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COMMITTED TO IMPROVING THE STATE OF THE WORLD

Perspectives on a Hyperconnected World

Insights from the Science of Complexity

By the World Economic Forum's Global Agenda Council on Complex Systems

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Executive Summary

Every day our world becomes more complex and dynamic. The global population continues to rise with urbanization occurring at an exponential rate. Economic growth brings people from diverse cultures and regions into contact with one another through increased trade and travel. The Internet and social media now seem to connect each person to everyone else, and to make information available to all.

This accelerating interconnectedness has in many ways made life better. But it has also brought greater complexity to world affairs. Many of the grand challenges that confront humanity—problems as diverse as climate change, the stability of markets, the availability of energy and resources, poverty and conflict—often seem to entail impenetrable webs of cause and effect.

But these problems are not necessarily impenetrable. Powerful new tools have given scientists a better understanding of complexity. Instead of looking at a system in isolation, complexity scientists step back and look at how the many parts interact to form a coherent whole. Rather than looking at a particular species of fish, for example, they look at how fish interact with other species in its ecosystem. Rather than looking at a financial instrument, they look at how the instrument interacts in the larger scheme of global markets. Rather than think about poverty, they might look at how income relates to conflict, politics and the availability of water. Whatever the object of study happens to be, complexity scientists assemble data, search for patterns and regularities, and build models to understand the dynamics and organization of the system. They step back from the parts and look at the whole.

This kind of thinking is a major departure from traditional science. For centuries, scientists have worked by reducing the object of study down to its constituent components. Complexity science, by contrast, provides a complementary perspective by seeking to understand systems as interacting elements that form, change, and evolve over time.

The multiplicity of ideas, concepts, techniques and approaches embodied by the science of complexity can be applied to people, organizations and society as a whole, from economies and companies to epidemics and the environment. The aim of this paper is to raise awareness about this new science and its ability to bring clarity and insight to many of the complex problems the world faces today.

The Science of Complexity: New Tools for New Perspectives

Complexity is not so much a subject of research as a new way of looking at phenomena. It is inherently interdisciplinary, meaning that it derives its problems from the real world and its concepts and methods from all fields of science. Complexity lies at the root of the most burning issues that face us every day, such as hunger, energy, water, health, climate, security, urbanization, sustainability, innovation, and the impact of technology.

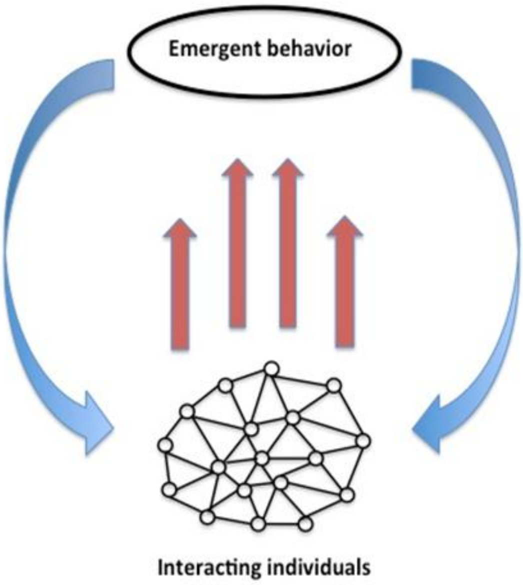
To get a feeling for how complexity science can work in the real world, consider the very concrete problem of automobile traffic. The vehicle through-rate of a highway rises as the density of motor vehicles increases, and at a critical point a traffic jam forms. The jam can disappear and reappear over time, or slowly move up or down the highway. Over the network of roads that form the wider metropolitan area, traffic jams appear, disappear and reappear—not randomly, but in patterns, such as a series of waves.

Complex systems by their very nature resist simple examples, but for the sake of clarity our traffic example can illustrate some of the characteristics of complex systems. At the heart is a collection of objects, or agents (cars, in this case) that compete for some kind of limited resource, such as food, space, power, energy or wealth (roads, in this example). The complexity of the problem lies in the large number of interactions between these agents. From many individual interactions, new and often surprising phenomena emerge (waves of traffic jams). The emergent behavior of the whole cannot be reduced to the individual agents of the system: the whole is more than the sum of its parts.

All complex systems exist within their own environment and are part of that environment. As the environment changes, they adapt. Traffic is not merely a question of the number and speed of cars but on the existing roads, traffic lights and potholes. Change those components and traffic patterns change — the agents adapt to their environment. In this sense, the system and its environment co-evolve. The agents are connected to one another (drivers see the tail lights of the car in front of them). They are interconnected, which means they can interact.

Most other real-world phenomena have these key qualities. An influenza outbreak involves a complex interplay of people, viruses, and an environment that includes plane travel, health care and social mixing. The interaction of financial instruments, banks and investor psychology makes for a complex financial system that fluctuates constantly, most of the time in small degrees but every once in a while with a crash. Ideas and social norms — acceptance of gay marriage, say, or market-driven socialism — can propagate through society according to the principles of complex systems.

Working to resolve or influence many of the most important issues that society faces requires a basic understanding of complexity, not least because complex systems have a propensity to make sudden, unpredictable and drastic changes



Generic Characteristics of Complex Systems

- Self-organization
- Interdependence
- Feedback
- Far form equilibrium
- Exploration of the space of possibilities
- History and path dependence
- Creation of new order

Major issues related to complexity

- Spread of epidemics
- Climate change
- Escalating conflicts
- Governance of increasingly complex social systems
- Potential collapses or shifts in ecosystems
- Cascading failures e.g. in electricity networks
- Irrational effects of financial speculation
- Networks of terrorist
- Diffusion of fashions, innovations and spread of rumors
- Self organizing mass movements, e.g. London riots, Arab spring

This list can be extended endlessly.

Governance and non-linearity

Scientific knowledge is organized by disciplines (physics, chemistry, biology, sociology, anthropology). Government agencies are organized by policy issues (food, health, huma
n rights). Public and private institutes frequently follow the same framework. The trouble is, all the world's challenges are essentially non-disciplinary. When competition for water triggers war and disease is the aftermath, no government agency or NGO is set up to see the whole picture. This mismatch stands in the way of understanding the real nature of the grand challenges we face and in taking appropriate action in response to a crisis. It also stands in the way of finding sustainable approaches to meeting our challenges.

One of the most dangerous assumptions in world governance, and in the sciences for that matter, is the assumption of linearity. Linearity basically means that each effect has a single cause, and that the cause and effect are proportional to one another. In a complex system, there are feedback loops and cycles that make emergent behavior unpredictable. Negative feedback can act to keep a condition stable, but it can also be destabilizing. So can positive feedback, or self-amplification. The "flash crash" of 2010, in which the DOW dropped 10 percent in the span of a few minutes, was one such non-linearity caused by negative feedback, in this case computer trading. The revolution in Tunisia and across the Arab world was a non-linear (disproportionate) response to the action (self-immolation) of a single street vendor. The failure of Lehman Brothers triggered a totally disproportionate collapse of the global financial system.

Reductionism

Most present-day leaders have been trained to assume that the world behaves according to simple rules. This mindset reduces complex facts, entities, phenomena, or structures to some simple notion. Reductionism totally ignores the phenomenon of emergence, i.e. the fact that the whole has properties that cannot be reduced to the properties of the parts. As complexity scientist John Holland notes, "For the last 400 years science has advanced by reductionism. The idea is that you could understand the world, all of nature, by examining smaller and smaller pieces of it. When assembled, the small pieces would explain the whole".

Reductionism and water

Water has the property of being liquid, but none of the molecules out of which water is constituted has this property. Liquidity is determined by the way the water molecules interact and the patterns resulting from this. These patterns are different for ice and for vapor.

The grand challenges or problems we are facing cannot be solved through a reductionist approach. Complexity thinking and science help us to build bridges between different specialties and disciplines. It can help us to understand dynamic, highly interconnected and interdependent systems, where traditional sciences fail.

Applications

Complexity science is not an applied science; it is a science that leads to insights or understandings that have been applied to real-world problems. Some of those applications have large implications for the governance of corporations, regional, national and international institutions, social and ecological systems. Given the increasing availability of "big data" about our techno-socio-economic-environmental systems, complexity science is quickly gaining practical importance.

Here are some of the issues that insights of complexity science have been applied to: combating HIV, military strategy, designing and using economic incentives, designing for resilience, using scarce resources more efficiently, software development, language acquisition, avoiding conflicts and crises or mitigating their severity or consequences.

These problems are interconnected (some strongly). Complexity science likely already has some tools or methods that can help address those problems, or has the potential to do so. Combining social and complexity sciences has led to a number of interesting applications, including models of self-organization and segregation (which suggest strategies to reduce crime and conflict), models of social cooperation (which imply ways of overcoming so-called tragedies of the commons), and models for the formation of opinions, which are used as prediction tools in the market.

Models of pedestrian dynamics can now help to anticipate and avoid crowd disasters.

Models of mobility patterns and traffic breakdowns support congestion avoidance and inform the design of smarter cities. Models of financial systems offer suggestions on how to make these systems more stable and resilient to shocks.

Simulations of supply chains facilitate more efficient production systems and provide a better understanding of business cycles. Models of conflict and organized crime hold the promise to reduce wars, insurgency, and drug traffic. Real-time measurement and simulation of pandemics can be used for scenario-based policy recommendations, e.g. regarding more effective immunization strategies.

Conclusion

It is only through intense interdisciplinary collaboration that one can discover and learn to understand the underlying principles that govern the complexity of our world. It is only through such understanding that one can hope to master the grand challenges facing our world.

To develop new approaches to how we govern our cities, our nations, our environment and our socio-economic and socio-ecological systems, we need to understand the principles that govern the complexity of our world. “The nations and people who master the new sciences of complexity will become the economic, cultural, and political superpowers of the twenty-first century,” said physicist Heinz Pagels. Physicist Stephen Hawking declared: “The twenty-first century will be the century of complexity.”

Data and social systems

Getting data about social interactions used to be very time consuming and cumbersome. Lately this has been simplified dramatically by new surveying methods and by the Internet. The enormous volume of data that is becoming available as a result is indicated as Big Data.

Parallel to this data explosion much progress has been made in modeling key elements of social systems. Examples are models for the emergence of cooperation in social dilemma situations (which normally promote a ‘tragedy of the commons’), the formation of social norms, the spreading of conflicts or violence, and for collective behavior (such as opinion formation, crowd disasters, and revolutions). Currently, scientists are working on models considering emotions, models explaining conditions for altruism, and models considering cognitive complexity. It is expected that using Big Data to calibrate and validate such models will enable many beneficial applications for society.

Resilient Adaptive Systems: A World of Increasing Uncertainty and Shocks

Our world is continuously faced with unexpected events of great consequences. Recall the financial crisis of 2007 - 2008, the Arab spring that erupted in December 2010 or the Tohoku earthquake in March 2011 that resulted in the nuclear disaster in Fukushima. They characterize the type of events and consequences that throughout history have challenged and changed the structure and functions of the ecological and social systems that we are part of. They have shaped our world and will continue to do so. While those unexpected events are both natural and manmade, its consequences are more and more determined by the interconnectivity of our world and thus by the interdependency of its natural, social, and artificial systems.

Unexpected events will continue to hit us. And although we will not know where the next one will come from or how it will affect us, we do know - because of the growing number of people in the world and the growing density of connections between them - that more people will be impacted by it.

As the introduction to the 2013 Annual Meeting of the World Economic Forum states: "… reality presents a new leadership context, shaped by adaptive challenges as well as transformational opportunities."

The challenge

The big challenge for public and private leaders is: "To prepare our natural, social and artificial systems to be able to quickly recover from the next unexpected event".

As we do not know the nature or the time of the next event that will hit us, we cannot build a static defense against it. We need systems that will adapt their functions and responses to the respective events as they happen.

Practically this means that our local, regional and global governance systems, as well as our public and private institutes need to detect the earliest signals of such events and adapt their analytic focus and responsive functions accordingly. It also points to the need of designing redundancy in governance as well as the capability to replace functions that are disturbed or destroyed.

If many functions are redundant, such disruptions may not lead to a loss of the overall functionality of the system. In that case systems are tolerant with respect to a certain shock. If a system tolerates many different shocks, we may call the system robust.

When the shock to the system is greater than what the system can tolerate, the number of functions the system can perform may decrease dramatically. An example is the temporary disappearance of the lending capacity of banks following the meltdown of the financial system in 2007. Another example is the loss of civic services after a natural or man-made disaster.

When the shock is over, the complex system recovers, i.e. its functions re-emerge, but may do so in a different way. It might have explored different options and co-evolved, and new or modified functions may have emerged. The measure in which that happens is a measure of the resilience of the system. When a function that has broken down recovers, the actors providing the function may also have changed.

Resilience

In the case of major catastrophes infrastructure is damaged or destroyed. When this infrastructure is rebuilt, we recover some of the lost functions. Fragile complex systems permanently lose critical functions after a large shock. We therefore think of a resilient complex system as one in which mechanisms are in place for the ecology of functions to either recover back to, or close to its original level, or for different or modified functions to emerge to fit the changed environment.

It is important to note that the recovery process works bottom-up. At first, lower-level functions will recover locally, determined by short time scales. As we recover higher- and higher-level functions, the necessary and sufficient conditions become more and more global in character, and the time scale to recovery becomes longer and longer. As a society, we can usually wait longer for such global functions to recover, but local functions need to recover on a shorter time scale. Therefore, an important consideration within the context of resilient dynamism is to build local resilience to enable global resilience.

Finally, after every large shock, the complex network of functions is permanently altered. Sometimes the reorganization makes the complex network better at coping with the same type of shock. Sometimes it makes it worse. More importantly, resilience towards one type of shock may weaken the resilience of the system to another type of shock. If we understand resilience from the complex network of functions point of view, it may be possible to engineer the network to become not the most resilient to any specific shock, but overall resilient to many shocks.

The leadership imperative

Problems like peak-oil, exponential resource use, corruption, poverty, inequality, climate change, urbanization, youth unemployment, terrorism, unreliable fiscal and financial systems erode the system's ability to be resilient. At the same time these problems provide us the opportunities embedded in the dynamics that lead to these problems, as well as to the continuous transitions that shape our world.

From the perspective of "improving the state of our world", the objective of such a resilient governance and institutional structure is to minimize the extent and duration during which the normal functioning of the system is affected. In other words, we need to adapt our systems to be maximally resilient in a dynamic and unpredictable world. For that to happen, we need to build the capacity of our leadership to understand the underlying dynamics from which new unexpected events may destroy the system's ability to function normally, and what creates resilience of systems. This implies the urgent need to establish a new study direction of complexity science globally at all major universities.

Resilience and complexity

The underlying dynamics of our world, the source of the resilience of our natural, social and artificial systems and the problems and challenges that our world faces, have one common denominator: complexity.

Resilience is a property of many complex adaptive systems. Social systems are complex adaptive systems. So are certain engineered systems when coupled with social systems, for which they are designed. The relationship between resilience and complex systems justifies a definition of resilience in the language of complex systems.

To thus define resilience, we need to understand the proliferation of functions in complex systems. Examples of such functions are the facilitation of the flow of capital in a financial market, the distribution of energy in a power system, the "killer function" of T-cells in our immune system, the search functions in Google.

However, a function is not a 'thing'. It does not exist independent of the system it is found in. Frequently, when two functions interact, after some time, a new function is created, i.e. functions proliferate in a complex system.

We may think of a complex system in terms of its complex network of relationships and functions, as distinct from its complex network of interacting agents.

We may then look at tolerance, robustness and resilience of the network in terms of the response to disruptions in the interaction of functions in the network.

Complexity

Complexity is not new, it is as old as the big bang. At its core lies the phenomenon that new properties emerge as a result of interactions of many independent agents. Such agents can be anything, from electrons to atoms, to molecules to cells, to animals, to human communities, to religions, to the World Bank or the United Nations.

Complex systems are complex not because of their many and heterogeneous agents, but because of strong nonlinear interactions between them. The interactions between these agents at each level and between the different levels, have shaped the universe and our world and give rise to the dynamism that enables systems to adapt themselves to external forces, or to bounce back if unexpected events or shocks unsettle the structure and functions of the system. Adaptation, however, is only the first step in a dynamic and ongoing process. When a system adapts and changes its behavior, it influences all other agents/systems that interact with it. If they change their behavior and that change in turn influences and changes the behavior of the initiator, then the interacting agents/systems have co-evolved. Resilience is essentially a co-evolutionary process.

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