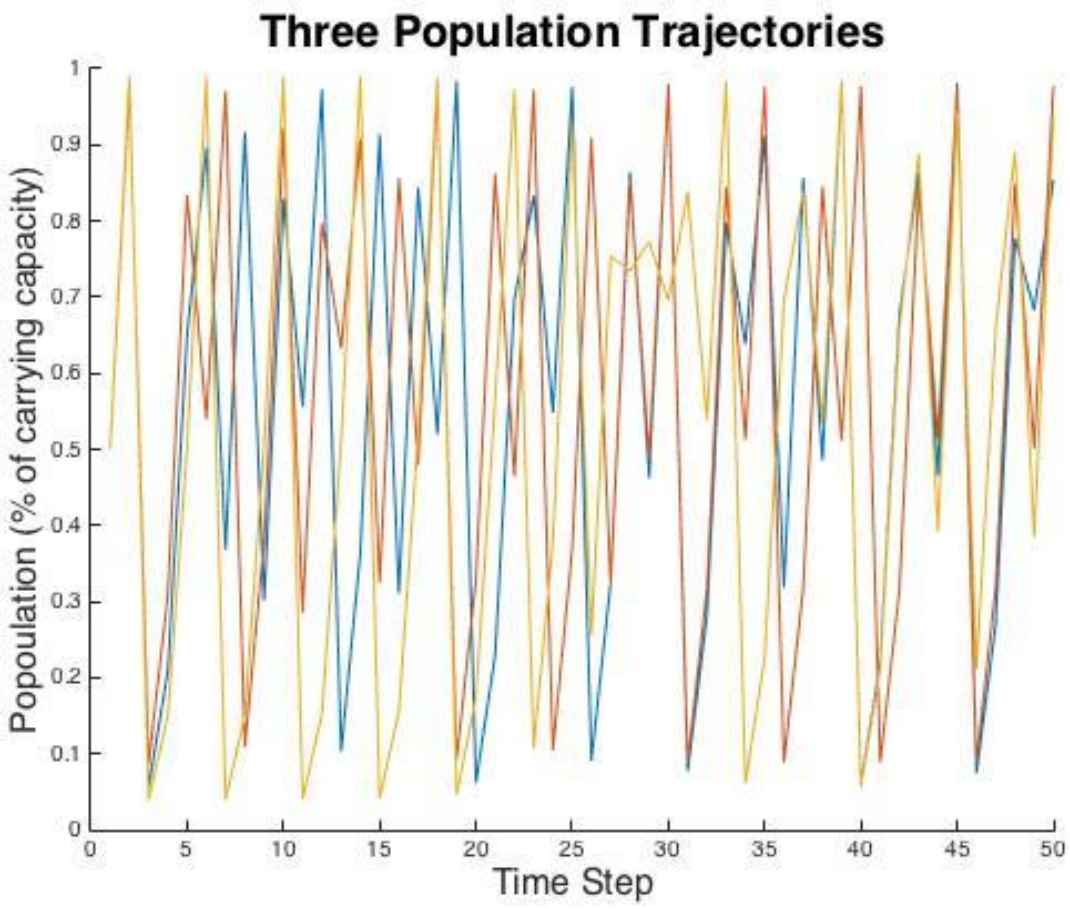
Overview of Course Topics

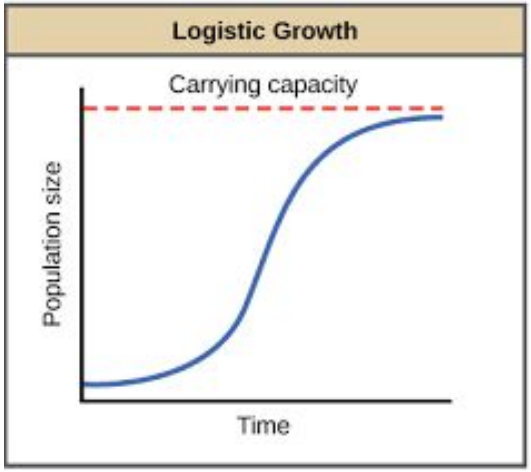
- **Chaos & Sensitive Dependence on Initial Conditions**
- **Information Theory**
- **Evolution**
- **COVID-19 pandemic**

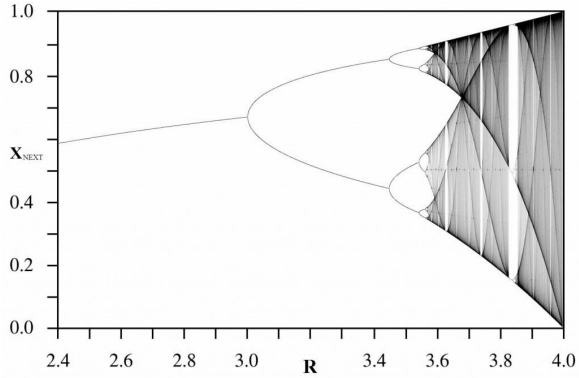
- **Genetic Algorithms**
- **Cellular Automata**
- **Swarm Robotics**
- **Ants & Ant Colony Optimization**
- **Brains, Neural Nets & Analogies**
- **Natural and Computational Immunology**
- **Modeling & the Prisoner's Dilemma**
- **Networks, scaling & fractals**

The Logistic Map: Chaos from a simple equation

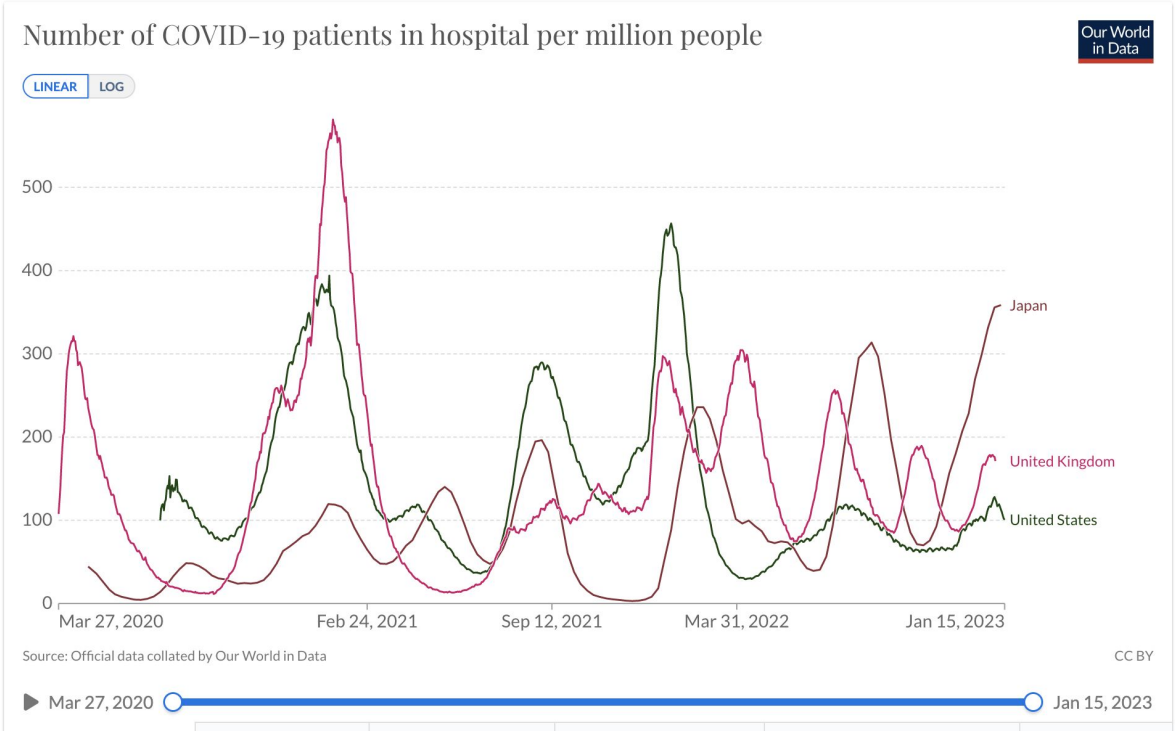
$$x_{n+1} = r x_n (1 - x_n)$$

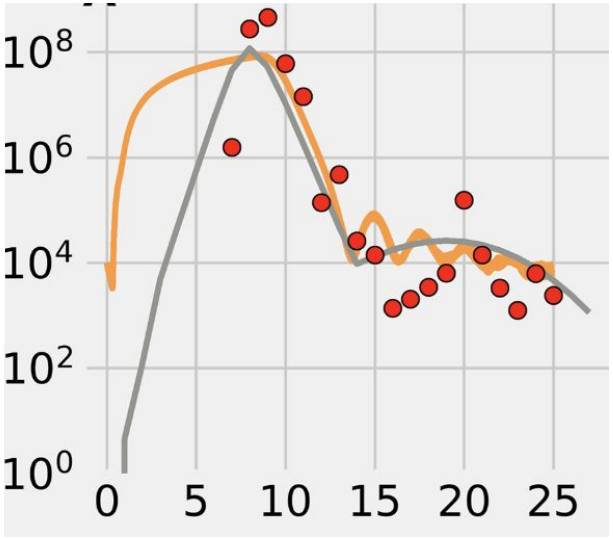






COVID population dynamics
Chaos from complexity





Virus load vs days post infection in a COVID patient
Modelled in SIMCoV

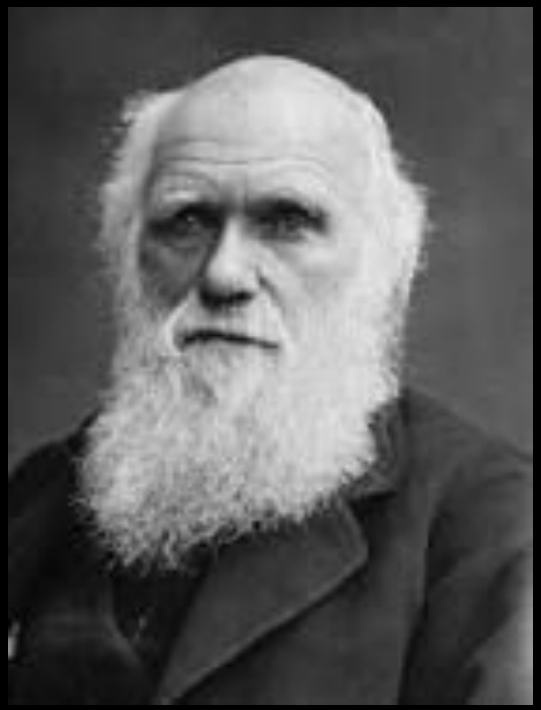
Shannon Information

- Entropy
- Mutual Information
- Transfer Entropy

$$H = -\sum_i p_i(\log_2 p_i)$$

"I blame entropy."

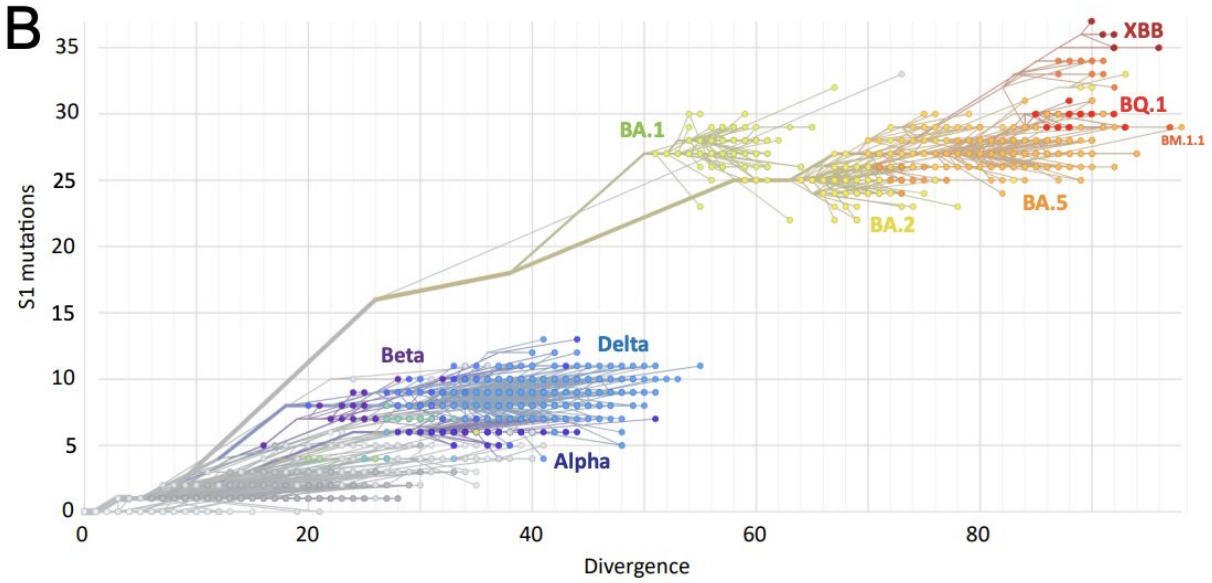
Evolution by Natural Selection

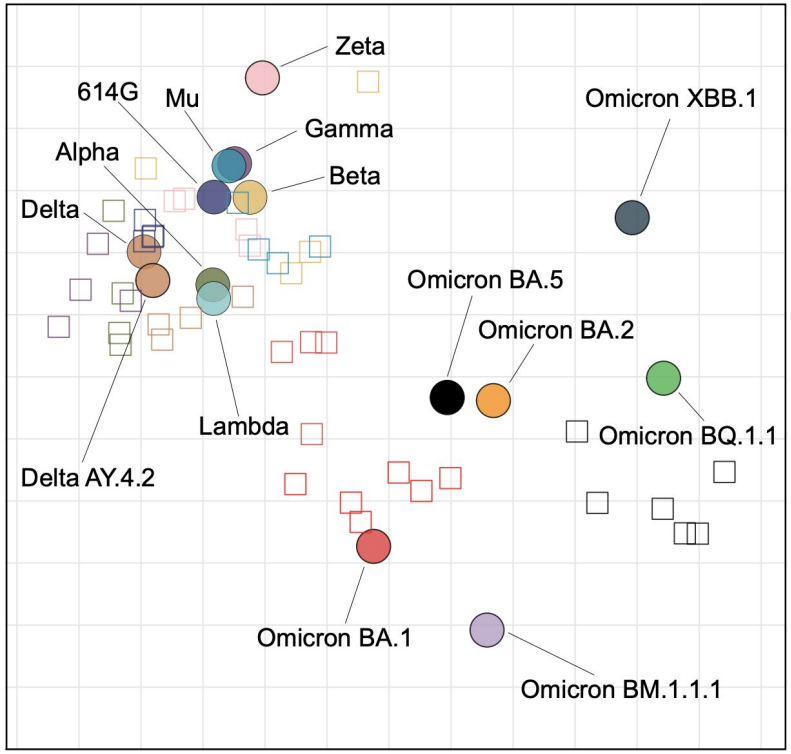


Variation

Inheritance

Selection





Antigenic mapping of emerging SARS-CoV-2 omicron variants BM.1.1.1, BQ.1.1, and XBB.1

Anna Z Mykytyn • Miruna E Rosu • Adinda Kok • Melanie Rissmann • Geert van Amerongen • Corine Geurtsvankessel • Rory D de Vries • Bas B Oude Munnink • Derek J Smith • Marion P G Koopmans • Mart M Lamers • Ron A M Fouchier • Bart L Haagmans ✉ • Show less

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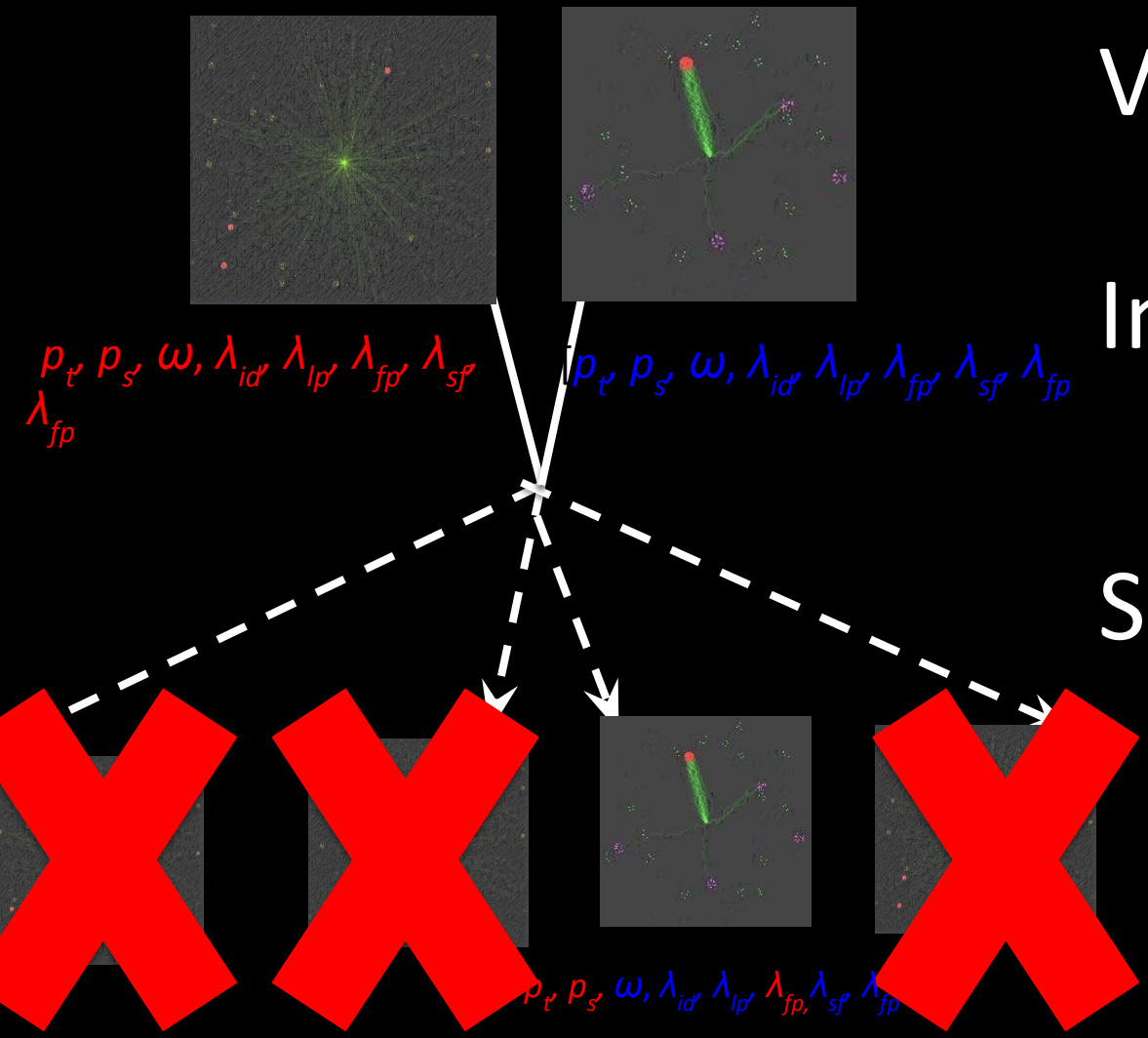
Genetic Algorithms



Variation

Diversity

Inheritance

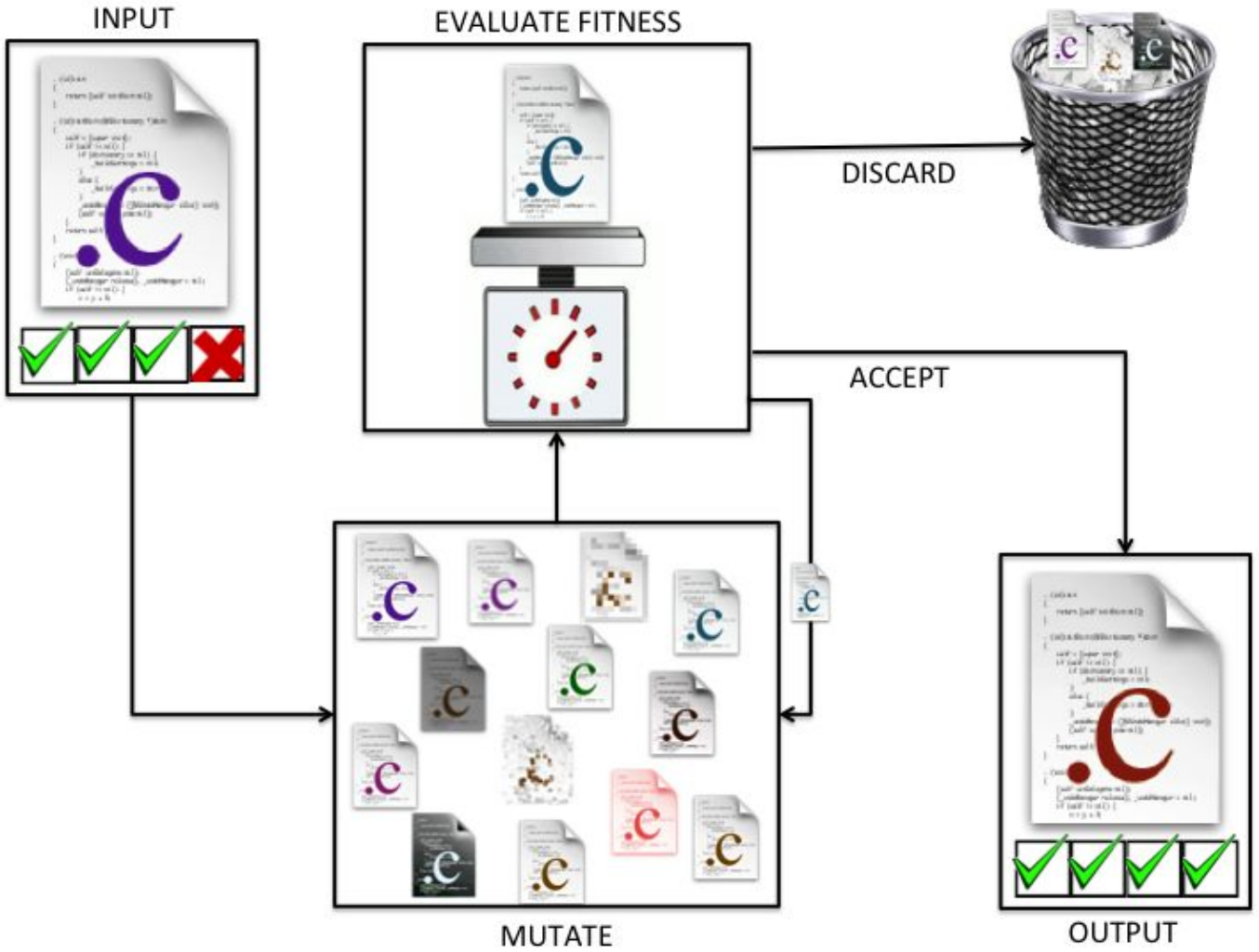
Mutation & Recombination

Selection

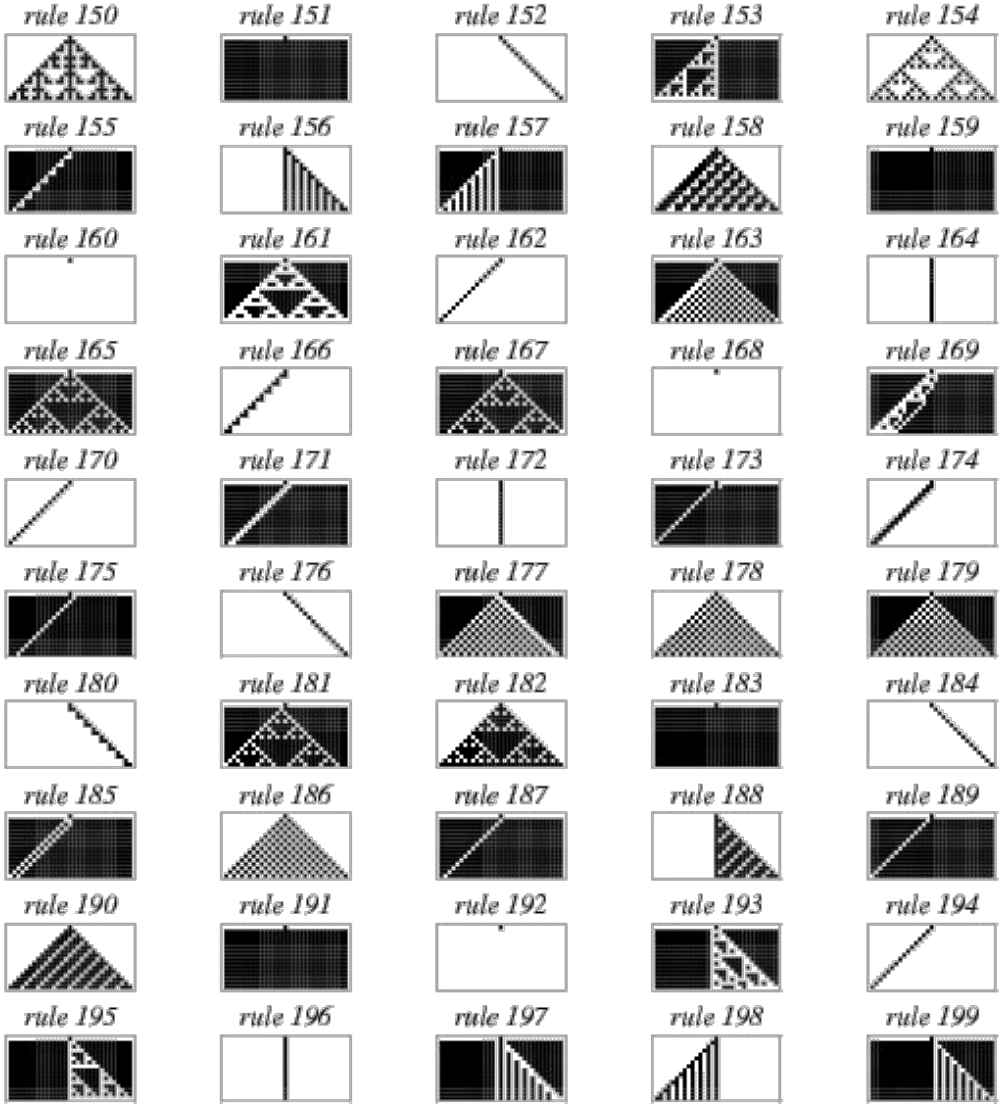
Environment

FITNESS = # Seeds Collecte

Genetic Programming

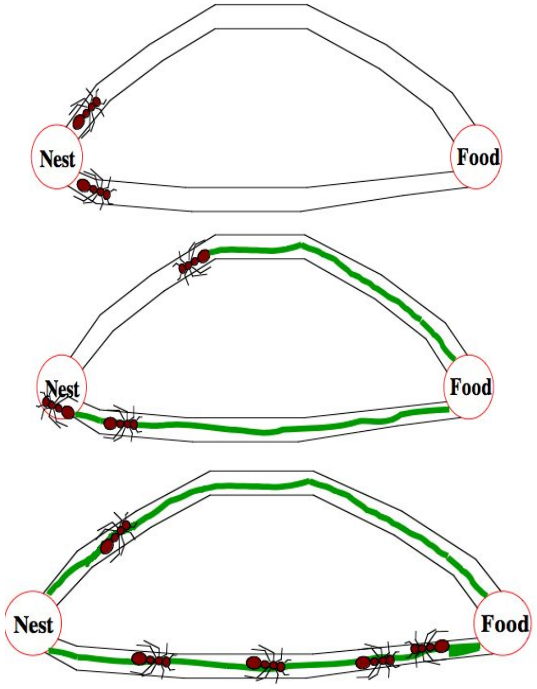


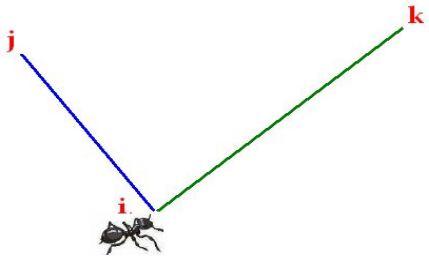
Cellular Automata




~20,000,000 Ants
Ants! Natures Secret Power

Pheromone recruitment: a well-studied emergent behavior

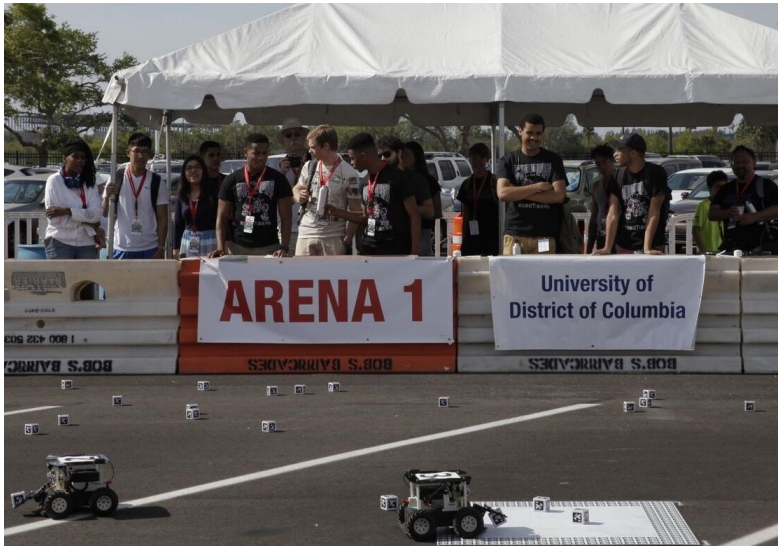


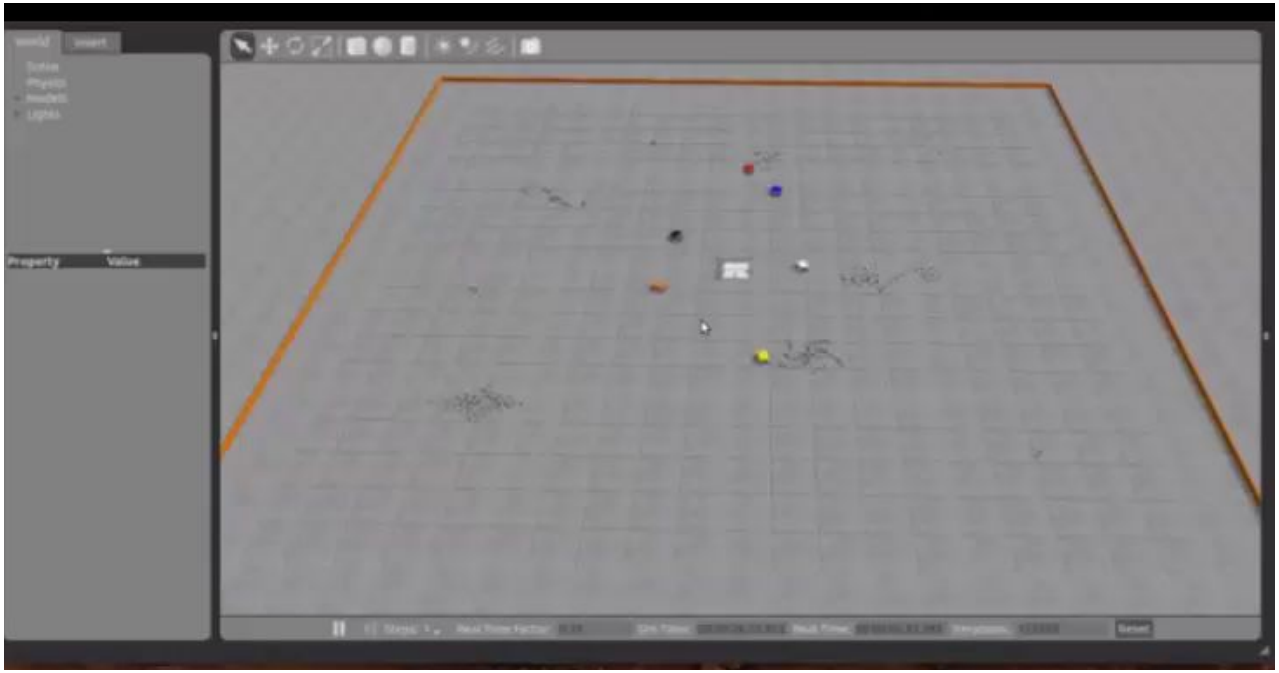


$$p_{ij}^{k}(t) = \frac{[\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta}}{\sum_{l \in N_i^k} [\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta}} \quad if \ \ j \in N_i^k$$

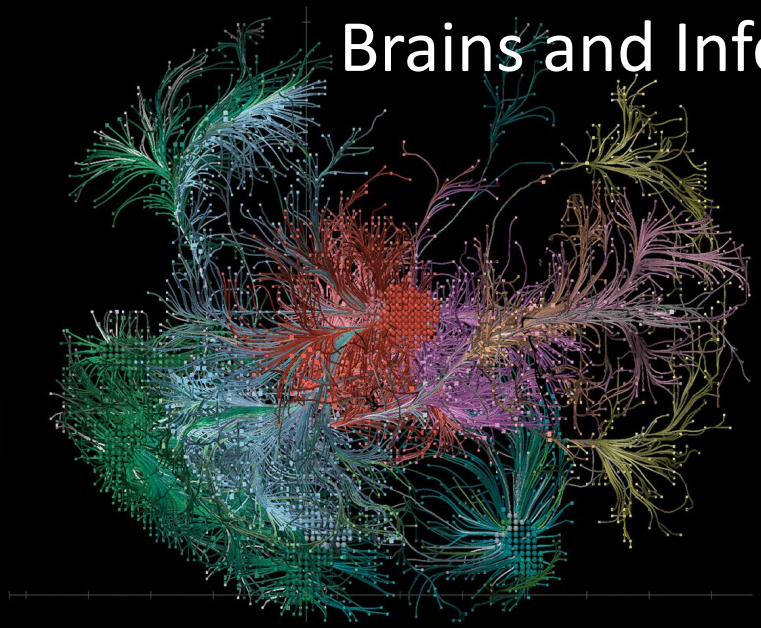
Ant colony optimization

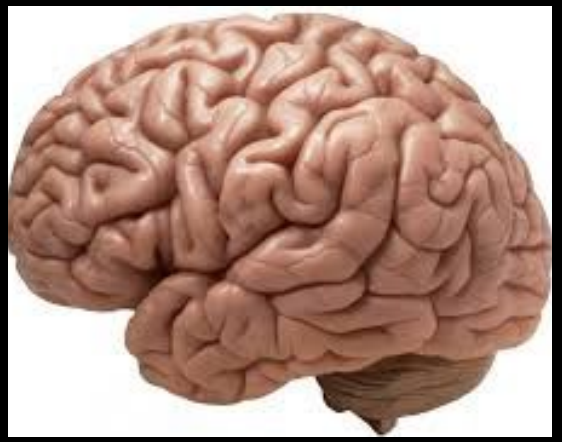
Swarm Robotics

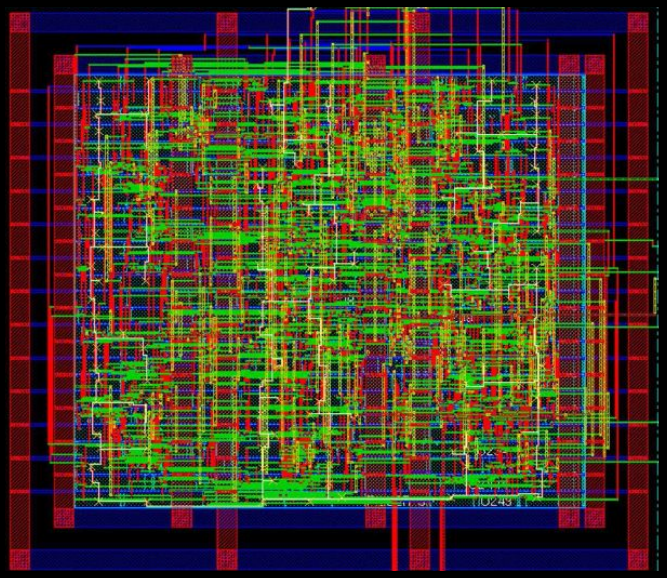


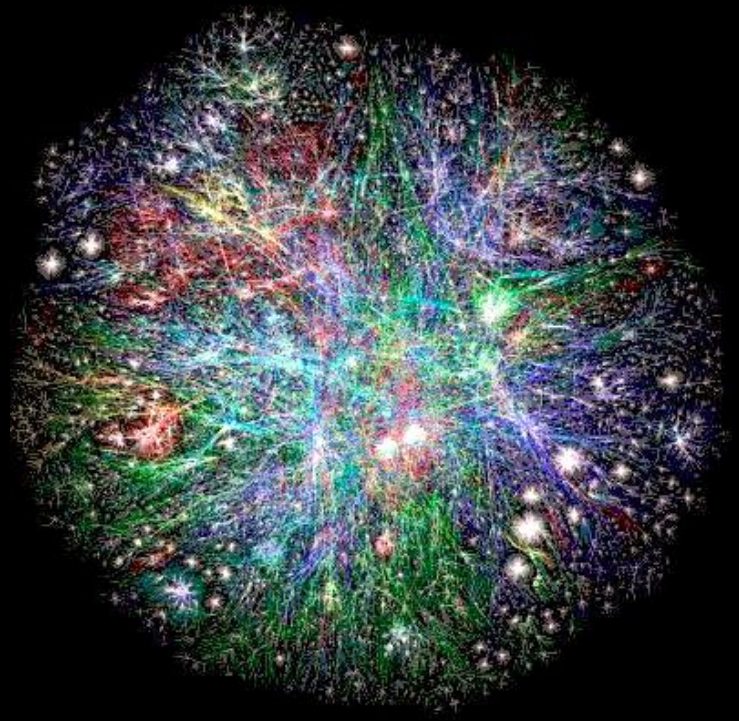


Brains and Information Processing

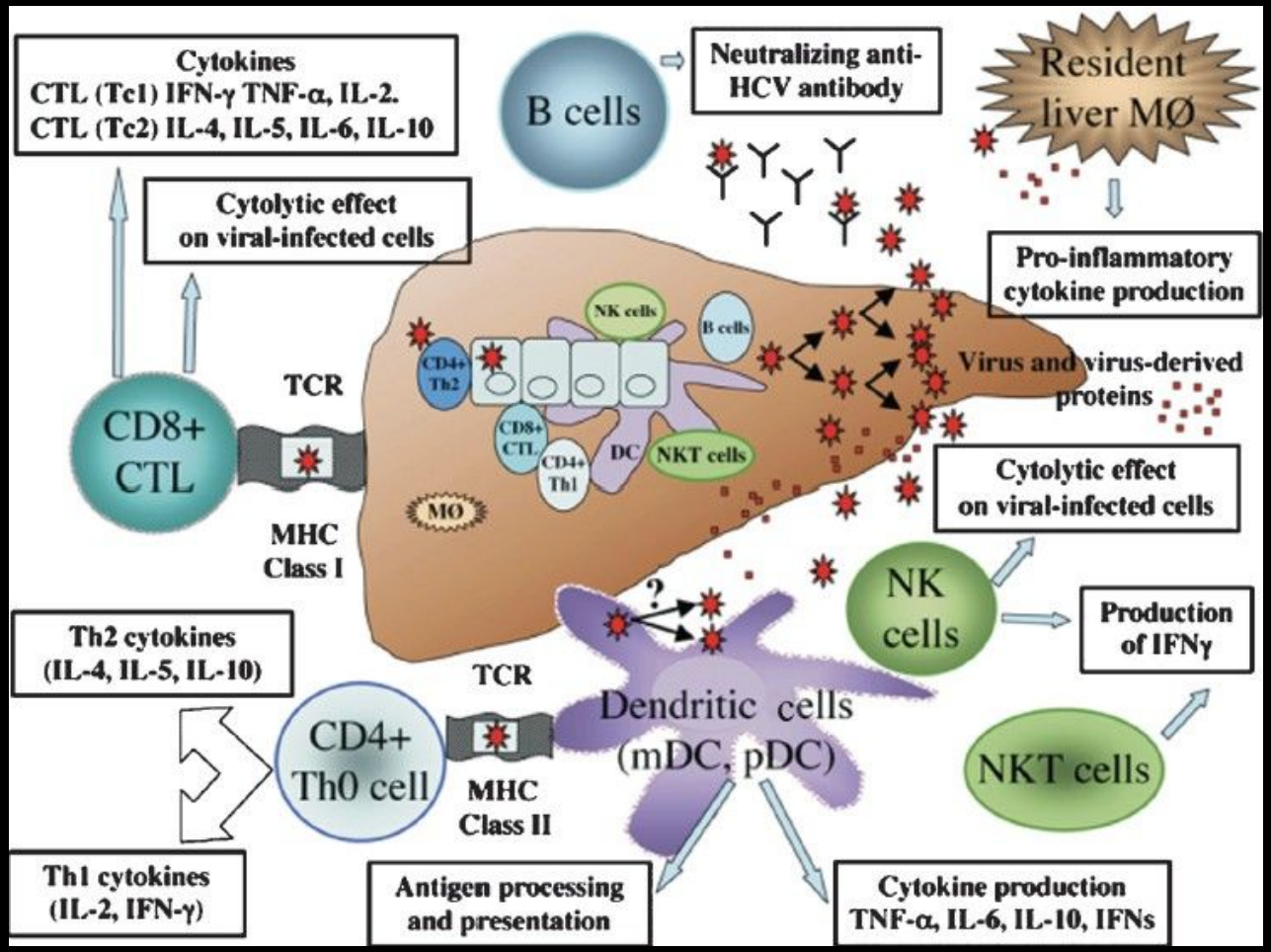


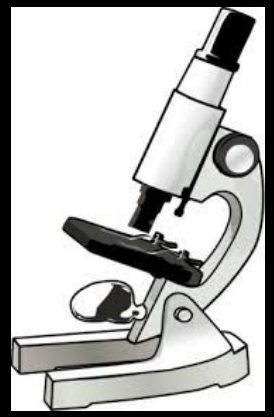




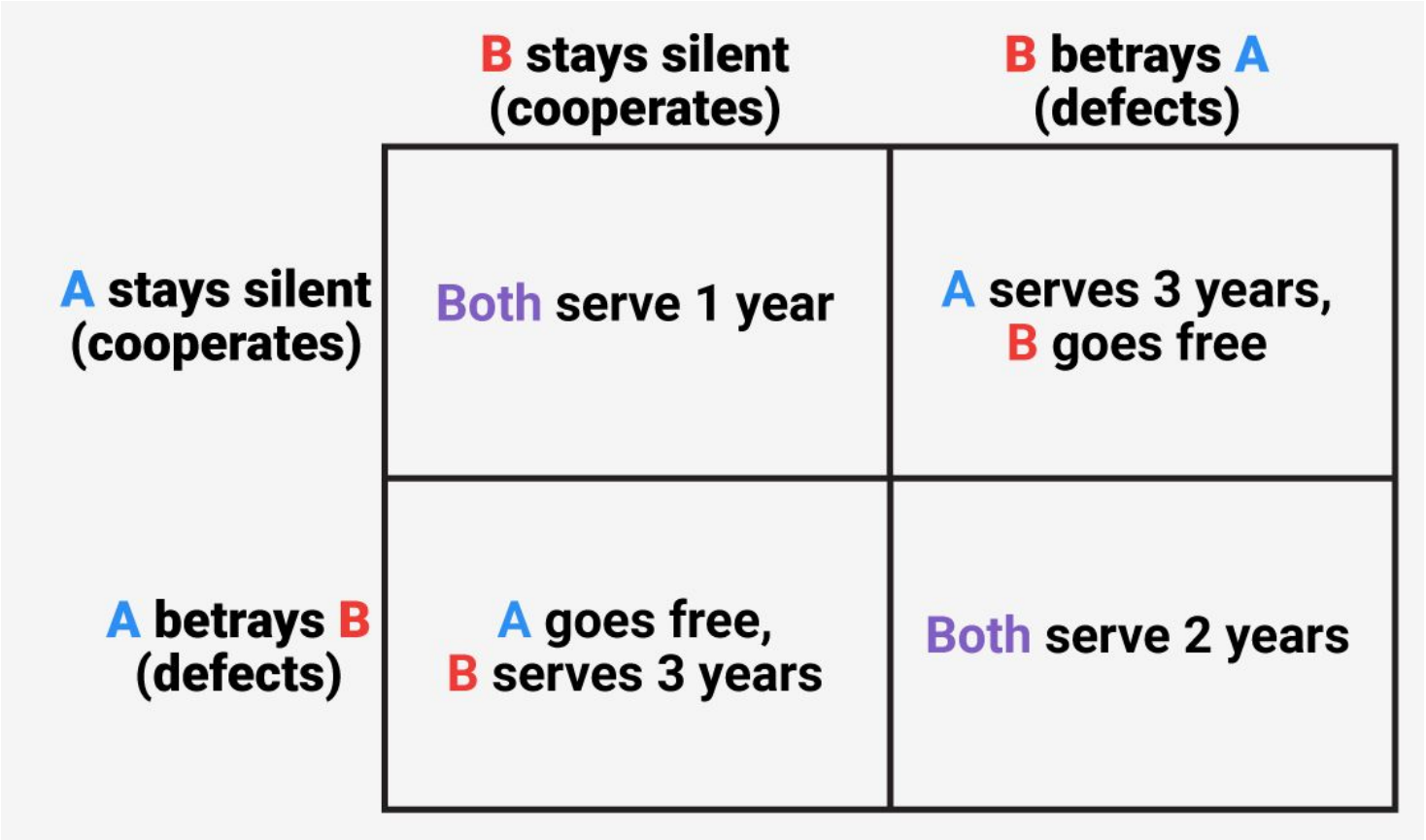


Immune systems are *really* complex

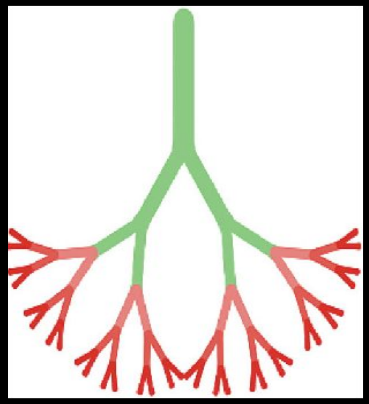


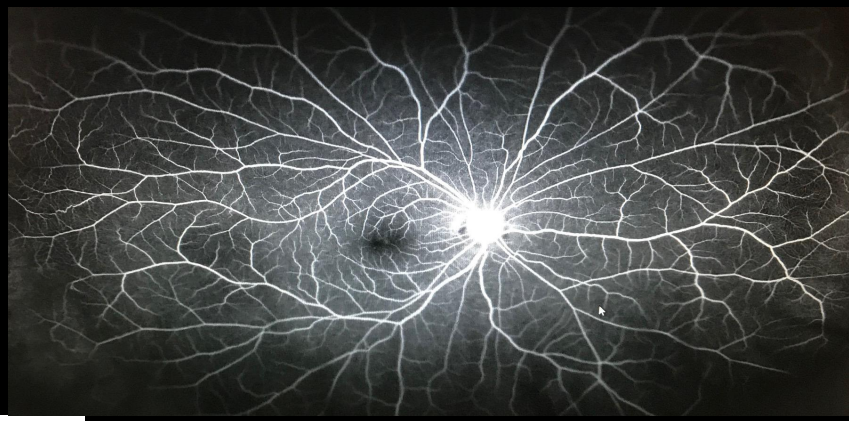


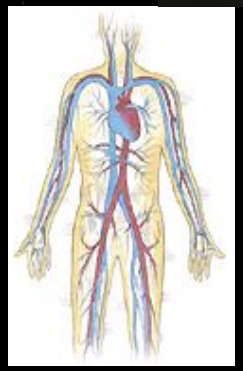
Modeling Cooperation: The Prisoner's Dilemma

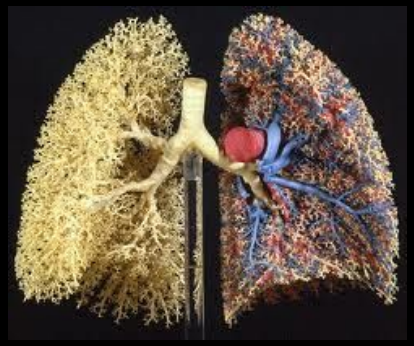


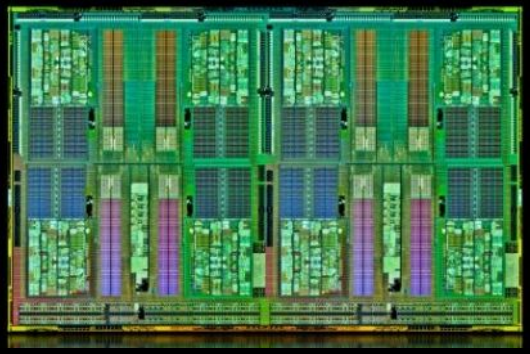
Scaling, Networks and Fractals

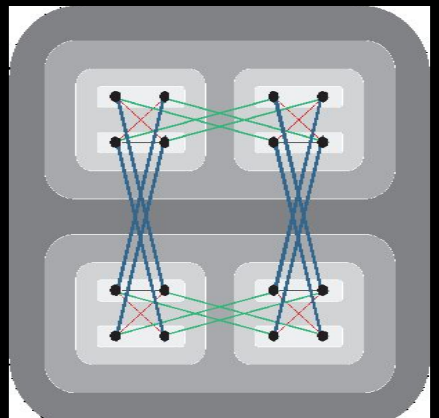


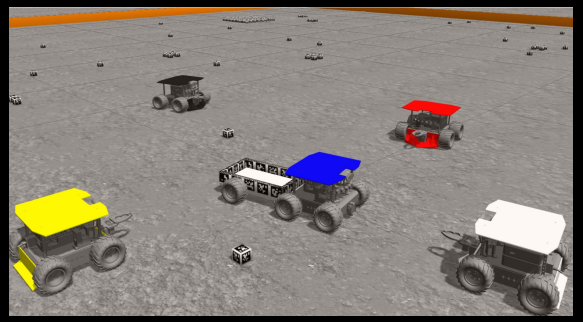




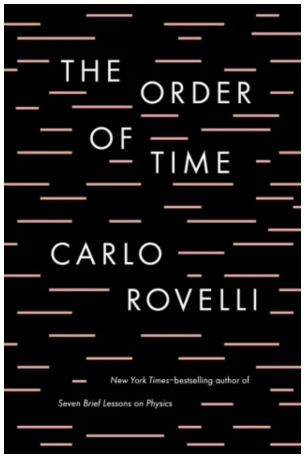








Entropy and time exist because interacting agents have a blurred view of the world



- If the first twenty-six cards in a pack are all red and the next twenty-six are all black, we say that the configuration of the cards is “particular,” that it is “ordered.” This order is lost when the pack is shuffled. It is particular because I am looking at the color. Another configuration will be particular if the first twenty-six cards consist of only hearts and spades. Or if they are all odd numbers, or the twenty-six most creased cards in the pack, or exactly the same twenty-six of three days ago. . . .

- If I distinguish between all the cards, the configurations are all equivalent: none of them is more or less particular than others.

- Boltzmann has shown that entropy exists because we describe the world in a blurred fashion. He has demonstrated that entropy is precisely the quantity that counts how many are the different configurations that our blurred vision does not distinguish between.

- So if I could take into account all the details of the exact, microscopic state of the world, would the characteristic aspects of the flowing of time disappear?