# What Organizational Leaders Should Know about the New Science of Complexity

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## THE SIMPLE

We have always had a tendency to simplify the world around us in order to understand it better and particularly to control it better. In physics, since Greek antiquity there has been an overriding drive to explain the world in terms of a few simple principles or laws, such as the primordial elements or the laws of general relativity. In the past few centuries, the urge to simplify was augmented by the belief that these simple laws would mechanically explain the world around us. Similarly, in a business firm in a more imperfect way, it is the management control system that is expected to mold the organization into a predictable machine. A manager is expected to make a plan, execute it, and deliver the results, all in order for the system to perform according to preset rules.

Overall this approach has been highly successful. According to this way of thinking, the inorganic world is shaped by forces described in only a few short equations. Much of the scientific world has followed the lead of the physical sciences in looking for simple fundamental principles that can explain everything. The business world has had a rougher ride, but the existing systems and theories have delivered unparalleled growth in material wealth. Since the Age of Enlightenment in the 18th century, this development has kicked into high gear and delivered theories, for example, on the workings of the psyche, on the biological fabric of nature through its genes, and on the working of the economy. Although these were often less rigorous than in physics, the approach has been essentially the same.

At the foundation of this approach lies an assumption on the nature of things, whether in nuclear physics or in a corporation: It is assumed that the world is fundamentally deterministic and that phenomena are mechanically driven by fundamental laws. Laplace worded this principle splendidly by describing the world as a clock where everything is knowable and understandable by just following a predictable evolution through the immutable laws of nature. In business this principle is not often made explicit, but it is pervasive everywhere. "Business process reengineering" infers that what is being engineered is a machine that needs tuning. The language of business expresses it in words such as management control and pulling levers. It is this view of the world that I would like to call "the Simple." Simple in the narrow sense that its phenomena are described by linear equations, in the wider sense that everything is in essence predictable.

There is a proverb that to the hammer everything looks like a nail. Is it possible that we have become Simplifiers and see only Simple things around us? Recent developments in science suggest that this is indeed the case. We have become so enthralled by the success of our Simplification approach that we seem to have force-fitted many phenomena into the rules and laws that we have devised. Thus, perhaps we may have missed some exciting features and possibilities. Thanks to the emerging science of Complexity, scientists of multiple disciplines are starting to unearth the consequences of recognizing some phenomena for what they are: Complex and not Simple. They are Complex in the sense that randomness plays a large role in them.

**Think of a clock, the archetypal example of a simple system: everything is done in a clock to stamp out the effect of randomness. Similarly theories in which chance plays an important role are sometimes seen as awkward or approximations at best.**

The reader should not be needlessly put off by the word Complexity, because this does not mean complicated; in fact, we will see that Complex phenomena often follow elementary rules! Likewise many of the processes in large organizations, such as logistics, strategy, and organizational learning, seem to be Complex rather than Simple.

The short history of the Simple that I have sketched has not been the only view of the world on offer; there have been other currents of thought, whether philosophical or inspired by religion. Some state that the world is not mechanistic, pointing to divine intervention, others perhaps to its holistic nature. For better and for worse western scientific thought has been the dominant shaper of our intellectual culture. The cardinal point of the new science of Complexity is that the traditional way of looking at things as Simple is now expanding to include the Complex, while remaining within the method of Western science. Western science has the advantage over many other schools of thought of allowing rational debate and a structured expansion of knowledge. I believe that this is why the development of Complexity is so important, even if there are those who will say that some of the insights and conclusions have been reached before and elsewhere. Scientific method is necessary in order to be able to debate an idea beyond just sharing individual intuitions. "Scientific" is one of the most misused words, and stopping short of trying to define it, I want to limit its meaning here to strict and fundamental science, contrasting it to the kind exposed by Sokal.[1] This is not to deny or demean the value of individual intuition in any way, just to recognize that it is difficult to build up a systematic and collective system of knowledge without the structure and methods of Western science, in particular the requirement for theories to be falsifiable.

The purpose of this article is to share with organizational leaders what lessons can be learned so far from the field of Complexity to better design and utilize the processes in their organizations.

## INNOCENCE LOST

We saw that a fundamental drive of Western thought has been to look for laws that simplify phenomena in order to make their behavior predictable. Before turning to the Complex, it is worth stopping and wondering what the indications are that there are things that are not Simple in a fundamental sense.

The first indications that something was afoul were in the formulation of quantum mechanics at the beginning of the century. Quantum mechanics is one of the very few fundamental pillars of our entire scientific building, even if it perhaps is distant for many people. It is also a funny theory, and I used to wonder with fellow students what made us take it on faith instead of rebelling against the professors who were teaching us these wild theories! Many scientists share this amazement, but the position of quantum mechanics is secure through the spectacular success of the theory in terms of explaining and predicting. The meaning and the interpretation of quantum mechanics have been the object of much discussion[2] and are ongoing today.[3,4] The key element that was introduced in quantum mechanics was chance; no longer was the behavior of the most fundamental building blocks of matter predictable and mechanistic like a billiard ball, but randomness played an essential role. Einstein's well-known comment ("God does not play dice") expressed the repugnance of many to this interpretation of the world. However, it is becoming clear that the fundamental uncertainty in quantum mechanics is a key driver for development and evolution.

Somewhat similarly, many people in corporate planning or logistics departments believe that their task is to model the corporation as accurately as possible and to eliminate chance. Of course, they will admit to the fact that they cannot know everything, but they perceive random events as a nuisance rather than as a desirable instrument of change and order. We will see below that in Complex systems, chance has a much more positive role than its reputation in the mechanistic view.

**Using the approach of Complexity, scientists are letting computer chips design themselves. Mimicking the approach of nature in combining natural selection and evolution, chip designs have been achieved in record time, with far fewer logical components than in the traditional way.[23]**

Later in the 20th century, chaos[5] mathematics appeared on the scene.

This made matters even worse for the determinists because now it was demonstrated that perfectly simple systems can exhibit chaotic behavior in a perfectly deterministic way. Simple feedback loops are enough in the right circumstances to send a system into hopelessly chaotic behavior. For our purpose, the important feature of chaos mathematics is the concept that very small causes or fluctuations can have enormous (i.e., nonlinear) effects. The well-publicized example of the wing of a butterfly in Rio causing a storm in Chicago illustrates this point eloquently, if not very realistically.

Chaos mathematics (theory is too grandiose a word) has been widely popularized in management literature, often unfortunately in a rather shallow interpretation. Two points are most relevant in my opinion for managers: First, the fact that simple feedback systems can exhibit chaotic behaviors, very much in contradiction with our (deterministic) intuition. Thus, order-flow between distributors and a factory can quite readily exhibit chaotic patterns given certain feedback loops. Second, that small causes can propagate to have very large effects. Again using the example of production planning, a seemingly innocuous element in the production line or in the sales channel can cause havoc in the entire stream. In Complex systems we will see that feedback loops and the nonlinear amplification of small effects can be essential drivers of order. This should be counter-intuitive to many of us, because we deeply hold the belief that small causes have small effects, i.e., assume linearity above all.

Thus, quantum mechanics and chaos mathematics have exposed the shortcomings of the Simple way of viewing the world, and the mechanists lost their innocence. In the following paragraph my goal is to give a general intuitive understanding of Complexity and to point to some consequences for organizational leaders.

## THE COMPLEX

What is a Complex adaptive system (CAS)? It is a system of *semi-independent agents* that interact more or less randomly to influence each other's behavior. The agents must realize when their interactions have left them better or worse off according to a *fitness criterion.* Think of a group of door-to-door salespersons who know that selling more is a good thing and who randomly meet colleagues to exchange ideas and gossip. The right combination of a fitness criterion (more sales) and random encounters are what leads to a nonlinear growth of order in a Complex adaptive system (in this case more sales). Like in a neural network, the combination of a fitness criterion and random feedback loops has become a highly efficient information processing system. It turns out to be much more efficient than the traditional method of having each salesperson report back to a central marketing entity.

To illustrate this point, imagine that you are such a semi-independent agent in a Complex adaptive system. You are perhaps an employee of a large multinational corporation, an amino acid, an element in an ecosystem or even a stockbroker. You are bouncing around, randomly interacting with other agents in the system. The one thing you "know" is what is "good": the fitness criterion. Most often the fitness criterion has to do with survival in a wide sense, such as the long-term profitability of the corporation that you are in, survival of the species that you are a part of, etc. In every random interaction you receive information on how your actions enhance or decrease your fitness through you contribution to the system. Your fitness is not absolute, but is relative to the fitness of other agents in the system around you. Thus you "learn" to adapt your behavior to increase your fitness. This web of very local and random interactions, occurring without following any explicit directives, lead to an increase of the fitness of the entire system. How does this happen? Quite simply, because your behavior contributes to the fitness of the system in a positive way and is linked to the system as a whole through the feedback in the interactions. Contrast this with a mechanistic view where for every move you wait for an explicit instruction, either deduced from a rule or given by another agent (i.e., the boss) in the system.

**Peter Senge[8] describes the "beer game" that he uses to familiarize managers with the power of feedback loops. In this game the time delay in communication between consumers, distributors, and the factory leads to chaotic fluctuations in the quantity of beer that moves through the supply chain: An effect that is undesired and detrimental to all parties, but one that they together "cause" nevertheless.**

Before moving on, it is worth pausing and wondering why this science Complexity has become a topic now and not much earlier? Traditionally science has had two methods of investigation: theory and experiment. The general idea was for experiments to either confirm of falsify the theories. On the one hand theory was developed either to explain experimental results and on the other hand, often out of intuitive or aesthetic considerations to then be verified by experiments. This virtuous exchange has one serious limitation, namely, that the theories have to predict something. This means that their strict formulation, most often in the form of mathematical formulas, needs to have well-defined solutions. For example, in economics the requirement to have equations be solvable contributed to the assumption of the economy being a balanced system, tending back to equilibrium through the mechanism of diminishing returns when destabilized. Of course economists were concerned with having their theories say something useful about the real world, but the development of theory was severely limited by the mathematics of the Simple. When seen as a Complex adaptive system, the economy seems on the contrary to be very far from equilibrium, as described by Brian Arthur[6] of the Santa Fe Institute and others. Arthur describes how, in certain markets, through positive feedback a mechanism of increasing returns arises, which explains the dominance of certain technologies such Microsoft Windows, the QWERTY keyboard, or the VHS video standard. In this kind of markets, random initial fluctuations in market share are amplified nonlinearly to become dominant. With initial funding from Citibank to work this very problem, the Santa Fe Institute went on to play an essential role in the development of the science of Complexity.

In the postwar years the computer erupted on the scene and with it an entirely new way of doing science: theory and experiment where joined by simulation.[7] A problem that was too Complex to understand theoretically or understand through experiments could be simulated on a computer. All this simulation has lead to a surprising discovery: Very simple rules can lead rather easily to very Complex behavior. The pictures of fractals have been well publicized and serve as a vivid illustration of how much Complexity and also beauty can be generated using very elementary rules.

Not only can computers help us understand how chaos emerges from order, but also quite surprisingly how order emerges from chaos (or more precisely disorder). Complex adaptive systems, under the right conditions, organize themselves through the spontaneous emergence of system level properties. These are properties that cannot be attributed to the different parts of the system, which means that they do not arise from any component of the system. This is an uneasy concept in our mechanistic world view, but a manager can perhaps relate to it by thinking of a corporate culture or the identity of a successful team. Corporate culture has an intuitive reality, and although it cannot be attributed to any specific employee or machine, it is a recognizable property of the system as a whole.

In a similar development in management literature and theory, emphasis is being given to the system-like nature of the firm by Senge,[8] or to the life-like properties of an organization by Maturana and Varela,[9] and more recently by de Geus.[10] These thinkers all share an interest in seeing an organization as something radically different from a machine to produce certain results, but more as a system with its own properties and identity. Complexity helps us understand this concept more readily.

With the Santa Fe Institute[11] serving as somewhat of catalyst, many computer simulations have been made of different Complex adaptive systems. The goal is to understand what minimal ingredients are necessary in terms of fitness and in terms of interactions to explain Complex phenomena. Once the ingredients are identified, they are simply played out on a computer to see where they lead. Successful models have been constructed that mimic the behavior of such diverse phenomena as the stock market,[6] the origin of life,[12] or the evolution of strategy. This has, for example, led to a better understanding of why bubbles and crashes occur in stock markets and to an understanding that the appearance of life on the planet is not so improbable after all. The following example of strategy evolution is worth looking at in a more detail because of its potential interest for business firms. It illustrates the approach to a problem using the methods and insights of Complexity.

When Robert Axelrod[13] issued an international competition for the best strategy for winning at a long series of games of Prisoner's Dilemma,[14] second place went to a strategy called tit for tat. In tit for fat, a player rewards her opponent who co-operates by co-operating in return. Conversely, if the opponent defects, she will retaliate with defection in the ensuing round of the game. First place went not to a strategy, but to a computer program that continuously evolves new strategies. This program not only won the game, but perhaps more important, demonstrated the very nature of the evolution of strategies. John Holland[15] built a simulator that had two very simple ingredients that were sufficient not only to discover the tit for tat strategy by itself, but also generate a continuous stream of alternate strategies. The key is to code every possible strategy into a DNA-like sequence then, to give every strategy a fitness criterion, namely the amount of points collected in the game. Finally, to design a mechanism whereby strategies could interact randomly and crossover like DNA molecules, taking successful pieces of strategy from other strings. In other words, the system not only had a mechanism for generating new strategies (interaction) but also one for getting new strategies accepted as dominant ones (fitness criterion). Most business firms could probably benefit from understanding this fundamental model of strategy evolution.

**Brian Arthur of the Santa Fe Institute has simulated the behavior of the buyers and sellers on the stock markets, thereby reproducing the bubble and crash cycle of stock exchanges.**

Some of the best examples of putting the insights of Complexity into practice come from the US armed forces. A particularly interesting one has been described in a study from the University of California at Berkeley and concerns the method for landing fighter aircraft on the deck of the *USS Enterprise* aircraft carrier. Such an aircraft carrier has 5000 people on board, and obviously, having the aircraft land safely is one of the most critical processes of the entire system. Four cables are strung across the deck that decelerates the planes through a hook that is dropped from the rear of the aircraft. The tightening of each cable must be tuned differently for every landing, depending on, for example, the wind and the weight of the plane. Interestingly the Navy has not opted for a computer-controlled algorithm, but instead every cable is operated by a team that negotiates with every other team for the best cable setting for every landing. Because the setting of one cable depends on the others, in this way the teams interactively reach a consensus. In a mechanistic prospect, this seems an inefficient way of doing things. In the light of complexity, it is an elegant application of the principles: a clear fitness criterion (safe landings) and lots of interactions between the agents.

As a final analogy, I would like to invite the reader to imagine taking a walk in an imaginary rugged landscape. The goal of the walk is to find the deepest valley; our fitness criterion in this case. One strategy could be to always walk downhill from every point. This will certainly achieve the goal of reaching a deep point, but it will be unclear whether this is the deepest point or just a local pit. Another strategy could be to walk downhill, but randomly change direction at a certain frequency and then compare the altitude: This will avoid becoming stuck in a local valley because the random deviation from the downhill path can very well send you back uphill in some direction. However, if there is too much changing of direction, this will result in purposeless wandering. The key to success in Complex adaptive systems is to strike the right balance between order (always walking downhill) and disorder (random changes of direction). Given the right feedback mechanisms, a system far from equilibrium poised at the edge of order and disorder will spontaneously organize itself in a sustainable and efficient way. What the "right" balance is depends on the circumstances, and it is the role of the leader to understand the dynamics of Complexity and to design the right balance into his or her organization.

**The image of a landscape can be pursued in concrete examples: consider IBM in 1970, operating in what seemed like a very smooth landscape. Corporate processes could be optimized for efficiency, with little energy expanded in exploring the changes in the landscape around it. When the landscape changed radically with appearance of the PC, IBM found it lacked the capability to explore the new nature of the landscape and adapt its processes accordingly. A radical and painful overhaul was needed to adapt to the new landscape.**

## COMPLEXITY AND BUSINESS

Unfortunately there are no "eight easy steps" to use Complexity or "twelve key rules" to apply as in much of management literature. Rather, Complexity is a very fundamental evolution of our mental model of how (Complex) systems work, which more closely seems to explain the behavior of stock markets, ecosystems, large firms, than the traditional approach. Complexity provides a fundament for the thinking of writers such as Senge,[8] Zohar,[16] and De Geus.[10] The emphasis on the company as a system, on the importance of servant leadership, on the organization as living entity that needs to learn and be diverse to survive: these are all aspects of Complex adaptive systems.

What lessons can be drawn for organizational leaders out of Complexity? A leader in an organization can learn about Complexity and then tune his or her intuition to be able to manage the key ingredients that drive the emergence of order in a complex adaptive system. For reasons of space they are only mentioned here in summary form. A further detailing of these rules and their origin in Complexity will be the subject of another article. These ingredients include the following items:

- an appreciation for the holistic nature of a system and emergence of system level properties
- a nondirective style of leadership
- creating clear fitness criteria for the organization (goals)
- having just enough rules to limit randomness in the organization to where it is fruitful, but no so many as to put the organization into a state of equilibrium. The organization will function at its best when poised at the edge of disorder. Designing the rules to achieve this balance is probably the most important and challenging tasks of the leader.

These are uncomfortable prescripts for many of us, but we should seek comfort and insights in the formal models of the new science of Complexity to help us understand them. Many systems (but not all) are very much complex adaptive systems, and managing them as if they were deterministic systems will be suboptimal. It will be suboptimal not only in terms of the survival of the system itself, but also in terms of the development of the individuals in it, for they will not be challenged to use all their creativity to optimize their own fitness and that of the whole.

## FURTHER READING

For those who are intrigued by and want to know more about Complexity, Mitchell Waldrop has written a lively introduction[17] to the history of the people and the thinking of the Santa Fe Institute. Nobel prize winner Ilja Prigogine and Isabelle Stengers have laid the foundation of the subject with a fundamental book on the origin of order.[18] Fritjof Capra in a recent work places Complexity in the context of the evolution of 20th century thought.[19] Finally another Nobel prize winner, Murray Gell-Mann has put his considerable didactic and intellectual resources into an excellent and fundamental introduction to the topic.[4]

Several consultants are putting the lessons of Complexity into practice by advising organizations. Michael McMaster has written on the organizational consequences of Complexity.[20] Richard Pascale has described the transformation of one of the shell's divisions.[21] Ton van Asseldonk has looked at how Complexity can help firms deal with individualized consumer demand in an eloquent dissertation.[22] Howard Sherman has published a book on the evolution of strategy in the light of Complex adaptive systems.[23]

## NOTES


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