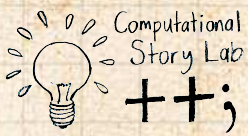
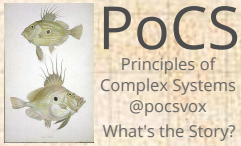
Why Complexify?

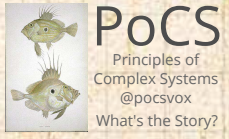
Principles of Complex Systems | @pocsvox
CSYS/MATH 300, Fall, 2015 | #FallPoCS2015

Prof. Peter Dodds | @peterdodds

Dept. of Mathematics & Statistics | Vermont Complex Systems Center
Vermont Advanced Computing Core | University of Vermont







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Outline

PoCS
Principles of Complex Systems
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What's the Story?

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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.

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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?

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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...?

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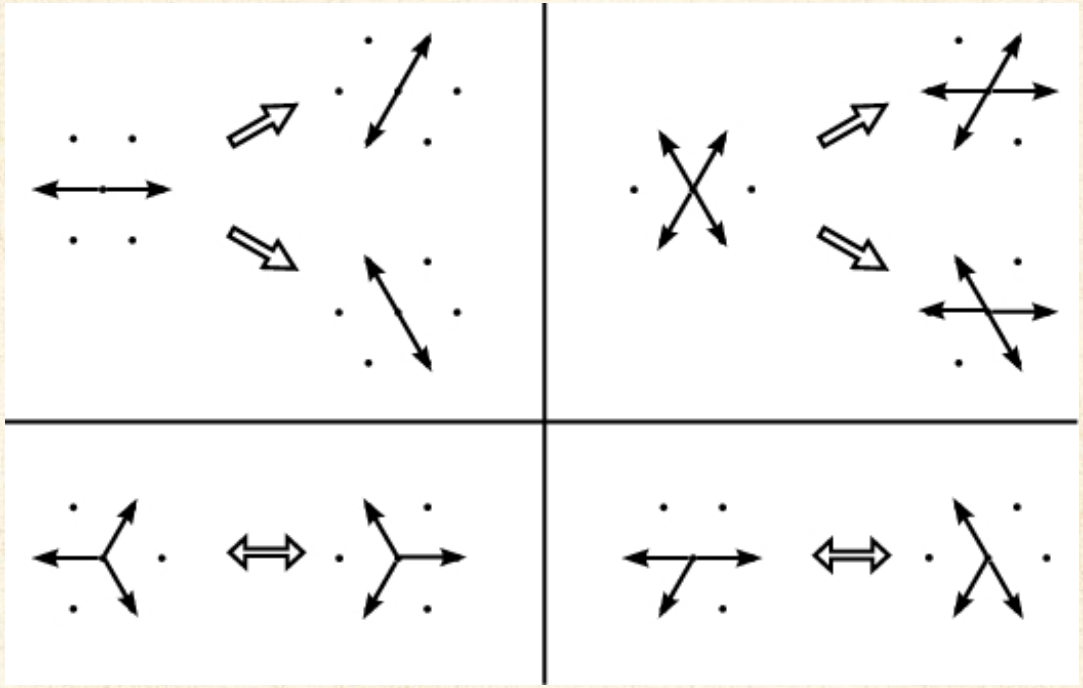
Lattice gas models

Collision rules in 2-d on a hexagonal lattice:



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- Upshot: play with 'particles' of a system to obtain new or specific macro behaviours.

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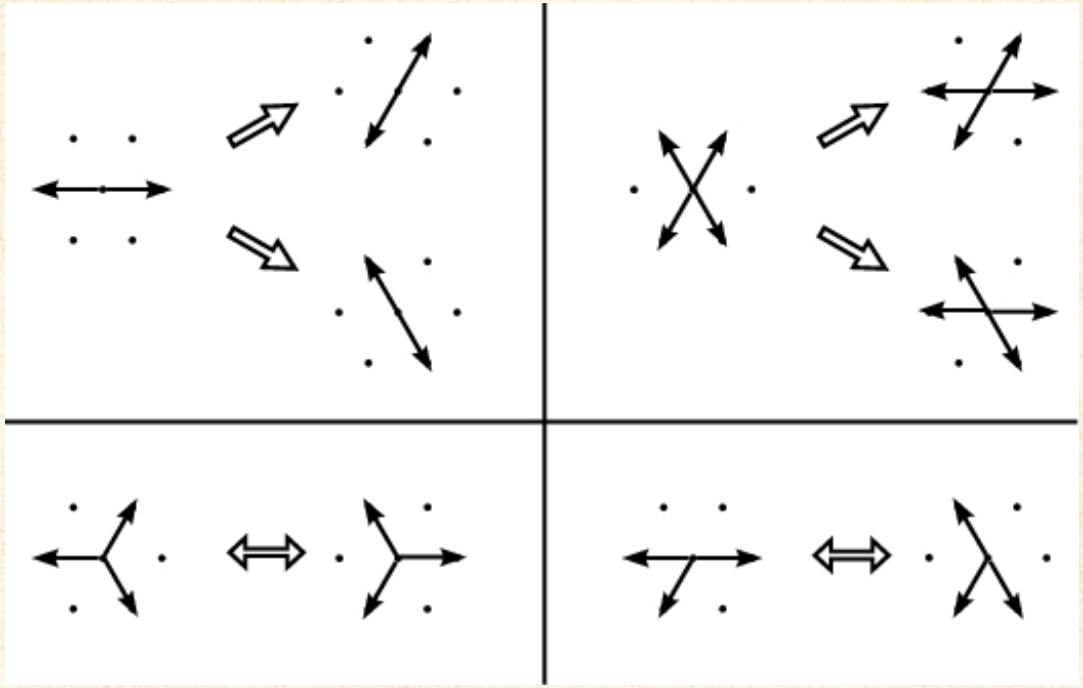

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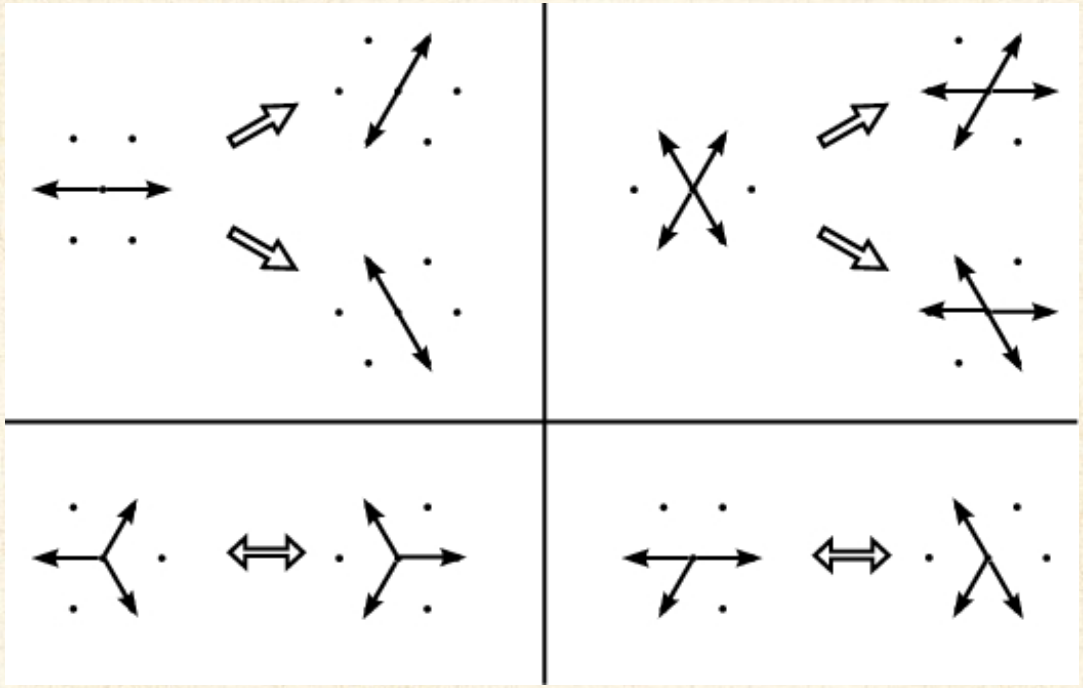

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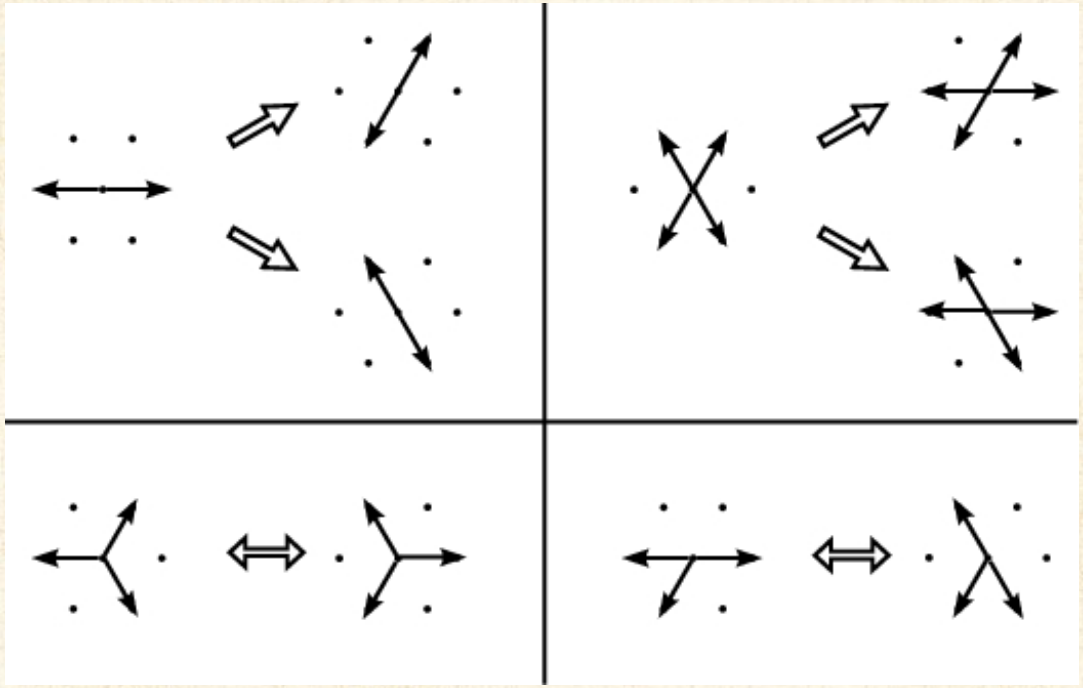

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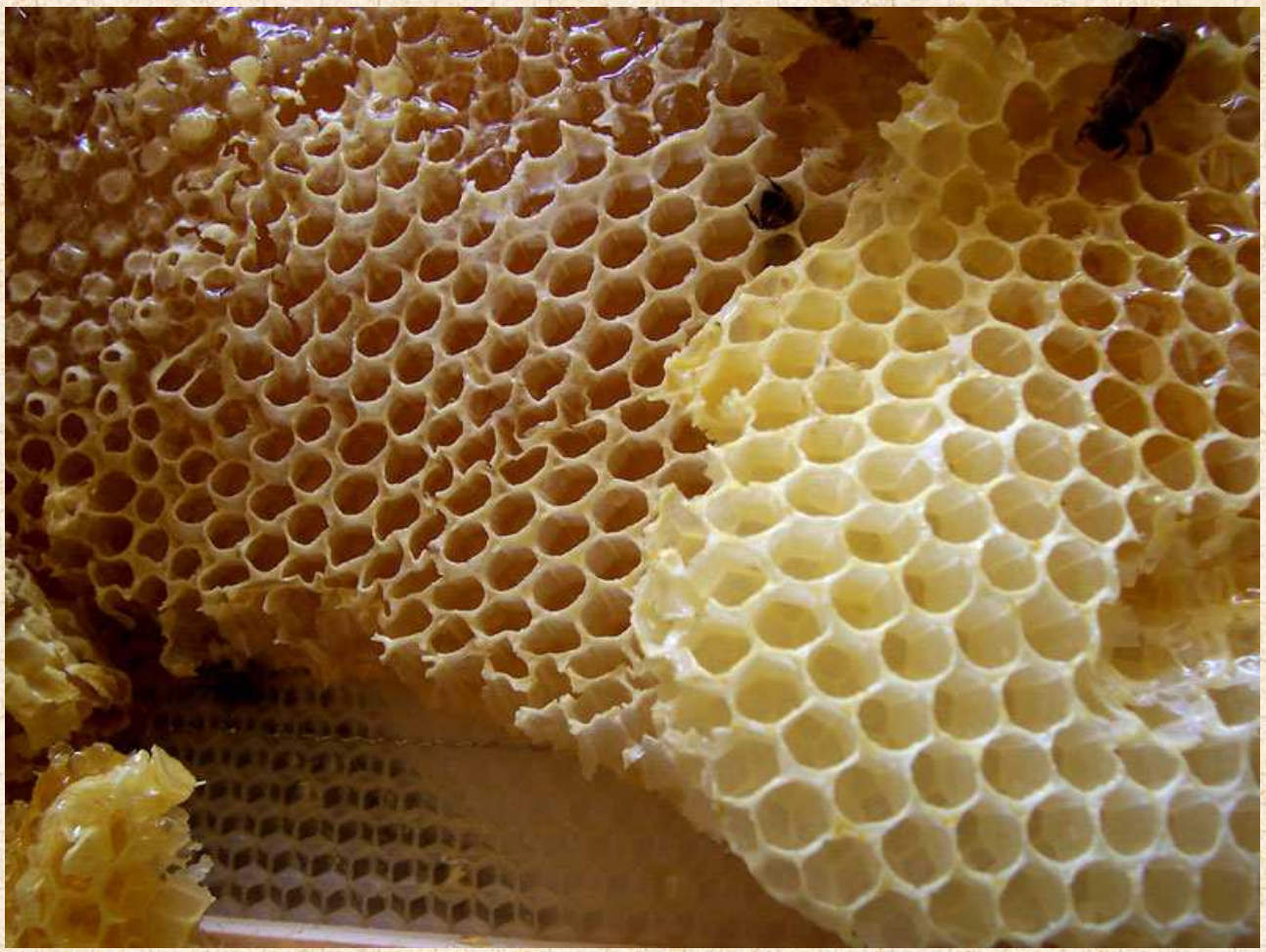
Hexagons—Honeycomb:



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

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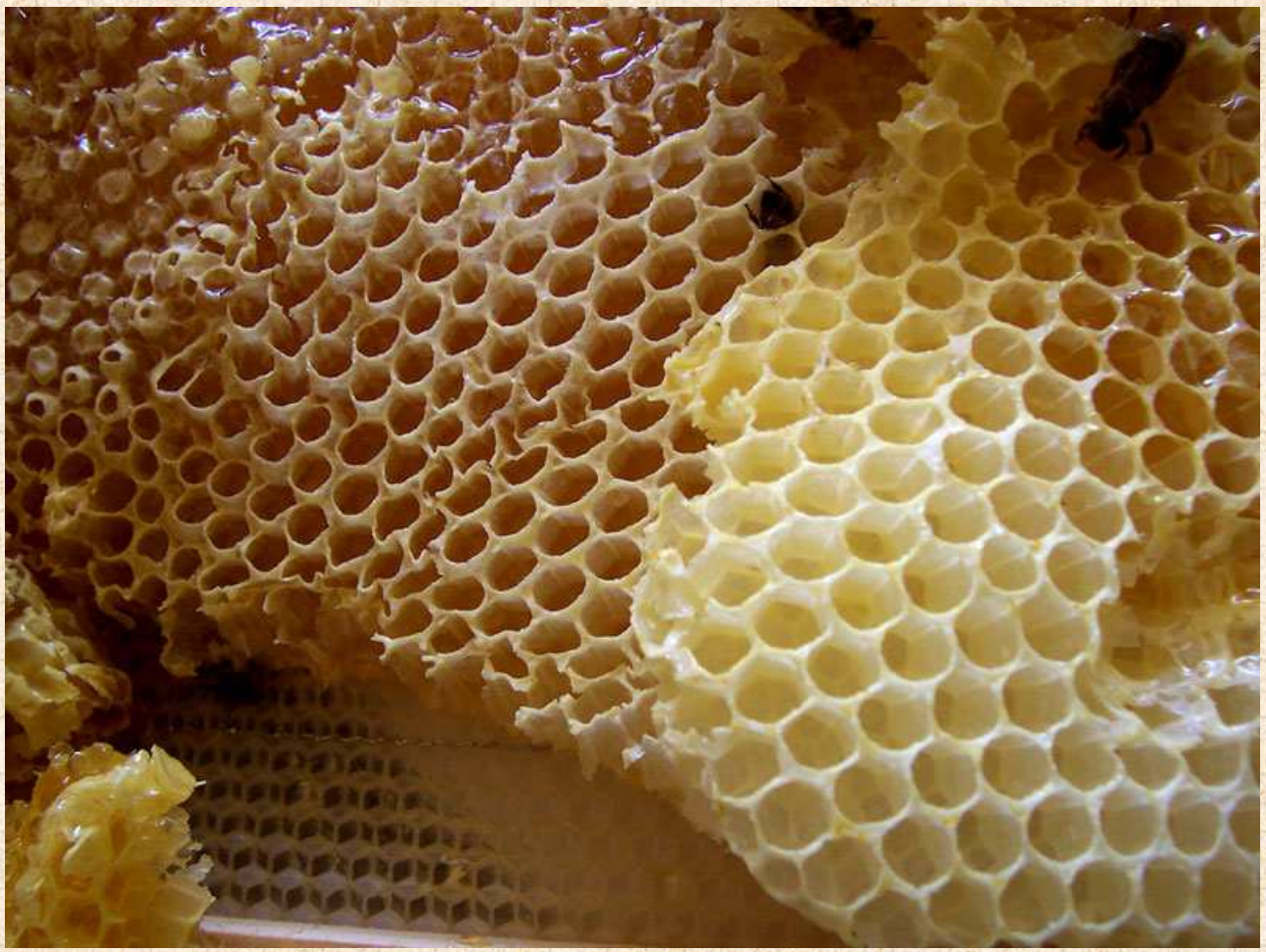

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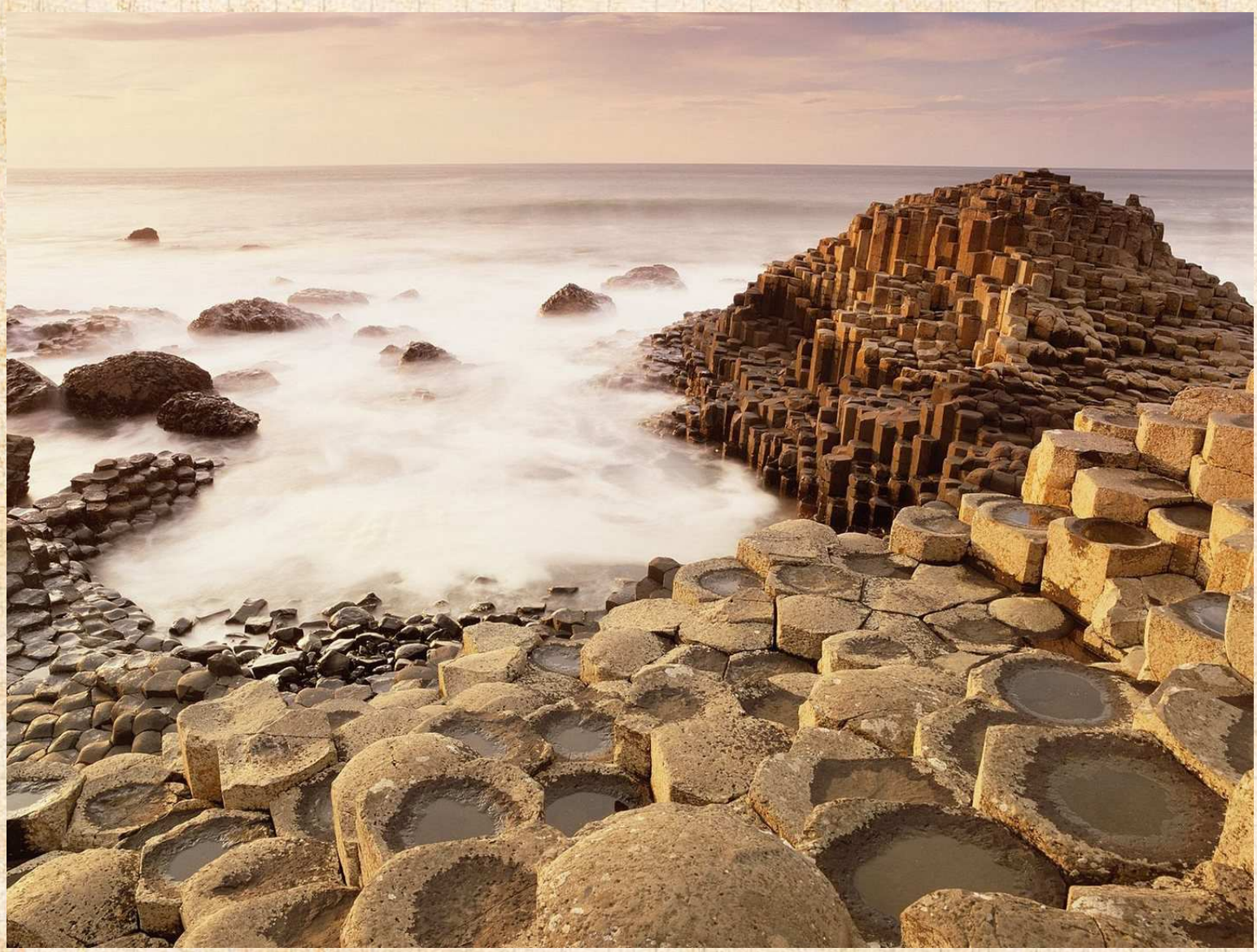
Hexagons—Giant's Causeway:

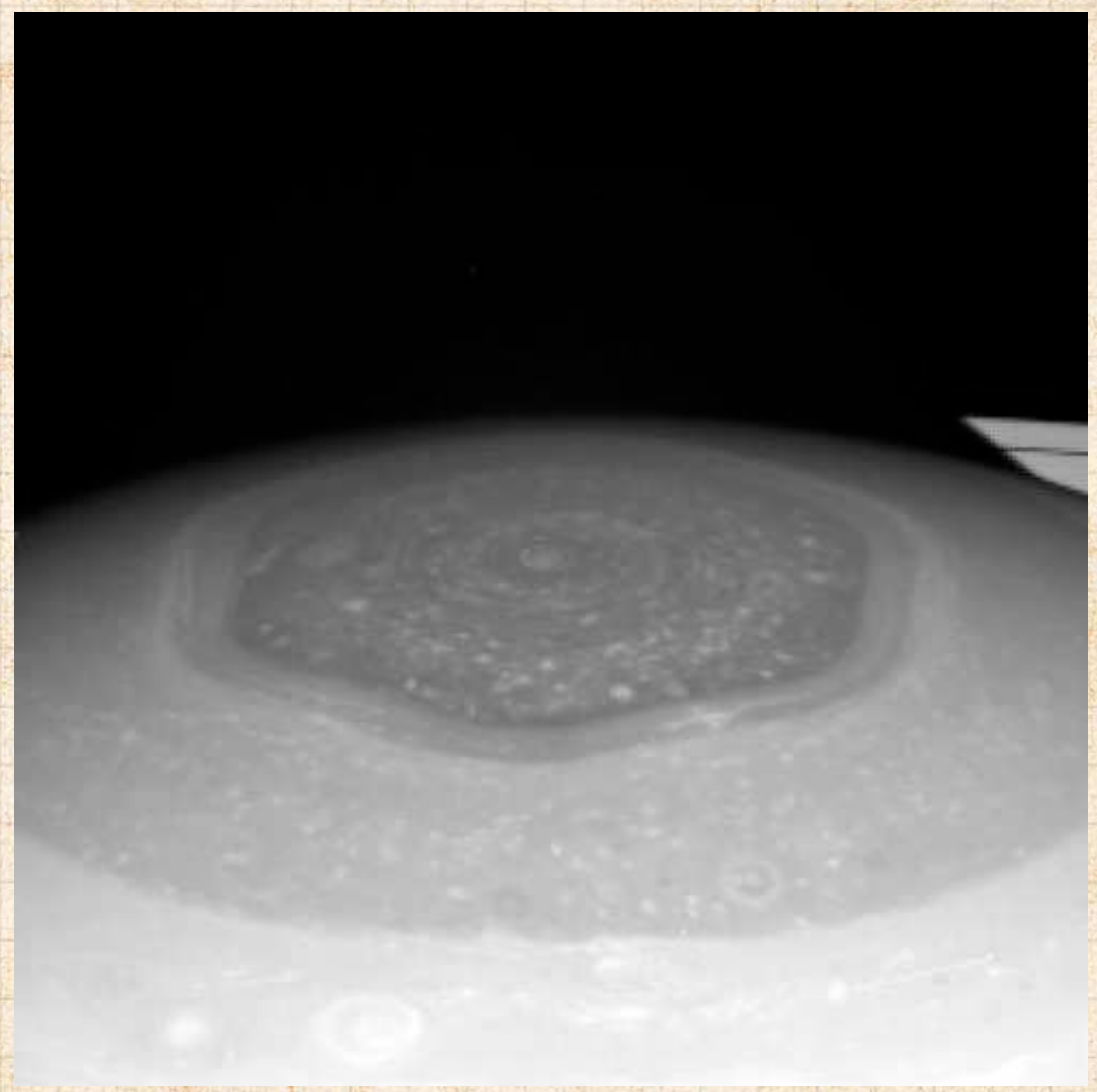


http://newdesktopwallpapers.info

Hexagons—Giant's Causeway:

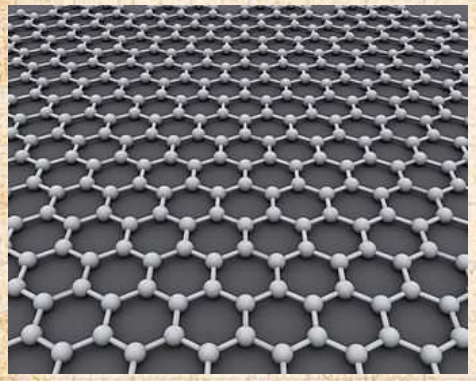
http://www.physics.utoronto.ca/

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.

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Symmetry Breaking


SCIENCE

4 August 1972, Volume 177, Number 4047

More Is Different

Broken symmetry and the nature of the hierarchical structure of science.

P. W. Anderson

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

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2006 study: "most creative physicist in the world"

Symmetry Breaking

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

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

- Y
- elementary particle physics
- solid state many-body physics
- chemistry
- molecular biology
- ⋮
- physiology
- 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.

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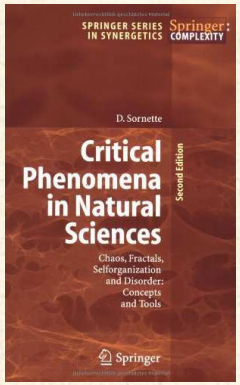

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- Page 291–292 of Sornette [5]: Renormalization ≡ Anderson's hierarchy.
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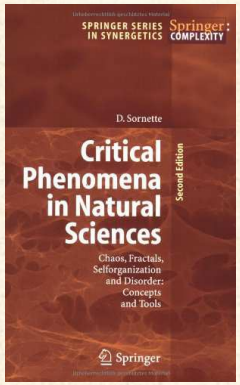

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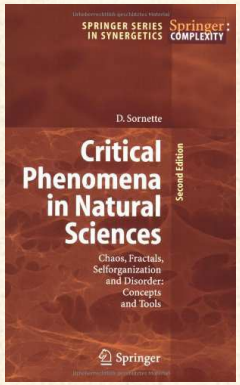

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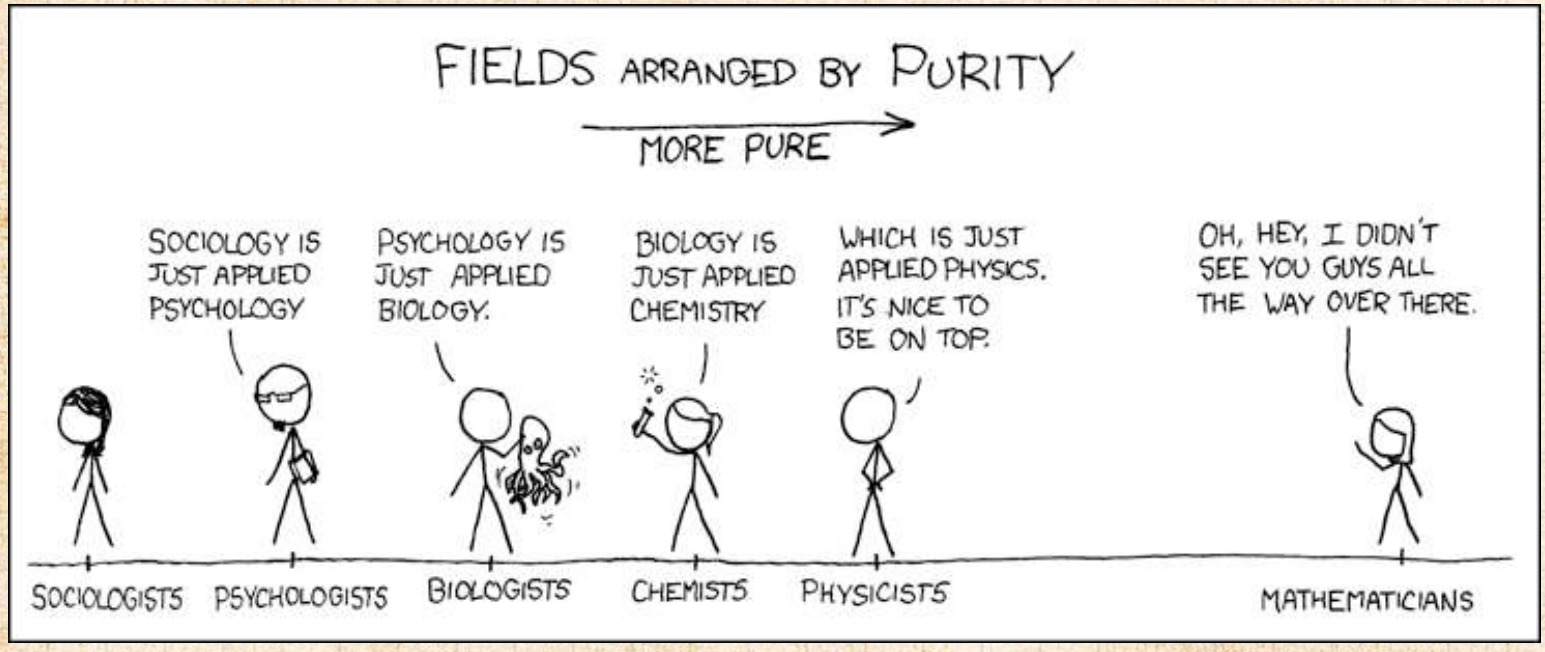

http://xkcd.com/435/

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?

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ESSAY by W. Brian Arthur

Why Do Things Become More Complex?

"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)?

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Driving complexity's trajectory:

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

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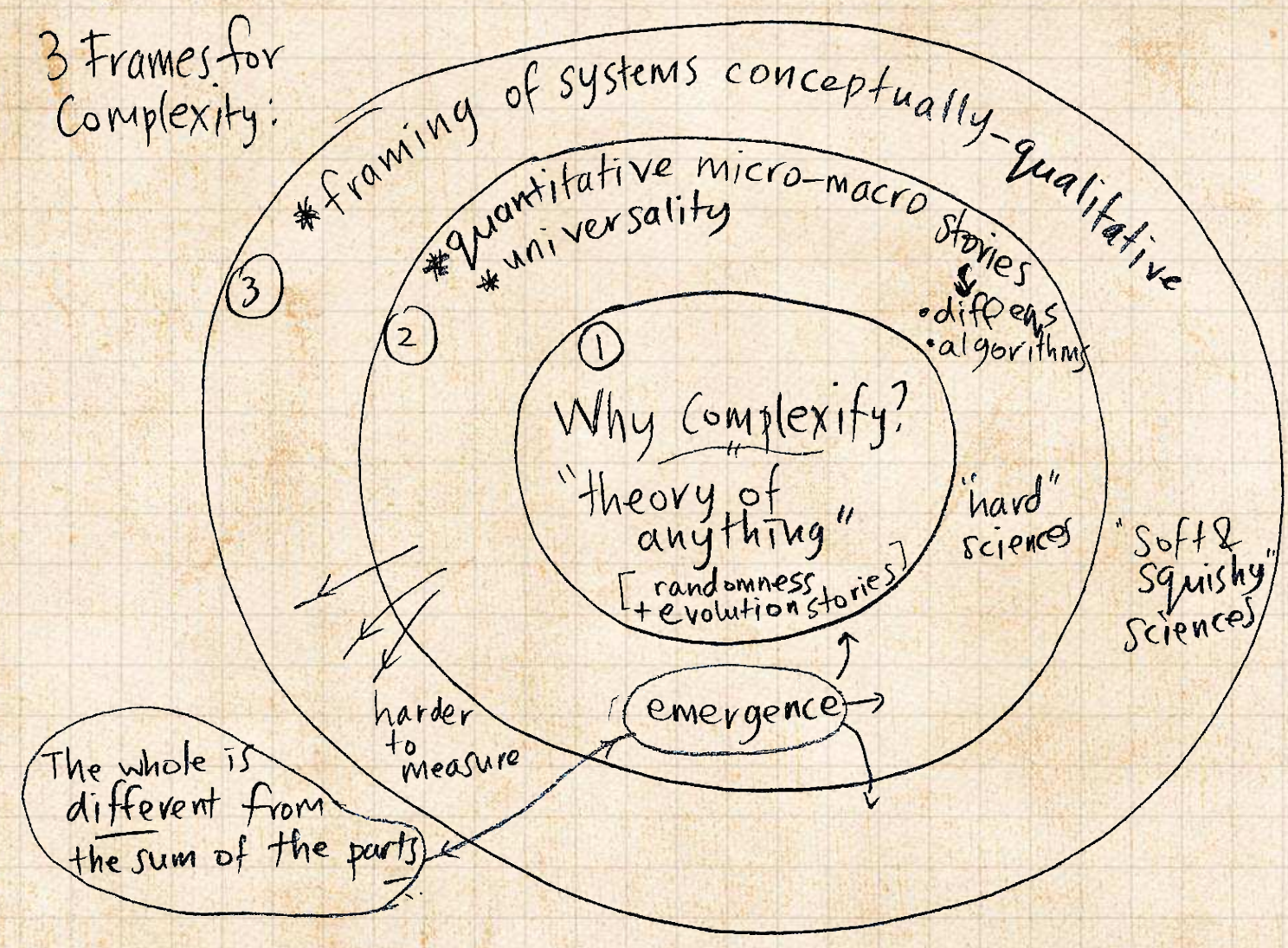
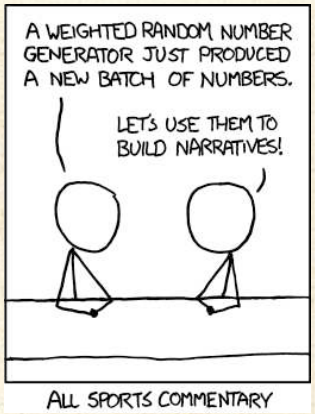
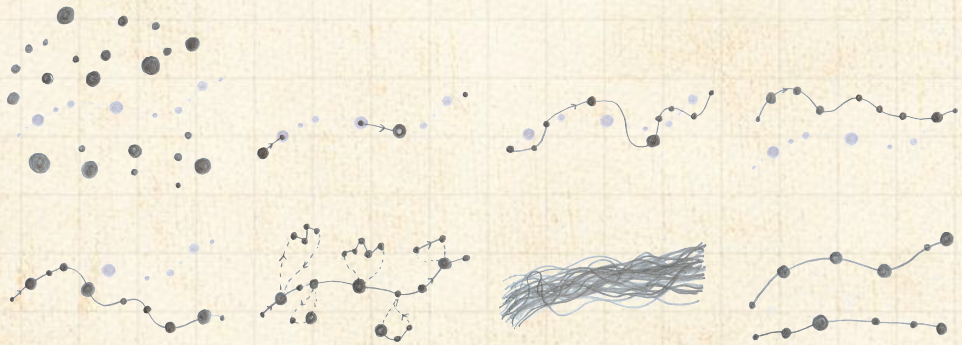


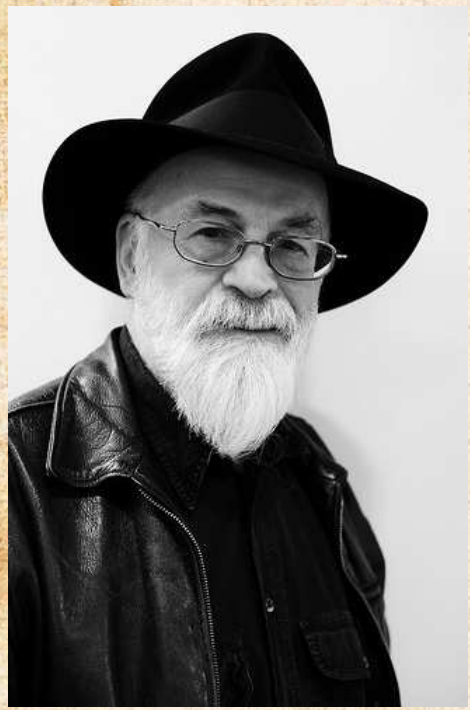


http://xkcd.com/904/

- 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.



(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."

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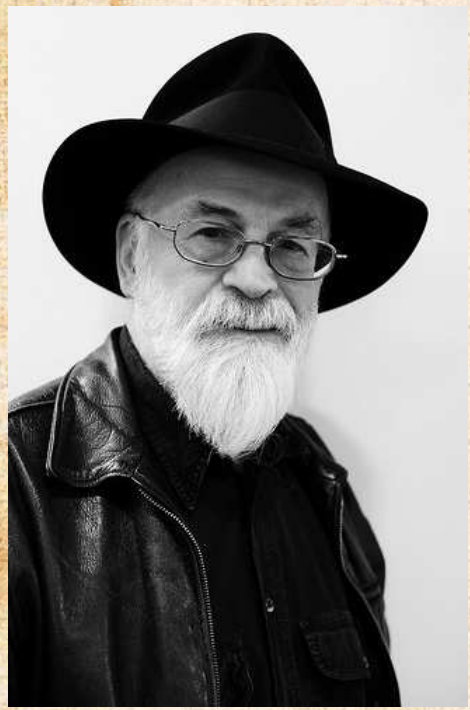

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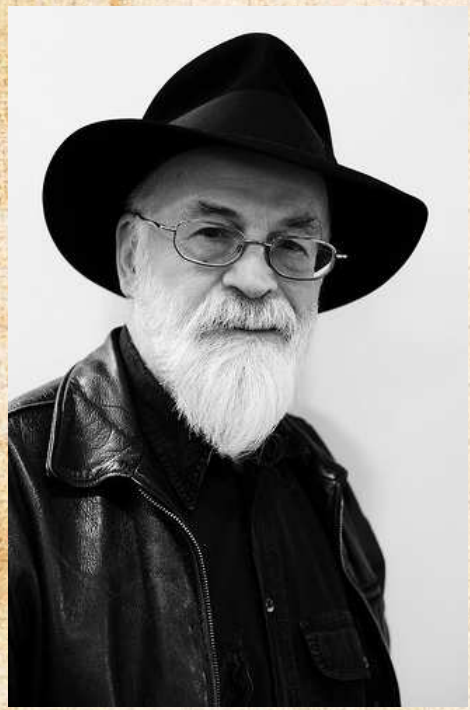

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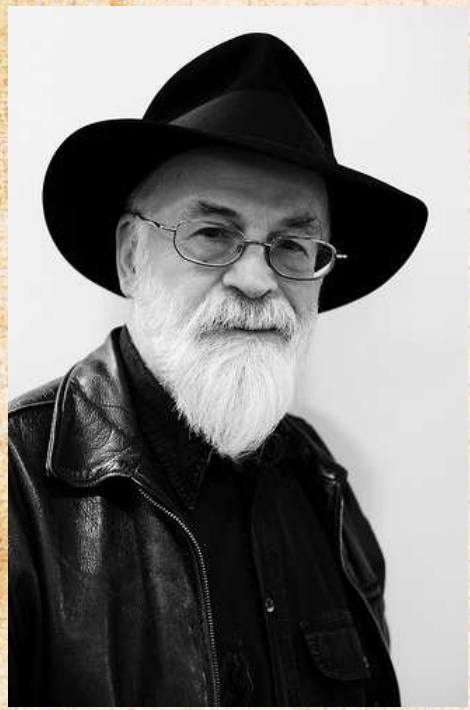

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Kurt Vonnegut on the shapes of stories:

The Shapes of Stories
by Kurt Vonnegut

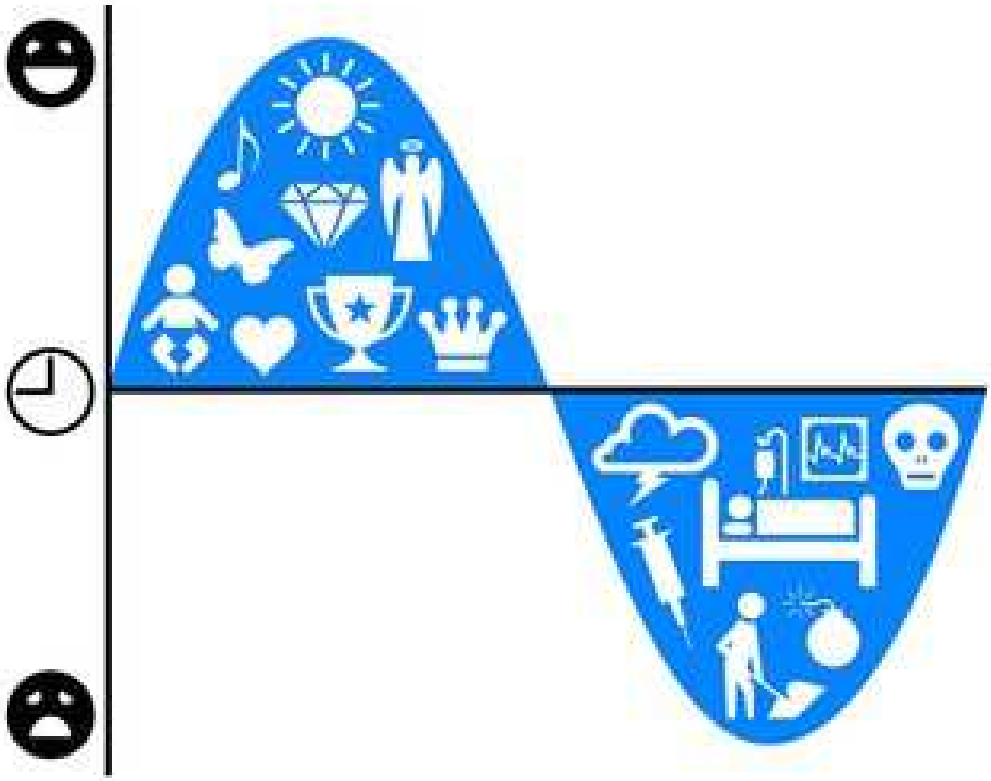
Kurt Vonnegut gained worldwide fame and adoration through the publication of his novels, including *Slaughterhouse-Five*, *Cat's Cradle*, *Breakfast of Champions*, and more.

But it was his rejected master's thesis in anthropology that he called his prettiest contribution to his culture.

The basic idea of his thesis was that a story's main character has ups and downs that can be graphed to reveal the story's shape.

The shape of a society's stories, he said, is at least as interesting as the shape of its pots or spearheads. Let's have a look.

Designer: Maya Eilam, www.mayaeilam.com
Sources: *A Man without a Country* and *Palm Sunday* by Kurt Vonnegut



Kurt Vonnegut on the shapes of stories:

Man in Hole

The main character gets into trouble then gets out of it again and ends up better off for the experience.

- Arsenic and Old Lace
- Harold & Kumar Go To White Castle

Boy Meets Girl

The main character comes across something wonderful, gets it, loses it, then gets it back forever.

- Jane Eyre
- Eternal Sunshine of the Spotless Mind

From Bad to Worse

The main character starts off poorly then gets continually worse with no hope for improvement.

- The Metamorphosis
- The Twilight Zone

Which Way Is Up?

The story has a lifelike ambiguity that keeps us from knowing if new developments are good or bad.

- Hamlet
- The Sopranos

Creation Story

In many cultures' creation stories, humankind receives incremental gifts from a deity. First major staples like the earth and sky, then smaller things like sparrows and cell phones. Not a common shape for Western stories, however.

Old Testament

Humankind receives incremental gifts from a deity, but is suddenly ousted from good standing in a fall of enormous proportions.

- Great Expectations

New Testament

Humankind receives incremental gifts from a deity, is suddenly ousted from good standing, but then receives off-the-charts bliss.

- Great Expectations with Dickens' alternate ending

Cinderella

It was the similarity between the shapes of Cinderella and the New Testament that thrilled Vonnegut for the first time in 1947 and then over the course of his life as he continued to write essays and give lectures on the shapes of stories.

Kurt Vonnegut on the shapes of stories:

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

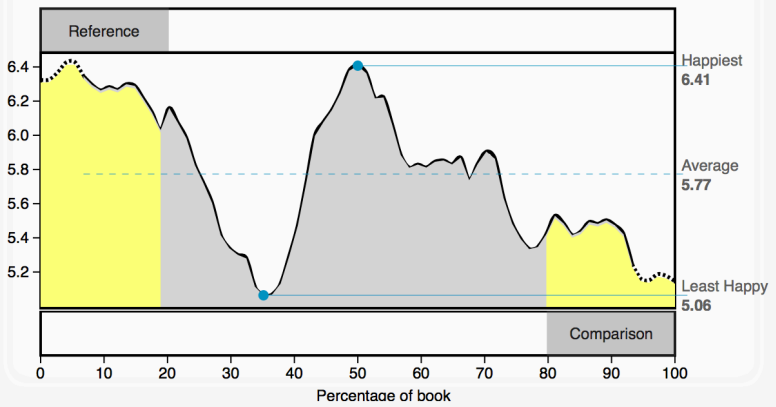
Frankenstein; Or the Modern Prometheus (wiki)

by Mary Shelley

Search Gutenberg Corpus | by Title | Classics | Harry Potter | Random

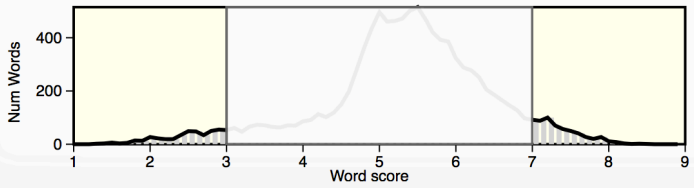
Book happiness time series:

Explore the work's emotional dynamics by sliding and resizing the reference and comparison sections.



Lens (for advanced users):

Slide and resize the stop-window to change the lens:

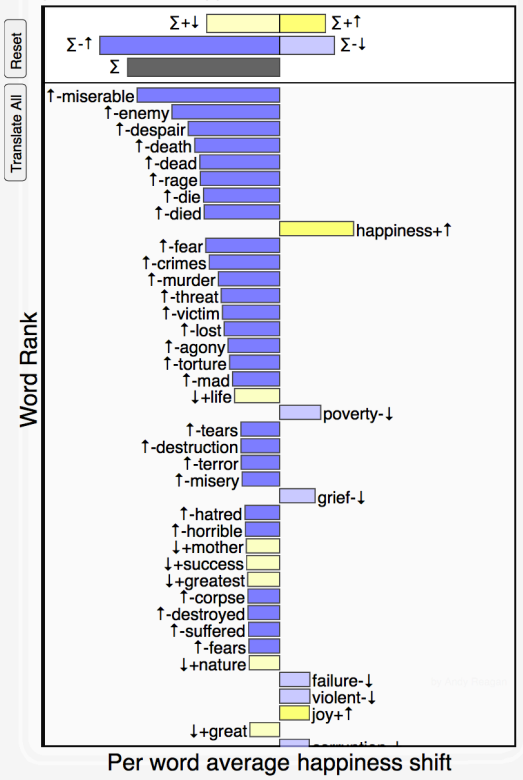


Word Shift:

Why comparison section is less happy than the reference one

Reference sections's happiness = 6.31

Comparison section's happiness = 5.35



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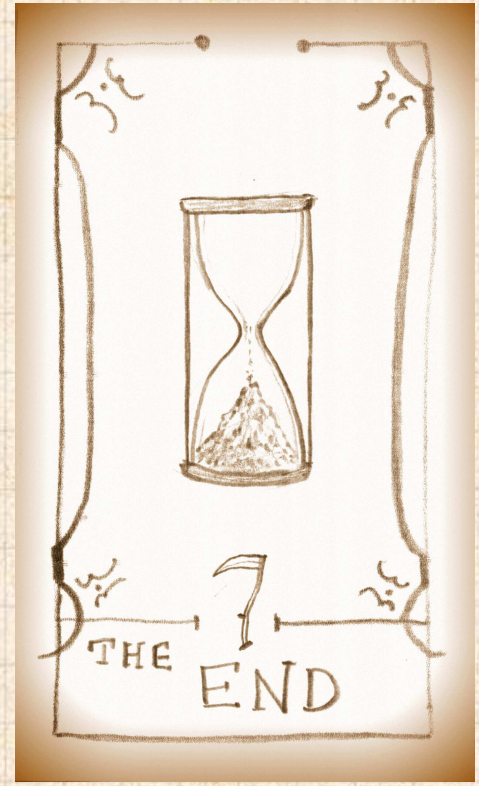

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The absolute basics:

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 ...

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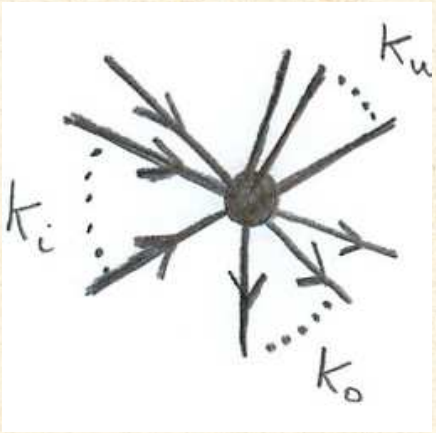
This is a thing that could be next:

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.
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- Deeper investigations of scale-free networks.
- and more ...

PoCS
Principles of Complex Systems
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What's the Story?

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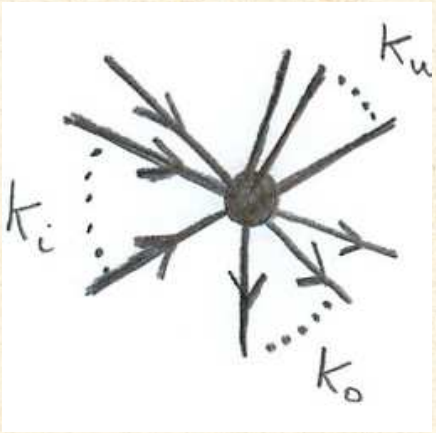
This is a thing that could be next:

CoNKs: The PoCS strikes back:



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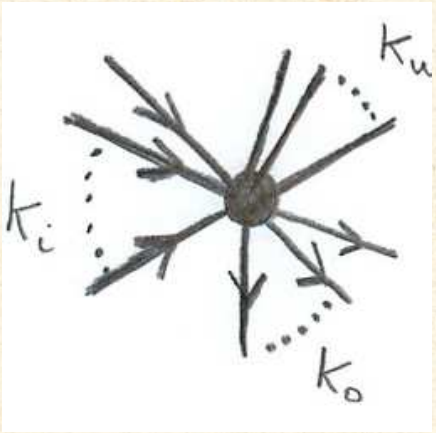

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