# COMPLEX SYSTEMS

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A complex system is a special class of system that has the characteristic of complexity. Meaning it is composed of many diverse and autonomous components that interact in a nonlinear, networked fashion with the whole system evolving over time. There is no agreed upon definition for a complex system, but here are some typical examples. The Advances in Complex Systems Journal gives us this definition: "A system comprised of a (usually large) number of (usually strongly) interacting entities, processes, or agents, the understanding of which requires the development, or the use of, new scientific tools, nonlinear models, out-of-equilibrium descriptions and computer simulations." Next, the social scientist Herbert Simons gives us this definition: "A system that can be analyzed into many components having relatively many relations among them, so that the behavior of each component depends on the behavior of others." Jerome Singer tells us that a complex system is: "A system that involves numerous interacting agents whose aggregate behaviors are to be understood. Such aggregate activity is nonlinear, hence it cannot simply be derived from a summation of individual components behavior."

## Systems

A complex system is a special class of system. A system is simply a set of parts called elements, and a set of connections between these parts called relations. These parts can be ordered or unordered. An unordered system is simply a set of things. Because there is no specific structure or order, we can describe a set by simply listing all of its elements and their properties. A pile of stones on the ground is an example of an unordered set. As there is no pattern or order to the system, we can only describe it by describing the properties of each element in isolation and then adding them all up, with the whole set being nothing more than the sum of its individual parts. If in contrast, through the relations these parts are ordered in a specific way, then they can function together as an entirety and out of these parts working together we get the emergence of a global pattern of organization that is capable of functioning as a coherent whole. For example if all the parts in our car are arranged in a specific way, then we will have the global functionality of a vehicle of transportation, or out of the specific arrangement of billions of cells and the different specialized organs that make up our body we get the emergence of a global system that enables us to operate as an entire organism. So that is the basic model of a system. It consists of elements and relations. When those elements work together, we get the emergence of a new level of organization.

## Many Parts

Probably the only property that will be in all definitions of a complex system is that they consist of many parts, that is, many elements interacting on many different levels. With the phenomenon of emergence, a whole new level to the system develops, which then starts to interact with other systems in its environment, the result being that new patterns of organization develop and once again we get the emergence of another level of organization and so on. People form part of social groups that form part of a broader society which in turn forms part of humanity; which gives these systems a hierarchical structure. This is a pervasive phenomenon in our world. Elements are nested inside of subsystems which in turn form part of larger systems and so on. All complex systems have this multidimensional property to them. They are composed of many elements on many different scales, with all of these levels affecting each other. A business is part of a local economy, which is part of a national economy, which in turn is part of a global economy. Each is interconnected and interdependent with the others. We cannot fully isolate one component or reduce the whole thing to one level, and this is a primary source of complexity. If you can place yourself into one of these systems with all of these parts interacting on may different levels, then you should have a good sense for why they are called complex. This can be identified as the first property to a complex system, many different elements interacting on many different scales.

## Nonlinearity

Almost all well-formulated definitions for complex systems involve the term nonlinearity. It is a continuously reoccurring and pervasive theme. Nonlinearity in its most basic and intuitive sense describes how the input and output to a system are not proportional to each other. Nonlinearity arises from the fact that when we put two or more things together, the result may not necessarily be a simple addition of each element's properties in isolation. In contrary, we can get a combined effect that is greater or less than the simple sum of each part. Examples of this might be two sound waves that are perfectly out of sync, canceling each other out through noise interference or the division of labor as can be seen in many human and insect communities, resulting in synergies that mean the output will be far greater than what the individuals could accomplish in isolation. Due to what are called feedback loops, non-linear systems may grow or decay at an exponential rate. These periods of rapid change are defined as phase transitions. Thus complex systems are known to be able to shift or flip into whole new regimes within very brief periods of time. Some small change in input value to the system can through feedback loops trigger a large systemic effect. Examples of this can be seen in financial crisis and the clap of ecosystems such as coral reefs. Nonlinearity is in many ways an expression of the deep interdependent nature to complex systems.

## Connectivity

Many definitions for complex systems involve dense or high levels of interconnectivity between components. As we turn up the degree of connectivity, it becomes the nature and structure of these connections that define the system. As opposed to the properties of its components, how are things connected and what is connected to what becomes the main question. At some critical level of connectivity, the system stops being a set of parts and becomes a network of connection and it is now all about how things flow in this network. Networks are the true geometry of complex systems, for these systems do not operate in a 3-dimensional Euclidean geometry. Whether we are talking about the global air transportation system, the flow of financial capital or information on the internet, space is redefined in terms of the topology created by connectivity. What matters is your position in the network structure and your degree of connectivity. Connectivity again leads us into the world of complexity as the number of relations between elements can grow in an exponential fashion. If we take just a handful of elements, they can be connected in possibly thousands or even millions of different ways.

## Adaptation

Lastly, Autonomy & Adaptation: Whether we are talking about a flock of birds, the internet, or our global economy, there is no top-down centralized mechanism for coordinating the whole system within complex systems. Elements have a degree of autonomy often through their capacity to adapt to their local environment according to their own set of instructions. Without centralized coordination and with a degree of autonomy comes the capacity for elements to self-organize. They can synchronize their states or cooperate, resulting in the emergence of patterns of organization from the bottom-up. With autonomy and adaptation also come the capacity for a variety of different responses for any given phenomenon, meaning complex systems are often heterogeneous with high levels of diversity. Ecosystems and multi-cultural societies are good examples of this.

## Evolution

Without centralized coordination, complex systems develop on the macro-level through a process of evolution. Elements within complex adaptive systems are subject to the evolutionary force of selection where those that are best suited to that environment are selected and replicated while others are not. Products are subject to selection within a market environment. In democracies, politicians are subject to selection by voters, and creatures in ecosystems are subject to natural selection through competition. In such a way, the whole macro scale system manages to adapt to its environment without centralized coordination and develop to exhibit higher levels of both differentiation and integration. The greater the autonomy and capacity for adaptation that elements have, the more complex the system we are dealing with.