THE IMPLICATIONS OF COMPLEXITY

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Contents

Summary: The Promise of Complexity

"We believe that everything in the world is wisdom, although in many things our understanding of it is very imperfect..." Ibn-Rush'd (Averroes in Latin)

The end of the twentieth and beginning of the twenty-first century marks an unprecedented passage of eras, between the end of the Industrial Age and before the full consolidation of the emerging Information Age. This transition is exhibiting a radical increase in global complexity due to an explosive growth of inter-connectivity via world-wide communications technologies. The consequence is a vast interdependence

in global economies, technologies, cultural environments, and resources. Although this passage is clearly fraught with difficulty and uncertainty, it also comes with new opportunities and new promises, not the least of which is the arising of new scientific and mathematical approaches to the study of complexity that can help us not only better understand its nature but also can help us more successfully navigate through these turbulent times. In particular, complexity theory with its focus on the adaptative capacity of complex systems can be a guide for promoting sustainable economic, social, and cultural policies not just for our current generation but on into the future.

This article will look at both the current explosion in complexity as well as how complexity theory is helping us come to terms with various aspects of it. In the first section, we will discuss the many factors involved with the increase in global complexity. Then, in the next two sections, we will focus on the new conceptual maps offered by complexity theory. The articles under "Implications of Complexity" will be summarized as we discuss the features of complex systems. Characteristics will be described and then strategies deriving from the characteristic will be drawn-out. What follows, therefore, includes both descriptions and prescriptions.

1. The Increase in Global Complexity

"The simplest cannot help become more complicated, and if we look to the first origin, there must be progress". Charles Darwin

The twentieth century witnessed an exponential growth of technology in many areas but particularly salient were advances in transportation, communication, and information. While new technologies in each area are connecting different parts of the globe in unforeseen and dramatic ways, they also have the potential for exacerbating differences and conflicts. Developments in these infrastructure technologies have stimulated the growth of all other technologies resulting in a rate of development in all sectors that has made unrelenting novelty a hallmark of modern civilization, sometimes testing the limits of our adaptive capabilities. Indeed, technological advances in food production, medicine, and health care have led to an increase in population that it is straining our planet's carrying capacity.

The invention and development of the computer has led to the following technological advances acting as catalysts for the incoming of a new mode of civilization:

- *Miniaturization* that has created the possibility of inserting a small computer in an endless number of machines, tools and other devices.
- The *silicon chip* which has sharply *decreased the price of computers* and advanced the diffusion of the personal computer.
- The development of *fiber optics* that has greatly increased our ability to increase the flow of information.
- The enormous *advances in the capabilities of personal computers* that now more than equal the capabilities of former supercomputers.
- The *variety in the means of communication* (fax, email, chat programs, telephone, video, TV, radio, mobile phones etc.).
- *Satellites and micro-waves* that have done away with the need for lines to be able to communicate throughout the world.

- The development of *computer graphics*, scanners, and programs that allow the representation of events and processes that have previously escaped visual representation (this capacity is one of the capabilities that led to complexity theory).
- The spread of *internal and external networks* between all kinds and levels of systems allowing the real time flow of information between them, e.g., between financial and currency markets, producers, suppliers, and customers (we'll be looking closer at networks below).
- The *Internet* and the world wide web which has joined the world into an actual global village economically, politically, socially, culturally, scientifically and educationally.

The Information Age is composed of two interacting aspects, the *Network Revolution* and the *Knowledge Era*, whose co-evolution is having far-reaching implications in terms of work, culture, economy, national autonomy, business, organizations, identity and ecology. First, we will consider the Network Revolution made possible by the impact of computers on communication and amplified through the decline in the price of communication devices resulting in the unprecedented ability of almost anyone being able to communicate with anyone else in the world. This means that all parts of the world are being tied together in ways not thought possible a hundred years ago.

The tendency to globalization in policies concerning economics and financing of industry is bringing the industrialized countries to similar monetary, banking, insurance and securities trading policies. There is a steady growth in the developed countries of investment in other countries. Multinational corporations thrive in this world economy where complex transnational alliances, mergers and common ventures are created daily. Moreover, enormous sums of money in electronic form circulate throughout the world and capital and currency markets are so tied up with one another a fall in a market in one country may reverberate throughout the world.

But this linkage has also created an intricate web of sensitivity among the linked nodes which expresses another characteristic of increased complexity: the way a small event, which at first goes unnoticed, may lead to an avalanche of effects. This iterated sensitivity to small differences is the breeding ground of what has become known as "chaos" in chaos theory. An important consequence is the rise of unpredictability and uncertainty in complex systems.

Concomitantly, there appears to be a decrease in the influence of the nation state as a political entity apart from these internationally constituted entities. This can be seen in how national governments no longer have total control over the value of their currency. Indeed, foreign investors can vote against a government by not investing in its industries. Reliance on foreign markets for its products makes a country more susceptible to the ups and downs of world markets. Commercial and technological considerations push governments to expand their external production and trade which can decrease their autonomy and increase their vulnerability. Furthermore, it is becoming impractical for nations to try to control the international spread of technological information as a means of improving their competitive advantage.

The same communication network revolution that is creating a global economy, however, has also created the conditions for the proliferation of global crime. Criminal networks seek their fortunes in countries other than their country of origin. However the spread of international crime does not confine itself to its regular fields -- it spreads into economic, political and national fields, even aiding in the destabilization of nation states.

Not only is computer technology growing but it also appears to be expanding at an increasing rate from year to year. This means that the more technology society has, the faster it breeds. A positive feedback cycle develops so that those who possess the technology acquire even more, whereas those who are behind in technological advance are left further behind. This is related to the phenomenon of *lock-in* in which a technology gets locked-into a relatively stable state even though it may not be optimal (we will be discussing lock-in below).

The free flow of products, services, capital and labor over boundaries spurs the spread of hyper-competition. The Information Age necessitates globally distributed planning, designing, production, assembly, transportation and marketing across and between continents and states. Computers and other technologies allow this flow to be coordinated throughout the world. The long-range economic and social effects of hyper-competition among countries are largely unknown.

1.1. The Knowledge Era

Within thirty years computers and networks have advanced societies' knowledge base, learning ability, and information diffusion greater than in all of previous history. There is a movement in all areas of human production to activities based on a much higher level of knowledge, information, and communication. Certainly, the passage to each new era in the past always involved an increase in human knowledge. What distinguishes the current passage is not only the quantum leap in human knowledge, but the central role knowledge is coming to play in every social and economic endeavor. New areas of production in agriculture, industry, and the service economy are both developing out of new knowledge and dependent on the growing number of knowledge workers.

In the Information Age, the new system for wealth creation depends more and more on the exchange of data, information, and knowledge. In other words, if knowledge is not exchanged, wealth is not created. Wealth takes the form of electronic exchanges of information. Moreover, the knowledge gained from science has become a major factor in the advancement of all forms of production. New knowledge is prompting innovations in biology, materials science, transportation, entertainment, medicine, communication, to name just a few. For example, we are just at the very beginning of a revolution in medicine and agriculture derived from knowledge gained in the new field of genetic engineering. The practical as well as moral, even spiritual dimensions of this revolution are already staggering our collective imagination.

Entire cultures are shifting from domination by heavy industries (e.g., steel mills, coal mines, and sweat-shops) to industries based on knowledge, information, and scientific

breakthroughs. Biological sciences are replacing the physical sciences in the major industries of the future. Cellular biology, molecular biology and ecology are fast advancing into experimental techniques on the way to understanding the basic processes of life. Cross-fertilization between the biological sciences, added to scientific and technological advances in other sciences and technologies such as nano- (or miniature) technology are pushing forward in a variety of areas such as medicine and agriculture. For example, plants can be created that are weather resistant and engineered to generate special drugs to conquer specific diseases, and bacteria are genetically altered to clean-up pollutants such as oil spills. In addition, research is developing completely new materials with special properties based on progress in the knowledge of solid state physics. This is allowing for advances in areas such as superconductors, fiber optics, semiconductors for computer chips, lightweight construction materials, materials for magnetic storage of information, and fiber optics for speedy communication.

1.2. Knowledge Workers

These major advances in production lie less within the scope of the inventive tinkerer, and more and more necessitate knowledge acquired by costly interdisciplinary research projects and large-scale technology. The ever-growing services sector of the workforce is assuming a much more important role in the economy, exceeding already the percentage of people employed in industry and agriculture. Services already make up over 20% of global trade. Many of these services, such as health, social welfare and culture facilities, require a horde of new professionals on whose knowledge and know-how the service depends. Indeed, entire new areas of production are becoming focused around the knowledge gained by cross-fertilization of new sciences. Production has also moved from standard mass production to catering to a variety of different needs and custom-built products, each of which requires new knowledge.

One result is that the workforce is transforming from a society of blue-collar workers to a society of "gold-collar" knowledge workers. Knowledge workers must have skills in manipulating languages, symbols and concepts, and tend to identify more strongly with their peers and professions than their organizations. In addition, knowledge workers suffer from a much more rapid obsolescence in skills. In the Knowledge Era, companies can move capital and jobs around he world, like pieces on a chessboard. Hyper-competition favors those who can, in different countries and regions, utilize advantageous conditions for labor costs, taxes, services, transportation, infra-structure, currency rates, and so on. Also, hyper-competition makes it more and more difficult to compete, and decreases the sustainability of those who have difficulty adapting to these new conditions. Globalized hyper-competition is a major factor behind the growing survival difficulties of many human systems. Where there is a greater mobility between countries of both production plants and of workers, workers from the poorer countries are flocking to countries that are more fortunate and filling the less desired occupations in those countries. These trends are behind the decreasing power and influence of the trade unions.

1.3. The Global Effects of Knowledge-based Economies

In the Information Era, mega-science has now reached such a scale that it is beyond the

capability of any nation to support independently. This can be seen today in the war against AIDS as well as in space research. International, cooperative scientific research is becoming ever more critical. Indeed, technological and scientific knowledge is becoming the major source of power and will supplant both force and wealth as the basic resource of power. But, this shift to power based on knowledge is causing an upheaval in the economic, financial, and industrial world. The movement from an industrial economy to one based on computers and knowledge necessitates enormous transfers of power, and changes the focus of business advantage to one based on a knowledge or an intelligence advantage.

Knowledge has assumed a key role in global power struggles replacing power conflicts over material and energy resources. Power shifts into the hands of those who have control over knowledge. They also control resources of force and wealth. Similarly, with the rise in the centrality of knowledge and information comes the growing importance of the media and others who handle and direct the flow of information. Wealth loses its material form as money and takes an informational, nonmaterial form as numbers stored in and transferred by computers. The success of an enterprise depends increasingly on the quality of its people in terms of the level of knowledge, information, and know-how at their disposal.

One of the founders of *Wired* magazine, Kevin Kelly, calls this new knowledge economy the "crunch" economy. The increasing importance of industrial knowledge, the rapidly increasing expenditures on accumulating and transferring it, and its economic vulnerability to competing knowledge elsewhere constitute some of reasons for today's complexity in the economy. A new economy is developing based on a different set of rules. According to Zhang's article in this topic area, economic growth and knowledge acquisition exhibit complicated nonlinear interdependencies including path dependence, catastrophes, bifurcations, and chaos, subjects we'll be discussing below. Surviving in the crunch economy is an increasingly difficult enterprise since wealth creation is a function of innovation, not optimization. This is where the speed of networks is so important. The introduction of new products, new materials and novel services multiplies itself at a rate that many human systems have difficulty keeping up with. This is posing an unprecedented adaptation problem for human systems of all kinds used to a more leisurely change rate. Flexibility, speed, creativity, novelty and entrepreneurship are becoming a condition of survival.

According to Zhang, knowledge has acquired the unique property of being an "international public good". Societies with a greater and faster ability to acquire knowledge and information advance more and outstrip other societies. The free flow of knowledge, information, and immediate internal and external feedback and sensors are becoming critical factors in the successful running of an enterprise. Moreover, Zhang points out that, because of their technological supremacy, most of the world's scientific knowledge is mainly accumulated in European and American cultures. However, this same knowledge, because of advances in the technologies of communication and transportation, can be utilized quickly by Eastern Asian economies traditionally based on agriculture. Again, the rules guiding traditional economic development are changing under the shift to a knowledge economy. For example, Zhang argues that in spite of the supposedly universal value of free trade, sometimes limited trade may be of more

benefit under the right conditions. Furthermore, there are changes in individual preferences for goods and services, a customary parameter of economics, due to knowledge utilization. Nevertheless, it is also a fact that a poor and uneducated country can find it quite difficult to simultaneously achieve democracy and industrialization. It has become almost impossible to maintain social and economic order in a democratic society in which the population is mostly without education.

There are also environmental effects of the new knowledge-based economy. Zhang points to the effect of environmental damage on a country's economy even though this same damage may mean the country is gaining rapidly economically from the utilization of some resource such as wood from a rain forest. Simultaneously, there is the concomitant rise of green movements which strive to change public consumption habits that are damaging the environment.

1.4. Sustainability or Future Threat?

As reported by the Nobel Prize winning physicist Murray Gell-Mann and his associates at the World Resources Institute, a set of basic transitions must take place early in the twenty-first century if human society is to approach sustainability:
1) A demographic transition to roughly stable populations across the world;
2) A technological transition to a situation where the environmental impact per person and per unit of conventional material prosperity is reduced as much as possible;
3) An economic transition to a world in which serious attempts are made to charge real costs, so that there are incentives for the world economy to be based on nature's "income" rather than depletion of its "capital";
4) A social transition to a broader sharing of that income, with the generation of relatively nondestructive employment for the poor families of the world;
5) An institutional transition to a situation in which global cooperation to solve planetary problems is facilitated and in which the various aspects of policy are integrated with one another, in recognition of their actual interdependence;
6) An informational transition to a world in which scientific research, education, and the refinement of indicators permit large numbers of people to understand the nature of the challenges they face.

Currently, there are sustainability crises in many human systems including families, organizations, institutions, communities, polities, and so on. Crisis, breakdowns, disintegration, bankruptcies and takeovers are increasing. In the industrialized countries, studies point to an increase in the rate of bankruptcies and takeovers and a decrease in the life span of families and organizations in the last thirty years. The hardest hit are new organizations and small organizations. These trends are in opposition to the lengthening life span of individuals.

In attempting to increase flexibility in dealing with the crunch economy and hyper-competition, organizations resort to downsizing their workforce, outsourcing parts of their production or other processes, creating external networks of alliances and cooperation and building a more fluid decentralized, less controlled structure of autonomous self-organizing subsystems.

At the level of the individual there is a surge of powerful expressions of collective identity that challenge globalization and cosmopolitanism on behalf of cultural uniqueness and local control over lives and environments. These expressions include ethnic and religious movements, extreme and not so extreme, as well as feminism, environmentalism, and other new causes attempting to create a better future.

In the face of all of these indications of a quantum leap in global complexity, fear and despair may be the most appropriate responses. However, along with this increase in complexity, there has been a concomitant development of new scientific constructs and methods that are providing new insights into the nature of complexity, and it is to these that we now turn.

2. The Rise of Complexity Theory

"...in the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist". Herbert Simon

Developments in the sciences and mathematics, known under the broad term of "complexity theory", are changing the way we think about and navigate through this growing complexity. Since complexity theory is not just one science but has evolved out of diverse scientific and mathematical disciplines, defining "complexity" or "complex system" is not a straightforward task. Yet, in spite of this heterogeneity, there are what may be called "family resemblances" among these diverse fields that provide hints as to a set of features characterizing the complexity of complex systems The various articles included under this topic area provide accounts of the research on complexity in various areas, so the reader will acquire a sense of complexity from reading these articles. However, here we will be providing some preliminary remarks on complexity theory plus summaries of some of the main points of these articles in this topic area.

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Biographical Sketches

Jeffrey Goldstein is Associate Professor in the School of Business of Adelphi University, Garden City, New York, USA, where he has taught since 1989. Dr. Goldstein has also taught at Columbia University, Rutgers University, NYU, and Cornell. He is recognized as one of the pioneers in the application of chaos and complexity theories to organizations. His book, *The Unshackled Organization: Facing the Challenge of Unpredictability Through Spontaneous Reorganization*, was touted by Industry Week as a "fascinating

vision." His work has been profiled in many publications including: *Scientific American; The Scientist; Issues and Observations (from the Center for Creative Leadership); Contemporary Psychologist; The Hartford Courant*; and *Emergence: A Journal on Complexity in Organizations and Management*. Dr. Goldstein is also the co-author of two video-based training programs on workplace diversity: *Brainwaves: New Patterns in a Diverse Workplace* and *Bridges: Skills for Managing a Diverse Workforce*. He has over 70 articles in academic and professional journals. Prof. Goldstein has consulted to many public and private organizations. In addition, he has given presentations at universities around the world including: Lomonosov State University, Moscow, Russia; Harvard; University of Pennsylvania; University of California at Berkeley; Johns Hopkins; University of Tel-Aviv; University of Pavia - Italy; University of Toronto; University of Quebec at Hull; Creighton University; Miami University - Oxford, Ohio; Springfield College; Marist College; and Boston University.

Uri Merry had a distinguished career as a social scientist and political activist. He was one of the founders and later elders of one of the most successful Kibbutz in Israel, Maagan Michael, which has managed to adhere to its original idealistic principles, a fact to which Uri contributed greatly. He received his Ph.D. in Organizational Studies from the University of California at Santa Barbara and was a pioneer in spreading Organization Development practices throughout the world. He authored many articles and books including his insightful *Coping with Uncertainty: Insights from the New Sciences of Chaos, Self-organization, and Complexity*. Westport, CT. (1995).