Introduction and Motivation for Complex Networks

IV124

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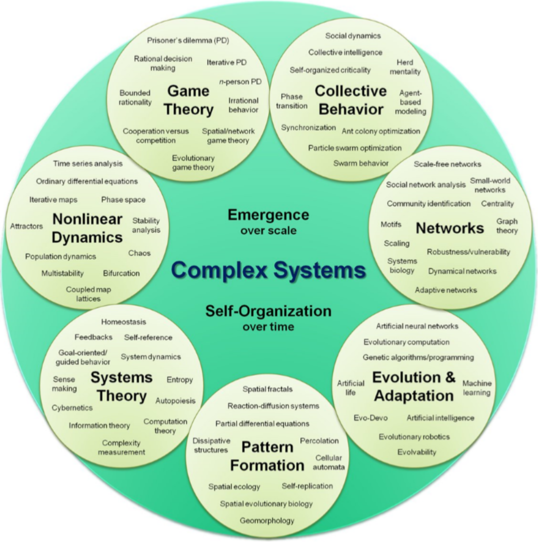
Course Organization

- Formally: 0 + 2
- Practically: lecture, hands-on activities (laptop is welcome), demonstrations, discussion

- Pass-the-Course Criteria:
  - 60 % attendance
  - submission of seminar work
    - scope: at least 3 NP
    - either Reader's Journal or Project Report

Complex Systems Areas



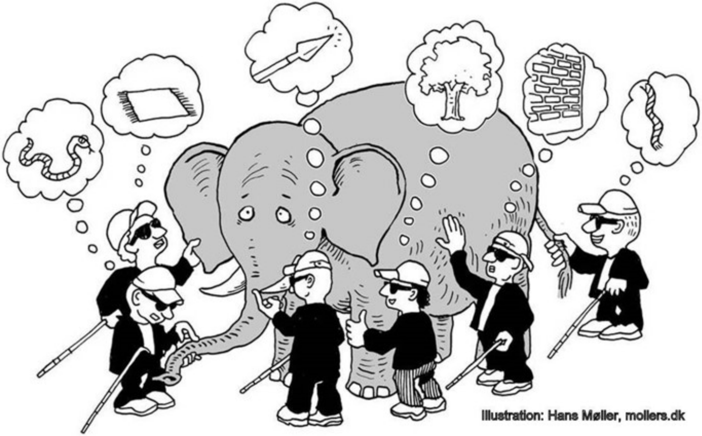
Emergence of Complex Systems Theory

"You don't see something until you have the right metaphor to let you perceive it."

James Gleick, Chaos: Making a New Science

- From 1960' onwards, scientists were randomly discovering that an observation made in one domain can be successfully applied in another domain
- These observations were collected and generalized, which gave foundations to the Chaos Theory
- Further development in this area lead to the emergence of the Complex Systems Theory

Blind Men and an Elephant



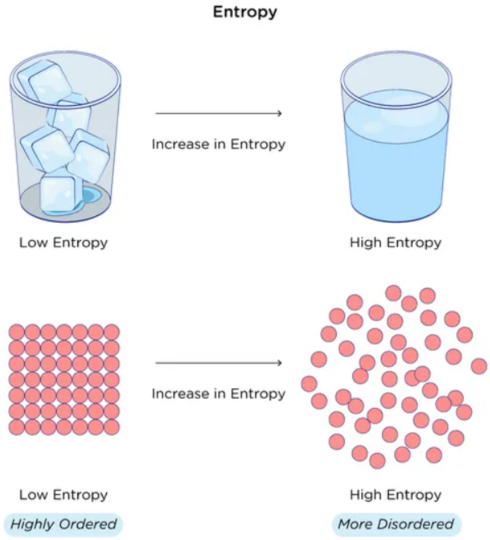
Definition of CS

- CS consists of many components (agents)
- Agents interact together in a non-trivial manner (typically adjust their behavior based on what others do)
- The system as a whole shows certain behavior or quality that cannot be attributed to (or perceived at the level of) an individual agent

Some Underlying Physics

- There are principles which are common to all natural systems
- These are based on physical laws
- In particular, second thermodynamic law:
  - Hot objects transfer heat to cold objects (not vice versa)
  - Ordered systems become less ordered (more random) – entropy increases
  - Systems "seek" energetic optima

Second Law of Thermodynamics



You Get on a Train...

Your car

Next car

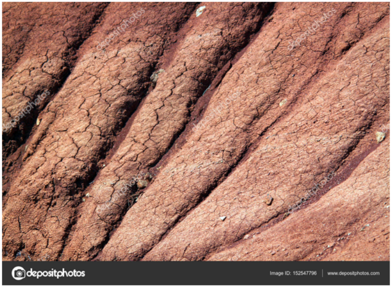
Energetic Field

High concentration Optimum Low concetration

A motion is created as a consequence of two neighbouring fields with different energy concentration.

Systems "Prefer" Efficient Energy Flow

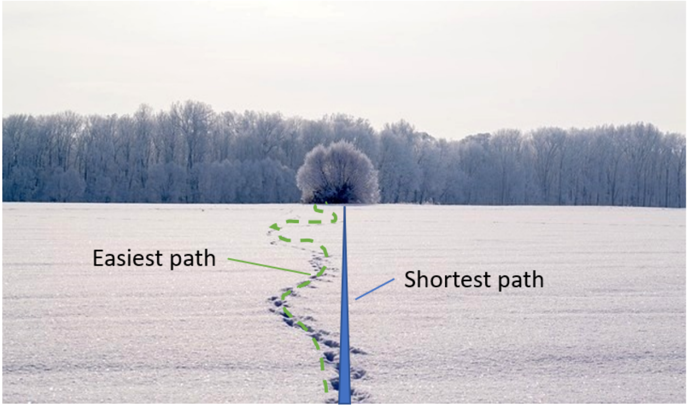
When there are more paths or channels through energy may flow, natural systems will prefer those with higher capacity



... both organic and anorganic!

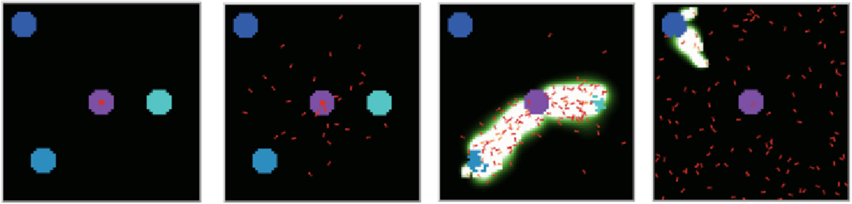
You Want to Get to the Tree...

You Want to Get to the Tree...



- Lowest resistance = most efficient way how to invest energy
- Once created, existing paths tend to be followed, hence becoming more attractive

Systems Prefer Existing Paths



Ant Colony Simulation – NetLogo Demo

Systems Prefer Existing Paths

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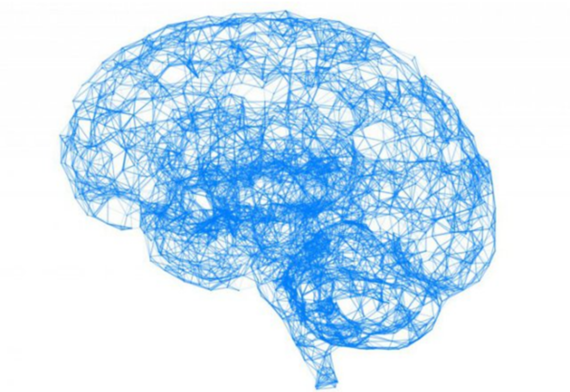
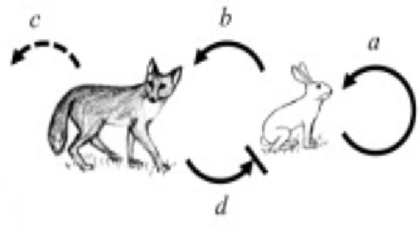


- Personality Structure
- Learning New Information
- Psychotherapy

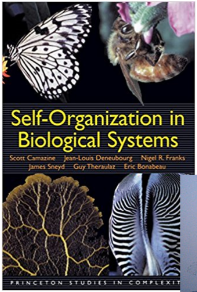
Self-Organization

- Natural systems prefer efficient energy flow but there is no central coordination
- It is self-organized
- Self-organization is achieved by positive and negative feedback loops
- Feedback is balancing the system which searches for energetic optimum



Order

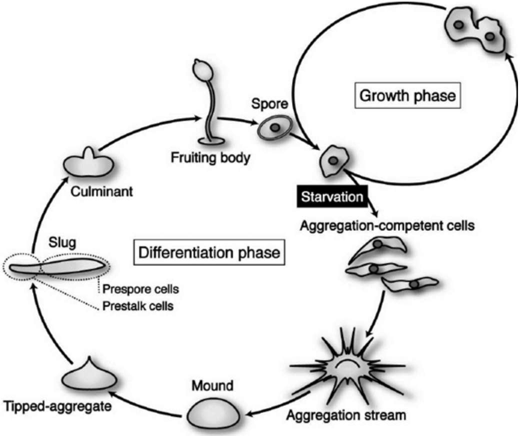
- Order is more efficient for energy transfer than chaos
- Order or coherence is spontaneously emerging in both organic and anorganic systems which seek energetic optima



Emergent Property

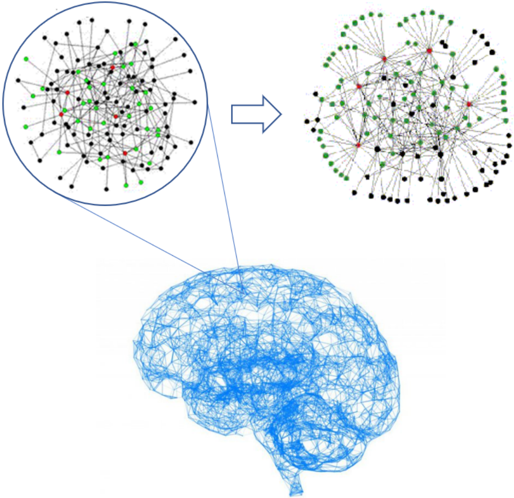
Dicyostellium

- Positive feedback: cell expansion
- Negative feedback: limited resources
- Chemical communication
- Starvation $\rightarrow$ tension $\rightarrow$ novel behavior

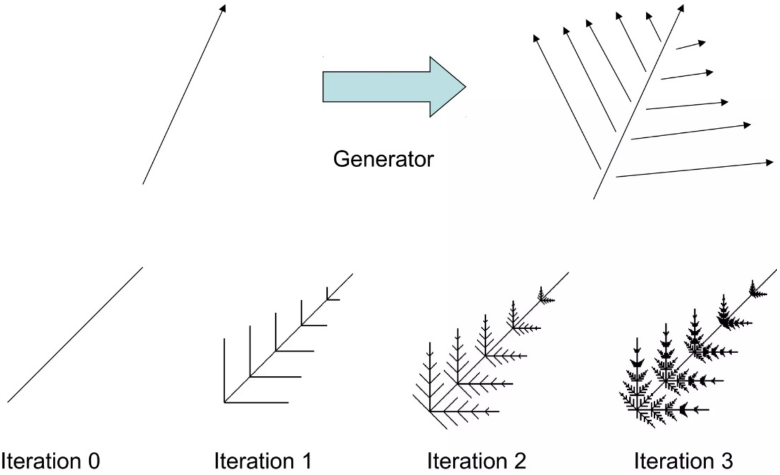


Conscious Knowledge as Emergent Property

- Positive feedback: willpower to learn something new
- Negative feedback: forgetting (weak paths, links perish)
- Communication through neurotransmitters
- Stimulation $\rightarrow$ critical threshold $\rightarrow$ conscious awareness



Self-organization Produces Self-similarity

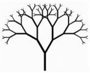


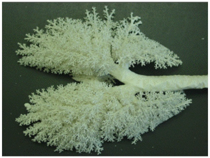
Fractal Structure

- Feedback loops typically apply over multiple scales ("levels of zoom")
- Same "forces" or "processes" apply at macro-level as well as micro-level
- *Coastline Paradox* – the more precise measurement, the longer the coast length (virtually infinite)

Google Maps: Fractals in Tibet

Fractals Around Us

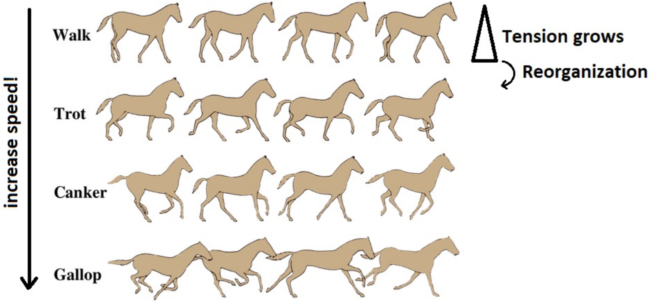




- Energy is exchanged through a surface – the bigger the surface, the more energy may be transferred
- However, we live in a limited space
- Fractal structure is nature's architecture how to get virtually infinite surface in a finite space

Different Perspective on Change

- Our intuitive thinking leads to linear perspective of change – inputs are commensurate to outputs
- However, changes in real-world systems are rarely linear
- Rather than that, a system "re-organizes" once the accumulated tension reaches a "tipping point"

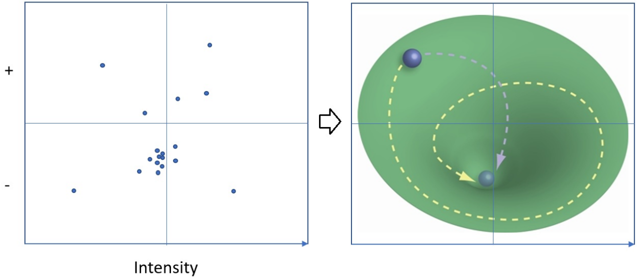


Stability & Instability

- Complex systems may be very robust to change in certain settings but also very sensitive to change in a different setting
  - A tiny input may cause massive change – "*Butterfly Effect*"
  - A huge input may cause nothing at all
  - Why? $\rightarrow$ Attractors

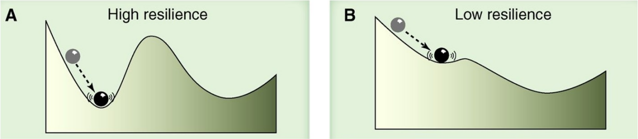
Phase Space & Attractors

Observing dynamics of a system, some states are more probable than other:



Equifinality – a tendency of a system to reach similar final states from different initial conditions.

Phase Space & Attractors

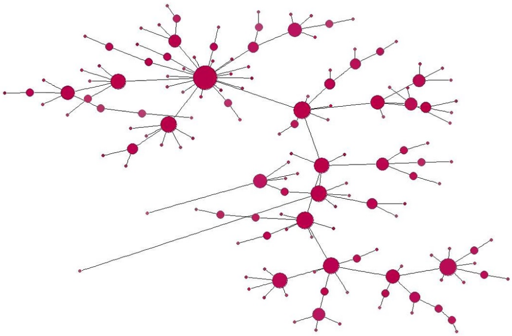


- In an attractor domain, the system is stable, robust to change and locally (not globally) predictable
- At a saddle between two attractors, the system is unstable and sensitive to input conditions – small inputs may result in two qualitatively different states
- The saddle may be also called "repellor"

Interactive Introduction to Attractor Landscapes

Complexity Concepts in Networks

- Attractors (hubs)
- Self-organization (network formation)
- Pattern-formation (network motifs)
- Emergent properties (global phenomena)
- Fractal structure (self-similarity)
- Tipping points (giant component emergence)



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