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CHAOS, COMPLEXITY, AND THE MILITARY

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This paper examines chaos and complexity theory, two aspects of the "new science" that has sought to push beyond the Newtonian scientific paradigm that continues to define the core of Western scientific inquiry [1] Whereas the Newtonian paradigm is concerned with deterministic mechanics, linear causality, and reductionism, advancements in computers and computational mathematics, particularly over the past 20 or 30 years, have provided new tools for the study of non-linear dynamic processes. The new science postulates that structure and deterministic rules lie buried within nonlinear processes that have been largely unaccounted for by Newtonian concepts Although still open to some significant challenges, the new science represents the potential for a more profound "paradigm shift" in the Western world view than Alvin and Heidi Toffler's popularized formulation of a deterministic, technology-driven, and historically simplistic "Third Wave" shift from an industrial to an information age. [2]

The paper briefly explains the key concepts behind chaos and complexity theory, looks at some of the efforts to apply them to military analysis, examines criticisms of these theories, and draws some implications from them for the military in the future.

Chaos Theory

Chaos theory is the developing scientific study of nonlinear systems Linear systems are depicted by equations which share the characteristics of proportionality (where changes in input are proportional to changes in output) and additivity (in which the whole is equal to the some of its parts) Knowing the inputs means knowing the output in linear systems even though the equations describing them can be very complex This allows one to predict or forecast the system's development In contrast, nonlinear, or chaotic, systems are characterized by complex feedback loops and large changes in results based on small changes in initial conditions These factors combine to produce events and outcomes that do not conform to clear, predictable patterns

Chaotic systems are neither random nor periodic They are not random because their future is dependent upon initial conditions They are not periodic because their behavior never repeats Very small differences in initial conditions eventually cause large changes in system behavior. Weather is frequently used as an example of a chaotic system Sensitivity to initial conditions is sometimes popularly referred to as the "butterfly effect," alluding to an illustration provided by Edward Lorenz, one of the pioneers in chaos theory, who said that a butterfly flapping its wings in one part of the world could lead to a tornado thousands of miles away.

Although unpredictable, chaotic systems can also be depicted by a set of equations. Since the equations that govern chaotic systems are nonlinear, however, they generally are not analytically soluble. The advent of computer modeling has greatly advanced the understanding of nonlinear system dynamics Essentially, computers have enabled scientists to model a chaotic system and then play out future states of the system which cannot be predicted beforehand These models reveal the extent to which minute changes in variables (initial conditions) produce larger or smaller changes in future states

If warfare is viewed as a chaotic process, chaos theory indicates that one cannot predict its future reliably even if one can reduce its dynamics to a set of equations Nevertheless, there are bounds to the unpredictability of a chaotic system Chaotic systems are highly dependent upon initial conditions but not equally so at all times Chaos theory provides tools that can predict patterns of system behavior and define the bounds within which the behavior is predictable Chaos theory has given weather forecasters, for example, a means to determine if their forecasts are more or less likely to be accurate

The mathematical equations that describe a chaotic system can be depicted as a "phase space," a plot of the parameters that describe the system's behavior. Each point on the plot represents a particular state of the system at a particular time. A simple example of a phase space is one which plots the velocity and position of a pendulum as it swings The longer a chaotic system is observed, the messier the phase space plot appears. However, the paths taken by a chaotic system tend to trace out a complicated, woven surface that still remains within some bounded region of its phase space Chaos theorists term the collection of points on this woven surface an "attractor"--the regions of phase space that attract the system's dynamics

The sensitive character of chaotic dynamics makes predicting the long-term behavior of a system impossible, regardless of how accurately one can measure its current state. Nevertheless, tracing the system's attractors reveals the relative amount of time the system spends in certain regions of its phase space and illustrates trends that can at least help in predicting the future. Attractors indicate whether a chaotic system is in a region of its phase space where initial conditions are critical, in which case a large number of outcomes is possible, or whether the system is in a region of its phase space where initial conditions are not critical, in which case prediction of its short-term future is more likely [3]

No one has claimed that chaos theory can be used by itself to derive a theory of warfare However, a number of authors have argued that war is essentially chaotic, or nonlinear, and they have made efforts to apply chaos theory to various aspects of warfare Military students of chaos theory have suggested, for example, that campaign planners can find centers of gravity where nonlinear processes exist in an enemy's politcal, economic, or military system By identifying the "attractors" in this nonlinear process, planners will know where an attack is likely to achieve disproportionately large effects [4] An attractor can also provide key probability information to a military decisionmaker on the likely short-term future of an enemy system in many scenarios [5] If the enemy system is in a region of great uncertainty, chaos theory might also help a campaign planner determine which conditions would need to be changed to move the system to a position where the outcome was more predictable and desirable.

Chaos theory has also inspired a reinterpretation, or reappreciation, of Carl von Clausewitz as a nonlinear thinker whose ideas remain highly pertinent, despite critics who argue that OnWar is essentially outdated and no longer relevant to present or future warfare. Alan Beyerchen, for example, has demonstrated convincingly that Clausewitz perceived war as a profoundly nonlinear phenomenon, as revealed in his discussions of the interplay of chance and probability, the effects of friction and the fog of war, and the dynamics of acting upon an enemy who is subject to these same forces and who thinks and reacts [6] Other military analysts have pointed out that Clausewitz chooses a quintessential nonlinear metaphor to illustrate the interaction of his famous trinity--primordial violence, hatred and enmity, the play of chance and probability, and war's subordination as an instrument of policy "Our task," says Clausewitz, "is to develop a theory that maintains a balance between these three tendencies, like an object suspended between three magnets" A pendulum suspended between three magnets is one of the elementary physical demonstrations of a chaotic system, since the pendulum's path is nonlinear and unpredictable [7]

Steven Mann, who calls the international environment "an exquisite example of a chaotic system," argues that U S military and national security strategy continue to rest heavily on a mechanistic framework too arbitrary and simple for the nonlinear processes that are an inescapable feature of the complex, interactive international system Mann points out that our views of reality often rest on scientific paradigms, and the paradigm that continues to permeate contemporary Western thought is the Newtonian worldview While he recognizes the limitations of any framework, Mann believes that chaos theory is uniquely suited to "provoke us toward realistic policies in an incessantly changeable age, and inaugurate the overdue liberation of strategic thought " [8]

While one may agree with Mann's eloquent call for a more encompassing and flexible definition of strategy, his argument raises a central epistemological issue It remains to be demonstrated convincingly that the kinds of dynamic patterns (such as the Lorenz curve or butterfly effect) identified in mathematics by applications of chaos theory necessarily translate automatically into the kinds of dynamics that we note in human systems, such as societies or armies It may be more probable that human systems map to material systems only in metaphorical ways, as Mann himself seems to suggest, and that the basic typologies common to human or cultural systems need to be thoroughly understood before attempting to apply (or misapply) chaos mathematics to war, international relations, or other human undertakings.

From Chaos to Complexity

Chaos theory also has lost a good deal of the impetus it seemed to enjoy a few years ago, when enthusiasts claimed that it would eventually allow us to comprehend many, if not most, physical, biological, and human phenomena Chaos theory has turned out to apply to a restricted set of phenomena that change in unpredictable ways [9] Moreover, scientists working on nonlinear dynamics have moved beyond chaos theory to what has become popularly known as complexity theory While chaos theory tells a lot about how certain simple rules of behavior can give rise to extremely complicated dynamics and unpredictable outcomes, it has nothing to say about the seemingly inexorable growth of order and structure in the universe--including the growth of order in human behavior, as manifested in societies, economies, political systems and militaries--which seems just as inexorable as the increase in entropy and disorder (the second law of thermodynamics) [10]

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Complexity theory deals with systems that are large collections of interacting agents Like chaotic systems, these systems show complex structures in time or space, often hiding simple deterministic rules In recent years, complexity theory has been applied to a wide variety of physical science disciplines, including mechanical, electrical, chemical, marine and aeronautical engineering, physics, astrophysics, and physical chemistry Moreover, complexity models and paradigms have been used in developmental biology, ecology, neurology, and physiology, as well as economics and the social sciences. Complex systems are held to exist within cultural, social, political, and economic spheres of human society

Despite their diversity, complex systems share certain fundamental behaviors.

Emergent behavior Interactions among agents in complex systems may lead to emerging global (or system-wide) properties that are very different from the behaviors of individual agents These properties, which cannot be predicted from prior knowledge of the agents, in turn affect the environment that each agent perceives, influencing its behavior in a synergistic feedback loop Thus the "whole" of a complex system is something greater than the sum of its parts, and analysis of complex systems requires a holistic approach

Adaptive self-organization Complex systems tend to adapt to their environments and to self-organize Rather than tending toward disorder, or entropy, complex adaptive systems spontaneously crystallize into more highly ordered states, in contrast to weakly interacting systems isolated from an environment out of which they can draw energy (and thus counterpoise the second law of thermodynamics)

Evolution to the edge of chaos All dynamic systems exist in one of three regimes a stable regime, in which disturbances tend to die out, a chaotic regime (the province of chaos theory), and the boundary or phase transition between stability and chaos. Whereas increasing disturbances in the environment cause some systems to move from stability to chaos, complex systems learn from their environments and add new functions to cope with previously unknown conditions Thus they increase their complexity and adapt along the edge of chaos According to complexity theorists, the same type of growth in complexity occurs in biological systems, man-made systems such as jet engines and microprocessors, as well as societies and economies.

Information processing. Finally, complex systems exhibit the ability to process information sensed from their environment and react to it based on internalized models. Information processing is closely related to a system's ability to learn and adapt near the edge of chaos [11]

Like chaos theory, complexity theory has made major strides through computer modeling and simulation techniques Models and approaches such as cellular automata, artificial life, and neural networks have greatly altered scientific appreciation of how complex systems evolve in turbulent environments. The essential contribution of these and other novel techniques is their ability to generate rich patterns of behavior from sets of relatively simple underlying rules The emergent properties of a complex, adaptive system are not due to a central control mechanism or overarching equation but to the fundamental bottom-up rules governing the interactions of the agents or components in a system

Like chaos theory, complexity theory also has its critics Among the problems with the theory is a lack of agreement on what constitutes a "complex" system One researcher recently compiled a list of 31 different ways that complexity has been defined In addition, complexity theory often is unclear about what constitutes a "system," a longstanding issue in the social sciences, where the term "system" is applied indiscriminately to a community, a society, an economy, a business corporation, an army, etc Some leading proponents of complexity theory also have been taken to task for asserting grandly that this scientific paradigm will lead to a unified way of looking at nature, biological phenomena, human social behavior, and the evolution of life and the universe itself One should remain appropriately skeptical of whether complexity theorists are any more likely to succeed than chaos theorists or other scientists--for example, quantum physicists--in creating a grand theory Moreover, as a recent critique suggested, complexity theory is open to the charge of being based on a seductive syllogism: There are simple sets of mathematical rules that, when followed by a computer, give rise to extremely complicated patterns. The world also contains many extremely complicated patterns It does not necessarily follow, however, that simple rules therefore underlie many extremely complicated phenomena in the world. [12]

These criticism's and the overblown claims of some complexity enthusiasts notwithstanding, insights drawn from complexity theory are being applied profitably to a wide and growing variety of disciplines Not surprisingly, complexity theory is being employed in military and national security analysis One major area is targeting methodologies A recent study by an Air Force analyst, for example, argues that viewing an enemy economy as a complex adaptive system reveals interconnectivities that go far beyond the bottlenecks and choke points sought by previous air targeting planners. According to this study, while engineering and nodal analyses are beginning to appear in military writings, they address only a single element of the economy, such as the electric power or telecommunications networks What is still needed is a method that allows analysis of multiple economic elements and preserves the complex interconnections among them Computer models such as genetic algorithms may be particularly suited for this kind of targeting process, where the overall effects of attacking an enemy's economic infrastructure cannot be guessed a priori [13]

Complexity theory may hold its potentially most profound implications for the military in the area of command and control. In a recent review of prize-winning essays on the Revolution in Military Affairs, Andrew Marshall observes that the critical aspects of future warfare "may center less on tangible platforms than on concepts--especially those related to command and control, which are difficult to envision, model, and simulate."[14] Complexity theory--in particular, the notion that militaries can be thought of as complex, adaptive systems seeking to thrive in the competitive, chaotic environment of warfare--lies behind a growing debate over what kind of command and control systems are likely to prove most effective in future wars.

Implications for Command and Control

Complexity theory suggests that one should look beyond the advantages of "dominant battlefield awareness" expected to accrue from the military's incorporation of new information technologies and consider the rules likely to govern the interaction of system elements (defined in terms of individuals, combat units, or weapon platforms). Thus, the Army's Force XXI digitized battlefield concept can be viewed as an effort to take full advantage of information processing capabilities to provide more dynamic and proactive top-down command and control by direction. The "System of Systems" effort advocated by Vice Chairman of the Joint Chiefs of Staff Admiral Owens also has the potential to be used as a vehicle for enhancing centralized command and control through increasingly synchronized and simultaneous operations at the strategic and operational levels [15]

In contrast to these concepts, the Marine Corps' Sea Dragon initiative envisions a radically new, decentralized system of command and control. Hallmarks of this concept are command by influence through mission orders, reliance on the initiative of subordinates based on local situational awareness, and more self-contained units capable of semi-autonomous action on a distributed battlefield.[16] If the military organizations are viewed as complex systems, complexity theory suggests they are most likely to succeed at learning and adapting to a turbulent environment when there is a free flow of information among system components that interact according to relatively simple, bottom-up rules. They are less likely to be effective at learning and adapting to a chaotic environment when their behavior is governed by top-down rules. Thus the implications of complexity theory are that many advantages of "Information Age" warfare will be lost if information technologies are employed in efforts to enhance centralized command and control rather than to enable a more decentralized system of command and control.

Implications for Strategic Planning

Complexity theory also holds important implications for military and national security strategic planning. Andrew Marshall's comments on the current state of the debate over the Revolution in Military Affairs notes that, while there appears to be a growing consensus that major changes in warfare are underway, a coherent vision of how warfare might look by the year 2015 and beyond seems lacking.[17] This lack of a coherent vision is unsurprising given prevailing uncertainties over the future kinds of threats and opportunities the United States is likely to face over the next several decades. The lack of consensus is perhaps bolstered by chaos and complexity theories, with their stress on a nonlinear, unpredictable future. Complexity theory also suggests that predicting the long-term future is less important for a complex system to survive than is maintaining the ability to learn and adapt to a rapidly changing and largely unpredictable environment. Management analysts who have applied complexity theory methodologies have identified several characteristics that appear to produce the most successful self-learning organizations minimal process specification from the top down, coupled with latitude to experiment, flexible organizational architectures, and permeable organizational boundaries.[18] The implication is the most important aspect of the Revolution in Military Affairs may lie in the military's ability to create and enhance the conditions for continuing adaptation to an ambiguous, unpredictable long-term future

NOTES

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