9

Human Civilization II:
A Complex(ity) Transition

Conceptual Outline

9.1 A danger of thinking about collective human systems is that our perspective on the importance of the individual may be diminished. However, this is only a problem because emergence and interdependence are not generally understood.

9.2 By treating human civilization as a complex system, we may go beyond qualitative analogies in our efforts to understand it.

9.3 In recent years, human civilization has become manifestly interdependent. Therefore we conclude that it is a complex organism.

9.4 There is evidence that a transition in the structure of human organizations is occurring with intriguing consequences. Historical and contemporary evidence suggests that human organizations are undergoing a transition away from hierarchical control. From a complex systems perspective, a hierarchical system implies that the complexity of the behavior of the entire organization (at its own scale) must be less than the complexity of the controlling individual. Thus, the transition away from hierarchical control is consistent with a transition in complexity—previously human organizations behaved in a manner that is simpler than an individual, now they are more complex.

9.5 For an individual, the consequences of this transition are manifold and manifest. There is increasing specialization of social and professional contexts. As individuals, we cannot fully understand the social and economic processes that are going on around us. However, as components of a complex organism, we are protected from many dangers.

9.6 Our ability to predict the collective behavior of human civilization is limited. Nevertheless, there are a variety of intriguing questions that may be discussed.

9.1 Introduction: Complex Systems and Social Policy

Our objective in this chapter is to consider complex systems that are composed of collections of human beings. There are many such complex systems, ranging from a family unit to the totality of civilization. This endeavor brings us to the domain of a set of fields that we have not yet encountered in this text—social psychology, sociology, anthropology, political science and economics, and to the borders of public policy, social work and social welfare.Once we enter into this societal domain, we must evaluate carefully how to apply scientific methods. One of the central difficulties is ensuring that our desires and concerns don't interfere with our observations. We must strive to understand what is happening, and defer questions of how we would like the society to be, or to become. In order to understand, the scientist must first act as an observer rather than evaluator of good and bad. The questions, What is happening? Why is it happening? and How is it happening? are primary. While there has been a call for scientists to become involved in social policy, there are dangers to this approach. The dispassionate analytic perspective can inform, but is not a substitute for, a compassionate social policy.

Our concern in this section,however, is not to discuss the general problems of the scientific approach in social policy, but rather to discuss a specific way that the study of human civilization in a scientific context may have a negative impact on social policy thinking. There are specific dangers to be avoided. Considering the collective behavior of human beings as a complex organism can,and historically has,led to problems in attitudes that inform social policy when the value of individuals is dismissed in comparison to objectives of the collective. The danger is that we will cause a decrease in respect for the importance of the individual. In the following paragraphs we discuss and clarify this problem as a cautionary preface to our discussion of human civilization as a complex system.

Various forms of collective human systems are taken for granted in anthropology, sociology, politics and economics. In much of recent history the nation-state has been the most prominent political organization. Similarly, the corporation has been the primary economic organization. In Western law corporations are recognized as individuals with rights that are similar to the rights of individual human beings, though there are some distinctions. Other collective human systems of the past and present are the tribe, city-state and community.

In the field of biology, the existence of collective behavior of organisms has been described using the terminology "superorganism." The superorganism terminology expresses the concept that the "actual"system of interest is not the individual biological organism but rather the collective system formed out of many individuals. Applied originally to insect colonies,this term has also been applied more broadly, even to human civilization. However, within the context of complex systems, there are important distinctions that can be made between different kinds of superorganisms. The existence of interactions between insects does not necessarily imply that the collective is

the relevant organism rather than the individual insect. We could try to determine the relevant organism by comparing the complexity of the individual to that of the collective. However, it is more important to understand the interdependence of individual and collective organism behavior. The primary significance of the term "superorganism," when applied to a collective,is the implicit suggestion that all of the standard biological concepts of a living organism apply to the collective. Some of these concepts—reproduction, consumption of food and production of waste—can also apply to collections of noninteracting, or decoupled individuals. These may, however, be modified in a collective context. Other concepts, such as interdependence and specialization, which occur in an insect colony, are directly relevant to our discussions of complex systems.

It is not a novel concept to consider human society as analogous to a biological organism. In some elementary biology textbooks the concept of an organism as a collection of interdependent cells is explained by analogy to interdependent human beings in society! The use of analogies, such as the analogy of a biological organism to society, is sometimes helpful in pointing out similarities. However, the limitations of analogies are not often discussed. Analogies can be misleading when they break down, suggesting similarities that are invalid. This leads to a danger of drawing conclusions that are really improper extrapolations. It is the objective of science to develop principles or mathematical models that explicitly capture the commonalties and display the differences between systems, in part so that improper extrapolations are not made. We will discuss specific analogies in Question 9.2.1.Our objective here is to understand possible conceptual implications of a superorganism analogy for human civilization in order to clarify and bound the scientific discourse.

Implications of a superorganism analogy center around relationships between the collective and a part of the collective. In a social context, there are consequences for our understanding of rights and responsibilities. When one person hits another, the hand is not considered responsible for the act. The individual is responsible. Why is this the case? Is it because the hand cannot act by itself, or because the hand is under direct control of the brain? A better answer is that it is due to interdependence of the various parts of the person. What is the level of interdependence at which the part becomes responsible for the act rather than the whole? If an individual is part of a collective, when is the collective responsible for his or her acts? In another type of circumstance,a limb may be amputated to save the individual. When we consider an individual cell, we notice that for the benefit of the collective organism,many individual cells are killed—skin cells are constantly dying to create a protective layer around the body. When can a part of the organism be sacrificed for the benefit of the collective? How much benefit or loss of harm justifies how much sacrifice? We will illustrate these considerations by corporate and societal examples.

The first example pertains to the use of the superorganism concept in limiting both rights and responsibilities of the individual as part of the superorganism. In a corporation,the individual's rights of commerce and communication may be superseded by the rights of the corporation; at the same time,the corporation relieves the individual of responsibilities for certain actions. This is manifest in the protection of

employees,including presidents and chairmen of the board,from direct accountability for the consequences of decisions that are made with respect to company policy. This release from accountability has been challenged in recent years. It is enlightening to consider the arguments both pro and con in the context of a complex system framework. Let us say that a president of a corporation makes a decision that causes a faulty product to be manufactured, which leads to the death of some of those who purchase the product.Should the president be held accountable? The problem is that the decision was made in the context of company policies that reflect the history of the company as well as the individual. Other individuals at the corporation would by necessity have to cooperate in order for the product to be manufactured. Moreover, we can ask whether most other people in the same position governed by the same corporate policies would have made the same decision. One could also ask whether production-line employees have the responsibility to evaluate the implications of their work,and thus responsibility for device failure and its consequences. The question to be addressed in this context is whether the corporation and its policies should be punished and through this punishment cause change in the corporate policies that led to the harm to others, or whether the individual who made the decision should be punished to change individual behavior? The answers may require more specific information about a particular case. For us,the questions reveal a balance between the existence of a corporation as a superorganism and the individuals from which it is formed.

Throughout this text we have focused on the interdependence of parts and the whole of a collective complex system. When we think about this relationship in the context of human beings, we can also identify mutual benefit and conflict. Benefit arises when the actions of the individual and the collective are mutually advantageous. Conflict arises when the actions of an individual or the collective do not benefit both individual and collective. Considering the interplay between these is made more difficult when we recognize that collective actions are manifest as actions of individuals,and individuals may misinterpret or misrepresent their actions as collective actions. An extensive discussion of these issues is beyond the scope of this text. However, what is pertinent is that there are many circumstances where the objectives of individuals are subordinated to objectives of the superorganism. This may be illustrated by statements of the following form: Your rights/interests are secondary to the benefit of the society, corporation, or state. Examples include the firing of corporate employees, and the jailing of criminals or of political prisoners.

The need to protect the individual has been recognized. For example, democratic ideals were designed to prevent dominance of the rights of the state over the rights of the individual. The legal system is generally designed to delineate the rights and responsibilities of the individual with respect to society as a whole and with respect to other individuals within the society. Most laws restrict the independence and freedom of individual action. The concept and articulation of human rights (e.g., in the U.S. Bill of Rights) is directly related to ensuring respect for individual goals and benefits in the context of society. Various labor laws are designed to avoid the dominance of corporate rights over those of employees.

Thus, the existence of a balance between the rights of the individual and of the collective can be seen to be necessary. Our cautionary remarks are directed at the process of arriving at this balance.

There is a key distinction between implicit and explicit use of the superorganism concept. Implicit use of the concept means that rights are established by directly considering the benefit to both the individual and the collective. From the ancient times of widespread slavery to the present,the historical progression has often led to greater rights of the individual rather than of the collective. Yet, even in the present context of strengthened individual rights,it is understood that limitations must be placed on the individual in the context of society. The justifications for this are either the protection of the rights of others, or the prevention of substantial financial or other loss to the society as a whole. Such limitations are debated as social policy issues without reference to the superorganism concept. The superorganism concept enters the discussion only through the consideration of collective benefits.

In contrast, explicit use of the superorganism concept invokes the superorganism as a reason for subjugation of the rights of the individual. Claims that the state or corporation has a greater importance than the individual may directly lead to the suspension of individual rights. A telling example is the use by the Nazis of a particular biological superorganism analogy. They described the Jewish people as a cancer to be eradicated from the flesh of Germany. This superorganism concept was used to motivate and justify the involvement of physicians in the design of gas chambers for the Holocaust. The main distinction between the explicit and implicit form of the superorganism is that in the explicit form it is the concept of superorganism itself that is used to justify actions. There is no direct accounting for individual and collective benefits. Aside from the terrible consequences, we may recognize that the biological analogy is inherently ambiguous. It would be impossible to tell if the Nazi actions were an immune response or an autoimmune disease. What is more significant for our concern here is that any collective biological analogy distances us from individual human tragedy.

The preceding paragraph is a cautionary statement about the use of superorganism concepts to direct social policy. In general,science avoids consideration of analogies from physical or biological systems to social or political conditions. This is to be commended, since such analogies have led to abuses and loss of human rights. The advent of the field of complex systems,however, places an additional burden on science—not to ignore the analogies but rather to test and verify or reject them. The use of the organism analogy for the human collective may suggest that once again the rights of individuals are forfeit to the collective. The difficulty will be to keep the use of such models in perspective. In this regard, the most important conceptual tool is recognition of the interdependence in a complex system that gives rise to emergent behavior. This implies that the collective should be concerned about the well-being of its parts. However, there is a further, more specific conclusion that we reach in this chapter that should limit the motivation to utilize complex system models to address social policy matters. In the previous chapter we estimated the complexity of various organisms. In this chapter we will continue this discussion to evaluate the complexity

of human civilization. Our analysis will suggest that traditional superorganisms such as states and corporations have been less complex than the individuals of which they are formed, implying the historical importance of individual rights and responsibilities. However, it appears that we are making a transition to a global superorganism that is more complex than an individual human being. Should we conclude that the rights of an individual human being should therefore be diminished in importance? In a sense this might be justified when we consider these rights with respect to the totality of human civilization. However, there is a crucial catch. Our argument is inherently based on the understanding that the superorganism is qualitatively more complex than any human being. This must mean that there is no individual who can understand it. Thus there is no individual who can be trusted to know which, if any, individual rights should be sacrificed. We find that in the context of individuals that are more complex than the superorganism, the rights of the individual are paramount. When the rights of the individual can be said to be secondary, we can at least be assured that no individual has the right to prescribe the nature of this sacrifice. We conclude that it would be unreasonable to base social policy decisions on the benefit or consequence to a system that we as individuals cannot understand.

Before we proceed with the central topic of this chapter—the complexity of the global human superorganism—we discuss a few related issues. One of the recent popular movements has suggested that the biosphere of the earth is in some sense alive. This suggestion is known as the Gaia hypothesis, where Gaia (from the Greek word for Earth) is the name given to the biosphere. The central proposal is that the biosphere is able to react to disturbances and, for example, rebalance itself. Considered in the context of complex system behavior, such a reactive organism is very simple. From the point of view of conventional science, even a chemical equilibrium reacts to disturbances. It would be highly unlikely that the biosphere, when affected on a global scale, does not have similar reactive capability. However, the notion of the collective of life on earth acting in concert is not a conventional view. We will be pursuing this further to explore the complexity of such a global organism, though our focus will be on the human superorganism. It should be understood that there is no clear understanding at this time of the nature of the boundaries of this organism. Should we expand the organism to include the flora and fauna of the earth, or even the earth itself? It may be correct to include all of the biosphere, since at the present time it would be impossible for the "human superorganism" to survive without the rest of the biosphere. This, however, is also true about any animal in its environment. For our purpose, the problem of defining the boundary of the organism is not critical, since we have considered the nervous system as a complex system despite its inseparability from the biological organism that contains it.

The Gaia hypothesis is not generally considered to be within the fold of science. Yet our objective is to pursue the topic of the global economy as a collective human superorganism that is far beyond the Gaia hypothesis in many ways. It is helpful to return to the discussion in the preface to this text, where the question of addressing the origins and destiny of man was briefly mentioned. As pointed out there, these questions have been traditionally within the domain of religion and more recently of

science fiction. The field of complex systems is an endeavor to understand a new aspect of our environment as well as of ourselves. There is a natural connection between this field and the subject of the origins and destiny of man. If we did not authorize ourselves to enter into such areas and explore the possibility of scientific inquiry, we would be unduly limiting the field. This is an opportunity "to boldly go" into a new domain of scientific inquiry.

9.2 Inside a Complex System

One of the difficulties we face when discussing human civilization as a complex system is that we know of only one example. The scientific approach inherently does not allow discussion of a single system. An individual system can be discussed as one of a class of systems when principles that apply to the class can be determined. This only works when an appropriate class of systems can be described. For example, Newtonian mechanics enables prediction of the trajectories of planets because there is a broad class of systems that satisfy the same principles. Through observations, the principles could be inferred and then applied to them all. Even though the solar system is, in our experience, unique, it is still part of the class of systems that satisfy Newton's laws, and therefore its dynamics may be predicted.

The question we face is whether human civilization is a completely unique system or whether it is a member of a class of systems. There are nonscientific ways of grouping systems, or describing the similarity between one system and another. These are analogies. Analogies suggest that distinct systems share common properties. When we think about human civilization as a complex system, we can think about it as analogous to other complex systems about which we are more knowledgeable because there are many instances of them. For example, we can think about human civilization as a growing plant, or we can think about it as a colony of cells in a pond, or we can think about it as an animal formed out of various tissues. Such analogies may suggest qualitative similarities and point out features of human civilization. However, they are inherently laden with various assumptions that are not valid. This is apparent in the great variation between the three distinct analogies that have just been mentioned.

Mathematical models are the scientific form of analogies. This kind of analogy shows more precisely how two systems are similar. It may also reveal limitations of the similarities. For example, within every mathematical model are quantitative parameters. The values of these parameters are often different when applied to different systems. The extent to which model parameters are similar, or the degree to which they are different, can inform us about the similarity or difference of the original systems. It should be understood that a mathematical model that is used to capture a particular aspect of two systems does not necessarily capture other aspects. Similar to qualitative analogies, the relevance of mathematical models to describing a system is limited. This is particularly true when we consider the modeling of complex systems where, by their very nature, simplified mathematical models cannot capture the full description or complexity of the system being modeled.

In this context we see how the theory of complex systems has both its most difficult challenge in describing the properties of human civilization,and its greatest opportunity for contributing to our understanding. It is precisely the application of general principles of complex systems that can teach us about human civilization. The class of systems being considered consists of all complex systems,and so human civilization can be included. Moreover, rather than simply rejecting the apparent qualitative analogies between human civilization and other complex systems,the theory of complex systems may reveal both their validity and their limitations. Analogies should not be dismissed out of hand;neither should they be taken beyond their realm of validity.

We thus anticipate that the study of human civilization will be an important application of the study of complex systems. It should be emphasized, however, that there is a realm beyond which science cannot go. The unique aspects of the existence of a single organism cannot be predicted by science. A similar statement applies to an organism's environment. To the extent that the human organism is unique, there will always be aspects of its environment that cannot be predicted—they must only be experienced.

Question 9.2.1 Describe analogies between (1) a corporation and (2) a nation-state and a biological organism. In what ways do the analogies break down?

Solution 9.2.1 Biological organisms have many and varied properties. For example,plants and animals are qualitatively different in their behavior and in many of their attributes. The degree of cooperativity between cells in organisms also varies widely. Thus a discussion of analogies to biological organisms either allows for a broad class of properties, or must be made more specific to capture intended properties. Here we consider some universal biological properties:

1. Corporation

Reproduction—Corporations can split into smaller corporations; individuals from one corporation can leave to start a new one. It is not clear, however, in what way the resulting corporations are reproductions of the original one. Specifically, what are the hereditary traits and how are they transmitted from generation to generation? Characteristic size is typically a hereditary trait among biological organisms, but not among corporations.Generally there is no well-defined equivalent of sexual reproduction among corporations,unless we allow ourselves to consider the formation of a company by several individuals previously working at different corporations as a form of sexual reproduction. Corporations also merge and acquire other corporations. This process seems like the reverse of reproduction. We could try to fit mergers and acquisitions into the analogy by suggesting that they are similar to the consumption of food. However, biological organisms generally decompose

food into molecular components. By contrast, corporate mergers and acquisitions have a wide variety of effects. The previously existing corporate structures may remain largely intact, or they may be completely dismantled. Such variety is not characteristic of consumption in conventional biological organisms.

Growth—Like biological organisms, corporations grow. Corporations grow by increasing net worth, number of employees, sales and net profits. However, they also shrink. We might try to think about this as similar to trees that grow new leaves each year and lose them, or animals adding layers of fat and then consuming them in times of scarcity. However, the processes are quite different. Unlike fat tissue, the growth of corporations is of functional rather than nonfunctional tissue. Unlike trees, what is grown and lost is not manifestly distinct from what is retained.

Food consumption and waste excretion—Corporations consume sources of energy and raw materials. Waste is produced by corporations in the form of used chemicals, smoke, paper or other byproducts of the work being done. Corporations produce products. What is the biological analogy of a product? It is hard to consider the product as excreted waste!

Differentiation of parts—Corporations have significant functional differentiation of parts.

Breakdown of the analogy—The above comments point out some differences between corporations and biological organisms. Other distinctions include the observation that ownership defines a corporation. There is no analog of ownership for biological organisms. In particular, there is no mechanism for a takeover by outside agents. Diseases are not a comparable concept. The mechanisms of reproduction of corporations and biological organisms are quite different, even if we use the concept of reproduction loosely. Corporations can also form spontaneously without being reproduced. This is not the case for biological organisms. Corporations may be directed/guided/owned by a single individual. This is not the case for biological multicellular organisms. Large substructures in complex biological organisms cannot be traded among biological organisms the way people or even corporate divisions can be traded among corporations.

2. State

Reproduction—The primary example of state reproduction is the formation of a colonial settlement followed by independence of the settlement. What are the hereditary properties? The form of governance is a possibility, but it may not persist. The size of the state is not hereditary. Similar to corporations there is no well-defined equivalent of sexual reproduction.

Growth—States grow by increasing territory through wars; populations grow by migrations as well as by biological reproduction. Biological reproduction of populations is similar to the growth of biological organisms by cellular reproduction. However, war and migrations are not similar, because

the growth of one state occurs at the expense of shrinking another state. Similar to the discussion of corporations,the possibility that states shrink is not analogous to a property of biological organisms.

Food consumption and waste excretion—States consume resources and produce wastes like biological organisms.

Differentiation of parts—Different parts of the nation may be differentiated in function.

Breakdown of the analogy—We have pointed out several distinctions in discussing reproduction and growth. Among the most dramatic of these is the possibility that part of, or the entirety of, one state will be conquered by another. As with corporate acquisitions, this is not analogous to biological consumption.

We see that analogies between human organizations and biological organisms break down even when we consider quite fundamental biological properties. The limited usefulness of the biological analogies does not carry over to the more general concepts of complex systems that have been developed in this text. As will be discussed in the Question 9.4.1, these concepts continue to be useful in the context of human organizations. ∎

9.3 Is Human Civilization a Complex System?

The reader of this text is, if he or she has followed the discussions of the previous chapters, an expert in the new field of complex systems. As a participant in human civilization, and given information generally known about human interactions and organizations, the reader is in a position to directly address whether we should consider human civilization as a complex system. Questions 9.3.1–9.3.3 are designed to encourage the reader to review various attributes of complex systems and consider their application to human civilization. We rely upon collective knowledge rather than specific references in this discussion.

For quick reference, we briefly review again the central concepts.A complex system is composed out of many elements. These elements interact in such a way as to give rise to collective behaviors on various scales up to that of the entire system.Our principal approach to characterizing the properties of a complex system has been to consider interdependence and substructure. By removing or modifying part of the system and observing the effects of this modification on the rest, we can determine the degree of interdependence of the system. We associate such interdependence with the properties of a complex system. This connection was made more specific by the study of complexity—the length of the description of a system. The complexity of a system on its own scale was shown to be related to the dependence of its behavior on its components' behavior. If we have to specify the state of each of the parts of the system in order to describe the behavior of the whole, then it requires a lot of information to describe. We distinguished between two types of complex systems—complex materials and complex organisms.A complex material has the property that removal or mod-

ification of a large part of the system affects a smaller part of it. A complex organism has the property that removal or modification of a small part of the system affects the rest. Thus, we are particularly interested in whether civilization satisfies the properties of a complex organism—whether the collective behavior is affected by removing or modifying part of it.

Question 9.3.1 To illustrate the relevance of the concepts of complex systems in the context of collectives of human beings, discuss the nature of interdependence in corporations.

Solution 9.3.1 In corporations, the degree of interdependence varies tremendously. Some corporations are loose federations of smaller, essentially independent units. Other corporations are tightly knit—interdependent organizations, where a loss of part of the system would cripple the rest. In cases where the corporations are loose federations, a unit (division) may be removed without substantially affecting either the division or the rest of the corporation. This suggests that corporations that satisfy these properties have simple collective behavior. On the other hand, when various parts of a corporation participate in joint manufacture of a product, the interactions and interdependence may be quite complex. When one factory manufactures components that are used by another factory, there are many ways that changing what happens in one will affect what happens in the other. Indeed, this applies whether the two factories are part of the same corporation or part of different corporations. Recognizing the level of interdependence is relevant to various issues pertinent to the functioning and planning of corporations. ∎

Question 9.3.2 Complete both of the following sentences with a list of properties that describe human civilization.

a. Human civilization appears to be a complex system because …

b. Human civilization does not appear to be a complex system because …

The objective of this question is not to determine whether human civilization is a complex system, but rather to list some of the necessary or typical features of complex systems that apply to human civilization. Question 9.3.3 addresses more directly whether human civilization is a complex system.

Solution 9.3.2 Human civilization appears to be a complex system because it is characterized by:

1. Many elements: human beings, machines
2. Interactions:

   Communication: oral and written languages, mail, telecommunications

   Economic: buying and selling, borrowing, renting

   Social: meetings, celebrations, gatherings, conferences

   Long-range interactions:

in space (travel and telecommunications) and
in time (books, music, pictures and sculptures preserved over time)

3. Substructure:
   Family, community, town, city, state
   Company, industry, profession, association, organization
   Nationality, religion, race, language
4. Processes of Organization:
   Biological evolution, social evolution, history
5. It is interdependent (see Question 9.3.3)
6. It has a complex behavior (see Section 9.4)

Human civilization does not appear to be a complex system because:

1. It does not interact with other complex systems of the same kind.
2. Its response to the environment is not manifestly complex. ∎

Question 9.3.3 Discuss the divisibility/interdependence of human civilization. Consider a few other times in the history of civilization as well as the present. What is the evidence that changes in one part of the world affect other parts of the world? Would the life of people in one place change if dramatic changes happened in another part of the world? When possible, give specific historical events as evidence.

Solution 9.3.3 Our discussions of interdependence (Section 1.3, Chapter 2) were based upon considering the effect of changes in 10%–20% of the system. Geographically this would correspond to subdividing the world into continents: North America, South America, Asia, Africa, Europe, Australia and Antarctica, and considering what would happen to the others if one of them was dramatically affected. In recent years, there has been a general awareness of global interdependence in discussions of the global economy and various geopolitical events. We will place this in a historical context.

Over the course of history there are indications that some areas were interdependent, but other areas were essentially independent over substantial periods of time. For example, human civilization in North and South America was essentially independent of the rest of the world during much of recorded history. Even within the connected continents of Europe, Asia and Africa, there are parts that were almost completely isolated from each other. Great empires of antiquity occupied limited spheres of influence. The Persian Empire and the Roman Empire did not generally affect events in the Far East, including the Chinese Empires. For most purposes, Asia was separated into three regions isolated from each other. These regions are delineated by drainage basins of great rivers: the Tigris and Euphrates Rivers, the Indus River, and the Huang He (Yellow River). There were migrations and cultural transfers that did involve substantial fractions of humanity over the course of centuries—time scales characteristically much longer than a human

lifetime. Nevertheless, even as recently as the early 1900s,there were only limited ways in which the disappearance of a substantial fraction of the population in one part of the world, on one of the six populated continents, would impact the others.

One might ask, for example, how the disappearance of North America would have affected the rest of the world. The impact would have been greater after European settlement, but would still be limited to specific major trade items, and migrations from Europe to the Americas. One might also trace the transfer of a particular technology around the world to see the limited degree of influence. An example that comes to mind is the iron plow, invented in the United States and then transferred to other parts of the world in a manner that is slow on time scales that we are used to today. However, the interdependence has increased over time. In recent times it has become manifest. The time scale has become shorter, and the scale of interdependence has reached that of the individual.

The signature of change became apparent through the World Wars, especially World War II, when alliances and battles spread through all major parts of the world and directly involved a significant fraction of the world's economic and social systems. Even World War I was essentially a European conflict. In considering interdependence, we focus on how changes in one part affects the others. The global conflict in World War II arose because of changes that originally occurred in only a few nations. These changes then affected individuals throughout the world. In recent times, global interdependence has been manifest in events that primarily involved individual nations, but which resulted in the attention and involvement of people throughout the world. Some of these are geopolitical,others are geoeconomic in nature.

The following list of keywords is designed to evoke events and concerns that indicate the global interdependence:

Political/Military—governmental changes, civil wars, local wars, nuclear weapons

Economic—trade, depressions, industrialization, global corporations

Environmental—rain forests, polar ice caps, depletion of fish, acid rain

Natural disasters and disaster relief—flooding, famine, hurricanes,earthquakes

Information—publication, invention, software/hardware, global science

For example, the invasion of Kuwait by Iraq in 1990 had a manifest global response despite originally involving only a tiny proportion of the global population. The effects of the oil embargo and OPEC in the 1970s illustrated the global impact of the supply of oil from the Middle East and is reflected in the continued global concerns in that region. The impact on consumers, corporations and economies of the world of the production of automobiles and consumer electronics in Japan is well appreciated, as is the growing impact of the exports of other Pacific Rim nations.A disruption of the supply of products, even a partial disruption,as occurred for example in

the wake of the earthquake in Kobe, can have global impact. The potential impact that a small nation can cause through development of nuclear weapons has recently been manifest in the global response to events in North Korea. The widespread destruction that could result from use of nuclear weapons of the arsenals of the nuclear powers is well recognized. The drug production in specific parts of the world, such as in Colombia,has relevance to individuals and the public in many other areas of the world. Various recent occurrences of social disruption and conflict in Somalia, Bosnia and Rwanda illustrate the global response to social disruption in what are considered relatively out of the way places of the world. Since World War II, various local conflicts have attained global significance and attention, e.g., Korea, Vietnam, and the Middle East. Changes of government in diverse countries such as Iran in the 1970s and South Africa in the 1990s occurred in an environment of global influences and consequences. The example of South Africa is of particular interest,since the global influence (the boycott) was directed at internal civil rights rather than external interactions. The global aid in response to famines in Africa, and earthquakes and floods in other parts of the world,are further indications of the global response to local events. The impact of fluctuations of the value of currencies during the 1990s in Italy and England, Mexico, and recently the United States have illustrated the power of global currency markets.

These examples illustrate how, at the present time, events on a national scale can have global effects. However, we can also analyze smaller-scale events that can have a global effect. One of the manifestations of the global interdependence is the wide geographic distribution of product manufacturing and utilization. Manufacturing a product involves raw materials,capital, design,assembly and marketing. Today each may originate or occur in a different part of the world, or even in several. The loss of a factory in any one of tens of countries may significantly affect the production of a corporation. Since individual corporations can be primary suppliers of particular products, this can in turn affect the lives of individuals throughout the world.

In order to consider the effects of the world on a particular individual, we must specialize. We can consider, for example,the influx of students from around the world into universities in the greater Boston area and analyze how this affects faculty, students, and the Boston area economy, as well as how the existence of Boston affects them. We might ask even more specifically how one student from one part of the world can affect another student from another part of the world when both meet in Boston.Or how an individual faculty member affects students that come from many parts of the world,and how students coming from many parts of the world affect a faculty member. Even to ask these questions demonstrates the interdependence at the individual level that now exists throughout the globe. Moreover, we did not yet account in detail for the effects of direct information exchange through the telephone, global mass media, international journals and conferences, and recently the Internet. ∎

Our conclusion from Question 9.3.3 is unambiguous—human civilization is a complex organism. It is clear that the behavior of parts of the system is strongly interdependent. It is also apparent that the behavior of the whole is strongly dependent on its parts. The strength of interdependence is to be measured by the amount of information (bits) needed to describe all of the distinct ways that one part affects the others.Our conclusion is based upon common and well-known phenomena. In this regard we are only echoing many discussions of the global economy, global communications and global interdependence. Yet it is a significant observation. It is also significant that the phenomena of interdependence have become manifest relatively recently. Thus we have an indication that a transition to a manifestly complex organism has occurred during this century. Prior to this time the behavior was not characteristic of a complex organism. In the following section we focus on this transition.

9.4 Toward a Networked Global Economy

In Section 9.4 we used evidence of interdependence to arrive at the conclusion that human civilization is a complex organism. In this section we use a different approach to arrive at the same conclusion. By taking a different route, we will reinforce our conclusion and gain a deeper insight into processes that are taking place in society around us. Our primary tool in this section will be the concept of complexity and the complexity profile discussed in Chapter 8. There is a fundamental connection between the behavior of the complexity profile and interdependence of substructure. We know this because at every level of organization the complexity of the whole arises from correlations in the behavior of the components. However, there are also more direct ways to connect the complexity profile with the functional structure of human organizations, as will become apparent in this chapter.

We begin our discussion with an effort to understand the changes that have occurred in recent years that have led to greater global interdependence. This interdependence led us to conclude that civilization is a complex organism. What is significant is that arriving at this conclusion one hundred years ago, or even fifty years ago, would have been much more ambiguous. Thus,there appears to have been a transition in the behavior of global civilization that is important for us to understand.

9.4.1. *Evidence for decrease in central control*

The history of human civilization has been marked by various stages identified by the nature of social/political/economic structures and tools/technology. One of the more recent transitions is the industrial revolution. From the point of view of technology, the industrial revolution marked a transition to the widespread use of machines powered by coal and oil, which replaced animal and human labor. From the social point of view, it marked the transition from rural to urban life.Economically, it marked the transition from family agriculture to large corporation manufacturing. Politically it strengthened but did not change qualitatively the existence of nation-states, which emerged during the Middle Ages.

In recent years there have been many discussions of the possibility that another significant change in technology, society and the economy is taking place. This has been variously characterized as the information revolution, growth of the service economy, or emergence of the global economy. Other changes that are occurring include geopolitical changes in the significance of national boundaries—the development of trading blocks, global free trade,the end of the cold war, and the emergence of widespread international cooperation in addressing various geopolitical events.

We will first discuss the current change in the global economy as a change in the manner of the exercise of control.Specifically, the hierarchical control structures that have characterized political, economic and other social organizations since antiquity may be disappearing in favor of cooperative networks. Such networks of interacting elements are more characteristic of complex systems we have been considering. Indeed, we have not discussed any specific example of control hierarchies in other complex systems. The change from hierarchies to networked systems is a specific and dramatic indicator of many changes that are taking place. It suggests that the present changes are more significant than those of the industrial revolution. We will show that these changes are related to an increase in complexity of the collective behavior of human beings and the related emergence of civilization as a complex organism. In this section we discuss some of the evidence in historical and current events that a change away from control hierarchies is taking place. In Section 9.4.2 we consider possible reasons for loss of viability of central control that are not satisfactory. In Section 9.4.3 we discuss why the loss of central control is consistent with a transition in complexity. Section 9.4.4 reviews historical phenomena in this light.

In the following paragraphs we review a series of changes that have occurred in recent years, ranging from the nature of governments to the state of interpersonal relations. While no one of these changes could be interpreted to suggest a dramatic change in the structure of civilization, their collective evidence gives some weight to this suggestion. In approaching this discussion it is important to distance ourselves from the notion of proof. Indeed, proof is not possible except in closed mathematical model systems. Our objective is to provide a reasonable case, where counter arguments are possible and to be respected.

1. *Dictatorships in the western hemisphere*—During the early 1980s a series of events occurred in the Americas and in several other countries around the world that decreased significantly the number of nations governed by dictatorships (Table 9.4.1). In many of these countries democracy and dictatorship have come and gone a number of times over the past century. It would be hard to conclude from a single government change that recent events are extraordinary. However, it should be noted that at this time there are no dictatorships in the western hemisphere except Castro's Communist regime in Cuba.Of particular importance is that among the changes of government were revolutions that did not follow the pattern of historical revolutions. Historically, a revolution begins from an attempt to reform the government,then more extreme views and individuals take over; these extreme views lead to a bloody conflict and finally a return to a form

Table 9.4.1 List of mainland Central and South American countries and the date and kind of their most recent major change of government. Until the late 1970s a patchwork of military dictatorships and democracies existed. By the early 1990s a transition to almost universal democratic governments had occurred. A tilde (~) before the word Democracy indicates significant control is still exercised by military leaders within the democratic regime. For countries whose governments have not changed since the early 1970s, no transition is indicated. While not part of the Americas, we added Greece, South Africa and the Philippines at the bottom of the list. Their recent governmental changes were not characteristic of the historical process of revolutions. ∎

Country	Before change	After change	Year of change	Manner of change
Argentina	Military Dict	Democracy	1983	Peaceful
Belize	Colony	Democracy	1981	Peaceful
Bolivia	Military Dict	~Democracy	1979	Peaceful
Brazil	Military Dict	Democracy	1985	Peaceful
Chile	Military Dict	Democracy	1990	Peaceful
Colombia	Democracy			
Costa Rica	Democracy			
Cuba	Military Dict			
Ecuador	Military Dict	Democracy	1979	Peaceful
El Salvador	Military Dict	~Democracy	1980-92	Bloody
French Guiana	Possession			
Guatemala	Military Dict	~Democracy	1985	Background violence
Guyana	Democracy			
Nicaragua	Dictatorship	Democracy	1978-90	Bloody
Panama	Military Dict	Democracy	1989	US Military Intervention
Paraguay	Military Dict	Democracy	1989	Peaceful
Peru	Military Dict	~Democracy	1980	Peaceful
Suriname	Military Dict	~Democracy	1985	Peaceful
Uruguay	Military Dict	Democracy	1984	Peaceful
Venezuela	Democracy			
Greece	Military Dict	Democracy	1974	Peaceful
Philippines	Dictatorship	Democracy	1986	Peaceful
South Africa	Apartheid	Democracy	1991	Peaceful

of government structurally similar to that which existed before. This pattern was exemplified by the French and Russian revolutions, but has been realized more recently in the revolution in Iran (1970s). It may be necessary to point out that the American Revolution was actually a war of independence rather than a revolution and did not follow this pattern. The historical pattern of revolutions suggests that there are underlying reasons for a dictatorial form of government. A desire for change does not necessarily eliminate these underlying causes. In contrast,several of the recent revolutions occurred in a peaceful manner and resulted

in structural changes in government. Of particular interest was the revolution in the Philippines, where violence was imminent but was averted. While violence did occur in some other revolutions, the pattern of these transitions, and their consistent outcome, may suggest a change in the underlying factors.

2. *Communism*—During the late 1980s the Soviet Union and the Soviet bloc disappeared along with communism as it was known before (Fig. 9.4.1). This dramatic change did not occur in any obvious way as a result of external forces, such as the military ones that characterized geopolitics during most of the twentieth century. Instead it appeared to occur as a result of internal forces. The change occurred peacefully. The change was a great surprise to most observers, as was the lack of violence. The surprise suggests and is consistent with the observation that this process did not fit previous patterns of governmental change. Moreover, once the change occurred, in hindsight it appeared inevitable. Internal weaknesses, and particularly an inability to maintain an effective modern economy, seemed to doom the government. Effectiveness was measured by the ability to supply citizens with products ranging from necessities to advanced technology. The system appeared to simply break down. Since this change, other communist governments around the world, with the exception of Cuba and North Korea, have relinquished control over their economies. This is particularly apparent in China, which still maintains a form of communist government but allows a rapidly growing free market economy.
3. *Privatization in democracies*—Democracies are less centrally controlled than countries with other forms of government. There are still ways in which elected governments exercise control. Control is exercised through government-run services and industries, taxes and purchases, and regulations. These should not all be considered equivalent. One way in which control was recently reduced in democratic countries throughout the world is through privatization of government-run industries. In the United States there were few government-run industries to begin with, so this has not been as manifest. On the other hand, there has been privatization of governmental services. Even garbage collection/recycling has been privatized in many communities.
4. *Decrease in proportion of U.S. government to economy*—The total amount of taxes and the federal budget, as a fraction of the U.S. economy, has not changed significantly in recent years. However, this includes a growing proportion of the budget devoted to social security and interest on the national debt. These are parts of the budget over which little control is exercised. If we measure the size of the government by purchases that are more directly controlled, and that affect the direction of economic activity, then the picture is quite different. Recently the fraction of the economy represented by governmental purchases has declined significantly (Fig. 9.4.2).
5. *Decrease in proportion of large corporations to the economy*—The proportion of the economy that reflects the activity of the largest corporations has decreased in

Figure 9.4.1 A map of the nations that resulted from the breakup of the Soviet Union. All of the unshaded nations were part of the Soviet Union prior to 1989. The dark shaded areas, prior to 1989, were part of other countries governed by communist regimes that collapsed just before the Soviet regime. Most of these countries were part of the Soviet bloc of nations whose policies were strongly affected by Soviet policy. The change in the governmental structure of the region that occurred during the years 1989–91 was dramatic, unprecedented, largely unanticipated, and in retrospect appeared inevitable. (Adapted from a map produced in 1995 by the United States Central Intelligence Agency). ∎

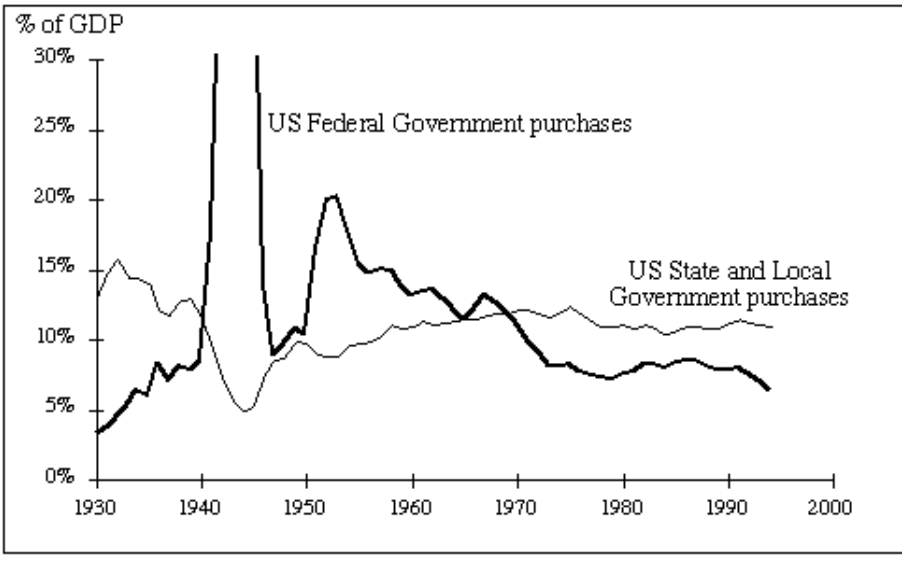


Figure 9.4.2 Size of the U.S. federal government measured by purchases as a fraction of the total U.S. economy (GDP — gross domestic product). By this measure, the federal government has declined in size since the mid-1950s. For comparison the aggregate size of state and local governments is shown (source: Bureau of Economic Analysis, U.S. Department of Commerce). ∎

recent years.One company that for many years was considered to be the basis of the economy is General Motors. It used to be said, "What's good for GM is good for the country." This was not only because this company was large as measured by sales, but also because the number of its employees was a significant fraction of the workforce. The proportion of the workforce employed by Fortune 500 companies as a function of time is shown in Fig. 9.4.3. We note that the changes in corporation size in this and the next two points are only relevant to our argument as long as the companies are centrally controlled. We will address whether they are in point 8.

6. *Systematic downsizing of large corporations*—Since the late 1980s the predominant process in corporation change has been downsizing. More generally, the economy has followed a time-dependent behavior that results in better and worse times, both for the economy as a whole and for individual corporations. These somewhat cyclical variations have been superimposed on a general trend toward increasing value—expansion—of the economic activity. In previous decades, some corporations followed these trends by increasing and decreasing employment when sales increased and decreased. This is to be contrasted with recent trends. During the late 1980s and early 1990s corporations systematically de-

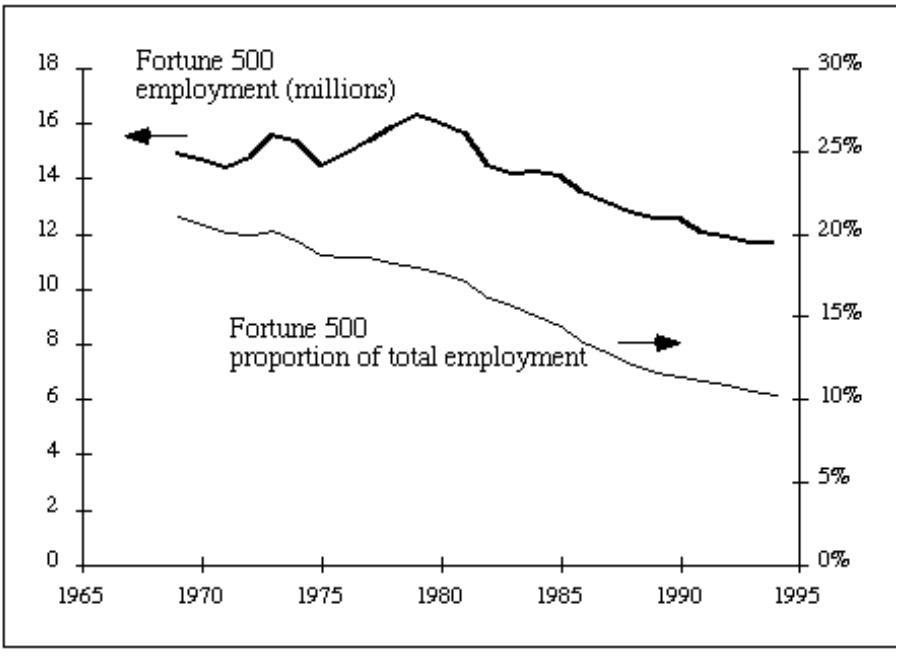


Figure 9.4.3 Total employment of the 500 largest U.S. corporations as compiled by *Fortune* magazine. Since the early 1980s the total employment of the largest companies has declined. Starting much earlier, it has declined as a fraction of the total U.S. employment (source: D. Birch, Cognetics Inc.). ∎

creased the number of their employees,almost independent of whether general expansion or contraction was occurring. This reduction is counter to the previous dominant trend of increasing numbers of employees. In prior times, increased profitability of a corporation was assumed to be based upon increased numbers of employees. This seems natural,since a greater number of employees implies greater production, greater market share and profits. In contrast, at the present time,improved profitability appears to be based on reducing the number of employees. Production appears to be largely unaffected by major cuts in employment. This suggests that changes in the underlying mechanisms of production have occurred.

7. *Growth of small corporations*—While large corporations have systematically decreased in size, certain small corporations have increased in size. In recent years, jobs added by rapidly growing companies have more than compensated for the loss of jobs in large corporations. In the meantime, this suggests a turnover of corporations rather than a change in the nature of corporations. Thus we could interpret the changes in the economy as reflecting a transition to a service or information economy, where the new large corporations are merely different in

their products from the industrial corporations of the past. We will not adopt this approach, because there are more fundamental changes that appear to be occurring in the management of corporations.

8. *Changes in corporate management*—There have been a number of changes in recent years that suggest a detachment of upper-level corporate management from production activities, and a redistribution of decision making within corporations. Upper-level management in many corporations has been active primarily in acquisitions and mergers that often have little to do with company operations. In the past, progressively larger corporate bureaucracies appeared to be an essential part of a corporation. Currently, the downsizing discussed in point 6 is often primarily at the expense of the bureaucracy. Management approaches such as total quality management (TQM) are based on decision making arising from teams of employees rather than directives passed down from upper management. In some cases, individuals or small groups are assigned greater responsibility for the profitability of their own work and consequent decision-making power. This implies that the corporation acts not in the manner of a single entity but more as a collection of individuals interacting in part through the external market system. In other cases, the coordination of employee activities within a corporation are implemented through process-oriented corporate restructuring, which relies upon distributed decision making.

9. *Boundaries of corporations*—A related development that diminishes corporate control is the existence of porous corporate boundaries. A corporation's activities include subcontracting, and hiring consultants and temporary employees. Companies focus on core technologies and "outsource" other aspects of their activities. A single company is also typically formed out of many smaller groupings of individuals. One of these groups may produce a product, while a second group may use a similar product purchased from a different corporation.

10. *Military control restructuring*—Even in the military, generally understood to be a strictly hierarchical structure, there is significant local independence. One example of this is described by General Norman Schwarzkopf in his autobiography. In discussing logistical activities, he writes, "US logistics officers in the field could never tolerate an unresponsive centralized decision-making process. Every unit …[had its own logistics officer]…to take care of his troops." (in H. Norman Schwarzkopf with P. Petre, *H. Norman Schwarzkopf: The Autobiography: It Doesn't Take a Hero* [Bantam Books, New York, 1992], p. 423, see also pp. 358–363). The process of decentralization of control has continued with development of decision teams and military hierarchy flattening—applications of TQM and reengineering within the military.

11. *Individual loss of dominance*—A recent topic of discussion is a change in interpersonal relations both in the context of conventional control hierarchies and elsewhere. This is especially apparent in the relationships between men and women, and parents and children. There are substantial social forces that are

directed to prevent abuse of power, or even the existence of power, in such interpersonal contexts. This has also given rise to the phenomenon of the "angry white male," who according to reports is faced with the loss of power and control.

9.4.2 *Hierarchy versus the individual*

Why is there a change away from hierarchical and centrally controlled structures? We start by considering the effects of technology on the abilities of an individual. We consider the impact of technological change because it is an important driving force in modern civilization, as it was in the industrial revolution. Moreover, individual empowerment is traditionally a natural counterpoint to the control hierarchy. In this context, empowerment is the ability to perform tasks with the aid of technology. We will find, however, that this approach is less than satisfactory.

The effects of technological advance on the abilities of an individual can be attributed to at least seven major interdependent areas of progress:

1. Knowledge—the availability of shared information and tools.
2. Energy—the availability of energy and mechanisms for using it to achieve tasks.
3. Transportation—rapid movement of individuals as well as materials and products.
4. Computation—particularly its decentralization in the form of personal computers.
5. Duplication and storage—mass production, printing, electronic reproduction and storage.
6. Communication—telephone, mass communication, computer networks.
7. Health—well-being through medical knowledge and technology.

How can we quantify the effect of technology on the abilities of an individual? One approach is through the notion of slave-equivalents. It was suggested, as early as the late 1970s, that U.S. citizens could think of themselves as slaveholders owning the equivalent of roughly 10,000 slaves. This figure was based solely on per capita energy consumption, and the corresponding number of slaves that would expend the same amount of energy. By such an estimate today, not for energy consumption but for computations by computers and other tasks facilitated by technology, we would reach a number of slave-equivalents many orders of magnitude higher. This suggests that modern technology greatly empowers individuals to perform tasks through control over the equivalent of large armies of slaves.

What should be the consequences of these advances on human organizations? There would seem to be several possibilities. The first is that the increased abilities could lead to independent and self-sufficient individuals,each providing for his or her own needs. Examples of such behavior do exist, but it is not the dominant trend. The second is that these abilities could enable dictators,CEOs, etc., to control more effectively. This projection was manifest in the dystopian novel *Brave New World,* by Aldous Huxley. However, this projection is counter to the evidence discussed above.

Instead,a third possibility appears to be happening—the formation of networks of interdependent individuals.

A tentative argument for a transition to networks based on technological developments would require several steps, not all of which are obvious. An individual is empowered by the development of tools. These tools allow an individual or small group of individuals to perform tasks that would previously have been possible only for a larger number of people, or would not have been possible at all. As a consequence,individuals can perform complementary and diverse tasks. This results in an increasing complexity of activity. The diverse individual activities are difficult to control because it is impossible for an individual to know how to control and coordinate many diverse activities. At the same time,the coordination of activities through a network becomes possible through advances in communication.

This argument does not withstand detailed scrutiny. However, we can extract from it that the quantity that can be tied most directly to a loss of effectiveness of central control is complexity. Simply stated, the complex behavior of a collection of individuals is impossible for one individual to control. This argument is described more thoroughly in the following section.

9.4.3 *Hierarchy versus network: A complexity transition*

We have argued that a dramatic change is taking place—the hierarchical structures that have been part of human civilization for thousands of years are disappearing. What are the underlying changes that have taken place that might result in this transition? Why is it happening now? What are the primary driving forces? How are they related to the progression in development of civilization? In the following paragraphs we begin to address these questions in the context of our study of complex systems and particularly through the quantitative concept of complexity and the complexity profile developed in Chapter 8.

In order to understand why hierarchical structures are disappearing, we must first understand what the hierarchical structure represents from the point of view of complex systems.Our studies of other complex systems in previous chapters did not reveal such structures. Structural hierarchies were discussed in Chapter 2, but not control hierarchies. The essential point is that the nature of a hierarchically controlled system requires that the behavioral complexity of the controlled group is smaller than the controlling individual. Thus,a hierarchical system implies a limit to the complexity of the collective behavior on whatever scale and in whatever aspect the control is exercised. To understand this further we turn to our discussions of the complexity profile in Section 8.3.

An extreme example of a hierarchical control structure is when a single individual is in direct (absolute) control over the behavior of a large number of other individuals. Biologically, such control structures exist—for example, the collective contraction of the cells of a muscle in response to control by nerve cells. It is apparent that the descriptive complexity of the muscle contraction is not larger than the descriptive complexity of the nerve cell activity that triggers the contraction. However, this analysis is missing the essential discussion of scale. Thus we might consider the

complexity profile of a muscle compared to that of a single muscle cell or the nerve cell that is directing it. This is similar to our discussion of the complexity profile of coherent movement in Section 8.3.5. There, we contrasted the complexity profile of coherent motion with that of incoherent motion. Incoherent individuals with a complexity C_0 on their scale L_0 would have a very small collective complexity on the collective scale L_1. The collective complexity was increased in two steps. First, the pattern of behavior of the individual was modified to be simpler on the scale L_0, but fully visible and thus more complex on the scale L_1. This resulted in an individual complexity $C_0' < C_0$ at both scales. Second, the movements of different individuals were made coherent. Under these circumstances, the collective complexity at the scale L_1 was larger, but it was bounded by the simplified individual complexity C_0'. Because the individual behavior must be simplified in order to be visible on the larger scale, the collective behavior on all scales is simpler than the potential behavior of an individual.

Using this model, we can also understand both similarities and differences between two classic forms of human organization associated with the exercise of control: military force and factory production. Conventional military behavior is closer to our discussion of coherent behavior and large-scale motion in the model in Chapter 8. Similar to this model, in the military the behavior of an individual is simplified to follow a limited set of patterns. The behaviors—such as long marches—are designed to be visible on a larger scale. Then, many individuals perform the large-scale behaviors coherently. Consistent with our discussion of changes in the modern military, this model is better used to understand the activities of ancient armies—Roman legions, or even U.S. Civil War armies—than many types of modern military activity.

A conventional industrial production line also simplifies the behavior of an individual. Each individual performs a particular repetitive task. The effect of many individuals performing repetitive tasks results in a large number of copies of a particular product. However, both the simplification of behavior and the coherence is not the same as in the military model. The actions of each individual are not visible on a larger scale, and all individuals do not perform the same actions. Instead, the activities of the individual are coordinated to those of others so that the larger-scale behavior can arise. Thus, there is a relationship between the actions of different individuals that serves in place of direct coherence. As with the military model, the factory model we are describing is more appropriate to early versions of the factory and less appropriate to modern factory production. The differences between the factory and the military model are relevant to our understanding of the role of hierarchical control, which we now discuss.

We must now expand our understanding of complexity profiles in order to describe control hierarchies. It is important to recall that a complexity profile describes the complexity of the entire system, but at different scales of observation. A military force, a corporation, or a country has a collective behavior on various scales, including the scale of the system as a whole. While we have discussed ways to define the scale of observation of behavior in Section 8.3, it is not essential that we use a formal definition to appreciate the concept of collective behavior at the scale of the entire system.

At this scale, many of the details of the behavior of individuals are not apparent. In this context we can understand that a control hierarchy is designed to enable a single individual (the controller) to control the collective behavior, but not directly the behavior of each individual. Indeed, the behavior of an individual need not be known to the controller. What is necessary is that there be a mechanism for ensuring that control over the collective behavior be translated into controls that are exercised over each individual. This is the purpose of the control hierarchy.

We can thus draw a complexity profile for a system controlled by a hierarchy (Fig. 9.4.4). We assume, as is the case in human control hierarchies, that the maximum complexity of any individual in the hierarchy is essentially the same value C_0. There are two reference complexities—the maximum complexity of an individual on his or her scale C_0, and the "ideal" complexity of N individuals NC_0. We can understand the complexity profile of a hierarchy by comparison with the model of coherent behavior—the

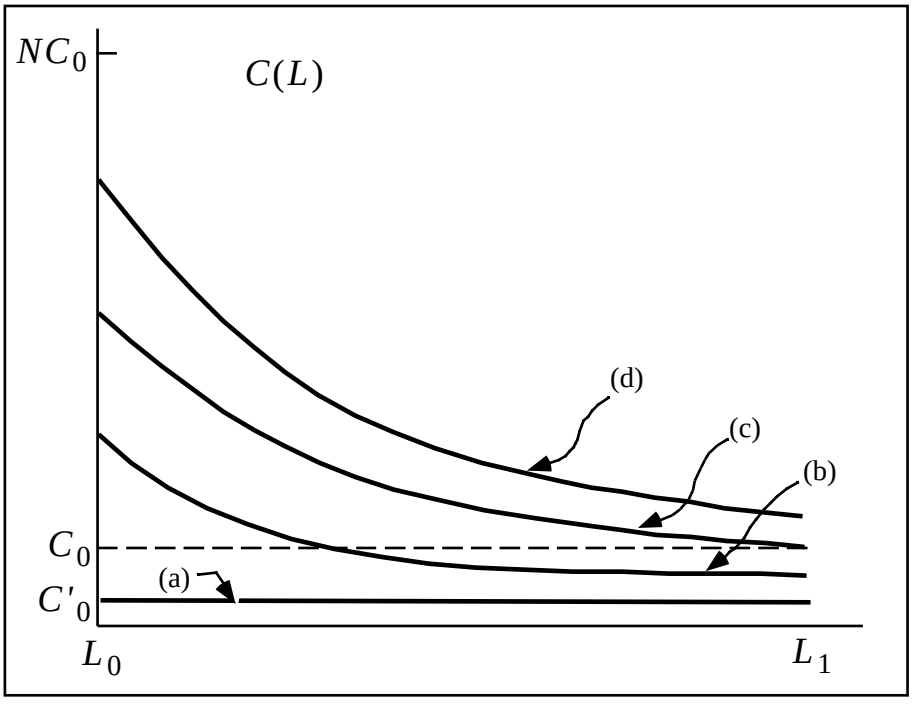


Figure 9.4.4 Comparison of schematic complexity profiles of collective systems that are controlled in distinct manners. The maximum complexity of an individual C_0 is indicated by a dashed line. The scale of an individual L_0 and the scale of the collective L_1 bracket the scales that are shown. The individual curves are as follows.(a) Coherent behavior of simplified individuals, with complexity C'_0, whose entire behavior is visible on the collective scale. (b) A system coordinated by a control hierarchy. (c) A system that has the maximum complexity a control hierarchy can achieve. (d) A network which has emergent collective behavior of higher complexity than an individual. ∎

simplest control hierarchy. There are two primary differences between them that pertain to the complexity at the scale of the individual and at the scale of the collective. These differences can be understood by reference to the factory model.

The first difference is that the complexity on the scale of the individual—the complexity of describing the behavior of all of the individuals—can be higher for the control hierarchy. Indeed, the complexity on the scale of the individual can be much larger than C_0. There are two reasons for this. First,since the behavior of each individual need not be manifest on the scale of the collective, it need not be limited by a specific smaller complexity C_0' and may be closer to the maximum complexity C_0. Second, the behavior of different individuals is not the same; therefore describing one individual is not enough to describe what all the individuals are doing. Thus, the complexity of describing all of the individuals on the scale L_0 may be greater than C_0. There is, however, a limit to the complexity at the scale of the individual—it must be significantly smaller than NC_0. This limitation arises because the individual behaviors must be correlated so that the collective behavior can arise. The correlation/coherence/coordination of different individuals is imposed by the hierarchy. The assumption is that lateral communication is not essential for the functioning of the system, and therefore does not play a role in creating the correlations that enable the collective behavior to occur.

The second difference is that the complexity on the scale of the entire system can be higher than C_0'—the complexity of the simplified individual designed for coherent actions. Since the individuals do not act coherently, the complexity of their actions is not directly related to the complexity of the system. What is not changed, by the existence of the hierarchy of control,is that the complexity on the scale of the collective must still be smaller than C_0, because this is the complexity of the controlling individual—a group of individuals whose collective behavior is controlled by a single individual cannot behave in a more complex way than the individual who is exercising the control. This must be true as long as the individual exercises control over the collective behavior. Thus, while the complexity of the whole can be larger than the simplified individual C_0', it cannot be larger than the maximum complexity of an individual C_0. We can now understand why control hierarchies did not appear in our earlier studies of complex systems in previous chapters. In those studies, we were interested in the emergence of complex collective behavior from simple individuals. Hierarchical control structures are symptomatic of collective behavior that is no more complex than one individual.

The limit we have established on the collective complexity of a hierarchy does not yet explain why such hierarchies should disappear. More generally, we would like to understand the forces that cause changes in human organizations over history. To understand this we must understand that corporations and other human systems exist within an environment that places demands upon them. If the complexity of these demands exceed the complexity of a system,the system will fail. Thus,those systems that survive must have a complexity sufficiently large to respond to the complexity of environmental demands. As a result,a form of evolutionary change occurs due to competition between organizations. As discussed in Chapter 6, such competition is a nat-

ural process by which complexity may increase. While the detailed process of evolution involving processes of reproduction, variation and selection can be discussed in the context of human organizations,our purposes are served by simply postulating a progressive complexity of the collective behavior of organizations. This is a self-consistent statement, because the environment itself is formed out of organizations of human beings. Thus, there is a self-consistent process of complexity increase where competition between organizations causes the complexity of one organization to serve as the environment in which others must survive. Using the progressive increase of complexity, we can understand the nature of the transition that is under way. To do this we must assume that the complexity of demands upon collective human systems have recently become larger than an individual human being. Once this is true,the hierarchy is no longer able to impose the necessary correlations/coordination on individuals. Instead, interactions and mechanisms characteristic of networks in complex systems like the brain are necessary.

We can now make a powerful connection between the apparent transition toward networked structures from hierarchical structures in the economy and in society and our discussion of human civilization as a complex organism. The transition is consistent with a collective behavior that is more complex than the behavior of an individual. Thus, it implies that various collectives of human beings are now behaving in a manner that is more complex than an individual. This statement could not be made tens or hundreds of years ago. The breakdown of hierarchies at scales up to essentially the scale of civilization as a whole (e.g., the Soviet Union) is consistent with our observation of the recent increase in interdependence of civilization,and the conclusion that civilization is a complex organism. We will pursue this discussion further in the following section.

Question 9.4.1 Consider the properties of a hierarchical organization in response to its environment. How does this contrast with sensorimotor response in an animal?

Solution 9.4.1 In a hierarchical organization, there are various sources of information that might affect the organization's behavior. The information that is obtained about the environment generally flows up the hierarchy. The response to this information may occur at any level of the hierarchy, but this response can only involve the part of the organization that is under the control of the manager that directs the response. If the entire organization must respond to the information,the information must reach the individual who controls the entire organization. Thus the rate of response of the organization is limited by the rate of response of the individual in control,and his or her complexity as indicated above.

The sensorimotor system in an animal also involves a process of filtering of the necessary information. However, the response is dictated by the collective behavior of the network, and is not dependent on a single individual component, i.e., on a single neuron. ∎

9.4.4 *Historical review of the complexity transition*

If we review history, we can see how the development of hierarchies enabled progressively more complex behaviors up until the present time, when this process broke down in favor of networks (Fig. 9.4.5). There are two complementary aspects to the development, complexity at the scale of the individual and at the scale of the collective. In general they do not relate directly to each other. In the context of a control hierarchy, however, there is an association of greater complexity of the individual behaviors with greater complexity of the collective behavior.

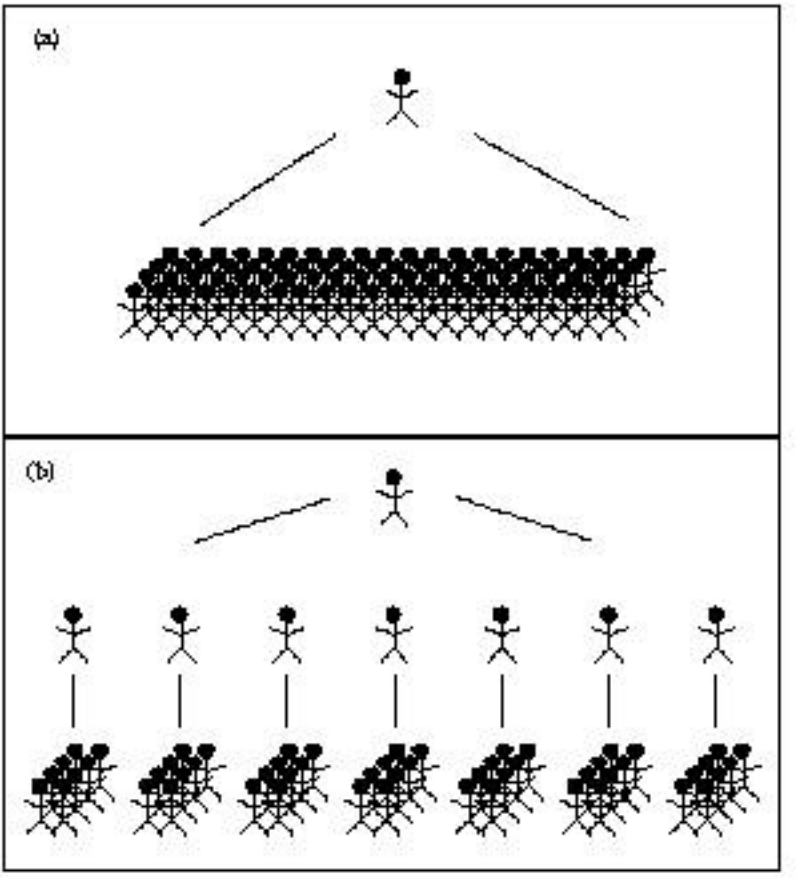
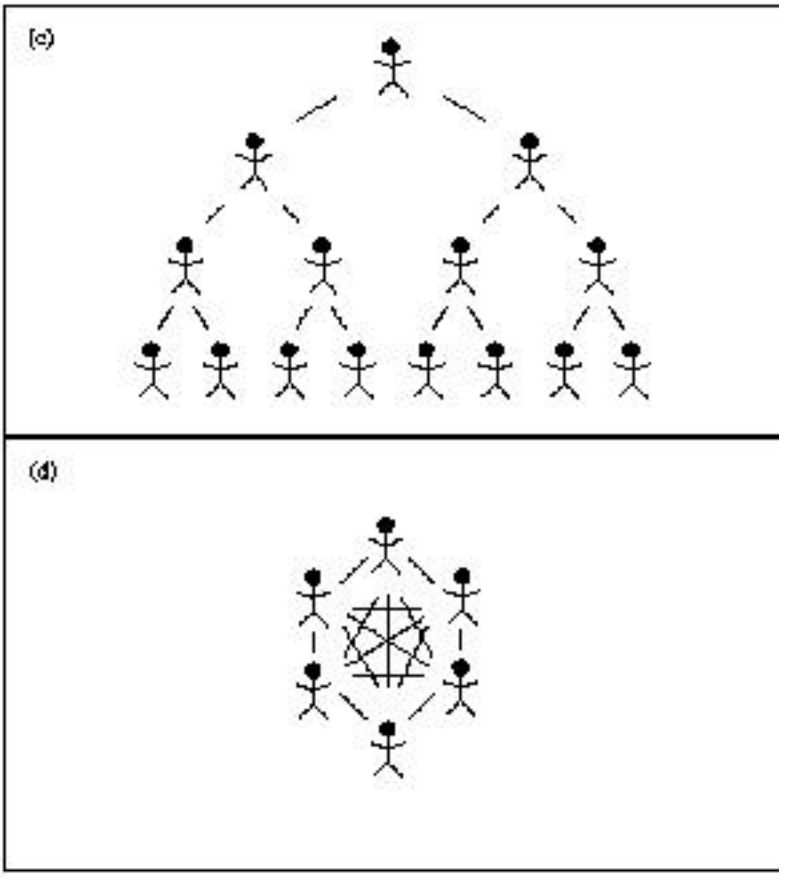


Figure 9.4.5 A brief history of human organizations capturing the effect of increasing collective complexity as illustrated in Fig. 9.4.4. (a) In the first stage a single individual directs the behavior of a large number of other individuals. This coordinates their activities, which are simple when viewed individually and collectively. (b) As the organizations become more complex, intermediate layers of hierarchy are added to the control structure. They filter information about the activities of the workers so that only a simplified picture of the activities reaches higher levels. They also elaborate the directives given by the higher levels so as

Ancient empires replaced various smaller kingdoms that had developed during a process of consolidation of yet smaller associations of human beings. The degree of control in these systems varied, but the progression toward larger more centrally controlled entities is apparent. As per our discussion of the difference between independent individuals and coherent behaviors, this led to a decrease of complexity of behavior of many individuals, but a more complex behavior on the larger scale.

During the time of ancient empires,large-scale human systems executed relatively simple behaviors, and individuals performed relatively simple individual tasks that



to implement them in the workers' activities. This control structure is effective only if the collective behavior can be meaningfully simplified. (c) The transition occurs when the collective complexity exceeds the maximum complexity of an individual. Then, filtering of information on the way up, and elaboration of directives on the way down, are ineffective. (d) The system structure becomes a network of individuals exerting mutual influence similar to other systems with complex emergent collective behavior. ∎

were repeated by many individuals over time to have a large-scale effect. This applies to soldier armies,as well as slaves working in agriculture, mines or construction. The scale of ancient empires controlled by large armies,as well as the scale of major projects of construction, would be impressive if performed today. However, the activity was simple enough that one individual without much of a hierarchy could direct a large number of individuals. The scale of activity was possible, without modern technology, because of the large number of individuals involved. Thus, hierarchies had a large branching ratio—a large number of controlled individuals for each controller.

As time progressed, the behavior of individuals diversified as did the collective tasks performed by them. Diversity of individuals implies that the behavior of the entire system on the scale of the individual became more complex. This required reducing the branching ratio by adding layers of management that served to exercise local control. As viewed by higher levels of management, each layer simplified the behavior to the point where an individual could control it. The hierarchy acts as a mechanism for communication of information to and from management. In our perspective,the role is also a filtering one, where the amount of information is reduced on the way up. Conversely, commands from the top are elaborated (made more complex) on the way down the hierarchy. As the collective behavioral complexity at the scale of an individual increases,the branching ratio of the control structure becomes smaller and smaller so that fewer individuals are directed by a single manager, and the minimum possible number of layers of management increases. The formation of such branching structures allows an inherently more complex local behavior of the individuals, and a larger complexity of the collective behavior as well.

However, at the point at which the collective complexity is the maximum individual complexity, the process breaks down. Hierarchical structures are not able to provide a higher complexity. We can recognize,however, that a hierarchy serves to create correlations in the behavior of individuals that are similar in many ways to the behavior of a network. The hierarchy serves as a kind of scaffolding for creating a complex system. At the complexity transition, it becomes impossible to exercise control, so the management effectively becomes divorced from the functional aspects of the system. Lateral interactions that replace the control function must be introduced. These interactions act like those of other networks to achieve the correlations in behavior that were previously created by management. As such mechanisms are introduced,layers of management can be removed. Over the course of the transition, the hierarchy exercises control over progressively more limited aspects of the system behavior. Some of the behavior patterns that have been established through the control hierarchy may continue to be effective; others will not, since an increase in system complexity must come about through changes in behavior. Among these changes are the coordination mechanisms themselves, which must be modified to involve lateral interactions. It could be argued that this picture describes much of the dynamics of modern corporations. Upper levels of management have often turned to controlling fiscal rather than production aspects of the corporation. Corporate downsizing has often been primarily at the expense of the middle management, with a subsequent lowering of payroll and little change in production. Hierarchical control has been re-

placed by decision teams that are introduced by corporate restructuring; and the reengineering of corporations has focused on the development of processes that are task related and do not depend on direct hierarchical control.

Ultimately, the development of greater complexity of collective behavior must continue to involve correlations/coordination of activities of various individuals. Without central control, coordination involves groups of interacting individuals achieving a collective behavior both through external influences and through mutual agreement. Among the many forms of modern corporations discussed are adhocracies, virtual corporations and networked corporations. Some of these structures may act similarly to the networks we used to describe the brain in Chapter 2. However, it is not likely that we understand at this time the various forms that coordination networks may take.

Using this argument we can understand in a straightforward way why control structures ranging from communism to corporate hierarchies could not perform the control tasks required of them in current times. As long as the activities of individuals are uniform and can be simply described—for example, soldiers marching in a row, or manufacturing workers producing a single product by a set of repetitive and simple activities (pasting eyes on a doll,screwing in bolts)—control can be exercised. The individual's activities can be specified once for a long period of time, and the overall behavior of the collective can be simply described. The collective behavior is simple when it can be summarized using a description of a simple product and the rate of its production. In contrast, central control cannot function when activities of individuals produce many products whose description is complex; when production lines use a large number of steps to manufacture many different products; when the products vary rapidly in time; and the markets change rapidly because they themselves are formed of individuals with different and rapidly changing activities.

It is useful to distinguish networks that coordinate human activity from markets that coordinate resource allocation. Markets are a distinct type of system that also results in an emergent collective behavior based upon the independent actions of many individuals. Markets such as the stock exchanges or commodity markets coordinate the allocation of resources (capital,labor and materials) according to the dynamically changing value of their use in different applications. Markets function through the actions of many agents (individuals, corporations and aggregate funds).Each agent acts according to a limited set of local objectives, while the collective behavior can coordinate the transfer of resources across many uses. Markets are distinct from networks in that they assume that the interactions among all agents in regard to a single resource can be summarized by a single time-dependent variable, which is the value of the relevant resource.

To illustrate the problem of central control of a complex economic system, we might consider examples of the problem of resource allocation. An example might be the supply of oil to a country. For an individual to allocate the supply of oil,all of the needs of different users in amounts and times, the capabilities of different suppliers, and the transportation and storage available must be taken into account. Even if one were to suggest that a computer program might perform the allocation, which is

recognized as a formally difficult computational problem, the input and output of data would often eliminate this possibility. One of the crucial features of such an allocation problem is that there are both small and large suppliers and small and large users. As the number of independent users and the variation in their requirements increases,the allocation problem becomes impossible to solve. At the same time,a market is effective in performing this allocation with remarkable efficiency.

A more familiar example, which in many ways is more salient,is the problem of food supply to a metropolitan area. The supply of food is not a market,it is a network based upon a market structure. In a metropolitan area, there are hundreds to thousands of small and large supermarkets,thousands to tens of thousands of restaurants, each with specific needs that in the optimal case would be specified by immediate requirements (on demand) rather than by typical or average need over time. The suppliers of foods are also many and varied in nature. We might start by considering general categories of foods—produce, canned goods, baked goods, etc. The transportation and storage requirements of each are subject to different constraints. The many types of vehicles and modes of transportation represent another manifold of possibilities. The market-based system achieves the necessary coordination of food supply without apparent hitch and with necessary margins of error. To consider conceptually the dynamic dance of the supply of food to a city that enables daily availability is awe-inspiring. Even though there are large supermarket chains that themselves coordinate a large supply system, the overall supply system is much greater. When we realize that this coordination of effort relies upon the action of many individuals,it gives meaning to the concept of emergent behavior. We can also understand why in a centrally controlled system, consistent and adequate food supply becomes a problem. In order to have any hope of controlling such a supply problem, it would have to be simplified to allow for only a few products in only a few stores. These were well-known characteristics of food supply in communist regimes. They were seen to reflect the general economic ineffectiveness of such forms of government. In this context we see that the connection is quite direct. While considering the allocation problem in the context of food supply may illustrate the problems associated with central control, the same argument can be applied to various resource allocation and other coordination problems in large and small corporations.

In conclusion, the result of this discussion is that we can understand the implication of the disappearance of central control structures. The implication is that the behaviors of collections of human beings do not simplify sufficiently to be controlled by individuals. Instead of progressive simplification from an individual to larger and larger collections of individuals, we have the opposite—an increasing complexity that is tied to an increasing complexity of the demands of the environment. This makes it impossible for an individual to effectively control collective behaviors. While specific individuals have been faulted for management errors that have led to corporate failures,the analysis we have performed suggests that it is inevitable for management to make errors under these circumstances.

In Chapter 8 we estimated the complexity of various systems by several approaches. The first approach used linguistic descriptions, either imagined or actual,

of the systems. The complexity of a human being was estimated to be roughly 30 books (10^8 bits)—the length of an encyclopedia. If we consider the functioning of the global economy and the behavior of its intermediate scale components (corporations, states, etc.) we can readily see that the complexity of its description using language is much larger than the estimate given for a human being. This conclusion may apply to a single product manufactured by a single company. The number of pages of text necessary to describe an airplane, a car, a computer or the processes necessary to produce them would exceed the length of an encyclopedia. It is generally acknowledged that large computer programs exceed the ability of a single person to understand. The UNIX operating system, found on many computers, requires a storage of 4×10^9 bits, which is comparable to our estimate of human complexity. This is only a very small part of the information necessary to describe the operation of civilization. Estimates of complexity of a product or an operating system are relevant to understanding the complexity of the internal functioning of civilization. This does not by itself imply that the complexity of the behavior of collections of human beings is of this size. Thus, more directly relevant to obtaining an estimate are: the inability of one individual to coordinate human activities, the apparent breakdown of central control, and the manifest interdependence of human civilization. As we have argued in the previous chapter, an actual estimate of the complexity of civilization should be impossible for an individual to obtain if the human being is less complex than civilization.

Finally, we can rethink our previous discussion of the global economy and global civilization in this context. In Question 9.3.3 we discussed the growing interdependence of the global system. This interdependence is directly related to increasing complexity. After all, it is precisely the dependence of events in one place on events in another place that leads to much of the complexity that affects all decision making. Thus, we have established a connection between increasing global interdependence, increasing complexity, and the breakdown of hierarchical control in political and economic systems. What is still missing is a realization of the implication that global human civilization is manifestly a complex organism in relation to which we, as individuals, are elementary parts.

9.5 Consequences of a Transition in Complexity

The result of our discussion up to this point is the suggestion that a complexity transition is occurring in human civilization at this time. Prior to the transition, the complexity of various organized structures of human beings was less than the complexity of the individual; now the organized structures have greater complexity. When we say there is a growing complexity to life, this appears to be justified. What are the consequences of such a transition? The disappearance of central control is one that we have discussed and utilized to argue the existence of the transition. There are other important consequences. We will discuss these in two parts (Section 9.5.1 and 9.5.2). The first part is the consequences for an individual human being in the context of an environment that has recently become more complex than himself or herself. The second part reflects the relationship of human civilization as an organism to the

individual human being. When we consider an individual in the context of a more complex environment, we find a strong motivation for specialization and for insecurity. When we take into account the relationship of the human organism to the human individual, we find reasons to eliminate the insecurity.

9.5.1 *Consequences for the individual*

We can develop a perspective on the complexity transition by recognizing that until the present, an individual human being was,as far as we know, the most complex organism. We pointed out in Chapter 8 that the demands of survival are much simpler than a human being. How are we to understand the consequences of the existence of a more complex organism which is now the environment of individual human beings? We consider the circumstances of other organisms that are in environments more complex than themselves. Most animals are simpler than the environment in which they live. They survive by limiting their exposure to the environment—restricting themselves to only a limited part of the possible environments that might be found. This results in a substantial simplification. A second strategy is to reproduce rapidly, where the excess reproduction compensates for low probability of individual survival.

The former strategy can be applied to human beings. We can anticipate that individuals will specialize professionally and socially so as to limit their exposure to the complexity of modern civilization. The degree of professional specialization has been increasing. Specialization occurred because of the existence of an increasingly large body of knowledge. This can be understood by comparing the number of books in the Library of Congress, 10^7, with the number of textbooks (courses) in a college education,30. The existence of a large amount of knowledge does not necessarily mean that all of the knowledge is relevant to the functioning of human civilization. However, for other reasons discussed in this chapter, we see that the functional complexity of civilization has increased as well. This should motivate still more dramatic forms of specialization that relate not only to the information necessary for an individual to know, but also to the nature of his or her interactions with various aspects of the environment.

The complexity of civilization suggests that there are many possible sets of knowledge that an individual might need to know in order to achieve the analog of survival in society—beyond physical survival,this may include other goals such as a successful social and professional life. These sets of knowledge are analogous to ecological niches. In a sense we can consider them to be possible realities. The social and professional reality of one individual may be qualitatively different from the social and professional reality of another individual. This implies, for example,that decision-making strategies cannot be transferred in a simple way from one such reality to another. Moreover, it will be difficult if not impossible for an individual to be suited to more than one such reality. It will be impossible for an individual to address all possible realities. The specific skills inherent in performing a particular task become of crucial relevance to the ability of an individual to perform it. This also implies that education

should be directed toward specific and individualized professions,and that these professions must be well suited to the individual's talents in order to enable success.

One oversimplified way to understand specialization is to consider examples where professional specialization is apparent. We might consider singers or athletes as examples. Viewed in an oversimplified way, we can argue that the existence of mass communications, recording and duplication makes it possible for a few singers to perform for a large number of people. This means that fewer singers are able to support themselves, the few that do are wildly successful, and the competition for the attention of the audience increases. Moreover, there are more opportunities for potential singers to try to sing, and the best of these will be the ones selected. In this way only the best of the best are professional singers. The high degree of competition is equivalent to the selection of one from among many. This corresponds (by information theory) to the high complexity of the tasks involved. In order for an individual to be selected,he or she must be well suited in every way, genetically and educationally, to this specific task. Similar statements can be made about the selection of the best athletes in a particular sport, or in a particular competitive event.

The suggestion that only a few—the best of the best—can succeed in a particular profession is not a complete picture. The intensive competition for a single profession is complemented by the increasing existence of diverse professions,including diverse forms of music,and diverse athletic events,in which different individuals can be successful. Thus, while each niche must be filled by a very specific individual,there are many such niches that are to be filled by distinct individuals. Moreover, this oversimplified view does not take into account the nature of collective behavior. We have chosen examples of professions where individual competition is apparent. By virtue of the nature of human civilization as a complex system,the tasks to be performed occur at many levels of organization and involve various numbers of individuals. Thus, while specialization is essential,the nature of competition as a process of selection is not well described by these professions.

A generally recognized feature of the present economy is a dramatic increase in changes of profession by individuals. This is not restricted to changes in employment, but also reflects rapid changes in projects and activities in a single job. We can attribute this to the rapid development of diversification and the rapid changes of technology. We might consider this as symptomatic of economic restructuring, which may resolve itself and result ultimately in a return to stability. This would be similar to the dislocation in employment and changes of profession that occurred during the industrial revolution. However, we can also consider this process in light of the necessity of placing individuals into occupations (niches) that are best suited to their abilities. In a complex system where diversity of professions is a principal property of the system, it may be essential to have such a dynamic flow of individuals until each finds optimal or near optimal suitability to a profession. This process would occur during the transition,and might not continue afterward.On the other hand,an individual in the complex system may also play a number of different roles, requiring various combinations of skills and capabilities. This would be similar to a network of

neurons with various collective states,each composed out of a distinct set of activities of individual neurons, as discussed in Chapter 2.

Another implication of the complexity transition is a shift in the objectives and goals of individuals. Since control becomes impossible,the traditional goals of achieving authority, power and control become largely obsolete. For many individuals, as well as entire professions, achieving a position of power and control is the definition of accomplishment and fulfillment. We can already see a significant change in popular literature of the United States away from the traditional descriptions of an individualistic superhero/superachiever and toward the description of team players,networks of interacting individuals, and other more cooperative models for behavior. This is true even in circumstances where control appears to be exercised.A good example may be found in the difference between the original *Star Trek* TV series and the subsequent *Star Trek: The Next Generation* TV series, where the importance of crew members, teamwork,specialization, and complementary functions are more prominent. This change reflects the transition we have been discussing, which must be echoed in a change of personal goals and perspectives on success. While our objective is not to place value on developments, we can see that while some may applaud disappearance of the abuses of central control,the loss of the opportunity to exercise authority may be a disappointment in the context of the individual goals of the past. This is consistent with negative emotional reactions when an individual recognizes his or her inability to control, or even to understand, his or her environment.

When we consider an individual encountering a system of greater complexity, we may ask how the individual will model it. The construction of models by a simple observer of complex systems was discussed briefly in Section 8.3.7,and we continue the discussion here. Our discussion is an effort to gain perspective on how an individual human being will understand his or her environment. Any model developed by the individual must remove some features of the more complex system.One possibility is to ignore all but a limited part of the environment. In this case an individual's model of reality denies the existence of many of its aspects. A second possibility simplifies the complexity to a random process. Events are considered to be random, uncorrelated and thus unpredictable. This reflects our understanding that a random process has a low behavioral complexity. Finally, a model may presume associations or relationships that are overly simplified and therefore inconsistent with reality under all but a limited set of circumstances.

The discrepancy between models of reality and the reality itself has implications for individual actions, decision making and attitudes toward this decision making. Individuals are faced with the necessity for making decisions based upon their models of reality; this is the primary reasons for such models. Models take the form of an expectation that particular actions lead to anticipated outcomes. When the models are incomplete,the anticipated outcomes are not always realized.One of the primary conventional human responses to such inconsistency is to learn and adapt by improving the model. This is the usual process of trial-and-error learning. As long as the complexity of the individual is larger than the environment, adaptation can enable the

individual to respond correctly to all circumstances. However, when the complexity of the environment is larger, adaptation becomes less effective.

To understand this point, we consider the behavioral complexity of the individual as a measure of the length of description of his or her pattern of responses to the environment. By our discussion in Question 8.3.8,different responses to distinct environmental conditions must be correlated. The degree of complexity of the individual reflects the extent to which independent responses can be made to distinct conditions. The complexity of the environment is a measure of the complexity an organism needs to survive in the environment. Thus, for an environment with higher complexity, there are more distinct conditions that require independent responses. If a simpler organism adapts to one subset of these conditions, then its responses to others are dictated by this,and are inadequate. Thus, it does not help to adapt to every new condition that arises,since this adaptation causes the individual to lose the ability to respond to conditions that the individual was suited to before. This may explain why simpler animals are not as adaptive as human beings: adaptation is less effective when the organism's complexity is smaller than that of its environment.

There are direct implications for the ability of an individual to perform common and special tasks—to find and retain jobs or conduct interpersonal interactions. We may assume that for many individuals,this inability to develop an effective set of responses to the environment will lead to frustration. Indeed, such frustration has become widespread. We note that in the complex environment, both success and failure are temporary; success at one time does not imply continued success, failure at one time does not imply continued failure.

Another aspect of this problem is the response by one individual to the behavior of another. This has relevance in various aspects of interpersonal and professional interactions. In a complex environment, the reality of one individual may not have a large overlap with the reality of another. We infer that one individual will view another individual as behaving in a random or incomprehensible fashion. Due to the increasing exposure to occurrence of such behavior, individuals may presume that others will not be comprehensible. This may either lead to respect for incomprehensibility or disdain for others. Both are manifest in scientific discourse and are likely to appear in other social and professional contexts.

The increasing specialization of individuals also implies and is consistent with an increasing specialization in sources of information. In this context it might be anticipated that conventional news sources which report on globally important events may become progressively irrelevant to an individual. This occurs because of the general inability of the individual to retain large amounts of information and because of the increasing irrelevance of general news to an individual's decision making. Instead, a system of more individually directed communication is likely to become dominant. In such a system, each individual would be better able to select the nature of information to which he is exposed. This self-consistent process of information exposure and selection may have all of the interesting properties of iterative maps that were discussed in Section 1.1, or self-consistent collective behaviors discussed in Section 1.6.

A better model, however, may be the pattern-formation processes in Chapter 7, in which the pattern of activities of individuals ultimately forms the basis for collective function of the human superorganism.

9.5.2 *Relationship of the individual to civilization*

Thus far our discussion of consequences of the complexity transition has taken the approach of considering an individual human being in the context of an environment whose complexity is greater than him or herself. We now turn toward considering the implications of the relationship between an individual and the complex organism of which he or she is a part. The difficulty in discussing this relationship is the inherent one—that we must assume that we cannot understand the behavior of the collective. Nevertheless, we will attempt to proceed in part by analogy and by assuming that the interdependence of a system and its components has universal implications. We can evaluate the consistency of the conclusions by comparison with observations.

In order to set the stage for this discussion we may note that the number of human beings in the world is of order 5×10^9, roughly comparable to the number of neurons in the brain. No functional analogy between the brain and humanity should be assumed. If we were to adopt a physiological analogy, we might be better off considering the analogy of human beings with mobile cells such as the immune cells in the body. However, there should be no assumption that the physiological analogy can be direct. The main purpose of the numerical analogy is to establish some sense of scale. It suggests that the relationship of an individual to the collective may be much more impressive than we might otherwise assume. The elimination of central control may be only a first step toward the potential complexity of the global system of which we are a part. As long as the human collective did not function as an organism, it played a small role in our perspective on the world, and on our actions. This may change rapidly in upcoming years so that our conscious recognition of this relationship as well as its effects becomes an important part of our existence.

As just described, the various changes that are taking place have led to an increasing sense of insecurity in individuals that are unable to plan for the future in a complex system whose behavior cannot be anticipated. However, when we consider the relationship of a complex organism to its components, rather than an individual in an environment of greater complexity, we see that this insecurity may be only temporary. The complex organisms we know act at least in part to protect and support the existence of their components. We may suggest that the human collective will protect individual human beings. It is likely to protect the individual better than the individual would be able to protect him or herself.

We can test this perspective in the light of historical developments. One way to measure the possibility that the human superorganism will protect individual human beings is through the improvements of life expectancy and quality of life from ancient to modern times. We have argued in the previous chapter that survival of a primitive human was possible because an individual was more complex than his environment. This survival was a statistical one (of order 10%–50% is sufficient) and required only survival to reproductive age. We can contrast this with the ongoing in-

crease in life expectancy and quality of life, particularly during the twentieth century. The improvement in life expectancy occurred first in the West and has been spreading throughout the world. It was achieved through eradication of diseases and other hazards. It originates in technological and social advances that require collective actions of many individuals. This improvement in the human condition does not have as its objective the reproductive success of an individual human being. It is related to collective objectives of societal progress. More recently, collective actions have led to an alleviation of major sources of suffering and death around the world. Famines and natural disasters as well as other forms of social disruption have been addressed by global responses that are historically unprecedented. Moreover, the risk of self-inflicted worldwide cataclysm by nuclear destruction has been dramatically reduced in recent years.

The continued existence of local wars or revolutions in such places as Bosnia and Chechnya may be interpreted as a gap in this argument. The possibility of global conflict may be reduced, but local conflicts appear to continue. This, however, is likely to be temporary, since there is a growing recognition that the main cause of such conflicts—a desire for territory and control—has diminished in importance or practicality. Wealth no longer accumulates from national territory per se. Much of modern wealth is achieved through technological developments in industrial production, services and information. Moreover, from our previous discussion, in many cases control is only possible in name. It is likely that the current local conflicts are a residuum of outdated perspectives. The collapse of the Soviet Union released individuals to act on these perspectives. The individuals involved must interact with the new circumstances in a direct way before they recognize that gain cannot be achieved through military conflict.

At the same time as actions have been taken to alleviate global disease and suffering, there are other developments that increase life expectancy and quality in developed nations. In the United States, deaths from major disease categories, such as heart disease and cancer, have been declining. Deaths from the largest source of accidental death, automobiles, have consistently declined over the last few years. We should contrast the goal of an individual with the goal of the collective in relation to accidental death or death by disease. If we think about the goals of an individual, we realize that it is sufficient to reduce the probability of accidental death to the point where it is unlikely for the individual—say 1 in 100 in a lifetime. From the point of view of the collective, this is unacceptable, because it means that 1 in 100 individuals will die from this cause. We can argue that a new attitude is appearing that the loss of an individual human being has become unacceptable. This is a fundamental change of perspective. A goal of no loss of life is an inherently collective one. Various forms of factory work or building construction are known to have a certain statistical probability of injury or death. These probabilities give rise to a certain number of deaths each year. In the past, this death rate was known and considered to be acceptable. In more recent times goals have been set to reduce the risks to the point where even a single death is improbable. In addition to occupational hazards, this discussion is consistent with standards for product safety (from toys to buildings), where the basic

criteria for safety is not just that products are safe under proper use, but that even improper use does not result in death or injury.

If the collective system serves in part to protect its components—individual human beings—then the relationship between the individual and the complexity of the environment changes. Rather than inducing a continuing struggle for survival, which currently appears to be manifest in the struggle for financial well-being, the collective may accommodate individual needs. There is some evidence for this, though the eventual resolution is not yet apparent. The evidence that exists is in the relative lack of dislocation when compared to the magnitude of changes that are taking place. Whether we consider the collapse of the Soviet Union or the job loss in the U.S. economy, the changes have been dramatic. However, the individual dislocations have been relatively mild compared to what can be easily imagined. In particular, there has not been general violence in the former Soviet Union despite several opportunities. In the United States, despite the dramatic reduction in employment at large corporations, it has been possible for small companies to more than compensate for the job loss. Thus it is possible that the collective organism is functioning constructively to transfer individuals from one framework to another in at least a partially effective manner.

In the context of considering human civilization as an organism in relation to individuals, we should revisit the traditional conflict between individual and collective good and rights. This philosophical and practical conflict manifested itself in the conflict between democracy and communism. It was assumed that communism represented an ideology of the collective while democracy represented an ideology of the individual. If we accept the transition to a complex organism, we may consider this conflict to be resolved, not in favor of one or the other, but rather in favor of a third category—an emergent collective formed out of diverse individuals. The traditional collective model was a model that relied upon uniformity of the individuals rather than diversity. Similarly, the ideology of the individual did not view the individual in relation to the collective, but rather the individual serving himself or herself. It should be acknowledged that both philosophies were deeper than their caricatures would suggest. The philosophy of democracy included the idea that the individualistic actions would also serve the benefit of the collective, and the philosophy of communism included the idea that the collective would benefit the individual. Nevertheless, the concept of civilization as an emergent complex organism formed out of human beings is qualitatively different from either form of government.

9.6 Civilization Itself

Our discussions of the relationship of the individual to civilization apply only to the finest scale of civilization as a complex organism formed out of human beings. In this section we turn to discussion of various other aspects of civilization as a complex organism. It is important to accept that there are many matters that we will not be able to describe or predict. This is consistent with the perspective that human civilization is more complex than we are as individuals. When we strive to understand, we expect that this knowledge will, at least in part, enable us to gain additional control. The pre-

vious statement makes clear that our knowledge may be limited in its ability to serve this function when applied to the entirety of human civilization.

From this discussion we should realize that there are limits to useful speculation due to lack of predictability. This limit was anticipated in the discussion in Section 9.1. In a sense, it points to a difference between our model and Newtonian models of simple systems with predictable behavior. The study of complex systems is more akin to quantum mechanics, where it is understood that certain questions cannot be answered within the context of science. Moreover, even if we were discussing a phase transition in a thermodynamic system (Sections 1.3 and 1.6), we would find an inherent lack of predictability. In a first-order phase transition, the ability to predict the specific behavior of the system is limited by the properties of nucleation that are sensitive to impurities. In a second-order transition, fluctuations make the local properties of a system inherently unpredictable. The inherent lack of predictability, however frustrating, does not mean that other questions cannot be asked and addressed. Interesting examples of questions follow.

Question 9.6.1 The basis of our discussion of human civilization as a complex system in Section 9.4 was the disappearance of central control in social and economic systems. Do our conclusions about the complexity of these systems mean that we can predict a further decline, or even the complete disappearance of hierarchical structures in human civilization?

Solution 9.6.1 One of the seemingly natural predictions of the model of loss of central control due to increasing complexity is that hierarchical systems or instruments of central control that exist today will continue to disappear over the upcoming years. However, the model of emergence of a collective complex organism suggests that this prediction is not a definite one. Functional segregation in a complex system may lead some parts of the system to retain central control, while others become networks. This is analogous to the existence of a neural network on the one hand, and muscles on the other. Thus, hierarchies may well continue to exist. Without any prior knowledge about the eventual structure that human civilization is to attain, we cannot predict where and in what way. Even though we might expect that dictatorships or centrally controlled economies which still exist in some parts of the world will completely disappear, such predictions may not be valid due to functional segregation.

An example is the relatively centrally controlled economy of Japan. Compared to the U.S. economy, the Japanese economy has a much more hierarchical (centrally controlled) structure. If it is generally true that such systems must fail due to increasing complexity, then we should anticipate that the Japanese economy will experience difficult times. These will occur due to inevitable mistakes made by the central authorities. Eventually the central control will be abandoned. However, a different scenario is possible—that the Japanese economy will continue to be effective and centrally controlled, but that the products of this economy will be limited to those that can be ef-

fectively produced in such a system. This is consistent with the model of functional segregation. A second example can be identified in the instruments of central control in the U.S. economy. At present the most powerful instrument of central control over the economy appears to be the Federal Reserve. It may be suggested that this mechanism of control will also fail due to the problem of increasing economic complexity. However, the argument may not apply here as well. In physiology there are glands, such as the adrenal gland,that control various aspects of the overall behavior of the system, such as metabolic activity. By such an analogy, the Federal Reserve may serve its function through controlling the overall level of financial activity even in the complex economy. ▮

Question 9.6.2 Consider global civilization as a single complex organism. What are the implications for the possibility of colonization on other planets?

Solution 9.6.2 Standard scenarios of colonization follow the model of colonization that occurred on Earth. A few individuals are sent to a new location and they independently function as a new society. This scenario does not work in the context of a complex organism. The interdependence of the complex organism implies that we cannot take part of it away and expect the part to function in the same manner as the whole. This is precisely the property of interdependence that we have used to characterize the complex organism.

There are two different models for how colonization might work. One of these is that the colony is not separate from the rest of human civilization but continues to function as a part of it. The second is that the process of colonization follows the same historical process that was followed by human civilization. This would be akin to a process of reproduction that occurs in other complex organisms. In order for the colony to follow the same developmental process, rather than beginning from modern technology it would have to start from a primitive state and develop technology through a similar process to that which occurred on Earth. ▮

Question 9.6.3 (for further thought) Discuss the possible origins of human civilization as a complex organism. Consider the various possible mechanisms for forming complex systems—spontaneous formation by a dynamical process, evolution,and development. Which of these can be relevant to the formation of a single complex organism? What conditions are necessary for it to occur? Which of the mechanisms for forming complex systems might apply to the formation of human civilization as a complex organism?

Question 9.6.4 (for further thought) We have concluded that global civilization (as a collective organism) is more complex than an individual human being. We have also concluded that an individual human being is more complex than the environmental demands upon him or herself. What process would cause an organism to form that is more complex than the environment?