

# 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

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References



Licensed under the *Creative Commons Attribution-NonCommercial-ShareAlike 3.0 License*.



These slides are brought to you by:

PoCS | @pocsvox  
Why Complexify?

Sealie & Lambie  
Productions



Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References



# Outline

PoCS | @pocsvox

Why Complexify?

Universality

Universality

Symmetry  
Breaking

Symmetry Breaking

The Big Theory

Final words

The Big Theory

For your  
consideration

Final words

References

For your consideration

References





Universality

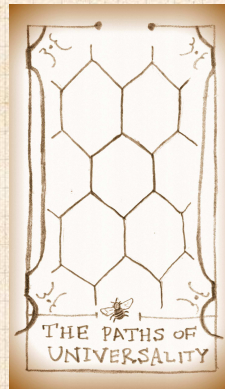
Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration


References





# 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" <sup>[3]</sup>

## Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References

## Examples:

- ▶ The Central Limit Theorem:

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

- ▶ 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?

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References



- ▶ 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 ...?**

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

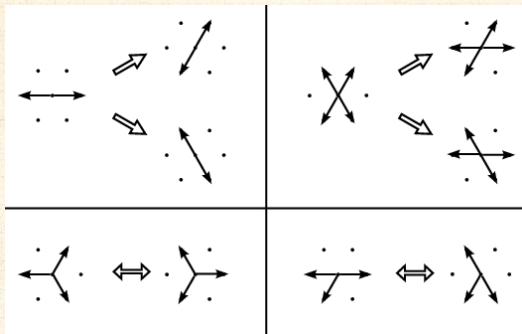
References





# Lattice gas models

Collision rules in 2-d on a hexagonal lattice:



Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References

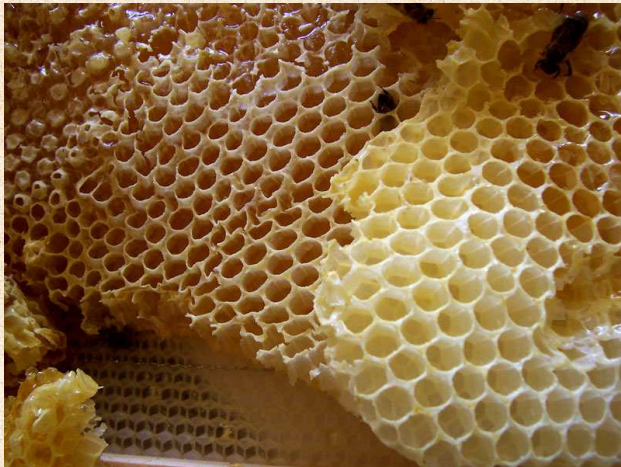
- ▶ Lattice matters ...
- ▶ No 'good' lattice in 3-d.
- ▶ Upshot: play with 'particles' of a system to obtain new or specific macro behaviours.



# Hexagons—Honeycomb:

PoCS | @pocsvox

Why Complexity?



Universality


Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

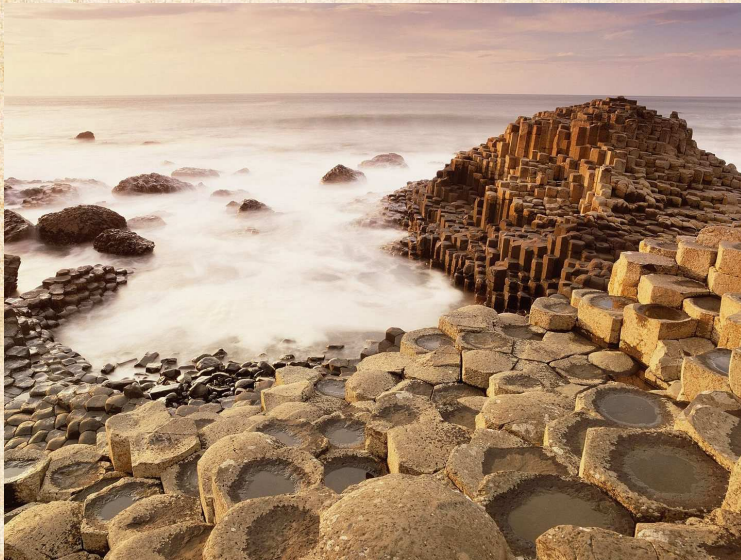
References

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



# Hexagons—Giant's Causeway: ↗

PoCS | @pocsvox  
Why Complexify?



Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References

<http://newdesktopwallpapers.info>





# Hexagons—Giant's Causeway: ↗

PoCS | @pocsvox  
Why Complexity?



Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

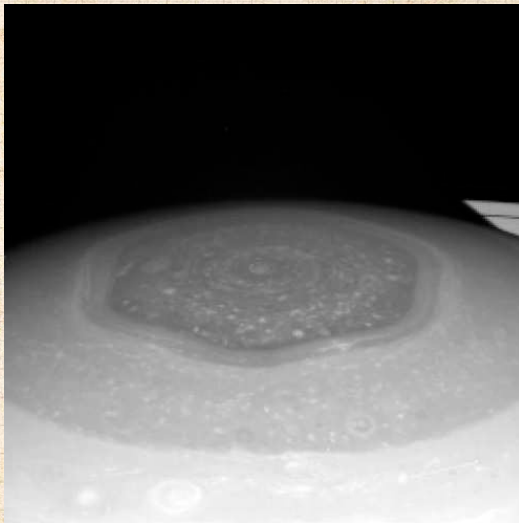
References

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



# Saturn has a hexagon:

PoCS | @pocsvox  
Why Complexify?



Universality

Symmetry  
Breaking

The Big Theory

Final words

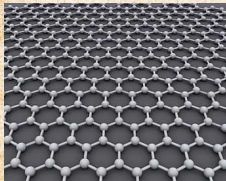
For your  
consideration

References

► 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 ↗ ...

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References





# Triumph of the Hexagon

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References

From the remarkable [Hexnet.org](http://Hexnet.org), the Global  
Hexagonal Awareness Resource Center.



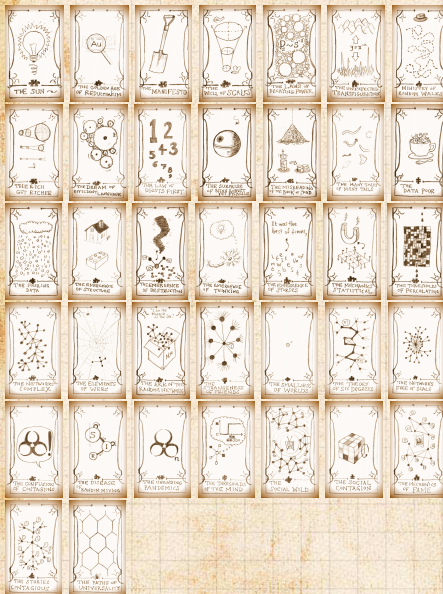
UniversalitySymmetry  
Breaking

The Big Theory

Final words


For your  
consideration

References





# Symmetry Breaking



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



- ▶ 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" 

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References





# 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

Universality

Symmetry Breaking

The Big Theory

Final words

For your consideration

References



# Symmetry Breaking

Universality

Symmetry  
Breaking

The Big Theory

Final words

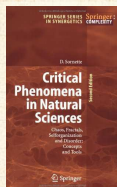
For your  
consideration


References

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.





“Critical Phenomena in Natural Sciences”   
by Didier Sornette (2003). <sup>[4]</sup>

- ▶ Page 291–292 of Sornette <sup>[5]</sup>:  
Renormalization  $\equiv$  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).

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References





# More is different:

PoCS | @pocsvox

Why Complexify?

Universality

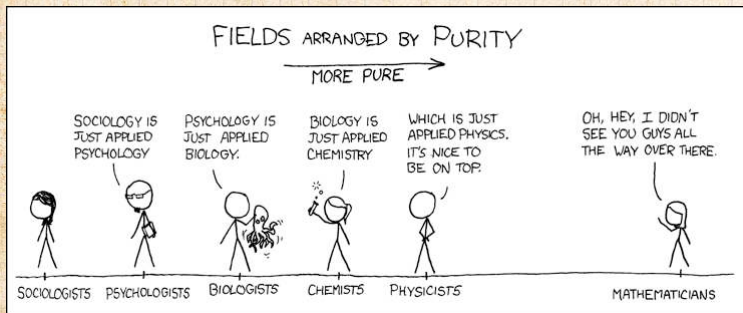
Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References



<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?

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References



# 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)?

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References





# Why complexify?

PoCS | @pocsvox  
Why Complexify?

## Driving complexity's trajectory:

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

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References



# Complexification—the Big Transitions:

PoCS | @pocsvox  
Why Complexify?

- ▶ 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 ...?

Universality

Symmetry  
Breaking

The Big Theory

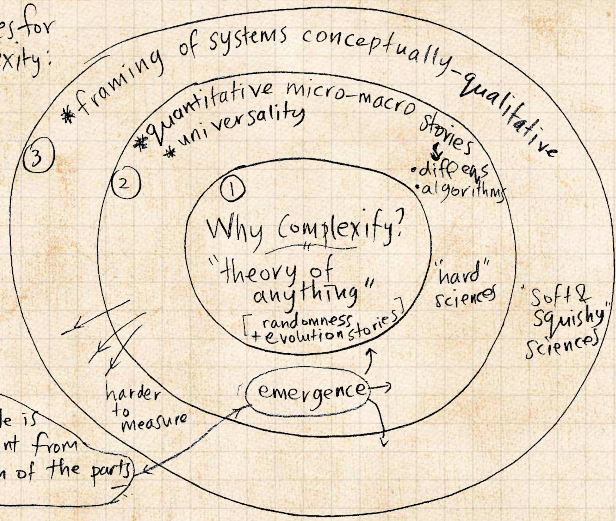
Final words

For your  
consideration

References



3 Frames for Complexity:

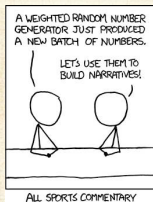


- Universality
- Symmetry Breaking
- The Big Theory
- Final words
- For your consideration
- References

The whole is different from the sum of the parts

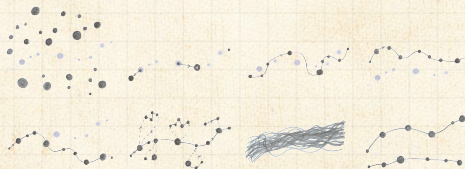
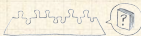






<http://xkcd.com/904/>

- ▶ 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.



Universality

Symmetry  
Breaking

The Big Theory

Final words

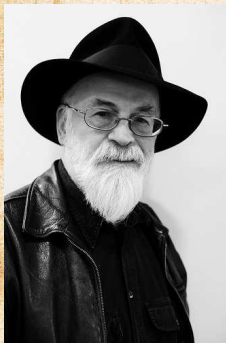
For your  
consideration

References



# (Sir Terry) Pratchett's Narrativium

PoCS | @pocsvox  
Why Complexify?



- ▶ “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.”

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References



# The Shapes of Stories

## by Kurt Vonnegut

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

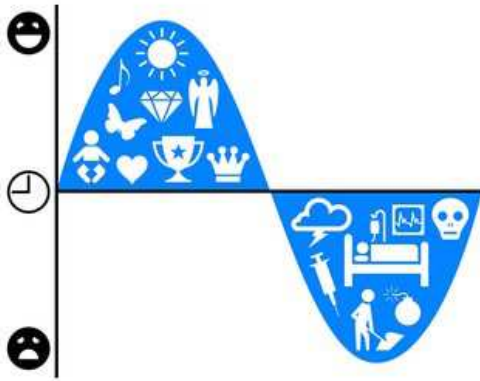
But it was his rejected master's thesis in anthropology that he called his prettiest contribution to his culture.

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](http://www.mayaeilam.com)

Sources: *A Man without a Country* and *Palm Sunday* by Kurt Vonnegut



ity  
y  
theory  
ds  
ation  
es

PoCS  
ples of  
ix Systems  
pocsvox  
the Story?

UNIVERSITY  
MONT 





# 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.

diversity

mmetry  
eaking

e Big Theory

ial words

r your  
nsideration

ferences



## Kurt Vonnegut on the shapes of stories:

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References



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

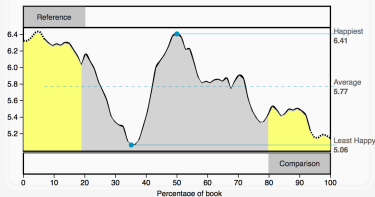
## Frankenstein; Or the Modern Prometheus [\(wiki\)](#)

by Mary Shelley

Search Gutenberg Corpus by Title Classics Harry Potter Random

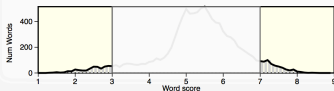
### Book happiness time series:

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



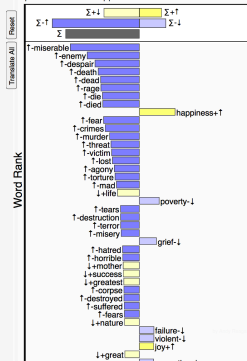
### Lens (for advanced users):

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



Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References







# 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 ...

Universality

Symmetry  
Breaking

The Big Theory

Final words

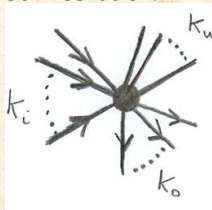
For your  
consideration



References



# 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 ...

Universality

Symmetry  
Breaking

The Big Theory

Final words




For your  
consideration

References





# 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.

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References



- [5] D. Sornette.  
Critical Phenomena in Natural Sciences.  
Springer-Verlag, Berlin, 1st edition, 2003.
- [6] D. W. Thompson.  
On Growth and Form.  
Cambridge University Pres, Great Britain, 2nd  
edition, 1952.
- [7] D. W. Thompson.  
On Growth and Form — Abridged Edition.  
Cambridge University Press, Great Britain, 1961.

Universality

Symmetry  
Breaking

The Big Theory

Final words

For your  
consideration

References

