Why Complexify?

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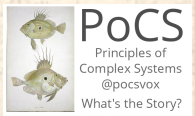
Principles of Complex Systems, Vols. 1 & 2
CSYS/MATH 300 and 303, 2021–2022| @pocsvox

Prof. Peter Sheridan Dodds | @peterdodds

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



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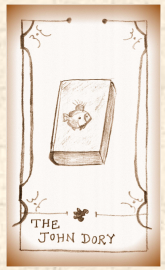

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Outline

Universality

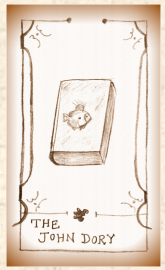
Symmetry Breaking

The Big Theory

Midseason Finale

For your consideration

References

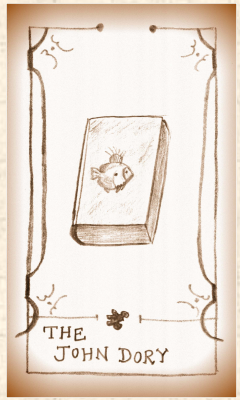



THE SUN
THE GOLDEN AGE OF REDUCTIONISM
THE MANIFESTO
THE WELL OF SCALES
THE LAWS OF DECAYING POWER
THE UNEXPECTED TRANSFIGURATION
MINISTRY OF RANDOM WALKS
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING BORGET BY PARADISE
THE MISREADING OF THE BOOK OF SAND
THE MANY TALES OF MANY TAILS
THE MEASURING
THE DATA POOR
THE POOLING DATA
THE CHARMS OF THE MANY WRING PATHS
THE BOOKS THAT SHOULD NOT BE OPENED
THE KNOWLEDGE OF DEAD MANKS
THE EMERGENCE OF STRUCTURE
THE EMERGENCE OF DESTRUCTION
THE EMERGENCE OF THINKING
It was the best of times,
THE EMERGENCE OF STORIES
THE MECHANICS STATISTICAL
THE THRESHOLDS OF PERCOLATION
THE NETWORKS COMPLEX
THE ELEMENTS OF WEBS
THE BIRDS OF A FEATHER
THE BIRDS OF NOT A FEATHER
"I am the Monarch of the Sea."
THE ARK OF THE RANDOM NETWORK
THE STRANGENESS OF FRIENDS
THE SMALLNESS OF WORLDS
THE THEORY OF SIX DEGREES
THE NETWORKS FREE OF SCALE
CLASSIFIED PHOENIX BIO HAZARD
THE CONTAGION
THE CONFUSION OF CONTAGIONS
THE DISEASE OF RANDOM MIXING
THE UNENDING PANDEMICS
THE THRESHOLDS OF THE MIND
THE SOCIAL WILD
THE SOCIAL CONTAGION
THE RATIO OF GAIN
THE MECHANICS OF FAME
THE TALK OF FAME
THE STORIES CONTAGIOUS
THE JOHN DORY
THE ADJACENT NARRATIVES
THE STORYTELLERS
THE FATED ASTRAL PATH
THE DEPENDENT PATHS
THE TROUSERS OF BIFURCATING REALITIES
THE UNKNOWN MECHANISM
THE LANDSCAPES OF FORKING PATHS
THE NETWORKS OF BLOOD
THE TREES OF REALITY
THE RIVERS OF STREAMS
THE LAWS OF BRANCHING
THE SCALING OF BROKEN HIERARCHIES
THE BRAID OR THE BRANCH
THE LAW OF OPTIMAL FORKS
THE CHURCH OF QUARTERLOGY
THE TRUTHICIDE
THE FAMILY OF PANCAKE COWS
THE FAMILY OF SPHERICAL COWS
THE IMPROBABLE PACHYDERM
THE ILL-SCALING OF ALLOMETRIC BODIES
THE SUPPLY MOST FAIR
THE SUPPLY TO THE MOST
THE DARK ART OF GENERATING FUNCTIONS
THE RANDOM SUM OF RANDOMNESS
THE TWO-SIDED WORLDS
THE STORIES AND THE TROPES
THE TRUTH OF DIFFUSION
THE UNVEILING OF HIDDEN POWERS
THE SCRYING FOR THE SHAPES OF THINGS
THE LIMITS OF ORGANIZATIONS
THE OVERCOMING OF CATASTROPHE
THE TROUBLES ILL-FORMED
THE NETWORKS OF MANY ILKS
THE CHAOS OF FETTERED CONTAGION
THE END
THE PATHS OF UNIVERSALITY

Limits to what's possible:

Universality:

- The property that the macroscopic aspects of a system do not depend sensitively on the system's details.



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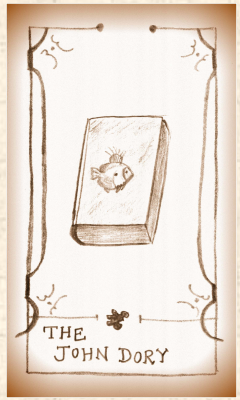

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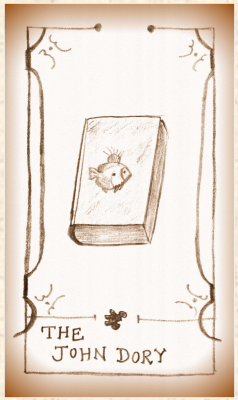

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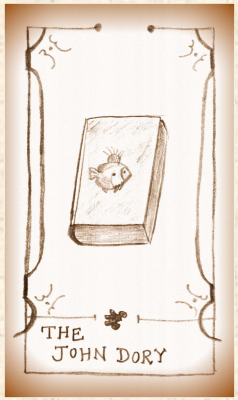

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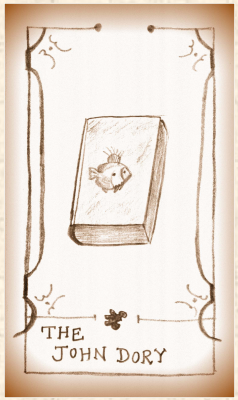
Examples:

- The Central Limit Theorem:

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



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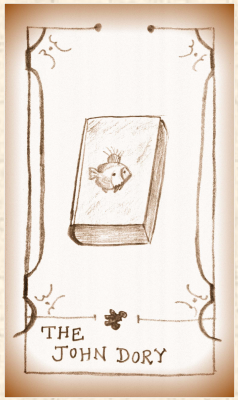

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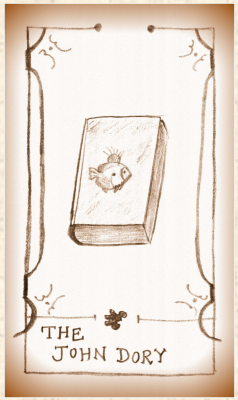
- Nature of phase transitions in statistical mechanics.



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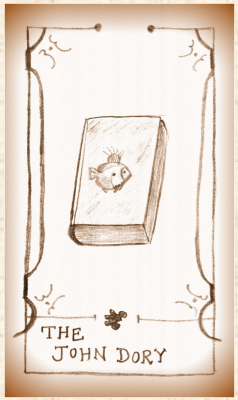

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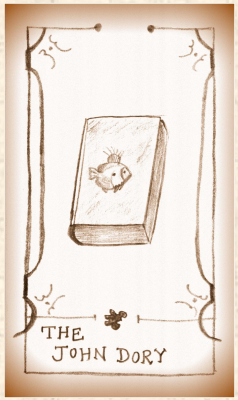

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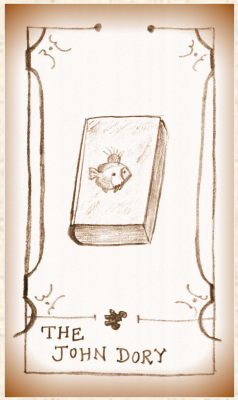

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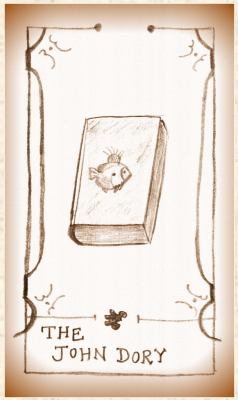
Large questions:



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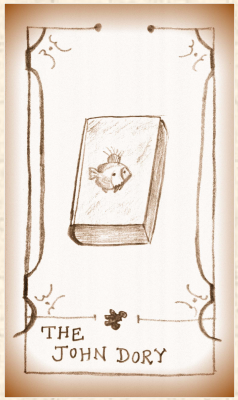

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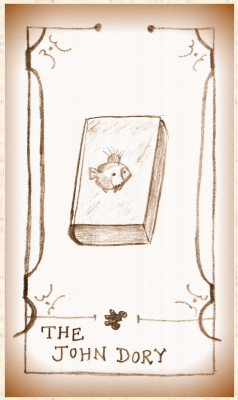
- What are the possible long-time states (attractors) for a universe?



Fluid mechanics

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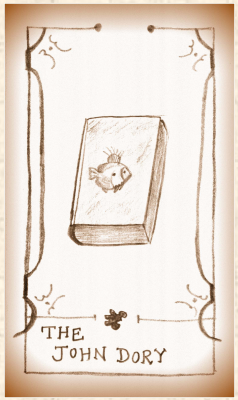

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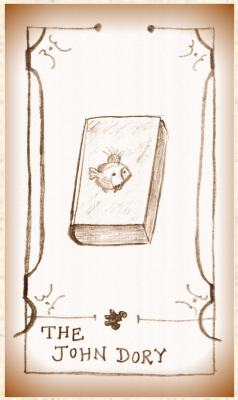

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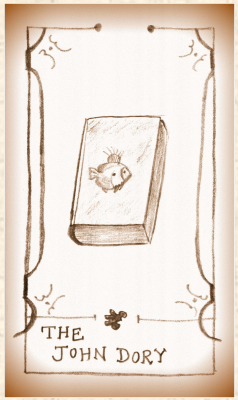

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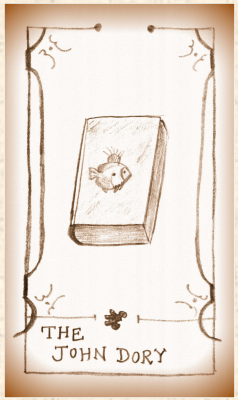
  - galaxies, ...



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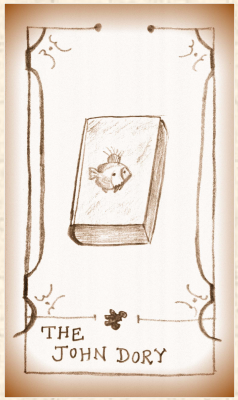
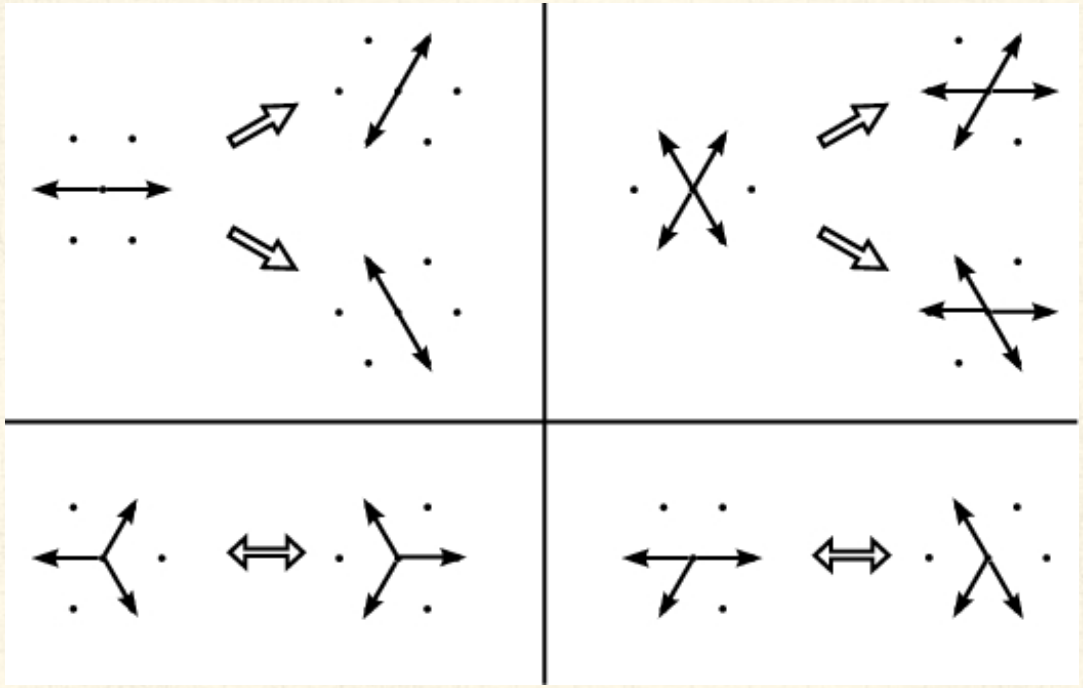
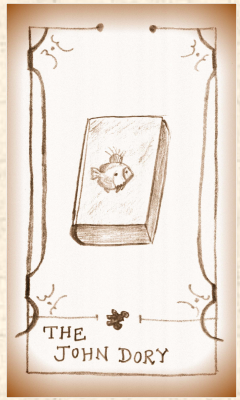
  - and ball bearings on lattices ...?



Lattice gas models

Collision rules in 2-d on a hexagonal lattice:





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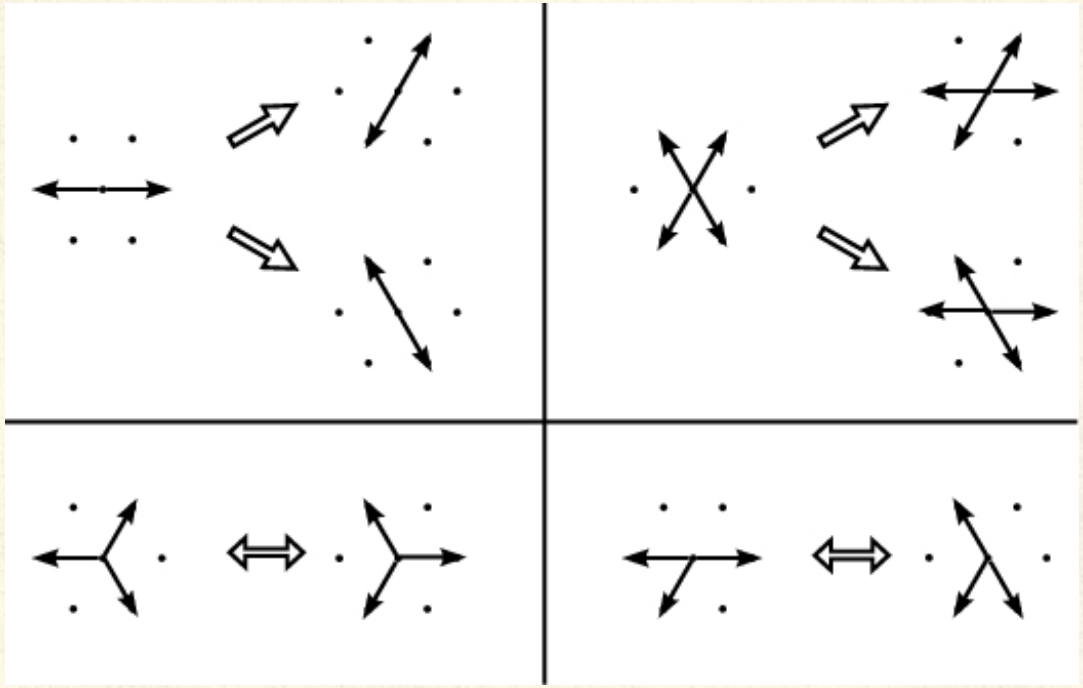

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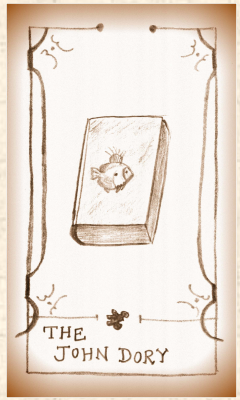

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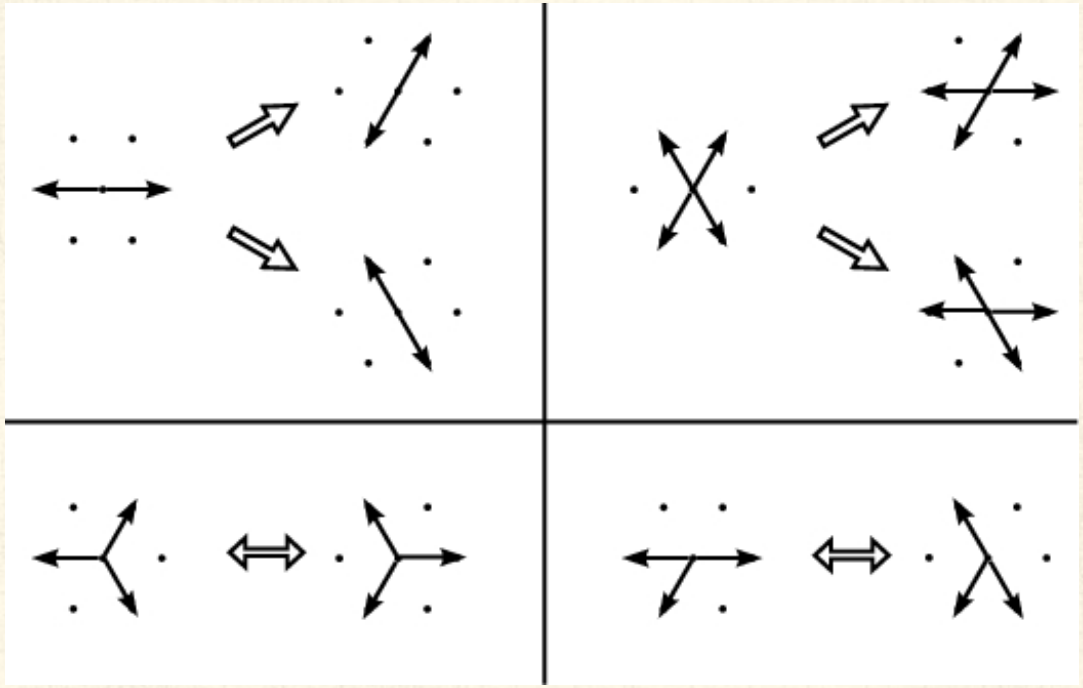

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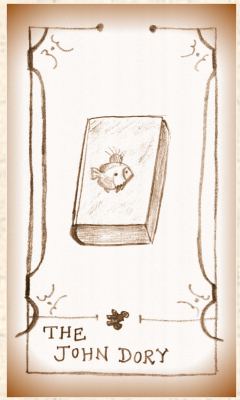

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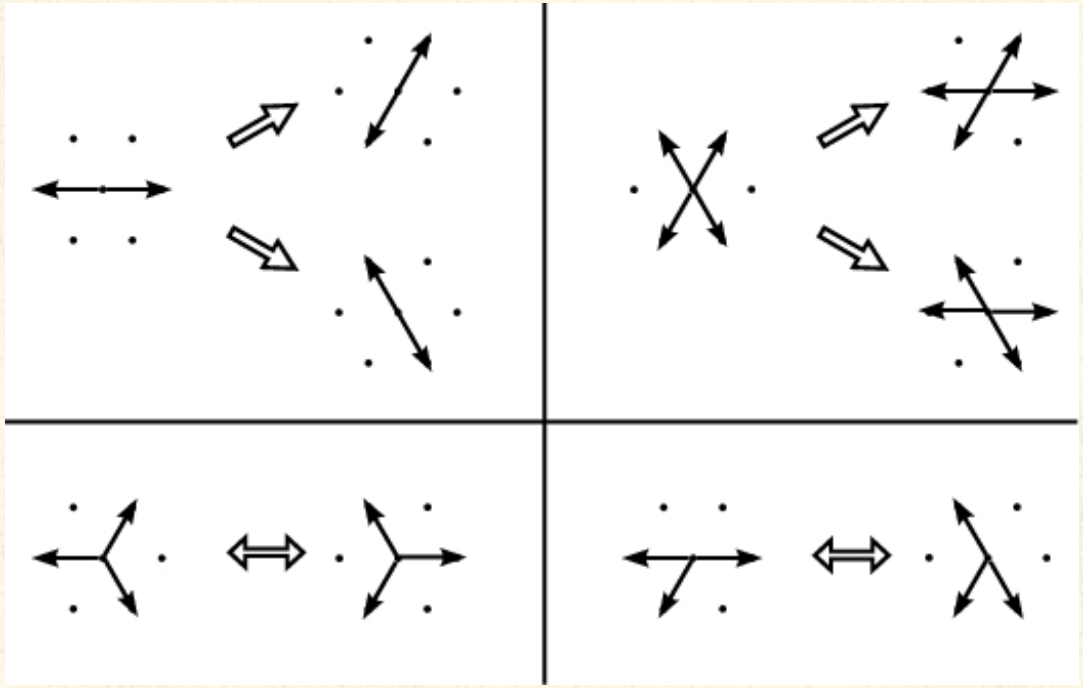

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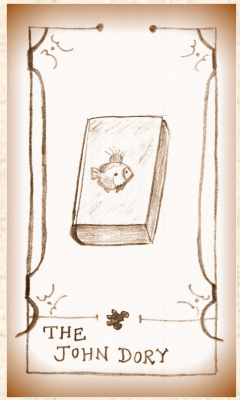
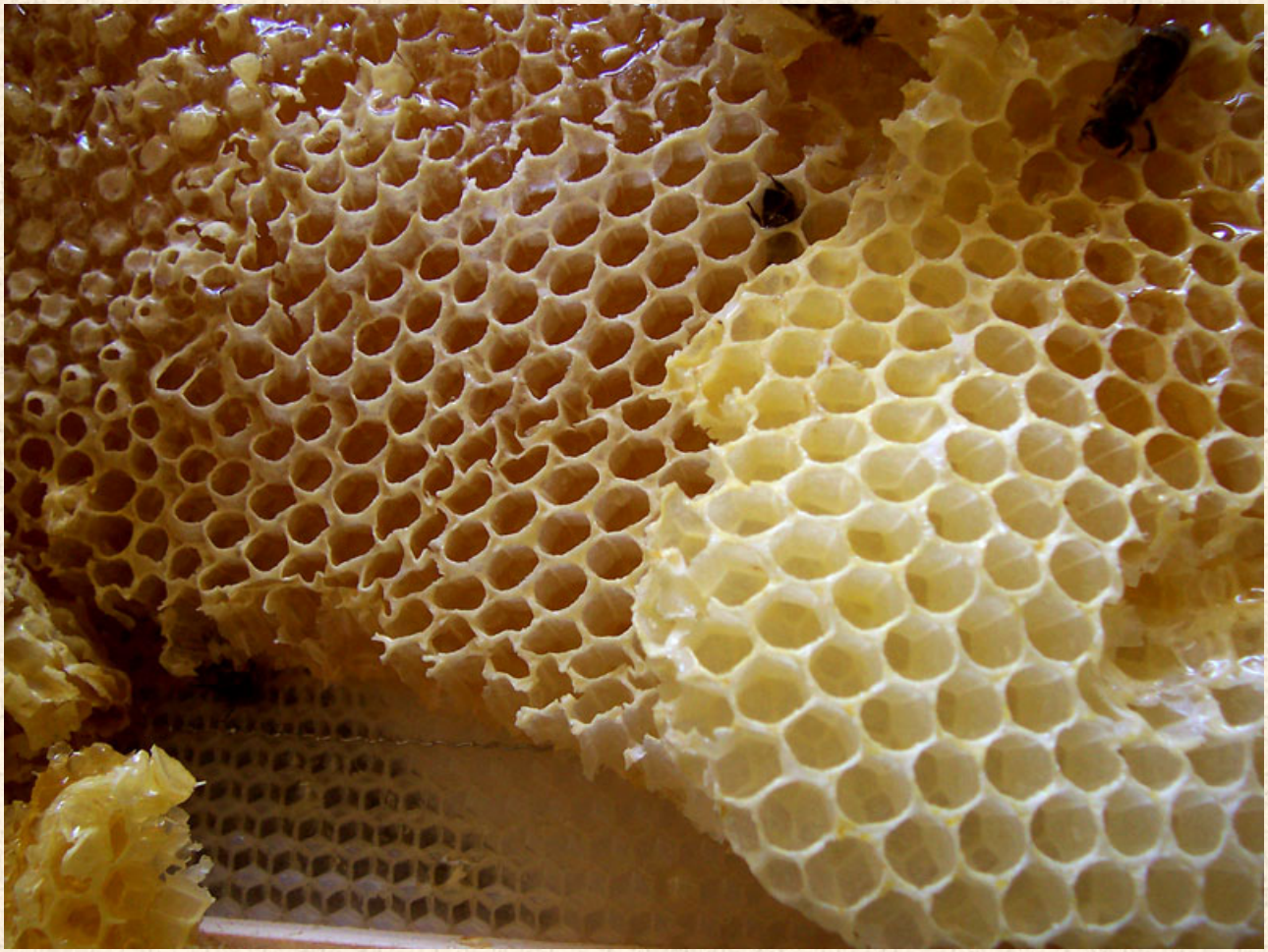
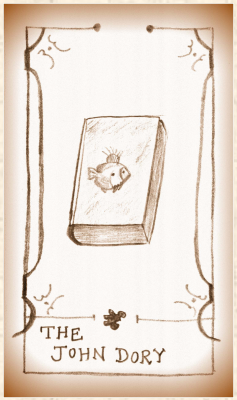
- Upshot: play with ‘particles’ of a system to obtain new or specific macro behaviours.



Hexagons—Honeycomb:



- Orchestrated? Or an accident of bees working hard?



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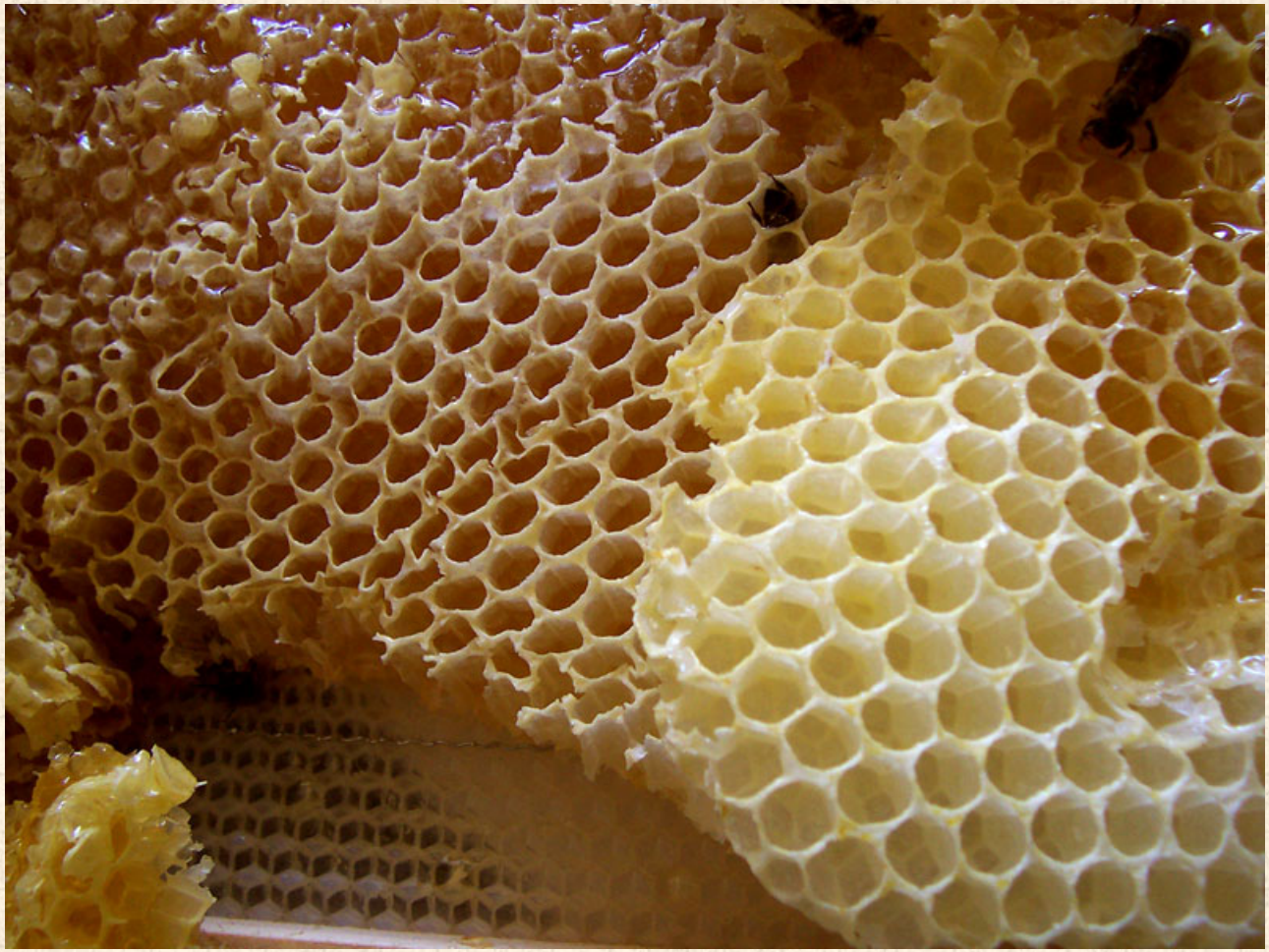

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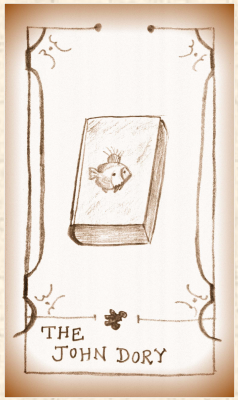
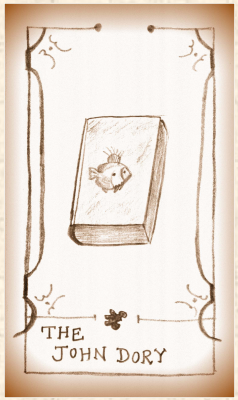
- See “On Growth and Form” by D’Arcy Wentworth Thompson. [7, 8]



Hexagons—Giant's Causeway:

http://newdesktopwallpapers.info



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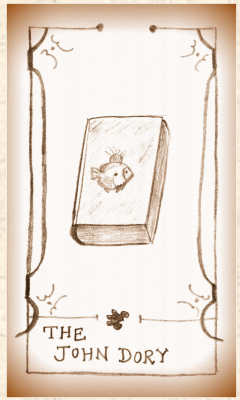
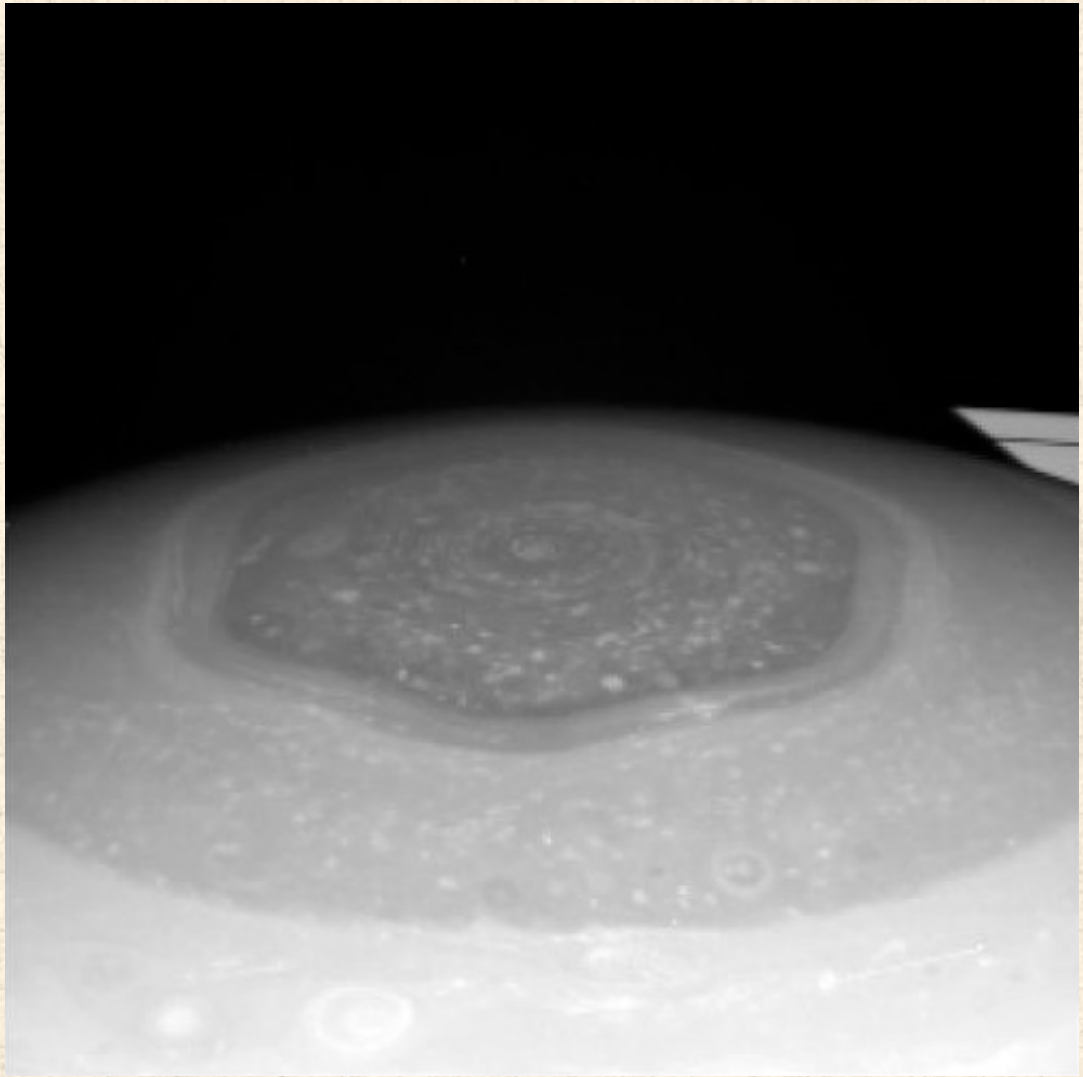
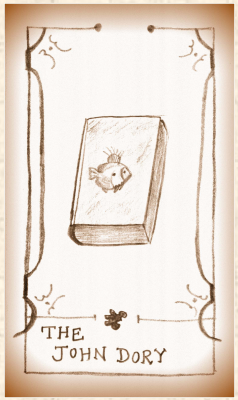


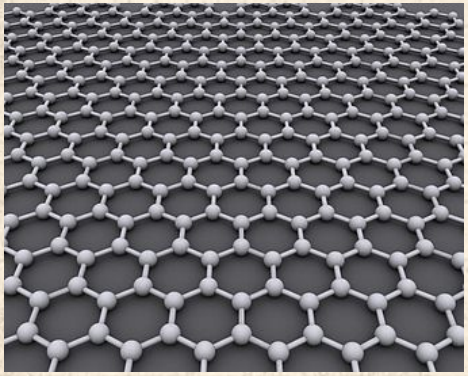
Saturn has a hexagon:



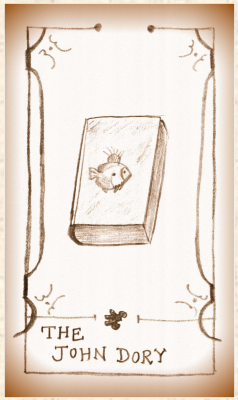
One side is longer than Earth's diameter



Hexagons run amok:



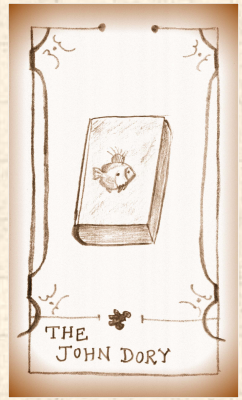
- Graphene: single layer of carbon molecules in a perfect hexagonal lattice (super strong).
- Chicken wire ...



Triumph of the Hexagon

http://www.youtube.com/watch?v=xyY0ymMYXPo?rel=0

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

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Symmetry Breaking

"More is different"

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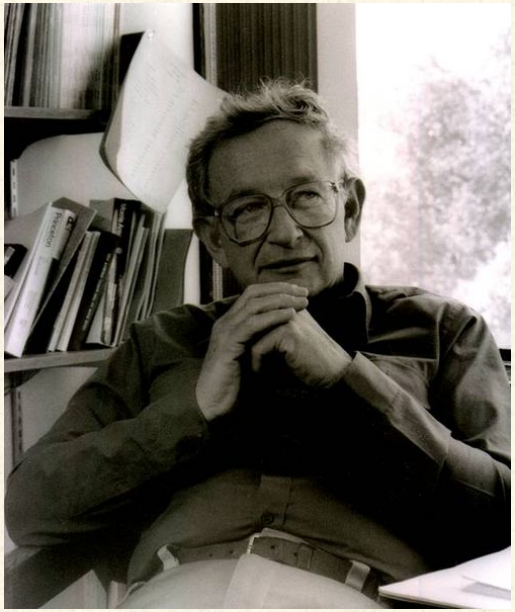

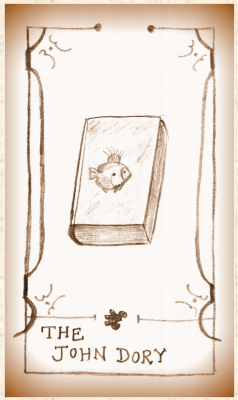

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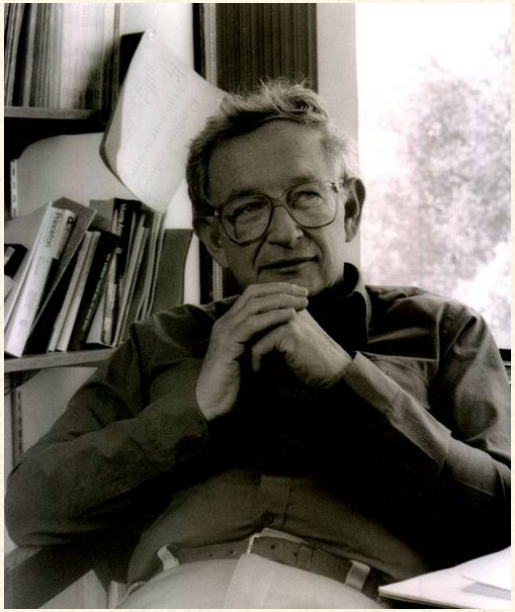

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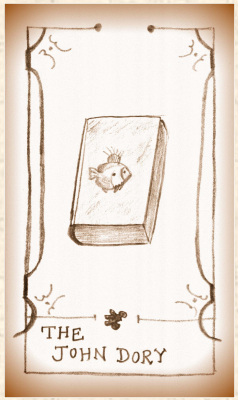

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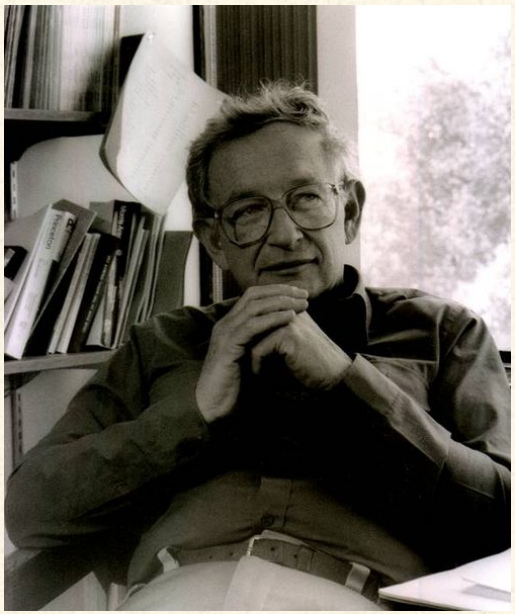

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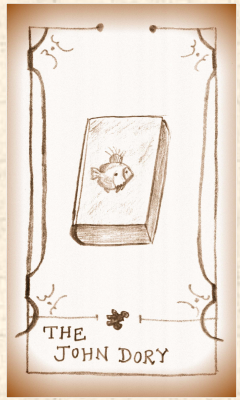

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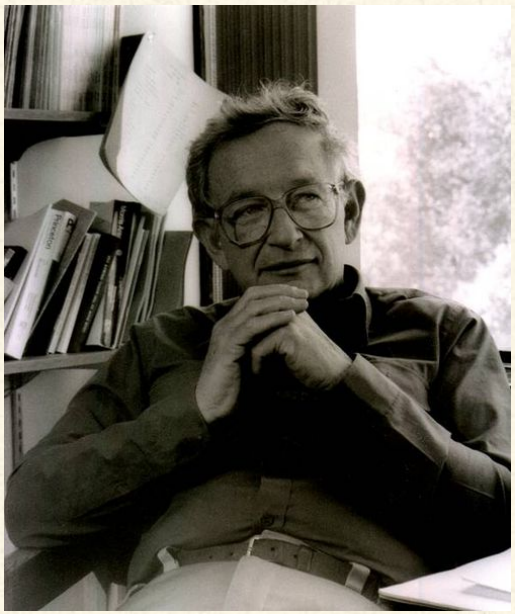

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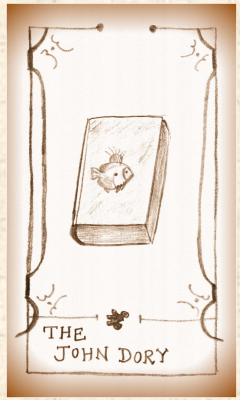
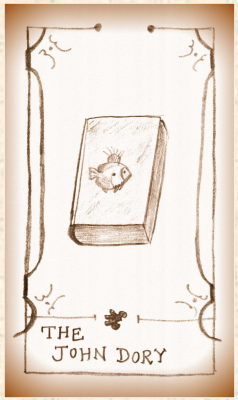


2006 study: "most creative physicist in the world"

Symmetry Breaking

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

X	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



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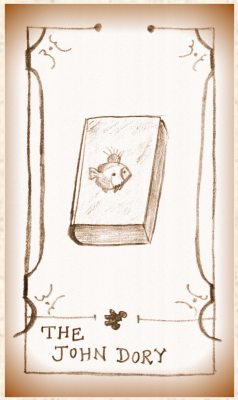

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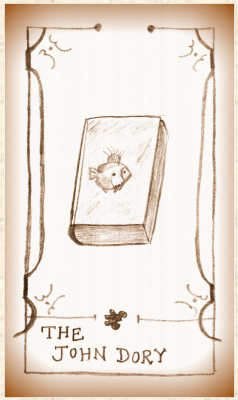

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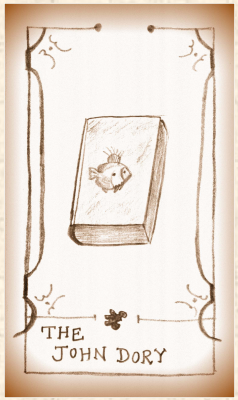

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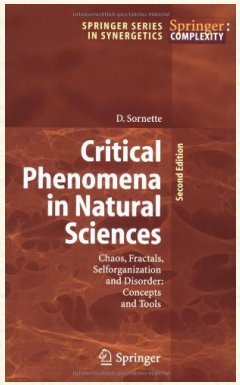

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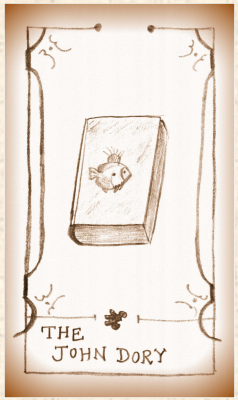

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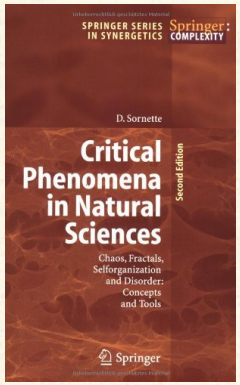

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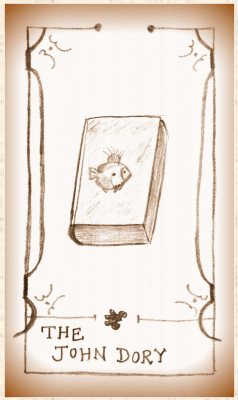

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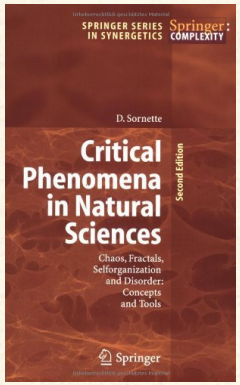

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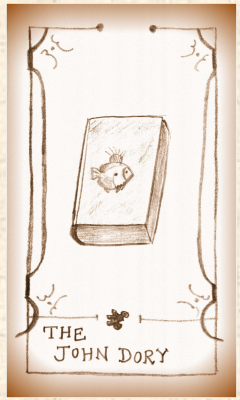

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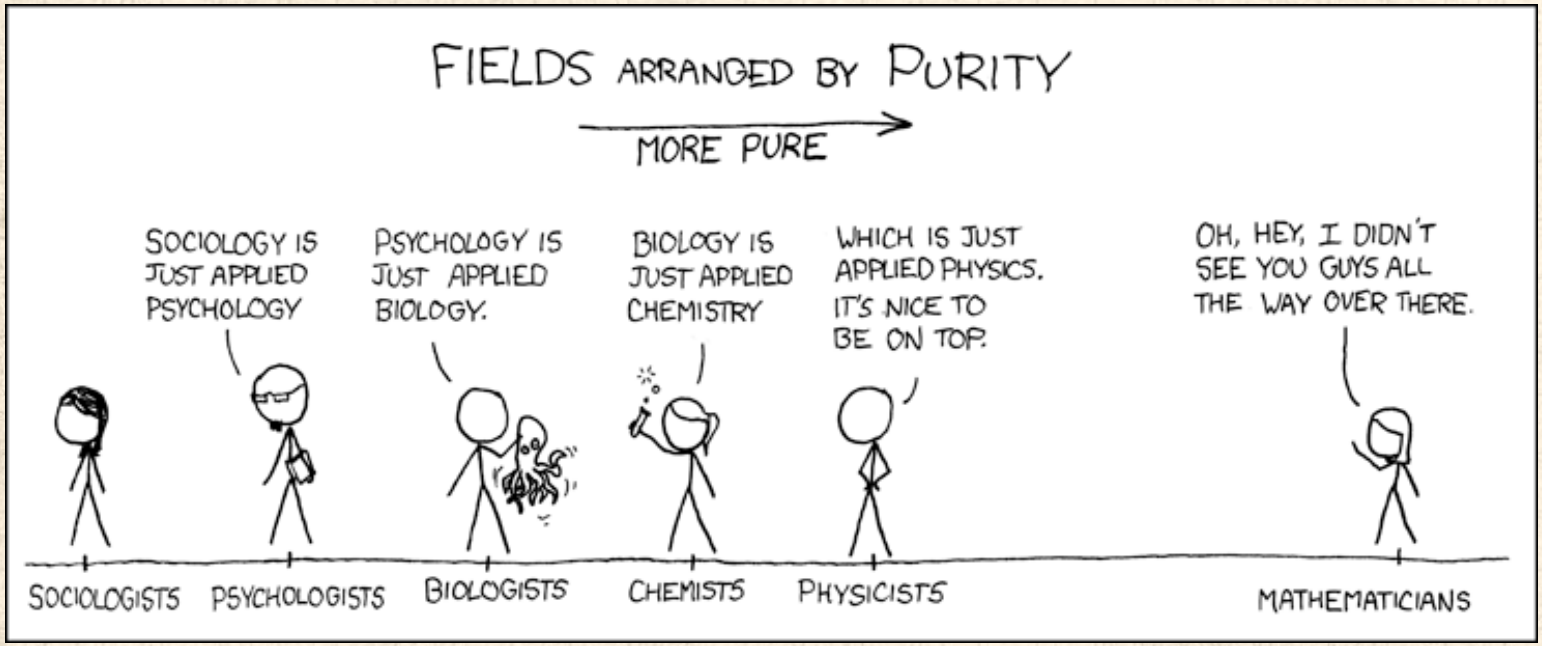
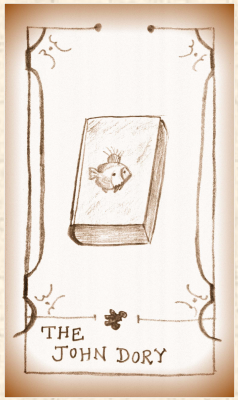


http://xkcd.com/435/

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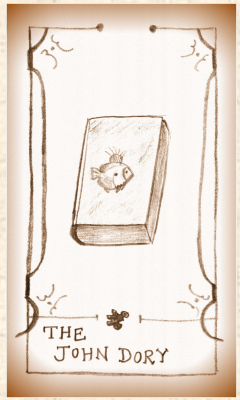

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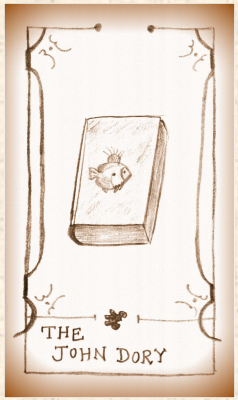

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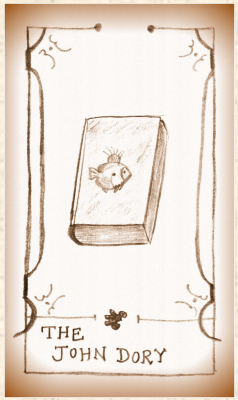

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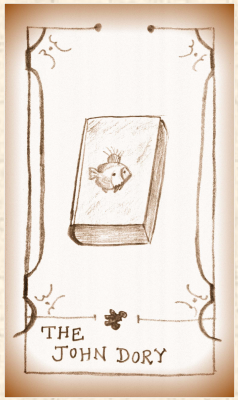

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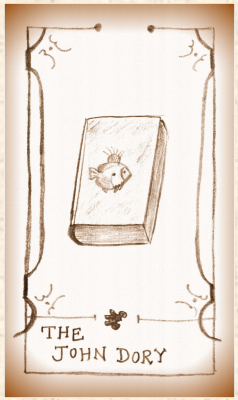

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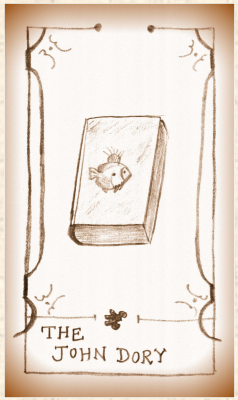

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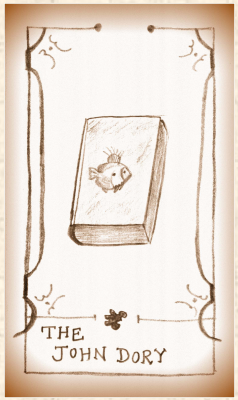

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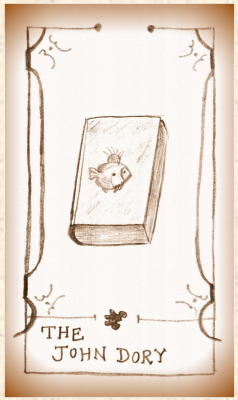

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Why complexify?


ESSAY

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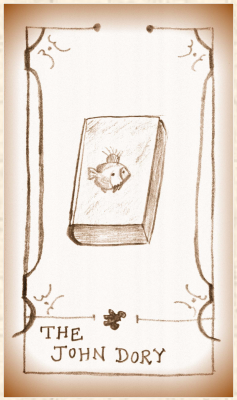

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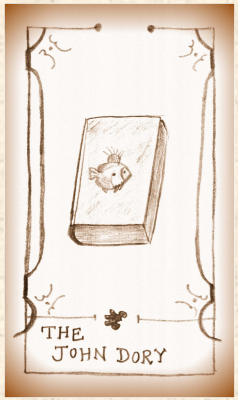

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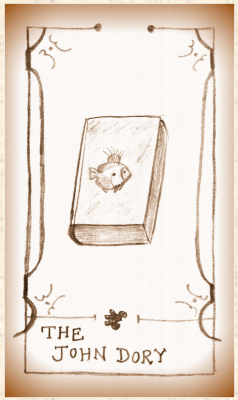

Why complexify?


ESSAY

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.
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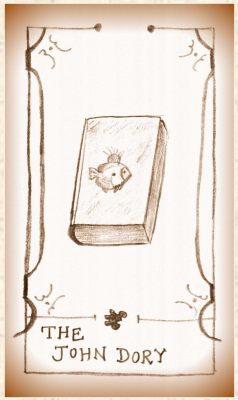

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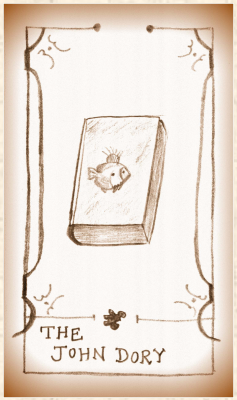
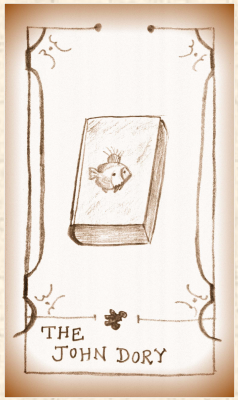


Why complexify?

Driving complexity's trajectory:

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



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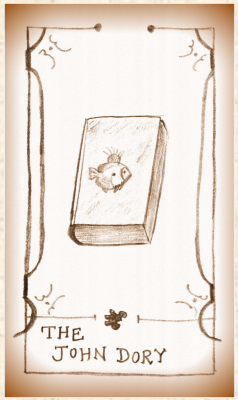

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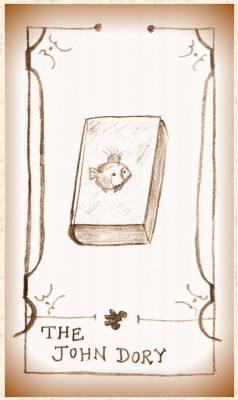

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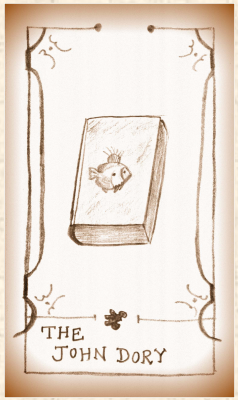

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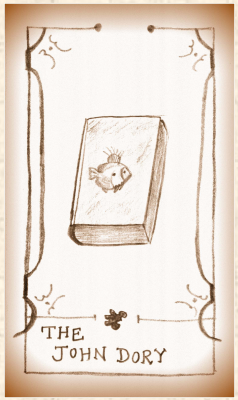

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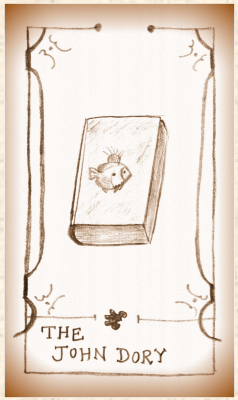
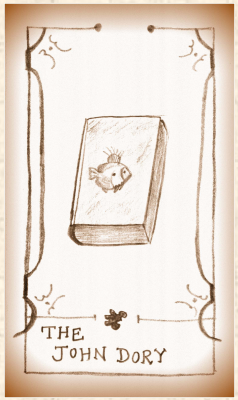
Any object whose motions are dominated by gravity will have energy decreasing as temperature increases and energy increasing as temperature decreases."



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.



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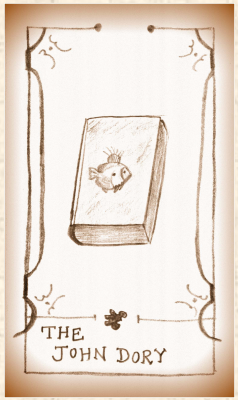

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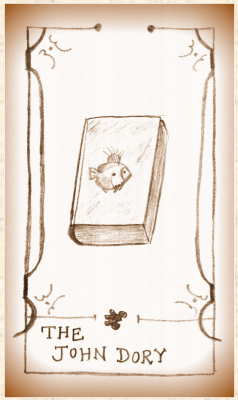

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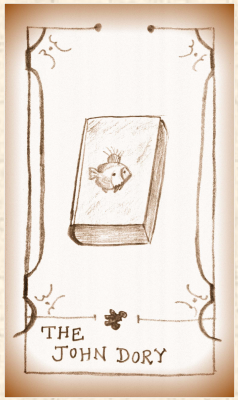

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The diversity of astronomical and terrestrial objects, including living creatures, tends to increase with time, in spite of the second law.

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."

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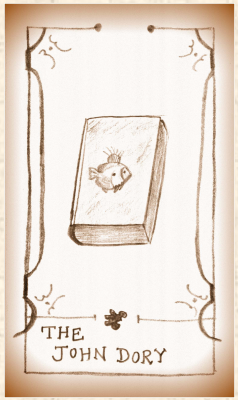

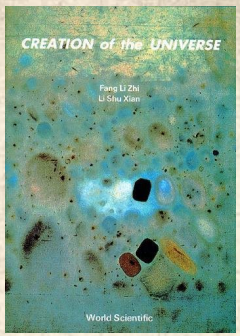

"Creation of the Universe" by Zhi and Xian (1989). [9]

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

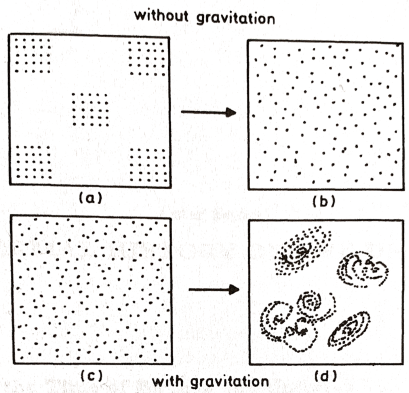

Fig. 6.6. In a system without gravitation, the evolution of the distribution of matter is from non-uniform (a) to uniform (b); in a system with gravitational interaction, the evolution is from uniform (c) to non-uniform (d).

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.

Complexification—the Big Transitions:

- Big Bang.
- Big Random-ness.

Complexification—the Big Transitions:

- Big Bang.
- Big Random-ness.
- Big Structure.

Complexification—the Big Transitions:

- Big Bang.
- Big Random-ness.
- Big Structure.
- Big Replicate.

Complexification—the Big Transitions:

- Big Bang.
- Big Random-ness.
- Big Structure.
- Big Replicate.
- Big Life.

Complexification—the Big Transitions:

- Big Bang.
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- Big Structure.
- Big Replicate.
- Big Life.
- Big Evolve.

Complexification—the Big Transitions:

- Big Bang.
- Big Random-ness.
- Big Structure.
- Big Replicate.
- Big Life.
- Big Evolve.
- Big Word.

Complexification—the Big Transitions:

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- Big Replicate.
- Big Life.
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- Big Word.
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Complexification—the Big Transitions:

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Complexification—the Big Transitions:

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- Big Social.
- Big Awareness.
- Big Spread.

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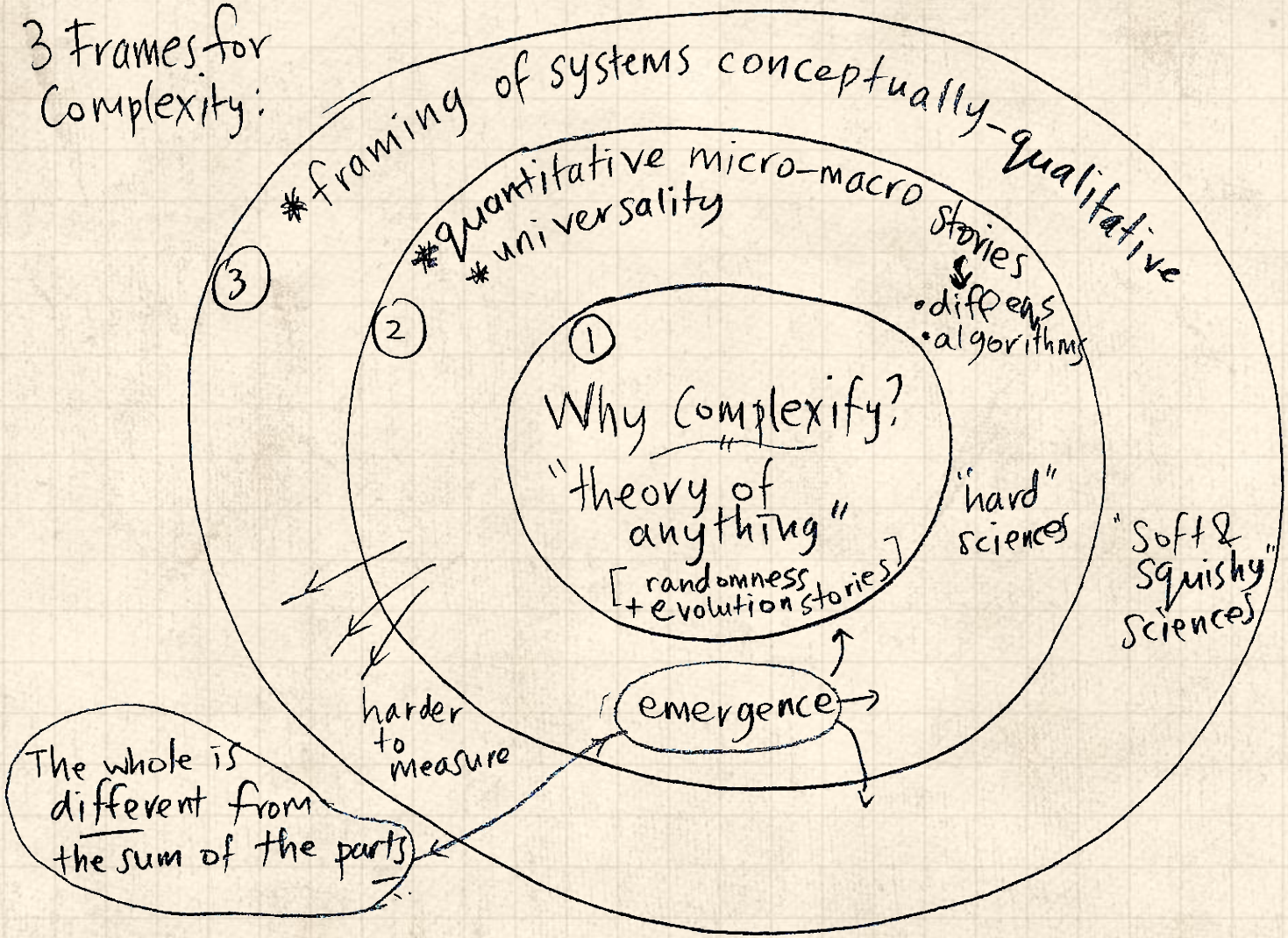


THE SUN
THE GOLDEN AGE OF REDUCTIONISM
THE MANIFESTO
THE WEIL OF SCALES
THE LAWS OF DECAYING POWER
THE UNEXPECTED TRANSFIGURATION
MINUTIAE OF RANDOM WALKS
THE RICH GET RICHER
THE DREAM OF EFFICIENT LANGUAGE
THE LAW OF DIGITS FIRST
THE SURPRISE OF BEING BORROWED
THE MISREADING OF THE BOOK OF MIND
THE MANY TALES OF MANY TAILS
THE MEASURING
THE DATA POOR
THE POURING DATA
THE CHARMS OF THE MANY WRONG PATHS
THE BOOKS THAT SHOULD NOT BE OPENED
THE KNOWLEDGE OF DEAD MANIKS
THE EMERGENCE OF STRUCTURE
THE EMERGENCE OF DESTRUCTION
THE EMERGENCE OF THINKING
It was the best of times,
THE EMERGENCE OF STORIES
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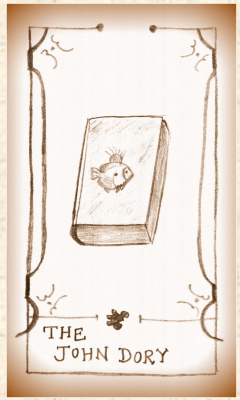
THE THRESHOLDS OF PERCOLATION
THE NETWORKS COMPLEX
THE ELEMENTS OF WEBS
THE BIRDS OF A FEATHER
THE BIRDS OF NOT A FEATHER
THE ARK OF THE RANDOM NETWORK
THE STRANGENESS OF FRIENDS
THE SMALLNESS OF WORLDS
THE THEORY OF SIX DEGREES
THE NETWORKS FREE OF SCALE
CLASSIFIED PHOENIX BIO HAZARD
THE CONTAGION
THE CONFUSION OF CONTAGIONS
THE DISEASE OF RANDOM MIXING
THE UNENDING PANDEMICS
THE THRESHOLDS OF THE MIND
THE SOCIAL WILD
THE SOCIAL CONTAGION
THE RATIO OF GAIN
THE MECHANICS OF FAME
THE TALK OF FAME
THE STORIES CONTAGIOUS
THE JOHN DORY
THE ADJACENT NARRATIVES
THE STORYTELLERS
THE FATED ASTRAL PATH
THE PATHS OF UNIVERSALITY
THE DEPENDENT PATHS
THE TROUSERS OF BIFURCATING REALITIES
THE UNKNOWN MECHANISM
THE LANDSCAPE OF FORKING PATHS
THE NETWORKS OF BLOOD
THE TREES OF REALITY
THE ORDERS OF STREAMS
THE LAWS OF BRANCHING
THE SCALING OF BROKEN HIERARCHIES
THE BRAID OR THE BRANCH
THE LAW OF OPTIMAL FORKS
THE CHURCH OF QUARTERLOGY
THE TRUTHICIDE
THE FAMILY OF PANCAKE COWS
THE FAMILY OF SPHERICAL COWS
THE IMPROBABLE PACHYDERM
THE ILL-SCALING OF ALLOMETRIC BODIES
THE SUPPLY MOST FAIR
THE SUPPLY TO THE MOST
THE DARK ART OF GENERATING FUNCTIONS
THE RANDOM SUM OF RANDOMNESS
THE TWO-SIDED WORLDS
THE STORIES AND THE TROPES
THE TRUTH OF DIFFUSION
THE UNVEILING OF HIDDEN POWERS
THE SEEKING FOR THE SHAPES OF THINGS
THE LIMITS OF ORGANIZATIONS
THE OVERCOMING OF CATASTROPHE
THE TROUBLES ILL-FORMED
THE NETWORKS OF MANY ILLS
THE CHAOS OF FETTERED CONTAGION
THE END

The absolute basics:

Modern basic science in three steps:



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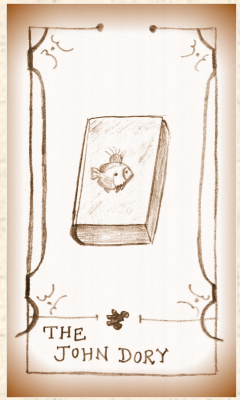
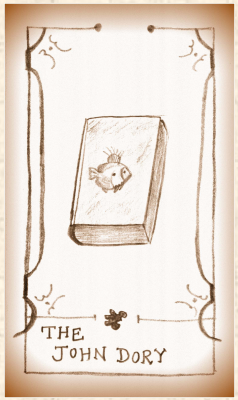


The absolute basics:

Modern basic science in three steps:

1. Find interesting/meaningful/important phenomena, optionally involving spectacular amounts of data.
2. Taste matters. Develop taste in research.



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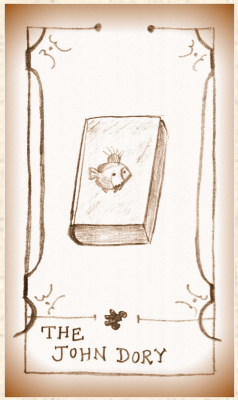

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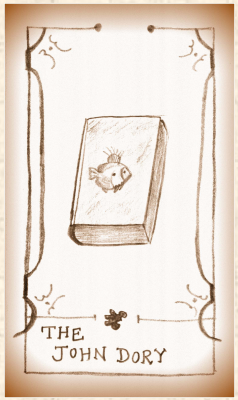

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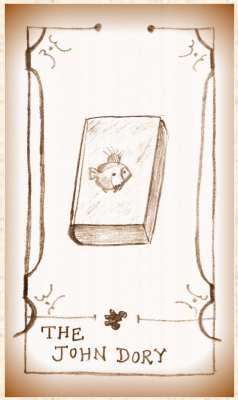

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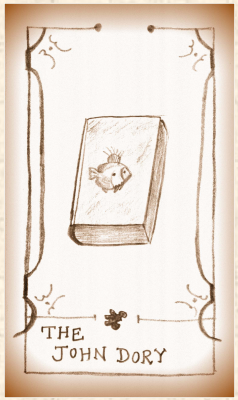

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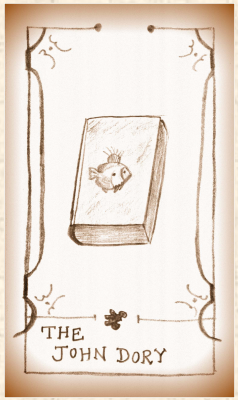
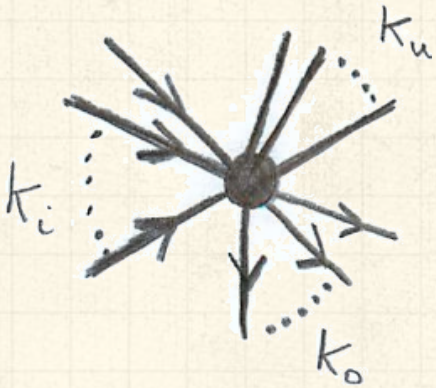
Beware your assumptions: Don't use tools/models because they're there, or because everyone else does ...



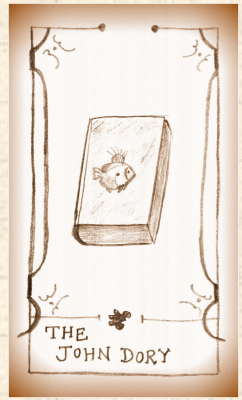
This is a thing that could be next:

Principles of Complex Systems, Vol. 2

Once was CocoNuTs:
The PoCS strikes back



CSYS/MATH 303:
Complex Networks
@networksvox
@storyologyvox



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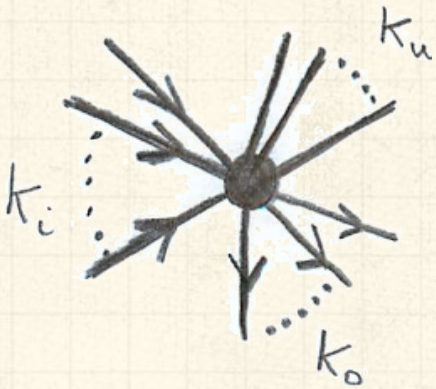

CSYS/MATH 303: Complex Networks
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- Branching networks (rivers, cardiovascular systems).
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- Random networks-arama.
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- Organizational networks.
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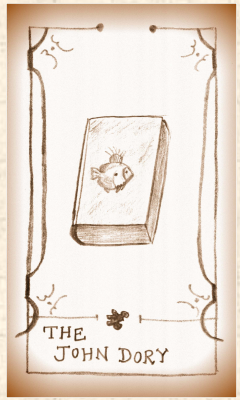

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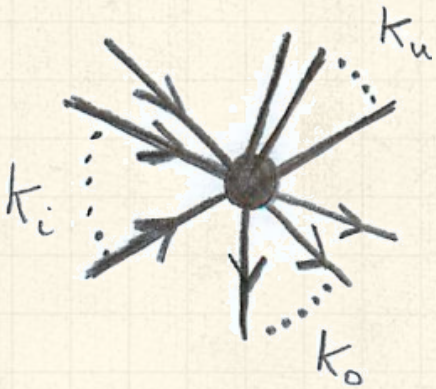

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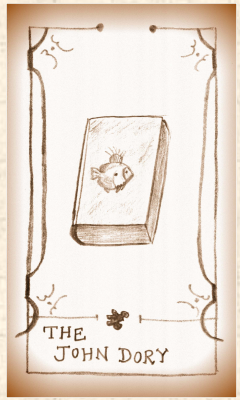

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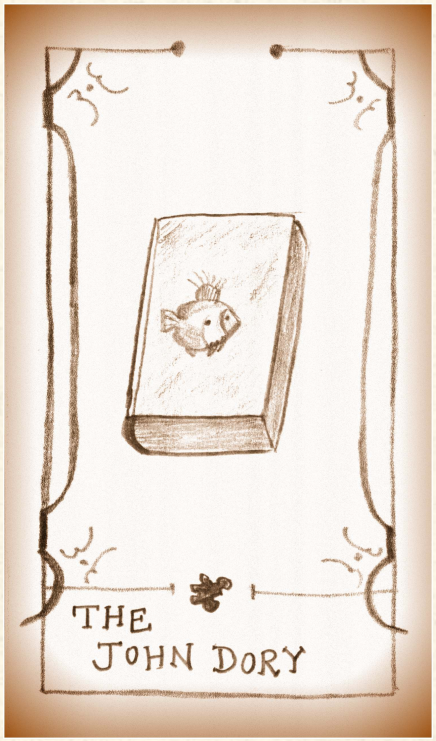
Storyology
Episode VI:
PoCS with ewoks



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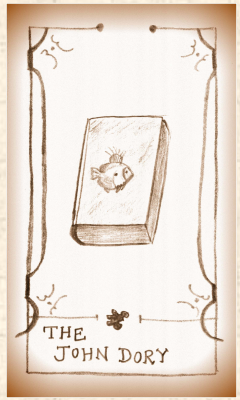

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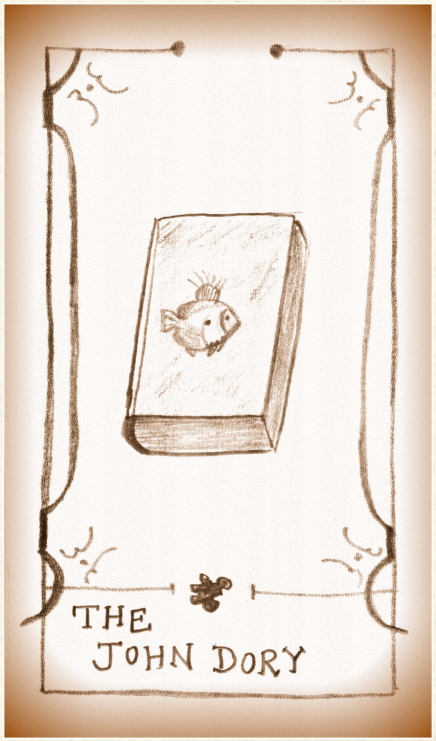
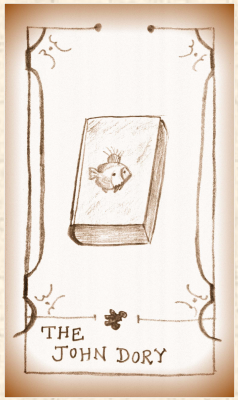


- Exploring texts of all kinds, centrality of stories.
- News, social media, fiction, Twitter.
- Dark arts of text parsing, cleaning, regular expression.
- Measuring happiness and sadness through text.
- Measuring and understanding cultural evolution through texts: legal and government texts, music lyrics,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



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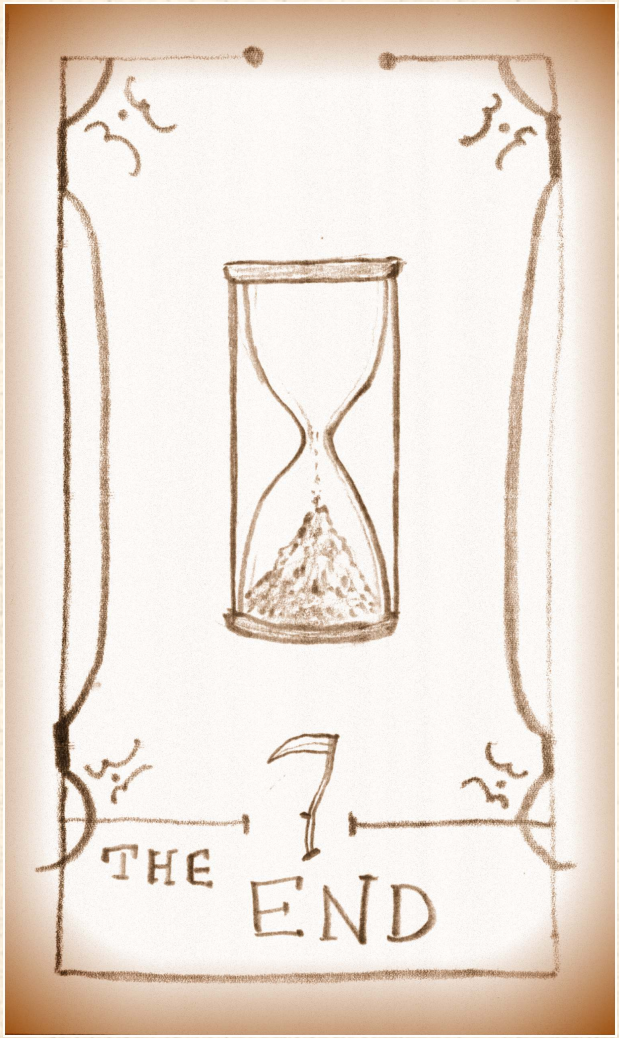

References I

[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] F. Dyson.
The key to everything, 2018.
http://www.nybooks.com/articles/2018/05/10/the-key-to-everything/. pdf

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

References II

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

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

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

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

References III

[9] F. L. Zhi and L. S. Xian.
Creation of the Universe.
World Scientific Publishing Company, 1989.