Systems Research and Behavioral Science
Syst. Res. **19**, 3–26 (2002)
DOI: 10.1002/sres.421

■ *Research Paper*

'Devolution' as an Opportunity to Test the 'Synergism Hypothesis' and a Cybernetic Theory of Political Systems

Peter A. Corning*

Institute for the Study of Complex Systems, Palo Alto, California, USA

'Devolution' is a political buzzword these days as empires, nations, bureaucracies and even business firms collapse, divide, downsize, outsource and in various ways become less than they once were. But what does devolution mean? How can we measure it? And, most important, how do we explain it? Some years ago it was proposed that synergistic functional effects of various kinds have been the underlying causal agency in the progressive evolution of complex, goal-oriented (teleonomic) systems at all levels of biological organization, including human societies. (The term 'synergy' refers to otherwise unattainable combined effects that are produced by the interactions among various elements, parts or individuals.) Support for this theory has continued to mount over the past decade or so, and we will briefly review some of the evidence. One important corollary of this theory is the proposition that all teleonomic systems require cybernetic control processes which, in human societies, are typically referred to as political systems, management systems, or governments. In accordance with the synergism hypothesis, it is postulated that the fate of any cybernetic control process in a living system is ultimately contingent upon the underlying functional effects that the system produces; the functional synergies are the very cause of the differential selection and survival of complex systems and their cybernetic subsystems. Can this theory of government *qua* social cybernetics be tested? It is argued here that the phenomena often referred to as 'devolution' provide just such an opportunity. A causal explanation of socio-political systems should be able to account not only for various 'progressive' trends but also for the many cases in which regression or collapse occurs. Some studies related to political devolution will be discussed, and the arguments for competing hypotheses will be considered. A major example of political devolution will also be invoked in support of this theory. Copyright © 2001 John Wiley & Sons, Ltd.

Keywords Cybernetics; synergy; politics; evolution; devolution

*Correspondence to: Peter A. Corning, Institute for the Study of Complex Systems, 119 Bryant Street, Suite 212, Palo Alto, CA 94301, USA
Published online 12 December 2001

Received 29 April 2000
Accepted 8 March 2001

THE DEVOLUTION OF 'DEVOLUTION'

'Devolution' is a political buzzword these days as empires, nations, bureaucracies and even business firms collapse, divide, downsize, outsource and in various ways become less than they once were.

In the political sphere, the term devolution is commonly used in two different ways. On the one hand, it is associated with the current trend in Western countries toward reducing or relinquishing the central government's role (control and resources) in relation to various social programs and services—welfare, education, health care, railroads, public utilities and the like. States and provinces (and even the private sector) are being granted greater responsibility for these functions.

On the other hand, 'devolution' is also widely used in connection with a broader political trend that involves the breaking up of entire polities—nation-states and empires. Devolution in this sense often involves the redrawing of political boundaries. Whole populations may be divided into new political units. Thus the British Commonwealth today exists largely on paper; the Soviet Union is long gone (though the situation bears watching); the old Yugoslavia is still fighting about its dismemberment (more on this below); the United Kingdom is in the process of devolving as we speak; and there was recently a near-miss in Canada when the issue was put to a vote in Quebec. (Whether or not political devolution will become a longer-term trend remains to be seen.)

Yet, paradoxically, in the biological and social sciences the very concept has lately become taboo; for many biologists and anthropologists in particular, devolution is redolent of 'orthogenesis'—the view that evolution has an inherent directionality toward some form of improvement or perfection. Many nineteenth and early twentieth-century evolutionists claimed that there has indeed been a broad, 'progressive' trend in evolution which, needless to say, culminated in humankind. In this paradigm, devolution amounts to a setback, or a deviation from the main course. There are hints of this orthogenetic vision in Aristotle, but it was more clearly enunciated by Jean Baptiste de Lamarck, Herbert Spencer and a veritable host of their intellectual progeny during the twentieth century. For instance, anthropologist Robert Carneiro, following Spencer, defines cultural evolution as a directional change toward greater complexity, while devolution to him connotes a temporary step backward, a regression (Carneiro 1972, 1973).

The critics of orthogenesis contend that this conception of the evolutionary process is fundamentally flawed, and wishful thinking. 'Progress' is unavoidably a value-laden term that imposes external criteria on a process that is not, in fact, guided or pointed in some specific direction. Darwin's theory of evolution is deeply opposed to deterministic theories like Herbert Spencer's universal 'law' of evolution and the many similar formulations, from Tielhard de Chardin's Omega point to Ilya Prigogine's thermodynamic law of evolution. Darwinian evolution has no hidden agenda. It is governed by adaptation to the immediate context, or local circumstances, and any observed trends are artifacts of past evolutionary history.

'PROGRESS' IN EVOLUTION

These criticisms are well taken. However, some 'anti-progressives' have thrown out the baby with the bath water; they deny, or at least downgrade, the reality and significance of cumulative, functionally based (naturally selected) trends in evolution. It is perfectly legitimate and proper to recognize that there have in fact been specific directional trends of various kinds over the course of evolutionary history that are not the products of orthogenesis, or vitalism, or thermodynamics, or, for that matter, random accidents (a 'drunkard's walk' in the i/vivid metaphor of Stephen Jay Gould, 1996).

This is not to say that such trends are irreversible; they are at all times contingent. But they can properly be labeled 'progressive' in relation to some specific functional criterion, and in many cases these criteria involve functional (economic) improvements: greater efficiency, lower costs, higher yields, greater reliability, etc. Indeed, a great many traits in complex organisms, from the four nucleotide bases that comprise the genetic 'alphabet' to the homeobox gene complex, nucleated eukaryotic cells and endoskeletons, represent evolutionary inventions that have been 'conserved' over countless generations. Accordingly, 'devolution,' 'adaptive simplification', 'regressive evolution' and similar terms may imply nothing more sinister than the reversal of a clearly defined functional trend of some sort.

To illustrate, compound, image-focusing eyes with some 2.5 million photoreceptors and complex neural processing systems, which are capable of rendering full-color, stereoscopic, 'motion-picture' images of the surrounding environment, are functionally superior to a single photoreceptor cell or even a small cluster of light-sensing cells behind a small pinhole. There has been evolutionary 'progress' in the sense of cumulative functional improvements over time in the eyes of certain lineages with respect to clearly defined functional criteria. However, this has not been the product of a unilinear trend. Eyes of various kinds have arisen perhaps 40 or more different times over the course of evolutionary history and have utilized several different functional principles.

Conversely, devolution in the sense of the loss of some functional trait or capability has been a common occurrence in the course of evolutionary history. There are many examples: for instance, the loss of eyesight in cave-dwellers; the stubby wings of flightless birds; the atrophied forelimbs of kangaroos; hair loss in the naked mole-rats (and humans); the loss in humans of the ability to synthesize ascorbic acid; the loss of mitochondria in some eukaryotic protists; or the surrender of some 254 genes by the chloroplasts of land plants which has resulted in a loss of the ability to synthesize some 46 proteins that can be produced by their free-living cousins (Margulis and Sagan, 1995).

COMPLEXITY IN EVOLUTION

Accordingly, one of the major contingent, reversible trends in evolutionary history, it is generally agreed, has been an overall increase in biological complexity. However, the problem of how to define and measure complexity remains a much-debated subject. What criteria do you use to define it? How do you know it when you see it? Or don't see it? Needless to say, you cannot measure it unless you can define it. Many theorists side-step this issue, or assume their definition of the term is self-evident, or use criteria that are highly debatable, or else limit their usage to some narrow phenomenon. In a recent essay called 'Complexity is just a word!' (Corning, 1998b), it was argued that there is no one right way to define complexity; there is no deep property of nature that can be identified with the term, and much may depend upon the eye of the beholder. In fact, there are many different, sometimes incommensurable kinds of complexity.

Nevertheless, for the purpose of explaining biological and social complexity (our purpose here), we can utilize the functional criteria that are widely employed both in biology and the social sciences (and control engineering). These criteria do not by any means exhaust the possible ways of measuring complexity in living systems, but they are significant because they are associated with important functional attributes and capabilities in nature, and in social systems as well. These criteria are: the number of parts in the system; the number of different specialized roles or functions performed by those parts (or 'functional differentiation' to use a Spencerian term); and the number of cybernetic feedback loops involved—a direct indicator of cybernetic communications and control relationships, and of functional interdependencies among the parts. (It remains to be seen whether or not it is possible to develop a synthetic 'index' that combines these attributes.)

Applying these criteria to living organisms, it could be argued that humans are not the most complex forms to walk (or swim) on Earth. Dinosaurs and blue whales were/are obviously vastly larger. A 150-pound human has an estimated 10^{13} cells of about 250 different types. A blue whale weighs about 425,000 lbs (roughly 2830 times as much as a human) and has an estimated 2.8×10^{15} cells. The number of different cell types in blue whales has not been determined to my knowledge, but it is unlikely that there would be a great many more or many fewer than the number of cell types in humans. On the other hand, if one counts the functional specializations that occur within each cell type, the number of discrete functional tasks performed by human cells is vastly greater. The human brain alone has an estimated 100 billion neurons that perform an immense number of different information-processing, communications and control tasks. So, if these finer-grained functional criteria are used, humans are unquestionably at the pinnacle of morphological complexity.

An obvious analogy in human societies would be the number of different types of workers in a large corporation—say, General Motors. If you differentiate only between blue-collar and white-collar workers, or hourly and salaried employees, you will find only a small number of different worker types (two). But if you differentiate in terms of the specific task each employee performs, the total number is vastly larger—in the thousands. Although the use of more fine-grained functional criteria to define biological (and biosocial) complexity obviously presents a major research challenge, it also introduces a more sophisticated way of measuring the capabilities of the whole.

THE SYNERGISM HYPOTHESIS

But more to the point, these functional criteria provide a useful common metric for defining complexity in living systems, both in the natural world and in human societies. And this, in turn, has facilitated the development of a general causal theory to account for the evolution of complex systems in nature and humankind. The theory was first described in *The Synergism Hypothesis: A Theory of Progressive Evolution* (McGraw-Hill, 1983). (Updated summaries of this theory can be found in Corning, 1996a, 1996b, 1997, 1998a, 2001.) In essence, the synergism hypothesis represents an economic theory (broadly defined) of organized complexity in evolution. The hypothesis, in a nutshell, is that it is the selective advantages arising from various forms of functional synergy that account for the directional trend toward greater complexity in evolution. Over the course of evolutionary history, a common functional principle has been operative; synergy of various kinds has been the common denominator, so to speak, in the process of evolutionary complexification—from bacterial colonies to eukaryotic cells and human societies.

An important corollary of the synergism hypothesis, which makes it especially relevant for social scientists, is that cybernetic processes (goal setting, decision making, communications, control activity and feedback) are a necessary concomitant of organized biological complexity. In fact, cybernetic processes are found at all levels in living systems, from genomes to animal societies, and the fate of these control processes is intimately tied to the underlying functional synergies that the systems produce. In human societies, these systems are typically referred to as political systems, management systems and government—though every family, every football team and every factory also has one. Accordingly, a political system can be defined as being *the cybernetic aspect, or subsystem, of any socially organized, goal-oriented group or population. Politics in these terms is a social process involving efforts to create, or to acquire control over, a cybernetic subsystem, as well as the process of exercising control.*

This definition is not original, of course. In fact, the term 'cybernetics' can be traced back to the Greek word *kybernetes*, meaning steersman or helmsman, and it is also the etymological root of such English words as 'governor' and 'government'. In the nineteenth century, the French scientist André Ampère took to using the term cybernetics as an equivalent for politics, but it was the physicist Norbert Wiener (1948) who launched cybernetics as a scientific discipline. Following his lead, a number of political scientists over the past half century have utilized the cybernetic model as an analytical tool, including Karl Deutsch (1963), David Easton (1965, 1993) and John Steinbruner (1974), among others. (See also Corning, 1974, 1983, 1996b, especially the peer-reviewed 1996 article in the *International Political Science Review* on 'Synergy, cybernetics and the evolution of politics'.) Also relevant is the work of William Powers (1973), James G. Miller (1995/1978) and the historical review by

Charles François (1999). Some theorists may object that human politics involves much more than cybernetic processes. Perhaps so, but the cybernetic elements are essentials, as a pilot and a flight control system are to an airplane.[1]

To summarize the elements of the synergism hypothesis very briefly, the theory is based on two relatively straightforward ideas. The first is that, in the dynamics of the evolutionary process, effects are also causes. It is the functional effects produced by a gene, or a genome, or an interdependent set of genomes (symbionts, individual cooperators or social groups) in a given environmental context that determine the survival and reproductive success of the 'replicators'—the genes and their 'vehicles' or 'vessels.' Likewise, in human societies it is the functional effects produced by a behavior, a tool, a technology or a social practice in a given cultural context that (by and large) determines its ultimate persistence or disappearance over time—as the economists never tire of pointing out. (Biologist Richard Dawkins, 1976, coined the neologism 'memes' as a cultural analogue for genes, and there is some value in thinking of cultural practices in this light.) There are, of course, many contingencies and historical 'accidents' shaping the course of evolution as well—from mutations to monsoons. There are also many physical and biochemical 'laws' and constraints that serve to canalize the process in various ways. The Nobel geneticist Jacques Monod (1971) famously characterized these influences as 'chance and necessity.'

Nevertheless, the evolution of functional 'design' in nature is primarily governed by natural selection—the differential survival and reproduction of functional variants. But natural selection is not a mechanism. And nothing is ever literally 'selected' (with the exception of sexual selection and predator-prey interactions—another story). In reality, natural selection is a metaphor, an umbrella term that serves to label and characterize a vast array of specific influences with survival consequences. The selection process is shaped by whatever functionally important effects are the proximate causes of differential survival in a given situation. (Another way of putting it is that every biological adaptation involves a structure and its activity, or behavior, in a specific environment; the organism–environment relationship is crucial.) Accordingly, what we term natural selection refers to the survival consequences of various adaptations, which may work better—or worse—in relation to the ongoing survival challenge.

Similarly, there is an analogue to natural selection in cultural evolution that can be called—out of a sense of fairness to its originator if nothing else—'neo-Lamarckian selection'. Neo-Lamarckian selection refers to behavioral selections that influence evolutionary change, and it is now more widely appreciated by evolutionists that behavioral influences have played a major role in shaping evolutionary history. (The eminent biologist Ernst Mayr, in a classic 1960 article, characterized behavioral innovations as the 'pacemakers' of evolution.) Neo-Lamarckian selection has played a major role in shaping the course of human evolution, needless to say, and even today it is deeply involved in everything from personal well-being to market dynamics and the fate of entire nations.

The second element of the synergism hypothesis concerns the fact that, among the many different kinds of functional effects that might influence differential survival and reproduction, synergistic effects of various kinds are of particular importance and, moreover, have been centrally involved in the evolution of cooperation and complexity in nature. Synergy is frequently identified with the familiar slogan 'the whole is greater than the sum of its parts' (or 2+2=5),

[1]Nevertheless, many theorists remain skeptical of the value of the cybernetic model. One reason, we believe, is that an important element was missing from Norbert Wiener's original cybernetic paradigm, and this omission has diminished its utility as an analytical tool over the years. In concert with information theory pioneer Claude Shannon, Wiener used a statistical rather than a functional (content and meaning) approach to measuring information. This severely limited the ability to model the functional properties of information in biological and social processes. A possible solution to this long-standing conundrum was recently proposed in Corning and Kline (1998a,1998b) and Corning (1999) under the concept of 'control information'. Control information is not a 'thing' but an attribute of the relationships between things. It is defined as the capacity (know-how) to control the acquisition, disposition and utilization of matter/energy in purposive (cybernetic) processes. Despite its relativity, the concept of control information can be formalized, as we show. But, more important, control information can be measured with precision in various ways. We suggest in our papers using the quantity of 'available energy' that can be controlled by a given unit of control information in a given context as one possible metric.

which dates back to Aristotle in *The Metaphysics*, but this is actually an inadequate and even misleading caricature. There are, in fact, a vast array of different kinds of synergies in nature, and many of them are not in any sense greater than the parts; they involve effects that are simply *different* from what the parts can produce alone. Accordingly, synergy may be defined broadly as the *combined effects produced by two or more parts, elements or individuals that are not otherwise attainable*. Some of the many different kinds of synergistic effects are described and categorized in Corning (1983, 1995, 1996a, 1997, 1998a, 2001). There are synergies of scale, threshold effects, functional complementarities, combinations (or divisions) of labor, information pooling, and much more.

SOME EXAMPLES

One non-obvious illustration involves the center of gravity of an automobile. Although the center of gravity greatly affects a vehicle's performance, it is in reality a combined, synergistic effect produced by the car's 15,000 or so parts and how they are assembled.

Another commonplace illustration of synergy involves the chemical combination of chlorine and sodium. These two substances are both toxic to humans by themselves, but when they are combined they produce a totally new substance that is positively beneficial (in moderate amounts)—ordinary table salt (NaCl).

One cup of beans, eaten by itself, provides the nutritional equivalent of two ounces of steak. Three cups of whole grain flour consumed alone provides the equivalent of five ounces of steak. But when the beans and flour are ingested together in a taco, they provide the equivalent of 9.33 ounces of steak, or 33% more usable protein. The reason is that their constituent amino acids are complementary. Grains are low in lysine, while legumes are low in methionine. Together they compensate for each other's deficiencies.

Synergy is also associated with many human technologies. For instance, Duralumin is a compound of aluminum, copper, manganese and magnesium that combines the light weight of aluminum with the strength of steel. There is also synergy in the so-called superalloys composed of nickel, cobalt and various other elements. Superalloys are favored for jet engines and spacecraft because they can resist very high temperatures, high pressures and oxidation.

Or consider the technology of cogeneration. If an industrial plant needs both electricity to power its machinery and steam heat or hot water for various other needs, a cogeneration system can do both jobs at once with results that are synergistic. An electrical power plant alone has an efficiency that rarely exceeds 40%. A conventional hot water heater has an efficiency of about 65%. In both cases, the unused energy goes to waste (entropy). By combining the two processes in one system, energy efficiencies of 95% can be achieved at a much lower overall cost. Cogeneration systems typically pay for themselves in three to five years.

Needless to say, synergy is also ubiquitous in social life, from bacterial colonies to human polities. One unique example involves the huddling behavior of emperor penguins. During the brutally cold Antarctic winter, when temperatures can fall to $-15.5°$ C and winds can reach hurricane force, the penguins that live in this desolate, snow-swept environment huddle together in tightly packed groups for several months at a time. In so doing, they are able to share precious body heat and provide insulation for one another. As a result, the penguins are able to reduce their energy expenditures by as much as 50% (Le Maho, 1977).

SYNERGY VIA SYMBIOSIS

Symbiosis between organisms of different species is also an important source of synergy in nature. One dramatic illustration involves the African honey guide. The honey guide is an unusual bird, with a peculiar taste for beeswax, a substance that is more difficult to digest even than cellulose. In order to obtain beeswax, however, the honey guide must first locate a hive then attract the attention of a co-conspirator, such as the African badger (or ratel). The reason is that the ratel has the ability to attack and dismember the hive, after which it will reward itself by eating the honey while leaving the wax behind. However, this unusual example of cooperative predation by two very different species depends upon a third co-conspirator. It happens that the honey guides can't digest beeswax. They are aided by a symbiotic gut bacterium which produces an enzyme that can break down wax molecules. So this improbable but synergistic feeding relationship is really triangular (Bonner 1988).

What makes this example of synergy via symbiosis particularly apropos for social scientists is the fact that the African honey guides also form symbiotic partnerships with humans, the nomadic Boran people of northern Kenya. (It is, of course, only one of many examples of animal—human partnerships.) Biologists Hussein Issack and Hans-Ulrich Reyer (1989) conducted a systematic study of this behavior pattern some years ago and quantified the synergies. They found that Boran honey hunting groups were approximately three times as efficient at finding bees' nests when they were guided by the birds. They required an average of 3.2 hours to locate the nest compared with 8.9 hours when they were unassisted. The benefit to the honey guides was even greater. An estimated 96% of the bees' nests that were discovered during the study would not have been accessible to the birds had the humans not used tools to pry them open. The bird-human partnership is also aided by two-way communications—vocalizations that serve as signals. (This illustrates our contention that complex systems in nature also require cybernetic communications and control processes.)

One of the most extraordinary examples of a symbiotic partnership in nature, however, involves the single-celled protist *Mixotricha paradoxa*. In fact, each *Mixotricha* cell represents an association of at least five different kinds of organisms. In addition to the host cell, there are three external (surface) symbionts, including large spirochetes, small spirochetes and bacteria. The function of the large spirochetes, if any, is not clear; they may even be parasites. However, the small hair-like spirochetes, which typically number 250,000 to 500,000 *per cell*, cover the surface and provide an effective propulsion system for their host through highly coordinated undulations. Each of these spirochetes is, in turn, associated with a third symbiont, a rod-shaped anchoring bacterium. Finally, each *Mixotricha* host cell contains an internal symbiont—a bacterium that may serve as an energy factory (like the mitochondria in other cells). What makes this five-way partnership all the more remarkable is that each *Mixotricha* cell is itself an endosymbiont. It populates the intestine of the Australian termite, *Mastotermes darwinensis*, where it performs the essential service of breaking down the cellulose ingested by its accommodating host (Margulis and McMenamin, 1993; Mayr, 1974).

SYNERGY VERSUS EMERGENCE

Although many theorists these days have adopted the term 'emergence' (which dates back to the nineteenth century) to characterize the synergies produced by complex systems, there are problems with this terminology. One objection is that the term emergence has, in effect, been corrupted by its common use as a synonym for 'appearance'. For instance, the word emergence is illustrated in one of my dictionaries with 'the sun emerged from behind a cloud'. Similarly, an on-line search using the term 'emergence' yielded a plethora of journal and book titles related to such things as the emergence of democracy in Central America, the emergence of soccer as a high school sport in the United States, the emergence of the environmental protection movement, the emergence of complexity theory, and many others.

Equally important, emergence does not encompass or adequately characterize many of the diverse kinds of synergies that occur in nature. As noted above, synergy is a multifaceted phenomenon. For instance, a beach might consist of an aggregate of, say, 10^{14} grains of sand. When they are packed together, these minute crystals can provide a firm surface that is able to support the weight of a human. But a beach is not an emergent phenomenon; it is a 'synergy of scale'—a synergistic effect involving a large collection of more or less identical units. Similarly, if you add an extra player to one side in an evenly matched tug-of-war, the war may soon be over. The outcome produced by all of the players pulling together exemplifies a very different kind of synergistic effect, a threshold phenomenon.

Accordingly, it seems preferable to associate the term emergence with a limited domain in the much broader universe of synergistic effects, namely those that have distinctly new physical properties (say, when hydrogen and oxygen combine to produce water). Emergent effects in this sense are unambiguous and clearly distinct from aggregate effects of various kinds, or anything that merely appears to our perceptions to be a unified whole. (It should also be noted that the term synergy is widely employed in such 'hard' biological sciences as biochemistry, molecular biology and neurobiology. It would seem desirable to use the same term to characterize analogous effects at other levels in the natural world.)

But whatever term may be used to label it, the synergism hypothesis asserts that various forms of functional synergy represent the underlying cause—the common denominator—in the evolutionary trend toward cooperative relationships, symbiosis and functional complexity, both in nature and in human societies. The synergism hypothesis is thus a unifying theory of cooperation/complexity. Moreover, it is also the simplest and most parsimonious explanation of cooperation/complexity, because it encompasses the broadest array of these phenomena and identifies a fundamentally important common aspect. However, I hasten to add that the synergism hypothesis does not involve a different theory of evolution but rather a different focus on the same process—a focus on the 'economics' (broadly defined) of evolution. The battle flag (and slogan) that I have been using for this paradigm is 'Holistic Darwinism' (see Corning, 1997, 2001).

Among the many ways in which the synergism hypothesis challenges the reigning neo-Darwinian paradigm in evolutionary biology is the fact that synergy is the universal (necessary if not sufficient) ingredient in the various paths to cooperation in nature that have been identified by behavioral biologists. Lee Dugatkin (1999) lists four—(1) altruism among kin; (2) reciprocal altruism; (3) mutualism; and (4) by-product mutualism—though more paths (like teamwork or functional interdependency) could be added to Dugatkin's list. All of these paths require synergy. Synergy is also the common element in the wealth of game theory models of cooperation; it is merely disguised in the numbers used in the pay-off matrices. (See especially Axelrod, 1984; a full discussion of this point can be found in Corning 1998a.) Likewise, synergy is the common feature in the many forms of symbioses between different species; cooperative functional effects are often produced by symbionts that would not otherwise be possible. The honey guide–human partnerships mentioned above provide one example among many.

One objection to this theory might be the charge that there is nothing new here; beginning with Aristotle, it might be argued, innumerable theorists through the centuries have recognized that wholes are more than the sum of their parts. Yes, but . . . ! To reiterate, what *is* new here is the idea that the functional effects produced by the wholes (the synergies) are the very cause of their existence, their reason for being. As noted earlier, in evolutionary processes, causation works backwards from our conventional view of things; in evolution, functional effects are also causes. It is the functional effects of various kinds (in a given environment) that determine the differential survival of the genes, and structures, and behaviors that are responsible. Hence, it is the synergies that are the cause of cooperation in nature, not the other way around. Equally important, this theory is by no means unchallenged, or undisputed. A major alternative theme—from Lamarck in the eighteenth century to biologist Stuart Kauffman today to the well-known science writer Robert Wright in his newest book *Non Zero: The Logic of Human Destiny* (2000)—is that there is an inherent, deterministic trend in evolution toward greater complexity which allows us to predict future developments. In other words, the evolution of complexity is seen as an autonomous self-organizing process. I fundamentally disagree.

A FAVORABLE TIDE?

There is a metaphor in Shakespeare's *Hamlet* that has been borrowed by many modern authors, perhaps because it seems to capture an eternal truth: 'There is a tide in the affairs of men, which, taken at the flood, leads on to fortune; omitted, all the voyage of their life is bound in shallows and in miseries.' Thus, in the 1930s the historian Arthur Schlesinger (senior) used Shakespeare's famous image in a widely acclaimed article called 'The tides of American politics' (1939). In the 1960s, the historian Jacques Pirenne wrote a magisterial volume that was translated and published in English as *The Tides of History* (1962). Political scientist Karl Deutsch also used this metaphor in the title of his classic text on the *Tides Among Nations* (1979).

Tide changes can also affect the reception of scientific theories. A classic case in point is biologist Barbara McClintock's work on the so-called 'jumping genes'—genetic rearrangements during the development of an organism via what are now called *transposons* (or transposable elements) which can produce variations in the fully developed phenotype of an organism (such as the different color patterns in maize). This phenomenon, painstakingly documented by McClintock over many years, remained in the shadows until late in her life. The main reason was that it contradicted the then reigning central dogma of molecular biology—namely, that the genes are expressed during development in a linear, deterministic fashion (DNA to RNA to proteins). Now, of course, it is recognized that development is a much more complex process and that a variety of non-linear, self-organizing, feedback-dependent influences may affect the outcome (Keller, 1983).

A similar tide change currently seems to be taking place with respect to the role of cooperation, symbiosis and synergy in evolution. One early sign was the adoption of the synergy concept in the 1980s by the eminent biologist John Maynard Smith, who developed a 'synergistic selection' model to characterize the interdependent functional effects that can arise from altruistic cooperation. (Maynard Smith later broadened the concept to accord with a strictly functional interpretation of cooperation, whether altruistic or not; (see Maynard Smith, 1982a, 1983, 1989.) Also important was the growing body of work in game theory on the evolution of cooperation, using the methodology pioneered by Maynard Smith (1982b, 1984).

Another significant contribution was made by biologist Leo Buss in his 1987 book on the evolution of higher levels of organization. Buss invoked the concept of synergy, though in a narrow sense and without much elaboration. The biologically oriented psychologist David Smillie (1995) also utilized the concept of synergy in connection with his study of social interactions in nature.

Biologist David Sloan Wilson and various colleagues have also played an important role with their dogged efforts over the past 20 years to put the much-criticized concept of 'group selection' on a new footing. Although Wilson's approach remains gene centered, he stresses the role of what he calls a 'shared fate' among individual cooperators, which implies a functional interdependency (Wilson, 1975, 1980; Wilson and Sober, 1994; Sober and Wilson, 1998). Another significant contribution is the experimental work of biologist Lee Dugatkin on cooperation, along with his recent books on the varieties of cooperation in nature (Dugatkin, 1997, 1999).

Especially important, however, is the work of biologist Lynn Margulis and others on the role of 'symbiogenesis' in evolution, particularly in relation to the origins of complex, eukaryotic cells. Now recognized as a major theoretical contribution, this concept—which traces back to a group of Russian botanists at the turn of the last century—has focused our attention on a domain in which synergistic functional effects have been of decisive importance as a causal agency in evolution (Khakhina, 1979, 1992; Margulis and McMenamin, 1993).

But perhaps the most significant sign that a favorable tide now exists for the synergy concept are the books co-authored by John Maynard Smith and Eörs Szathmáry on the evolution of complexity, *The Major Transitions in Evolution* (1995) and *The Origins of Life* (1999), which highlight the central role of synergy at various levels of biological organization. To quote Maynard Smith and Szathmáry: 'Co-operation will not evolve unless it pays. Two co-operating individuals must do better than they would if each acted on its own. In later chapters we look in detail at the various transitions in which independent entities have come to exist. Usually, both relatedness and synergy were important' (1999, pp. 22, 25). Maynard Smith now recognizes the universal importance of functional synergy (in a personal communication), as does Ernst Mayr (also in a personal communication).

SUPPORT FOR THE SYNERGISM HYPOTHESIS

The evidence for the role of synergy at every level of living systems is compelling. To mention just a few highlights: beginning with the very origins of life, synergy is the common implicit premise in all of the various formal hypotheses that have been proposed for the earliest steps in the evolutionary process, from Eigen and Schuster's (1977, 1979) 'hypercycles' to Szathmáry and Demeter's (1987) 'stochastic corrector' model and Wächtershäuser's (1988, 1990) surface metabolism model. All share the common assumption that cooperative interactions among various component parts played a central role in catalyzing living systems.

DNA, the basic molecule of life, also utilizes synergy. Among other things, the double-stranded, antiparallel backbone, or scaffolding, of each giant DNA molecule hangs together only because there are covalent electron bonds that 'glue' together the atoms of its constituent phosphate and deoxyribose molecules. By the same token, the vital role of DNA in biosynthesis is made possible by a highly coordinated division of labor between three different forms of RNA: the messenger RNA that makes copies of the relevant DNA sequence, the transfer RNA that assembles the appropriate amino acids, and the ribosomal RNA that lines up the amino acids in the proper order for assembling a protein.

Similarly, at the level of the genome, it goes without saying that genes do not act alone, even when major single-gene effects are involved. In fact, the human genome sequencing project has established, among other things, that there are 1195 distinctive genes associated with the human heart, 2164 with white blood cells and 3195 with the human brain (Little, 1995). The functional (morphogenetic) implications of those numbers are awesome to contemplate.

The origin of chromosomes, likewise, may have involved a cooperative/symbiotic process (see Maynard Smith and Szathmáry, 1993). Sexual reproduction, one of the major outstanding puzzles in evolutionary theory, is also a cooperative phenomenon, as the term is used here. Although there is still great uncertainty about the precise nature of the benefits, it is assumed that sexual reproduction is, by and large, a mutually beneficial joint venture.

As we move up 'the great chain of being' (in that still-useful anachronism), we find further variations on the theme of functional cooperation. Once upon a time bacteria were considered to be mostly loners, but no longer. It is now recognized that large-scale, sophisticated cooperative efforts—complete with a division of labor—are commonplace among bacteria and can be traced back at least to the origin of the so-called stromatolites (rocky mineral deposits) that were constructed by bacterial colonies some 3.5 billion years ago (Shapiro, 1988; Shapiro and Dworkin, 1997; Margulis, 1993). Shapiro suggests that bacterial colonies can be likened to multicellular organisms.

Complex eukaryotic cells (several thousand times the size of a bacterium on average) can also be characterized as cooperative ventures—obligate federations that may have originated as symbiotic unions (parasitic, predatory or perhaps mutualistic) between ancient prokaryote hosts and what have now become cytoplasmic organelles, particularly the mitochondria, the chloroplasts and, possibly, eukaryotic undulipodia (cilia) and certain internal structures that may have evolved from structurally similar spirochete ancestors (Margulis, 1993).

SYNERGY IN SUPERORGANISMS

Of particular relevance to social scientists is the synergy associated with social organization, what Herbert Spencer called a 'superorganism'. One compelling example of a superorganism in nature involves the naked mole-rat (*Heterocephalus glaber*), a unique African rodent species that lives in large underground colonies (usually numbering 75–80 but sometimes over 200). Naked mole-rats represent a particularly significant illustration of an economic division of labor, because these odd-looking animals—affectionately dubbed 'saber-toothed sausages'—have morphologically specialized castes and a pattern of breeding restrictions that is both unique among mammals and suggestive of eusocial insects. Typically (but not always), the breeding is done by a single 'queen', with other reproductively suppressed females waiting in the wings. The smallest of the non-breeders, both males and females, engage in cooperative tunnel-digging, tunnel-cleaning and nest-making, as well as carrying pups, foraging and the transportation of food (succulent tubers) within the colony's often extensive tunnel systems. (One investigator, Robert A. Brett, found a tunnel system in Kenya that was more that 3 kilometers long, in total, and occupied an area equivalent to 20 football fields.) Paul Sherman and his colleagues, who have studied these animals extensively, provide the following description of the mole-rats' cooperative tunnel-building efforts:

> The animals line up head-to-tail behind an individual who is gnawing [with its outsized, powerful front teeth] on the earth at the end of a developing tunnel. Once a pile of soil has accumulated behind the digger, the next mole-rat in line begins transporting it through the tunnel system, often by sweeping it backward with its hind feet. Colony mates stand on tiptoe and allow the earthmover to pass underneath them; then, in turn, they each take their place at the head of the line. When the earthmover finally arrives at a surface opening, it sweeps its load to a large colony mate that has stationed itself there. This 'volcanoer' [so-called because its actions appear to an observer outside to resemble miniature volcano eruptions] ejects the dirt in a fine spray with powerful kicks of its hind feet, while the smaller worker rejoins the living conveyor belt. (Sherman *et al*., 1992, p.75).

The vital and dangerous role of defense in a mole-rat colony is also allocated to the largest colony members, who respond to intruders, such as predatory snakes, by trying to kill or bury them and by sealing off the tunnel system to protect the colony. The mole-rats' 'militia' will also mobilize for defense against intruders from other colonies.

Why do mole-rats utilize this highly cooperative survival strategy? Eusociality is relatively rare in nature, and the traditional view has been that a haplodiploid reproductive pattern provides a genetic facilitator. But this is obviously not the case with mole-rats, which are diploid. (Indeed, it seems that haplodiploidy is neither necessary nor sufficient; all species of Hymenoptera are haplodiploid, but most are not eusocial; on the other hand, all termites are eusocial and diploid.) Sherman *et al.* (1992, p.78) provide a bioeconomic (synergy) explanation for the mole-rat strategy: 'We hypothesize that naked mole-rats live in groups because of several ecological factors. The harsh environment, patchy food distribution and the difficulty of burrowing when the soil is dry and hard, as well as intense predation, make dispersal and independent breeding almost impossible. By co-operating to build, maintain and defend a food-rich subterranean fortress, each mole-rat enhances its own survival' (see also Sherman *et al*., 1991). (Although it is not stressed in the mole-rat research literature, another critically important facilitator is a cooperative relationship—and synergy—between the mole-rats and endosymbiotic bacteria that are able to break down the cellulose in succulent tubers.)

If the bioeconomics—the functional synergies—provide an important part of the explanation for the naked mole-rat survival strategy, the 'political' (cybernetic) aspects are equally important, and are also well documented. As is the case with many other socially organized species, naked mole-rats exhibit a combination of self-organized cooperation (pre-programmed individual 'volunteerism') and orchestrated social controls that are policed by various coercive means. The control role of the breeding queen is of central importance. The queen is usually the largest animal in the colony (size usually determines the dominance hierarchy), and she aggressively patrols, prods, shoves and vocally harangues the other animals to perform their appointed tasks. Indeed, it has been observed that her level of aggressiveness varies with the relative urgency of the tasks at hand. In addition, the queen acts to suppress breeding and reproduction on the part of non-queen females, who are always ready to take over that role. (Occasionally other females are allowed to share the breeding function with the queen; why this is so is not known.) The queen also intervenes frequently in the low-level competition that goes on among colony members over such things as nesting sites and the exploitation of food sources. And when the reigning queen dies, there is a sometimes a bloody contest among the remaining females to determine her successor.

All of this control activity is facilitated by an elaborate communication system that includes 17 distinct categories of vocalizations: alarms, recruitment calls, defensive alerts, aggressive threats, breeding signals, etc. In fact, the mole-rats' communication system rivals that of some primate species in its level of sophistication. Thus, a naked mole-rat colony may be characterized as a superorganism with a superordinate system of cybernetic control ('government'). In accordance with the synergism hypothesis, in mole-rat colonies functional synergy and cybernetic processes go hand in hand.

TESTING THE SYNERGISM HYPOTHESIS

Can this theory of complexity—and the corollary theory of political complexity—be tested? One method involves a standard research methodology in both the life sciences and the social sciences—comparative studies. Often a controlled comparison will allow for the precise measurement of a synergistic effect. One quantitative example, mentioned earlier, involves the energy savings associated with emperor penguin huddling behavior. Another is the marked efficiencies achieved by the symbiosis between humans and honey guides. Lichens provide yet another ready-made example. Many of these symbiotic partnerships—which have developed independently in some 20,000 different species of green algae or cyanobacteria and various fungi—are facultative; the two partners can also exist independently. In a careful comparative study, biologist John Raven found that overall nutrient and energy uptake was significantly better in the partnerships than in their asymbiotic cousins (Raven, 1992).

Another way of testing for synergy involves experiments or 'thought experiments' in which a major part is removed from the whole and the consequences are then documented, an idea originally suggested by Aristotle in *The Metaphysics* (H-1043b-1044a)—to my astonishment. Thus, for example, it is not hard to imagine what would happen if a major gene were to be removed from the homeobox gene complex, or if the mitochondria were removed from a eukaryotic cell, or the gut bacteria from a termite, or the sub-majors (porters) from an army ant colony, or a wheel from an automobile, or the water supply from human settlement. Or, for that matter, electrical power from a modern industrial society. I refer to this methodology as 'synergy-minus-one', after the recordings that were popular a few years ago called 'Music Minus One', which allowed a singer or instrumentalist to fill in the missing part.

This and other ways of testing for synergy are discussed in more detail elsewhere (Corning, 1983, 1996a, 1997, 1998a, 2001). For our purpose, the synergism hypothesis is also highly relevant to the problem of explaining macro-level political devolution, because it predicts that the specific causes are likely to vary from one case to the next and that the disruption of even one major element of the full 'package' of basic survival requisites for a human population may prove fatal (see below). For the Easter Islanders, the decisive factors were (apparently) the exhaustion of their wood supply and soil depletion. For the Ik it was a drought. For the Moriori it was a genocidal invasion. For the Aboriginal Australians, the South African San people, the Mississippian chiefdoms and many other Native American civilizations, it was imported disease epidemics. And for a large number of Mesopotamian civilizations, according to the theory proposed by Harvey Weiss and his colleagues (Weiss *et al.* 1993; Weiss, 1996; Weiss and Bradley, 2001), a severe, sustained region-wide drought about 4000 years ago most likely devastated and depopulated almost simultaneously many otherwise thriving Middle Eastern societies—along with their political systems. As Weiss and Bradley (2001, p. 609) put it in their recent *Science* article, 'these climatic events were abrupt, involved new conditions that were unfamiliar to the inhabitants of the time, and persisted for decades or centuries. They were therefore highly disruptive, leading to societal collapse—an adaptive response to otherwise insurmountable stresses.'

In short, if synergy refers to the combined effects produced by wholes, the removal of even a single major part should have a negative effect on the performance of the whole and may even be fatal. And if political cum cybernetic control systems arise to facilitate the operation of complex, synergistic systems at all levels of social organization, then the fate of the political system is necessarily tied to the functional viability—the economics—of the system and its parts.

POLITICAL DEVOLUTION DEFINED

The term political devolution can be defined in a number of different ways. It could refer to reduced complexity, or it could mean only the complete collapse, dissolution or physical extinction of a population. Likewise, it could refer to a voluntary disaggregation, or only to an externally imposed or coerced change.

Here the focus will be limited to the cybernetics—systems of communications and control among various individuals, groups, and populations. To be specific, the 'progressive' evolution of political complexity is associated here with the communications and control processes that are necessary concomitants of being able to mobilize people and resources for one or more collective purposes—from group hunting to cooperative foraging, large-scale farms, manufacturing enterprises or military defense and offense against other groups (or other species for that matter). The converse, then, involves a decline or collapse of a cybernetic (political) system and its capabilities. In these terms, political devolution can be either voluntary or coerced. It can involve only a limited functional decline or it can be accompanied by the physical disappearance of a population. But, in any case, the hypothesis is that both the development and the dismemberment of any political (cybernetic) system is ultimately determined by the 'economics'—its integral relationship to the production of various functional synergies.

Many forms of political devolution in these terms involve the termination of a system that was only temporary, narrowly focused and ephemeral to begin with. The research literature on primates and social carnivores provides many examples: temporary coalitions of lions, hyenas, or chimpanzees that coordinate individual efforts for the purpose of joint predation, or for collective defense against another group, or to compete with other males for mating privileges, or even to contain and resist a dominant animal. In these cases, devolution occurs when the job is done.

The ethnographic research literature on human societies is laced with apt examples. One of the most famous involves the Great Basin Shoshone of the American southwest. Until very recently, the native Americans who inhabited this dry, harsh environment survived mainly by foraging in small family groups for various plant foods—nuts, seeds, tubers, roots, berries and the like. Occasionally, however, these families would gather into larger groups numbering 75 or more, when there were opportunities for a large-scale rabbit (or antelope) hunt under the leadership of a 'rabbit boss.' These joint ventures involved highly coordinated efforts with huge nets, rather like tennis nets only hundreds of feet long, that were used to encircle and capture large concentrations of prey. But when the hunt was completed and the prey were consumed, the family groups would disperse once again (Steward, 1938; Johnson and Earle, 1987). In a similar vein, the Indians of the North American Great Plains were legendary for their massive summer encampments. Dozens of small foraging bands, each with 50 or fewer people, would congregate into tribes numbering in the thousands each year under a tribal council and a chief, who organized and directed various tribal activities, including especially the annual buffalo hunt (Carneiro, 1967).

There are also a great many examples of ephemeral political systems in contemporary human societies. When the basketball game is over, the team members go home for the night when the show is over, the actors disperse; and when the collective response to a local disaster has achieved its immediate objectives, the ad hoc political system that arose to coordinate the efforts of various agencies (fire, police, repair services, shelter and food distribution services, volunteers, etc.) will be disbanded. Such systems have been studied in depth by political scientist Louise Comfort (1994a, 1994b, 1998).

Similarly, in the business world there are innumerable joint ventures and partnerships between separate firms that are short term and single purpose, while many others are multifaceted and enduring. Some are highly successful, while others are abject failures that are quickly abandoned. In either case, devolution is a common occurrence in the private sector as well. The downsizing of many 1960s conglomerates during the past decade or so provides one obvious example. By the same token, there have been innumerable military alliances between 'bands, tribes, chiefdomships and states' (in the anthropologists' terminology) over the past few millennia that have lasted only so long as there was a common enemy to be resisted—or attacked.

However, the most significant cases of political devolution involve the systems that are identified with the overarching 'collective survival enterprise'—i.e., a human population that is more or less permanently associated for the procurement or protection of their basic survival needs. This is not a vague, impressionistic formulation. As indicated in Figure 1, the 'survival enterprise' can be operationalized as an analytical frame of reference in terms of an array of at least 14 basic needs that, to a first approximation, provide the specifications for the survival and reproduction (adaptation) of any given individual or an entire human population. (The full delineation of this paradigm and a discussion of its use as an analytical tool can be found in Corning, 1983, and, in updated form, in Corning, 2000.)

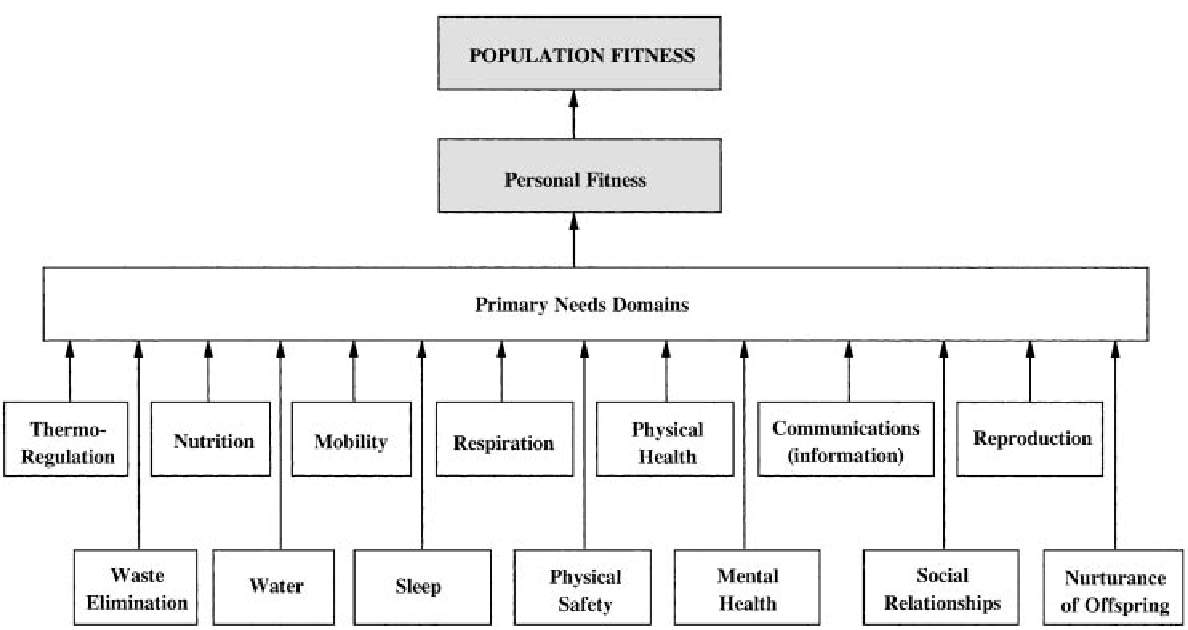

Figure 1. Biological adptation in humankind: the 'basic needs'

STUDIES OF DEVOLUTION

There is, needless to say, a long tradition of scholarship on the political devolution of human societies, from Edward Gibbon's *Decline and Fall of the Roman Empire* to the writings of Oswald Spengler, Arnold Toynbee, Herbert Simon, various systems theorists, catastrophe theorists, chaos theorists and, of course, many modern-day environmentalists (the Club of Rome and the 'Limits to Growth' theorists come to mind). There is even a specialized area of engineering, called 'failure analysis', that encompasses social systems as well.

Especially important, however, are the data and case studies of political devolution that are found in the research literature in anthropology, archeology and ancient history. The examples are, of course, plentiful; a great many societies have downsized, disaggregated or disappeared over the millennia. Some were defeated on the battlefield and were put to the torch. Others disappeared mysteriously. Still others seem to have been burdened by a complicated nexus of destructive factors—a negative synergy. By the same token, in some cases the society's central places were completely depopulated while in other cases the population continued to grow in succeeding centuries, albeit under new management. The list of relevant case studies includes, among many others, the Mayans, the Incas, the Aztecs, the Olmec, Teotihuacan, the Anastazi, the Hohokam, the Sumerians, the Babylonians, the Akkadians, the Hittites, the Minoans, Mohenjo-Daro, the Easter Islanders, the Moriori, the Tasmanians, the Maasai, the Hawiian and Zulu kingdoms, Han China, Carthage and, of course, Rome.

Among the more systematic studies related to this subject, four are particularly relevant here. One indirect treatment can be found in Robert Edgerton's 1992 book *Sick Societies*. Edgerton's overall focus is the problem of adaptation in human societies. He debunks the 'Panglossian' notion held by some anthropologists that human societies/cultures are generally well adapted and that every cultural practice, no matter how bizarre it may seem, is adaptive for the society in which it is found. (In other words, Edgerton rejects the argument that, because of our cultural blinders, we just don't understand other societies.)

On the contrary, Edgerton argues, there are a great many practices that are objectively harmful to individuals and, in some cases, to entire populations. Some of these practices even imperil biological survival. To cite one example, the Bena Bena of the New Guinea highlands suffer from a shortage of protein, yet they have a taboo against eating the chickens (or chicken eggs) which are plentiful in their environment. Other clear-cut examples of maladaptation, according to Edgerton, include the Nuer and the Tasmanians and perhaps such communal organizations as the Shakers and the Oneida Community.

The list of maladaptive practices compiled by Edgerton includes witchcraft, slavery, infanticide, human sacrifices, rape, torture, wife beating, female genital mutilation, homicide, feuding, bizarre nutritional and health practices, environmental pollution, and more. Even in modern industrial societies, Edgerton notes, there are many maladaptive practices—smoking, drinking, doing drugs, rape, homicide, wife beating, anorexia, and so on. (Indeed, Edgerton claims that maladaptive practices in folk societies have been under-reported by generations of overly sympathetic anthropologists.) As Edgerton puts it: 'All societies are sick, but some are sicker than others.' Nevertheless, many sick societies seem to thrive and continue to grow in numbers. How come? The short answer is that one must take into consideration the entire array of 14 basic needs domains mentioned above. From this perspective, the maladaptive practices reported by Edgerton may, or may not, seriously threaten the viability of the society.

This conclusion is supported by two major anthropological studies of societal collapses. One is the edited volume by Norman Yoffee and George Cowgill, *The Collapse of Ancient States and Civilizations* (1988), which includes 11 detailed case studies and analyses, from Rome to Mesoamerica and Han China. The editors also draw a clear distinction between political decline/collapse and the collapse of a 'civilization', although they are a bit vague about exactly what these terms delineate.

In any case, Yoffee and Cowgill's most important overall conclusion is that every collapse was different in character. No consistent pattern could be found, and there are no evident prime movers that propelled the political decline; each case was unique. Although a variety of contributing factors could be identified—poor leadership, trade disruptions, climate changes, government corruption, inflation, etc.— many of the examples utilized in this volume seemed to involve what Rice Odell is quoted (p. 6) as calling a 'synergistic result' of a combination of factors, rather than a single decisive coup. Yoffee also cites political scientist Herbert Kaufman's description (in his contributed chapter) of a 'downward spiral' of mutually harmful endogenous and/or exogenous factors.

Rome was one of the prime examples that they cited. To embellish the old saying, Rome was neither built nor destroyed in a day. The sack of Rome by Alaric in AD 410, and its ignominious aftermath, culminated several centuries of progressive decline involving a complex nexus of ecological, economic, social and political factors. No doubt this is one reason why the fall of Rome is a source of endless fascination—and endless scholarship. Rome provides a relatively well-documented example of a multifactored, 'dysergistic' process, but it is not unique. (For a more in-depth analysis of Rome's rise and decline, incorporating recent scholarship and new insights, see Corning, 2001.)

TAINTER'S THEORY

By contrast, Joseph Tainter's *The Collapse of Complex Societies* (1988), a formidable single-authored synthesis, represents an attempt to develop a broad explanatory principle for political devolution. Tainter was able to support his thesis with material drawn from 20 different case studies from both Old and New World settings and various historical eras.

Complex human civilizations, Tainter points out, are 'fragile, impermanent things', and a study of the many known examples of societal collapse can, he says, illuminate what underlying principles govern both their rise and their decline. Tainter's objective, then, is to offer a general explanation for why such reversals of fortune have occurred over the course of human history.

Tainter begins by noting that there have been at least 11 specific themes (not mutually exclusive or free of overlaps) that various theorists have invoked to account for sociopolitical collapses: (1) depletion or denial of a major resource; (2) the establishment of a new resource base; (3) the occurrence of an 'insurmountable' catastrophe; (4) an 'insufficient' response to some challenge; (5) the actions of other societies; (6) 'intruders'; (7) class conflicts or elite mismanagement; (8) social 'dysfunction'; (9) 'mystical factors'; (10) a chance concatenation of events; and (11) economic factors. However, Tainter disagrees with these theorists. He finds all of their explanations insufficient, except perhaps as contributing factors.

Tainter's key proposition is that the collapse of a complex socio-political system will predictably occur when there are 'declining marginal returns'—when the economic costs of additional investments in complexity outweigh the additional benefits. In effect, Tainter's theory represents an alternative to the synergism hypothesis; it is based on an internal economic calculus relating to the costs and benefits of complexity in the political system itself.

Unfortunately, there are some technical problems with the theory. First, Tainter does not define the term 'complexity' in such a way that one can measure it, and in his accompanying discussion he blurs the distinctions between complexity, inefficiency, bloat and the sheer number of workers, and similar phenomena. Indeed, a collapse in his terms only differs from a decline in its relative suddenness and rapidity, not its concrete, measurable consequences. Nor does Tainter give us any measuring rod for devolution, or even a surrogate 'indicator'. Likewise, we are not given any way of measuring either the inputs to, or the outputs from, greater complexity—i.e., the marginal value. It also begs the question: marginal value to whom? bureaucrats? a political elite? an underclass of slave laborers?

But most important, the theory does not accord well with more recent findings related to this issue. Even if, for the sake of argument, complexity in Tainter's terms could be defined and measured, a marginal value relationship would, at best, constitute but one variable—neither necessary nor sufficient to explain the many historical instances of political devolution. As we noted earlier, there is now strong evidence that, in many cases, precipitous sociopolitical collapses were directly attributable to such exogenous variables as conquests, epidemics, key resource depletions and drastic environmental changes, independently of any discernible political dynamic. Conversely, there are many other cases in which political devolution has occurred when the mission was accomplished; there was no longer a need and no further potential for realizing positive synergies (see below).

However, it should also be noted that, in a recent, jointly authored article (Allen, *et al*., 1999), the focus of Tainter's paradigm is shifted from diminishing marginal returns to the system to a broader economic calculus associated with the marginal returns to the total population and the economy from 'extracting resources' or other societal benefits. This iteration represents a major change; it is now much more compatible with the synergism hypothesis, where the burden of maintaining a political system is weighed against the underlying functional objectives of the system. Thus, according to the synergism cum cybernetics paradigm, even a bloated, inefficient army will continue to be publicly supported if it effectively deters potential invaders, but the converse is far less likely to be the case.

JARED DIAMOND'S 'PACKAGE' APPROACH

Finally, there is Jared Diamond's recent study, *Germs, Guns and Steel* (1997). Diamond's work is focused on explaining the rise of large complex civilizations over the past 13,000 years or so, but his explanatory framework is also relevant to the converse problem of explaining political devolution and collapse.

Very briefly, Diamond takes up the forbidding challenge of explaining not only how and why the evolutionary trend toward societal complexity occurred in humankind but also why it happened where and when it did and why it did not happen elsewhere, or elsewhen. A key aspect of Diamond's approach, one that directly contradicts some of the deepest metatheoretical assumptions of the social sciences, is that one cannot explain these fundamentally historical phenomena in terms of some context-free, deterministic (law-like) mechanism. The evolutionary process, including the evolution of humankind, is inescapably historical in nature; context-dependent factors have played a crucial role in the process. What is required, Diamond says, is 'a science of history'.

Accordingly, each major breakthrough in the evolution of complex societies, as well as each replication in some other geographic venue, was the result of a site-specific, synergistic nexus—a convergence of many 'ultimate' and 'proximate' factors (terms Diamond uses in a different sense from evolutionary biologists). Diamond does not use the term synergy. He refers to a 'package' of contributing factors. But the meaning is the same; each instantiation involved a combination of necessary and sufficient elements (see Figure 2).

Food production and the surpluses that resulted was a key, Diamond argues, but this in turn depended upon many other factors. One important precursor was the prior emergence of anatomically modern humans, inclusive of language skills and sophisticated cultural resources, by about 50,000 BP. Another factor was the decline and mass extinction of many of the large megafauna upon which evolving humans had depended, coupled with a rise in human population levels. This demand–supply imbalance created increasing pressure to find suitable supplements to the standard hunter–gatherer diet. The fortuitous co-location only in the Fertile Crescent of key 'founder crops', especially emmer wheat (which could be domesticated with a single gene mutation), together with legumes and animal husbandry (which allowed for a balanced diet), meant that this was the most likely location for the breakthrough that could

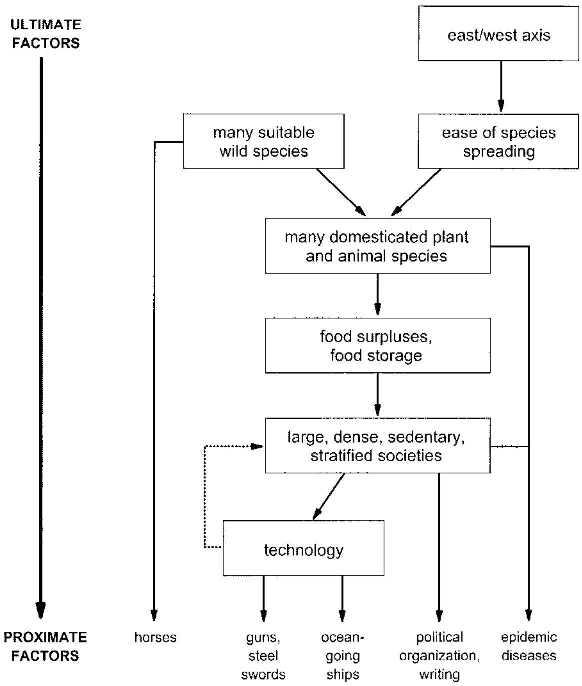

Figure 2. Jared Diamond's evolutionary 'package'. From: Jared Diamond, Guns, Germs and Steel: The Fates of Human Societies (W. W. Norton: New York, 1997). Reproduced by permission of W. W. Norton and Company, Inc.

sustain a large, sedentary population. Equally important, though, were such cultural inventions as food storage, draft animals, record-keeping and complex political organization. (Needless to say, this brief summary can hardly do justice to a much more elaborate synthesis.)

RISING TO THE CHALLENGE OF DECLINE

In applying the synergistic 'package' approach to the reverse phenomenon of devolution, some additional, implicit factors must be added to Diamond's package. What is missing is a more complete inventory of what is both necessary and sufficient to sustain a human society and its members over time, and this is where the 'basic needs' (survival indicators) framework can be of use. The thesis, in a nutshell, is that all of the 14 basic needs mentioned earlier are prerequisites for the continued viability of a human population, and if any one or more of these needs are not met, the associated political system will be threatened and may collapse.[2]

Furthermore, the challenge of meeting these basic needs entails a multilevel hierarchy of causal factors, as illustrated in Figure 3. This hierarchy is defined (somewhat arbitrarily) in terms of the span of cybernetic control—from 'the piling up of little purposes' in ecosystems (to borrow a term from Lynn Margulis and Dorion Sagan) to the potentially destructive power of large-scale political systems. The main point of this graphic, however, is to underscore the fact that many different factors interact in complex ways to affect the fate of a human population and its political system. (Note especially that the causal arrows in Figure 3 point in both directions.)

Although space does not permit a detailed discussion of this paradigm, perhaps we can illustrate with reference to a recent case study. I am referring to the Balkanization (literally) of the former Yugoslavia. It could be argued that there were no obvious survival threats to the population of that country; their basic needs were adequately provided for. Yet, on closer inspection both the political union forged by Marshall Tito earlier in the twentieth century and its recent fragmentation were driven by deep underlying survival concerns.

A key to understanding the progressive evolution–devolution of Yugoslavia lies in the

[2]One reviewer for this journal charged that this theory of political systems is 'circular'. Basic survival needs, by definition, determine the survival of a society's individual members, and if they don't survive neither does the macro-level political regime, it was argued. Unfortunately, it is not quite that simple. First, it should be noted that many other, non-survival-related explanations for political devolution have been advanced in the past, from the overthrow of capitalist economies or political elites by the oppressed masses (the Marxists) to moral declines (Gibbon) and the marginal value of complexity itself (Tainter). Nor is basic need satisfaction an either-or thing; there can be more or less (look at North Korea and Cuba) and is subject always to empirical verification. But more important, the relationship between basic needs satisfaction at the individual level and the survival of the political system per se (or even a specific regime) is by no means deterministic and axiomatic. People die in a complex society every day without threatening the viability of the system, and millions of citizens may die defending their country without major consequence for the political system. Finally, and most crucial of all, political/cybernetic systems as defined here have all manner of purposes. The subset that are concerned with securing and advancing the macro-level 'collective survival enterprise' are unique in having a special purpose that is closely tied to the basic survival needs of the population as a whole. And, as the case study below regarding the United States in World War Two clearly shows, this relationship is direct and non-trivial.

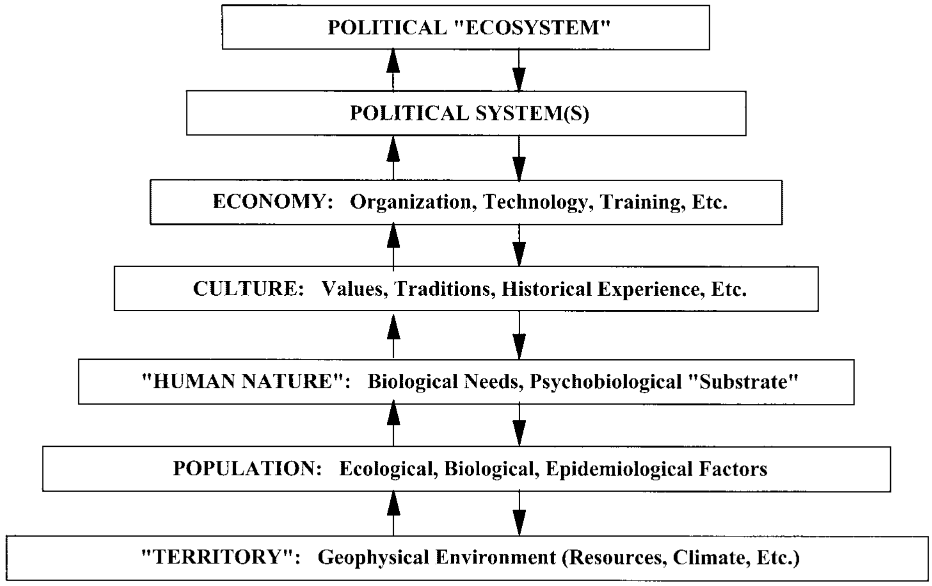

Figure 3. The multi-level causal dynamics of political evolution

fact that it represented a *de facto* forced alliance, under a charismatic leader, among historically antagonistic smaller units that were united against a perceived external survival threat (a common enemy). However, the country never became fully integrated or interdependent economically. Hence, when at long last the various external threats to the population dissolved, so did Yugoslavia's functional foundation—its *raison d'être*. In the process, historical hatreds and tensions among the nation's constituent ethnic groups re-emerged and became a serious internal physical threat. The dynamic of devolution at the national level was exacerbated by a process of political mobilization and conflict among its 'parts'—its ethnic constituents—and eventually these antagonisms erupted into bloodshed. As the casualties mounted, it became painfully clear that physical survival was at issue for the parties to this conflict (however senseless it may seem), and the political process has come to be driven by this life-and-death imperative.

How could this tragedy have been avoided? Setting aside the egregious failures of leadership and other contributing factors, true economic integration (interdependence) and/or a new external menace might have succeeded in holding this jury-rigged nation together.

In Tainter's original theory, the process of political collapse was viewed as being governed by an internal cost–benefit calculus related to the burden of complexity itself. This can hardly account for what has happened to Yugoslavia. In contrast, the synergism hypothesis posits that the fate of a political system is determined by the underlying functional processes (the synergies) to which it is related. Again, it is the functional synergies that are ultimately responsible both for the 'progressive' evolution of more complex political systems and, in their absence, for the reverse dynamic of political 'devolution'. In the absence of a functional basis for unity, Yugoslavia was destined to devolve. And, in this case, the dissolution process was hastened by ethnic conflicts that were inflamed and exacerbated by the political regime itself.

THE DEVOLUTION OF THE UNITED STATES

A more benign, peaceable example of political devolution—theoretically significant because it exemplifies the many systems that are created to meet a defined, short-term goal—can be found in, of all places, the United States. Although the image of 'Big Government' and the election campaign rhetoric about the Federal government as a 'bloated bureaucracy' has been a recurring theme in American politics over the past two decades, the reality is quite different if one contrasts the size and scope of the Federal government, and the level and intensity of cybernetic control over the population, in 1944 (at the height of World War Two) and in 1994, fifty years later.

World War Two is now only a dim memory, and the generation that fought the war is mostly gone. However, the conversion of the United States from a depression-plagued peacetime economy with a pitifully small military (350,000 in 1939) to a huge war machine (the 'Arsenal of Democracy') with 11.4 million uniformed military personnel and 3.3 million civilian employees (compared to less than one million in 1939) is well documented.[3] And this does not include the many millions of Americans who became involved in war production work (17 million new jobs were created during the war, a 34% increase in the labor force), or the 10 million organized civilian volunteers of various kinds. In short, the war produced a radical economic, political and military transformation, a national mobilization (cybernation) at every level of society, and the degree of regimentation and control exerted over the population and the economy were totally unprecedented in the United States, before or since. To be sure, this massive undertaking succeeded only because the population was united against two formidable enemies and (by and large) willingly accepted the sacrifices and constraints that were imposed. Nevertheless, the changes were radical and convulsive.

Over a six-year period the American military establishment inducted, trained, clothed, housed and fed a total of 15 million soldiers, sailors and airmen, including several million who were shipped overseas to fight on far-flung battlefronts. In addition, the US Lend-Lease Program provided (and delivered to its various allies, despite losses to enemy submarines) food and war *matériel* amounting to a total of $50 billion (or $435 billion in 1995 dollars). This part of the war effort alone dwarfs the lunar space program or the Desert Storm operation against Iraq. Indeed, the avalanche of wartime production generated, among other things, a cornucopia of statistics: 30,000 airplanes, 87,000 warships of all types, 88,000 tanks, 400,000 artillery pieces, 634,000 jeeps, 2.7 million machine guns, 7.3 million 500-pound bombs, 25 billion rounds of .30-calibre ammunition, 57.5 million wool undershirts, 519 million pairs of socks, 116 million pounds of peanut butter, 15.6 million shaving brushes and 106.5 million tent pins, among many other items.

Needless to say, it is not feasible to measure directly the cybernetic aspects of this vast enterprise—the total volume of decision-making, communications and control activities by the Federal government during 1944 (or any other year). Although archival materials and historical accounts do exist—in abundance—the task of tabulating them is so overwhelemingly large that it is obviously not practicable. Instead, we must rely on some surrogate statistics that, it is argued, are highly correlated with the relevant cybernetic processes. For instance, total Federal government employment, including military personnel, went from approximately 1% of the total population in 1939 to 10% in 1944. The Federal budget, likewise, went from $9 billion in 1939 (or 10% of the GNP) to $98.4 billion (or 46.8%). Meanwhile, the percentage of the economy that was directly engaged in war production went from less than 5% to over 40%.

The impact of the war on the US economy and population in cybernetic terms are also well documented. There were tight controls on prices, wages, rents, profits, raw materials, manufacturing, construction activity, transportation services, merchant shipping, and more. Some 20 major consumer items were strictly rationed, including gasoline, heating oil, meat, butter, sugar, tires, shoes and coffee. Many other items became scarce or simply disappeared from store shelves—liquor, soap, cigarettes, stockings, burlap, cotton, etc.—because available supplies were diverted for military use or the raw materials were used for military goods. Cars and other major appliances were also unavailable during

[3] Sources used for the following discussion include Snyder (1960); Blum (1976); Bailey (1978); Harris *et al*., (1984); Sidey (1994); and US Department of Commerce (1953, 1975, 1997).

the war; the manufacturers of non-essential consumer goods were mostly recruited for war production work. The news media were also heavily censored, as were all overseas letters, and the scientific and educational establishments were both enlisted for war work of various kinds. (The budget for the Office of Scientific Research, for example, went from $74 million in 1940 to $1.6 billion in 1945.)

An 'alphabet soup' of government agencies was created on a crash basis to oversee this mobilization process and do the cybernating. The Office of Price Administration, with 5500 local boards and 60,000 employees, was the most intrusive. However, the War Production Board, the Office of Civilian Defense, the Office of War Information (censorship and propaganda), the Office of Defense Transportation, the Public Health Service and several other agencies collectively redirected the entire economy and society. For instance, there was a huge increase in the need for overland transportation during the war. But fuel rationing drastically reduced the usage of trucks and cars. So people turned to using trains, and this put the nation's railroad system under tremendous pressure. By 1945, passenger mileage alone had jumped to three times the pre-war level. The agency responsible for coping with this need was the newly created Office of Defense Transportation, which, in effect, commandeered the nation's complex network of privately owned rail companies for the duration.

But perhaps the most significant indicators of the increased level of Federal government control over the economy were the changes that occurred in the tax system. For the first time in US history, the government mandated that income tax payments were to be withheld from paychecks and forwarded by employers directly to the Treasury. Taxes were also drastically increased (partly to finance the war but also as one means, among others, of drawing excess consumer demand out of the economy); the top (marginal) tax rate jumped to a confiscatory 94%. Federal government tax receipts in 1940 were $2.7 billion. In 1944 they had increased to $35.4 billion, more than 13 times the pre-war level.

DEVOLUTION BY DESIGN

Even before the war was over, the US government began planning for 'reconversion' to a peacetime economy. A special concern was how to meet the pent-up demand for consumer goods, from automobiles to washing machines, without causing runaway inflation. (Despite the level of high taxes, liquid assets waiting to be spent had increased from $50 billion in 1941 to $140 billion in 1944.) So industries that were expected to experience a rapid surge in demand after the war were given a priority in shifting out of war production work. In this and many other areas, the government deliberately planned for a demobilization and downsizing (and a devolution of the Federal government's role) that was not only successful but, despite the Cold War that followed, never reverted to anything approximating the broad scope and pervasive power that was exercised during World War Two.

Fifty years after the war ended, the statistics tell the story. Federal employment in 1994, including the military, amounted to 1.53 percent of the total US population, versus 10.7 percent during the war. In fact, the total number of civilian and military personnel combined in 1994 represented less than one-third the number in 1944. Despite the perceptions of most Americans, Federal employment was only one-half a percentage point higher than in 1939. Likewise, total Federal government outlays as a percentage of GDP amounted to 21.1%, less than half the 1944 percentage (46.8%) and roughly equivalent to the percentage in 1939, after subtracting transfer payments for Social Security, welfare and the like, plus interest on the national debt (see Table 1).

Moreover, the declines in Federal employment, expenditures and taxes were correlated with a drastic reduction in the degree of government control over the economy after the war. Again, the statistics that are available must serve as surrogates.

CONCLUSION

As these data show, the political devolution that occurred in the United States after World War

Two fulfilled the theoretical expectation that political devolution can be the result either of success or failure. From a functional, synergy perspective, this duality is not at all paradoxical. It was a direct consequence of the disappearance of the underlying functional need, which was clearly survival related. No other theory that we are aware of can reconcile this seeming paradox.[4]

Accordingly, none of the long list of vanished polities, past or present, conforms to any rule—except one. The rule is this: if a 'collective survival enterprise' and its political system are unable to secure one or more of the basic needs for its members (or is no longer needed), the regime will in due course be threatened with collapse or be replaced. This is not exactly a revelation, but the framework of basic needs and the hierarchy of causation outlined above makes the argument more explicit (and testable) and enables us to see why all of the impressive scholarship on this issue has failed to identify a universal doomsday scenario. There is none.

In sum, history matters. But so do the imperatives of survival and reproduction. Our basic biological needs profoundly shape our cultures, whether we are consciously aware of this fact or not. (This point is explored in depth in Corning, 2000.) And the synergy-minus-one test identifies and makes explicit the implicit rationale that societies and their rulers/leaders utilize to prioritize their problems and allocate resources—whether it be a tsunami, a disease epidemic, a military threat, a drought, the depletion of a key resource, or an internal threat to the regime and those who depend upon it for their survival and well-being. And if the history of the human species has been marked by many political failures as well as successes, the record suggests that the future will hold more of the same. This is not a counsel of despair but a call to acknowledge and prepare for the challenges that future generations will inevitably face.

[4]One other alternative approach to the explanation of political evolution should be mentioned briefly. Jong Heon Byeon (1999) has proposed that political change is a 'self-organizing' process, with a 'prevailing tendency' (along with all other 'fundamental processes') toward greater complexity. Over time, Byeon claims, entropy (defined as 'disorder') decreases and order (i.e., a patterning or thermodynamic order) increases. As noted elsewhere (Corning and Kline, 1998a, 1998b), this popular formulation (Byeon follows the lead of many other contemporary theorists) involves a serious and unwarranted conflation of energetic and physical order, a concept of complexity (order) that cannot be operationalized, the use of statistical information concepts from information theory that cannot be applied to cybernetic, feedback-controlled systems, and, most serious, a core premise that can readily be falsified. As noted earlier, modern evolutionary biologists find the postulate of an inherent, 'orthogenetic' trend in evolution to be unsupportable and in fundamental conflict with Darwin's theory. Indeed, if there is an inherent tendency toward political complexity, how can the many examples of political devolution be accounted for? The cybernetic, functional theory of political complexity and the synergism hypothesis predict what will happen to a complex society that suffers a prolonged, severe drought. A thermodynamic theory cannot.

REFERENCES

Allen TFH, Tainter JA, Hoekstra TW. 1999. Supply-side sustainability. *Systems Research and Behavioral Science* **16**(5): 403–427.

Axelrod R. 1984. *The Evolution of Cooperation*. Basic Books: New York.

Bailey RH. 1978. *The Home Front: U.S.A.* Time-Life Books: Alexandria, VA.

Blum JM. 1976. *V was for Victory: Politics and American Culture During World War II*. Harcourt Brace Jovanovich: New York.

Bonner JT. 1988: *The Evolution of Complexity by Means of Natural Selection,*. Princeton University Press: Princeton, NJ.

Buss LW. 1987. *The Evolution of Individuality*, Princeton University Press: Princeton, NJ.

Byeon JH. 1999. Non-equilibrium thermodynamic approach to the change in political systems. *Systems Research and Behavioral Science* **16**: 283–291.

Carneiro RL. 1967. On the relationship between size of population and complexity of social organization. *Southwestern Journal of Anthropology* **23**: 234–243.

Carneiro RL. 1972. The devolution of evolution. *Social Biology* **19**(3): 248–258.

Carneiro RL. 1973. The four faces of evolution. In *Handbook of Social and Cultural Anthropology*, Honigmann JH (ed.). Rand McNally: Chicago, IL.

Comfort LK. 1994a. Risk and resilience: inter-organizational learning following the Northridge earthquake of 17 January1994. *Journal of Contingencies and Crisis Management* **2**(3): 157–170.

Comfort LK, 1994b. Self-organization in complex systems. *Journal of Public Administration Research and Theory* **4**(3): 393–410.

Comfort LK, 1998. Shared risk: a dynamic model of organizational learning and action. In *Handbook of Administrative Communication*, Garnett JL, Kouzmin A (eds). Marcel Dekker: New York; 395–411.

Corning PA, 1974. Politics and the evolutionary process. In Dobzhansky, Th, Hecht MK, Steere WC. (eds.), *Evolutionary Biology*, (Vol. VIII, Plenum Press: New York; 253–294.

Corning PA, 1983. *The Synergism Hypothesis: A Theory of Progressive Evolution*. McGraw-Hill: New York.

Corning PA.1995. Synergy and self-organization in the evolution of complex systems. *Systems Research* **12**: 89–121.
Corning PA. 1996a. The co-operative gene: on the role of synergy in evolution. *Evolutionary Theory* **11**: ,183–207.
Corning PA. 1996b. Synergy, cybernetics and the evolution of politics. *International Political Science Review* **17**(1): 91–119.
Corning PA. 1997. Holistic Darwinism: 'synergistic selection' and the evolutionary process. *Journal of Social and Evolutionary Systems* **20**(4): 363–400.
Corning PA. 1998a. The synergism hypothesis. *Journal of Social and Evolutionary Systems* **21**(2): 133–172.
Corning PA. 1998b. Complexity is just a word! *Technological Forecasting and Social Change* **58**: 1–4.
Corning PA. Control information: the missing element in Norbert Wiener's cybernetic paradigm? *Kybernetes* (in press).
Corning PA. 2000. Biological adaptation in human societies: a 'basic needs' approach. *Journal of Bioeconomics* **2**: 41–86.
Corning PA. *Nature's Magic: Synergy in Evolution and the Fate of Humankind*. Forthcoming.
Corning PA, Kline SJ. 1998a. Thermodynamics, information and life revisited, part I: to be or entropy. *Systems Research and Behavioral Science* **15**: 273–295.
Corning PA, and Kline SJ. 1998b. Thermodynamics, information and life revisited, part II: thermoeconomics and control information. *Systems Research and Behavioral Science* **15**: 453–482.
Dawkins R. 1976. *The Selfish Gene*. Oxford University Press: New York.
Deutsch KW. 1963. *The Nerves of Government: Models of Political Communication and Control*. Free Press: New York.
Deutsch KW. 1979. *Tides Among Nations*. Free Press: New York.
Diamond JM. 1997. *Guns, Germs and Steel: The Fates of Human Societies*. Norton: New York.
Dugatkin LA, 1997. *Cooperation Among Animals: An Evolutionary Perspective*. Oxford University Press: New York.
Dugatkin LA, 1999. *Cheating Monkeys and Citizen Bees*. Free Press: New York.
Easton D. 1965. *A Systems Analysis of Political Life*. Wiley: New York.
Easton D. 1993. *An Approach to the Analysis of Political Systems*. Irvington: New York.
Edgerton RB, 1992. *Sick Societies: Challenging the Myth of Primitive Harmony*. Free Press: New York.
Eigen M, Schuster P. 1977. The hypercycle: a principle of natural self-organization. *Die Naturwissenschaften* **64**(11): 41–65.
Eigen M, Schuster P. 1979. *The Hypercycle: A Principle of Natural Self-Organization*. Springer: Berlin.
Franois C. 1999. Systemics and cybernetics in a historical perspective. *Systems Research and Behavioral Science* **16**: 203–219.
Gould SJ. 1996. *Full House: The Spread of Excellence from Plato to Darwin*. Harmony Books: New York.
Harris MJ, Mitchell FD, Schecter SJ, 1984. *The Homefront: America During World War II*. Putnam: New York.
Issack HA, Reyer HU, 1989. Honeyguides and honey gatherers: interspecific communication in a symbiotic relationship. *Science* **243**: 1343–1346.
Johnson AW, Earle T. 1987. *The Evolution of Human Societies: From Foraging Group to Agrarian State.* Stanford University Press: Stanford, CA.
Keller EF. 1983. *A Feeling for the Organism*. Freeman: New York.
Khakhina LN. 1979. *Concepts of Symbiogensis* (in Russian). Akademie NAUK: Leningrad.
Khakhina LN, 1992. Evolutionary significance of symbiosis: development of the symbiogenesis Concept. *Symbiosis* **14**: 217–228.
Le Maho Y. 1977. The emperor penguin: a strategy to live and breed in the cold. *American Scientist* **65**: 680–693.
Little P. 1995. The genome directory: navigational progress. *Nature* **377**: 288.
Margulis L. 1993. *Symbiosis in Cell Evolution* (2nd ed.). Freeman: New York.
Margulis L, McMenamin M, (eds). 1993. *Concepts of Symbiogenesis: A Historical and Critical Study of the Research of Russian Botanists*. Yale University Press: New Haven, CT.
Margulis L, Sagan D. 1995. *What is Life?* Simon & Schuster: New York.
Maynard Smith J. 1982a. The evolution of social behavior: a classification of models. In *Current Problems in Sociobiology*, King's College Sociobiology Group (ed.). Cambridge University Press: Cambridge, UK; 29–44.
Maynard Smith J. 1982b. *Evolution and the Theory of Games*. Cambridge University Press: Cambridge, UK.
Maynard Smith J. 1983. Models of evolution. *Proceedings of the Royal Society of London B* **219**: 315–325.
Maynard Smith J. 1984. Game theory and the evolution of behaviour. *Behavioral and Brain Sciences* **7**: 95–125.
Maynard Smith J. 1989. *Evolutionary Genetics*. Oxford University Press: Oxford.
Maynard Smith J, Szathmáry E. 1993. The origin of chromosomes I. Selection for linkage. *Journal of Theoretical Biology* **164**: 437–446.
Maynard Smith J, Szathmáry E. 1995. *The Major Transitions in Evolution*. Freeman Press: Oxford.
Maynard Smith J, Szathmáry E. 1999. *The Origins of Life: From the Birth of Life to the Origin of Language*. Oxford University Press: Oxford.
Mayr E. 1960. The emergence of evolutionary novelties. In *Evolution after Darwin*, Vol. I, Tax S (ed.). University of Chicago Press: Chicago, IL; 349–380.
Mayr E. 1974. Behavior programs and evolutionary strategies. *American Scientist* **62**: 650–659.

Miller JG. (1995/1978). *Living Systems*. University Press of Colorado: Niwot, CO.
Monod J. 1971. *Chance and Necessity* (Wainhouse A, trans.). Alfred A. Knopf: New York.
Pirenne J. 1962. *The Tides of History*. Dutton: New York.
Powers WT. 1973. *Behavior: The Control of Perception*. Aldine: Chicago, IL.
Raven JA. 1992. Energy and nutrient acquisition by autotrophic symbioses and their asymbiotic ancestors. *Symbiosis* **14**: 33–60.
Schlesinger AM. 1939. Tides of American politics. *Yale Review* **29**: 217–230.
Shapiro JA, 1988. Bacteria as multicellular organisms. *Scientific American* **258**(6): 82–89.
Shapiro JA, Dworkin M (eds). 1997. *Bacteria as Multicellular Organisms*. Oxford University Press: New York.
Sherman PW, Jarvis JU, Alexander RD (eds). 1991. *The Biology of the Naked Mole-Rat*. Princeton University Press: Princeton, NJ.
Sherman PW, Jarvis JUM, Braude SH, 1992. Naked mole rats. *Scientific American* **267**(2): 72–78.
Sidey H. 1994. The home front. *Time* **143**(24): 48–49.
Smillie D. 1995. Darwin's two paradigms: an opportunistic approach to natural selection theory. *Journal of Social and Evolutionary Systems* **18**: 231–255.
Snyder LL. 1960. *The War: A Concise History, 1939–1945*. Jillian Messner: New York.
Sober E, Wilson DS. 1998. *Unto Others: The Evolution and Psychology of Unselfish Behavior*. Harvard University Press: Cambridge, MA.
Steinbruner JD. 1974. *The Cybernetic Theory of Decisions: New Dimensions of Political Analysis*. Princeton University Press: Princeton, NJ.
Steward JH. 1938. *Basin-Plateau Aboriginal Sociopolitical Groups*. US Government Printing Office: Washington, DC.
Szathmáry E, Demeter L. 1987. Group selection of early replicators and the origin of life. *Journal of Theoretical Biology* **128**: 463–486.
Tainter JA. 1988. *The Collapse of Complex Societies*. Cambridge University Press: Cambridge, UK.
US Department of Commerce. 1953. *Statistical Abstract of the United States*. US Government Printing Office: Washington, DC.
US Department of Commerce. 1975. *Historical Statistics of the United States: Colonial Times to 1970*. US Government Printing Office: Washington, DC.
US Department of Commerce. 1997. *Statistical Abstract of the United States*. US Government Printing Office: Washington, DC.
Wächtershäuser G. 1988. Before templates: theory of surface metabolism. *Microbiological Reviews* **52**: 452–484.
Wächtershäuser G. 1990. Evolution of the first metabolic cycles. *Proceedings of the National Academy of Sciences, USA* **87**: 200–204.
Weiss H. 1996. Desert storm: weather brought destruction to the first ancient civilization. *Sciences* **36**(3): 30–36.
Weiss H, Bradley RS. 2001. What drives societal collapse. *Science* **291**: 609–610.
Weiss H, County MA, Wetterstrom W, Guichard F, Senior L, Meadow R, Curnow A. 1993. The genesis and collapse of third millennium north Mesopotamian civilization. *Science* **261**: 995–1004.
Wiener N. 1948. *Cybernetics: Or Control and Communications in the Animal and the Machine*. MIT Press: Cambridge, MA.
Wilson DS. 1975. A general theory of group selection. *Proceedings of the National Academy of Sciences* **72**: 143–146.
Wilson DS. 1980. *The Natural Selection of Populations and Communities*. Benjamin/Cummings: Menlo Park, CA.
Wilson DS, Sober E. 1994. Reintroducing group selection to the human behavioral sciences. *Behavioral and Brain Sciences* **17**: 585–608.
Wright R. 2000. *Non Zero: The Logic of Human Destiny*. Pantheon Books, New York.
Yoffee N, Cowgill GL. (eds). 1988. *The Collapse of Ancient States and Civilizations*. University of Arizona Press: Tucson AZ.