

Definitions of Complexity

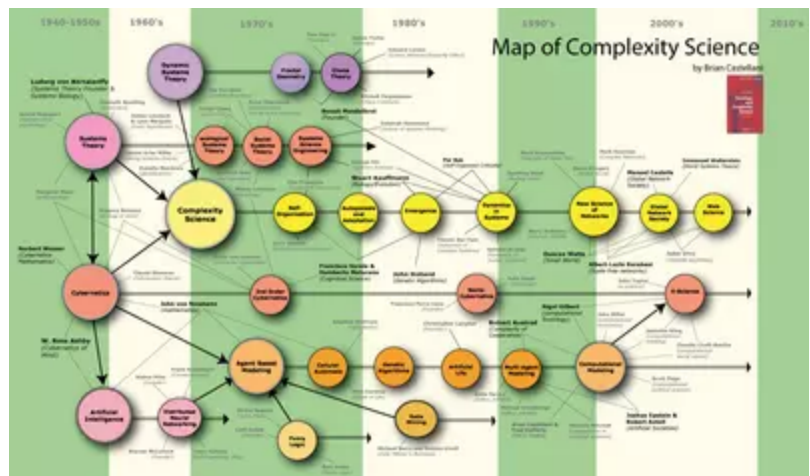
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The study of complex systems is an emerging discipline that has not developed a consistent theoretical framework on par with the major theories that frame the study of the geosciences, such as plate tectonics, evolution, mechanics, and thermodynamics. There are a wide range of geologic systems that exhibit complex behavior including soils, drainage basins, earthquakes and tectonic systems.

Complex systems have been studied from a wide range of mathematical, scientific and engineering perspectives. **Therefore, a range of definitions have been developed to define and describe complex earth systems.** Some of these definitions are below:

- Complex systems exhibit several defining characteristics, including feedback, strongly interdependent variables, extreme sensitivity to initial conditions, fractal geometry, and self-organized criticality, multiple metastable states, and a non-Gaussian distribution of outputs (Kastens et al., 2009). See the [Introduction to Complex Systems](#) page for detailed information on these characteristics.
- Complex systems consist of a large number of mutually interacting and interwoven elements, parts or agents defined by the structure of the system, the types of interactions between system elements, and the dynamics and patterns of the system that emerge from these interactions (Herbert, 2006, in [Earth & Mind](#), Manduca and Mogk eds.).
- A complex system is a group of "agents" (individual interacting units, like birds in a flock, sand grains in a ripple, or the individual units of friction along a fault zone), existing far from equilibrium, interacting through positive and negative feedbacks, forming interdependent, dynamic, evolutionary networks, that are sensitive dependent, fractally organized, and exhibit avalanche behavior (abrupt changes) that follow power-law distributions (Fichter, 2010, JGE, in press).
- "Complex systems are those with many strongly interdependent variables. This excludes systems with only a few effective variables, the kind we meet in elementary dynamics. It also excludes systems with many independent variables; we learn how to deal with them in elementary statistical mechanics. Complexity appears where coupling is important, but doesn't freeze out most degrees of freedom" (Boccara, 2004).
- "Ecological complexity refers to the complex interplay between all living systems and their environment, and emergent properties from such an intricate interplay. The concept of ecological complexity stresses the richness of ecological systems and their capacity for adaptation and self-organization. The complex, nonlinear interactions (behavioral, biological, chemical, ecological, environmental, physical, social, cultural) that affect, sustain, or are influenced by all living systems, including humans. It deals with questions at the interfaces of traditional disciplines and its goal is to enable us to explain and ultimately predict the outcome of such interactions. Ecological complexity can also be thought of as biocomplexity in the environment" (Li, 2004, editorial in Ecological Complexity).
- "Complex system: a system with numerous components and interconnections, interactions or interdependence that are difficult to describe, understand, predict, manage, design, and/or change" ([Magee and de Weck, 2004](#)).
- The study of complex systems requires a system approach. Such an approach "focuses on the arrangement of and relations among the parts, which connect them into a whole (von Bertalanffy, 1968). This approach is necessary for two reasons: first, system properties emerge at a higher level as the result of interactions among system components (von Bertalanffy, 1968; Holland 1998) and second, the emergent pattern itself exerts a downward causation on the lower level from which it has emerged (Campbell, 1974)" ([Raia, 2005](#)).



Conceptual and historical overview of complexity science. This image is from the [Art & Science Factory](#) website. Click on the image to view a larger version.