A Complex Systems Manifesto

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Principles of Complex Systems, Vols. 1, 2, & 3D
CSYS/MATH 6701, 6713, & a pretend number, 2023–2024| @pocsvox

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Santa Fe Institute | University of Vermont

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Outline

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The Boggoracle Speaks: ⊞ ↗

THE GOLDEN AGE OF REDUCTIONISM

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THE END

THE SUN

THE MANIFESTO

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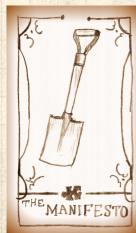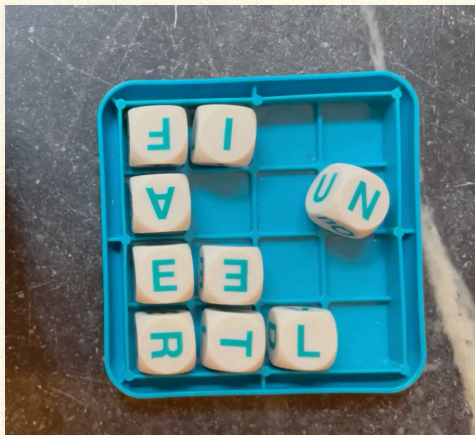
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Complex: (Latin = with + fold/weave (com + plex))

Adjective:

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

Definitions

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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

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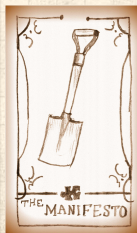
References

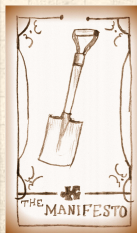### A working definition of a Complex System:

🎲 Distributed system of many interrelated (possibly networked) parts with no centralized control exhibiting emergent behavior—'More is Different'[1]

Other features/aspects:

🎲 Explicit nonlinear relationships.

🎲 Presence of feedback loops.

🎲 Being 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:

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- 🪙 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:
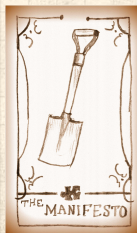
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- Physics
- Economics
- Sociology
- Psychology
- Information Sciences

- Cognitive Sciences
- Biology
- Ecology
- Geociences
- Geography

- Medical Sciences
- Systems Engineering
- Computer Science
- Data Science
- …

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

A visualized history of Complex Systemsish fields:

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2018 Map of the Complexity Sciences
by Brian Castellani

"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] 🎞️ ⬈

Carbon, 9 percent.

Carbon, 9.
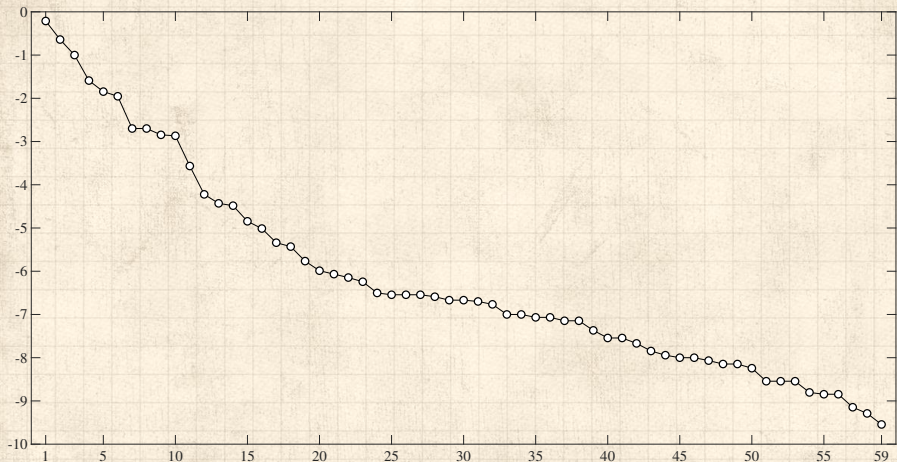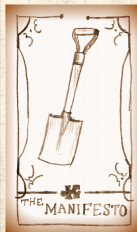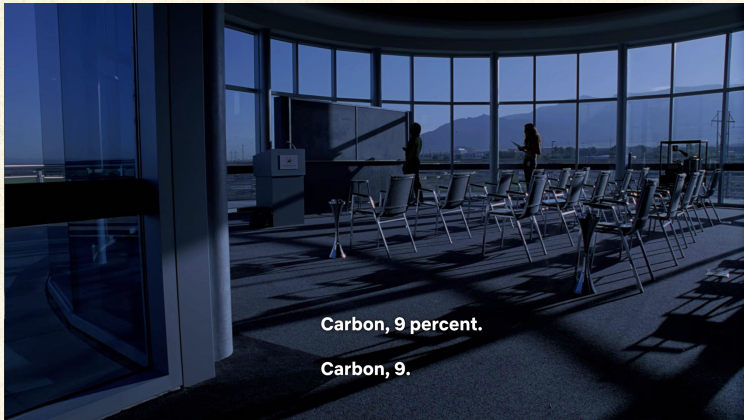
Fractional weight of typical human body by atomic species: ↗
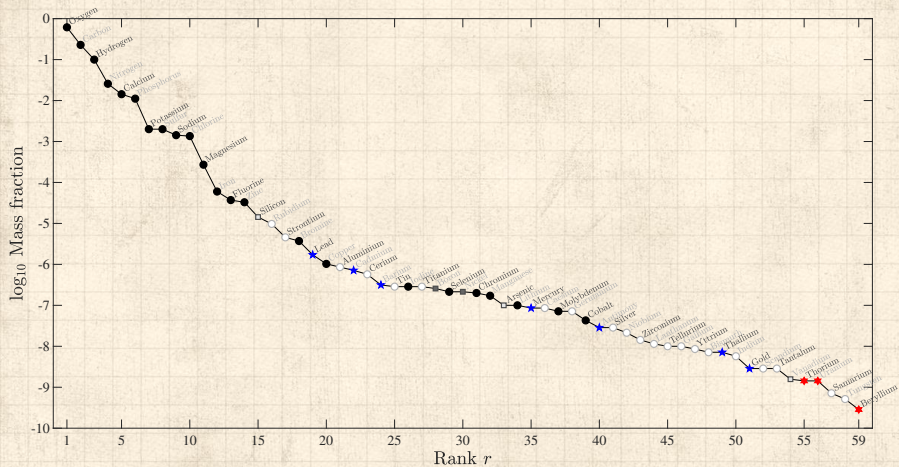
Baking soda and vinegar[1] ⊞ ⬀

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[1]S1E01 ⬀

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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.

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[1]Naturally varies with evilness

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

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"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")
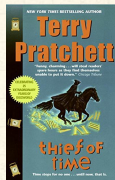
"Thief of Time" 𝐚 ☐
by Terry Pratchett (2002). [5]
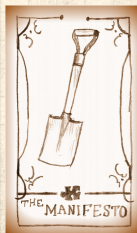
Reductionism:

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Democritus ⧉
(ca. 460 BC – ca. 370 BC)

- Atomic hypothesis
- Atom $\sim$ 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

THE GOLDEN AGE OF REDUCTIONISM

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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."
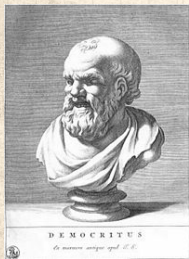
"In 1904 at a physics conference in St. Louis most physicists seemed to reject atoms and he was not even invited to the physics section. Rather, he was stuck in a section called "applied mathematics," he violently attacked philosophy, especially on allegedly Darwinian grounds but actually in terms of 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 ☑.

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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.
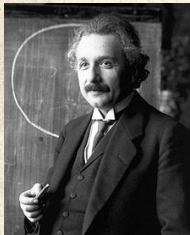

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Feynmann:

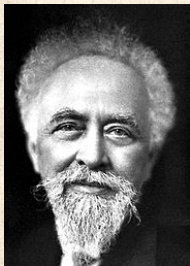"If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words?

"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."
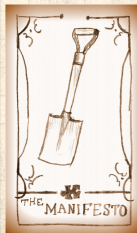
Snared from brainpickings.org

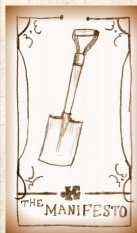## The Science of Complex Systems Manifesto: 🔗

1. Systems are ubiquitous and systems matter.

2. Consequently, much of science is about understanding how pieces dynamically fit together.

3. 1700 to 2000 = Golden Age of Reductionism: Atoms!, sub-atomic particles, DNA, genes, people, ...

4. Understanding and creating systems (including new 'atoms') is the greater part of science and engineering.

5. Universality 🔗: systems with quantitatively different micro details exhibit qualitatively similar macro behavior (fate, but real and limited)

6. Computing advances make the Science of Complex Systems possible:

   6.1 We can measure and record enormous amounts of data, research areas continue to transition from data scarce to data rich.
   6.2 We can simulate, model, and create complex systems in extraordinary detail.

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[1] P. W. Anderson.
More is different.
Science, 177(4047):393–396, 1972. pdf🖝

[2] A. Einstein.
Über die von der molekularkinetischen theorie der wärme geforderte bewegung von in ruhenden flüssigkeiten suspendierten teilchen.
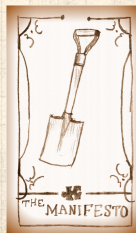Annalen der Physik, 322:549–560, 1905.

[3] A. Einstein.
On the movement of small particles suspended in a stationary liquid demanded by the molecular-kinetic theory of heat.
In R. Fürth, editor, Investigations on the theory of the Brownian motion. Dover Publications, 1956. pdf🖝

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[4] A. S. McCall, C. F. Cummings, G. Bhave,
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Cell, 157:1380–1392, 2014.

[5] T. Pratchett.
Thief of Time.
HarperTorch, 2002.