

# 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

Prof. Peter Sheridan Dodds | @peterdodds

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



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1 of 26

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A Manifesto

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2 of 26

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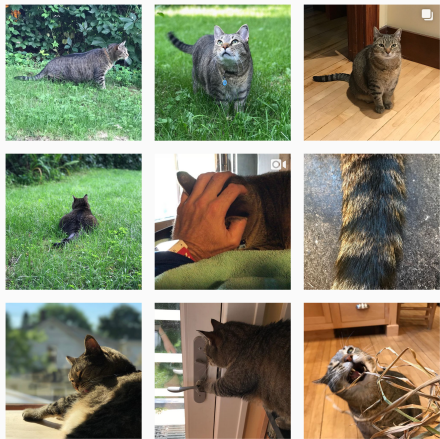
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Manifesto  
3 of 26

Defining  
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A Manifesto

References



# Outline

The PoCSverse

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4 of 26

Defining  
Complexity

A Manifesto

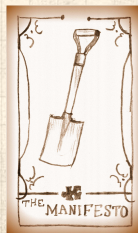
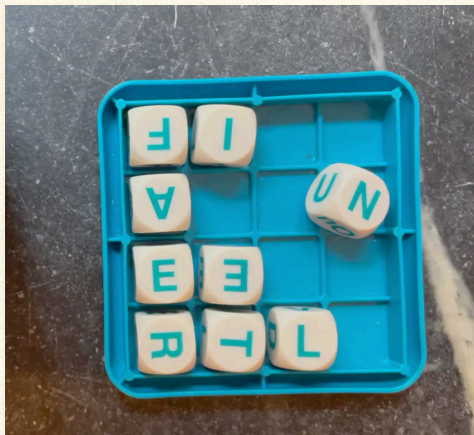
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References

## The Boggoracle Speaks:







# Definitions

**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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9 of 26

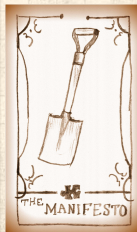
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A Manifesto

References

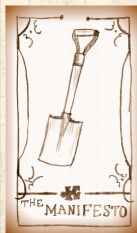
## Complicated versus Complex:

 Complicated: Mechanical watches, airplanes, ...



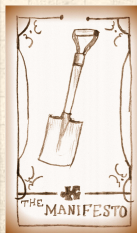
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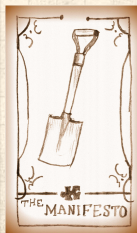
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- ⊞ Engineered systems can be made to be **highly robust but not adaptable**.
- ⊞ But engineered systems can become complex (power grid, planes).



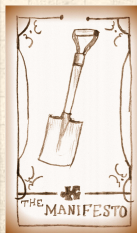
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- ⊞ They can also **fail spectacularly**.




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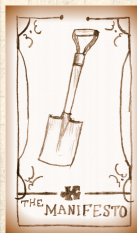
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- ⊞ Engineered systems can be made to be **highly robust but not adaptable**.
- ⊞ But engineered systems can become complex (power grid, planes).
- ⊞ They can also **fail spectacularly**.
- ⊞ Explicit distinction: **Complex Adaptive Systems**.



# Definitions


## 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'<sup>[1]</sup>

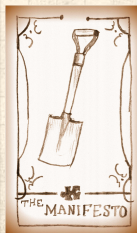


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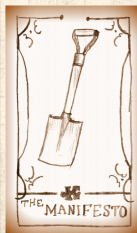
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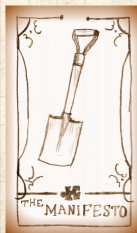
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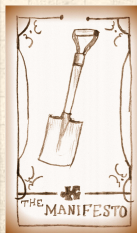
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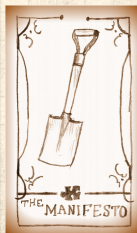
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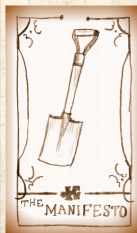
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-  Modular (nested)/multiscale structure.









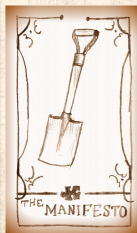
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-  Presence of feedback loops.
-  Being open or driven, opaque boundaries.
-  Memory.
-  Modular (nested)/multiscale structure.
-  Mechanisms range from being purely physical to purely algorithmic in nature.




# Examples of Complex Systems:


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Manifesto  
11 of 26


Defining  
Complexity


A Manifesto


References


 human societies


 animal societies


 financial systems


 disease ecologies


 cells


 brains


 ant colonies


 social insects


 fluids, weather  
systems


 geophysical  
systems

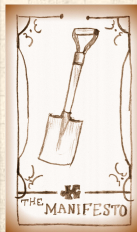
 ecosystems

 forests

 power grids

 Internet + Web


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

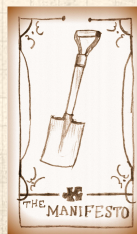


# Relevant fields:

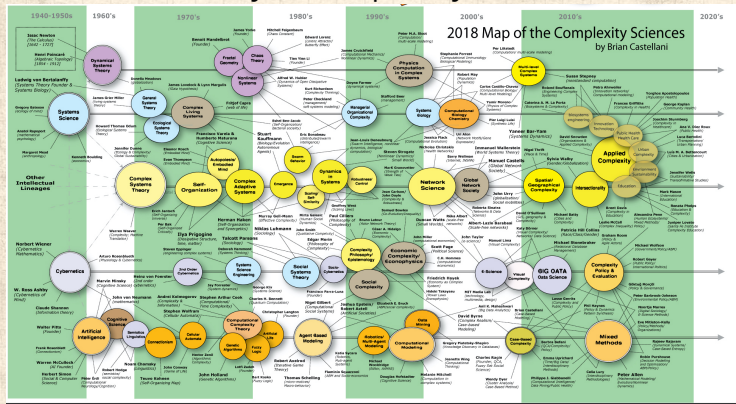
- Physics
- Economics
- Sociology
- Psychology
- Information Sciences
- Cognitive Sciences
- Biology
- Ecology
- Geosciences
- Geography

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


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




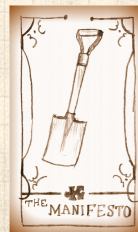
# A visualized history of Complex Systemsish fields:



"Complexity Map" by Brian Castellani, Kent State

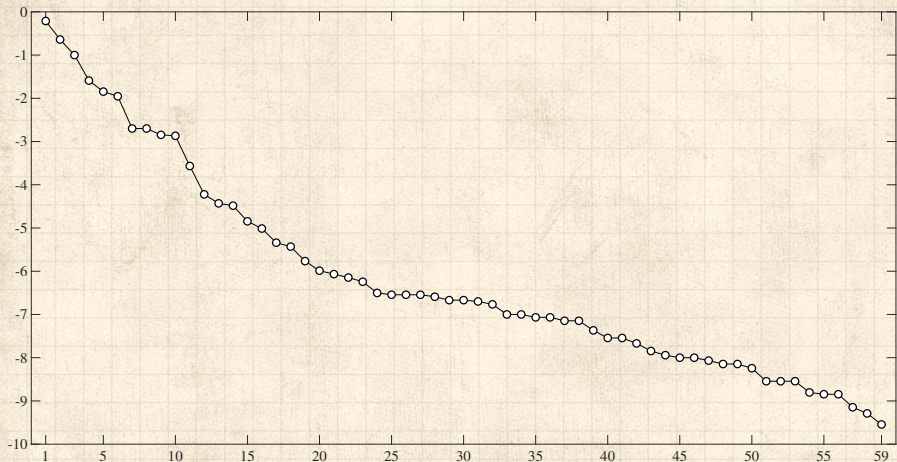
 Online [here](https://art-sciencefactory.com), at [art-sciencefactory.com](https://art-sciencefactory.com).


 Complex Systems is bigger than this (e.g., fluid dynamics; more later).

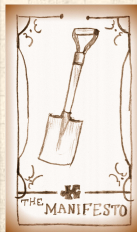
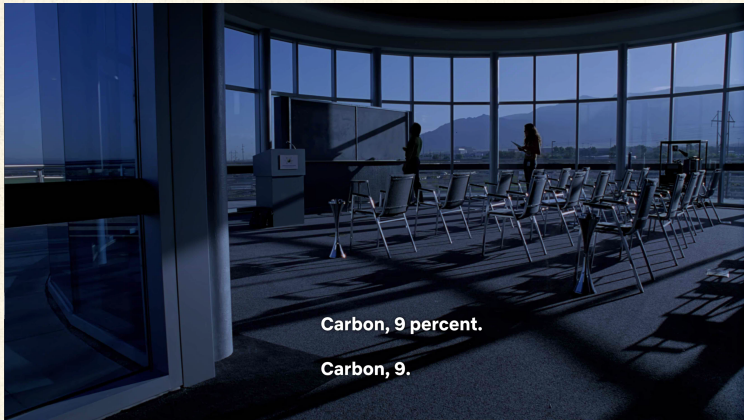




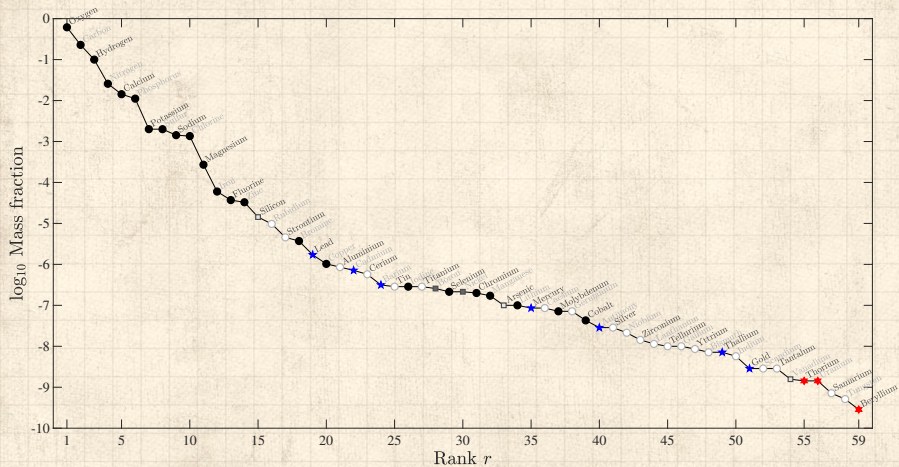
# Cryptograph—What's being plotted here?:



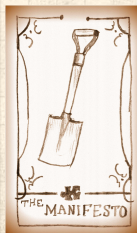
A hint<sup>1</sup>  



# Fractional weight of typical human body by atomic species: ↗



## Baking soda and vinegar<sup>1</sup>



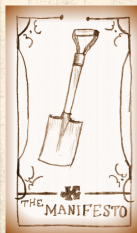
# We are a somewhat difficult LEGO™ set:

The PoCSverse  
Manifesto  
18 of 26


Defining  
Complexity

A Manifesto

References



## We are a somewhat difficult LEGO™ set:

 Written on the box: “Nearly  $10^{27}$  of 29 kinds of pieces!”

The PoCSverse  
Manifesto  
18 of 26

Defining  
Complexity

A Manifesto

References



## 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. <sup>[4]</sup>

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Manifesto  
18 of 26


Defining  
Complexity



A Manifesto


References



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 **Only in 2014** was bromine shown  to be an essential trace element. <sup>[4]</sup>


 6 elements make up  $\approx 99\%$  of the body's elements:



Oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorous.







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Potassium, sulfur<sup>1</sup>, sodium, chlorine, and magnesium.



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- Next 5 elements make up  $\approx 0.85\%$ :  
Potassium, sulfur<sup>1</sup>, 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.

<sup>1</sup>Naturally varies with evilness



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

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19 of 26

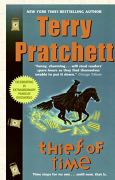
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Complexity

A Manifesto

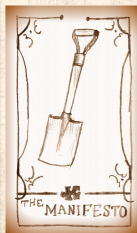
References

“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]



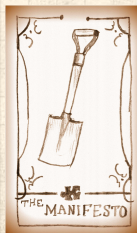
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The PoCSverse  
Manifesto  
20 of 26

Defining  
Complexity

A Manifesto

References



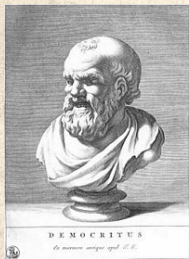
# Reductionism:

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Manifesto  
21 of 26

Defining  
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A Manifesto

References



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.”

The PoCSverse  
Manifesto  
22 of 26

Defining  
Complexity

A Manifesto

References





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Manifesto  
22 of 26

Defining  
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A Manifesto

References



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Manifesto  
22 of 26

Defining  
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A Manifesto

References



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The PoCSverse  
Manifesto  
22 of 26

Defining  
Complexity

A Manifesto

References



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The PoCSverse  
Manifesto  
22 of 26

Defining  
Complexity

A Manifesto

References



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The PoCSverse  
Manifesto  
22 of 26

Defining  
Complexity

A Manifesto

References



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See: epigenetics .

The PoCSverse  
Manifesto  
22 of 26

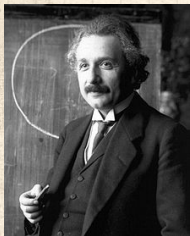
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References




## Albert Einstein 1879-1955

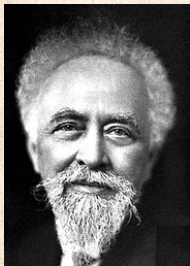


 Annus Mirabilis paper:  “the Motion of Small Particles Suspended in a Stationary Liquid, as Required by the Molecular Kinetic Theory of Heat” [2, 3]

 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?"



The PoCSverse  
Manifesto  
24 of 26

Defining  
Complexity

A Manifesto

References

Snared from [brainpickings.org](http://brainpickings.org)





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"I believe it is the atomic hypothesis that all things are made of atoms"

Snared from [brainpickings.org](http://brainpickings.org)

The PoCSverse  
Manifesto  
24 of 26

Defining  
Complexity

A Manifesto

References



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"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](http://brainpickings.org)

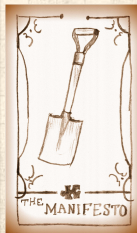
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Manifesto  
24 of 26

Defining  
Complexity

A Manifesto

References





# The Science of Complex Systems Manifesto:

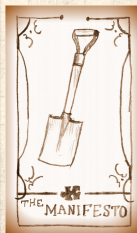
1. Systems are ubiquitous and systems matter.

The PoCSverse  
Manifesto  
26 of 26

Defining  
Complexity

A Manifesto

References



# 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.

The PoCSverse  
Manifesto  
26 of 26

Defining  
Complexity

A Manifesto

References



# 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, ...

The PoCSverse  
Manifesto  
26 of 26

Defining  
Complexity

A Manifesto

References



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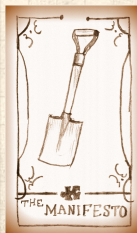
1. Systems are ubiquitous and systems matter.
2. Consequently, much of science is about understanding how pieces dynamically fit together.
3. 1700 to 2000 = Golden Age of Reductionism:  
Atoms!, sub-atomic particles, DNA, genes, people, ...
4. Understanding and creating systems (including new 'atoms') is the greater part of science and engineering.

The PoCSverse  
Manifesto  
26 of 26

Defining  
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
A Manifesto

References





# 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)

The PoCSverse  
Manifesto  
26 of 26


Defining  
Complexity

A Manifesto

References



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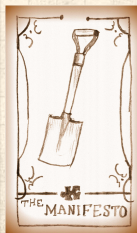
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The PoCverse  
Manifesto  
26 of 26

Defining  
Complexity

A Manifesto

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The PoCSverse  
Manifesto  
26 of 26


Defining  
Complexity

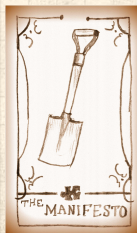
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  - 6.2 We can simulate, model, and create complex systems in extraordinary detail.



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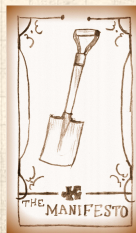
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