Why Complexify?

Principles of Complex Systems | @pocsvox
CSYS/MATH 300, Fall, 2015 | #FallPoCS2015

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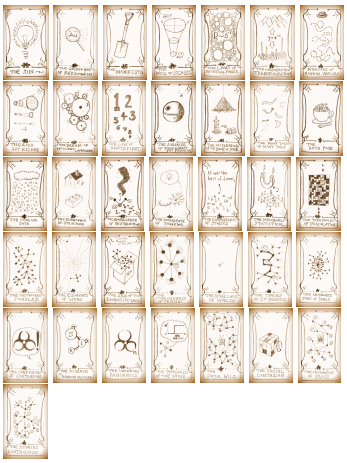


These slides are brought to you by:

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" [3]

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.

Outline

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:

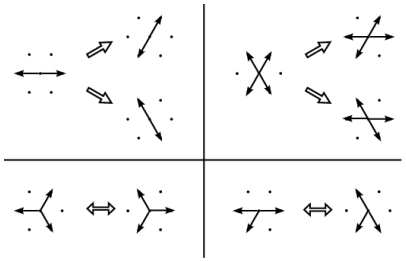
- How universal is universality?
- What are the possible long-time states (attractors) for a universe?

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,
  - galaxies,
  - the earth's mantle ...
  - and ball bearings on lattices ...?

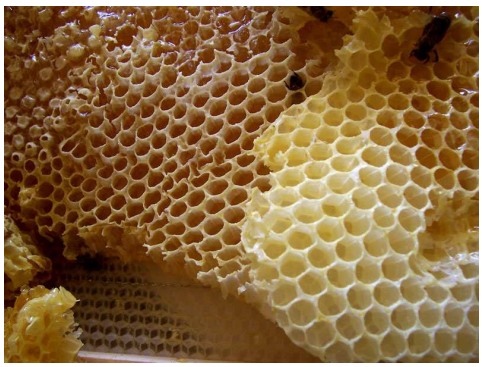
Lattice gas models

Collision rules in 2-d on a hexagonal lattice:



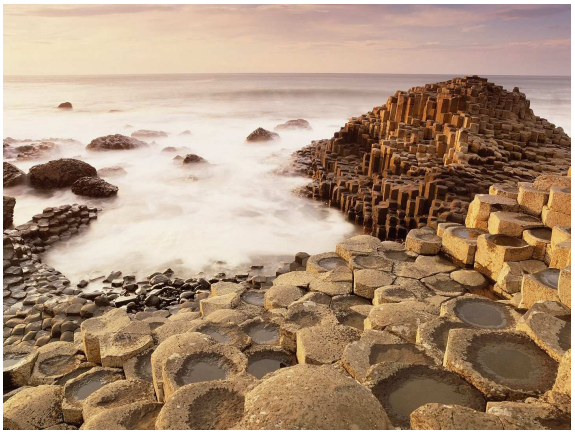
- Lattice matters ...
- No 'good' lattice in 3-d.
- Upshot: play with 'particles' of a system to obtain new or specific macro behaviours.

Hexagons—Honeycomb:



- Orchestrated? Or an accident of bees working hard?
- See "On Growth and Form" by D'Arcy Wentworth Thompson. [6, 7]

Hexagons—Giant's Causeway:

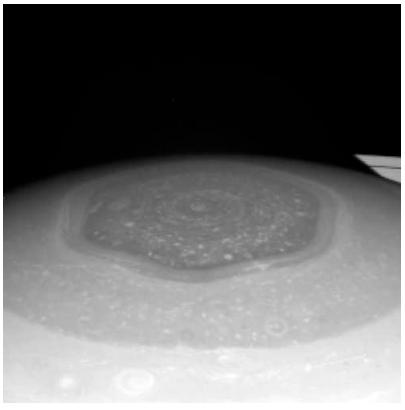


http://newdesktopwallpapers.info

Hexagons—Giant's Causeway:

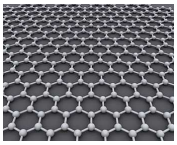
http://www.physics.utoronto.ca/

Saturn has a hexagon:



- One side is longer than Earth's diameter

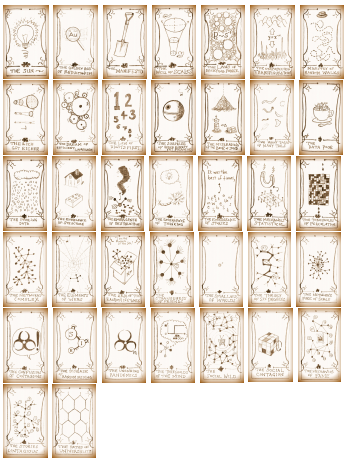
Hexagons run amok:



- 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:

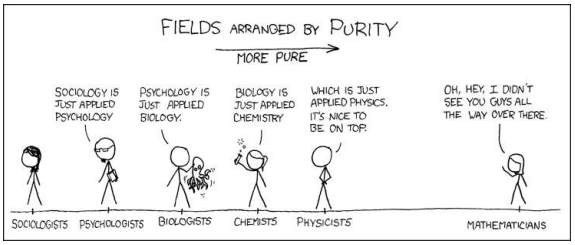
- [the more we know about] "fundamental laws, the less relevance they seem to have to the very real problems of the rest of science."
- Scale and complexity thwart the constructionist hypothesis.
- Accidents of history and path dependence matter.

Symmetry Breaking

"Critical Phenomena in Natural Sciences" by Didier Sornette (2003). [4]

- Page 291–292 of Sornette [5]: 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

Symmetry breaking/ Accidents of history vs. Universality

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

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 ≡ evolution of algorithms?
- Differential equations and stories ⊂ Algorithms.
- Life is a loaded word: The Search for Extraterrestrial Algorithms (SETA)?

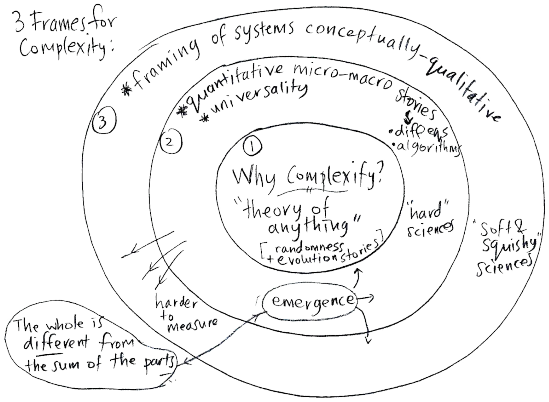
Why complexify?

Driving complexity's trajectory:

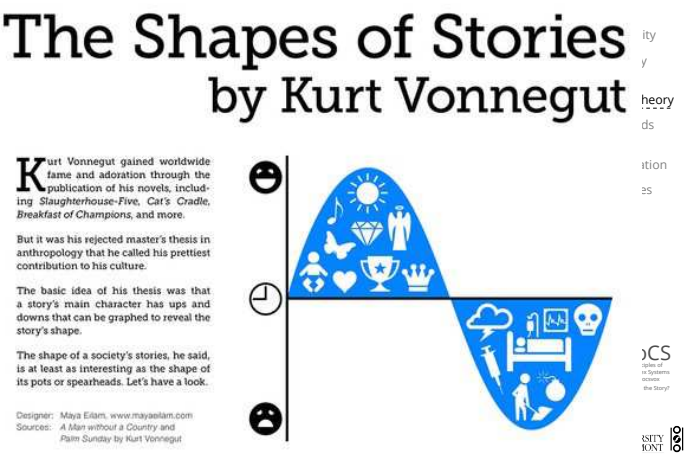
- Big Bang
- Randomness leads to replicating structures;
- Biological evolution;
- Sociocultural evolution;
- Technological evolution;
- Sociotechnological evolution.

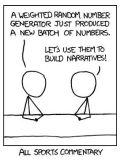
Complexification—the Big Transitions:

- 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 ...?



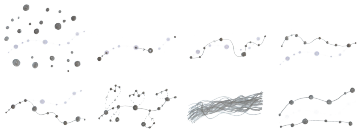
Kurt Vonnegut on the shapes of stories:





http://xkcd.com/904/

- Homo narrativus—we run on stories.
- Extraction of metaphors, frames, narratives, and stories from large-scale text.
- The narrative hierarchy: Scalability of stories.
- Adjacent narratives, mistruths, and conspiracy theories.
- The taxonomy of human stories.



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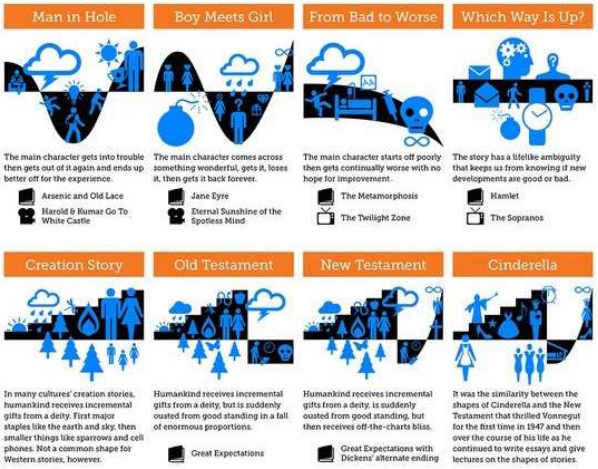
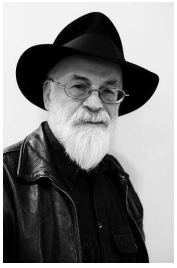
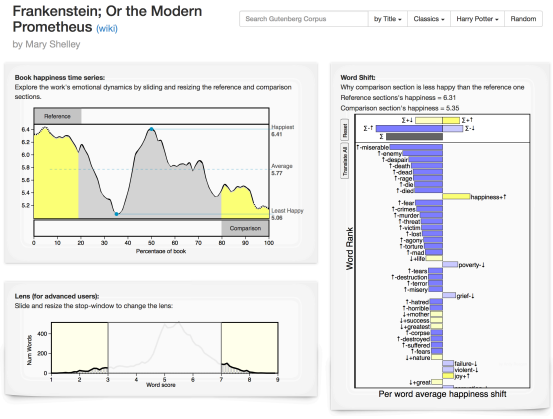


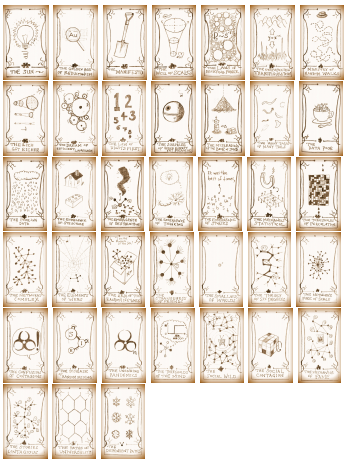
(Sir Terry) Pratchett's Narrativium:

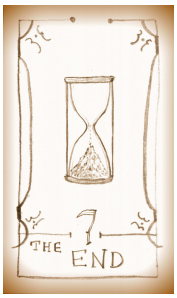


- "The most common element on the disc, although not included in the list of the standard five: earth, fire, air, water and surprise. It ensures that everything runs properly as a story."
- "A little narrativium goes a long way: the simpler the story, the better you understand it. Storytelling is the opposite of reductionism: 26 letters and some rules of grammar are no story at all."
- "Heroes only win when outnumbered, and things which have a one-in-a-million chance of succeeding often do so."

Online, interactive Emotional Shapes of Stories for 10,000+ books:







The absolute basics:

Modern basic science in three steps:

1. Find interesting/meaningful/important phenomena, optionally involving spectacular amounts of data.
2. Describe what you see.
3. Explain it.

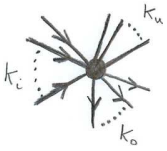
Unlocks our (limited) ability to: Create, predict, and control.

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:

CoNKs: The PoCS strikes back:



CSYS/MATH 303: Complex Networks @networksvox

- Branching networks (rivers, cardiovascular systems).
- 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.
- and more ...

References I

[1] P. W. Anderson.
More is different.
Science, 177(4047):393–396, 1972. pdf

[2] W. B. Arthur.
Why do things become more complex?
Scientific American, 268:92, 1993. pdf

[3] L. P. Kadanoff.
Innovations in statistical physics, 2014.
http://arxiv.org/abs/1403.6464. pdf

[4] D. Sornette.
Critical Phenomena in Natural Sciences.
Springer-Verlag, Berlin, 2nd edition, 2003.

References II

[5] D. Sornette.
Critical Phenomena in Natural Sciences.
Springer-Verlag, Berlin, 1st edition, 2003.

[6] D. W. Thompson.
On Growth and From.
Cambridge University Pres, Great Britain, 2nd edition, 1952.

[7] D. W. Thompson.
On Growth and Form — Abridged Edition.
Cambridge University Press, Great Britain, 1961.