HISTORY of COMPLEX SYSTEMS RESEARCH

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1. Reductionism and holism (philosophy of science, success stories of the twentieth century science: quantum physics and molecular biology)

2. Systems theory, cybernetics, nonlinear science

3. Dynamic structures: from being to becoming

4. New sciences and humanities
Reductionism and holism

- Philosophy of science. Success stories of the twentieth century science: Quantum Physics and Molecular Biology

- **Philosophical** position: a complex system is nothing else but the sum of its parts

- Methodological reductionism: a problem (the object of explaining something) is split up into separate parts or aspects and thus reduced to simpler components

- Epistemological reductionism: higher level phenomena can be explained by processes at a lower level

- Ontological reductionism: reality is composed of a minimum number of kinds of entities or substances.
Reductionism and holism

- The whole is somehow (?) more than the sum of its parts
- Methodological holism: An understanding of a certain kind of complex system is best sought at the level of principles governing the behavior of the whole system, and not at the level of the structure and behavior of its component parts.
- Ontological holism: Some objects are not wholly composed of basic physical parts.
- A holist is concerned with relationships not the pieces
Reductionism and holism

Holism

- semantic holism in linguistics: a certain part of language, be it a term or a complete sentence, can only be understood through its relations to a (previously understood) larger segment of language.
- self-referential systems
- Gestalt theory in psychology
- organizing principles: The idea of the solar system is based on the organizing principle that the sun is located at a central point, and all planets rotate around it.
- relational systems (say: networks - i.e. nodes connected by edges)
Reductionism and holism

Holism

Foodweb

![Foodweb diagram with various organisms and arrows indicating predation relationships]

E.M. Collins 2001
Reductionism and holism in Quantum Physics

Models of the Atom

Dalton model: indivisible

there ARE electrons -> Thomson model (1904): plum pudding

there IS a nucleus -> Rutherford model (1908)

Planck-Einstein quantum postulate -> Bohr model (1913)

cloud model: probability ! distribution, Schrödinger - Born (1925-27)
Reductionism and holism in Quantum Physics

wave-particle duality
de Broglie (1924)
The Physical world is indeterministic i.e. unpredictable

Quantum mechanics is generally regarded as the physical theory that is our best candidate for a fundamental and universal description of the physical world. The conceptual framework employed by this theory differs drastically from that of classical physics. Indeed, the transition from classical to quantum physics marks a genuine revolution in our understanding of the physical world.

\[ \Delta \chi \Delta \rho \geq \frac{\hbar}{2} \]

Heisenberg uncertainty principle (1926)

You cannot simultaneously determine the exact position and velocity of a particle with any great degree of accuracy no matter how good your measurement tools are. Quantum mechanics is inherently indeterministic
In some theories of particle physics, even such basic structures as mass, space, and time are viewed as emergent phenomena, arising from more fundamental concepts such as the Higgs boson or strings. In some interpretations of quantum mechanics, the perception of a deterministic reality, in which all objects have a definite position, momentum, and so forth, is actually an emergent phenomenon, with the true state of matter being described instead by a wave-function which need not have a single position or momentum. . . .

Phil Anderson formulated: “the ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe”

a very new blog: http://blogs.scientificamerican.com/the−curious−wavefunction/2014/01/22/physics−and−fundamental−laws−necessary−truth−or−misleading−cacophony/
Reductionism and complexity in molecular biology

- Mendel (1865) genes as the "atoms of heredity"
- Delbrück (1935) genes be viewed as molecules.
- How heritable information is stored in cells?
- Watson-Crick: double helix structure of DNA
- Genetic code: relationship between DNA structure and protein structure
The research program of “molecular biology” suggested that the replication, transcription and translation of the genetic material should and could be explained by chemical mechanisms. Crick’s central dogma of molecular biology stated that there was a unidirectional information flow from DNA via RNA (ribonucleic acid) to proteins. First, in the process of replication the information in the DNA is copied. Second, during transcription DNA codes for the production of messenger RNA. In the third phase (processing) RNA migrates from the cell nucleus to the cytoplasm. Fourth, messenger RNA carries coded information via ribosomes for protein synthesis (translation). The schema of the central dogma is:

\[
\text{DNA} \rightarrow \text{RNA} \rightarrow \text{protein}
\]
While the central dogma was enormously successful in discovering many detailed chemical processes of life phenomena, philosophically it suggested, as Crick himself wrote that “the ultimate aim of the modern movement in biology is to explain all biology in terms of physics and chemistry”.

Central dogma -> genetic determinism (?)

Genetic reductionism, in particular, has been abandoned as a useful explanatory scheme for understanding the phenotypic traits of complex biological systems. Genes are increasingly studied today because they are involved in the genetic program that unfolds during development and embryogenesis rather than as agents responsible for the inheritance of traits from parents to offspring.

M. H. V. Van Regenmortel: Biological complexity emerges from the ashes of genetic reductionism.
The circular life of the mRNA

Gene expression is a circular system
From Reductionism to Systems Biology

- Reductionism: very successful, BUT: underestimates the complexity of life
- Decomposing, dissecting and analyzing constituents of a complex system is indispensable and extremely important
- but not sufficient
- "upward causation": from molecules to behavior
- "downward causation" (also in the brain-mind problem: Cognitive Science)
Downward causation

- higher level systems influence lower level configuration
- the whole is to some degree constrained by the parts (upward causation), but at the same time the parts are to some degree constrained by the whole (downward causation).

CIRCULAR CAUSALITY