Why Complexify?

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Principles of Complex Systems, Vols. 1 & 2
CSYS/MATH 300 and 303, 2021–2022 | @pocsvox

Prof. Peter Sheridan Dodds | @peterdodds

Computational Story Lab | Vermont Complex Systems Center
Vermont Advanced Computing Core | University of Vermont

Outline

Limits to what's possible:

Universality:

- The property that the macroscopic aspects of a system do not depend sensitively on the system's details.
- Key figure: Leo Kadanoff
- Kadanoff's retrospective: "Innovations in Statistics Physics" [4]

Examples:

- The Central Limit Theorem:

$$P(x;\mu,\sigma)\mathrm{d}x = \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-\mu)^2/2\sigma^2}\mathrm{d}x\,.$$

- Navier Stokes equation for fluids.
- Nature of phase transitions in statistical mechanics.

Universality

- Sometimes details don't matter too much.
- Many-to-one mapping from micro to macro
- Suggests not all possible behaviors are available at higher levels of complexity.
- Universality means some things are fated.

Large questions:

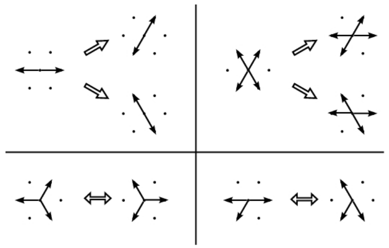
- How universal is universality?
- What are the possible long-time states (attractors) for a universe?

Fluid mechanics

- Fluid mechanics = One of the great successes of understanding complex systems.
- Navier-Stokes equations: micro-macro system evolution.
- The big three: Experiment + Theory + Simulations.
- Works for many very different 'fluids':
  - the atmosphere,
  - oceans,
  - blood,
  - the earth's mantle,
  - galaxies, ...
  - and ball bearings on lattices ...?

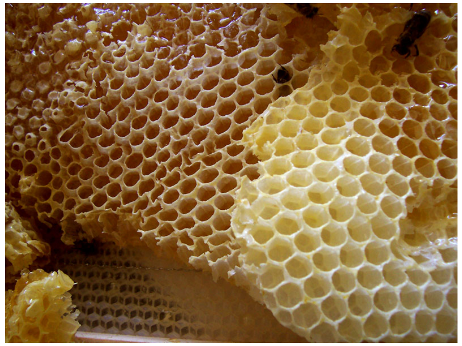
Lattice gas models

Collision rules in 2-d on a hexagonal lattice:



- Lattice matters ...
- No 'good' lattice in 3-d.
- Upshot: play with 'particles' of a system to obtain new or specific macro behaviours.

Hexagons—Honeycomb:



- Orchestrated? Or an accident of bees working hard?
- See "On Growth and Form" by D'Arcy Wentworth Thompson. [7, 8]

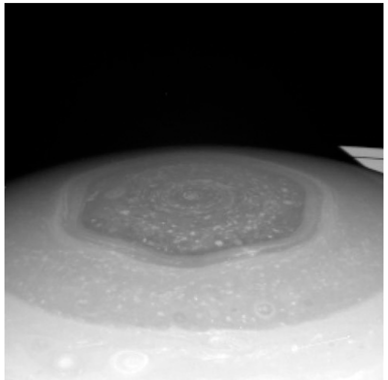
Hexagons—Giant's Causeway:

http://newdesktopwallpapers.info

Hexagons—Giant's Causeway:

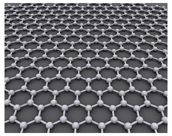
http://www.physics.utoronto.ca/

Saturn has a hexagon:



- One side is longer than Earth's diameter

Hexagons run amok:



- Graphene: single layer of carbon molecules in a perfect hexagonal lattice (super strong).
- Chicken wire ...

Triumph of the Hexagon

From the remarkable Hexnet.org, the Global Hexagonal Awareness Resource Center.

Symmetry Breaking

"More is different"
P. W. Anderson,
Science, **177**, 393–396, 1972.[1]

- Anderson argues against idea that the only real scientists are those working on the fundamental laws.
- Symmetry breaking → different laws/rules at different scales ...

2006 study: "most creative physicist in the world"

Symmetry Breaking

"Elementary entities of science X obey the laws of science Y"

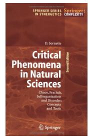
X	Y
solid state or many-body physics	elementary particle physics
chemistry	solid state many-body physics
molecular biology	chemistry
cell biology	molecular biology
⋮	⋮
psychology	physiology
social sciences	psychology

Symmetry Breaking

Anderson:

- [the more we know about] "fundamental laws, the less relevance they seem to have to the very real problems of the rest of science."
- Scale and complexity thwart the constructionist hypothesis.
- Accidents of history and path dependence matter.

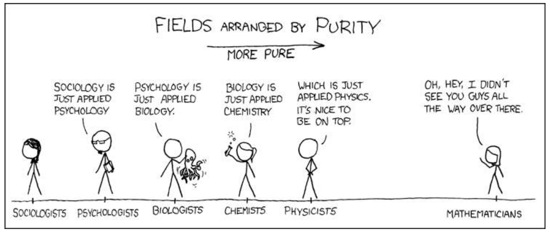
Symmetry Breaking



"Critical Phenomena in Natural Sciences" by Didier Sornette (2003).[5]

- Page 291–292 of Sornette[6]: Renormalization ≡ Anderson's hierarchy.
- But Anderson's hierarchy is not a simple one: the rules change.
- Crucial dichotomy between evolving systems following stochastic paths that lead to (a) inevitable or (b) particular destinations (states).

More is different:



http://xkcd.com/435/

A real science of complexity:

A real theory of ~~everything~~ anything:

1. Is not just about the ridiculously small stuff ...
2. It's about the increase of complexity

Accidents of history vs. Universality

- Second law of thermodynamics: we're ~~toast~~ soup in the long run.[1]
- So how likely is the local complexification of structure we enjoy?
- How likely are the Big Transitions?

[1] But: Gravity.[9]

Why complexify?

"Why do things become more complex?"
W. Brian Arthur,
Scientific American, **268**, 92, 1993. [2]

- Argues that evolution toward increased performance brings a ratcheting cycle of complexification and simplification.
- Jet engine replaced the complex piston engine and then itself became more complex.
- Complexification $\equiv$ evolution of algorithms?
- Differential equations and stories $\subset$ Algorithms.
- Life is a loaded word: The Search for Extraterrestrial Algorithms (SETA)?

Why complexify?

Driving complexity's trajectory:

- Big Bang
- Randomness leads to replicating structures;
- Biological evolution;
- Sociocultural evolution;
- Technological evolution;
- Sociotechnological evolution.

Freeman Dyson's of West's "Scale": [3]

The Key to Everything (nybooks.com)

"The astronomer Fang Lizhi published with his wife, Li Shuxian, a popular book, Creation of the Universe (1989), which includes the best explanation that I have seen of the paradox of order and disorder.

The explanation lies in the peculiar behavior of gravity in the physical world. On the balance sheet of energy accounting, gravitational energy is a deficit.

When you are close to a massive object, your gravitational energy is minus the amount of energy it would take to get away from the mass all the way to infinity.

When you walk up a hill on the earth, your gravitational energy is becoming less negative, but never gets up to zero.

Any object whose motions are dominated by gravity will have energy decreasing as temperature increases and energy increasing as temperature decreases."

Dyson:

"As a consequence of the second law of thermodynamics, when energy flows from one such object to another, the hot object will grow hotter and the cold object will grow colder.

That is why the sun grew hotter and the planets grew cooler as the solar system evolved.

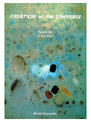
In every situation where gravity is dominant, the second law causes local contrasts to increase together with entropy.

This is true for astronomical objects like the sun, and also for large terrestrial objects such as thunderstorms and hurricanes.

The diversity of astronomical and terrestrial objects, including living creatures, tends to increase with time, in spite of the second law.

The evolution of natural ecologies and of human societies is a part of this pattern. West is evidently unaware of Fang and Li's insight."

Note: Unfortunately, Dyson takes the (disastrously wrong) biological scaling stuff as being sorted.



"Creation of the Universe"
by Zhi and Xian (1989). [9]

84 *Creation of the Universe*

The whole of thermodynamics starts from the existence of thermal equilibrium. For systems in which gravitation plays a decisive role, that sort of thermal equilibrium does not in fact exist. Such systems cannot be in a state of thermodynamic equilibrium, nor in some fixed state differing slightly from equilibrium, rather, they are in unstable states. It is not surprising that certain deductions in thermodynamics do not apply to such states.

Formation of Structures

Let us look at another instructive example for cosmology.

If, in a container of gas, the distribution of the gas molecules is not uniform and has structures (as in Fig. 6.6(a)), then the direction of its evolution is for the distribution to become uniform and structureless (as in Fig. 6.6(b)). This is to say, the mode of evolution decided by the Second Law of Thermodynamics is

$$\text{structured} \longrightarrow \text{structureless}$$
$$\text{non-uniform} \longrightarrow \text{uniform}\,.$$

If the effect of gravitation among the gas molecules in this box of gas cannot be completely neglected, what will be the result? Suppose the distribution of the gas molecules is uniform at the beginning (as in Fig. 6.6(c)). When there is no gravitation, this is the equilibrium state; when there is gravitation, this equilibrium state becomes unstable. As soon as some local region acquires a slightly higher density through fluctuation, its gravitation becomes stronger, attracting more matter, and forming an even greater density. Likewise, if the density in some region is slightly lowered by fluctuation, its gravitation is weakened and more matter will escape, forming a still lower density. In short, a small fluctuation will completely destroy the homogeneous state (see Fig. 6.6(c) & (d)). We therefore see that, in systems with strong gravitation, the direction of evolution is

$$\text{structureless} \longrightarrow \text{structured}$$
$$\text{uniform} \longrightarrow \text{non-uniform}\,.$$

Throughout the universe, gravitation is dominant. Therefore, even if the initial universe is uniform and structureless, it will spontaneously generate a non-uniform and structured state. Clusters of galaxies of various scales owe their formation to this process of inhomogeneity.

At this point, we can answer the question posed at the beginning of this chapter as follows.

How Order was Born of Chaos 85

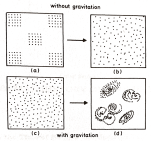


Fig. 6.6. In a system without gravitation, the evolution of the distribution of matter is from non-uniform (a) to uniform (b); in a system with gravitational interaction, the evolution is from uniform (c) to non-uniform (d).

Why is the world getting more complicated? Because there is gravitation.

Why does the simple change into the complex? Because there is gravitation.

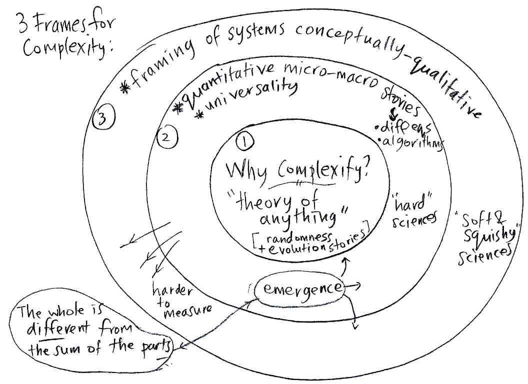
Why does chaos become order? Because there is gravitation.

Out of thermal equilibrium, how can thermal nonequilibrium be generated? Again because there is gravitation.

Of course, in addition to gravitation, the universe has to contain different forms of matter like radiation and particles, in order for the above mechanism to operate. In the next chapter, we shall prove that the universe does indeed have the radiation we expect.

Complexification—the Big Transitions:

- Big Bang.
- Big Randomness.
- Big Structure.
- Big Replicate.
- Big Life.
- Big Evolve.
- Big Word.
- Big Story.
- Big Number.
- Big Farm.
- Big God.
- Big Make.
- Big City.
- Big Culture.
- Big Science.
- Big Data.
- Big Information.
- Big Algorithm.
- Big Connection.
- Big Social.
- Big Awareness.
- Big Spread.
- Big ...?



The absolute basics:

Modern basic science in three steps:

1. Find interesting/meaningful/important phenomena, optionally involving spectacular amounts of data.
2. Taste matters. Develop taste in research.
3. Describe what you see.
4. Explain it.

Unlocks our (limited) ability to: Create, predict, and control.

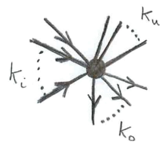
And be good people: Share.

Beware your assumptions: Don't use tools/models because they're there, or because everyone else does ...

This is a thing that could be next:

Principles of Complex Systems, Vol. 2

Once was CocoNuTs: The PoCS strikes back



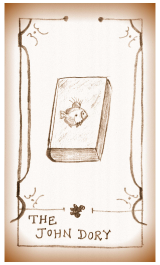
CSYS/MATH 303:
Complex Networks
@networksvox
@storyologyvox

- Branching networks (rivers, cardiovascular systems).
- The Church of Quarterology.
- Optimal (re)distribution networks (hospitals, coffee shops, airlines, post, Internet).
- Structure detection for complex systems.
- Moar Contagion.
- Random networks-arama.
- Distributed Search.
- Organizational networks.
- Deeper investigations of scale-free networks. Eh.
- and more ...

This is also part of a thing that could be next:

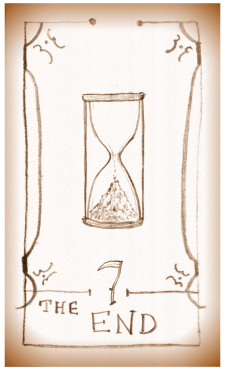
Principles of Complex Systems, Vol. 2

Storyology
Episode VI:
PoCS with ewoks



CSYS/MATH ???:
@storyologyvox

- Exploring texts of all kinds, centrality of stories.
- News, social media, fiction, Twitter.
- Dark arts of text parsing, cleaning, regular expression.
- Measuring happiness and sadness through text.
- Measuring and understanding cultural evolution through texts: legal and government texts, music lyrics, news.
- Structure, dynamics, and evolution of stories.
- Possible expansion to other storytelling realms: Music, images, audio, video, sports, games.



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