Why Complexify?

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Principles of Complex Systems, Vols. 1, 2, & 3D
CSYS/MATH 6701, 6713, & a pretend number, 2024–2025

Prof. Peter Sheridan Dodds

Computational Story Lab | Vermont Complex Systems Center
Santa Fe Institute | University of Vermont

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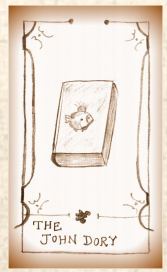
Outline

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THE JOHN DORY
THE ADJACENT NARRATIVES
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THE DEPENDENT PATHS
THE TROUSERS OF BIFURCATING REALITIES
THE UNKNOWN MECHANISM
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THE NETWORKS OF BLOOD
THE TREES OF REALITY
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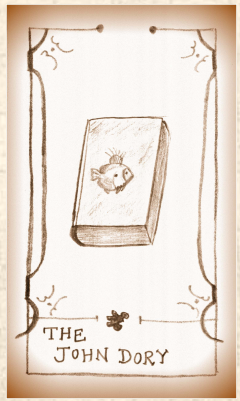
THE TRUTH OF DIFFUSION
THE UNVEILING OF HIDDEN POWERS
THE BUYING OF SHAPES OF THINGS
THE LIMITS OF ORGANIZATIONS


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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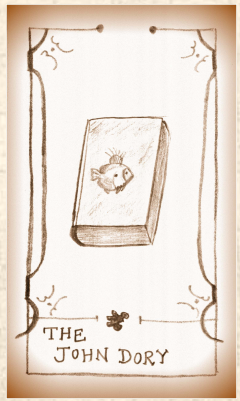

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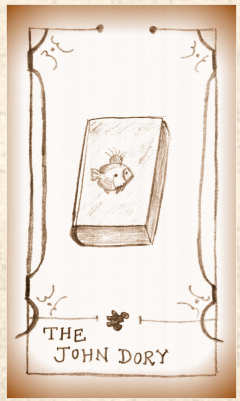

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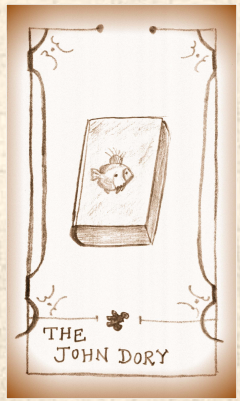

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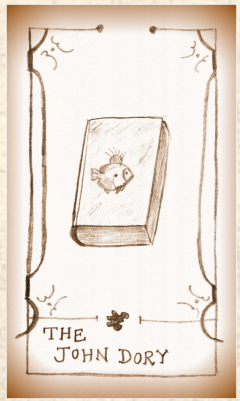
- The Central Limit Theorem:

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



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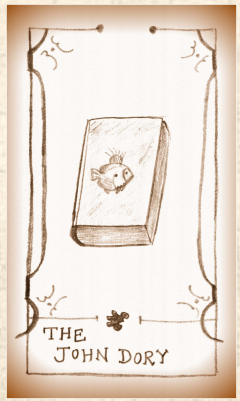

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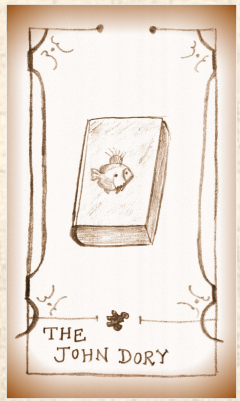
- Nature of phase transitions in statistical mechanics.



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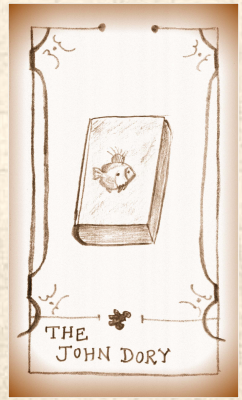

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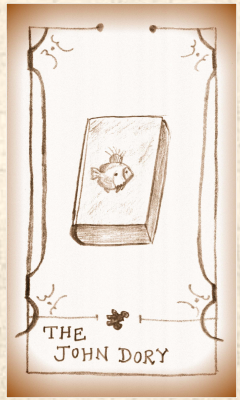

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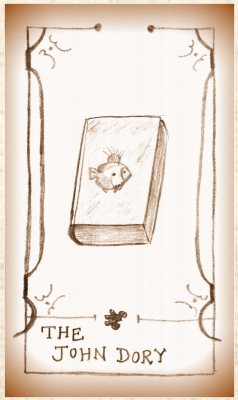

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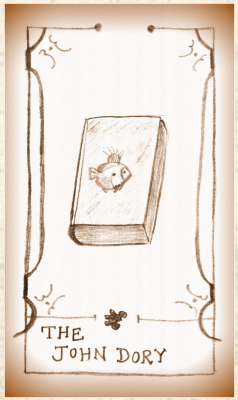

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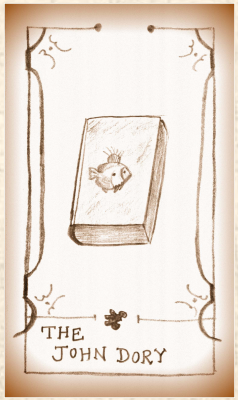

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Large questions:

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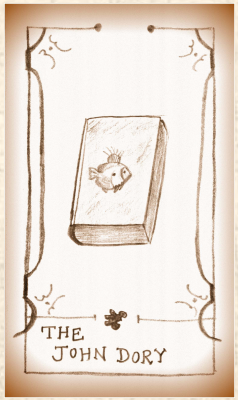
- What are the possible long-time states (attractors) for a universe?



Fluid mechanics

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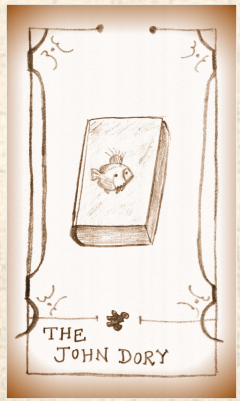

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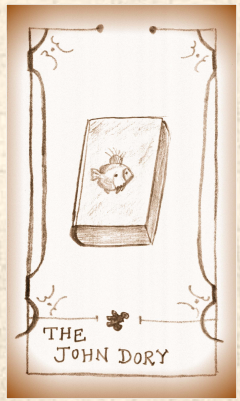

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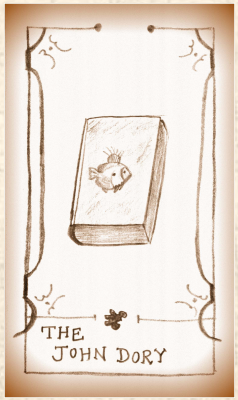

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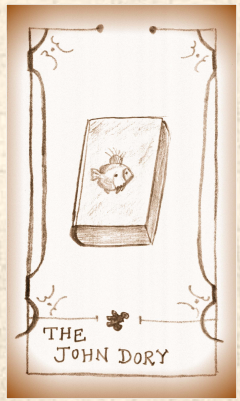
  - galaxies, ...



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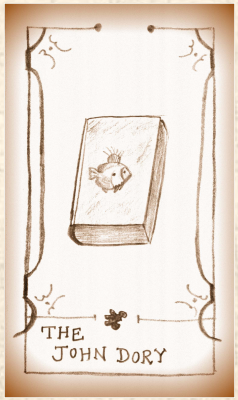
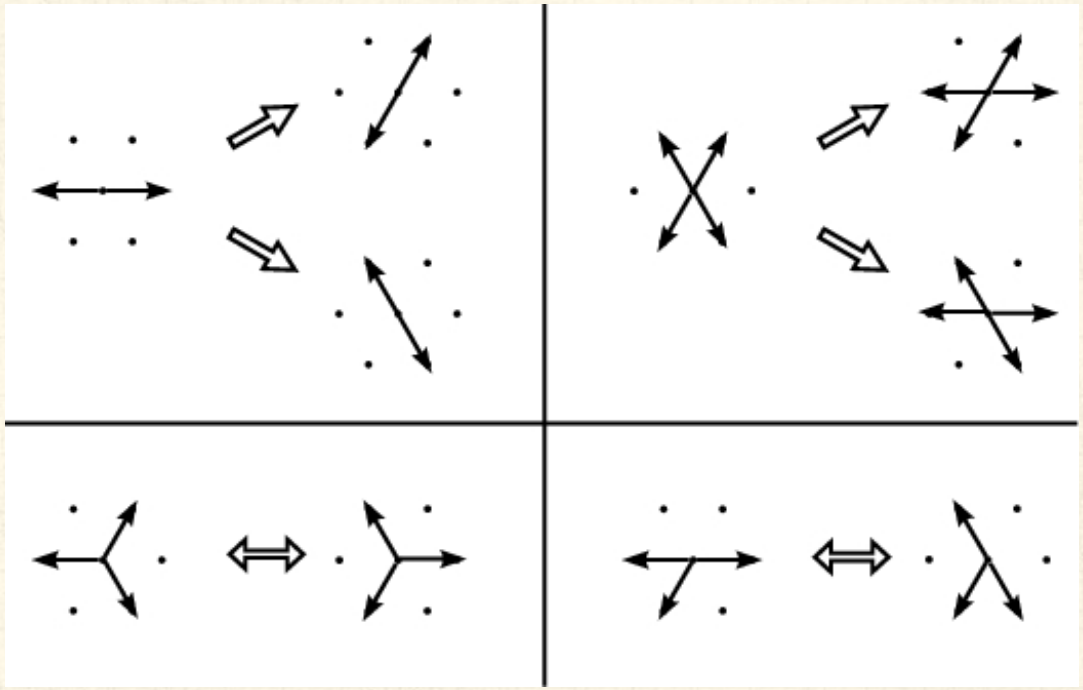
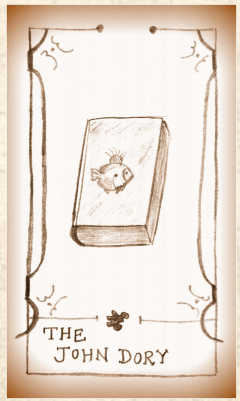
  - and ball bearings on lattices ...?



Lattice gas models

Collision rules in 2-d on a hexagonal lattice:





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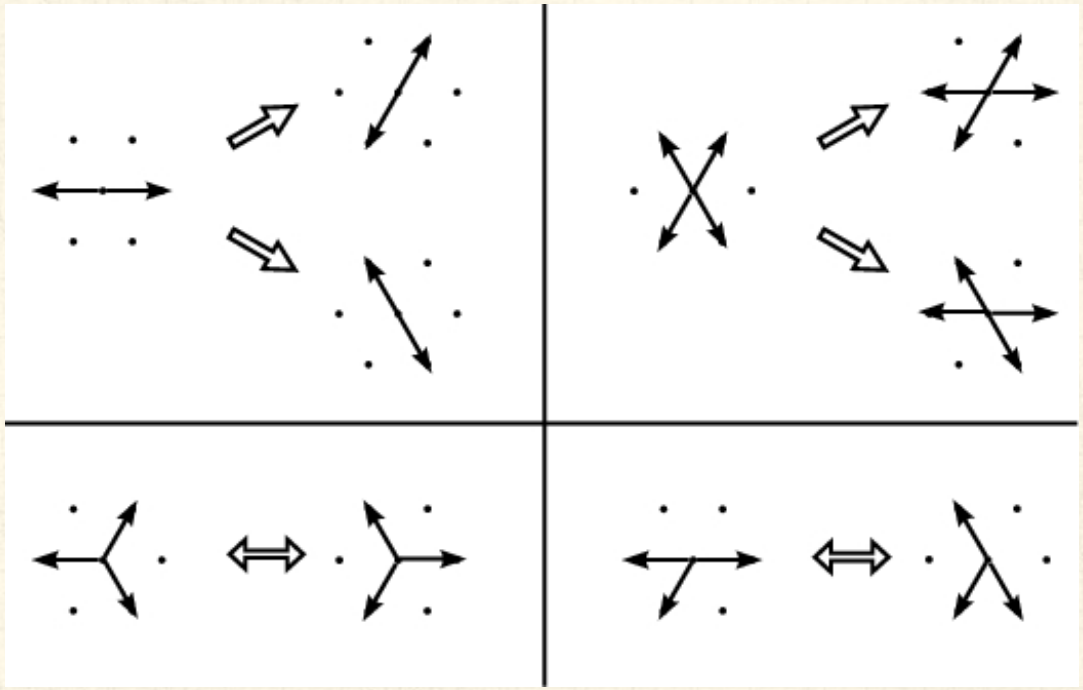

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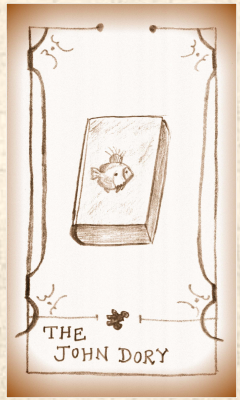

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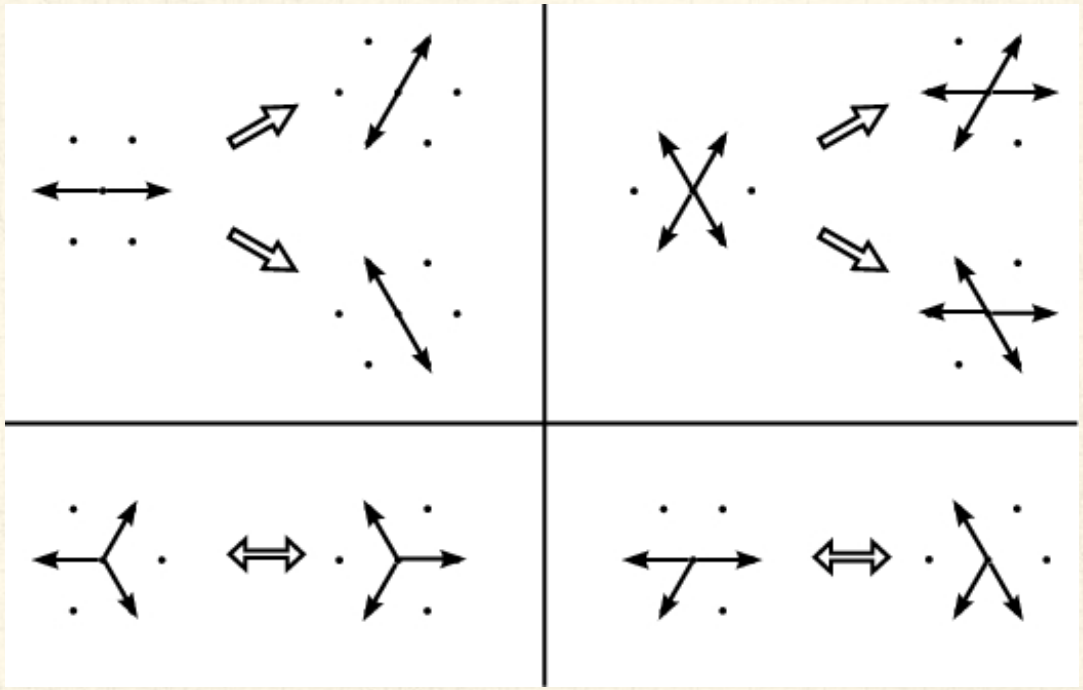

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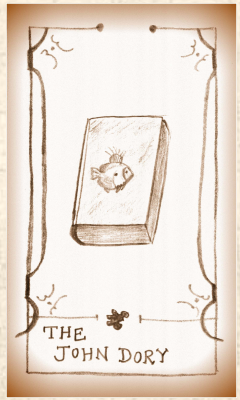

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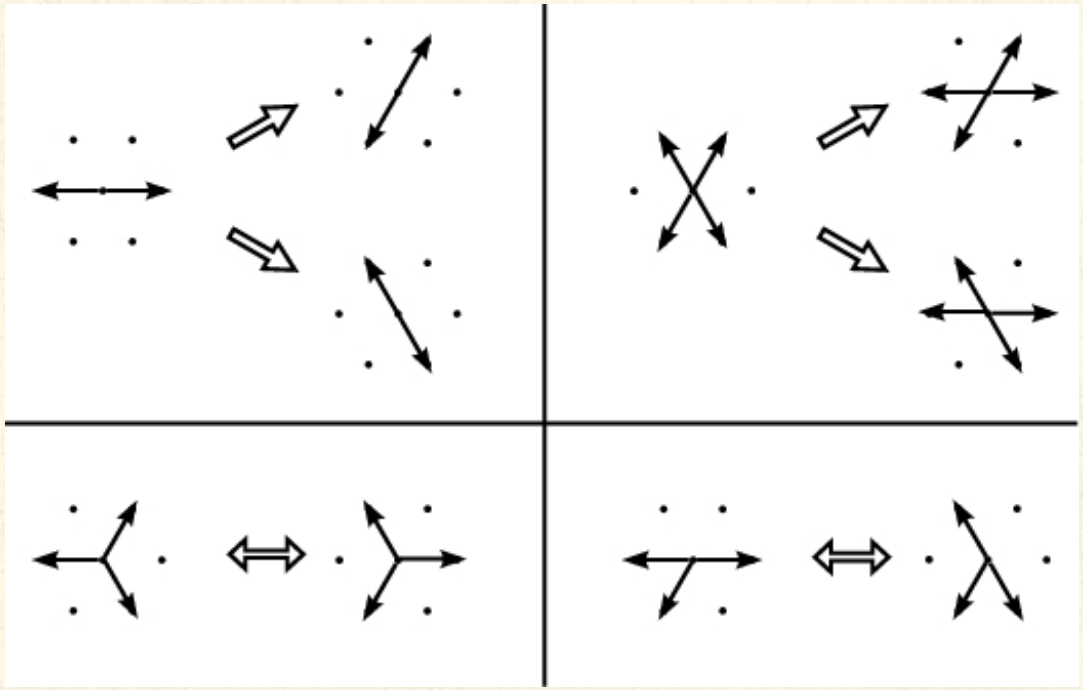
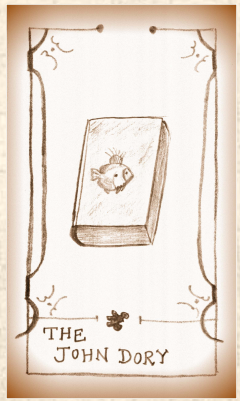
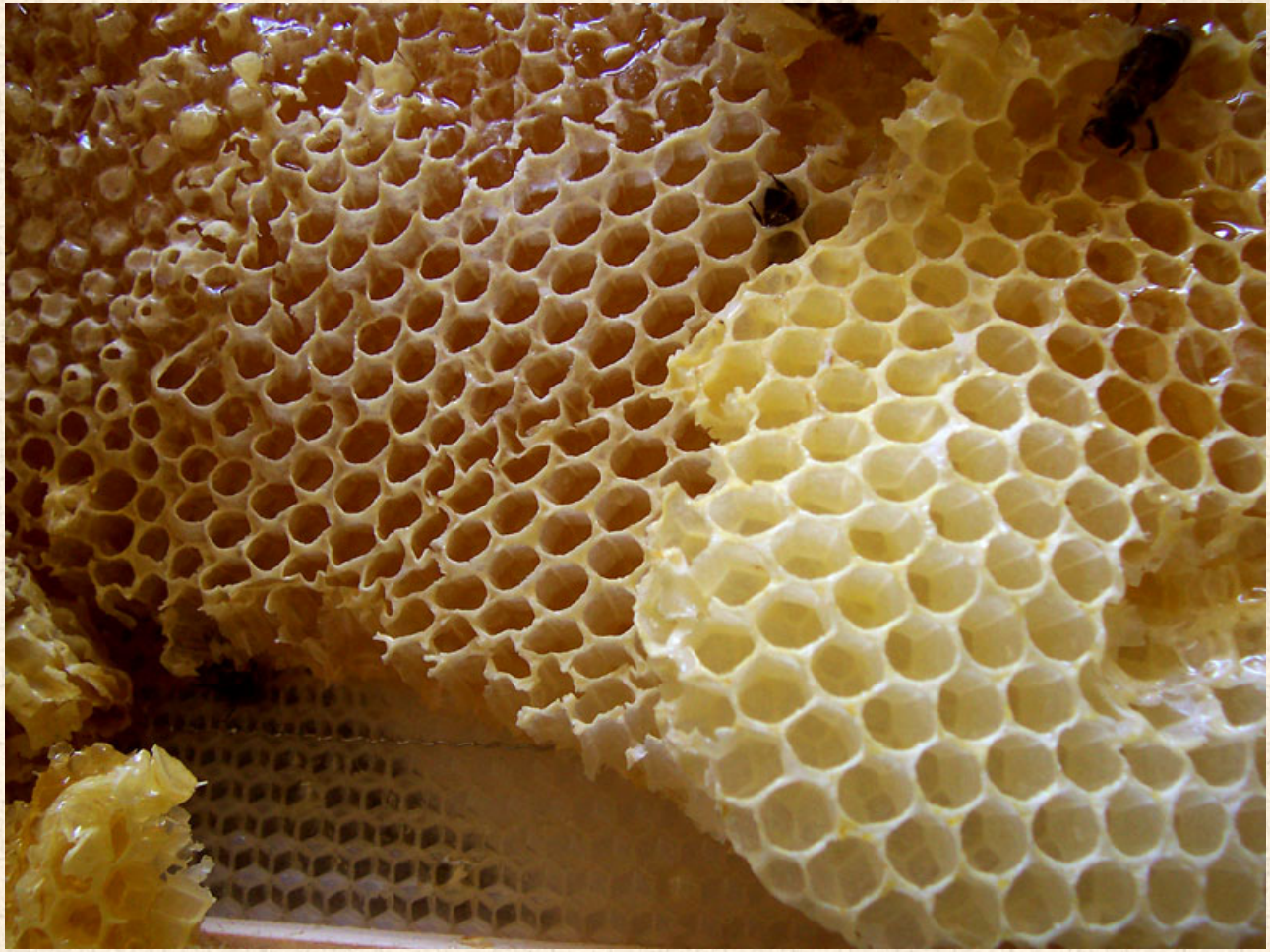


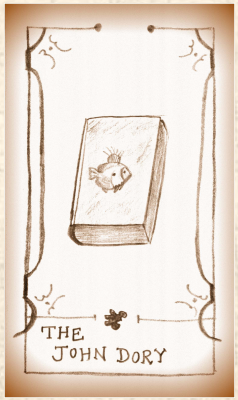
- Lattice matters ...
- No ‘good’ lattice in 3-d.
- Upshot: play with ‘particles’ of a system to obtain new or specific macro behaviours.



Hexagons—Honeycomb:



Orchestrated? Or an accident of bees working hard?



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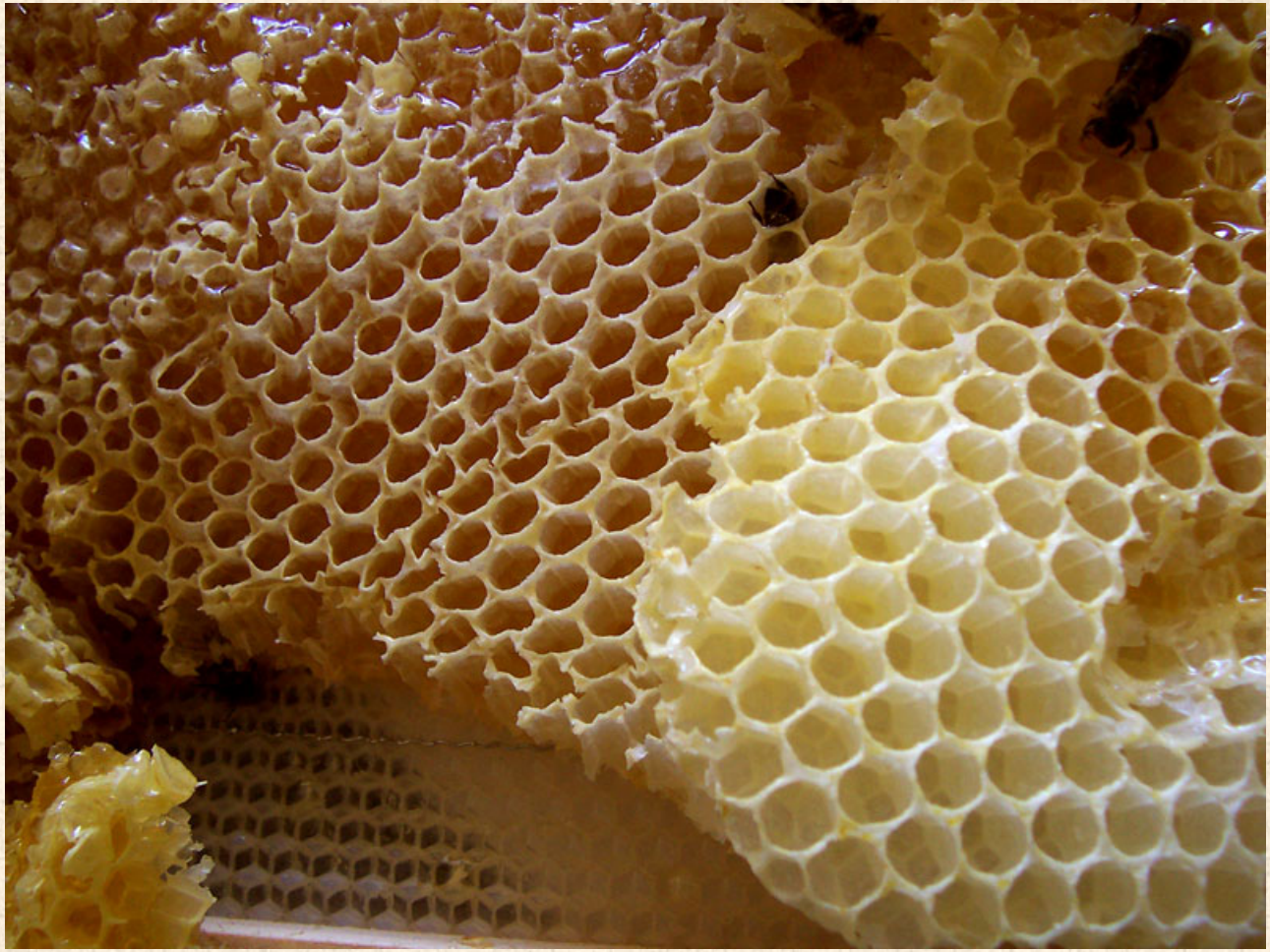

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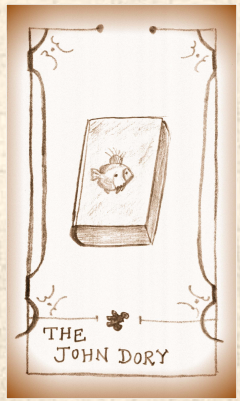
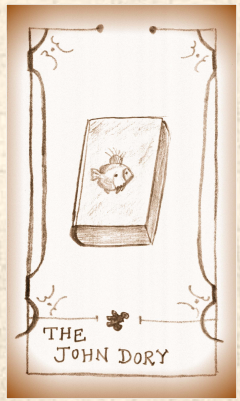
- See “On Growth and Form” by D’Arcy Wentworth Thompson. [7, 8]



Hexagons—Giant's Causeway:

http://newdesktopwallpapers.info



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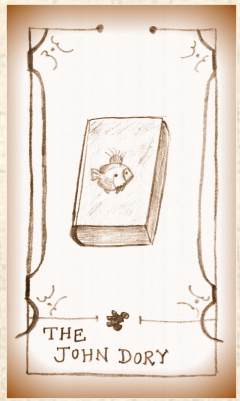
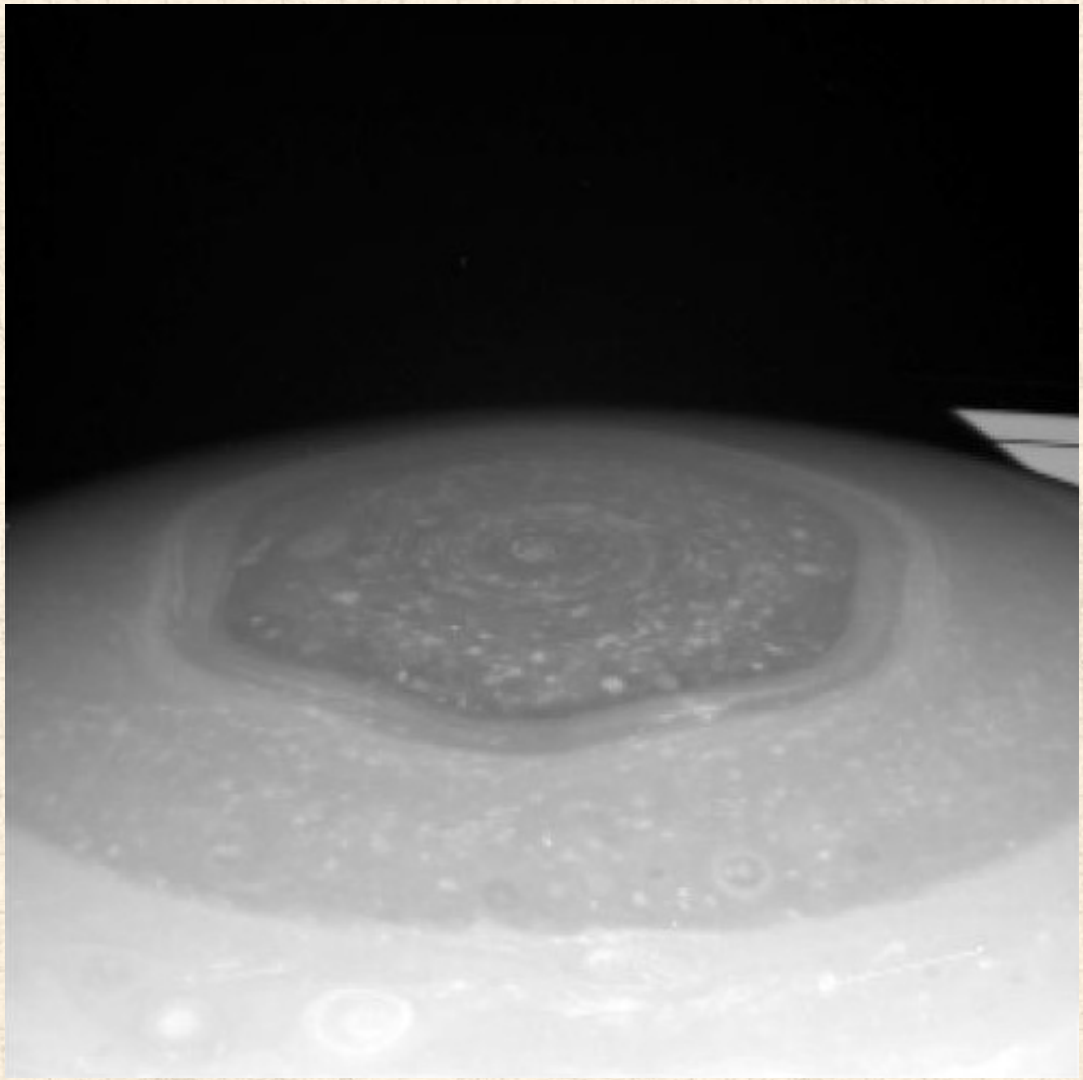
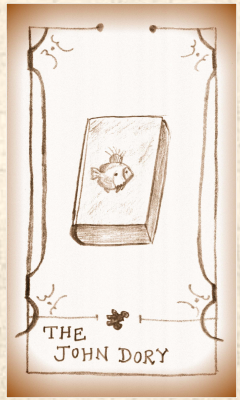


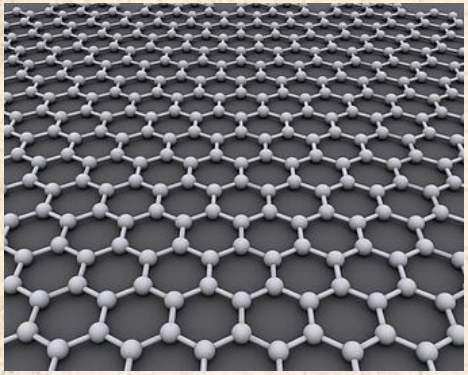
Saturn has a hexagon:



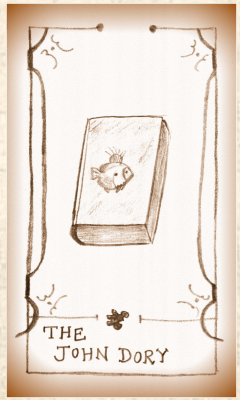
One side is longer than Earth's diameter



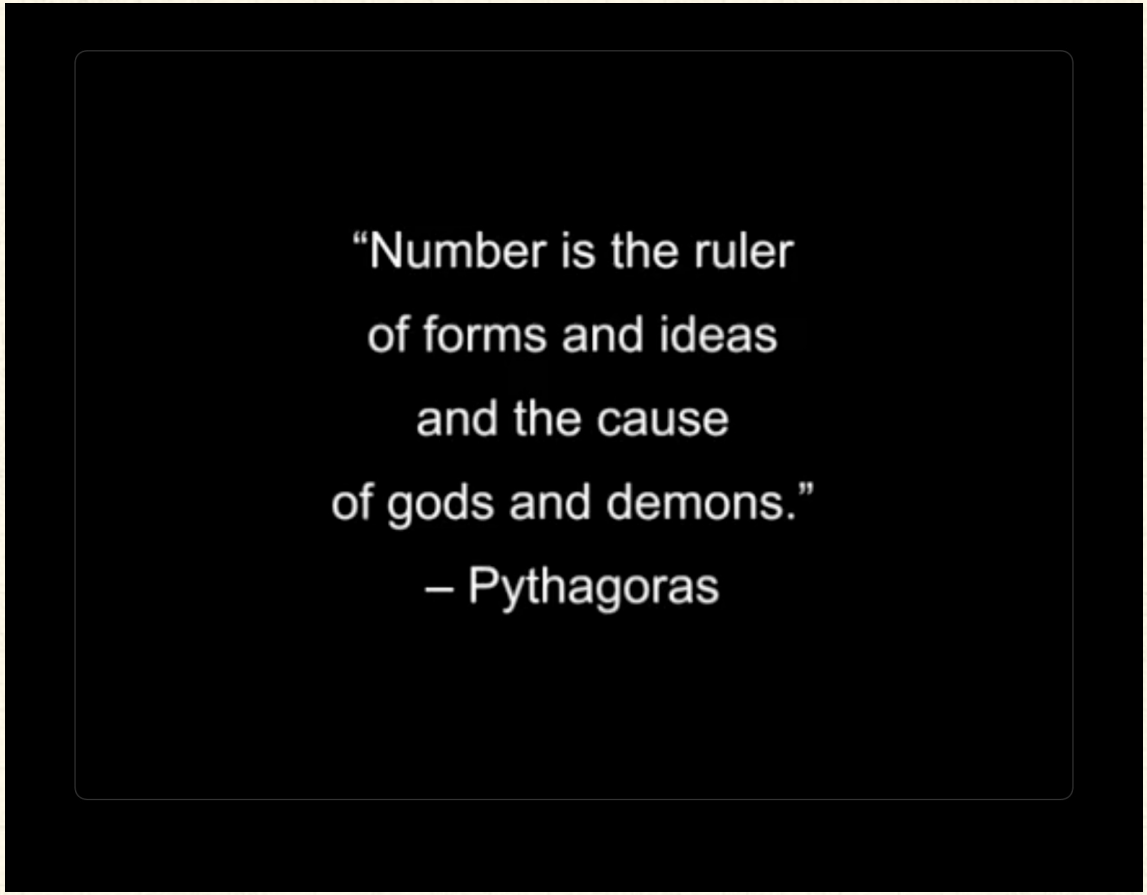
Hexagons run amok:



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

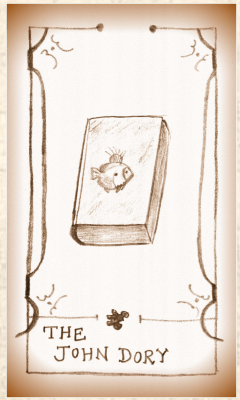


“Hexagons are the bestagons”



- From Hexnet.org, the (Legacy) Global Hexagonal Awareness Resource Center.
- Evolution: Hexagon Truth.

The comments

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THE DEPENDENT PATHS

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" 

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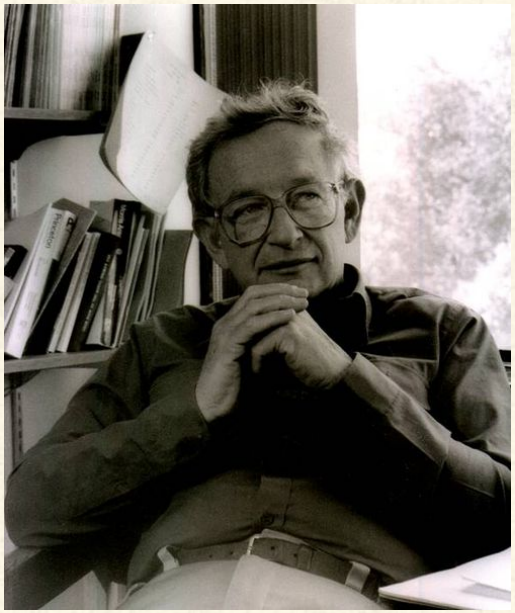

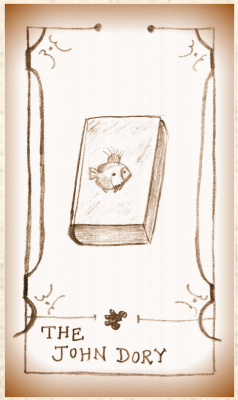

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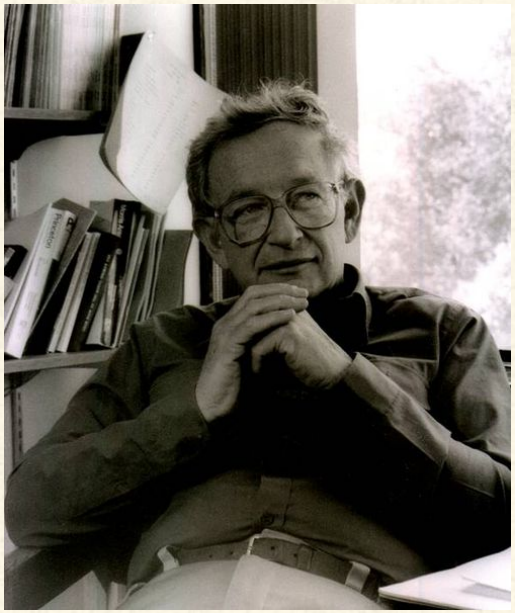

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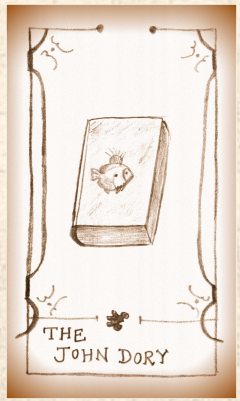

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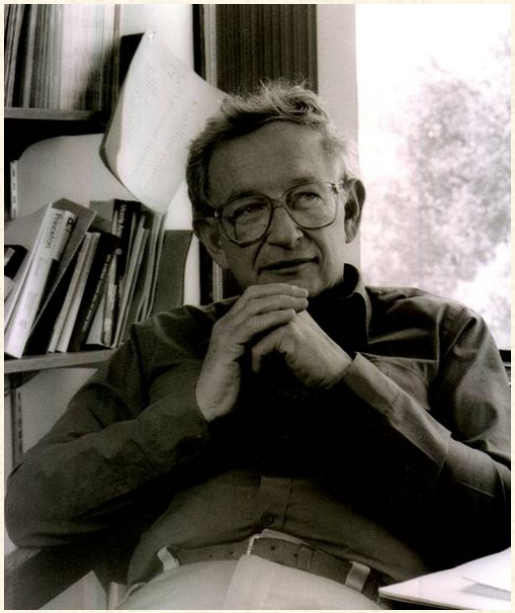

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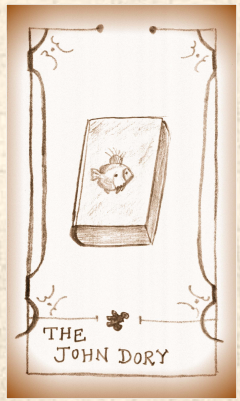

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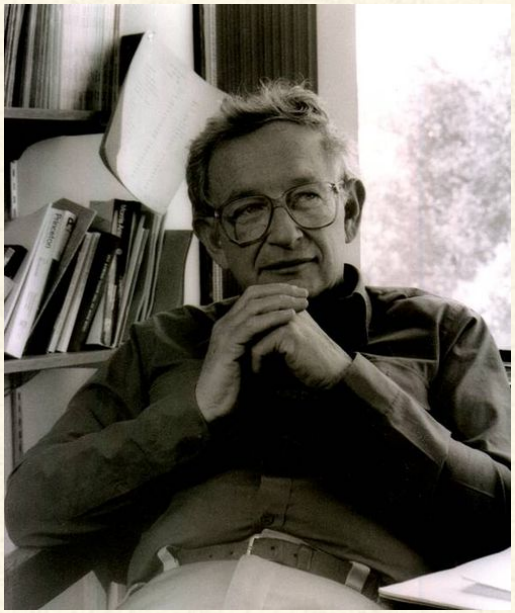

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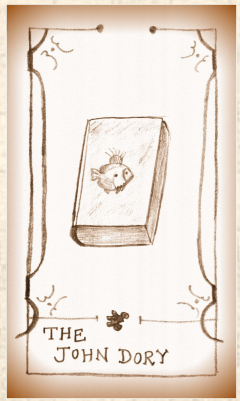
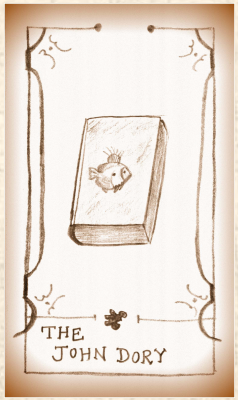


2006 study: "most creative physicist in the world"

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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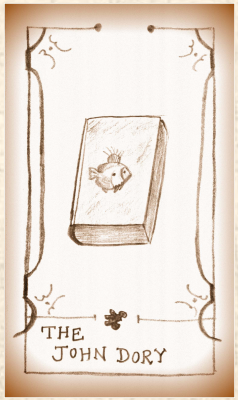

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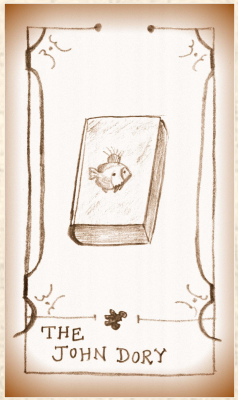

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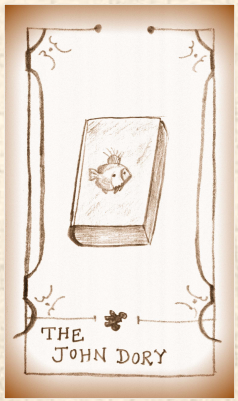

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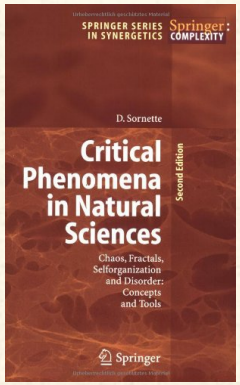

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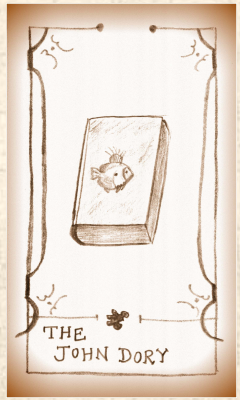

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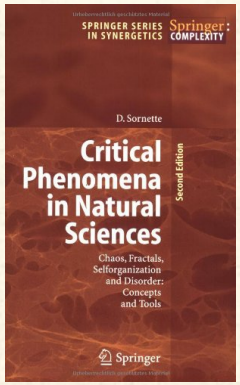

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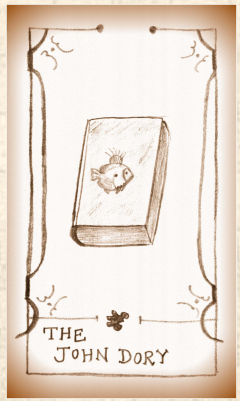

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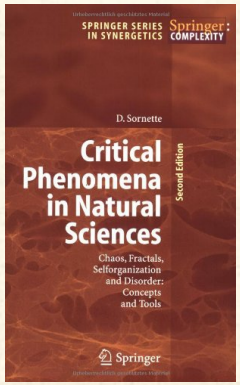

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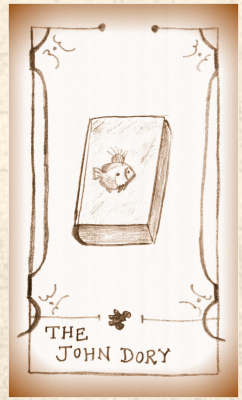

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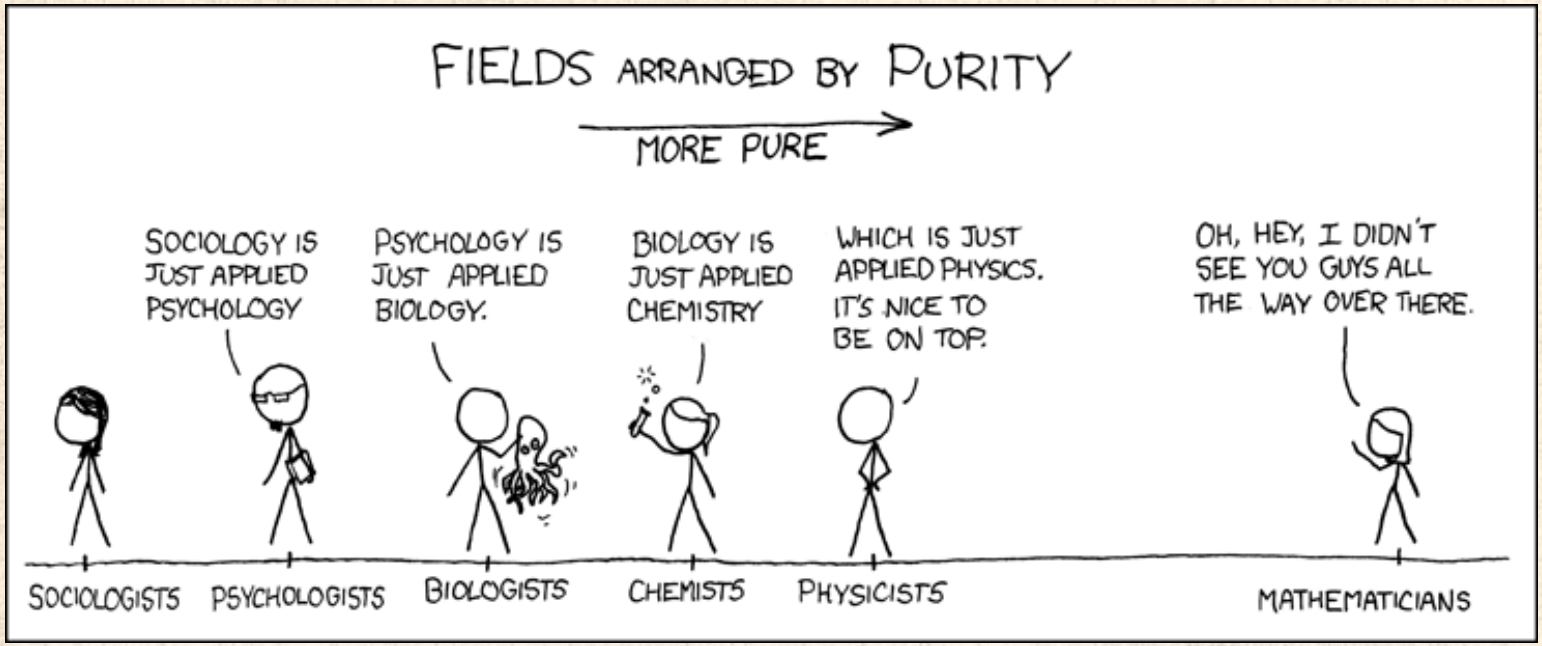
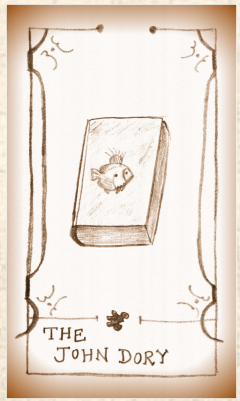


http://xkcd.com/435/




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 BORROWED YET FRIENDLY
THE MISREADING OF THE BOOK OF SAND
THE MANY TAILS OF MANY TAILS
THE MEASURING
THE DATA POOR
THE POORING DATA
THE CHARMS OF THE MANY WRONG PATHS
THE BOOKS THAT SHOULD NOT BE OPENED
THE KNOWLEDGE OF DEAD MINKS
THE EMERGENCE OF STRUCTURE
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THE EMERGENCE OF THINKING
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THE EMERGENCE OF STORIES
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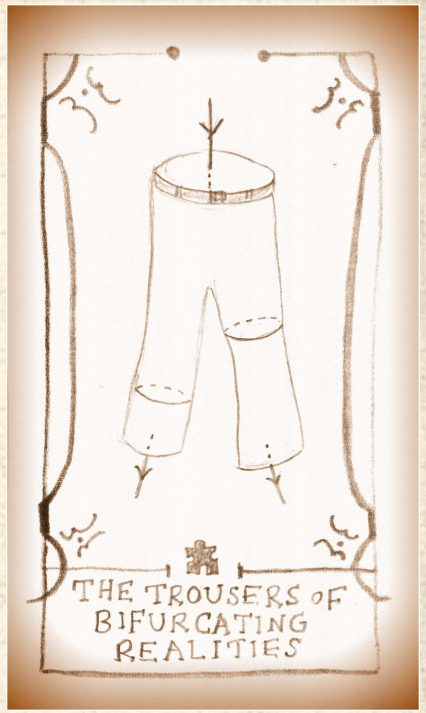
THE TROUSERS OF BIFURCATING REALITIES

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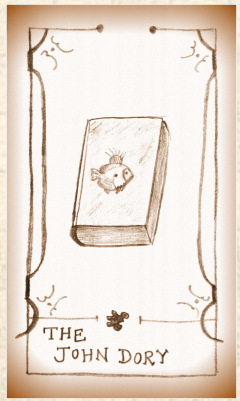
A real theory of ~~everything~~ anything:



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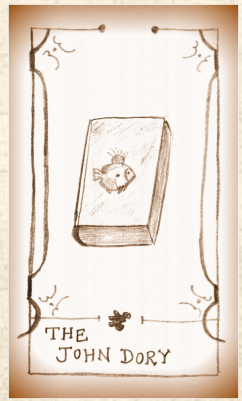

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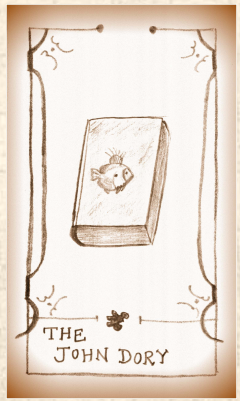

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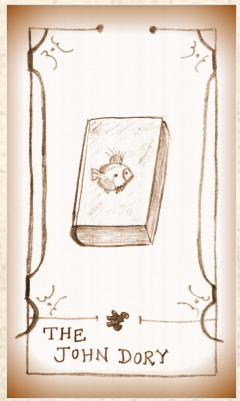

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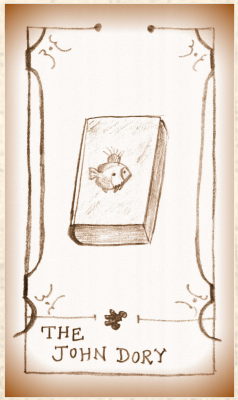

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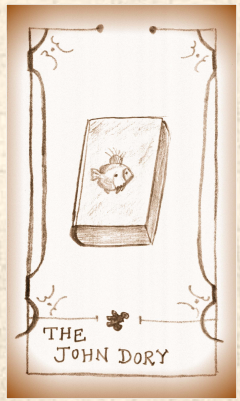

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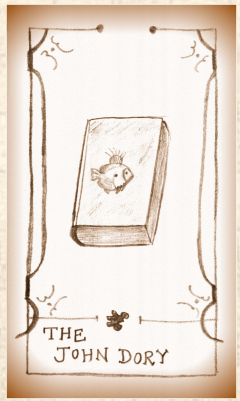

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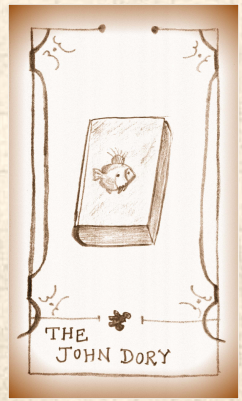

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Why complexify?


ESSAY

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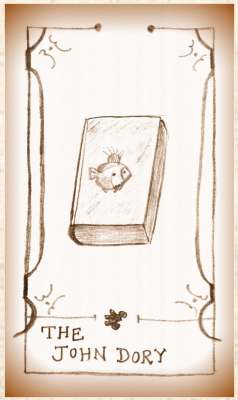

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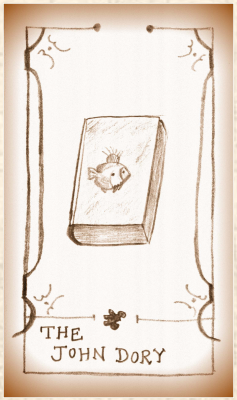

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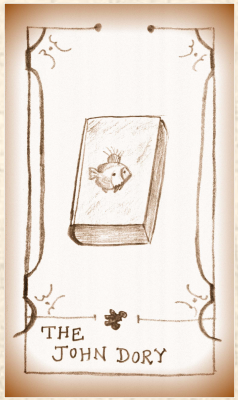

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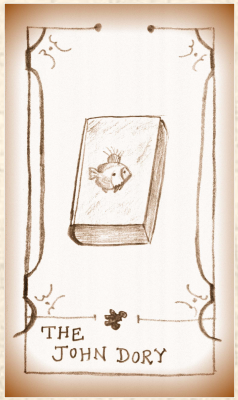

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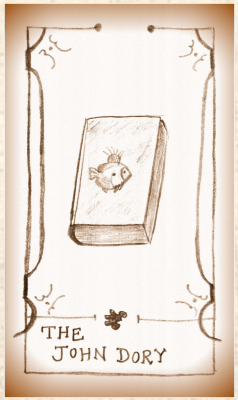
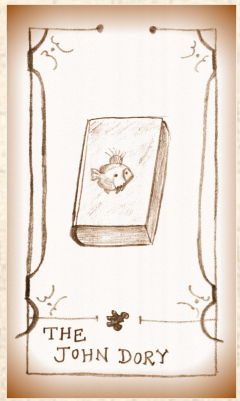


Why complexify?

Driving complexity's trajectory:

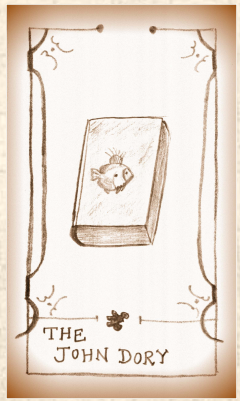
- Big Bang
- Randomness leads to replicating structures;
- Biological evolution;
- Sociocultural evolution;
- Technological evolution;
- Sociotechnological evolution.



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

The Key to Everything (nybooks.com)

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



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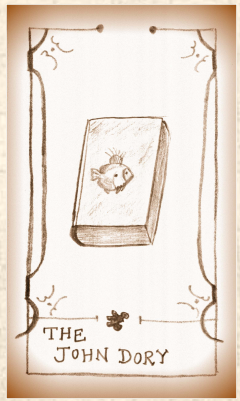

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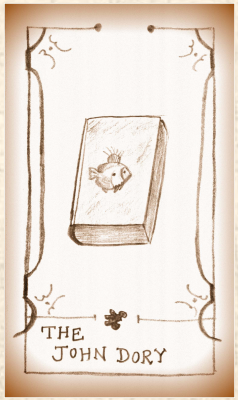

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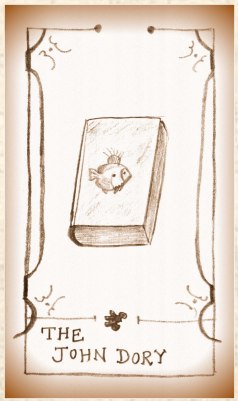
When you walk up a hill on the earth, your gravitational energy is becoming less negative, but never gets up to zero.



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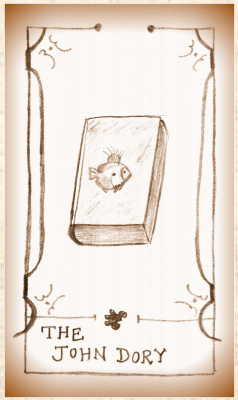
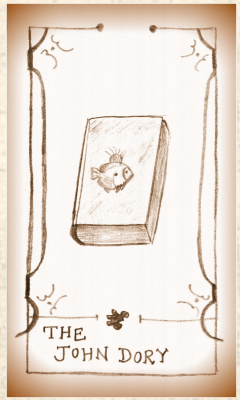
Any object whose motions are dominated by gravity will have energy decreasing as temperature increases and energy increasing as temperature decreases."



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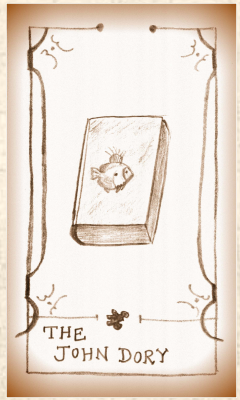
In every situation where gravity is dominant, the second law causes local contrasts to increase together with entropy.



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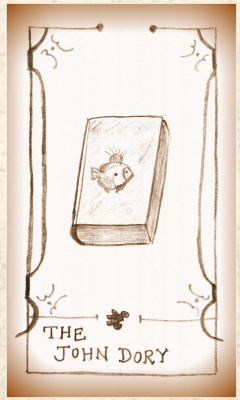
This is true for astronomical objects like the sun, and also for large terrestrial objects such as thunderstorms and hurricanes.



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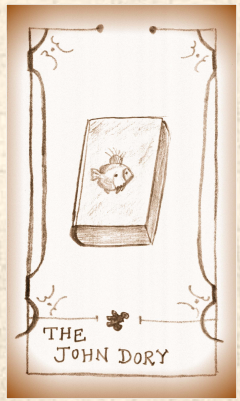
The diversity of astronomical and terrestrial objects, including living creatures, tends to increase with time, in spite of the second law.



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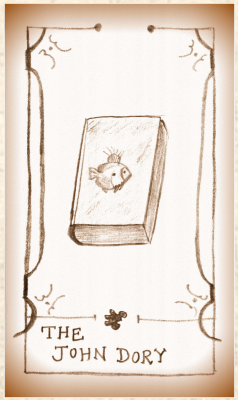
The evolution of natural ecologies and of human societies is a part of this pattern. West is evidently unaware of Fang and Li's insight."



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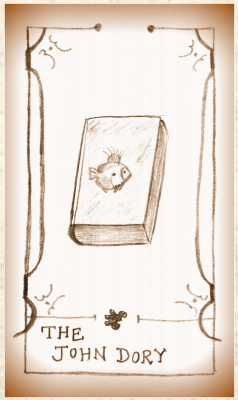
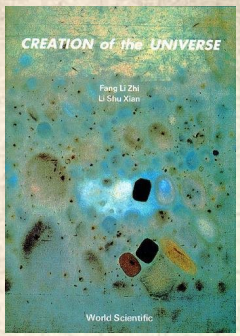
Note: Unfortunately, Dyson takes the (disastrously wrong) biological scaling stuff as being sorted.





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

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.

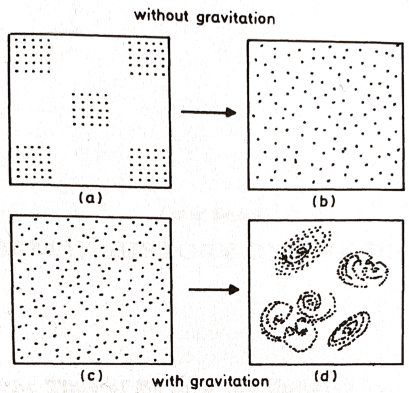


Fig. 6.6. In a system without gravitation, the evolution of the distribution of matter is from non-uniform (a) to uniform (b); in a system with gravitational interaction, the evolution is from uniform (c) to non-uniform (d).

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 Randomness.

Complexification—the Big Transitions:

- Big Bang.
- Big Randomness.
- Big Structure.

Complexification—the Big Transitions:

- Big Bang.
- Big Randomness.
- Big Structure.
- Big Replicate.

Complexification—the Big Transitions:

- Big Bang.
- Big Randomness.
- Big Structure.
- Big Replicate.
- Big Life.

Complexification—the Big Transitions:

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

Complexification—the Big Transitions:

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

Complexification—the Big Transitions:

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- Big Randomness.
- Big Structure.
- Big Replicate.
- Big Life.
- Big Evolve.
- Big Word.
- Big Story.

Complexification—the Big Transitions:

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- Big Evolve.
- Big Word.
- Big Story.
- Big Number.

Complexification—the Big Transitions:

- Big Bang.
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- Big Evolve.
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- Big Story.
- Big Number.
- Big Farm.

Complexification—the Big Transitions:

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- Big Number.
- Big Farm.
- Big God.

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- Big Make.

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- Big Data.

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- Big Information.
- Big Algorithm.
- Big Connection.
- Big Social.

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- Big Data.
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- Big Algorithm.
- Big Connection.
- Big Social.
- Big Awareness.

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- Big Algorithm.
- Big Connection.
- Big Social.
- Big Awareness.
- Big Spread.

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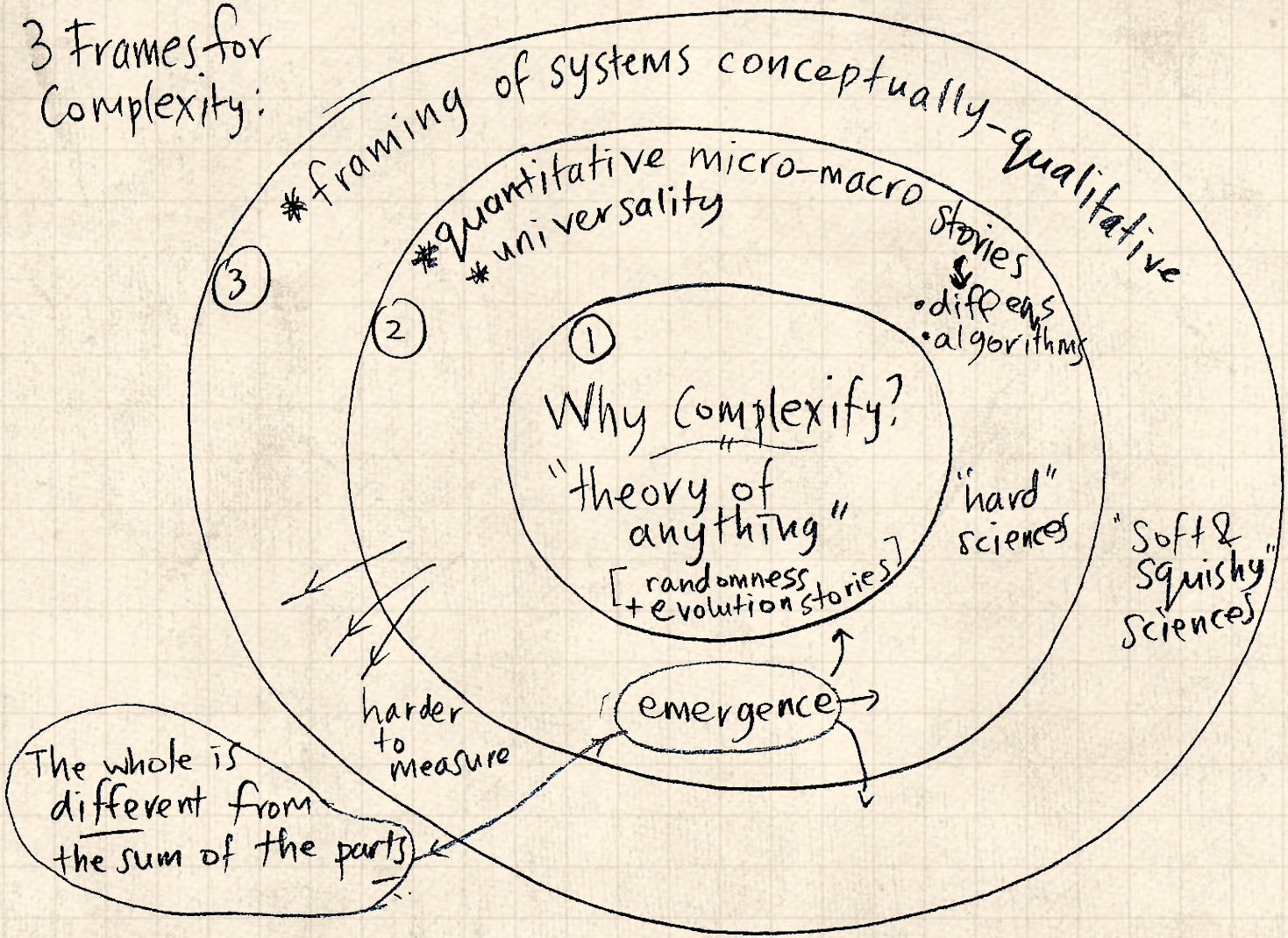
- Big Spread.
- Big ...?

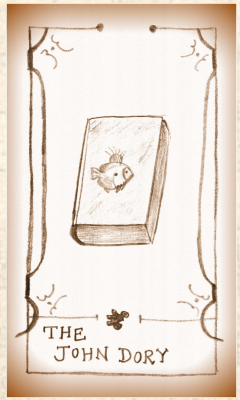

3 Frames for Complexity:
*framing of systems conceptually-qualitative
*quantitative micro-macro stories
*universality
• diffeqns
• algorithms
3
2
1
Why Complexify?
"theory of anything"
[randomness + evolution stories]
"hard" sciences
"Soft & Squishy" Sciences
harder to measure
emergence
The whole is different from the sum of the parts


THE FATED
ASTRAL PATH


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 BORROWED YET FRAGILE
THE MISREADING OF THE BOOK OF SAND
THE MANY TAILS OF MANY TAILS
THE MEASURING
THE DATA POOR
THE POORING DATA
THE CHARMS OF THE MANY WRONG PATHS
THE DOORS 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 OF TATTUTICAL
TWO THRESHOLDS OF PERCOLATION
THE NETWORKED 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 QUARTEROLOGY
THE TRUTHICIDE
THE FAMILY OF PANCAKE COWS
THE FAMILY OF SPHERICAL COWS
THE IMPROBABLE PACHYDERM
THE ILLSCALING OF ALLOMETRIC BODIES
THE SUPPLY MOST FAIR
THE SUPPLY TO THE MOST
THE DARK ART OF GENERATING FUNCTIONS
THE RANDOM PATH OF RANDOMNESS
THE TWO-SIDED WORLDS
THE STORIES AND THE TROPES
THE TRUTH OF DIFFUSION
THE UNVEILING OF HIDDEN POWERS
THE SCRYING FOR THE SHAPE OF THINGS
THE LIMITS OF ORGANIZATIONS
THE END

The absolute basics:

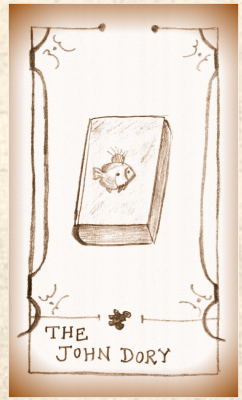
Modern basic science in three steps:



The absolute basics:

Modern basic science in three steps:

1. Find interesting/meaningful/important phenomena, optionally involving spectacular amounts of data.



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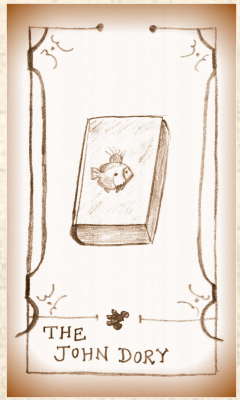
Modern basic science in three steps:

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



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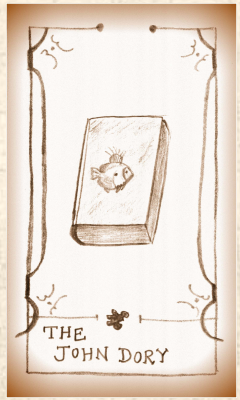
3. Explain it.



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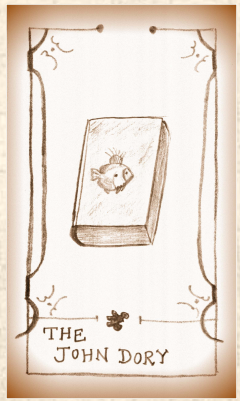
Unlocks our (limited) ability to: Create, predict, and control.



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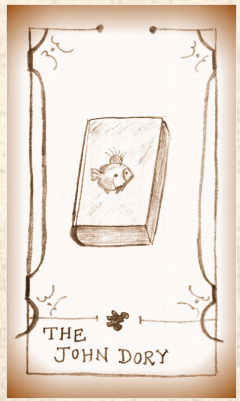
And be good people: Share.



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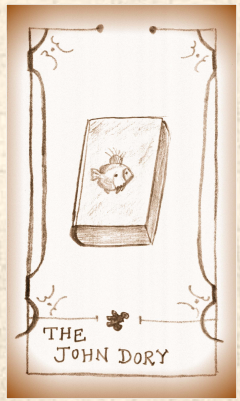
Taste matters. Develop taste in research.



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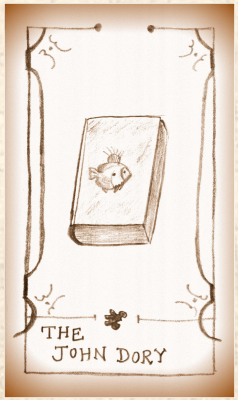
Taste matters. Develop taste in research.

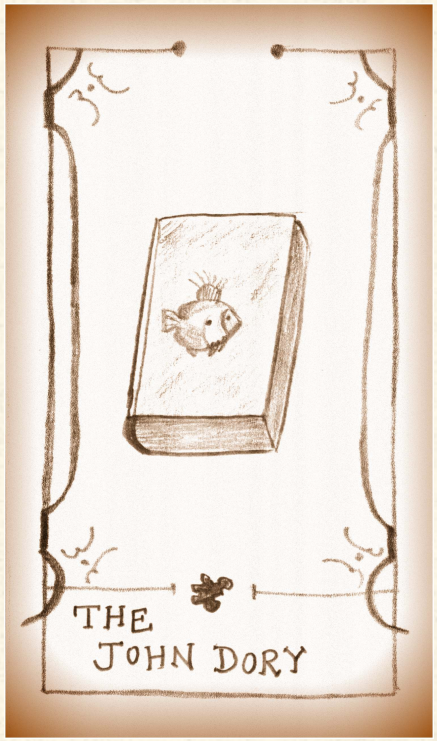
Beware your assumptions: Don't use tools/models because they're there, or because everyone else does ...

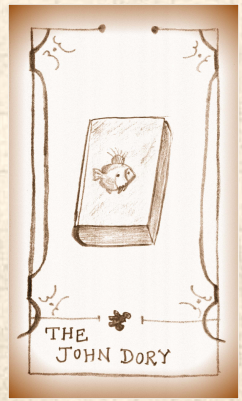


This is also part of a thing that could be next:

Principles of Complex Systems, Vol. 2

Storyology
Episode VI:
PoCS with ewoks





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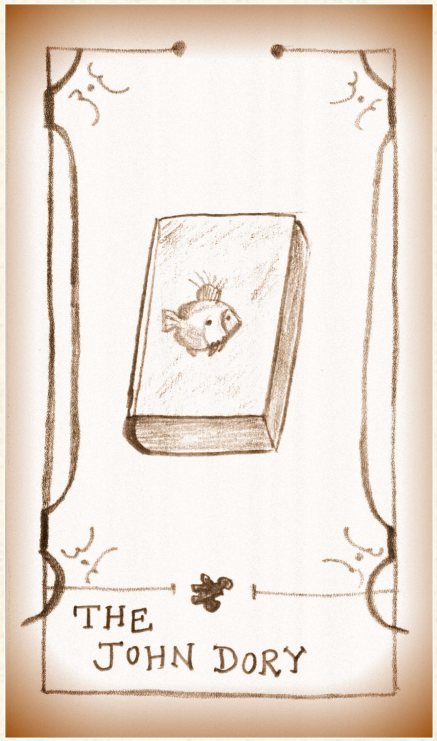
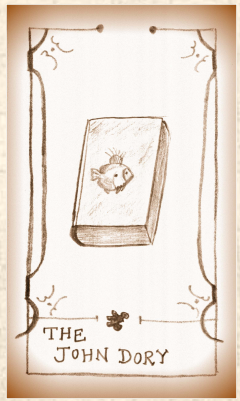
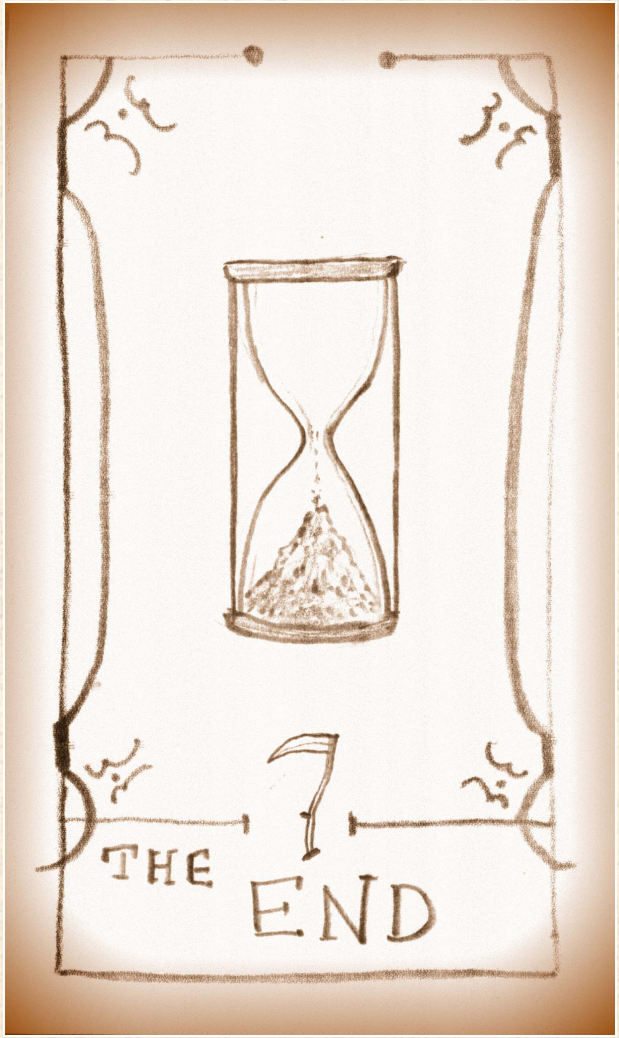


- Exploring texts of all kinds, centrality of stories.
- News, social media, fiction, Twitter.
- Dark arts of text parsing, cleaning, regular expression.
- Measuring happiness and sadness through text.
- Measuring and understanding cultural evolution through texts: legal and government texts, music lyrics,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




THE END

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.
https://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.