Defining Complexity

A Manifesto

References

A Complex Systems Manifesto

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

Prof. Peter Sheridan Dodds | @peterdodds

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Outline

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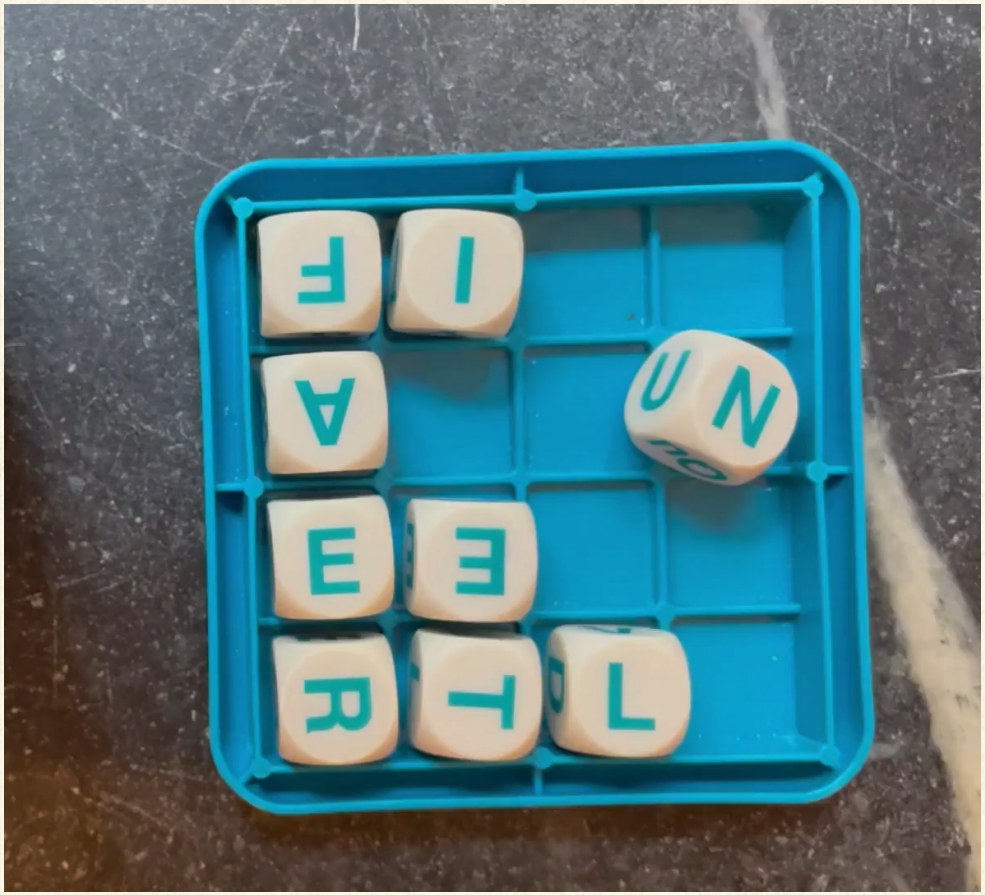
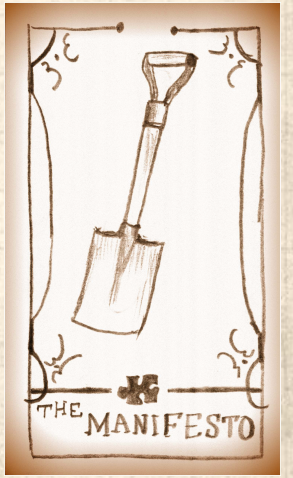
The Boggoracle Speaks:






THE SUN
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 ROBUST YET FRAGILE
THE MISLEADING OF THE BANK OF ZIND
THE MANY TALES OF MANY TAILS
THE MEASURING
THE DATA POOR
THE DOUBLING DATA
THE CHARMS OF THE MANY WRONG PATHS
THE DOORS THAT SHOULD NOT BE OPENED
THE KNOWLEDGE OF DEAD MONKS
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
THE ARK OF THE RANDOM NETWORK
THE STRANGENESS OF FRIENDS
THE SMALLNESS OF WORLDS
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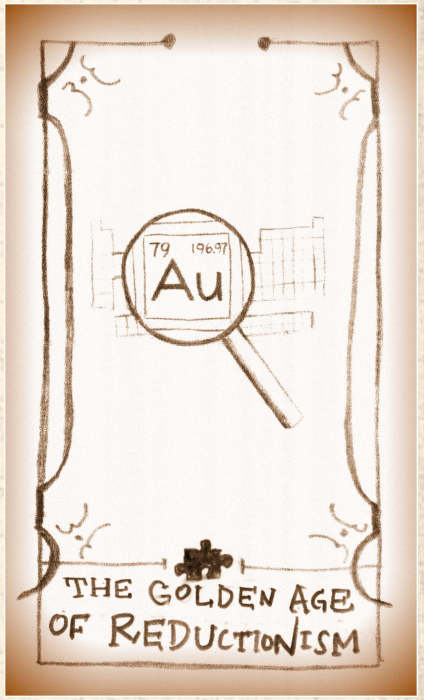
THE SUPPLY MOST FAIR
THE SUPPLY TO THE MOST
THE DARK ART OF GENERATING FUNCTIONS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THE GOLDEN AGE OF REDUCTIONISM


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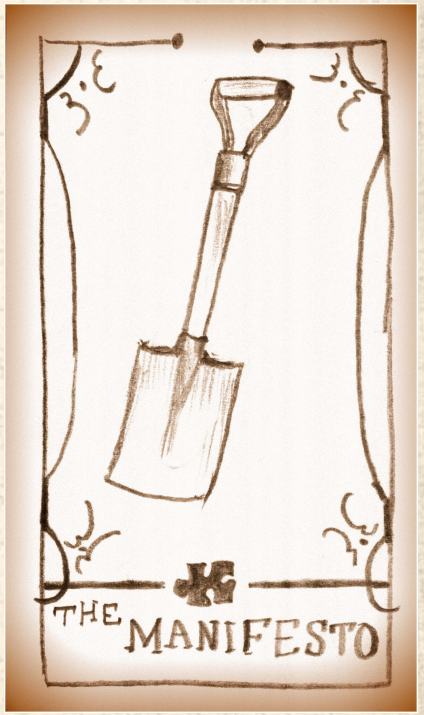
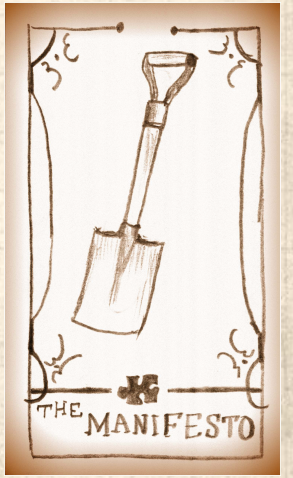

THE MANIFESTO

Definitions

Complex: (Latin = with + fold/weave (com + plex))

Adjective:

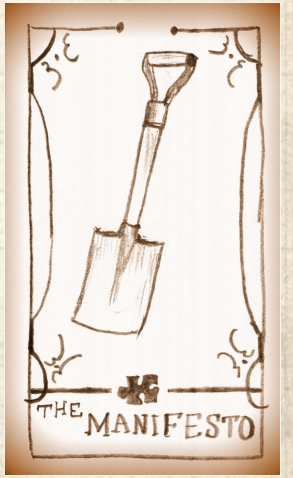
1. Made up of multiple parts; intricate or detailed.
2. Not simple or straightforward.



Definitions

Complicated versus Complex:

- Complicated: Mechanical watches, airplanes, ...
- Engineered systems can be made to be highly robust but not adaptable.
- But engineered systems can become complex (power grid, planes).
- They can also fail spectacularly.
- Explicit distinction: Complex Adaptive Systems.



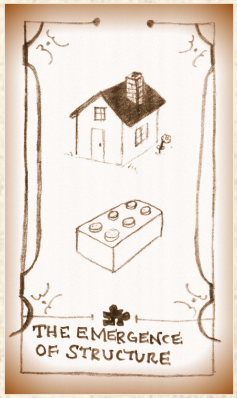
Definitions

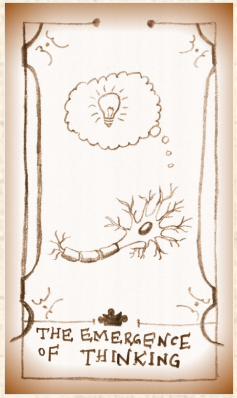
The definition of a Complex System:

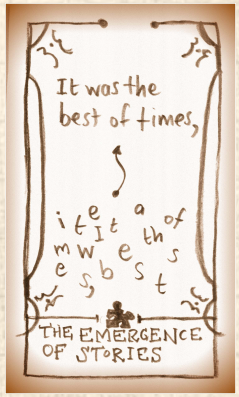
- Distributed system of many interrelated (possibly networked) parts with no centralized control exhibiting emergent behavior.

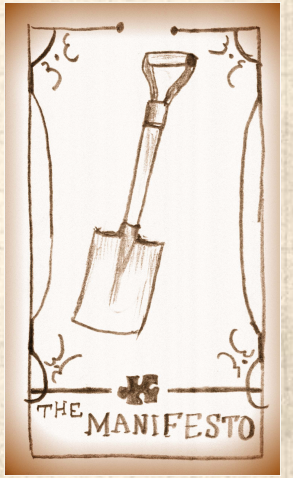
Emergence—'More is Different' [1]:

There's no tornado in a water molecule,
no financial collapse in a dollar bill,
no love in a carbon atom.



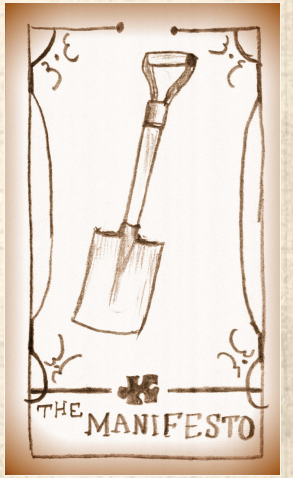






A few other features/aspects of complex systems:

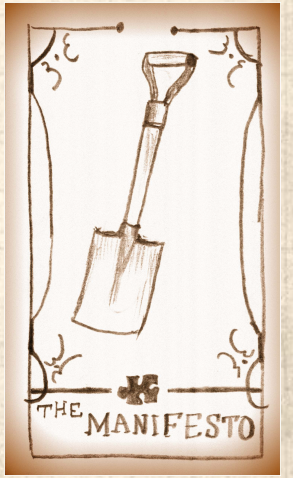
- Explicit nonlinear relationships.
- Presence of feedback loops.
- Open or driven, opaque boundaries.
- Memory.
- Modular (nested)/multiscale structure.
- Mechanisms range from being purely physical to purely algorithmic in nature.



Examples of Complex Systems:

- human societies
- financial systems
- cells
- ant colonies
- fluids, weather systems
- ecosystems
- power grids
- animal societies
- disease ecologies
- brains
- social insects
- geophysical systems
- forests
- Internet + Web

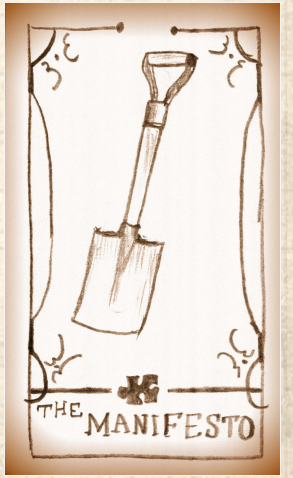
- i.e., everything that's interesting ...



Relevant fields:

- Physics
- Economics
- Sociology
- Psychology
- Information Sciences
- Cognitive Sciences
- Biology
- Ecology
- Geosciences
- Geography
- Medical Sciences
- Systems Engineering
- Computer Science
- Data Science
- ...

- i.e., everything that's interesting ...



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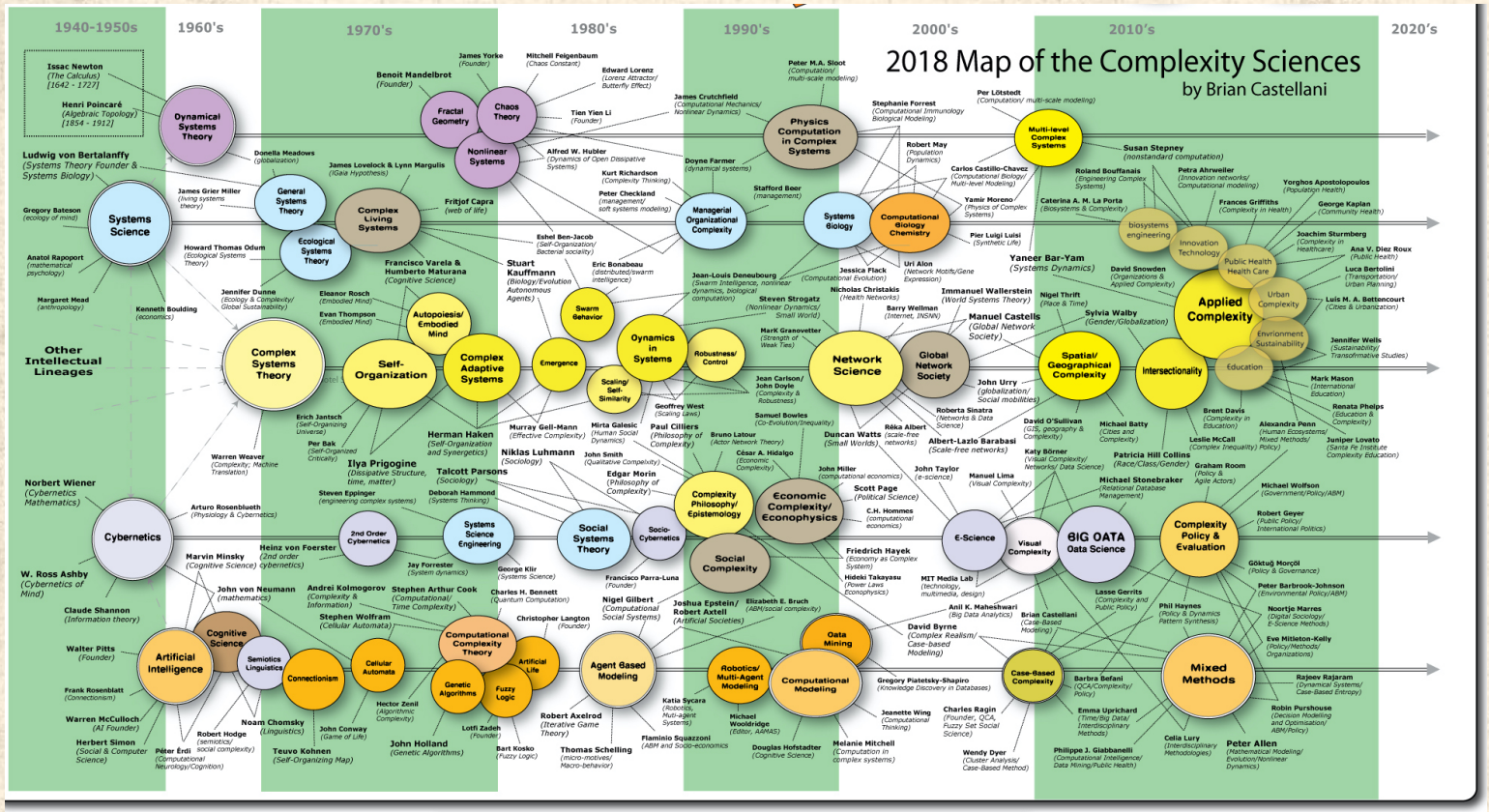
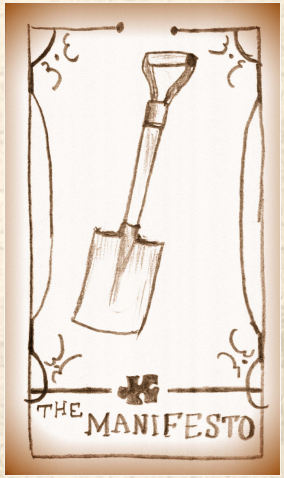
A visualized history of Complex Systemsish fields:

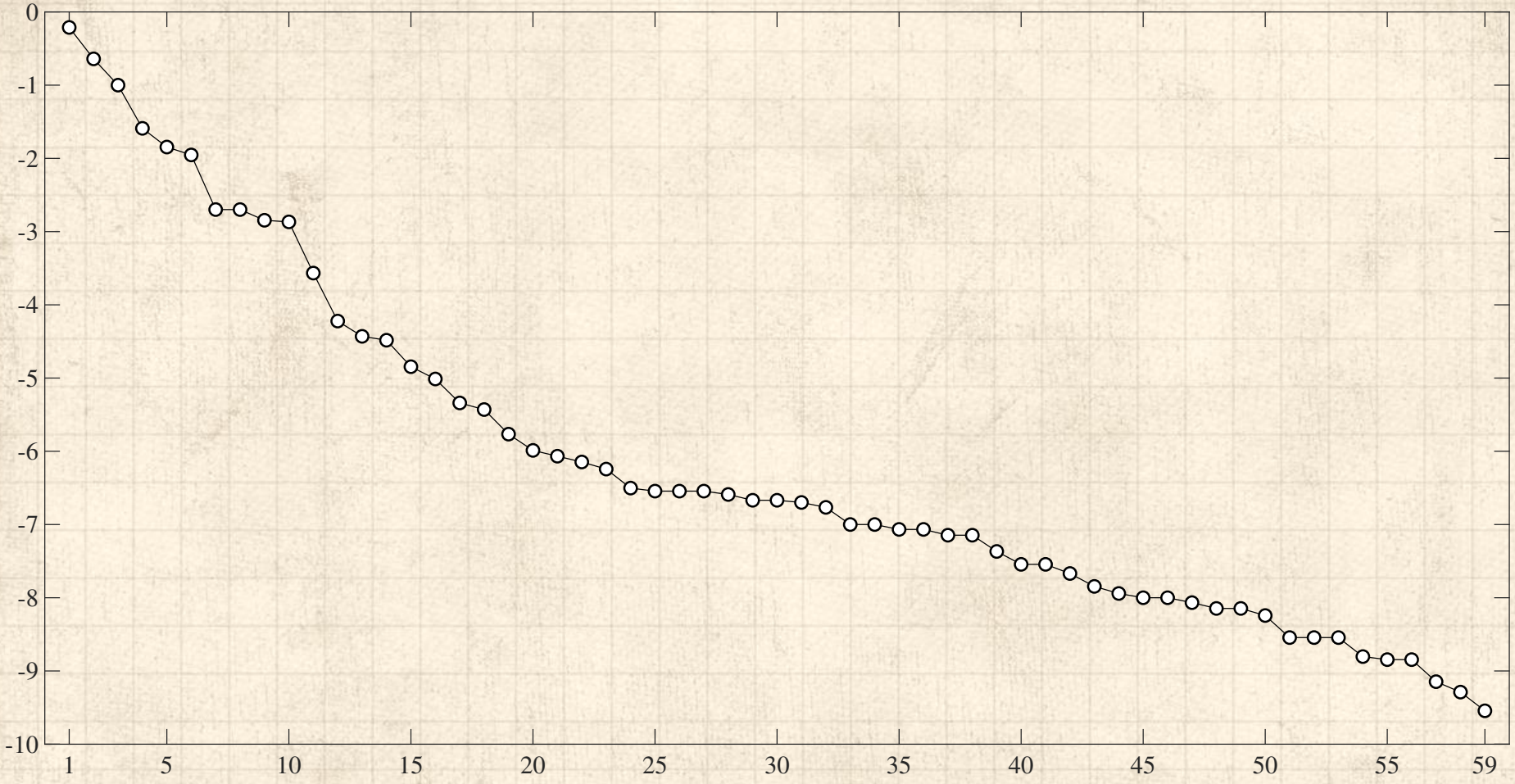


"Complexity Map" by Brian Castellani, Kent State

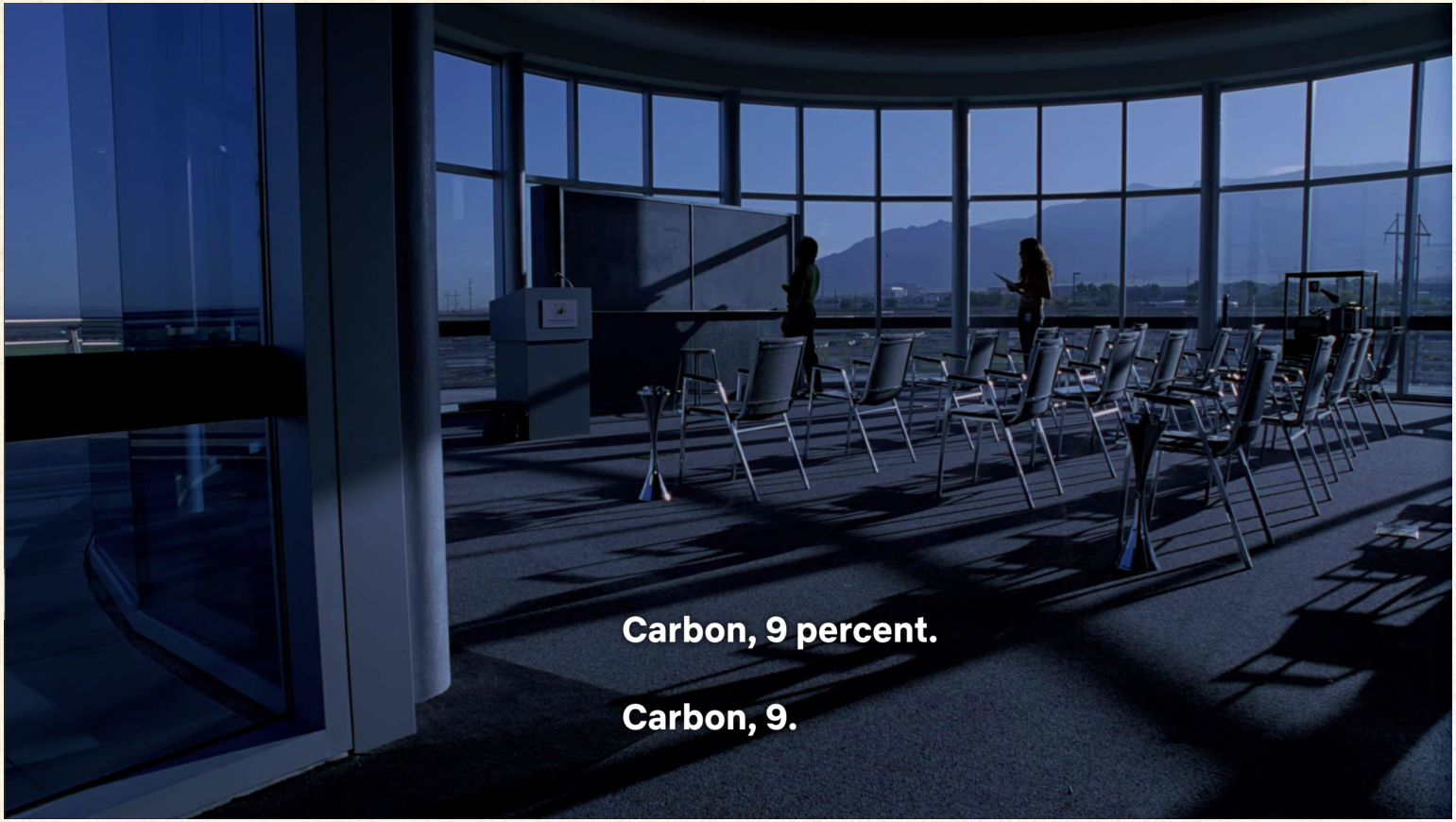
- Online here, at art-sciencefactory.com.
- Complex Systems is bigger than this (e.g., fluid dynamics; more later).

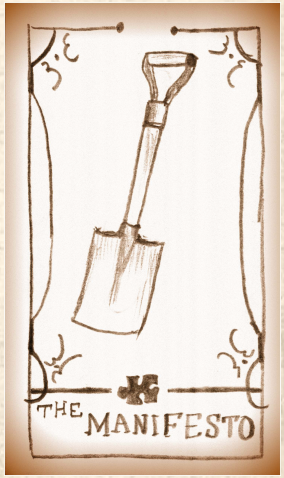


Cryptograph—What's being plotted here?:



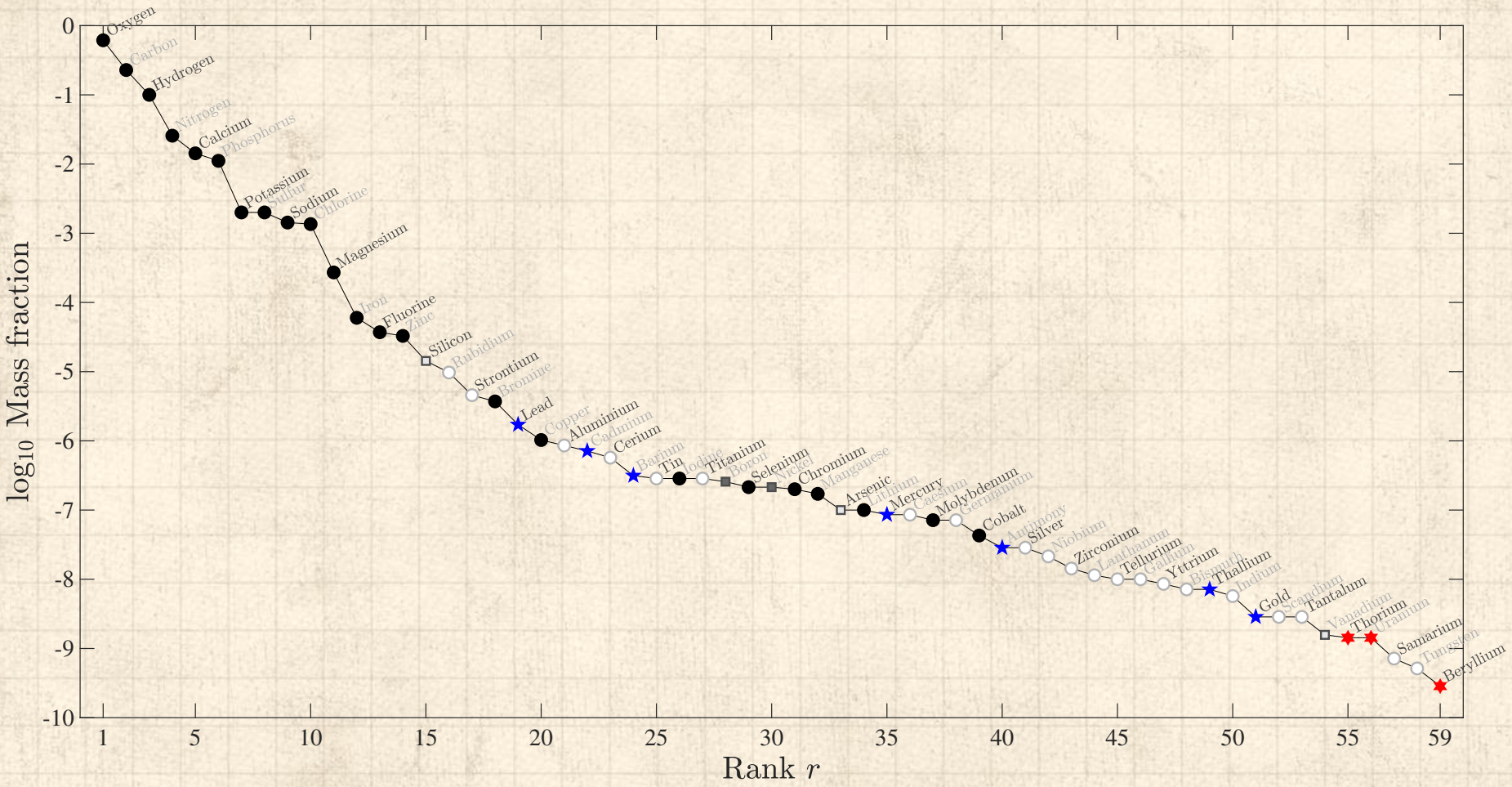
A hint[1]



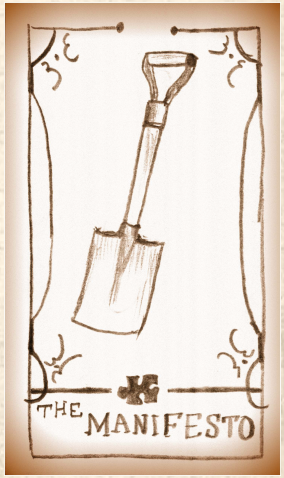


[1] S1E01

Fractional weight of typical human body by atomic species:



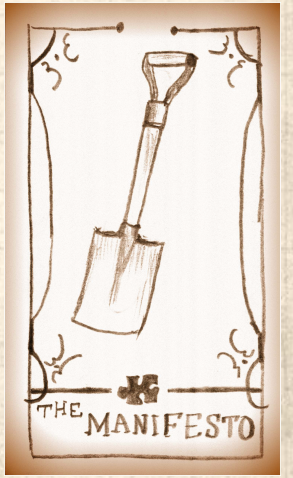
Baking soda and vinegar[1]



[1] S1E01

We are a somewhat difficult LEGO™ set:

- Written on the box: "Nearly 10^{27} of 29 kinds of pieces!"
- Only in 2014 was bromine shown to be an essential trace element. [4]
- 6 elements make up $\approx$ 99% of the body's elements:
  Oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorous.
- Next 5 elements make up $\approx$ 0.85%:
  Potassium, sulfur[1], sodium, chlorine, and magnesium.
- Remaining 18 necessary elements are trace elements.
- Could be worse: A box with three packets containing up quarks, down quarks, and electrons.

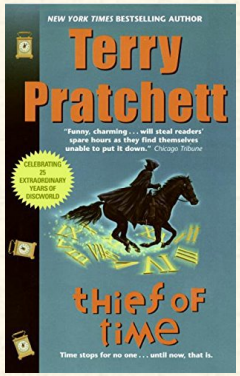


[1] Naturally varies with evilness

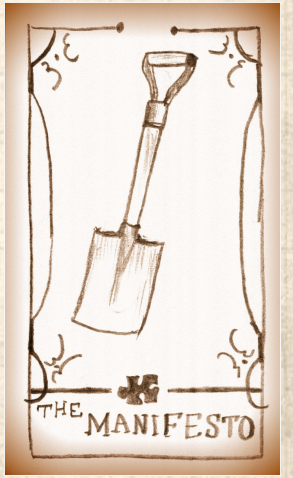
Best to see people as more than some kind of cleverly cooled quark soup:

"It was hard to deal with people when a tiny part of you saw them as a temporary collection of atoms that would not be around in another few decades."

—Susan Sto Helit (who is a "little bit immortal")

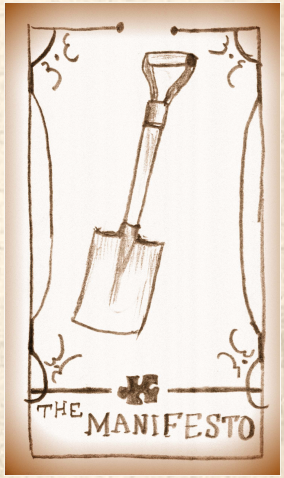


"Thief of Time"
by Terry Pratchett (2002). [5]



Or:[1]


Rick and Morty
S3E02: Rickmancing the Stone
July 30, 2017
BEER
That's because
losers look stuff up
[adult swim]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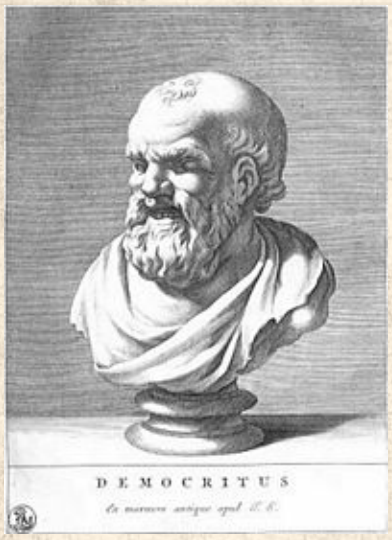
[1] S3E02

Reductionism:

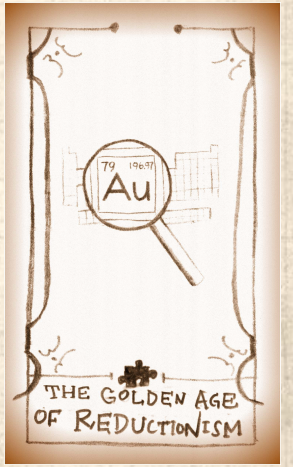


Democritus
(ca. 460 BC – ca. 370 BC)

- Atomic hypothesis
- Atom ∼ a (not) – temnein (to cut)
- Plato allegedly wanted his books burned.

John Dalton
1766–1844

- Chemist, Scientist
- Developed atomic theory
- First estimates of atomic weights

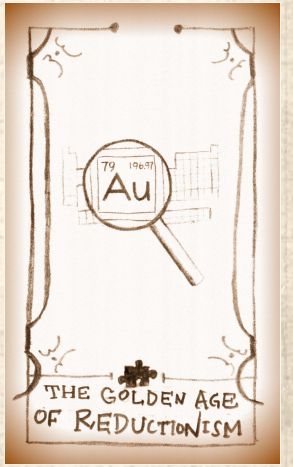


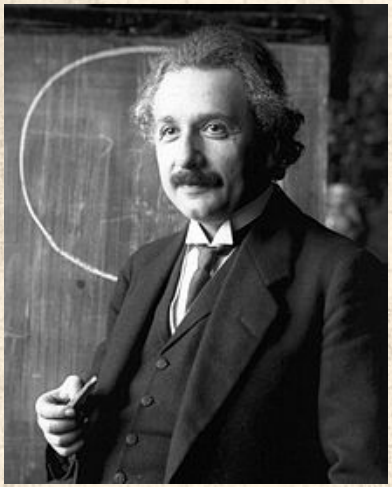
Ludwig Boltzmann, 1844–1906. Atomic Theory.

"Boltzmann's kinetic theory of gases seemed to presuppose the reality of atoms and molecules, but almost all German philosophers and many scientists like Ernst Mach and the physical chemist Wilhelm Ostwald disbelieved their existence."

"In 1904 at a physics conference in St. Louis most physicists seemed to reject atoms and he was not even invited to the physics section. Rather, he was stuck in a section called "applied mathematics," he violently attacked philosophy, especially on allegedly Darwinian grounds but actually in terms of Lamarck's theory of the inheritance of acquired characteristics that people inherited bad philosophy from the past and that it was hard for scientists to overcome such inheritance."

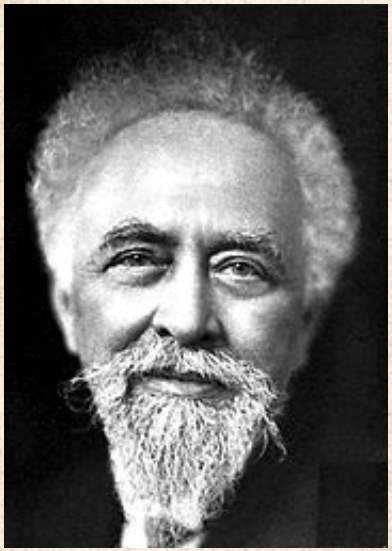
See: epigenetics.





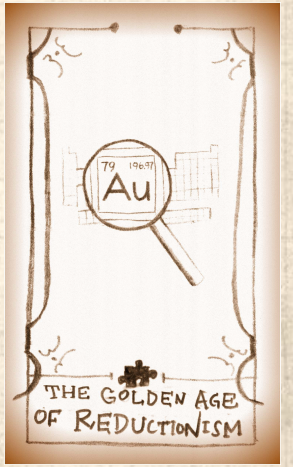
Albert Einstein 1879–1955

- Annus Mirabilis paper: "the Motion of Small Particles Suspended in a Stationary Liquid, as Required by the Molecular Kinetic Theory of Heat" [2, 3]
- Showed Brownian motion followed from an atomic model giving rise to diffusion.



Jean Perrin 1870–1942

- 1908: Experimentally verified Einstein's work and Atomic Theory.

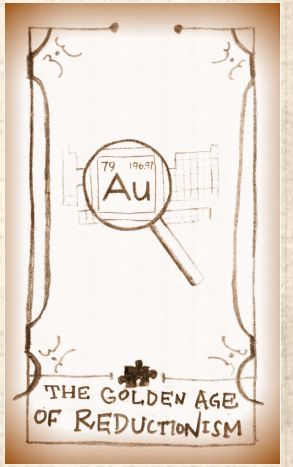


Feynmann:

"If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words?

"I believe it is the atomic hypothesis that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. "In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied."

Snared from brainpickings.org



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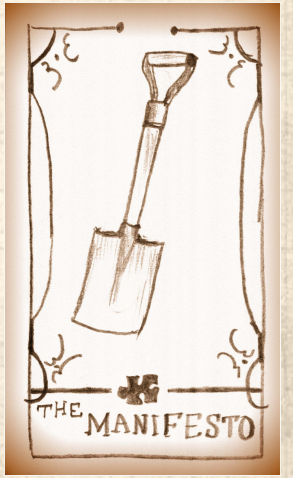
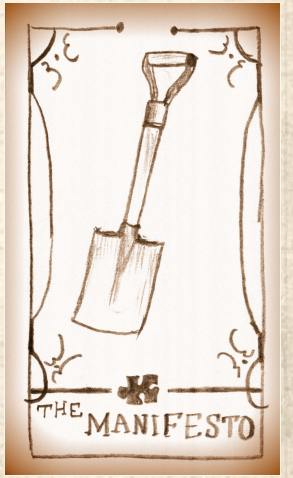


The Science of Complex Systems Manifesto:

1. Systems are ubiquitous and systems matter.
2. 1700 to 2000 = Golden Age of Reductionism: Atoms!, sub-atomic particles, DNA, genes, people, ...
3. Understanding and creating systems (including new 'atoms') is the greater part of science and engineering.
4. Universality: systems with quantitatively different micro details exhibit qualitatively similar macro behavior (fate, but real and limited)
5. Computing advances make the Science of Complex Systems possible:
   - 5.1 We can measure and record enormous amounts of data, research areas continue to transition from data scarce to data rich.
   - 5.2 We can simulate, model, and create complex systems in extraordinary detail.



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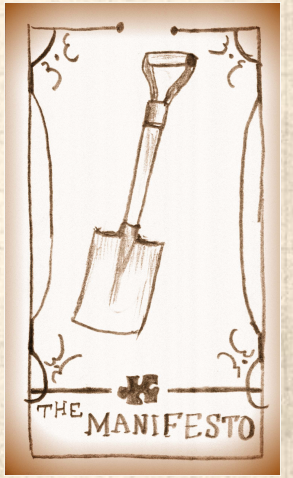

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[4] A. S. McCall, C. F. Cummings, G. Bhave, R. Vanacore, A. Page-McCaw, and B. G. Hudson.
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