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Chaos, Complexity and order in Dynamic Nonlinear Systems; Quantum Complexity; Order in Nonlinear Complex Systems; Complexity and the Universe

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Abstract:- The paper elucidates the features of dynamic nonlinear systems and the interconnections between Chaos, Complexity and order in such systems. A comparative analysis between Classical and Quantum Chaos is drawn and evolution of order in Complex systems is discussed .The appearance of Chaos and Complexity in various disciplines is described. Furthermore, Chaos, Complexity and order in the Universe is focused on , observing the ubiquitous nature of Chaos .

I. DYNAMICAL AND NONLINEAR CHAOTIC SYSTEMS

A dynamical system is a system whose state and concerned variables evolve over time , following certain rules. Such evolution is dependent on initial conditions, that is, the system's condition at some initial time. When the initial state is fed as an iteration following a set of rules, a solution is observed. Thus it may be predicted as to what state the system may be at some time in the future.

Both Chaotic and Complex systems are nonlinear dynamic systems [1]. Whereas a linear system can be decomposed into its units and saved separately , a nonlinear system cannot , due to the appearance of variables with higher powers than one, or variables with powers higher than one, or variables which are trigonometric functions , such as sin(x) or tan(x). Thus, in a nonlinear system, the inputs are not proportional to the outputs, and a small change in the initial conditions will not produce a small change in the output. Rather, in Chaotic systems, a small change in initial conditions can produce large changes in output [1,2].

The attractor is a related concept in Chaotic Systems. If the value of some variable is changed, the system changes, and takes some time to revert to a normal state. Subsequently, it reaches a state where the phase space corresponding to the normal behavior forms what is called an attractor. There are different types of attractors. The attractor may be a point which does not move, and is termed a point attractor[2,3]. Such attractors often characterize dissipative systems (systems which stray far from equilibrium and which lose energy, for example, through friction) .In general , an attractor can be thought of as the behavior of a system after the transient stage, or a state where it reaches normal behavior[1,3].

One of the other types of attractors is a cycle attractor, that is, an attractor that describes a system which periodically cycles over the same set of states and never comes to rest. In this system, there are several attractors, each of which depends on the initial conditions possessed by the system [1,2,3].

In point and cycle conductors, points of initial conditions remain close even after movement .In strange attractors, however, close points diverge exponentially over time. These attractors do not settle in a steady state and neither do they repeat the same pattern of behavior (the same household faucet is a example , when the flow is turned to a condition neither too high or too low.

Chaotic systems possess strange attractors compared to complex systems which have phase spaces which evolve and point attractors over a wide range[1,2,3]. The concepts have been applied to Biomedical Sciences. Chaos is found to be associated with good health of the brain , lungs and heart disease, epilepsy, bipolarity , all of which are characterized as dynamic diseases, that is, arising with time .

II. CHAOS AND COMPLEXITY

Chaos and Complexity have similarities and differences .Both systems are examples of dynamic nonlinear systems[4,5]. Chaos is achieved through the iteration of a simple rule and possesses non periodic and seemingly random behavior. Complexity Is a collection of dynamic behavior generated from the interaction of many subunits[6].

Chaotic systems are not inherently complex, and complex systems are not inherently Chaotic. Both are sensitive and dependent on initial conditions[6,7]. This implies that states which are close to each other and follow the same rules, will begin differing considerably over time. Thus the evolution of the system is difficult to predict , even when the initial conditions are described with some accuracy. Errors evolve, which increase exponentially over time.

Furthermore, complex systems exhibit self organization. Without the intervention of an external parameter, the system orders itself spontaneously in a procedure that can be termed as Chaotic[7]. Such systems also move out of equilibrium, which implies that they never settle to a steady state behavior. This concept is connected to open systems, since external influences can be taken into account.

Another characteristic of complex systems is feedback, where the output of the system is fed back to the input[6,7]. Feedback can be negative or positive, depending on the direction of application.

Feedback in Complex systems occurs between micro and macro levels of organization. Feedback can revert to subunits and generate a new pattern, thus generating a global to local feedback which is known as coevolution. This term is obtained from biological evolution, where organisms create their surrounding environment and the environment organizes them in return .

Complex systems possess a long memory; Thus, they are non Markovian and thus pose seemingly insurmountable problems for making causal predictions.

A Complex system is a coherent system, (whereas a Chaotic system is not) and involves interactions between units[7].

III. ORDER IN COMPLEX SYSTEMS

A factor of much importance is the control factor in complex systems. A general feature of a complex system is fine tuning the control factor (which is an external input to the system) to shift the system's properties between different phases. Another type of factor is an order parameter, which indicates the cooperation between different subunits in the complex system[6]

There can thus be ordered, Chaotic and critical phases in a Complex system. A critical phase lives on the edge of chaos and order.

Complex systems are such systems that are placed in a critical position, with high connectivity between their subunits, and every subunit is dependent on other subunits. Thus the system lies in a twilight zone between order and chaos.

Order in a complex system is produced by tuning the control parameter, whereby new patterns can emerge, and self organization can be achieved [6,7].

Complexity and Chaos are underlying concepts which possess related ideas such as nonlinearity and unpredictability. Contrary to the positivist tradition, using a reductionist approach, here we analyze from bottom. up and leave aside reductionism, rather using a holistic approach.

A complex system contains interacting variables , which may produce regular and predictable behavior, whereas Chaotic systems contain few variables producing unpredictable behavior. Complex systems concur with a classical and deterministic visualization of the surrounding behavior. Complex systems may be generated by Chaos, and order may be generated through a Complex system. The pattern extends all through the universe.

IV. QUANTUM CHAOS AND COMPLEXITY

Classical dynamical systems which are Chaotic can also be explained by Quantum Theory.

Classical Mechanics is generally understood as the limit of Quantum Mechanics, according to the Correspondence Principle.

Sensitivity to initial conditions is conjectured to arise in the Quantum realm, leading to chaos in the Quantum and extending to the classical domain.

However, it is not always possible to relate correspondence between Quantum and Classical systems.

The atom by itself is not Chaotic, but subject to a magnetic or electric field, its Classical motion becomes Chaotic [8].

Quantum Chaos and Complexity, although deemed probabilistic, has been shown in recent research to preclude prediction and determination of Quantum phenomena .

Questions arise on how chaos travels from the Quantum world to the Classical world. Chaos can be found existing in the energy level distribution in specific atomic systems[9]. Chaos even makes its appearance in the patterns of waves associated with those levels . The laser is the Quantum answer to Chaos , Complexity and order, where random light becomes coherent.

Quantum entanglement and Chaos are closely related. Quantum entanglement is a phenomenon that manifests itself when a collection of particles are generated, interacting with each other sharing closeness in space. Each particle ìn the group must be described in relations dependent on others in the group, even when separated by a large distance.

Although entanglement concepts in classical systems are yet to be established, entanglement in Quantum systems have been theoretically and experimentally verified[9]. It has been demonstrated that thermalization is the characteristic that connects Chaos with entanglement. This may be the concept of bringing entanglement to classical systems with chaos.

Applications of Chaos and Complexity in various fields including Science And Engineering . The emergence of Chaos Theory and Complexity has brought forth the analysis of innumerable phenomena in various fields which were previously considered impossible to analyze in precise detail. From the movement of pendulums, asteroids and planets in orbit, galaxies in motion, black holes and neutron stars, to blood flows of the heart, financial markets , meteorological phenomena , evolution of ecosystems, spacecraft sent to different missions, and life itself, the onset of Chaos, Complexity and order is seemingly inherent everywhere. The concepts are subjects of continuous research in the present and shall be vital in the future.

Various other applications include:

Analog/Digital electronic circuits , Gate arrays, Analog arrays which are field programmable, Microprocessors, Architecture, Landscaping, Economics, Finance, Medicine, Psychology, Information Security , Unsecured Communications, Robotics, Systems Dynamics, Electric Power systems, Power Electronic Devices, Electric Devices , Congestion control of traffic on the internet[10].

V. CHAOS AND COMPLEXITY IN THE UNIVERSE

Across the universe , there exist innumerable systems, including planets such as Earth, solar systems, galaxies, nebulae, black holes, neutron stars and quasars, which are inherently Chaotic and unpredictable, yet which evolve to become naturally ordered.This is in contrast to the increase in entropy in the universe , which results in a trend from order to disorder .

It is now known that simple laws which are predetermined, can produce predictable and time enduring patterns together with complex and irregular behavior , which seems random. Chaos and Complexity raise fundamental questions about the universe. Since order can degenerate into Chaos and generate patterns , does Chaos or order control the universe?[11].Or is the universe an admixture of Chaos, Complexity and order?

Does nature produce complex patterns from simple laws? The answers seem to be forthcoming in the near future.

Experts from every discipline, including physicists, engineers , economists, biologists, astronomers, chemists and meteorologists have manifested an understanding of Complexity and order from Chaos. The evolution of life on Earth itself may be explained by Chaos. Chaos Theory cmay , in the not too distant future, unlock the mysteries of atomic Physics. Many astronomers now believe that the solar system exhibits Chaos.

Chaos Theory shall probably also answer fundamental questions such as how a living being can emerge from the Chaotic and complex motion of cells and chemicals constituting it, or how a species or group can emerge with particular characteristics from evolution , or how the rhythm of a heartbeat emerges from a collection of cells.

Delicate dependence on initial conditions that is the hallmark of Chaos leading to Complexity and order serves to follow the path of creation and not destruction .

The evolving ideas of Chaos and Complexity with order can bring to light answers to questions on black holes, parallel universes , galactic collisions and many other mysteries of the Earth and the universe[11].

With the aid of computational methods , further advances in Artificial Intelligence can be understood, using Chaos Theory. In short, a revolution may be forthcoming.

VI. CONCLUSION

Chaos and Complexity are observed in Nonlinear Dynamic Systems. Concepts of attractors are connected to Chaos and may be characterized into point, cycle and strange types. Complex systems are composed of point attractors. Both Chaotic and Complex systems possess similarities and differences .Complex systems are capable of self organization and can evolve with order.

Order in a Complex system is produced by adjustments of a control parameter, whereby regular and predictive behavior may be produced.

Complex systems may be generated by Chaos and order may evolve from Complex systems.

Chaos also exists in the Quantum realm and the limits of the Quantum domain extend into the classical system.Lasers and Quantum entanglement as well as Quantum energy levels in the atom exhibit Chaos.

Chaos, Complexity and order exist everywhere in the universe :in solar systems, galaxies, nebulae, black holes and quasars, ubiquitous and inherent in the laws that govern it. From Chaos evolves creation and what appears as destruction is in essence the process of creative pattern

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