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CHAPTER 12

Field-Theoretic Framework for the Interpretation of the Evolution, Instability, Structural Change, and Management of Complex Systems

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Policy making and decision making and other aspects of the management of complex systems are becoming increasingly difficult. Management philosophies, approaches, and techniques were developed during simpler times. However, complex systems are dynamic rather than static, evolve or are driven into domains of instability, and emerge into new structures. There is now a growing gap or loss of fit between our systems-management capabilities and the real world. Policymakers and decision makers must deal especially with severely reduced time frames, consequences-of-action uncertainty, and actions that produce diminishing returns.

Fortunately, advances in systems theory provide a means for narrowing the gap and providing a better fit between systems management and reality. The theories have multifarious origins and different emphases. This question therefore arises: how can these theories be interfaced and interrelated? My approach is to use the integrating framework of field theory. As has historically been the case with the development of field theory in the several sciences, field theory is not so much a theory in itself as a framework for theoretical orientation and study.

I have coined the term *world system-field* (of forces), which consists of the dynamically interacting *world societal field* and the *world ecosystem*. A field describes the structure and behavior of space-time and the placement of objects in space-time. In fields, myriad state variables depend continuously on the space coordinates. Einstein's field equations relate the properties of space-time to those of matter, but thinking has proceeded quite far beyond Einstein's original rather static formulation that denied irreversibility and evolution (Nicolis and Prigogine 1989). A field can also describe the interactions between a system at a given hierarchical level of the organization of matter, energy, and information (e.g., a human institution) and its external environment(s). A (turbulent) field can induce structural changes in the various parts

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of the environment itself (e.g., De Greene 1990a). And in the vertical dimension, a field can describe micro-macro interrelationships. A field can be viewed as a macrolevel, semiautonomous, collective structure (or order parameter) that exists over a relatively limited period of time. Interactions at a more microlevel generate the field via positive-feedback mechanisms, and the field, reciprocally, through negative feedback, delimits the realm of the possible at the level of individual interactions (e.g., De Greene 1989; Weidlich and Haag 1983).

Fields show differential sensitivity over time and space, and a fluctuation or perturbation that is usually damped may surprisingly trigger a violent and explosive reconfiguration of the field. It is difficult, perhaps almost always impossible, for human actors to know the present stability state of the system-field. Hence, policies and decisions must be developed that preclude to the extent possible the precipitation of the system into an unsuspected realm of instability and reconfiguration. On the other hand, these policies and decisions must not result in rigidity and the stultification of desirable evolution and structural change. Field theory provides a framework for dealing with these complex issues.

This chapter is a presentation, with considerable further thinking and updating, of my research in this area over the past several years. In the sense of *fields within fields within fields*, a term sometimes used by systems theorists, the top-level organizing approach is the evolution, stability/instability features, and structural change of/within the world system-field and the effects of these dynamics on constituent systems. Within this context the next level of organizational emphasis is the order parameter as a sociotechnical, techno-economic, and macropsychological (collective-cognitive) structure. The third level of contextual approach is provided by the theory of the economic long wave or Kondratiev cycle/structure. Within this overall framework, constructs from a number of systems theories are utilized. Examples include the critical threshold or bifurcation point, far from equilibrium, order through fluctuation, and irreversibility. The constructs are general purpose in physical, biological, and social science, contributing to laws of nature, but they receive specific meaning only as properties of the given field of forces. Deterministic chaos is treated within these contexts, but the calculational specifics will not receive attention here because they are discussed more fully in other chapters of this book.

An additional integrating theme of this chapter is the wearing out and exhaustion of given order parameters or paradigms and their replacement by paradigms that are better fitted to the new evolutionary situation. Under such conditions we must reexamine our very methods of inquiry about nature and society, as well as status quo policies and practices. Paradigm change provides new, often surprising challenges, opportunities, and choices. The chapter discusses important systems management consequences of structural change and paradigm shift. The chapter concludes with some thoughts about the meaning of the new theories to the social sciences.

The approach is *transdisciplinary*. That is, basic constructs are sought from the physical and biological, as well as the behavioral and social sciences. Indeed, many of the constructs had their origins in the physical sciences. Transfer of constructs provides an exciting challenge.

The bibliography at the end of this book provides a rather comprehensive literature on systems theories and models, definitions of terms, and relevant examples. The reader should turn to these references for a fuller understanding of the basic ideas and of previous work. Space limitations preclude our starting from scratch in this chapter.

Evolution, Instability, and Structure of Complex Systems

All systems evolve, although the rates of evolution may vary over time both between and within systems. The rate of evolution is a function of both the inherent stability of the system and changing environmental circumstances. But no system can be stabilized forever. For the universe as a whole, an isolated system, time's arrow points toward greater and greater breakdown, leading to complete molecular chaos, maximum entropy, and heat death. For open systems, including the living systems that are of major interest to us and that interchange matter and energy with their external environments, time's arrow points to evolution toward greater and greater complexity. Thus, the universe consists of islands of increasing order in a sea of decreasing order. Open systems evolve and maintain structure by exporting entropy to their external environments.

The concept of evolution is finding increasing application in physics, chemistry, astronomy, and astrophysics, as well as, of course, in biology, geology, and paleontology. But it appears that all too few behavioral and social scientists use the evolutionary framework, and that all too many theories, hypotheses, and empirical research efforts are directed toward the static, the cross-sectional, the linear, the equilibrium seeking, the stable, the reversible, and the structurally constant. These efforts, as interpreted here, operate within a prevailing but exhausted paradigm. This chapter and this book represent attempts to move beyond this paradigm.

In organic evolution, as summarized by Neo-Darwinism, two principal processes are involved. First, random mutations lead to genetic differences among organisms. Second, natural selection tends to enhance the likelihood

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of genes that produce adaptive characteristics. Some parts of the genome may be more susceptible to mutation than are others, and environmental factors may also affect mutation rates. But any given mutation is considered to be independent of any adaptive or survival value imparted to the organism. Whether Neo-Darwinism provides a complete answer to organic evolution remains to be seen, and the issue continues to be debated. Alternative explanations are often dismissed as harking back to Lamarckism and teleology. But it seems intuitively unlikely that the organic evolutionary system would function open loop; that is, with no feedback between effect and cause.

Dissipative-Structure Theoretical Interpretations

Following dissipative-structure theory (Nicolis and Prigogine 1977, 1989; Prigogine and Stengers 1984), the evolution of open systems can be interpreted as follows. Movement of the system away from equilibrium, associated with some internal irreversible processes, increases the rate of dissipation as measured by the entropy production. Instability, triggered by nonequilibrium environmental conditions, leads to further dissipation and entropy production; this in turn leads to the appearance of further instabilities. Farther from equilibrium, the probability increases that the system, with its internal processes, is unstable with respect to given fluctuations.

This concept of evolutionary feedback regards energy dissipation as the driving force of evolution. It is characterized by nonequilibrium conditions leading to the system's crossing a critical threshold. Beyond this threshold the system becomes structurally unstable with regard to the fluctuations, which leads to increased dissipation and, in a positive-feedback loop, change in the threshold. Thus, there is an acceleration of irreversible evolution over time. Each new stage of organization has the potential for further evolution.

An important aspect of dissipative-structure theory and of its and other interpretations of evolution is the emphasis on the complementarity of stochasticity and determinism (or, put another way, chance and necessity, novelty and confirmation). Fluctuations (e.g., genetic mutations) arise randomly. Far from a critical threshold, called a bifurcation point, the larger system tends to express average behavior; that is, to follow the law of large numbers, with the damping of fluctuations. But near a bifurcation point, the fluctuations may self-amplify or cross-amplify (autocatalysis and cross-catalysis) via positive feedback to produce a nucleation. The nucleation may then enter into conflict with the larger system or external environment. The latter may still try to squelch the growing nucleation, but sometimes the nucleation prevails and becomes a new self-organized system. Dissipative-structure theory is also called *order through fluctuations*. Self-amplification is an example of nonlinear behavior, a topic widely discussed throughout this book.

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Logistic Evolution and the Constraints of Occupied Space

A further kind of evolution, *logistic evolution*, has been studied by dissipative-structure theorists (e.g., Prigogine and Stengers 1984), as well as others. The evolution of species can be interpreted as the filling or creating of ecological niches by successive species, each of which is better fitted than was its predecessor. The well-known mathematical model, the logistic differential equation, which defines exponential growth limited by a carrying capacity or saturation level, expresses population growth within the niche. But the carrying capacity need not be fixed, so it is the sequence or family of logistic functions (or better, logistic functions followed by domains of diminishing returns) that is of the greater interest in this chapter.

The question must be raised, however, as to how much more morphological diversification is possible, once most biospace has been occupied. Put another way, as a system-field achieves structure, does not this structure now constrain further differentiation? With regard to the evolution of arthropods, most divergence occurred in the Cambrian period, early in the evolution of multicellular animal organisms. A rigid evolutionary constraint has precluded further diversification of body plans. All possible body plans had become exhausted by the end of the Cambrian, and further evolution has involved only convergences and reversals. By the end of the Cambrian, the limits to divergence had been reached. The reasons for this constraint are unknown. (See the Technical Comments, "Cambrian and Recent Morphological Disparity," *Science*, 258, 1816–18, 11 December 1992.)

Societal evolution, as interpreted in this chapter, utilizes the ideas just summarized. The fluctuations can be scientific discoveries, inventions, technological and social innovations, and great persons who appear at the right time and place in history. Logistic evolution with diminishing returns is expressed as the evolution of successive Kondratiev cycles/structures. The saturation and constraining impacts of collective cognitive (macropsychological) space and the exhaustion of ideas and practices, at least occasionally and temporarily, are emphasized.

Order Parameter as Macropsychological Structure

Much of science is concerned with the interrelationship between the microscopic and the macroscopic. Evolving systems show feedback between macroscopic structures or collective fields and the events of individual interactions at the microlevel. Macrostructures or fields emergent from the microlevel in turn modify the individual interactions at each stage of irreversible evolution. This is a vertical perspective, like that of the familiar hierarchy/emergence

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theory. For systems management purposes, it should be noted here that things often look normal at the macrolevel of the established order parameter, but that at the microlevel things are seething with incipient change. Preceding a bifurcation of the macrostructure, the system has been reorganized via long-range correlations (see below).

A field in the *horizontal sense* at any given time reflects the competition between the stability provided by communication (and information) and the instability that can follow fluctuation and nucleation. The result dictates the threshold of stability. The threshold of stability reflects the interplay among forces. If the fluctuating area lies, say, below some critical point, the area will regress; if it lies above, the fluctuation and nucleation can spread across the entire field or take over the entire system. The field need not be limited to two dimensions (physicists, for example, provide both two- and three-dimensional models for many systems that show phase transitions.)

An order parameter (De Greene 1989, 1993; Haken 1983; Nicolis and Prigogine 1989; Weidlich and Haag 1983; Wilson 1979) is such an outgrowth of micro-macro interactions. It is a macrostructure or macrovariable that emerges along with a great reduction in the number of degrees of freedom of a system. The emergence of an order parameter can also be viewed from the horizontal perspective, but the vertical sense receives more emphasis in this chapter.

The Study of Phase Transitions

The term *order parameter* arose in the study of the physics of the equilibrium phase transitions mentioned above. It was used to describe a number of phenomena that are the properties of *collectivities* of subatomic particles, atoms, or molecules, rather than of the sometimes randomly ordered particles themselves. Order typically emerges at a critical threshold. Examples of physical order parameters include spontaneous magnetization, correlation length, the properties of metal alloys, density differences between the liquid and gaseous phases of a fluid, and concentration differences. The strong fluctuations that characterize these phase transitions take place in the order-parameter field. It is not necessary to know the precise form of the strongly nonlinear interactions. Collective behavior arises at a statistical level, and only probabilistic predictions can be made as to the behavior of any given element.

The system may display, as a function of fluctuations of state near the critical point, pockets of structure or order embedded in regions of disorder embedded in still greater domains of order, and so on. Well above a critical point (say the Curie point of temperature that is associated with magnetization), the system's elements are arranged essentially randomly, and the system shows only short-range order. As the critical point is reached from above,

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larger-scale order begins to emerge. At the critical threshold itself, disconnected patches of order expand to infinite size, but fluctuations of lesser scales still remain. A critical point is a discontinuity, above and below which the system is qualitatively different (e.g., paramagnetized and magnetized).

Associated with the description of the instability of fields and the emergence of new structure within fields is the concept of *correlation*. If a single element in the system is perturbed, the disturbance may propagate, neighbor-to-neighbor, across the entire field. Distant elements, now structured in the same way, have become correlated. *Correlation length* indicates the maximum distance over which correlation can be determined. Near the critical threshold, the correlation length grows rapidly. Long-range order has emerged out of the same short-range forces. At the critical point itself, the correlation length becomes infinite. Phase transition has not yet taken place, but the system is now hypersensitive to very small perturbations, the effects of which can now nearly instantaneously explode across and engulf the entire system.

Bifurcation and Order Parameter

Under nonequilibrium conditions, the amplitudes of the long-range correlations increase with distance from equilibrium. Even before bifurcation at the macrolevel, the system has achieved a prestructure via the long-range correlations.

The phase as well as the amplitude of a bifurcating branch can be an order parameter. Indeed, the very phenomenon of bifurcation can be described in terms of the order parameter rather than in terms of the state variables originally present. Larger numbers of equations can describe the interactions among several order parameters. As suggested above, order parameters can characterize the transition of a system from an uncorrelated state to a correlated state far from equilibrium. Near to a bifurcation point, a multivariable system may be describable in terms of a limited number of collective variables or order parameters (Nicolis and Prigogine 1989).

According to synergetics also, the nonlinear, coupled order-parameter equations may themselves permit bifurcations. The order parameter, the amplitude of a bifurcating macrovariable, slaves the individual constituents as some control parameter is changed. Equations can also show the competition among order parameters, and that elements obey that order parameter that wins the competition (Haken 1983).

Societal and Macropsychological Order Parameters

Closer to the emphasis of this chapter, Haken (1983) offers this example of an order parameter. Languages are the order parameters that slave the subsystems that consist of individual human beings. The language changes very little over

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a given person's lifetime. After his birth, a person learns a language (i.e., he is slaved by it), and over his lifetime he contributes to the survival of that language. Order parameters are considered to be unstable modes that slave stable modes. This makes sense in the longer term because *Homo sapiens* change less rapidly than do the myriad languages the species speaks and has spoken. Like languages, I have proposed, the great religions, the scientific and technological paradigms, and the Kondratiev structures are order parameters. Mind is also an order parameter, emergent out of a field of forces in the brain as the brain interacts with its internal and external environments. Beyond the scope of this chapter is my contention that studying the brain as a wiring diagram and the mind as a set of logical rules and procedures is fundamentally incorrect; beware of the claims for artificial intelligence and expert systems (De Greene 1991a, 1991b)!

A *societal field* emerges out of the myriad person-person and person-machine interactions of a sociotechnical system; the field reciprocally then constrains the realm of the possible at the microlevel. There may be a general principle of short-range randomness and activation at the microlevel and long-range order and inhibition at the macrolevel. The randomness provides the innovation necessary to explore the field or space, and the inhibition maintains a collective stability over a considerable amount of space-time. An order parameter is a collective phenomenon. It is emergent beyond the obvious other structures of organizations and societies. In my writings the order parameter is macropsychological, and it shows such characteristics as collective mind, collective intelligence, collective perception, collective belief structures, and collective anxiety. Moods of the time and overall social climates are expressions of macropsychological order parameters. Group and organizational cultures, climates, and cognitive styles are order parameters that may encourage or impede problem solving, learning, competition, and adaptation. Like other evolutionary features, order parameters rise and fall as the stability dynamics of the situation change. Experience shows that these cultures and climates cannot be directly managed, although they may be damaged or destroyed by management. We shall return to this topic at the end of this chapter.

The Kondratiev Cycle/Structure in Recent Societal Evolution

The Kondratiev cycle has been classified as one of the *business cycles*. Cycles of about three-to-four or four-to-seven, and ten, twenty, and fifty-five years mean duration have been identified. The first is the business cycle per se and the last is the Kondratiev cycle or economic long wave. Cycles of 150 or more years duration have also been identified. A large literature has now been built up in this area (e.g., Berry 1991; De Greene 1988a, 1988b, 1989, 1990d, 1992, 1993a, 1993b, 1993c, 1993d, 1994; Kondratiev 1984; Schumpeter 1939; Van Duijn 1983; Vasko 1987; Vasko, Ayres, and Fontvieille 1990).

The term *cycle*, however, is insufficient. I view each cycle as an order parameter that fits into even longer order parameters, such as the hegemonic cycle, which describes the rise and fall of nations (viz., the great powers) and the life histories of the Newtonian paradigm, our phase of world civilization, and world civilization as a whole (for the last, see Tainter 1988). Hence, my use of the term *Kondratiev cycle/structure* (and hegemonic cycle/structure, etc.). The Kondratiev cycle/structure can be viewed as a link between the study of science and the study of history. It is an important organizing principle for the study of the evolution of sociotechnical or techno-economic macrosystems.

The Three-Tiered Structure of a Modern Economy

In all the sciences it is difficult to explain a system simply on the basis of function or behavior. An understanding of structure is necessary. A modern economy can be viewed as three-tiered, with the most basic and constraining order-parameter field placed for convenience on the bottom. Here we are not dealing with individuals versus collectivities but rather with collectivities of different levels of profundity. The top tier is the world of mainstream economics, of prices, wages, money supply, inflation, simple supply and demand, hiring and firing, and so on, and of behaviors like the business cycle, per se. This is the world of the recessions and recoveries that presently draw the attention of policymakers, decision makers, and the media. The middle tier deals with the means of production and consumption—factories, equipment, tools, kinds of skilled workers, and model changes within the prevailing paradigm. The intermediary Juglar and Kuznets cycles arise here. This is no longer the world of mostly the economist. Industrial engineers, behavioral and social scientists, and ergonomists play important roles here. The third and lowest tier involves the basic capital, energy, and technology structures of society. It is the world of the eventual exhaustion of capital and of past investments and commitments, the wearing out of one technology and its replacement by another (Schumpeter's *creative destruction*), and the substitution of one energy source (and now informational structure) by another. The way of thinking in society and the prevailing paradigm may become exhausted (De Greene 1993a, 1993c). This is the world of the Kondratiev cycle/structure.

The Phases of the Kondratievs

Four Kondratiev cycles/structures have been identified, with the first beginning with the Industrial Production Revolution about 1785. We are now, an increasing number of authors believe, in the depression phase of Kondratiev number four, not in the state of recovery from a recent business-cycle recession. Kondratievs are conveniently divided into phases of recovery, prosperity, recession, and depression. The fourth Kondratiev started around 1940 at the end of the Great Depression of the 1930s. The rising leg of recovery and prosperity lasted until about 1970, when the system entered the Kondratiev phase of recession. The Great Depression of the 1990s probably began about 1989–90.

Assumptions obviously help structure policies and decisions as well as the associated intermediary models. Most economists, policymakers, decision makers, and the media assume the continued truth of the present paradigm. But if the world economy is in reality in a great depression that will accompany the end of meaningfulness of this paradigm, then it is likely that the continuation of present policies and the formulation of new policies based on the old paradigm will lead to counterintuitive results. Problems of knowability and controllability arise. The Kondratiev phenomenon, with its properties of nonequilibrium, nonlinearity, instability, and structural change, is far from transparent and far from conducive to personal psychological comfort. A business cycle is easy to understand and seemingly receptive to control actions. We shall return to this challenge to systems management later in this chapter.

Features of a Kondratiev Phase of Depression

A Kondratiev depression phase has a number of identifiable features. The overall picture is one of overcapacity, overextension, maturation of industries, saturation of markets, misalignment of subsystems, and wearing out. Industries, from hotels and office space to aerospace, automobiles, and oil, now show overcapacity. Services, from schools to health care, are overextended and cannot meet the needs of constituents. Stock markets are bloated with speculator shares. Trade and internal deficits have mounted. The markets for the products of a wide range of industries, from ships to commercial aircraft to most computers, are saturated or nearing saturation. Products are cloned and typically distinguished by packaging rather than by inherent worth. Myriad factories and most infrastructure are worn out. Maintenance is deferred. Labor has been replaced by capital, yielding an increased capital intensity. Unemployment has increased and remains recalcitrant to reduction. Many kinds of jobs have been eliminated, never to return. Relatively good jobs in manufacturing have often been replaced by relatively poor, minimum-wage jobs ("McJobs") in the services; and the proportion of involuntary part-time workers has increased. Wealth has generally flowed in the direction of the already well-to-do. Just as before the great depressions of the 1890s and the

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1930s, the number of millionaires has greatly increased. Productivity shows mixed patterns, but white-collar and professional productivity, including that in computerized operations, is largely stagnant. Organizational bloat, consequent to increased administrative overhead, is held to account for much of this stagnation.

Whereas there are local, regional, and national differences among the individual symptoms, the overall picture is worldwide. Indeed, differences are a source of further instabilities, as is attested to by continued deterioration in Eastern Europe and the countries of the old Soviet Union and by large-scale migration from poorer regions to regions that are better off. See De Greene (1990c) for a discussion of factors common to capitalistic as well as to communistic collapse.

Explanation of the Kondratiev Cycle/Structure

The Kondratiev cycle/structure can, in the cyclic sense, be explained in terms of the expansion and contraction of the basic capital sector (see the three-tiered economy discussed above). In the phase of recovery, new investment opportunities are perceived and investment decisions made, perhaps to a considerable extent on the basis of innovations that have "bunched" late in the phase of depression. New technologies and energy sources are developed. Factories are built, new kinds of jobs are created, and people are hired. The overall economy, that is, the sociotechnical or techno-economic macrosystem, grows exponentially as these elements and subsystems reinforce one another via positive-feedback loops. But eventually environmental and carrying-capacity constraints (social, economic, natural, etc.) and saturation effects operate as negative-feedback mechanisms to slow the rate of growth past some inflection point. Growth then slows to an asymptotic value, and may become negative in a domain of diminishing returns. This is a simple verbal description of logistic/diminishing-returns growth. A family of these curves can depict the four Kondratievs. See the discussion of logistic evolution earlier in this chapter.

Considerable evidence has suggested the bunching or clustering of innovations in the phase of depression (e.g., Schumpeter 1939). I interpret the phase of recession as a time of very rigid societal and individual thinking, when great efforts are expended to reconfirm the status quo. But in the phase of depression, it appears that society has given up and is ready to try just about anything to remedy the misery. A technological innovation is defined as the first commercial application of a scientific discovery or invention. During the phase of depression, entrepreneurs take the latter and develop the former, helping to stimulate recovery and the beginning of a new cycle as noted above. Just as important to true progress, however, are the social and institu-

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tional innovations and societal leaders that often appear to lag behind the new technological capabilities.

As mentioned earlier, scientific discoveries, inventions, innovations, and great persons are mutations in societal evolution. The dynamics of evolution, as interpreted in terms of dissipative-structure theory and order-parameter theory, are held to apply here. Each Kondratiev structure is bounded by instabilities. Each Kondratiev structure is an order parameter or *macrovariable*, initially emergent out of interactions at a more microlevel and sustained as a field that offers both opportunities and constraints. The order-parameter field defines the realm of the possible. During much of its fifty-five or so years duration, the field functions as a mean field and average behavior dominates, with the damping of fluctuations.

Finally, in the search for a basic causality, the order parameter is viewed as primarily macropsychological, and collective perceptions, intelligence, anxiety, and so on shape the investment decisions and other features discussed above.

Deterministic Chaos and Other Nonlinear Behaviors

In deterministic chaos (not to be confused with molecular chaos), the output wave forms or the phase portraits of a model look stochastic or unexpectedly complex even though the causal mechanisms of the iterated model are completely deterministic. Deterministic chaos is associated with very strong feedback and therefore with strong nonlinearities. In deterministic chaos the system is extremely sensitive to initial conditions, and trajectories with minuscule initial differences diverge exponentially fast. Small random fluctuations are amplified over several iterations and eventually take over the system. Deterministic chaos can be observed in discrete-system simulations involving only one difference equation (e.g., the logistic difference equation) and in autonomous (not externally forced) continuous-system simulations with three or more coupled differential equations (e.g., the Lorenz weather model).

Deterministic chaos has been identified in real-world simple systems like pendulums and lasers. However, its existence in real-world complex social and societal systems is still questionable and a matter of debate. To the extent that models are used for prediction, chaos does place a definite limit on their usefulness. The identification of chaos may be useful in distinguishing between normal and pathological states. Also important from my perspective is the extent to which deterministic chaos represents a kind of instability of fields that plays a major role in systems evolution. Chaos arises from self-amplification and cross amplification, perhaps of the hypercycle kind, of subsystems. These subsystems could, for example, be social and technological or demographic and natural environmental. Indeed, the related dy-

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namic behavior of turbulence has been interpreted as arising at the boundaries of moving subsystems.

Consideration of the routes to chaos such as the Feigenbaum scenario, use of Poincaré maps, and calculation of Lyapunov exponents is beyond the scope of this chapter. These matters are dealt with in other chapters of this book. However, a word of caution is in order. Critics point out, for example, that calculation of the Lyapunov exponents itself is insufficient, in the absence of some explanatory theory, for the identification of chaos. Beware the impulses to calculate prematurely and to overcalculate.

In system-dynamic computer simulation models, instability and deterministic chaos are often associated with negative-feedback loops possessed of relatively high loop gain together with appreciable delays, which permit the amplification of the small, random fluctuations. Alternatively, in simple models of the Kondratiev cycle, instability and chaos arise out of positive-feedback loops (Mosekilde, Aracil, and Allen 1988). An example is the self-amplification of the capital sector mentioned above. See also Forrester 1977.

Berry (1991) reports deterministic chaos in Kondratiev series of annual growth rates in wholesale prices. He generated a phase space by plotting each relevant year, t, against the previous year, $t - 1$. Rosser (1991) and Zeeman (1977) also discuss nonlinearities and discontinuities in economic behavior, particularly of the catastrophe theory kind. Gilmore (1981) provides a mathematical treatment of catastrophe theory, an important topic that space limitations place beyond the scope of this chapter.

Later in this chapter, we shall discuss the evolution of information structures (macropsychological order parameters) in relationship to both the Kondratiev cycle/structure and the several kinds of attractors, including chaotic attractors, and their behavior in phase space.

On Paradigm Change

A paradigm can be defined as a set of interrelated *Weltanschauungen*: theories, models, practices, findings, explanations, values, beliefs, and feelings that characterize a given culture at a given time. This definition is much broader than most. A simpler definition might equate a paradigm to a theory or a model. Some authors (e.g., Kuhn 1970) describe different paradigms within a scientific field like physics and present seminal interpretations of the nature of scientific revolutions. Because science and society or culture interact over long periods of time, and because scientists have all too human limitations, it is necessary to provide the broad definition given above.

The main paradigms dealt with in this chapter are the Newtonian paradigm, which has come under increasing scrutiny and criticism (e.g., Checkland 1981; De Greene 1993b and the many references therein; and Prigogine and

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Stengers 1984), and the "new" paradigm (which might be called the paradigm of evolution and reconfiguration).

The Newtonian paradigm may be viewed as part of the macrostructure of information and knowledge that emphasizes and usually tolerates only the following: rationalism; reductionism; parts isolated from wholes; detached objectivity of observation and measurement and separation of the observer from the observed system; simple causality; logical, steplike but iterative analysis; deduction of rules, procedures, and algorithms; maximum use of numbers; emphasis on average behavior; equilibrium; fixed, inviolable laws; reversibility; denial of variety and ambiguity; denial of subjectivity; and convergent focus on *the* correct answer or solution. The Newtonian paradigm is best fitted to a static or slowly changing world of stability and structural continuity, not one of evolution, instability, and structural change.

In contrast, the new paradigm encompasses nonrationality, nonlinearity, mutual causality, nonequilibrium, irreversibility, stochasticity/determinism, uncertainty, opportunity and choice seen in fluctuations and apparent noise. Moreover, the dominance of exceptions near critical thresholds, the generation and maintenance of variety, structural change, divergent thinking, and the recognition that there can never be eternal truth and reality but only different perceptions of such, also represent crucial elements of the new paradigm.

Following the broad definition above, paradigms structure the very way that science is conducted. Karl Popper emphasizes testability over truth because truth may never be reached. Further, scientific theories can never be proven or validated through experimental tests; they can only be disproven or falsified. Science thus cannot be reduced to the formal, logical method of the positivists. Popper considers conceptual structures like Marxism and psychoanalysis to be outside the realm of science because they cannot be tested and falsified. It appears to me that this orientation rules out of scientific inquiry all the really interesting systems—the large-scale, complex, unstable, evolving, self-organizing, structurally changing systems—of concern in this chapter. Because of instability, chance, fluctuation, bifurcation, and chaos, each such complex system is unique. Both organic and societal evolution are summations of chance occurrences over time. Even if testing of large-scale living systems were possible, the social objections and social and environmental dangers and costs would most likely preclude such activity (see, for example, many of the criticisms of the Strategic Defense Initiative). In some cases small, experimental studies (e.g., the comparison of small ecosystems with and without a given species) can be suggestive, but even here the generalization of the results requires caution.

A great deal of research in the behavioral and social sciences, both in the laboratory and in the field, has followed the Newtonian paradigm. One of the major purposes of this book can be the rethinking of the adequacy of this kind of scientific method. At the present time many scientists are taking a new look at the very purpose, meaning, and practice of science. This discussion is pursued further elsewhere (De Greene 1993b).

At the level of societal policy making, decision making, and design, different paradigms or subparadigms are needed, depending on the apparent linearity, equilibrium state, stability, and predictability of the system (De Greene 1987, 1990d, 1991b). These features can also be related to the phases of the Kondratiev cycle/structure.

The Challenge to the Management of Complex Systems

A sociotechnical or techno-economic macrosystem is a dissipative structure in the sense that high-quality inputs (energy and matter) are converted to low-quality outputs like heat and waste, with an increase in disorder and entropy. Within this overall process, of course, low-quality raw materials are converted into high-quality finished products, but these themselves eventually break down, yielding further entropy. This is one way to look at the product life cycle.

The Growth of Exhaustion of Information/Knowledge at the End of the Kondratiev Cycle/Structure

To the extent that information is the negative of entropy (see the Shannon and Boltzmann formulas), we can also speak of an information life cycle and a growth of exhaustion of information as the end of the cycle, identified by this author (De Greene 1993a) as the recession–early depression phase of the Kondratiev cycle. At the end of a Kondratiev, entropy is high and information level is low. The progressive uniformization of the system is associated with the loss of information. In the stages of recovery and prosperity, information is increasing as the new cognitive space or field is explored, and disorder and entropy are decreasing as new designs are implemented. In the phase of recession, when the field has been explored to its boundary, energy is dissipated and information decreases as confirmation of the status quo, with the aid of proliferating bureaucracies, becomes the established modus operandi. But eventually, reinforcement no longer works, real underlying instability arises, and the system starts oscillating, with the emergence of fads and hysterias as society attempts to preserve and regain order. We note here that entropy has a material meaning as well as informational and strictly energy-based meanings. The untoward consequences of the degradation of matter and energy by

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the economic process have been beautifully explicated by Georgescu-Roegen (1971).

Nicolis and Prigogine (1989) conclude that chaotic motions necessarily imply that phase-space volume is expanding in certain directions and contracting in others. Variety and choice are continuously generated along the expanding directions of the motion, and predictability increases along the contracting directions. Thus, chaotic attractors, which possess asymptotic stability, can be generators and processors of *information*. Lyapunov exponents can be used to describe the mean rates of expansion or contraction. It is tempting, therefore, to divide the Kondratiev cycle/structure into four epochs that are offset somewhat from the four phases, with chaotic attractors associated with innovation in the late depression and recovery phases, limit-cycle attractors and oscillatory behavior associated with both the early prosperity and late recession phases, and point attractors and equilibrium-seeking behaviors characterizing the late prosperity and early recession phases around the inflection point of the logistic curve. Modis and Debecker (1992) have identified chaotic waveforms at both the beginning and the end of the logistic function.

The overall Kondratiev system would evolve in the following manner: from chaotic attractor to limit-cycle attractor to point attractor to limit-cycle attractor to chaotic attractor, with successive growth of exhaustion of information and innovation (De Greene 1993a, 1993c), and so on. Evolution would show movement from nonequilibrium to equilibrium to nonequilibrium, and so on. Because of the irreversibility of structural change, of course, the specific structures would not be the same. Moreover, as noted earlier, the Kondratiev system overlaps or operates within still larger cycle/structures. In addition, the Kondratievs are bounded by a hyperbolic (or exponential) envelope curve depicting overall sociotechnical evolution (De Greene 1982). Further, similar curves depict changes in natural environmental variables, so that the overall picture is likely one of humanity moving farther and farther from equilibrium and closer and closer to the absolute limits of sustainability and stability, as they can realistically be perceived today. Any thinking about a fifth Kondratiev has to consider the major structural changes in the larger sociotechnical and natural environments of the present Kondratiev (De Greene 1993d). Potential exploratory space, in both the physical and abstract senses, may be much less than humanity might hope.

Let us look more closely at the growth of exhaustion of human cognitive models and artifacts, along with effective information and knowledge, that reflects the increasing loss of divergent thinking and the increasing dominance of convergent thinking at the macropsychological level of a nation or an interlinked group of dominant nations (De Greene 1993a, 1993c). Instead of nation(s), the words *the economy, the sociotechnical macrosystem*, and *the* *world system-field*, and so on, could of course be substituted. Information and knowledge (information integrated and fitted into a context) are more than just flows in an information-processing system; it is better to think in terms of evolving (and devolving) structures. In the evolution of a Kondratiev, users over time tend to select the more stereotyped forms of information and knowledge. People seek the expected, the riskless, the tried and true. There is a great deal of cloning of designs, processes, products, services, and organizational practices, and a great deal of bandwagon activity. Older organizations may lose their original purposes or, perhaps worse, may continue rigid, stereotyped behaviors derived from original purposes when dynamic, evolutionary changes in the external environments have long since passed them by. Information and knowledge embodied in the original designs gradually dissipate as the designs wear out. Nevertheless, in modern societies equilibrium structures like machines and technology in general can perpetuate the existence of an old system long after it would have expired naturally. And the collective mind or consciousness possesses tremendous inertia, introducing time lags into attempts at innovative systems management. Such powerful and well-known organizations as the United Nations, the World Bank, the International Monetary Fund, NATO, and NASA may fall into this category. Experience shows that it is quite difficult to jump start a renaissance in ingrained, postmature organizations. In addition, there is the vast morass of collapse that is the relic of the old Communist world. This suggests a world of worn-out ideas, designs, and practices; a world awaiting transformation (De Greene 1993b).

Following Shannon (1948), total certainty is equivalent to no information. New information can be interpreted as reconfirming and strengthening or stabilizing existing structures. Following Thom (1975), reduction of information to its scalar measure (given in bits) means loss of almost all the meaning that might be imparted to a message. Also, no information exchange is possible between static forms. A message that conveys what is already known provides no change in knowledge. A known answer provides no uncertainty and no information. Further, information is lost when a system has diffused into its environment, and it is no longer possible to distinguish the system from its environment. For example, an innovation may be viewed in a figure/ground relationship; but after the innovation has diffused throughout the society, figure merges into ground.

Information and knowledge are more than flows in information-processing systems. Information and knowledge are themselves structures that show collective or coherent behaviors at a more macrolevel emergent out of interactions at a more microlevel. The resulting *cognitive field* then helps regulate behavior at the more microlevel. The field can spontaneously and irreversibly reconfigure into different populations or complexions that display different information and energy qualities. See again our discussion of order parameter.

Systems Management at a Time of Transformational Change

Organizations and societies thus seek continuously to reconfirm themselves, which leads to a selective use of information and a dangerous narrowing of perception (De Greene 1991a). The evolution of new knowledge systems can be stifled in the search for continued equilibrium. The economy, for example, aims toward an equilibrium state dominated by confirmation. Predictability is thought by increasingly conservative mainstream policymakers and decision makers to be enhanced by attempts to restructure and therefore to control the overall environment and to maintain a static security. Control or apparent control reduces anxiety. Yet when the information/knowledge structure evolves into a stage of saturation or even diminishing returns following diffusion into the surroundings, most people do not perceive the incipient structural changes. The present epoch of diffusion saturation of innovations responsible for previous economic growth began about 1970, around the inflection point of Kondratiev number four. Policymakers, planners, and decision makers, and their analyst advisors, continue to apply the same tired, old logic and management methods to the increasingly evident symptoms of the reconfiguring field.

As discussed above, an attractor may over time degrade from chaotic to limit cycle to fixed equilibrium point. This process can yield a certainty, confirmation, and predictability that no longer possess information/knowledge. Old, decrepit systems may be more easily captured by an equilibrium attractor. Contrariwise, the emergence of a new self-organizing collective mind, which can provide a driving force for the next (now the fifth) Kondratiev, can follow the smallest of stimuli or fluctuations. Nucleations can then spread explosively across the field. Newly formed collectivities can stand out in a figure/ground sense from established structures and can thereby encourage a growth in knowledge. The insight learning interpreted by the Gestalt psychologists as a sudden reconfiguration of the cognitive field may represent capture by a chaotic attractor and its associated basin of attraction.

Referring back to the popularly understood meaning of information, massive investment in this technology has yielded no increase in the productivity of information workers. From 1980 through 1989, office equipment increased from 3 percent to 18 percent of U.S. capital equipment. But the average productivity of the workers was about the same as in the 1960s in spite of the huge increase in the amount of computer power. Lack of improvement appears to be due to a considerable extent to increases in organizational bloat. See the discussion and references in De Greene 1990b.

Further, computerized information systems can constrain and channel thinking, so that innovation is lost. The latest technologies can rigidify management functions like communications, coordination, and control (De Greene 1991a, 1991b). Such reinforcements can be part of a larger evolution toward greater standardization and reduced variety during the Kondratiev phases of recession and depression. The Office of Technology Assessment (cited in De Greene 1990b) comments that organization and management styles appear to be becoming more and more identical across such sectors and institutions as banking, insurance, large farms, supermarkets, construction, textiles, hospitals, and automobiles. Kinds of jobs and skills become increasingly identical, and responses to forces in the external environment like financial markets and world trade are increasingly standardized and stereotyped, as rationalized or optimized *best fits* diffuse and are implemented. Moreover, over the next decade or two, most applications of new technology will involve doing something familiar in a better way. These trends imply reconfirmation of the status quo and growth without innovation.

In evolution, however, processes, mechanisms, elements, and interactions are added or subtracted, and evolution selects for variety. Optimization and improved efficiency make the organization more vulnerable as organization, environment, and their interrelationships change over time. The efficiency of a single perspective or rationality may improve the organization only for a specific purpose and within a limited time. These matters are persuasively argued further by Allen (1993).

Each Kondratiev is characterized by a primary energy source, primary technologies, and primary institutional forms. However, any of these features can spill over to the next Kondratiev. The railroads and the telegraph were primary technologies of Kondratiev number two, and improved means of organizational communication arose out of the need to coordinate the far-flung operations of the railroads. Internal communications, coordination, and control also changed greatly, and these changes spread to manufacturing around 1880. Yates (1989) discusses the rise of the American system of management (my term, see her subtitle) over the years 1850–1920 based on the philosophy of system and efficiency. She states that managerial control is essentially management as we now know it. The important emphasis here is that the transformation of American firms was essentially complete by the end of World War I, the end of the phase of prosperity of the third Kondratiev. Subsequent advances in computer-communications technologies have reinforced the dominant managerial philosophy and organizational design and have enhanced the efficiency (but not necessarily the effectiveness) of organizational processes.

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The American system has been a dominant institutional form over part of the second and essentially all of the third and fourth Kondratievs. It has, of course, spread around the globe. The myriad criticisms of Tayloristic/Fordian work-system designs and their deleterious impacts on worker motivation, morale, job satisfaction, and productivity (e.g., De Greene 1982) can be noted here but are beyond the scope of this chapter. The Japanese system appears presently to be at least a partial alternative to the American system, but this topic, which has also received a tremendous amount of attention, is also beyond the scope of this theoretically based chapter. In keeping with other interpretations made herein, it is my belief that the American system of management is part of the exhausted machine model of humanity, part of the overall Newtonian paradigm. New theories, methods, observations, and findings should not be distorted and made to fit the old paradigm and outmoded designs.

Finally, a dynamic field of forces cannot be controlled or managed; but it can be perturbed, leading to surprising nonlinear, unstable, and reconfigurational results. These results could come about because critical thresholds were passed, the delicate balance among feedback loops disrupted, and the boundaries of stability passed. On the other hand, reconfiguration is natural in evolution and can provide new choice and new opportunity. The distinction is management within the field, not of the field (De Greene 1990b). The challenge for Americans, and for humanity in general, is *to try to* induce climates of creativity, small at first, that might generate desirable innovative fluctuations that could trigger the emergence of new order parameters better fitted to evolutionary reality. Note the absence of deterministic language and the absence of any implication of ultimate human understanding and control.

Concluding Remarks and Recommendations

How valuable are chaos and nonlinear systems theory to the social sciences? The answer depends on the nature of the driving force. If these theories act as perturbations and fluctuations, driving a restructure of social science, and if they help generate new paradigm thinking, then the future can indeed be promising. If, however, the new theories function just as new tools (like a new form of regression analysis), then the social sciences may find that the exciting and challenging aspects of social reality have been usurped by the more dynamic, the more imaginative, and the more adventuresome, and that traditional economics, sociology, political science, and so on have become increasingly irrelevant.

The same kind of situation pertains for the high-level systems practices of management (in this chapter policymaking and decision making in particular) and design. A time of major transformation of the existing force field always provides greater opportunity as well as greater challenge. A time of major transformation in societal as well as organic evolution leads to emergence of new forms as well as extinction or submersion of older or less adapted forms. The next few years may provide a window of opportunity that may not return for decades, if ever. This is because each force field is spatially and temporally unique, and because the magnitude and acceleration of the intersecting environmental and societal forces is probably now the greatest in the experience of humanity. If, say, policymakers can see the opportunity of chance is today's instability and transformation, then the chaos of messes and problems may be, as a whole, amenable to a new and enlightened management. If, on the other hand, energy and resources are directed to reconfirming the status quo, then it is likely that these efforts will compound present difficulties via acts of omission and commission linked to bad timing and bad placement.

The theory of dynamic, reconfiguring fields having only temporary stability is antithetical to concepts of absolute and everlasting truth and permanency of methods. The policy community must understand the cognitive/emotional ties to such recently and presently powerful belief systems as humanity's place in nature, organized religion, communism, capitalism, democracy, the market economy, free trade, and so forth. It is, of course, easy to argue for understanding. But (selective) understanding and not understanding can have apparent survival value to individual and society. Most of us feel comfortable with the familiar, the known, the tried and true. Most of us build up elaborate systems of rationalizations and systems of denial to defend ourselves against perceived vulnerability and psychic insult. For example, most mainstream economists deny the limits to growth, deny that free-market practices can lead to environmental destruction and societal impoverishment, and indeed deny the existence of uncontrollable situations. Because of time lags associated with growing up, education, and experience, it will probably be the rare individual who understands and grasps the opportunities now emerging through chaos in the broadest sense of the term.

History shows that great leaders arise at times of crisis. From a systems theoretic standpoint, the damping and stabilizing effect of average behavior (the law of large numbers) weakens as control parameters (e.g., human population growth, atmospheric change, biodiversity loss, and inequitable distribution of wealth) approach bifurcation points. This time around, because of the intensity of planetary crisis, the leaders may emerge too late, may not fit the field, or may be of the kinds that present thinking would find objectionable. Therefore, using perhaps overworked terms, we must be anticipatory and proactive. Thinking must be radical and revolutionary. But again this is easier said than done. There is no simpleminded, linear advice that can be offered like that of the evolved-away-from, left-behind, equilibrium-centered world of the 1950s and 1960s: use risk analysis, perform a decision analysis, optimize, reduce the scope of concern to the immediately manageable. There is no meaningful list of steps that can be taken. There are no real-world-sensitive panaceas that can be offered. A field of forces is imprecise. As system dynamics, dissipative-structure theory, and catastrophe theory all show, and as experience indicates, a field of forces can surprisingly swallow policy and decisional perturbations, or it can be destabilized by such perturbations. What happens is fortuitous and depends on the timing and placing. The task confronting us now is a highly individualistic and lonely one, but potentially a most creative one. Leaders and changers will be those persons who can overlap their cognitive/emotional models, themselves internal fields of forces, with the world system-field or a constituent part of that field. In the latter case, an energized local field could excite, or even inflame the entire field.

Yet in spite of the formidable nature of evolution and reconfigurational change in the world system-field and in spite of the great difficulty in mapping external reality onto the mind, certain general advice can be offered to those willing and able to accept it: recognize human limitations, do not compartmentalize your thinking, avoid linear thinking about cause and effect, respect and learn from history, expect the system to behave counterintuitively, expect surprises and anticipate the opportunities that surprises can provide, expect policy and decision actions to assume new meanings when imbedded in a field context, think instability, instability, instability. As emphasized here, rare persons will intuitively understand these matters, but this advice should help others.

Finally, we can note that there are implications for education. Once again the questions of appropriateness in a field and of direction of causality arise. At times of instability and chaos, rigidities such as programs, plans, curricula, learning objectives, fixed assignments, tests, and administrative control are likely to be indifferent at best and harmful at worst. Educational needs, expressed as fluid learning experiences, will evolve and emerge from the pioneering behavior of those who can sense and move with the dynamics of the field. If and when things quiet down, some further formalization of methods and designs will probably be desirable. But formalization should never again be allowed to reach the scope of the Newtonian paradigm of science, culture, and society.