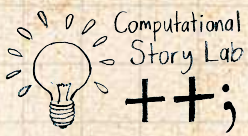
A Complex Systems Manifesto

Principles of Complex Systems | @pocsvox
CSYS/MATH 300, Fall, 2015 | #FallPoCS2015

Prof. Peter Dodds | @peterdodds

Dept. of Mathematics & Statistics | Vermont Complex Systems Center
Vermont Advanced Computing Core | University of Vermont



PoCS
Principles of
Complex Systems
@pocsvox
What's the Story?

PoCS
Principles of
Complex Systems
@pocsvox
What's the Story?

These slides are brought to you by:

Outline

Defining Complexity

A Manifesto

References

PoCS
Principles of Complex Systems
@pocsvox
What's the Story?

The UNIVERSITY of VERMONT

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.

A while ago: The Wikipedia on Complex Systems:

"Complexity science is not a single theory: it encompasses more than one theoretical framework and is highly interdisciplinary, seeking the answers to some fundamental questions about living, adaptable, changeable systems."

Now:

"Complex systems present problems both in mathematical modelling and philosophical foundations. The study of complex systems represents a new approach to science that investigates how relationships between parts give rise to the collective behaviors of a system and how the system interacts and forms relationships with its environment."

Definitions

Nino Boccara in *Modeling Complex Systems*:

[3] "... there is no universally accepted definition of a complex system ... most researchers would describe a system of connected agents that exhibits an emergent global behavior not imposed by a central controller, but resulting from the interactions between the agents."

Philip Ball in *Critical Mass*:

[2] "...complexity theory seeks to understand how order and stability arise from the interactions of many components according to a few simple rules."

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' [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:

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

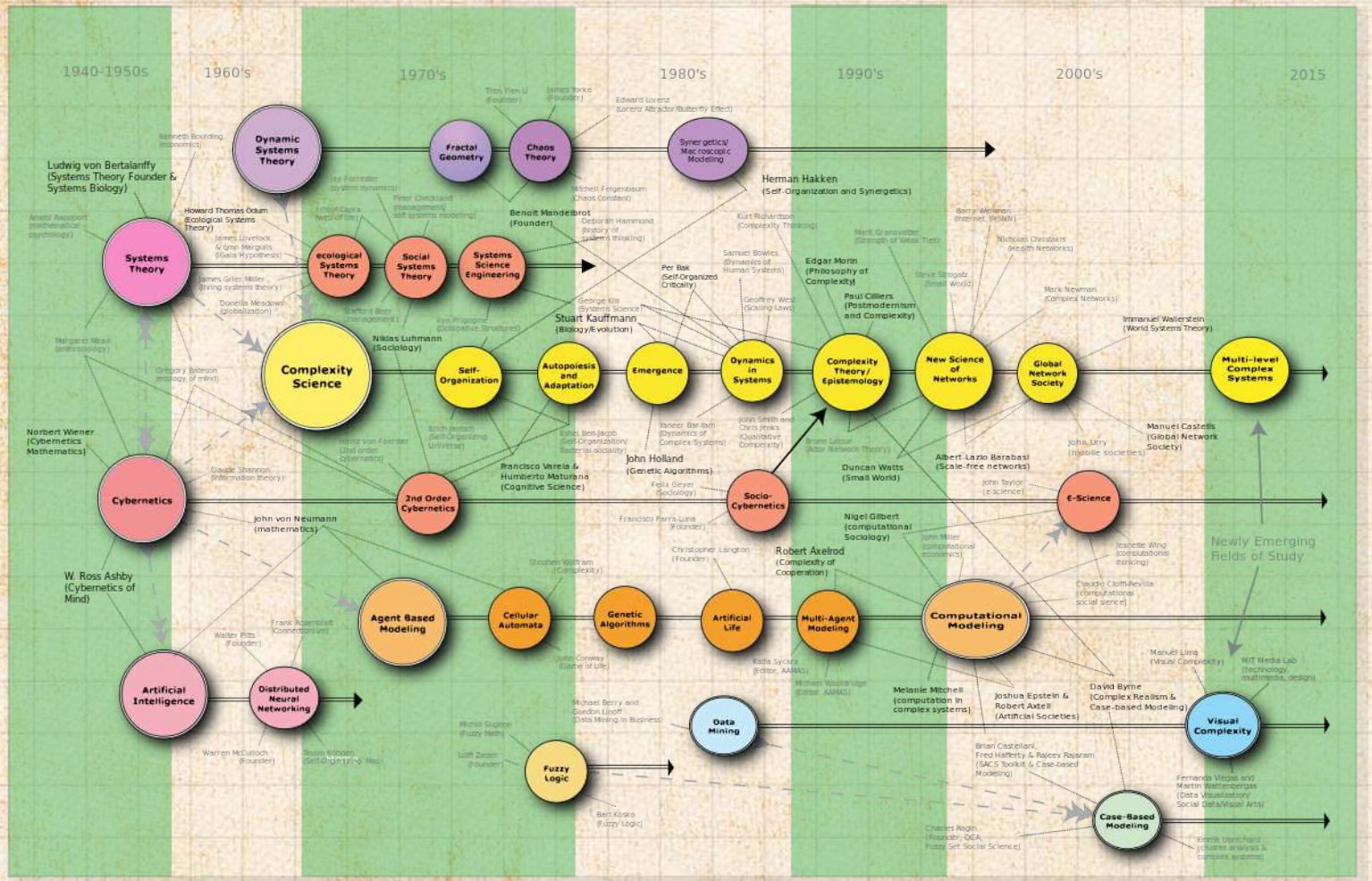
- i.e., everything that's interesting ...

Relevant fields:

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

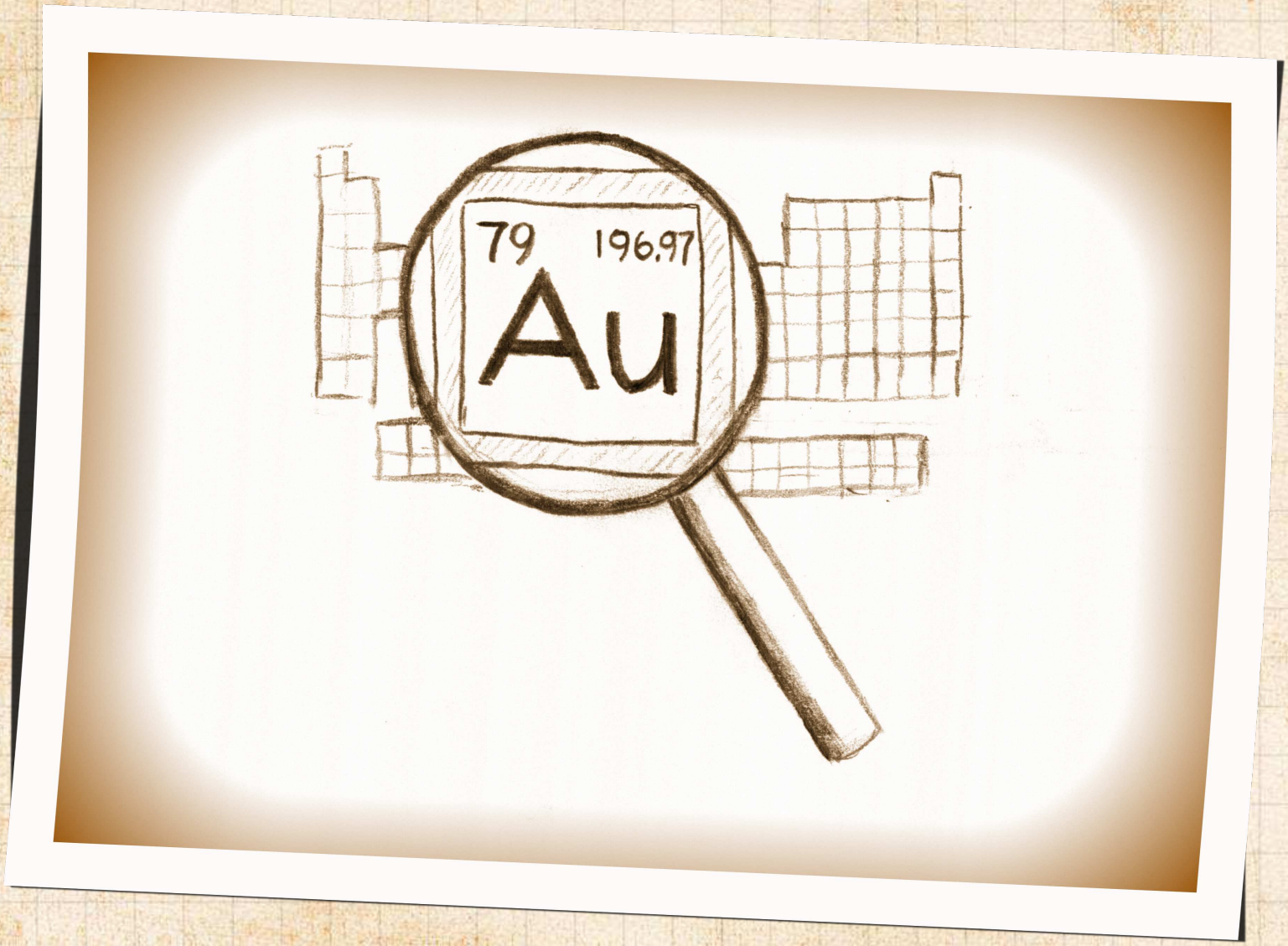
- i.e., everything that's interesting ...

A visualized history of Complex Systemsish fields:

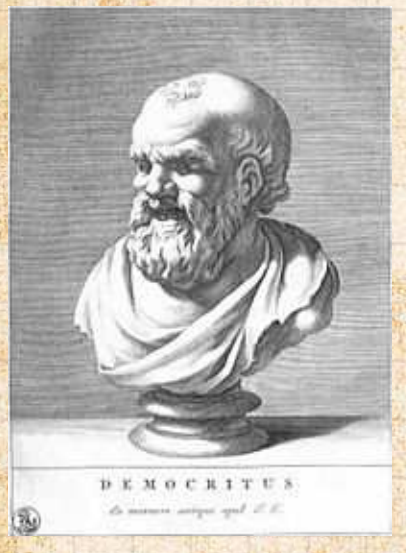


"Complexity Map" by Brian Castellani/Wiki
Online here: https://en.wikipedia.org/wiki/Complex_systems#History

The Golden Age of Reductionism:



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

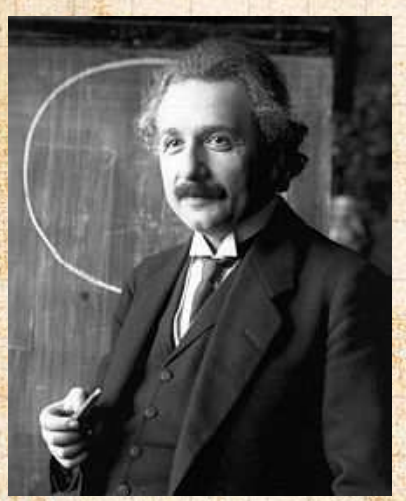
- Chemist, Scientist
- Developed atomic theory
- First estimates of atomic weights

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."

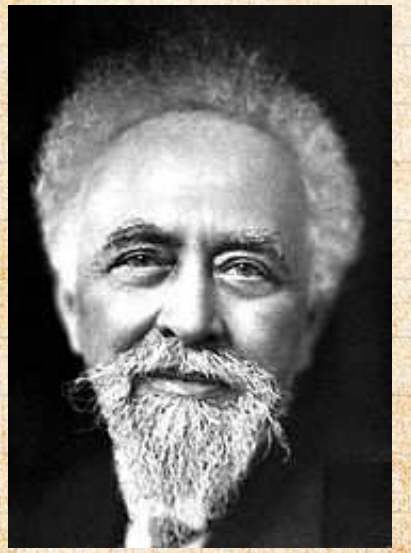
"In 1904 at a physics conference in St. Louis most physicists seemed to reject atoms and he was not even invited to the physics section. Rather, he was stuck in a section called "applied mathematics," he violently attacked philosophy, especially on allegedly Darwinian grounds but actually in terms of 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" [4, 5]
- 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

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.
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.

Neural reboot (NR):

Monotrematic Love

References I

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

[2] P. Ball.
Critical Mass: How One Thing Leads to Another.
Farra, Straus, and Giroux, New York, 2004.

[3] N. Boccara.
Modeling Complex Systems.
Springer-Verlag, New York, 2004.

[4] 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.

References II

[5] 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