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Enclosed please find a first draft of the concept paper called "Chaos, Complexity & War," which I have written for LtGen. Van Riper at MCCDC, Quantico, VA. It is part of an effort to introduce the Marine Corps to the new sciences and their military implications. I welcome your candid opinions, but I do not want any of you to feel obligated to respond. .

I can be reached at:



Thanks.

John Schmitt

DRAFT

CHAOS, COMPLEXITY & WAR:

WHAT THE NEW NONLINEAR DYNAMICAL SCIENCES
MAY TELL US ABOUT ARMED CONFLICT

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CHAOS, COMPLEXITY & WAR:

WHAT THE NEW NONLINEAR DYNAMICAL SCIENCES MAY TELL US ABOUT ARMED CONFLICT

War is chaotic. War is complex. At first glance these statements appear ridiculously self-evident. But there is deeper meaning here, because both of these terms have different levels of definition. In everyday usage, "chaos" refers to anything that is messy, formless, disorderly or unpredictable. But "chaos" has a more particular scientific meaning which refers to the operating behavior and the structure of certain types of "systems"* in the natural world. These scientifically chaotic systems appear to be all of the above--messy, formless, disorderly, and unpredictable--but they are something more structured than that as well. In everyday usage, "complexity"

*We will spend a lot of time talking about "systems." I will define a "system" very broadly as any group of elements which function together in some way as a whole. A machine comprising several parts is a system. A sports team comprising different players is a system. A human being, consisting of numerous different tissues and organs (many of them systems themselves), is a system. Military organizations, tactics and operations are systems. And for that matter, war, a hostile interaction between two independent wills, is a system.

describes anything that is complicated, involved, elaborate or is simply composed of lots of parts. But, in scientific terms, "complexity" also has a stricter meaning which also describes the behavior and structure of many natural systems. Again, in the scientific sense, the term describes systems which tend to encompass all of the everyday meanings, but explains them in a more comprehensive way.

Together chaos and complexity science are now allowing us to understand (if not necessarily predict) a vast array of nonlinear, dynamical phenomena we see in the world around us which have steadfastly defied explanation by classical science. Chaos and complexity are teaching us that most of the world simply does not operate the way we have long assumed it does. The nonlinear, dynamical sciences of chaos and complexity are forcing scientists across all fields to question some of their most fundamental assumptions about the nature of our world.

So should it be with the study of war. My thesis here is that chaos and complexity (as defined scientifically) predominate war, and understanding the theories of chaos and complexity can thus provide us valuable new insights into the nature and conduct of war. The implications for the way we do business may be--should be, even--nothing short of profound and radical.

Part I of this paper will discuss the relationship between science and military theory. I will demonstrate how the prevailing paradigm for studying war comes from Newtonian science and how that paradigm is no longer appropriate as a conceptual framework. Part II will provide a layperson's introduction to

the nonlinear, dynamical sciences of chaos and complexity. This introduction will be cursory--I purposely steer clear of the supporting mathematics--since there are plenty of existing sources that do more justice to the science than I ever could. My object here is to discuss only enough of the subjects to allow the reader to appreciate the unmistakable connections with military organizations, operations and occurrences. Part III will demonstrate how war qualifies as chaotic and complex. Part IV will posit a new paradigm and a new metaphor for thinking about things military that are compatible with the new sciences and the realities they describe, and will discuss some of the likely military implications of chaos and complexity.

Doubtless the ideas contained herein will seem heretical--even lunatic--to many military minds. So much the better: changing paradigms is invariably a painful process. But it is going to happen. I don't begin to suggest that these will be the final answers: we are just now at the beginning of the learning curve. I throw these ideas out to fuel the debate. Since feedback is essential to success in any complex system, I welcome comments and recommendations via the Concepts & Doctrine Division, Marine Corps Combat Development Command, Quantico, VA 22134 or directly at schmittzu@aol.com.

Part I: Introduction

SCIENCE AND MILITARY THEORY

Military theorists have frequently turned to science to try to help understand and explain war. In the observable, verifiable, reliable and predictable laws of the natural world they have sought explanations and analogies for the intractable and ineffable phenomena of war. Underlying this effort may be the hope that by applying a scientific method to the study of war we may approach a "scientific" level of knowledge and certainty. Most often military theorists have turned to the physical sciences, because those are the oldest, "purest" and most precise of the sciences and because their laws describing material bodies and physical forces impinging directly upon one another provide ready analogies for military forces engaging one another in combat.

Sun Tzu and "Science"

Consistent with his Taoist background, the greatest military theorist/philosopher who ever lived frequently employed analogies from nature to explain his military concepts. Sun Tzu would not have recognized the field of science per se (physics as we know it would not be created for some two thousand years), but he nonetheless relied heavily on its as-yet-uncodified universal laws. For example, when Sun Tzu said:

He who relies on the situation uses his men in fighting as one rolls logs or stones. Now the nature of logs and stones is that on stable ground they are static; on unstable ground, they move. If square, they stop; if round, they roll. Thus, the potential of troops skilfully commanded in battle may be compared to that of round boulders which roll down from mountain heights. [17/95]

he was using his intuitive understanding of the forces of gravity

and friction (although he would not have recognized the terms) to explain momentum in war. When he said:

Now an army may be likened to water, for just as flowing water avoids the heights and hastens to the lowlands, so an army avoids strength and strikes weakness. And as water shapes its flow in accordance with the ground, so an army manages its victory in accordance with the situation of the enemy. [17/101]

he was using a very rudimentary appreciation of fluid mechanics (again, he would not have recognized this branch of science) to explain movement and maneuver on the battlefield. And when he said:

When torrential water tosses boulders, it is because of its momentum; when the strike of a hawk breaks the body of its prey, it is because of timing. Thus the momentum of one skilled in war is overwhelming, and his attack precisely regulated. His potential is that of a fully drawn crossbow; his timing, the release of the trigger. [17/92]

he was using a variety of metaphors from the physical world to illustrate his view of the effective employment of military force.

Clausewitz and Science

The greatest military theorist-philosopher of the Western world also relied heavily on the physical sciences to explain his military concepts. But unlike Sun Tzu, Carl von Clausewitz was quite explicit in his "scientific" approach. Clausewitz was a child of the Scientific Revolution and quite interested in science. According to Alan Beyerchen of the Ohio State University, while he was composing *On War* Clausewitz attended the classes of physicist Paul Erman at the *Kriegsschule* without missing a single lecture. [1/71n] The writing in *On War* is

filled with science metaphors. For example, using analogies from both chemistry and classical physics, Clausewitz wrote:

War is a pulsation of violence, variable in strength and therefore variable in the speed with which it explodes and discharges its energy. War moves on its goal with varying speeds; but it always lasts long enough for the influence to be exerted on the goal and for its own course to be changed in one way or another. [4/87]

Here in the same passage Clausewitz uses the metaphor of an explosive chemical reaction, followed immediately by the metaphor of physical bodies acting upon each other as if by the force of gravity.

Two of Clausewitz' greatest concepts come directly from physics: friction and the center of gravity. He wrote:

Everything in war is simple, but the simplest thing is difficult. The difficulties accumulate and end by producing a kind of friction that is inconceivable unless one has experienced war. ... Countless minor incidents--the kind you can never really foresee--combine to lower the general level of performance, so that one always falls far short of the intended goal. [4/119]

About the center of gravity, he wrote:

What the theorist has to say here is this: one must keep the dominant characteristics of both belligerents in mind. Out of these characteristics a certain center of gravity develops, the hub of all power and movement, on which everything depends. That is the point against which all our energies should be directed. [4/596-6]

And:

... the blow from which the broadest and most favorable repercussions can be expected will be aimed against that area where the greatest concentration of enemy troops can be found; the larger the force with which the blow is struck, the surer its effect will be. This rather obvious sequence leads us to an analogy that will illustrate it more clearly--that is, the nature and effect of a center of gravity.

A center of gravity is always found where the mass is concentrated most densely. It presents the most effective

target for a blow; furthermore, the heaviest blow is that struck by the center of gravity. The same holds true for war. [4/485]

To us today, the concepts of friction and center of gravity seem pedestrian and elementary--hardly issues of contention. At the time that Clausewitz wrote, however, they would have been considered "cutting edge" science, and hardly matters of universal agreement--much like the sciences of chaos and complexity are for us today. (I have little doubt Clausewitz ran into a fair amount of resistance and scorn for his efforts to try to adapt "high-tech" science to the study of war.) It is significant that the state of the art of military theory is pretty much where Clausewitz left it nearly 200 years ago. (One notable exception is John Boyd, who has been looking to the new sciences for insights for over a decade and whose ideas the military establishment is just now starting to fully appreciate.)

IN SEARCH OF METAPHORS

Of course, Clausewitz does not suggest that friction, in its scientific sense of a physical force which acts to resist or retard the relative motion of two objects that are in contact, actually applies to warfare. Nor does he mean to say that an army actually has a physical center of gravity in the way that a material body acted upon by the force of gravity does. But it does not matter that these scientific concepts do not apply directly and exactly to war.

(In fact, Clausewitz got the concept of a center of gravity wrong, in a physics sense, when he wrote that "a center of

gravity is always found where the mass is concentrated most densely." As fighter pilot/scientist/theorist John Boyd is fond of pointing out, the center of gravity of a doughnut is not where the mass is densest, but is instead in the empty hole. This error has caused a certain amount of confusion for those who would interpret Clausewitz too literally. But it does not lessen in any way the usefulness of the concept as an analogy.)

What matters instead is that science can provide metaphors--transferrable examples that aid understanding--that help us understand and come to grips with the phenomena of war. Metaphors allow us to apply understanding from one domain in which we are knowledgeable to another domain in which we are not. In the words of physicist Robert Stetson Shaw: "You don't see something until you have a metaphor to let you perceive it." [Quoted in 6/262]

THE REIGNING PARADIGM: NEWTON RULES

Not only can science provide various metaphors for isolated military concepts, in this society science plays an even more fundamental role: it provides the overarching paradigm which characterizes modern Western culture. A paradigm is a conceptual framework for investigating and understanding a specific phenomenon or reality in general. It is our overall view of the way the world, or any other thing, works. In this sense we can say that a metaphor is an embodiment of the existing paradigm.

Theoretical physicist Fritjof Capra writes:

The world view and value system that lie at the basis of

our culture and that have to be carefully reexamined were formulated in their essential outlines in the sixteenth and seventeenth centuries. Between 1500 and 1700 there was a dramatic shift in the way people pictured the world and in their whole way of thinking. The new mentality and the new perception of the cosmos gave our Western civilization the features that are characteristic of the modern era. [2/53]

This fundamental view of how our world works (which continues to this day) comes from science--the science of Copernicus, Galileo, Bacon, Descartes and, most notably, Newton.

The Scientific Revolution

To appreciate the Newtonian paradigm, it is important to understand the Scientific Revolution which spawned it. The scientific framework in medieval Europe had been based dually on the authority of Aristotle and the Church. Thomas Aquinas had combined Aristotle's views on the workings of the natural world with Christian theology and had so established the paradigm that dominated the Middle Ages. As Capra points out, the nature of medieval science was very different from that of contemporary science. Based on faith as well as reason, its object was to understand God's meaning for the functioning of the world and man's rightful place within that world. [2/53] But, Capra explains:

The medieval outlook changed radically in the sixteenth and seventeenth centuries. The notion of an organic, living, and spiritual universe was replaced by that of the world as a machine, and the world-machine became the dominant metaphor of the modern era. This development was brought about by revolutionary changes in physics and astronomy, culminating in the achievements of Copernicus, Galileo, and Newton. The science of the seventeenth century was based on a new method of inquiry, advocated forcefully by Francis Bacon, which involved the mathematical description of

nature and the analytical method of reasoning conceived by the genius of Descartes. [2/54]

The Scientific Revolution began with Nicolas Copernicus, who overthrew the geocentric view of the world that had been accepted for over a thousand years and established that the planets revolved around the sun. Galileo Galilei, already famous for discovering the laws governing falling bodies, devised experiments which validated the Copernican hypothesis and discredited the Ptolemaic cosmology beyond a shadow of doubt. Perhaps more important, Galileo was the first to combine scientific experimentation with the use of mathematical language to formulate laws of nature. Galileo wrote that science

is written in the great book which ever lies before our eyes; but we cannot understand it if we do not first learn the language and characters in which it is written. This language is mathematics, and the characters are triangles, circles, and other geometrical figures. [Quoted in 2/55]

Contemporary with Galileo, Francis Bacon was developing and energetically advocating the empirical scientific method which developed generalized conclusions from systematic experimentation. With Bacon, the very object of science changed in a profound way. Spurred on by the rigorous "Baconian spirit," science now sought not merely to understand man's place in nature, but to control and dominate nature. In Bacon's own words, nature must be "bound into service" and "put in constraint." [2/56]

Rene Descartes did Bacon one better by arguing that anything worth knowing could be ascertained through a rational, analytical investigation. Descartes was a brilliant

mathematician and philosopher who constructed an entire system of analytical thought around science and mathematics. Descartes' method was reductionist--meaning that it involved breaking a subject down into pieces, understanding the pieces, and putting the pieces back together to understand the whole. This reductionist method remains a central tenet of modern science--and, as a result, of most other disciplines as well. (Consider our typical, pre-FMFM 1 approach to writing military doctrine, for example). Descartes' philosophy is encapsulated in his famous dictum, "*Cogito ergo sum*"--"I think, therefore I am"--which raised rational thought to the place of foremost importance. Descartes believed in the absolute certainty of scientific knowledge:

All science is certain, evident knowledge. We reject all knowledge which is merely probable and judge that only those things should be believed which are perfectly known and about which there can be no doubts. [Quoted in 2/57]

(Here Descartes was writing about science in the first half of the seventeenth century, but he could just as accurately be describing the Department of Defense approach to military command and control in the latter half of the twentieth.) The extremely significant result of Descartes' approach was a mechanistic view of the world--the world as a giant machine--to include living organisms, which Descartes considered to be merely living machines.

It was Descartes who envisioned an orderly machine-world governed by mathematics, but it was Isaac Newton who made that vision a reality. Capra explains:

Descartes created the conceptual framework for seventeenth-century science, but his view of nature as a perfect machine, governed by exact mathematical laws, had to remain a vision during his lifetime. He could not do more than sketch the outlines of his theory of natural phenomena. The man who realized the Cartesian dream and completed the Scientific Revolution was Isaac Newton, born in England in 1642, the year of Galileo's death. Newton developed a complete mathematical formulation of the mechanistic view of nature, and thus accomplished a grand synthesis of the works of Copernicus and Kepler, Bacon, Galileo, and Descartes. Newtonian physics, the crowning achievement of seventeenth-century science, provided a consistent mathematical theory of the world that remained the solid foundation of scientific thought well into the twentieth century. [2/63]

Taking as a given the Newtonian model, successors elaborated the mechanistic model of the universe in physics, chemistry, biology, psychology and the social sciences. As Capra explains:

The eighteenth and nineteenth centuries used Newtonian mechanics with tremendous success. The Newtonian theory was able to explain the motion of the planets, moons, and comets down to the smallest details, as well as the flow of tides and various other phenomena related to gravity. Newton's mathematical system of the world established itself quickly as the correct theory of reality and generated enormous enthusiasm among scientists and the lay public alike. The picture of the world as a perfect machine, which had been introduced by Descartes, was now considered a proven fact and Newton became its symbol. [2/66-67]

By the turn of the twentieth century, there was little doubt: we lived in a thoroughly Newtonian/mechanistic world. The preferred metaphor of the Newtonian worldview was the clock: finely tooled gears meshing smoothly and precisely, ticking along predictably and reliably, keeping perfect time.

HOW NEWTONIAN SYSTEMS BEHAVE

The Newtonian paradigm views the world, and all its subsystems,

as one huge mechanical system which operates with machinelike efficiency according precise mathematical laws. According to Capra:

In the Newtonian view, God created in the beginning the material particles, the forces between them, and the fundamental laws of motion. In this way the whole universe was set in motion, and it has continued to run ever since, like a machine, governed by immutable laws. The mechanistic view of nature is thus closely related to rigorous determinism, with the giant cosmic machine completely causal and determinate. All that happened had a definite cause and gave rise to a definite effect, and the future of any part of the system could--in principle--be predicted with absolute certainty if its state at any time was known in all details. [2/66].

Newtonian systems tend to be linear. In mathematical terms, an equation is linear if its variables can be represented as a straight line on a graph. Linear systems exhibit two key characteristics. [1/62] First, they are proportional, meaning that small inputs result in small outputs and large inputs result in correspondingly large outputs. In other words, small causes produce small effects, while large causes produce large effects. Importantly this means that small perturbations will not cause the system to go haywire; instead, they will dampen out. Newtonian systems are thus seen to be stable. Likewise, precise data leads to precise results while approximate data leads to correspondingly approximate results. Second, linear systems are additive, meaning that the system is a simple sum of its parts. In other words, Newtonian systems are amenable to reductionism. In order to understand a system we break it down into smaller and smaller pieces, until we find pieces that are small enough and basic enough to understand and control. Then we put all the

understood and controllable pieces back together, with the assumption that we can now understand and control the whole system. If we can decompose the system this way without altering the behavior of the system, the system is additive.

Newtonian systems tend to be "closed," which means that the parts of the system may interact with other parts but do not interact with the external surroundings. The system is a self-contained entity. Because it is closed, the system does not suffer external interference and can therefore often be highly efficient and stable. The preferred Newtonian metaphor, the clock, is a perfect example of a closed system. The gears of the clock mesh with one another but not with the outside environment; the clock is sealed. If dust or grit were to get inside the mechanism, it could hinder the functioning of the clock.

Newtonian systems are deterministic, which is to say they are predictable. They follow invariable rules of behavior. In such a system, if we know a little about the system, we know a lot, because if we know a little, we can calculate the rest. If we know the conditions of the system at any point in time and we understand the operating rules, we can predict the state of the system at any other point in time, past or future. This is an extremely important property because predictability implies at least the potential for controllability, and the offer of controllability is the great appeal of Newtonian systems.

As a result, Newtonian systems are orderly and stable. Generally speaking, they are tame. They are continuous--that is, they do not undergo sudden or drastic transformations. Changes,

when they occur, occur smoothly and gradually. Newtonian systems are "systematic." As Santa Fe Institute scientist John L. Casti puts it:

In short, intuition and common sense [which are at least in part determined by our ruling paradigm] say that small, gradual changes in causes give rise to small, gradual changes in effects. This fundamental principle underlies what's technically termed *structural stability*, a crucial property built in to most of the mathematical descriptions of natural phenomena we've inherited from classical physics. [3/44]

Understandably, this is a comforting view of nature. We want to believe our world is structurally stable, that it's not going to collapse around us or arbitrarily generate unpleasant surprises. It is the way the world "ought" to be. There is a neatness and a tameness about it. It is just the kind of world we can control.

THE PARADIGM DEEPLY INGRAINED

The Newtonian/mechanistic paradigm is so deeply ingrained that it is even reflected in our language. Our English vocabulary assumes an orderly, systematic world. [1/61] We have words like "linear," "rhythmic," "synchronous," "periodic," "regular," and "normal" to describe things that are neat and orderly. To describe things which are messy, we negate the "regular" words: "nonlinear," "arrhythmic," "asynchronous," "aperiodic," "irregular," and "abnormal." We don't usually do the opposite--that is, form "orderly" words by negating "messy" ones. In other words, our language treats order as the default setting and disorder as the special case. It reflects an innate bias that the "orderly" group reflects the norm--the rule--while the

"abnormal" group is, well, abnormal--the exception. (But, as mathematician Stanislaw Ulam has suggested, describing things in the natural world as nonlinear makes about as much sense as describing most animals as "non-elephants." [Quoted in 1/63n.]

Moreover, our everyday conversation is filled with machine analogies. When things are going well, we say they are going "like clockwork." When our unit or team is performing well, we describe it as a "well oiled machine," or we say we are "hitting on all cylinders." We refer to our individual contribution by saying we are "just one cog in the machine." We call a skilled Marine rifleman a "killing machine." And how do we commonly refer to the Marine Corps itself? What is our preferred metaphor for our Marine Corps? We call it a "lean, green machine."

We call military actions "operations," a term which has a strong mechanistic/procedural connotation. (The title of the "Operations" section (G-3/S-3) of a staff comes from the French, from whom we borrowed our basic staff organization in 1917. However, the wider use of "operations" and "operational" to describe practically all things military did not become pervasive until the Second World War, when the role of technology became predominant in the American way of war.) Much less frequently do we refer to military actions as "evolutions"--a term which has biological connotations rather than mechanistic ones.

WAR & THE NEWTONIAN PARADIGM

The Western approach to war has been as heavily influenced by the Newtonian paradigm as any other field. Clausewitz' contemporary

and main intellectual challenger, Jomini, is an excellent example of Newtonian framework in practice. Jomini devoted himself to trying to reduce the art of war as practiced by Napoleon to an essentially mechanical system of Cartesian geometry: all lines, points, angles and various other geometric shapes.

War As Deterministic

The Newtonian paradigm sees war as the simple cause-and-effect product of deterministic rules. Given knowledge of the initial conditions, and understanding the universal "laws" of combat, we should be able to predict the outcome of any battle. The more accurate the information, the more precise the prediction. By extension, by getting the right mix of variables (i.e., solving the equation) we ought to be able to guarantee victory.

And in fact, just such efforts to try to quantify results in war have abounded. Take for example Trevor Dupuy's Quantified Judgment Model (QJM), which asserts that outcomes in combat (specifically, as opposed to broader outcomes in war) can be derived quantitatively as the ratio of combat power of the two forces. Based on his reading of Clausewitz (of all sources), Dupuy asserts that the combat power (P) of each side is the mathematical product of the number of troops (N), the variable circumstance affecting each force (V), and the quality of the forces (Q). In other words, Dupuy argues:

$$P = N \times V \times Q.$$

Just as Newton's physics can be summarized by the simple formula, $F = MA$, so too can Clausewitz' theory of combat be summarized in an equally simple formula: $P = NVQ$. [5/30]

(It is extremely telling that Dupuy cites Newton. He explicitly assumes that war is a simple Newtonian system. If that were true, he might actually be on to something.)

War As Linear

Here again we run into the problem of a word having two meanings, an everyday meaning and a more specific meaning. In everyday military usage, "linear" refers to rigid battle formations. Mathematically, "linear" refers to systems that are proportional and additive. And here again, although I suspect we will find that (as with "chaos" and "complexity") the two different levels of meaning are not entirely unrelated, we are principally interested in the latter definition.

Dupuy's combat power formula shown above is a linear equation. The simplest and most common linear rule of combat is the three-to-one rule (which we could show as $x = 3y$): a division beats a regiment, a regiment beats a battalion, a battalion beats a company, and so on. Input equals output. It is easy to see how this approach can lead to a focus on attrition rates and body counts: if we kill more of the enemy than he does of us, we must be winning. A bunch of tactical victories add up to a strategic victory.

War As Decomposable

The mechanistic view of war is reductionist: we understand the nature and conduct of war by breaking war down into its various parts. The so-called "Principles of War," reduced to the

mnemonic MOOSEMUSS to aid memorization (as if that equates to understanding), are the prime example of this approach. Although J.F.C. repudiated the "Principles" shortly after he created them precisely because he feared they would be used as a checklist, MOOSEMUSS has become Holy Writ. Few acts will engender enmity in military professionals faster than questioning the validity of the principles of war.

Or, consider a recent draft of FMFM 6, *Ground Combat Operations*. A quick sampling reveals the following lists:

- Principles of War (9)
- Fundamentals of Ground Combat (11)
- Types of Amphibious Ops (5)
- Principles of MOOTW (5)
- Purposes of the Offense (6)
- Purposes of the Defense (3)
- Forms of Maneuver (4)
- Defensive Fundamentals (8, but no Offensive Fundamentals)
- Forms of Offensive Combat (4)
- Types of Attack (7)
- Types of Defense (2)
- Forms of Defensive Maneuver (2)
- Types of Retrograde (3)
- Fundamentals of Delay (6)
- Techniques for Delaying (2)

For example, for the conduct of a delaying action (which is included as a type of retrograde, itself considered a form of defensive maneuver), the draft manual requires the following considerations: nine Principles of War, eleven Fundamentals of Ground Combat, three Purposes of the Defense, eight Defensive Fundamentals, two Types of Defense, two Forms of Defensive Maneuver, three Types of Retrograde, six Fundamentals of Delay, and two Techniques for Delaying--a total of 43 items to consider. Presumably, by considering these 43 different items we will

understand how to conduct a delaying action.

War As Controllable

The mechanistic view recognizes that war may appear disorderly and confusing, but it is convinced (in a very Baconian way) that with enough information and enough command and control, we can impose order and certainty. With enough planning, communications and control measures we can make war neat and precise. We can eliminate unpleasant surprises and make it go "like clockwork." Just as Newtonian science seeks to dominate nature, the mechanistic approach to war seeks to tame the nature of war.

War As a Closed System

The mechanistic view of war tends to lead toward an internal focus--on the efficient internal functioning of the military machine. If war is deterministic, and if the machine is operating at peak efficiency, then victory ought to be guaranteed--without any consideration of what the enemy might do. The mechanistic view likewise leads to a focus on "optimization"--finding the optimal solution to the problem. (This is of course based on the Baconian-Cartesian-Newtonian assumption that for every problem there is an optimal solution.) War comes to be seen as a one-sided problem to be solved--like an engineering problem or a mathematics problem--rather than as an interaction between two animate forces.

War As Knowable

The mechanistic view sees war, like any good Newtonian system, as inherently knowable. Thanks to Descartes, we believe that what can be known, can also be quantified (leading to an emphasis on the quantitative vice the qualitative). We focus on body counts, targets neutralized, and objectives seized. Conditions can be measured, data can be ascertained, and uncertainty can be effectively eliminated. Gaining certainty becomes the object of command and control. That which we cannot directly observe, we can extrapolate. Perfect intelligence becomes the goal. As a result, we pursue "95 percent certainty" with a 200 mile by 200 mile area and reasonably believe that we can achieve it. We believe we can blow away Clausewitz' "fog of war." If we fail to do so, it is only because our technology is not quite capable enough yet--but we promise ourselves it will be soon.

War As Procedure

The overall result of all the above is a highly proceduralized, or methodical, approach to the conduct of military operations--war as an assembly line. Newtonian war tends to be highly doctrinaire--heavy on mechanistic and elaborate procedures and checklists, like the fifteen-step Command and Staff Action process, for example. It involves precise, positive command and control; rigid command and support relationships; highly orchestrated (or synchronized) schemes; and detailed, comprehensive plans and orders. Control measures, which compartmentalize the various components of the military machine and specify how those compartments cooperate with one another,

abound. Synchronization is merely the example nonpareil of Newtonian war: the military as one huge, highly efficient and precise machine--ticking along like a fine watch.

THE PROBLEM: REALITY CATCHES UP

The physical sciences led the way in creating the Newtonian worldview. Seeking the legitimacy of the physical sciences, other fields--in fact, an entire culture--bought into the paradigm and now believe in it as unquestioningly as the physicists ever did. But the great machine seems to be misfiring and in need of a serious tune-up (or, more precisely, a complete overhaul). The physical sciences have gradually come to realize--often reluctantly--that most of the world does not operate the way they had long assumed it did. Writes Capra:

The natural sciences, humanities, and social sciences [which include military science] all accepted the mechanistic view of classical physics as the correct description of reality and modeled their own theories accordingly. ... and many of them hold on to these concepts even now that physicists have gone far beyond them. [Quoted in 8/137]

The Newtonian paradigm offers a neat, clean and intellectually satisfying description of the world--and of war. There is only one problem: It does not match most of reality. Futurist Alvin Toffler states that

while some parts of the universe may operate like machines, these are closed systems, and closed systems, at best, form only a small part of the physical universe. Most phenomena of interest to us are, in fact, *open* systems, exchanging energy or matter (and, one might add, information) with their environment. Surely biological and social systems [of which war is one] are open, which means that the attempt to understand them in mechanistic terms is doomed

to failure.

This suggests, moreover, that most of reality, instead of being orderly, stable, and equilibrated, is seething and bubbling with change, disorder, and process.*
[12/xv]

The Newtonian paradigm was so compelling, so neat, so logical--in short, so "right"--that it saw--and imposed--regularities where none existed. According to Gleick

a good share of physics and mathematics was--and is--writing differential equations on a blackboard and showing students how to solve them. Differential equations represent reality as a continuum, changing smoothly from place to place and from time to time, not broken in discrete grid points or time steps. As every science student knows, solving differential equations is hard. ... So by the time a scientist masters this way of thinking about nature, becoming comfortable with the theory and the hard, hard practice, he is likely to have lost sight of one fact. *Most differential equations cannot be solved at all.*
[6/67; emphasis added]

So, mathematician Ian Stewart explains:

Classical mathematics concentrated on linear equations for a sound pragmatic reason: it couldn't solve anything else. In comparison to the unruly hooligan antics of a typical differential equation, linear ones are a bunch of choirboys. ... So docile are linear equations that the classical mathematicians are willing to compromise their physics to get them. So the classical theory deals with *shallow waves, low-amplitude vibrations, small temperature gradients.*

So ingrained became the linear habit that by the 1940 and 1950s many scientists and engineers knew little else. 'God would not be so unkind,' said a prominent engineer, 'as to make the equations of nature nonlinear.'

Linearity is a trap. The behavior of linear equations--like that of choirboys--is far from typical.
[16/83]

For the sake of finding solvable problems, science simplified reality--turned nonlinear functions into linear ones and assumed away or smoothed over the countless "bits of messiness that interfere with a neat picture." [6/41] Gleick continues:

The solvable systems are the ones shown in textbooks. They behave. Confronted with a nonlinear system, scientists would have to substitute linear approximations or find some other uncertain backdoor approach. Textbooks showed students only the rare nonlinear systems that would give way to such techniques. They did not display sensitive dependence on initial conditions. Nonlinear systems with real chaos were rarely taught and rarely learned. When people stumbled across such things--and people did--all their training argued for dismissing them as aberrations. Only a few were able to remember that the solvable, orderly, linear systems were the aberrations. [6/68]

In order to work, the Newtonian paradigm was forced to create an idealized and simplistic world. It smoothed out all the bumps, straightened out all the kinks, ironed out all the wrinkles, connected all the discontinuities--in short, it simply ignored all the countless inconsistencies and nonlinearities that make the world--and war--such a complex and interesting problem. The problem in this is that, according to Capra,

we are trying to apply the concepts of an outdated world view--the mechanistic world view of Cartesian-Newtonian science--to a reality that can no longer be understood in terms of these concepts.

What we need, then, is a new "paradigm"--a new vision of reality; a fundamental change in our thoughts, perceptions, and values. The beginnings of this change, of the shift from the mechanistic to the holistic conception of reality, are already visible in all fields and are likely to dominate the present decade. [2/16]

In short, the evidence is unmistakable: Newton's clock is broken. It no longer satisfactorily describes our world (if it ever did). Science is slowly coming to recognize that the world is not nearly an orderly, linear place after all. The "nonelephants" are the overwhelming rule rather than the exception. We need a new paradigm, and once again science may offer the catalyst. It is not after all a Newtonian world: it

is a complex and chaotic world.

Part II. The Sciences of Chaos and Complexity

Chaos theory and complexity theory are linked in that complex and chaotic systems exhibit the same general class of behavior, but it is not completely clear just what the linkage is. Some systems are clearly and purely complex; others are clearly and purely chaotic; but in the border regions they intermix like the plot of a Mandelbrot set (to be explained), in which the distinction is infinitely intricate and indeterminate. Complex systems often demonstrate chaotic behavior. Chaotic systems can demonstrate very complex structures. It is not often clear exactly where one ends and the other begins.

At the same time, however, there are noticeable differences. In general, chaos theory describes inanimate systems which behave according to (often simple) deterministic rules. There is no free will or "deciding" involved; the system runs according to regular operating rules, and the result is chaos. On the other hand, complexity theory describes systems comprising numerous interacting agents, each of which must act autonomously (or at least semiautonomously) based on its own circumstances. Complex systems as a result are driven by the numerous individual "decisions" of their agents and, compared to chaotic systems, tend to demonstrate more life-like quality.

CHAOS THEORY

The science of chaos broke into the popular consciousness with the publication of James Gleick's book, *Chaos: Making a New Science*, in 1987. Gleick wrote:

Now that science is looking, chaos seems to be everywhere. A rising column of cigarette smoke breaks into wild swirls. A flag snaps back and forth in the wind. A dripping faucet goes from a steady pattern to a random one. Chaos appears in the behavior of the weather, the behavior of an airplane in flight, the behavior of cars clustering on an expressway, the behavior of oil flowing in underground pipes. No matter what the medium, the behavior obeys the same newly discovered laws. That realization has begun to change the way business executives make decisions about insurance, the way astronomers look at the solar system, the way political theorists talk about the stresses leading to armed conflict. [6/5]

It had long been assumed (according to the Newtonian/mechanistic paradigm) that a system was either deterministic or it was random. If the system was deterministic, it behaved according to a set of immutable laws and was therefore orderly, predictable and potentially controllable. If the system was not orderly, predictable or potentially controllable, it must therefore be random--meaning that it did not behave according to any laws at all; its behavior was arbitrary and a matter of chance. Or rather, the system obeyed probabilistic rules. About the best we could do to understand random systems was to estimate probabilities based on repeated measurements.

Because a system did not behave according to any set of deterministic rules it was by definition not subject to scientific inquiry or understanding. This may explain why so many military theorists (Clausewitz and Sun Tzu included) have

denied (or at least seriously doubted) the existence of a military science. How could any system so obviously characterized by friction, chance, disorder and uncertainty follow a set of scientific rules? Given the choice between Newtonian determinism and randomness, most military theorists concluded that war clearly more resembled a random activity.

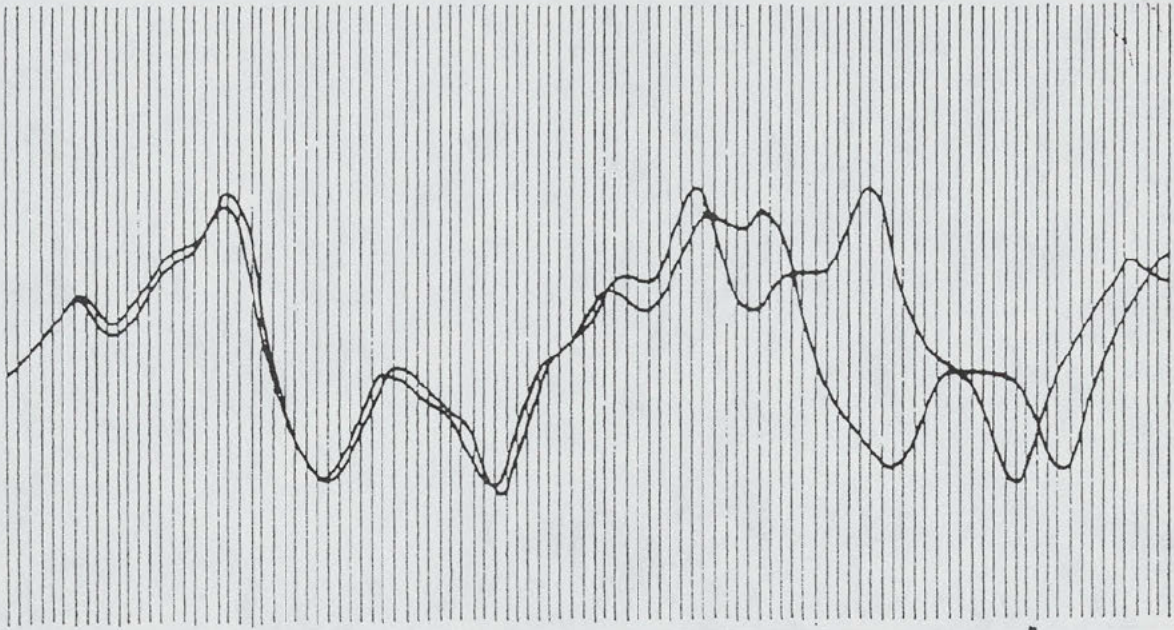
But starting in the 1960s scientists in a growing variety of fields began to sense that randomness and orderly determinism were not the only two choices--that in fact there was a type of system (actually common in the natural world) which paradoxically exhibited characteristics of both determinism and randomness. They began to discover natural and mathematical systems which definitely operated according to a set of deterministic rules (and sometimes the rules were extremely simple ones) and yet exhibited behavior which appeared totally random. Researchers sometimes called this phenomenon "deterministic chaos" or "pseudorandomness" to try to capture its paradoxical nature--random yet deterministic, scientific yet unpredictable. This was a significant contradiction of the Newtonian paradigm: simple rules could lead to complicated, disorderly behavior. ("Everything in war is simple," Clausewitz wrote, "but the simplest thing is difficult." [4/119])

The "Butterfly Effect"

One of the first to recognize chaotic behavior was mathematician-turned-meteorologist Edward Lorenz. Lorenz was using computer technology to try to predict weather patterns. Since weather was

nothing more than the product of inanimate (and quantifiable) natural forces like temperature, humidity, pressure, and wind direction and velocity, it followed that the weather should be precisely predictable given the right variables and accurate data. Lorenz had set up a system of three differential equations meant to model the development of weather patterns. Lorenz' weather model was extremely simplistic, and yet it created simulated weather patterns which were reasonably realistic. There was a certain "weatherness" about them. One day, Lorenz' computer crashed while he was running the weather program. To save time, Lorenz decided to back the program up to a point shortly before the crash rather than starting from scratch. He entered the data from the first run, restarted the program, and left for a coffee break. When he returned to the lab he expected the program to be exactly duplicating and then extrapolating its earlier pattern. What he found instead was that the second run had started at the same point as the first but had very quickly developed into a completely different pattern that bore little resemblance to the first. See Fig. 1. At first, Lorenz could not understand what he was witnessing--his Newtonian mental framework did not permit it. After all, the "weather system" was nothing more than a deterministic computer program "crunching" out a series of mathematical equations. It was nothing more than calculus. How could two deterministic systems using the same rules and the same inputs possibly reach completely different outcomes?

Actually, Lorenz realized, the systems did not use exactly



HOW TWO WEATHER PATTERNS DIVERGE. From nearly the same starting point, Edward Lorenz saw his computer weather produce patterns that grew farther and farther apart until all resemblance disappeared. (From Lorenz's 1961 printouts.)

Fig. 1.
Sensitivity to Initial Conditions. [6/17]

the same inputs. Lorenz' computer calculated values to six decimal places: .506127. To save space, Lorenz' printer printed out the values to only three decimal places: .506. When he reentered the data from the first run Lorenz had taken the figures from the printout rather than from the computer data base. A difference in input of about .0001 of a percent for one variable had resulted in a hugely different system output.

Lorenz had discovered the central feature of all chaotic systems: "sensitivity to initial conditions," or, as it more popularly came to be known, "The Butterfly Effect." The Butterfly Effect states that a "butterfly stirring the air today in Peking can transform storm systems next month in New York." [6/8]

Immeasurably small influences--"countless minor incidents," Clausewitz called them--can cause the system to change to an unpredictably and qualitatively different behavior pattern.

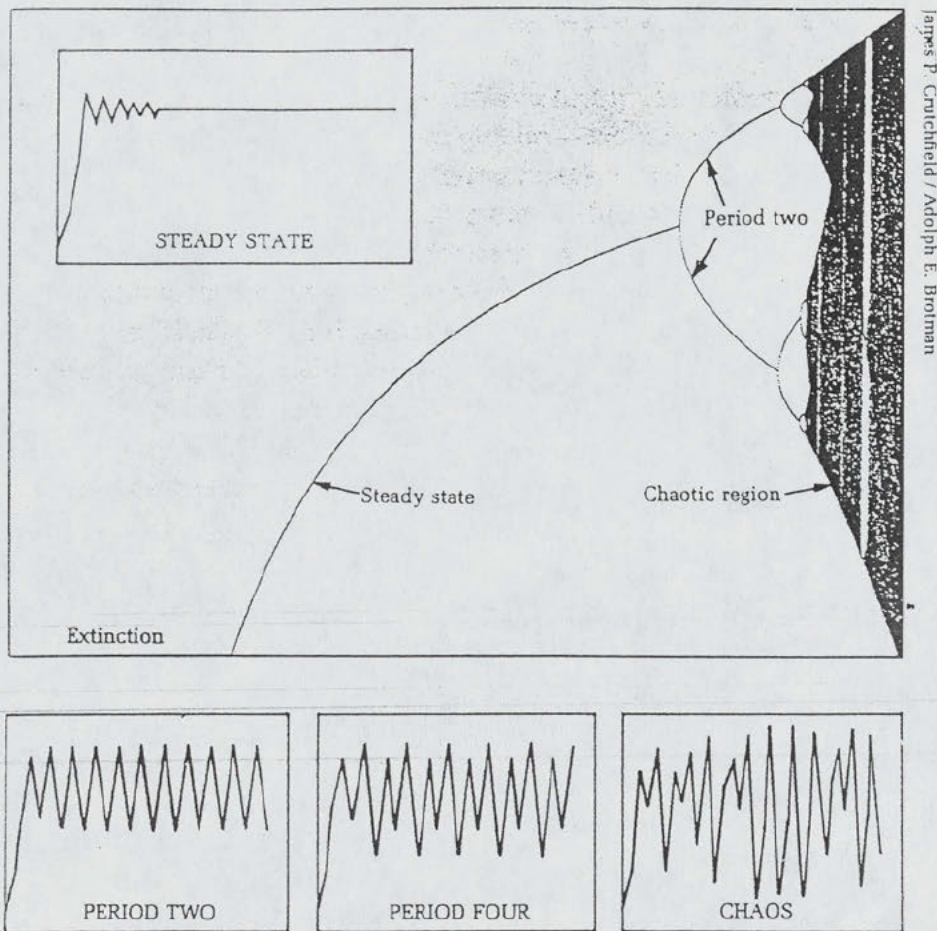
Significantly, Lorenz had proved that the inability to accurately predict long-term weather dynamics was not due to insufficient information about the system (as was often assumed). Rather, unpredictability was a direct and irreducible consequence of the system's sensitivity to initial conditions and the nonlinear rules that governed its dynamics. [9/39-40]

One of the qualities that makes chaotic systems so difficult for many people to come to grips with is that within certain parameters a system might behave in a linear, stable and predictable (i.e., Newtonian) way, but within other parameters the very same system might suddenly lurch into chaos. In other words, the system may behave fairly tamely at first, but turn up

the temperature or increase the pressure (even a little bit) and it suddenly goes wild. Such systems are said to undergo a "phase change." Many chaotic systems also undergo "bifurcation," a transition process by which a system in an apparently stable state suddenly splits into two possible states, and then into four, eight, sixteen, and so on until it finally collapses into chaos. Such a system is said to undergo "period doubling" to "period-2," the "period-4," and so on. But interestingly, even after the system has collapsed into chaos, islands of structure may reemerge spontaneously within the chaos in the form of bifurcations. In general, a bifurcation diagram chronicles a system's descent (or ascent, depending on your view of which constitutes the higher form of structure) from order into chaos. See Fig. 2.

Structure in Chaos: The Lorenz Attractor

To get a visual image of what he had witnessed, Lorenz plotted the values of his three differential equations in three-dimensional space--each set of three numbers formed a coordinate to specify the location of a point in space. The sequence of coordinates plotted over time traced a continuous path in three dimensions--a history of the system's behavior. What Lorenz discovered is that his map never repeated itself--the trajectory of coordinates never intersected itself, but wound around inside the three dimensions in a double-loop pattern of infinite complexity. Two coordinates could be immeasurably close together along the central axis of the pattern, but would suddenly split

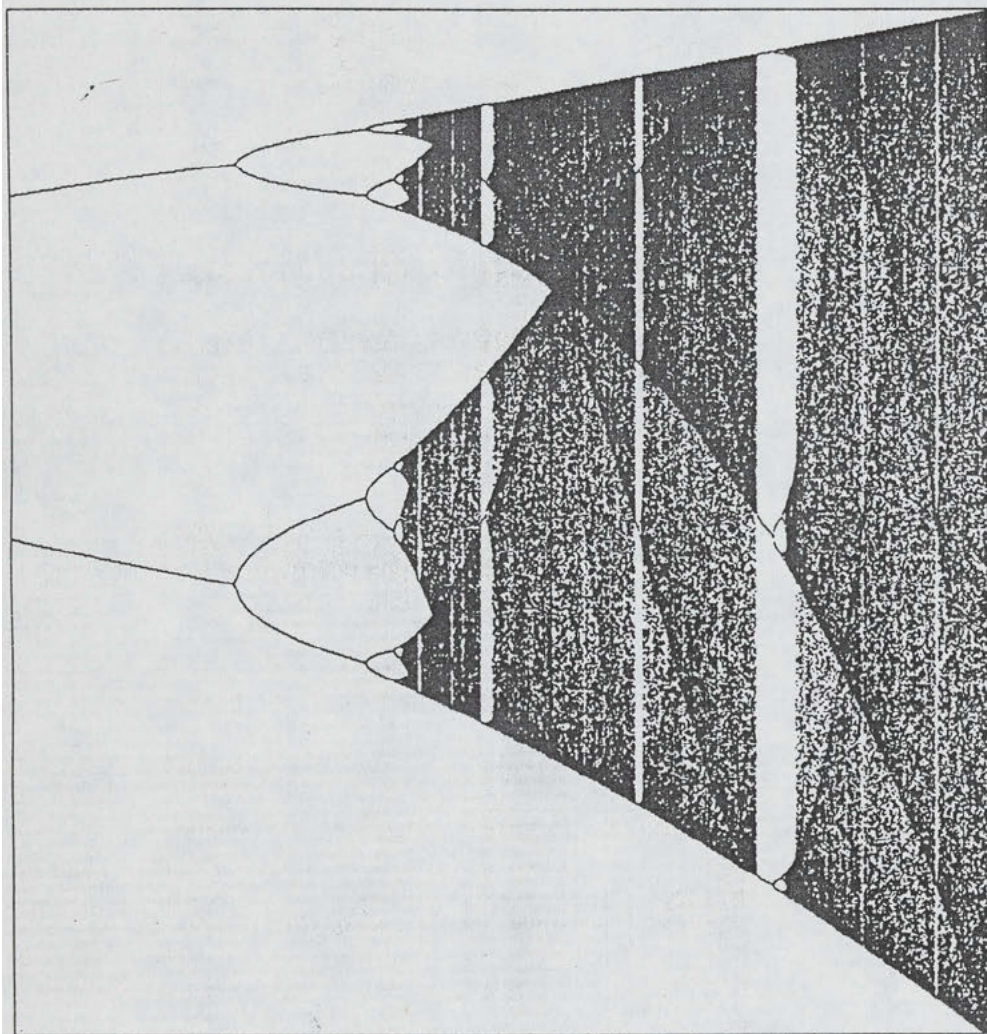


PERIOD-DOUBLINGS AND CHAOS. Instead of using individual diagrams to show the behavior of populations with different degrees of fertility, Robert May and other scientists used a "bifurcation diagram" to assemble all the information into a single picture.

The diagram shows how changes in one parameter—in this case, a wildlife population's "boom-and-bustiness"—would change the ultimate behavior of this simple system. Values of the parameter are represented from left to right; the final population is plotted on the vertical axis. In a sense, turning up the parameter value means driving a system harder, increasing its nonlinearity.

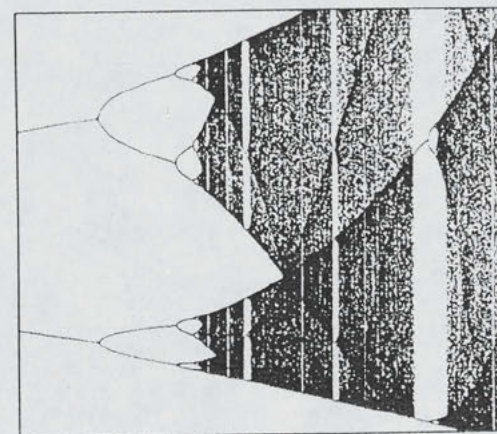
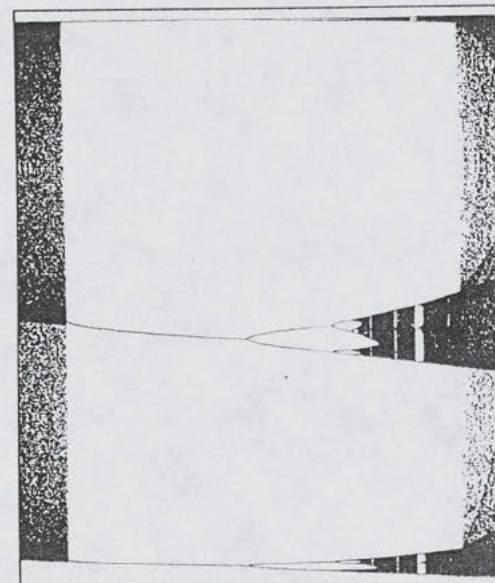
Where the parameter is low (*left*), the population becomes extinct. As the parameter rises (*center*), so does the equilibrium level of the population. Then, as the parameter rises further, the equilibrium splits in two, just as turning up the heat in a convecting fluid causes an instability to set in: the population begins to alternate between two different levels. The splittings, or bifurcations, come faster and faster. Then the system turns chaotic (*right*), and the population visits infinitely many different values. (For a blowup of the chaotic region, see pages 74–75.)

Fig. 2.
Bifurcation Diagrams. [6/71]



James P. Crutchfield / Nancy Sterngold

WINDOWS OF ORDER INSIDE CHAOS. Even with the simplest equation, the region of chaos in a bifurcation diagram proves to have an intricate structure—far more orderly than Robert May could guess at first. First, the bifurcations produce periods of 2, 4, 8, 16. . . . Then chaos begins, with no regular periods. But then, as the system is driven harder, windows appear with odd periods. A stable period 3 appears (blowup, *top right*), and then the period-doubling begins again: 6, 12, 24. . . . The structure is infinitely deep. When portions are magnified (such as the middle piece of the period 3 window, *bottom right*), they turn out to resemble the whole diagram.



James P. Crutchfield / Nancy Sterngold

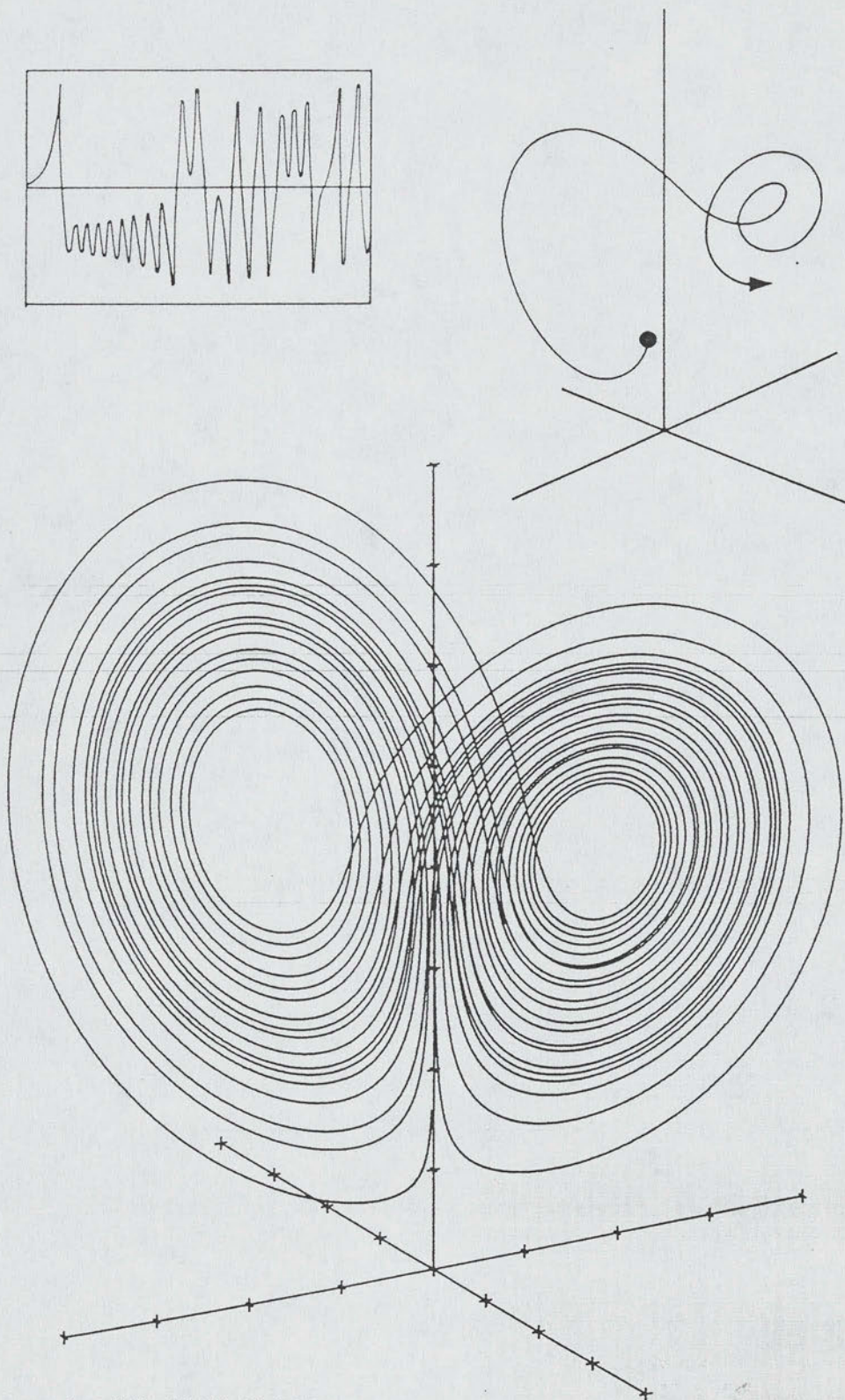
into either the right-hand loop or left-hand loop. There was no way to predict at the micro level whether the trajectory would veer to the right or the left, yet at the macro level a definite structure was building: a figure-8 appeared in the phase space, resembling a butterfly or a mask. Although the trajectory never repeated itself exactly, it nonetheless stayed within certain bounds. Paradoxically, the system was chaotic, yet broadly stable. See Fig. 3.

The conclusion: there were limits to chaos. Chaos and structure could coexist. A butterfly flapping its wings in Peking might cause a storm front to form over New York, but it could not cause a blizzard in equatorial Africa.

Structure in Chaos: Fractals

Many chaotic systems also exhibit fractal dimensions.

Mathematically, fractals refer to systems whose dimensions are not whole numbers. A line has one dimension; a plane has two; a solid has three. A fractal may have 1.7 dimensions, for example---more than a line but not quite a plane. Fractal structures are created by taking an operating function and repeating it upon itself indefinitely. We can thus think of fractals as organizing principles. In lay terms, what this means is that fractals exhibit self-similarity at different scales. A fern leaf seems to consist of smaller leaves of the same shape. A mountain consists of smaller land masses of the same general shape. A bank of clouds consists of smaller masses of clouds of similar shape, which in turn consist of smaller puffs, and so on.



James P. Crutchfield / Adolph E. Brotman

Fig. 3.
The Lorenz Attractor. [6/28]

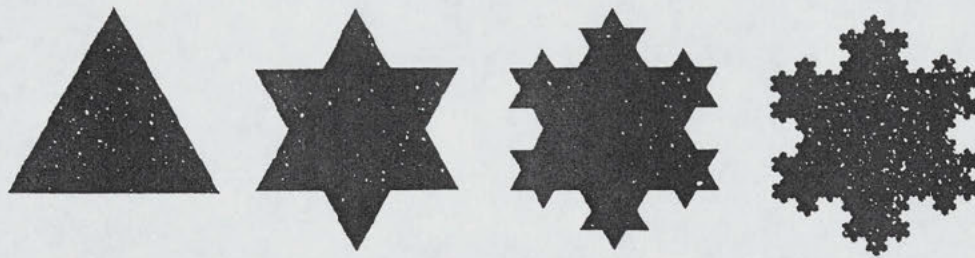
Coastlines are fractal--the closer you look, the more detail emerges.

Like the Lorenz Attractor which never quite repeats itself, fractals do not necessarily duplicate themselves with mechanical exactness (although they may--the Koch Curve, for example). Rather, fractal systems often exhibit a certain "sameness"--a never-quite-repeating pattern--on different scales. Like the Lorenz Attractor, a fractal is able to reconcile unpredictability and chaos at the micro--or local--level with structure and pattern at the macro--or global--level. Perhaps the most famous examples of fractal structures are the Koch Curve and the Mandelbrot Set. See Figs. 4 and 5.

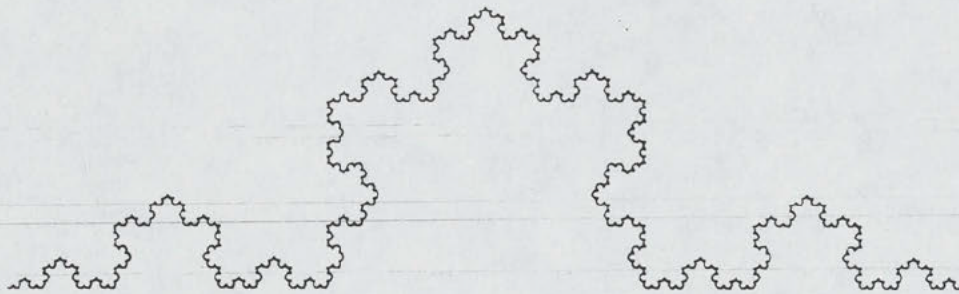
The Mandelbrot Set has practically become a registered trademark for chaos theory. Plotted visually, it is an infinitely complex and ornate, almost artistic, design of orbs and squiggles and curlicues. Mathematically, it follows the simple rule $z \rightarrow z^2 + c$: Take a number, multiply it by itself, and add the original number; then repeat. [6/227] Viewed at a distance, the set appears a solid mass sprouting self-similar squiggly tendrils. As Gleick describes it:

The set did prove to contain, when magnified enough, rough copies of itself, tiny buglike objects floating off from the main body, but greater magnification showed that none of these molecules exactly matched each other. There were always new kinds of sea horses, new curling hothouse species. In fact, no part of the set exactly resembles any other, at any magnification. [6/228; emphasis in original]

And in fact, viewed closely enough, the set does not appear so solid after all. Instead, it takes on the semblance of tiny specks of dust, collected densely in the main body but sprinkled



Benoit Mandelbrot



THE KOCH SNOWFLAKE. "A rough but vigorous model of a coastline," in Mandelbrot's words. To construct a Koch curve, begin with a triangle with sides of length 1. At the middle of each side, add a new triangle one-third the size; and so on. The length of the boundary is $3 \times \frac{4}{3} \times \frac{4}{3} \times \frac{4}{3} \dots$ —infinity. Yet the area remains less than the area of a circle drawn around the original triangle. Thus an infinitely long line surrounds a finite area.

Fig. 4.
The Koch Snowflake. [6/99]

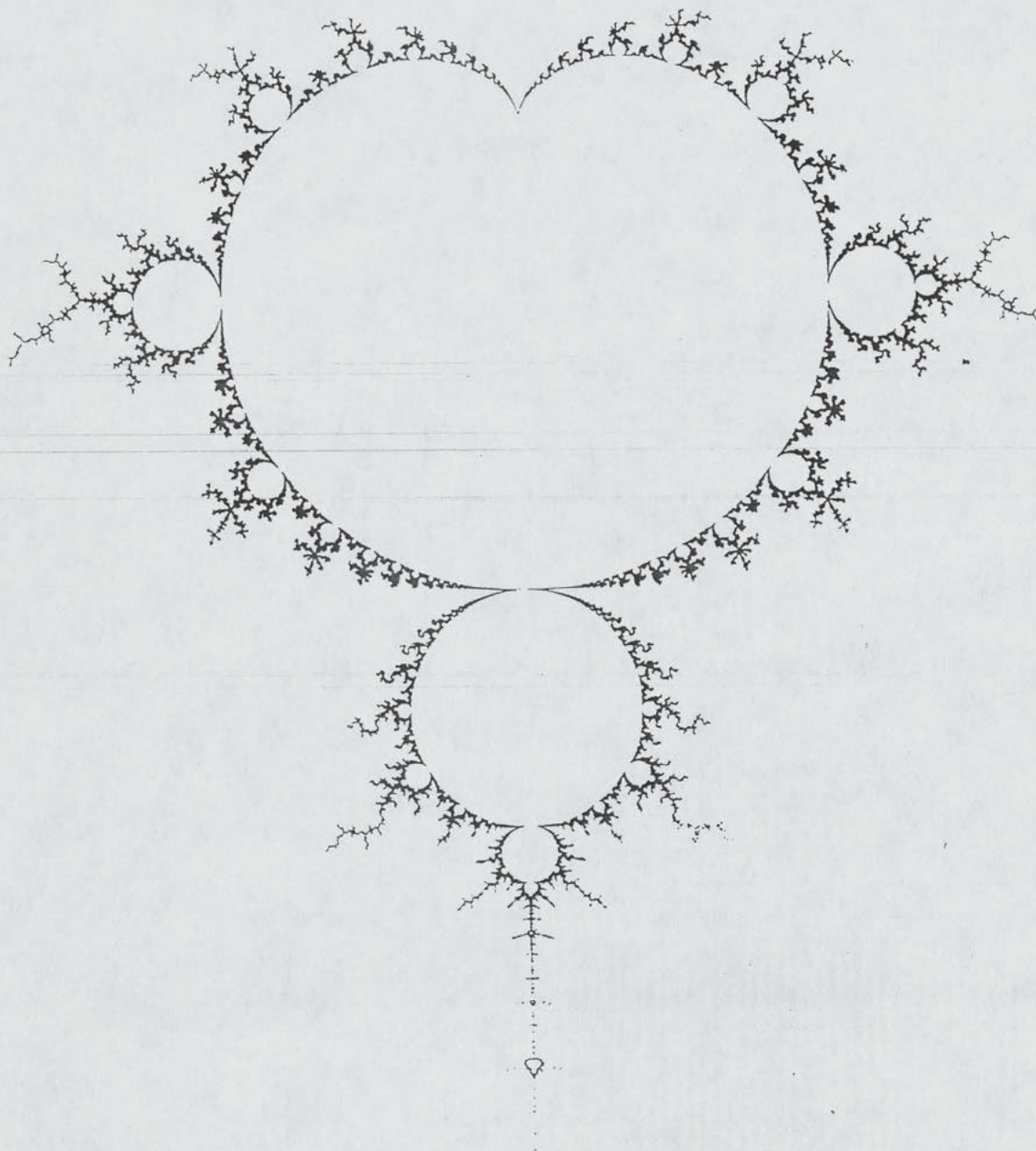


Fig. 5.
The Mandelbrot Set. [6/194-195]

in dispersed patterns, made up mostly of empty space, in the outer formations. [6/228]

Chaos and the Pendulum

Chaos can appear in the unlikeliest of places--even in the ultimate Newtonian system, a simple pendulum apparatus which operates purely according to the laws of gravity and friction. The pendulum has been an emblem of scientific order ever since the days of Aristotle. A pendulum set in motion assumes a regular trajectory that gradually runs down due to friction until it reaches a position of rest (equilibrium). But a metallic pendulum released over three magnetic fields (an experiment Clausewitz apparently witnessed) behaves in a much different way. Released over three equally powerful and equidistant magnets, the pendulum darts chaotically among the three points of attraction, sometimes kicking out wildly in an unexpected direction and actually gaining momentum, sometimes gyrating momentarily around a single point of attraction as if captured, only to escape and resume its chaotic and surprisingly long and intricate path. [1/69-70] The effect of the three magnetic fields upon the pendulum is much more complex and erratic than we might originally anticipate. In fact, this simple deterministic experiment is frequently cited as one of the classic examples of the onset of chaos. (We will return to this example.)

COMPLEXITY THEORY

While chaos and complexity are clearly related, there are also

significant differences. In the words of Mitchell Waldrop, author of *Complexity: The Emerging Science at the Edge of Order and Chaos*:

In the past two decades, chaos theory has shaken science to its foundation with the realization that very simple dynamical rules can give rise to extraordinarily intricate behavior; witness the endlessly detailed beauty of fractals, or the foaming turbulence of a river. And yet chaos by itself doesn't explain the structure, the coherence, the self-organizing cohesiveness of complex systems. [19/12]

Scientifically, complexity deals with the study of systems which exhibit complex, self-organizing adaptation. These systems are known by a variety of names: complex adaptive systems, networks, swarm systems, vivisystems, or collective systems. [11/21] A complex adaptive system is any system composed of numerous parts, or agents, each of which must act individually according to its own circumstances and requirements, and which by so acting changes the circumstances and requirements affecting all the other agents. A jaguar prowling the jungle in search of prey is a complex adaptive system, as is the prey it hunts. A boxer bobbing and weaving and trading punches with his opponent is a complex adaptive system. A soccer team is a complex adaptive system, as is the other team, as is the competitive interaction between them. And a squad-sized combat patrol, changing formation as it moves across the terrain and reacting to the enemy situation, is a complex adaptive system. The world fairly teems with complex adaptive systems. Other examples include: sports teams, musical groups, economies, flocks of geese, colonies of ants, swarms of bee, societies, communities,

governments, families, food chains, communications networks, city streets, stock exchanges, ecosystems, businesses, any living organism. While Newtonian systems tend to be "closed"--like a clock--complex adaptive systems tend to be "open," interacting freely (and messily) with their surroundings and with other systems.

Complexity is in the Interaction

It is not simply the number of parts that make a system complex (although more parts can certainly contribute to complexity): it is the way those parts interact. A machine can be complicated and consist of numerous parts, but the parts generally interact in a specific, designed way--or else the machine will not function. The parts are not even remotely autonomous (like the Marines in a squad are, for example). The machine is meant to operate predictably, because if it is predictable it is controllable. We want a machine to do just what we want it to do. We don't want it to do something unexpected. The parts of the machine do not have to adapt continuously to novel conditions created by the other parts or arising in the external environment, but operate mechanistically. The gears in a clock, for example, mesh precisely and systematically in only one way, and the result is precise, orderly behavior. Each component performs its assigned task mechanically and connects with other parts in prescribed ways, with little attention to the overall functioning of the machine. This overall functioning is the concern of the machine operator..

Rather, in a complex adaptive system, the parts interact freely in interconnected, and unanticipated, ways. Each individual agent within a complex adaptive system may itself be a complex adaptive system--as in the military, in which a company consists of several platoons and a platoon comprises several squads--creating multiple levels of complexity. But even if this is not so, even if each of the agents is fairly simple in itself, the *interaction* among the agents is what creates complexity. Complex adaptive systems are characterized by continuous feedback, adaptation and evolution. While machines operate, complex adaptive systems adapt and evolve. The result is system which behaves in highly nonlinear, complicated, unpredictable and even uncontrollable ways. Often, the behavior of complex adaptive systems qualifies as pseudorandom in the scientific sense. Each agent often affects other agents in ways that simply cannot be anticipated, and it is from these unpredictable interactions that complexity emerges. (This explains, for example, why an economic policy that all experts agree will have one effect can often have precisely the opposite effect.) With a complex adaptive system it is usually extremely difficult, if not impossible, to isolate individual causes and their effects, since the parts are all connected in a complex web. The element of chance, interacting randomly with the various agents in the system, introduces even more complexity and disorder.

Vivisystems

In his mind-blowing book, *Out of Control: The New Biology of*

Machines, Social Systems, and the Economic World, Kevin Kelly describes complex adaptive systems as "vivisystems," because they exhibit the qualities of living things. Compared to machines, complex adaptive systems have a definite organic, lifelike quality. In fact, Kelly argues, life requires complexity: even the simplest lifeforms are more complex than the most complicated machines. Mechanistic structures can only achieve and deal with so much complexity before they become ineffectual and dysfunctional--and maybe collapse of their own weight (witness government bureaucracies, synchronization and the fifteen-step Command and Staff Action sequence). To reach greater complexity--to reach life--only organic structure will do. Kelly argues that, as a result, machines in the future will necessarily become less machinelike and more lifelike. (Already we see the development of computers which do parallel processing like living systems do, rather than serial processing--and which are faster than even the most powerful serial computers. We are all familiar with computer viruses, those creepily lifelike and resilient programs which infect computer systems. Meanwhile, Artificial Life, an outgrowth of artificial intelligence, is a burgeoning field.)

The "Edge of Chaos"

Complex adaptive systems are often said to exist at the "edge of chaos"--the fluctuating balance point between order and chaos. The edge of chaos is "the constantly shifting battle zone between stagnation and anarchy, the one place where a complex system can

be spontaneous, adaptive, and alive." [19/12] If a complex system has too much order it becomes rigid and nonadaptive; too much chaos and it becomes directionless and incoherent. A healthy complex adaptive system never quite locks into equilibrium but never quite spins out of control either. Complex adaptive systems at the edge have enough structure to sustain themselves and enough fluidity to adapt to a wide variety of circumstances. It is at this edge of chaos that unpredictability, innovation and creativity become possible.

According to ecologist Tony Burgess:

Equilibrium is dead. Until the mid-1970s we were all working under a legacy which said that communities are on a trajectory towards an unchanging equilibrium, the climax. But now we see that it is turbulence and variance that really gives the richness to nature. ... Equilibrium is not only dead, it is death. [Quoted in 11/92-93]

Kelly describes the state as "persistent disequilibrium--a continuous state of surfing forever on the edge between never stopping but never falling." [11/470] A healthy complex adaptive system never falls, Kelly writes, but is always on the verge of falling--teetering in a constant state of "almost-fell." [11/79]

Nobel laureate Ilya Prigogine describes complex adaptive systems as "far-from-equilibrium" systems. [14] In the Prigoginian construct, when a system is far from equilibrium (which for many systems is most or all of the time) the tiniest perturbations at the micro level can cause radically different behavior at the macro level.

Likewise, John Holland of the University of Michigan and the Santa Fe Institute explains that

it's essentially meaningless to talk about a complex adaptive system being in equilibrium: the system can never get there. It is always unfolding, always in transition. In fact, if the system ever does reach equilibrium, it isn't just stable. It's dead. And by the same token ... there's no point in imagining that the agents in the system can ever "optimize" their fitness, or their utility, or whatever. The space of possibilities is too vast; they have no practical way of finding the optimum. The most they can ever do is to change and improve themselves relative to what the other agents are doing. In short, complex adaptive systems are characterized by perpetual novelty. [19/147]

Structure in Complexity: Emergence

Complex adaptive systems are also said to exhibit a property called *emergence*. Emergence is a *qualitatively* different systemic behavior arising out of the interaction of agents in a complex system. Consider a flock of birds--countless individual birds with no understanding of the meaning or structure of a flock. Each of these birds acts and reacts individually, according to its own local circumstances, and yet the result is that the aggregate acts like a single entity. The behavior of a flock is not just the sum of the behaviors of the individual birds. The flock has a quality all its own. The flock has "emerged" out of the interactions of all the individual birds.

Gleick writes:

Nothing in the motion of an individual bird or fish, no matter how fluid, can prepare us for the sight of a skyful of starlings pivoting over a cornfield, or a million minnows snapping into a tight, polarized array. ... High-speed film [of flocks turning to avoid predators] reveals that the turning motion travels through the flock as a wave, passing from bird to bird in the space of about one-seventieth of a second. [Quoted in 11/10]

The concept of "flock" is not a designed structure in its own

right; it "emerges" out of "birdness." The potential is contained in the genetic makeup of each bird.

Emergence is thus a case of the whole being greater than the sum of its parts. In a Newtonian system, $2 + 2 = 4$. But as Kelly puts it:

Here $2 + 2$ does not equal 4; it does not even surprise with 5. In the logic of emergence, $2 + 2 = \text{apples}$. [11/12]

Emergence is a form of structure and control. It allows distributed agents to form into a meaningful higher-order system. In complex systems, structure and control thus "grow" up from the bottom; they are not imposed down from the top. "

(Co)evolution Toward Complexity

Emergence is thus a process which allows agents and systems to group together and evolve into more advanced systems. In nature, all systems evolve toward greater complexity. More accurately, in the language of complexity, systems coevolve. As one component of the system evolves to improve its own "fitness," it compels other components to evolve in response to it. The milkweed evolves to protect itself against the larvae of Monarch butterflies. The Monarch larva evolves to defeat the toxic defenses of the milkweed. The result is a complex web of interconnection and interdependence. Now the Monarch will feed only on the milkweed, and only the Monarch can feed on the milkweed. [11/73]

Natural systems don't get simpler as they (co)evolve. (Co)evolution is a one-way process, from the simple to the

complex. Complexity is thus a good thing, because more complex means more advanced, more adaptable, more flexible, more resilient, more creative. (Remember, complexity is not the same thing as complicatedness. Complexity is not in the number of parts; it is in the ability of those parts to interact in useful and adaptable ways.)

In some sense, complexity thus equates to the ability to learn. Evolution is a learning process, but not an end state. In the words of cybernetician W. Ross Ashby:

[An organism's gene-pattern] does not specify in detail how a kitten shall kill a mouse, but provides a learning mechanism and a tendency to play, so that it is the mouse which teaches the kitten the finer points of how to catch mice. [Quoted in 11/74]

In Orson Scott Card's Hugo-Award-winning science fiction novel *Ender's Game*, military commander-in-training Ender Wiggin plays a series of computer wargames. The wargames get increasingly difficult, forcing Ender to continuously improve his tactics. Only after he wins the last game does Ender learn that he has been fighting real battles from his computer console and that his "teacher" was the actual enemy.

Complex Systems Irreducible

The reductionist approach of the Newtonian paradigm simply will not work with complex adaptive systems. The very act of breaking the system down into parts--of isolating even one component of the system--changes the fundamental dynamics of the system. It is no longer the same system. The only way to deal with complex adaptive systems is holistically, an approach the business world

These comments are interesting because they reveal a way (17-45) for making more complex systems by breaking such systems holistically into

also get to know what not to do with the system, ~~the~~ how much it is difficult to get out of it

has come to call "systems thinking." [15]

Part III. War as Chaotic and Complex

Once again: War is chaotic. War is complex. But in a more profound, more meaningful way than originally understood. We take it as given that war is chaotic and complex in the everyday meaning of those words. I think it is manifest that war is every bit as chaotic and complex in the scientific sense. In fact, I think that statement is not strong enough. I think *most* of the phenomena we witness in war are directly attributable to chaos and complexity theory.

Of the two, although they are tightly intertwined, complexity explains more about war and will hold the greater implications. Chaos can explain certain unexpected occurrences and outcomes in war, but offers little in the way of possible methods--"it identifies more problems than it does solutions," in Harned's words. "It is not chaos itself, but the dynamic tension between order and chaos, and the patterns created by that tension in certain nonlinear systems, that give practical value to the mathematics of chaos." [7/30] This "dynamic tension between order and chaos" is, of course, another way to say complexity.

Complexity offers similar explanations of the nature of war, but also offers insights into the more effective conduct of war. In other words, chaos identifies problems; complexity offers potential solutions. Complexity will hold dramatic implications

for organization, tactics, command and control and intelligence, among others.

"Everything in war is simple," Clausewitz wrote, "but the simplest thing is difficult." [4/119] He attributed this to "friction." Complexity may offer another explanation. It could be that the "simplest thing" just cannot be treated as a simple thing, because it is inseparably interconnected with all the other simple things in a complex interactive web. (Remember, complexity is not in the pieces--that is, "simplest things"--it is in the interactions among them.) I submit that this interpretation is not incompatible with Clausewitz. The concept of complexity is generally consistent with Clausewitz' descriptions of friction throughout *On War*. Complexity may simply be a way to update Clausewitz' theory with a twentieth-century scientific analogy.

In one of the best early efforts to incorporate chaos and complexity into military theory, Col. Glenn Harned, U.S. Army, writes:

Here was a science that even the military traditionalists could understand and accept. This scientific revolution was, in military terms, nothing short of Clausewitzian. It was all there: uncertainty, friction, the turbulent interplay of local actors creating global patterns that ebb and flow about the battlespace, the timelessness of general principles that govern the conduct of war despite its transformation by social and technological revolution. War, to borrow a phrase from Gleick, is "a delicate balance between the forces of stability and the forces of instability; a powerful interplay of force" on multiple scales. War is damped by Clausewitzian friction and the hostile interaction of opposing forces locked in deadly competition with one another; it is driven by the opposing commanders' will and the aperiodic introduction of more combat power. As military theorist James Schneider notes,

[the bifurcation diagram shown in Fig. 2] could be a model of ground tactical combat: ordered stability until the opposing armies make contact, a rapid transition to chaotic disorder when initial contact is made, "then leadership kicks in to create islands of stability." [7/30]

War As Sensitive to Initial Conditions

For example, chaos may explain why some many outcomes in war are unexpected and unpredictable--why outcomes of battles are not simply a matter of force ratios, why no two battlefield situations are ever remotely the same (even battles fought over the same terrain), why an outnumbered army may route a vastly superior, better equipped enemy, why the entire battle can hinge on the smallest detail. In the overused piece of folklore, an incident which would probably go entirely unnoticed leads to the downfall of the kingdom:

For want of a nail the shoe was lost;
For want of a shoe, the shoe was lost;
For want of a horse, the rider was lost;
For want of a rider, the battle was lost;
For want of a battle, the kingdom was lost! [Quoted in
6/23]

We can imagine countless other examples. An engagement is lost because a vehicle breaks down and an ammunition resupply does not arrive in time. A battle is lost because a tank throws a track on a narrow road and the reserve does not arrive to make the critical counterattack. An immediate suppression fire mission has no effect because two digits are transposed in the call for fire. A rifleman coughs, giving away the ambush and allowing the enemy to engage first. A reconnaissance patrol that is lost and therefore in the wrong place discovers an enemy force massing in

an unexpected sector.

Chaos theory may suggest that outcomes in combat are in fact deterministic, but that Dupuy's mistake was in thinking that the laws were linear. Clausewitz wrote that

success is not due simply to general [i.e., major] causes. Particular factors can often be decisive--details only known to those who were on the spot. There can also be moral factors which never come to light; while issues can be decided by chances and incidents so minute as to figure in histories simply as anecdotes." [4/595]

Even Clausewitz' thoroughly Cartesian contemporary, Jomini, recognizes this when he states that "armies have been destroyed by strategic operations without the occurrence of pitched battles, by a succession of inconsiderable affairs." [10/178]

S.L.A. Marshall describes the exact same phenomenon even more clearly in his *Men Against Fire*:

For the infantry soldier the great lesson of minor tactics in our time ... is the overpowering effect of relatively small amounts of fire delivered from the right ground at the right hour. The mass was there, somewhere in support, and the mobility was needed to put the vital element in the right place. *But the salient characteristic of most of our great victories (and a few of our defeats) was that they pivoted on the fire action of a few men.* [13/68; italics added.]

War As a Complex Adaptive System

If war does not satisfy the definition of a complex adaptive system, then nothing does. Military organizations and military operations are also complex adaptive systems. Military organizations consist of numerous different interactive parts, each of which in turn consists of numerous smaller interactive parts--all the way down to fire teams consisting of individual

Marines who must decide and act. Military operations may consist of the main attack, supporting attacks and reserve interacting in the scheme of maneuver, supported by the actions of artillery, mortars, aviation, logistics, intelligence and so on. War is an even more complex phenomenon--our complex adaptive system interacting with the enemy's complex adaptive system in a fiercely competitive way within a complex physical and moral environment. The fundamental point from our point of view is that any military action, by its very nature as a complex adaptive system, will exhibit messy, unpredictable and often chaotic behavior that defies orderly, efficient and precise control.

War as the Opposite of Simple

In his book *Complexification*, Casti identifies four defining properties of simple systems to contrast them with complex adaptive systems:

- Predictable behavior
- Few interactions and feedback/feedforward loops
- Centralized decision making
- Decomposable [i.e., reducible] [3/271-272]

Working from Casti's construct, Harned describes several opposite characteristics of war which thus qualify it as a complex adaptive system. First, as I think we have amply established, war is unpredictable. Second:

War is waged by complex adaptive systems composed of

hierarchical self-organized components--societies, governments, armed forces--operating on multiple scales--political, economic, strategic, operational, tactical--at the same time, with large numbers of hostile and cooperative interactions among those components and with multiple feedback loops that "enable the system to restructure, or at least modify, the interaction pattern." [7/43; emphasis in original]

Third:

War exhibits a diffusion of decision-making authority, with actual system behavior being generated by the aggregate actions of its components. Despite the centralized command and control mechanisms that characterize regular armed forces, combat provides ample opportunities for "smart" local agents to make myopic decisions that can reverberate into global patterns. This freedom of action at the local level is especially evident along the relatively thin forward edge of the battle area--a physical manifestation of the "edge of chaos" in conventional war--and even more evident in the decentralized and nonlinear military operations that characterize maneuver warfare and insurgencies. [7/43-44; emphasis in original]

And fourth:

War is holistic and irreducible: "Neglecting any part of the process or severing any of the connections linking its parts usually destroys essential aspects of the system's behavior or structure." [Casti, 272] How can one discuss the offense without understanding the defense? How can one discuss combat power except in relation to the military objectives it must achieve and the combat power opposing it? How can one devise strategy or tactics without linking the two with operational art? [7/44; emphasis in original]

The Fractal Organization of War

The "geometry" of war seems to have an unmistakably fractal quality to it. At the most obvious level, military units (ground units, at least) exhibit a self-similarity at different scales. regiments look roughly like divisions, battalions look roughly like regiments, companies look roughly like battalions, and so on. See Fig. 6. Tactics are organized the same way, with

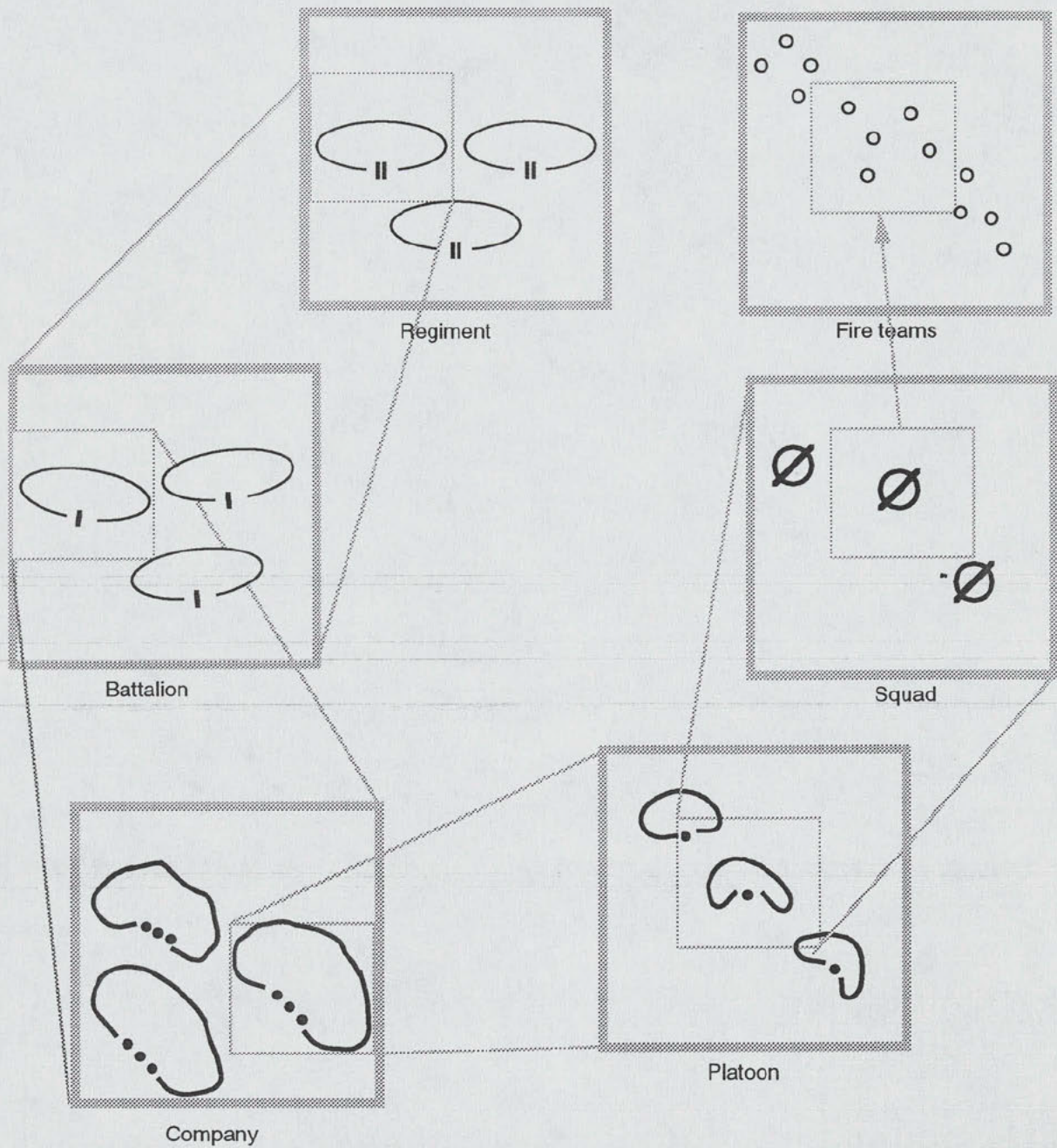


Fig. 6.
The Fractal Structure of the Battlefield

but the multitude does not comprehend this. Although everyone can see the outward aspects, none understands the way in which I have created victory. Therefore, when I have won a victory I do not repeat my tactics but respond to circumstances in an infinite variety of ways. [17/100]

On War As an Irreducible Web

We have already mentioned Sun Tzu's use of water flowing over terrain as analogy for battlefield maneuver. He concludes that passage by saying:

And as water has no constant form, there are in war no constant conditions. Thus, one able to gain victory by modifying his tactics in accordance with the enemy situation may be said to be divine. Of the five elements, none is always predominant; of the four seasons, none lasts forever; of the days, some are long and some are short, and the moon waxes and wanes. [17/101]

And, in another brilliantly insightful description of the irreducible web of interconnections that make a complex adaptive system:

In battle there are only the normal [cheng] and extraordinary [ch'i] forces, but their combinations are limitless; none can comprehend them all. For these two forces are mutually reproductive; their interaction as endless as that of interlocked rings. Who can determine where one ends and the other begins" [17/92]

Without question, for Sun Tzu war is fundamentally a chaotic/complex phenomenon.

CLAUSEWITZ ON CHAOS & COMPLEXITY

On the "Unscientific" Nature of War

Despite his obvious affinity for classical science, Clausewitz' unfailing intuition tells him that much of what he knows and has

experienced about war contradicts the scientific knowledge of the day. Forced to choose between war as scientific--that is, Newtonian--and war as unscientific, Clausewitz chooses the latter. He ends up by rejecting any efforts (like those of his contemporaries Jomini and von Bulow) to reduce war to principles, rules or systems. On attempts to turn war into a Newtonian science, Clausewitz wrote:

Efforts were therefore made to equip the conduct of war with principles, rules, or even systems. This did present a positive goal, but people failed to take adequate account of the endless complexities involved. As we have seen, the conduct of war branches out in almost all directions and has no definite limits; while any system, any model, has the finite nature of a synthesis. An irreconcilable conflict exists between this type of theory and actual practice. ... Theorists ... wanted to reach a set of sure and positive conclusions, and for that reason considered only factors that could be mathematically calculated. ... Numerical superiority was a material factor. It was chosen from all elements that make up victory because, by using combinations of time and space, it could be fitted into a mathematical system of laws. It was thought that all other factors could be ignored if they were assumed to be equal on both sides and thus cancelled one another out. That might have been acceptable as a temporary device for the study of the characteristics of this single factor; but to make the device permanent, to accept superiority of numbers as the one and only rule, and to reduce the whole secret of the art of war to the formula of numerical superiority at a certain time in a certain place was an oversimplification that would not have stood up for a moment against the realities of life. [4/134-135]

In fact, Clausewitz recognized quite clearly that numerical superiority was hardly a universal constant:

Superior numbers, far from contributing everything, or even a substantial part, to victory, may actually be contributing very little, depending on the circumstances. [4/194]

Clausewitz summarizes his opinion on the subject with a passage

titled "A Positive Doctrine Is Unattainable":

Given the nature of the subject, we must remind ourselves that it is simply not possible to construct a model for the art of war that can serve as a scaffolding on which the commander can rely for support at any time. Whenever he has to fall back on his innate talent, he will find himself outside the model and in conflict with it; no matter how versatile the code, the situation will always lead to the consequences we have already alluded to: *talent and genius operate outside the rules, and [prescriptive] theory conflicts with practice.* [4/140; italics in original]

On War As Holistic

For Clausewitz war is definitely irreducible:

The strategic elements that affect the use of engagement may be classified into various types: moral, physical, mathematical, geographical, and statistical. ... *It would however be disastrous to try to develop our understanding of strategy by analyzing these factors in isolation [i.e., the reductionist approach], since they are usually interconnected in each military action in manifold and intricate ways.* A dreary analytical labyrinth would result, a nightmare in which one tried in vain to bridge the gulf between this abstract basis and the facts of life. Heaven protect the theorist from such an undertaking! For our part, we shall continue to examine the picture as a whole ... [4/183]

Clausewitz and the "Remarkable Trinity"

Using another interactive description, Clausewitz called war a

remarkable trinity--composed of primordial violence, hatred, and enmity, which are to be regarded as a blind natural force; of the play of chance and probability within which the creative spirit is free to roam; and of its element of subordination, as an instrument of policy, which makes it subject to reason alone.

The first of these three aspects mainly concerns the people; the second the commander and his army; the third the government. [4/89]

Using yet another science analogy, he went on to say:

Our task is to develop a theory that maintains a balance

between these three tendencies, like an object suspended between three magnets." [4/89]

The conventional interpretation is that Clausewitz is trying to tell us to keep the three aspects in balance, not to let one dominate the others. [1/70] We have the image of a pendulum suspended immobile over the three magnetic fields, pulled equally by each--a system in static equilibrium. But in fact, as we saw earlier, that is not at all how the experiment works.

Beyerchen argues that Clausewitz almost certainly witnessed this experiment. Physicist Paul Erman, whose classes Clausewitz attended at the *Kriegsschule*, was studying in the new field of electricity, and his son was also studying physics, with a special interest in magnetism. [1/71n] If Clausewitz did witness this demonstration (and why would he use it as an analogy if he had not?), then it lends significant new insight into his views on the nature of war. The analogy is not meant to convey a steady-state balance. Rather, Clausewitz saw war as a fundamentally nonlinear phenomenon sensitive to initial conditions.

Part IV. Implications & Applications

THE NEW PARADIGM:

ORGANIC/BIOLOGICAL/ECOLOGICAL/EVOLUTIONARY

The single most important lesson of the new sciences of nonlinear dynamics is that we need a new paradigm that can account for the chaos and complexity so prevalent in the world.

Just as the physical sciences have dominated our past, so will the biological sciences dominate our future. "Biology always wins," writes Kelly:

Biology always wins because the organic is not a sacred stance. It is not a holy status that living entities inherit by some mystical means. Biology is an inevitability--almost a mathematical certainty--that all complexity will drift towards. It is an omega point. In the slow mingling of the made and the born, the organic is a dominant trait, while the mechanic is recessive. In the end bio-logic always wins. [11/183]

The new paradigm will view nature in biological/ecological/-organic/evolutionary terms. The world as a giant, seething ecosystem. Social systems as living, evolving organisms. Militaries as purposeful flocks or swarms. Battles and campaigns as coevolutionary systems. War as a particularly intense version of survival of the fittest. As Harned points out,

the history of warfare is filled with examples of armed forces transforming themselves in response to emerging changes in their environment. It is also filled with examples of military catastrophes--resulting from the failure of armed forces to adapt to changing circumstances. [7/43]

Kelly calls the coming age "Neo-Biological." If we have to attach an individual's name to the paradigm, Alvin Toffler has suggested that if the last paradigm was "Newtonian," after the individual who influenced it most, then the next one may have to be called "Prigoginian," after thermodynamicist Ilya Prigogine who won the Nobel Prize in 1977 for his work on what he called "dissipative systems" in "far-from-equilibrium" conditions. [14/xi-xxvi]

THE NEW METAPHOR: ENTER THE GREEN DRAGON

Stuck in our mechanistic worldview, with its preferred metaphor of the world-as-clock, we have failed to understand much of the seething chaos and complexity that surrounds us. This applies as much to our understanding of war in particular as to our understanding of the world in general. The nonlinear dynamical sciences of chaos and complexity suggest a new biological paradigm. Where do we find a suitable metaphor?

Rather than see ourselves as some "lean, green machine," we might better liken the military organization to a predatory animal--information seeking, learning and adapting in its hunt for prey. Like a living organism, a military organization is never in a state of stable equilibrium, but is instead in a constant state of flux--continuously adjusting to its changing surroundings. Most military actions do not proceed with clockwork mechanics, but instead evolve long the "edge of chaos."

The newly formed U.S. Marine Corps Warfighting Lab in Quantico is working on a concept for U.S. Marine Corps operations known as "Green Dragon." The name "Green Dragon" was not specifically chosen to provide an organic metaphor for the Marine Corps, but it provides a stunning counterpoint to the current "Green Machine."

In fact, "Green Dragon" is a highly appropriate metaphor. Like the Marine Corps, a dragon is a fearsome, man-eating, living creature with a definitely mythical quality about it. Both fire-breathing and taloned, at once reptilian and winged, the dragon is an exemplar of natural combined arms. The new metaphor: the

Marine Corps as a Green Dragon.

FIRST AND FOREMOST ...

The first and most important implication of all this is that we cannot even begin to predict the implications of all this.

First, we do not yet know nearly enough about complex and chaotic systems. Second, and more to the point, these systems are by definition unpredictable. The only way to figure out where a complex adaptive system will be at some given point in future time is to wait until it gets there. This will be a process of evolution and there is no way to anticipate the events--the "countless minor incidents," as Clausewitz would call them--which could cause the system to veer off onto different evolutionary tracks. As we have said, evolution does not have a predetermined destination.

This should not seem a scary prospect however. Chaos and complexity are necessarily bad only in a Newtonian world. In an organic world, they generate structure and life. If a system is adaptable enough, it goes where survival and success leads it. Once we succeed in implanting the new paradigm so that people begin to truly think in organic/ecological/biological/-evolutionary terms, the implications will begin to manifest themselves naturally and will continue to evolve into more advanced and complex forms. The military implications and applications of complexity and chaos may not be at all clear now, but I am confident that they will definitely begin to appear. It will happen, because, like it or not, our view of our world is

changing. Do we want to be ahead of the evolutionary curve, or behind it? Do we want to be one of the dinosaurs or one of the mammals?

We have some reason to be optimistic on this score. Numerous times the Marine Corps has faced potential extinction, usually thanks to the predatory efforts of one of the bigger animals in the DOD ecosystem. But so far, the Marine Corps has always succeeded in aggressively evolving itself into some other form and finding itself another niche--often staking out a valuable territory in some border region between the natural domains of the bigger animals. When one or more of the bigger animals have tried to lay claim to the Marine Corps' territory, as is happening now, the Marine Corps has always managed to evolve into a fitter state. Continuous adaption to a changing landscape has long been a strength of the Marine Corps.

MANEUVER WARFARE WORKS

Good news: the Marine Corps' doctrine of maneuver warfare as described in FMFM 1 is ideally suited for dealing with chaos and complexity. As Harned suggests, proponents of maneuver warfare

may find nothing new in this description of the dynamics of war, but complexity theory provides a new theoretical foundation for their doctrine and new insights into its successful implementation. [7/47]

Actually, this happy fit is not at all merely fortuitous, because the adoption of maneuver warfare in the Marine Corps represented an explicit effort to deal with a battlefield dominated by

friction,	uncertainty,	disorder	and ever-evolving	fluidity.	FMFM
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1 opens with:

War is a state of hostilities that exists between or among nations, characterized by the use of military force. The essence of war is a violent clash between two hostile, independent, and irreconcilable will, each trying to impose itself on the other. [18/3]

From its very outset, FMFM 1 describes war as a violent interaction (by definition nonlinear) arising from the co-imposition of two independent wills--Clausewitz called it a *Zweikampf*, literally a "two-struggle." [1/67] FMFM 1 goes on to say:

At first glance, war seems a rather simple clash of interests. But at closer examination, it takes shape as one of the most demanding and trying of man's endeavors. Fog, friction, and chaos are its natural habitat. Each episode is the unique product of the dynamic interaction of myriad moral and physical forces. While founded on the laws of science, war demands, ultimately, the intuition and creativity or art. [18/15]

If anything constitutes a complex adaptive system, this description of war does.

As for chaos, FMFM 1 says:

In an environment of friction, uncertainty, and fluidity, war gravitates naturally toward disorder. Like the other attributes of the environment of war, disorder is an integral characteristic of war; we can never eliminate it. In the heat of battle, plans will go awry, instructions and information will be unclear and misinterpreted, communications will fail, and mistakes and unforeseen events will be commonplace. ...

Each encounter in war will usually tend to grow increasingly disordered over time. As the situation changes continuously, we are forced to improvise again and again until finally our action have little, if any, resemblance to the original scheme. ...

The occurrences of war will not unfold like clockwork. Thus, we cannot hope to impose precise, positive control over events. The best we can hope for is to impose a general framework of order on the disorder, to prescribe the general flow of action rather than to try to

control each event. [18/8-10]

The rest of FMFM 1 is devoted to describing a philosophy for dealing with this type of environment. Most of the key concepts of maneuver warfare as described in FMFM 1 mesh pretty well with chaos and complexity.

THE FUTURE OF COMMAND AND (OUT OF) CONTROL

Since chaos and complexity deal with the behavior, or control, of systems, the greatest and most direct implication of chaos and complexity theory is likely to be in the area of command and control. Complexity theory is command and control theory: both deal with how a collection of numerous agents acting individually can nonetheless perform like a single entity. Command and control in the future will be radically different than we currently understand it.

To understand the future of command and control, we have to go back some two thousand years to the ancient Chinese classic, the *Tao Teh Ching*, by Lao Tzu:

Intelligent control appears as uncontrol or freedom.
And for that reason it is genuinely intelligent control.
Unintelligent control appears as external domination.
And for that reason it is really unintelligent control.
Intelligent control exerts itself without appearing to do so.
Unintelligent control tries to influence by making a show of force. [Quoted in 11/126]

The future of control is uncontrol, letting go. Complex adaptive systems simply cannot be controlled the way machines can. We should not think of command and control as a coercive form of

mechanistic control--the way an operator operates a machine. The object of mechanistic command and control is for the top of the organization to be "in control" of the bottom and for the bottom to be "under" the control of the top. Not so in the future, in which the object will be to keep the entire organization on the very edge of being "out of control"--"surfing forever on the edge between never stopping but never falling," as Kelly puts it--because that is where the system is most adaptive, creative, flexible and energized. In the future command and control will be decentralized, an emergent property building from the bottom up. Just as a genetic algorithm of "birdness" allows individual birds to become a flock, a genetic algorithm of "Marineness"--a product of the combination of training, education, socialization, doctrine and commander's intent--will allow Marines and units to act independently yet as a single entity.

Command and control will not try to impose precise domination over details, because we recognize that the details are inherently uncontrollable. Rather, it will try to provide a meaningful structure to the roiling complexity.

Kelly writes:

In an age of smartness and superintelligence, the most intelligent control methods will appear as uncontrol methods. Investing machines [or people] with the ability to adapt on their own, to evolve in their own direction, and grow without human oversight is the next great advance in technology. Giving machines freedom is the only way we can have intelligent control.

What little time is left in this century is rehearsal time for the chief psychological chore of the 21st century: letting go, with dignity. [11/127]

Here Kelly is talking about the development of "smart" machines,

increasingly smaller units employing roughly the same tactical concepts--frontal attack, flanking attack, fixing attack, etc.--on increasingly smaller scales. The focus of efforts and commander's intent reiterate down the chain of command in ever-increasing detail. Tactically, forces are distributed into main attacks, supporting attacks and reserves at various levels. The result is that a regiment, for example, may conduct an attack with one battalion conducting a supporting attack and two battalions conducting the main attack against the enemy flank. Within one of the flanking battalions, one of the companies may be conducting a supporting attack, while the other two are conducting the main attack of the main attack--on a smaller scale. And so on.

The battlefield itself is equally fractal. Consider the line of contact in conventional combat, between two divisions, say. At the macro (division) level the line of contact is fairly clear-cut; it appears to be the meeting of two solid masses--like the Mandelbrot set viewed from a distance. But at closer examination the distinction between friendly and enemy territory is not nearly so clear, and the solid appearance of the divisions is not so solid. Each regiment puts security forces forward of the main positions, snaking out in all directions like the tendrils growing out of the Mandelbrot main body. Friendly and enemy security forces intermix in the security area. As we look at the line of contact on a smaller scale, like looking at the Mandelbrot under greater magnification, the line is not nearly so straight; at the battalion level, say, salients appear on either

side. At the company and platoon levels the line is even more broken and uneven. Gaps appear between units, sometimes sizable ones, sometimes covered by fire, sometimes not. At the micro (squad and fire team) level, the "line" of contact is not even remotely a solid line anymore, but a series of individual positions--like the "dust" patterns of the Mandelbrot. The distinction between friendly and enemy territory, so clear at the division level, is not nearly so clear at the squad level. Even in areas that seem clearly in "our territory" on the macro map, the enemy has infiltrated various small patrols, just as we have infiltrated patrols into his areas. Likewise, aircraft and fires routinely interpenetrate at the micro level.

SUN TZU ON CHAOS & COMPLEXITY

On the Tension Between Order and Disorder

Not surprisingly for someone whose intellectual framework was based on the merging of opposites, as represented by the yin and yang, Sun Tzu clearly understood the paradoxical relationship between chaos and order:

In the tumult and uproar the battle seems chaotic, but there is no disorder; the troops appear to be milling about in circles [like the path of a Lorenz attractor?] but cannot be defeated. [17/92]

He recognized that within the chaos of the battlefield there was structure. Moreover:

The ultimate in disposing one's troops is to be without ascertainable shape. Then the most penetrating spies cannot pry in nor the wise lay plans against you. It is according to the shapes that I lay the plans for victory,

but he could just as easily be talking about human systems. Wherever he uses "machines" substitute "people," "commanders," or "units" and the passage is every bit as meaningful.

THE CONCEPT OF EVOLUTIONS?

Rather than thinking of a military action as an "operation," a predetermined plan unfolding with machinelike order and procedural precision, we should think of the action as an "evolution," a system adapting over time in response to its environment. Better yet, we should think of military actions as a form of coevolution, our action evolving in response to what the enemy does, and the enemy's action evolving at the same time in response to us.

The military action is a vivisystem of agents which are continuously learning, adjusting and seeking local advantage. As mentioned above, we need to give up the idea of precise, positive control. Vivisystems are inherently messy. They may exhibit structure at the macro level, but they are uncontrollable at the micro level.

Does this mean that Operation DESERT STORM would become Evolution DESERT STORM? Actually, in the case of DESERT STORM, "operation" might be more appropriate than "evolution." The plan for DESERT STORM was worked out well in advance in extreme procedural detail and executed with machinelike precision and little variation against an inanimate (or at least anesthetized) object. The Gulf War was less an interactive clash between independent, hostile wills than a one-sided physics problem on a

huge scale. But having said that, most military actions in the future will have more of an evolutionary nature and less of a mechanistic one.

Just as evolution does not have a predetermined destination, our plans should not prescribe detailed end-state conditions. It should define success (in evolutionary terms this would equate to the continued survival of the system), but it should not prescribe what the system should look like when it gets there. (Even the notion of preplanned branches and sequels, which in effect identifies several potential future evolutionary tracks in advance and reduces evolution to multiple choice, is a mechanistic device.)

(The possibilities are practically limitless: The Evolutions Order (EvOrd)? Required Evolutional Capabilities (REC)? Concept of Evolutions (ConEvs)? Special Evolutions (SpecEvs)? The S-3 (Evolutions and Training) Officer? Moreover, switching to "evolution" from "operation" could solve the problem with the dual meaning of "operational." "Evolutions/evolutional" could refer generically to all things military, while "operational" could be reserved for the operational level of war.)

UNCERTAINTY A SURE THING

Chaos and complexity tell us that war is inherently uncertain.

It is not that we currently lack the technological capability to gather enough information to generate certainty, but someday will someday have the capability. It is not a question of more

information technology. Rather, chaos and complexity tell us that war is uncertain in a deeply fundamental way. The best we can hope for is to work out probabilities. (We had previously known that; now we may understand why and know that it will ever be so.) Admiral Owens' dream of "95 percent certainty within 200 by 200 miles" is a thoroughly Newtonian concept that simply does not jibe with the nature of war as a complex and chaotic phenomenon. (Actually, it might be more accurate to say that the concept of "95 percent certainty" will likely only work for a narrow set of parameters within which war appears to behave in a relatively tame, linear way. Outside that set of parameters the system will defy attempts to gain certainty.)

As Beyerchen concludes, chance "is not extrinsic to war, because the interactive nature of military action itself generates chance." [1/90]

SOME "IMMUTABLE" PRINCIPLES MAY NEED TO MUTATE

For example, nonlinear dynamics offers the stunning possibility that the lead-off batter in the MOOSEMUSS line-up, the principle of mass--of achieving numerical superiority--may not be nearly as important as we have always believed. The combination of nonlinearity and sensitivity to initial conditions suggest that even a small amount of force exerted at just the right spot--at some bifurcation point, catastrophe point, singularity, or along the "edge of chaos"--can cause the enemy system to tip over the edge into total disorder. Forces outnumbered ten-to-one, or even twenty-to-one, may be able to cause the entire enemy system to

collapse. The fundamental tactical problem may no longer be generating superior combat power, but applying combat power in a way that shoves the enemy over the "edge of chaos." Clausewitz' science-analogy of searching for enemy "centers of gravity" may be replaced by searching for enemy "bifurcation points." (Not an actual recommendation; just a thought.) Perhaps the historical emphasis on mass and numerical superiority is a merely function of the inability to consistently locate such high-payoff points. Unable to effectively locate the singularities (as bifurcation points are sometimes also called) we resort to trying to muscle the system. (This is still a problem, since there is no reliable way scientifically to anticipate when a system will go from stable to unstable. We will still need to rely on the intuitive skills of command to identify enemy bifurcation points/centers of gravity.)

SYNCHRONIZATION OUT OF SYNC

One concept that does not mesh well at all with chaos and complexity theory is synchronization. (We should point out that our doctrine does not embrace synchronization, although some have argued that it should.) Synchronization and other Newtonian/mechanistic models are invalidated as general operating systems. They may work reasonably well within those parameters under which the system is behaving tamely. Synchronization is based on the assumption that warfare is a linear phenomenon--that it follows a smooth trajectory that is predictable and controllable. Like Newtonian equations, synchronization falls

flat when faced with a complex/chaotic system. In fact, complex adaptive systems tend to behave *asynchronously*--multiple agents acting independently of one another in response to local conditions.

THE RMA ON THE WRONG TRACK

In fact, it might even be more accurate to say that the Revolution in Military Affairs, *as currently configured*, has gone off the track completely--it is taking us nowhere fast. The RMA is firmly entrenched in the old paradigm and believes in the power of breakthrough technology to revolutionize war. New technology can certainly enhance evolutionary capabilities, but applied according to the old framework, the advancements will not have nearly the revolutionary effect desired or expected. Now, if we want truly revolutionary effects, we should apply the new technology within the new paradigm. Only then are we likely to get a true phase change in the system.

THE REDUCTIONIST APPROACH TO DOCTRINE HAS GOT TO GO

The traditional approach of describing--or, rather, prescribing--doctrine by decomposing the subject into countless parts is incompatible with the nature of complex adaptive systems. Instead we need to continue with the FMFM 1 approach, which pursues understanding by pulling concepts together into a cohesive whole, rather than by breaking things down.

Chaos and complexity tell us that the traditional MOOSEMUSS approach of trying to understand war by memorizing a set of so-

called "Principles" is necessarily arbitrary and artificial.

Beyerchen explains:

The simplicity of a set of "principles of war" will surely remain attractive, not least because they are so easy to comprehend and memorize. But we should understand that Clausewitz's concerns are to such principles as nonlinearity is to linearity (or fractals to Euclidean objects, or the real numbers to the integers). The elegance of military axioms is a mirage shimmering above the distant abstractions of implicitly idealized, isolated systems; the denseness of Clausewitz's forest of caveats and qualifications more faithfully represents the conditions and contexts we actually encounter. [1/89]

Moreover:

Production of an unchanging set of laws or even principles to be employed in all "similar" contexts is not merely useless, it can become counterproductive and lead to the kind of inflexible, mechanical mentality that is overwhelmed by events. Adaptability is as important in doctrine as on the battlefield. [1/90]

EXPLOIT SUCCESS

The maneuver warfare principle of ruthlessly exploiting success rather than redeeming failure holds up pretty well under the chaos microscope. In nonlinear systems sensitive to initial conditions, even small advantages can grow exponentially into decisive situations. In economics, Santa Fe economist Brian Arthur has called this the "Law of Increasing Returns"--them that has, gets. This, of course, is also the essential lesson of John Boyd's Orientation-Decision-Action (OODA) Loop: the antagonist who generates a higher operating tempo, even if the differential is only slight, gains an advantage that increases with each cycle. (This is not at all surprising because Boyd was one of the first to apply the concepts of the "new" sciences to military

theory.)

HIERARCHIES WORK (!)

The preferred structure of complex adaptive systems is the hierarchy. Nature is filled with hierarchies. We should be very careful in using this term, however, because I do not refer to the rigid, bureaucratic, mechanistic type of hierarchy that many of us are quite familiar with. I refer instead to the sort of flexible, fractal, organic hierarchies found in nature. Natural hierarchies are the product of self-organization. Natural systems create structure by chunking and clustering from the bottom up, building from the simple to the complex; they do not impose structure from the top down.

"SATISFICE," DON'T "OPTIMIZE"

Complexity tells us not to bother trying to find the perfect plan or reach the perfect decision. It simply won't happen: there are too many interconnected variables. As John Holland said earlier, in a complex system "there's no point in imagining that the agents in the system can ever 'optimize' their fitness ... The most they can ever do is to change and improve themselves relative to what the other agents are doing." [Quoted in 19/147] Instead, we should try to "satisfice"--find a solution which works locally and exploit the results. In maneuver warfare terminology this is called "reconnaissance pull."

PURSUE "PERPETUAL NOVELTY"

The most successful vivisystems--the ones that live longest--are the ones that can both adapt to and generate perpetual novelty.

In fact, the two are one and the same thing. The quality that allows a system to adapt to novel situations is the ability to generate novel solutions. ("Therefore, when I have won a victory," Sun Tzu says, "I do not repeat my tactics but respond to circumstances in an infinite variety of way." [17/100])

Complexity theory tells us to stay away from formulaic approaches to dealing with complex problems. Value creativity, innovation and experimentation. Encourage "outside-the-box" thinking. Promote difficult subordinates. Listen to the people who disagree with us. Or, as Kelly says, "maximize the fringes":

A uniform entity must adapt to the world by occasional earth-shattering revolutions, one of which is sure to kill it. A diverse, heterogeneous entity, on the other hand, can adapt to the world in a thousand daily microrevolutions, staying in a state of permanent, but never fatal, churning. [11/469]

EXCELLENCE CAN ONLY START AT THE BOTTOM

Kelly states:

The only way to make a complex system that works is to begin with a simple system that works. Attempts to instantly install highly complex organization--such as intelligence or a market economy--without growing it, inevitably lead to failure. ... Time is needed to let each part test itself against all the others. Complexity is created, then, by assembling it incrementally from simple modules that can operate independently. [11/469]

Evolution moves from the simple to the complex. Healthy complex adaptive systems grow by chunking. This merely confirms what the

Does freedom: how to maximize novelty?

Marine Corps has long recognized: success starts at the small-unit level. Build strong, adaptable fire teams and squads first. Train and equip them well--which includes giving them ample time to train themselves (i.e., to evolve). Give them the very best leaders. Give those leaders the freedom to lead (i.e., let them act as independent agents). Then chunk the teams and squads together into increasingly larger units.

REALISTIC MODELING AND SIMULATIONS

Chaos and complexity theory only became possible because of the computer. Computing power made possible the vast, repetitive calculations and visual representations required to model complex and chaotic systems. Accordingly, many of the early applications of chaos and complexity will come in the area of computer modeling and simulation.

If we now have a pretty good idea that battles are nonlinear systems sensitive to initial conditions, we may be able to use chaotic computer programs to provide more realistic developments and outcomes to our computer wargames.

Agent-based simulations, computer-created complex adaptive systems that can actually learn and evolve, currently exist, and are being used in industry to solve various problems like devising more effective, more flexible and faster production schedules. Given only the conditions of success, the software will actually evolve a way to get there--and will often do it faster and better than human managers could. One such program, known as Swarm, was developed in part at the Santa Fe Institute

and is being used by John Deere in Moline, Illinois. The Marine Corps Combat Development Command is currently working with SFI and ARPA to look into the possibility of developing an agent-based simulation that can evolve potentially better tactics, operations, strategies or organizations.

In play-against-the-computer wargames, agent-based simulations can provide much more challenging and lifelike enemy opposition (an enemy that actually learns and adapts to its human opponent). The potential as a training and education tool is unlimited. Extremely complex and challenging commercial games already exist. With titles like Civilization, PowerMonger, SimCity and SimEarth, they are known generically as "god games" because they challenge the player to evolve from scratch a successful community--civilization, city, planet, whatever--of countless individual agents. The technology of "god games" could very easily be applied to war games.

IN CLOSING: NEWTON'S CLOCK IS BROKEN

The physical sciences have dominated our world since the days of Newton. Moreover, the physical sciences have provided the mechanistic paradigm which frames our view of the nature of war. While some systems do behave mechanistically--the motion of the planets in the solar system, for example--the latest scientific discoveries tell us that many--probably most--things in our world do not function this way at all. The Newtonian/mechanistic paradigm no longer adequately describes our world--or our wars. Once again, Newton's clock is broken. Complex adaptive

systems--including military organizations, military evolutions, and war--most definitely do not behave mechanistically. Enter chaos and complexity. Ours is a complex and chaotic world. It is time to recognize this and to begin to relearn how things work. We need to get smart about chaos and complexity--especially the latter. We need to teach them at our professional schools. We need to send bright officers to study at places like the Santa Fe Institute.

War is chaotic. War is complex. But chaos and complexity do not merely present problems: they create opportunities for those who know how to see them. Most important of all, we need to learn how to see the opportunities in chaos and complexity and to find ways to exploit those opportunities

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