

Why Complexify?

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Principles of Complex Systems, Vols. 1, 2, 3D, 4 Fourever, V for Vendetta

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University of Vermont | Santa Fe Institute



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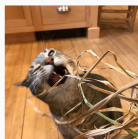
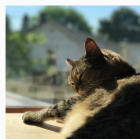
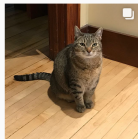
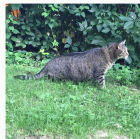
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 On Instagram at [pratchett_the_cat](https://www.instagram.com/pratchett_the_cat) 

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Outline

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Limits to what's possible:

Universality :



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

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Limits to what's possible:

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Key figure: Leo Kadanoff 

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Kadanoff's retrospective: "Innovations in Statistics Physics" [4]



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Examples:



Limits to what's possible:

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Examples:

 The Central Limit Theorem:

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



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Examples:

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 Navier Stokes equation for fluids.



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Examples:

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

 Navier Stokes equation for fluids.

 Nature of phase transitions in statistical mechanics.





Sometimes **details don't matter too much.**



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Sometimes **details don't matter too much.**



Many-to-one mapping from micro to macro



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Sometimes **details don't matter too much.**



Many-to-one mapping from micro to macro



Suggests not all possible behaviors are available
levels of complexity.

at higher



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- Sometimes **details don't matter too much.**
- Many-to-one mapping from micro to macro
- Suggests not all possible behaviors are available at higher levels of complexity.
- Universality means some things are fated.

Large questions:



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- Sometimes **details don't matter too much.**
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Large questions:

- How universal is universality?



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- Sometimes **details don't matter too much.**
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- Suggests not all possible behaviors are available at higher levels of complexity.
- Universality means some things are fated.

Large questions:

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



Fluid mechanics

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Fluid mechanics = One of the great successes of understanding complex systems.



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Fluid mechanics = One of the great successes of understanding complex systems.



Navier-Stokes equations: micro-macro system evolution.



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Navier-Stokes equations: micro-macro system evolution.



The big three: Experiment + Theory + Simulations.



Fluid mechanics

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References

-  Fluid mechanics = One of the great successes of understanding complex systems.
-  Navier-Stokes equations: micro-macro system evolution.
-  The big three: Experiment + Theory + Simulations.
-  Works for many very different 'fluids':
 -  the atmosphere,
 -  oceans,
 -  blood,
 -  the earth's mantle,
 -  galaxies, ...



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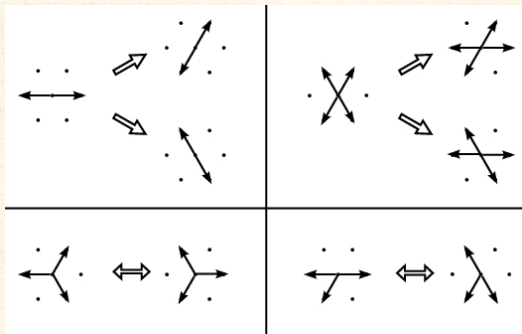
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 -  the earth's mantle,
 -  galaxies, ...
 -  and ball bearings on lattices ...?



Lattice gas models

Collision rules in 2-d on a hexagonal lattice:



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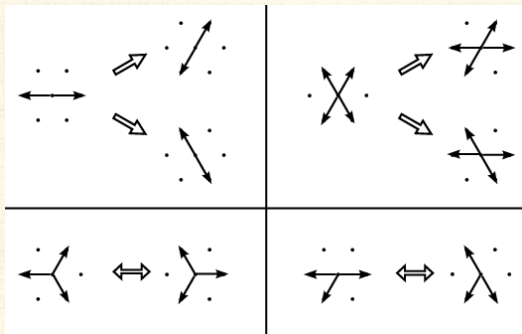
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Lattice matters ...

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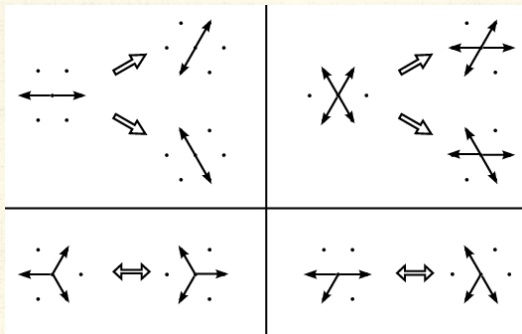
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Lattice gas models

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No 'good' lattice in 3-d.

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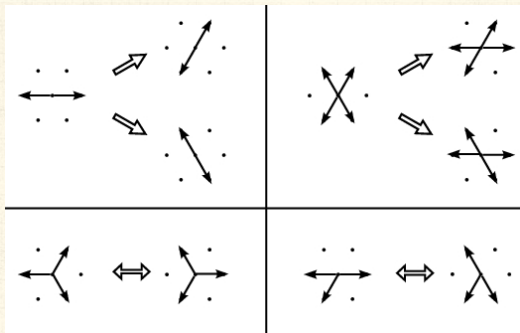
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Collision rules in 2-d on a hexagonal lattice:



Lattice matters ...



No 'good' lattice in 3-d.



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

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Hexagons—Honeycomb:

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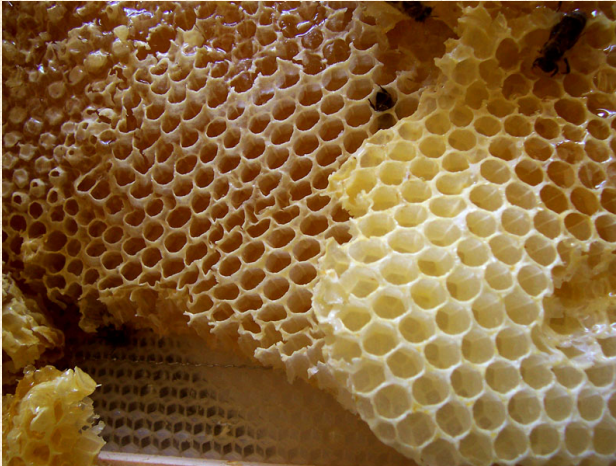
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Orchestrated? Or an accident of bees working hard?



Hexagons—Honeycomb:

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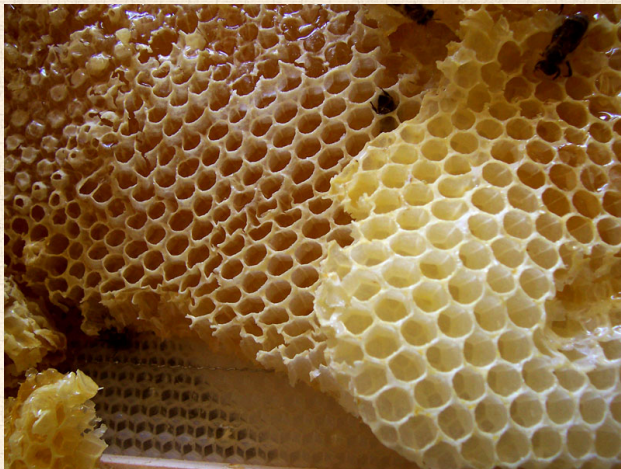
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Orchestrated? Or an accident of bees working hard?



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



Hexagons—Giant's Causeway: ↗



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<http://newdesktopwallpapers.info>



Hexagons—Giant's Causeway:



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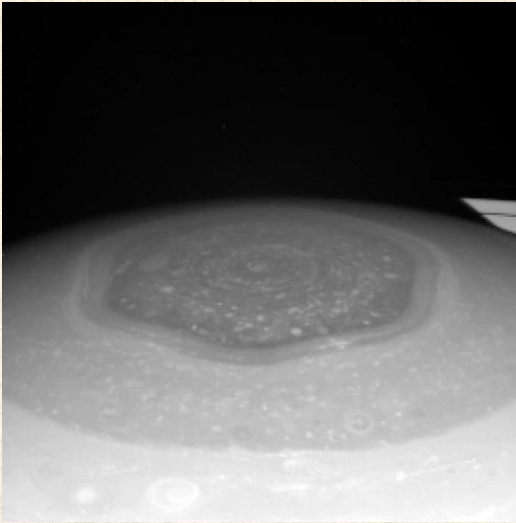
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<http://www.physics.utoronto.ca/>



Saturn has a hexagon:



One side is longer than Earth's diameter 

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Hexagons run amok:

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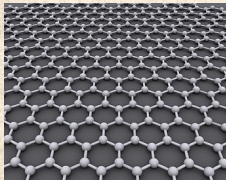
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Graphene : single layer of carbon molecules in a perfect hexagonal lattice (super strong).



Chicken wire  ...



"Hexagons are the bestagons"

"Number is the ruler
of forms and ideas
and the cause
of gods and demons."
– Pythagoras



From Hexnet.org , the (Legacy) Global Hexagonal Awareness Resource Center.



Evolution: Hexagon Truth. 



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“More is different” 

P. W. Anderson,
Science, **177**, 393–396, 1972. ^[1]



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“More is different” 

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Science, **177**, 393–396, 1972. ^[1]



Anderson  argues against idea that
the only real scientists are those
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Symmetry breaking → different laws/rules at different scales ...



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Anderson  argues against idea that the only real scientists are those working on the fundamental laws.



Symmetry breaking → different laws/rules at different scales ...

2006 study: "most creative physicist in the world" 



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“Elementary entities of science X obey the laws of science Y”



X



solid state or many-body
physics



chemistry



molecular biology



cell biology

⋮



psychology



social sciences



Y



elementary particle
physics



solid state many-body
physics



chemistry



molecular biology

⋮



physiology



psychology



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Anderson:



[the more we know about] “fundamental laws, the less relevance they seem to have to the very real problems of the rest of science.”



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Anderson:

 [the more we know about] “fundamental laws, the less relevance they seem to have to the very real problems of the rest of science.”

 Scale and complexity thwart the constructionist hypothesis.



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Anderson:

 [the more we know about] “fundamental laws, the less relevance they seem to have to the very real problems of the rest of science.”

 Scale and complexity thwart the constructionist hypothesis.

 Accidents of history and path dependence  matter.



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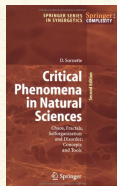
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“Critical Phenomena in Natural Sciences”  
by Didier Sornette (2003). ^[5]



Page 291–292 of Sornette ^[6]:
Renormalization $\equiv$ Anderson’s hierarchy.



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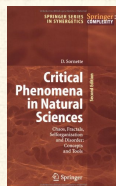
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But Anderson’s hierarchy is not a simple one: the rules
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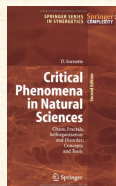
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-  Page 291–292 of Sornette ^[6]:
Renormalization $\equiv$ Anderson’s hierarchy.
-  But Anderson’s hierarchy is not a simple one: the rules change.
-  Crucial dichotomy between evolving systems following stochastic paths that lead to
(a) **inevitable** or (b) **particular** destinations (states).



More is different:

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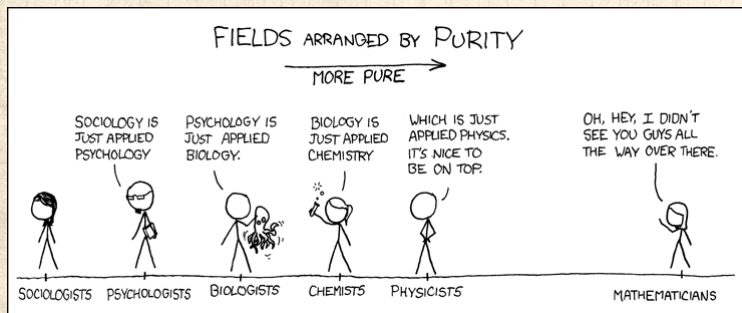
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<http://xkcd.com/435/>



A real science of complexity:

A real theory of ~~everything~~ anything:

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A real science of complexity:

A real theory of ~~everything~~ anything:

1. Is not just about the ridiculously small stuff ...

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Second law of thermodynamics: we're toast soup in the long run.¹



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¹But: Gravity. ^[9]

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Second law of thermodynamics: we're toast soup in the long run.¹



So how likely is the local complexification of structure we enjoy?



¹But: Gravity. ^[9]

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How likely are the Big Transitions?



¹But: Gravity. [9]

Why complexify?



“Why do things become more complex?” 

W. Brian Arthur,

Scientific American, **268**, 92, 1993. ^[2]



Argues that evolution toward increased performance brings a ratcheting cycle of complexification and simplification.

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Jet engine replaced the complex piston engine and then itself became more complex.



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“Why do things become more complex?” [!\[\]\(05be7c7a8995decd503647c99211f7c2_img.jpg\)](#)

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-  Jet engine replaced the complex piston engine and then itself became more complex.
-  Complexification $\equiv$ evolution of algorithms?
-  Differential equations and stories $\subset$ Algorithms.
-  Life is a loaded word: The Search for Extraterrestrial Algorithms (SETA)?



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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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The explanation lies in the peculiar behavior of gravity in the physical world. On the balance sheet of energy accounting, gravitational energy is a deficit.

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When you are close to a massive object, your gravitational energy is minus the amount of energy it would take to get away from the mass all the way to infinity.

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When you are close to a massive object, your gravitational energy is minus the amount of energy it would take to get away from the mass all the way to infinity.

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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When you are close to a massive object, your gravitational energy is minus the amount of energy it would take to get away from the mass all the way to infinity.

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

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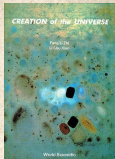
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Note: Unfortunately, Dyson takes the (disastrously wrong) biological scaling stuff as being sorted.





“Creation of the Universe” by Zhi and Xian (1989).^[9]

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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

structured $\longrightarrow$ structureless
non-uniform $\longrightarrow$ 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

structureless $\longrightarrow$ structured
uniform $\longrightarrow$ 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

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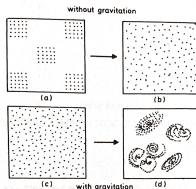


Fig. 6.6. In a system without gravitation, the evolution of the distribution of matter is from non-uniform (a) to uniform (b); in a system with gravitational interaction, the evolution is from uniform (c) to non-uniform (d).

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.

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Big Bang.



Big
Randomness.



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Big Bang.



Big
Randomness.



Big Structure.



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Big Bang.



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Randomness.



Big Structure.



Big Replicate.



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 Big Social.
 Big Awareness.



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 Big Spread.



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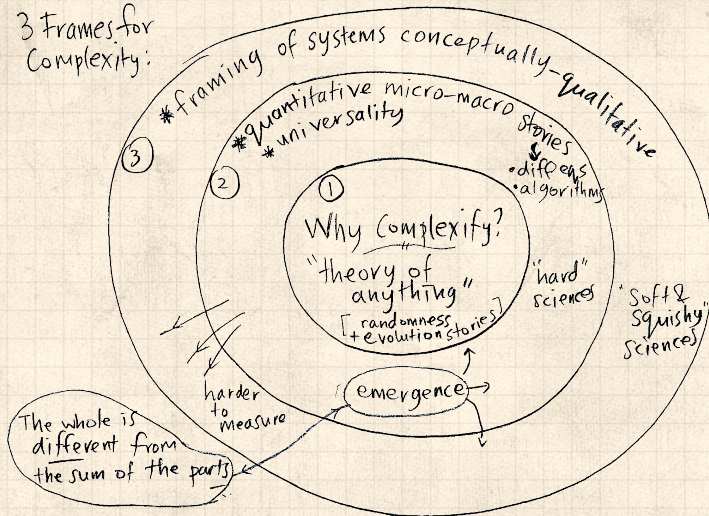
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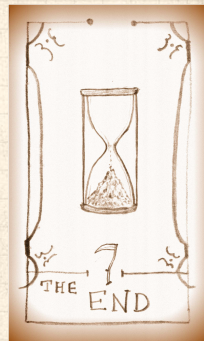
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 Big ...?



3 Frames for Complexity:





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.

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The absolute basics:

Modern basic science in three steps:

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

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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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And be good people: **Share.**

Taste matters. Develop taste in research.

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

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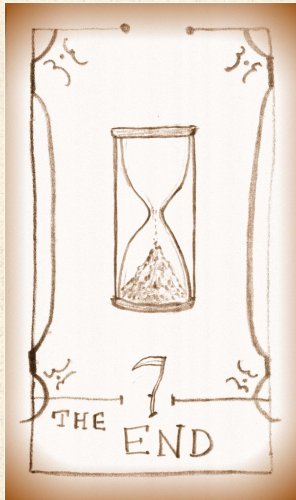
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