

Complex systems intro

Every day when we switch on the lights, connect to the Internet or commute to work we are forming part of what are called complex systems. But to understand complex systems we need to talk a bit about system in general first. A system is a type of model we use to understand the world around us. In its essence it is a group of parts called elements that function together to form a whole that is called the system. This very simple and abstract model can be used to describe a wide variety of things. Now let's add complexity to this. Although there is no formal definition for it we can understand complexity as a parameter, that is to say that it is a measurement of something. Firstly It is a measurement of the number of elements within our system. A society is more complex than say a small group of friends as it has many more sub-systems and elements interacting on various scales. Secondly it measures the degree of Connectivity within a system- When we have a low level of connections between elements within a systems, we can describe it by simply describing the properties of the individual elements. But as we increase the connectivity it is increasingly the relations between elements that come to define the system, thus complex systems are typically modeled as networks that can capture and quantify this information about the relations between elements.

Thirdly Adaptation, when elements become capable of adapting their behavior over time can become increasingly complex. Thus complex adaptive systems are often best modeled as the product of evolutionary dynamics that have shaped them overtime as opposed to the static analysis of their individual parts. The capacity of adaption also means that elements can self-organize, limiting the need for centralized control and allowing for the emergence of organization from the bottom up as individual element can interact and synchronize to form patterns.

Fourthly complexity is also a measure of the degree of diversity between elements within a system. Again the greater the diversity between the parts the more complex and abstract our models will have to be to capture the underlining common features. So now we have an idea of what systems and complexity are, let's put them together starting with a system with a low level of complexity. An example of this might be a set, of say five billiard balls on a table. There are quite few of them, they are all the same, they are all separate from each other and they are incapable of adapting.

If we input some energy into this systems by say pushing one of the balls, the outcome to this event is directly proportional to the input and is pre-deterministic by it, we can repeat the same action a million times and we will get the exact same result. We call this type of system a deterministic or linear-system because we can draw a direct line between cause and effect, that is input and out put to the system. Because linear systems are relatively easy to model and control much of our modern science, engineering and management practices rest upon

this type of linear understanding to the world. O.K. so let's think about what happens when we turn the complexity up. Take as an example an ecosystem, ecosystems typically have many elements or creatures. These creatures are diverse, interconnected and capable of adaptation.

Now let's add some input to this system, say we build an industrial zone right next to it. It emits pollution, given the ecosystem's capacity for adaptation the result or output of this may well be negligible to us initially. So we continue expanding our industrial area. At some point the stress from this additional input will reach a critical tipping point with some small additional input being able to propagate through the system creating a phase transition as our ecosystem collapses.

Thus complex systems can exhibit both extraordinary robustness and extraordinary fragility where some small scale event can have a large systemic effect, known popularly as the butterfly effect. The point to take away from this illustration is that complex systems are what is called non-linear meaning unlike our original example with the billiard balls cause and effect are no longer directly related. It is due to the fact that complex systems are non-linear and largely defined by their connections that make them unamenable to our traditional scientific methods of analysis that often relies upon linear models and a component based description of the world.

Thus the area of complex systems has risen over the past few decades as an alternative paradigm within science and engineering to deal with these non-linear systems by placing a greater emphasis upon connectivity and the relations between elements.

It currently represents a broad and diverse set of methods primary among which is the use of computation modeling, where elements are given a simple set of rules that govern their behavior and are left to interact and evolve over time to see if relevant patterns emerge.

As the world we live in becomes increasingly interconnected and interdependent the need for a greater capacity to model, design and manage complex systems, is making this area particularly relevant to the challenge we face in the 21st century.