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Two Meanings of Complex Adaptive Systems

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Abstract

In complex systems theory, two meanings of a complex adaptive system (CAS) need to be distinguished. The first, CAS1, refers to a complex system that is adaptive as a system; the second, CAS2, refers to a complex system of agents which follow adaptive strategies. Examples of CAS1 include the brain, the immune system, and social insect colonies. Examples of CAS2 include multispecies ecosystems and the biosphere. This chapter uses multilevel selection theory to clarify the relationships between CAS1 and CAS2. The general rule is that for a complex system to qualify as CAS1, selection must occur at the level of the complex system (e.g., individual-level selection for brains and the immune system, colony-level selection for social insect colonies). Selection below the level of the system tends to undermine system-level functional organization. This general rule applies to human social systems as well as biological systems and has profound consequences for economics and public policy.

Introduction

A colleague of mine once told me that he was thoroughly depressed by the Game of Life. He meant not his own life but the computer algorithm in which the on/off states of squares on a grid depend on the on/off states of the surrounding squares by a set of simple rules (Gardner 1970). My colleague was depressed by the fact that such simple rules produced such a dazzling variety of patterns on the grid and felt that if he didn't know the rules, it would be extremely difficult to infer them from the patterns. That was depressing.

The fact that systems composed of elements governed by simple rules of behavior can display a dazzling array of behaviors at the system level is a mainstay of complex systems theory and has often been used as a challenge to evolutionary theory. According to this reasoning, patterns which are currently explained as products of natural selection can be explained as emergent

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properties of complex systems without needing to invoke natural selection (e.g., Kauffman 1993).

This reasoning, while prominent in the early literature on complex systems and still voiced to some extent in the recent literature (reviewed by Corning and Szathmáry 2015), is very likely to be mistaken. In the absence of selection, the emergent properties of complex systems might be dazzling, but they are no more likely to adapt organisms to their environments than a random mutation. The most productive way to think about complex systems theory and evolutionary theory in conjunction with each other is not in an either-or fashion, but rather in terms of natural selection operating on complex systems, winnowing the few that are adaptive in relation to their environments from the many that are not (Wilson 2005; Corning and Szathmáry 2015).

Complex *adaptive* systems are therefore a subset of complex systems—the most important subset as far as public policy is concerned. After all, the purpose of public policy is to derive rules of behavior for individuals and organizations that cause large-scale societies to function for the benefit of their citizens. The business of economists and other public policy experts is to design complex adaptive systems.

The term complex adaptive system (CAS) is already a key phrase in complex systems theory, found in the titles of dozens of books and hundreds of articles. The following passage from Wikipedia's entry[1] illustrates the range of phenomena covered by the term.

> Typical examples of complex adaptive systems include: the global macroeconomic network within a country or group of countries; stock market and complex web of cross border holding companies; social insect (e.g., ant) colonies; the biosphere and the ecosystem; the brain and the immune system; the cell and the developing embryo; manufacturing businesses; and any human social group-based endeavor in a particular ideology and social system such as political parties, communities, geopolitical organizations, war, and terrorist networks of both hierarchical and leaderless nature. The Internet and cyberspace—composed, collaborated, and managed by a complex mix of human-computer interactions—is also regarded as a complex adaptive system.

While the range of phenomena covered by the term might be narrower than all complex systems, it is still too broad to be very helpful. The purpose of this article is to distinguish between two meanings of the term:

1. CAS1: A complex system that is adaptive as a system.
2. CAS2: A complex system composed of agents that employ adaptive strategies.

Biological examples of CAS1 include social insect colonies, the brain and immune system, and the cell and developing embryo; for CAS2 biological examples include ecosystems and the biosphere. When these two meanings are

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[1] https://en.wikipedia.org/wiki/Complex_adaptive_system (accessed June 21, 2015).

subsumed under a single term, there is an unstated assumption that they are compatible with each other; in other words, that a system composed of agents which employ adaptive strategies is adaptive as a system. The metaphor of the invisible hand, which has played such a central role in the history of economic thought, embodies the same assumption. But a proper understanding of evolutionary theory leads unequivocally to the conclusion that these two meanings are not compatible with each other, except under special conditions. In other words, complex systems composed of agents that employ adaptive strategies will typically not be adaptive as whole systems. An ecosystem or the biosphere is not at all like the immune system or a social insect colony—except under special conditions.

It would be hard to imagine a more important distinction for formulating wise public policy than these two meanings of CAS. We need to know how to engineer (or nudge, if you prefer) human social systems so that they qualify as CAS1. CAS2 isn't good enough and is frequently part of the problem.

I begin by reviewing the evolutionary concepts needed to distinguish between CAS1 and CAS2, including the special conditions required for a complex biological system to qualify as CAS1. Thereafter I outline how these concepts can be applied to complex human social systems.

A Primer on Multilevel Selection

Before Darwin, Western conceptions of the natural world were dominated by Christian philosphy. Since God is beneficent and all-powerful, all of nature must be harmonious at scales small and large: from a single insect to the biosphere. In other words, the Christian view assumed that CAS1 and CAS2 are compatible with each other.

Evolutionary theory, however, leads to a very different conclusion (Sober and Wilson 1998; Wilson and Wilson 2007; Wilson 2015): Functional organization exists at the level of individual organisms due to the process of natural selection among individuals. At the group level, functional organization requires individuals to perform services for each other or for their group as a whole. Members of a group who cooperate are likely to survive and reproduce less well than members who free ride or actively exploit cooperators. When this happens, functional organization stops at the level of the individual organism and does not extend to the social group or to higher levels, such as a multispecies ecosystem or the whole biosphere.

Darwin clearly perceived this dark implication of evolutionary theory and also the outline of a solution. Social interactions almost always take place in groups that are small, compared to the total population. Cooperators might be at a selective disadvantage compared to free riders and exploiters within the same group, but groups composed primarily of cooperators are at a selective advantage compared to groups crippled by free riders and exploiters. Natural

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selection takes place both within and between groups. Group-beneficial adaptations can evolve if between-group selection is strong enough to oppose disruptive within-group selection.

While Darwin was clear on these issues, other biologists continued to assume that natural selection results in functional organization at all levels of a multitier biological hierarchy, from individual organisms to the biosphere. This position, which in retrospect became known as "naïve group selectionism," was challenged in the 1960s (Williams 1966) and resulted in two outcomes. First, the field of evolutionary biology became sensitized to the problem of naïve group selectionism and the need to avoid functional explanations above the level of individual organisms unless a process of higher-level selection can be demonstrated. Second, a consensus emerged that between-group selection, while possible in principle, is almost invariably weaker than within-group selection. Most of the theories of social evolution that emerged during the second half of the twentieth century (e.g., inclusive fitness theory, evolutionary game theory, and selfish gene theory) were efforts to explain apparent group-advantageous behaviors without invoking group selection (Sober and Wilson 1998).

Fast forwarding to the present, the first outcome still holds: it is still important to be sensitive to the problem of naïve group selectionism and to avoid functional explanations at any level of a multitier hierarchy unless a process of selection at that level can be demonstrated. The general rule is: adaptation at level X requires a process of selection at that level and tends to be undermined by selection at lower levels.

The second outcome, however, has not withstood the test of time. Traits frequently evolve by virtue of increasing the fitness of groups, compared to other groups in a multigroup population, and despite being selectively disadvantageous within groups. In addition, the balance between levels of selection is not static but can itself evolve. Between-group selection can evolve to dominate within-group selection, a phenomenon which has become known as a major evolutionary transition (Maynard Smith and Szathmáry 1995, 1999). In retrospect, the theories developed to explain apparent group-advantageous behaviors without invoking group selection can be seen to have the logic of multilevel selection embedded within their own structures. They offer different perspectives on a single causal process rather than invoke a separate causal process, a topic discussed under such terms as pluralism and equivalence (Okasha 2006; Birch and Okasha 2014; Wilson 2015).

Major controversies in science have a way of appearing obvious in retrospect. It is puzzling that smart people took so long to agree on topics such as the Sun being at the center of the solar system, glaciers periodically covering the northern latitudes, and continental drift. So it is with the controversy over multilevel selection that took place during the second half of the last century. In my recent book (Wilson 2015), I offer a postresolution account that can be summarized as follows:

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1. Functional organization in nature requires a process of selection.
2. In a multitier hierarchy of units, functional organization at level X typically requires a process of selection at the same level and its frequency is undermined by selection at lower levels.
3. There is nothing about complex systems that contradicts points 1 and 2.

These statements enable us to identify the special conditions required for a biological system to qualify as CAS1. The system must be a unit of selection; otherwise, in all other cases, the system will simply qualify as CAS2. The elements of the system (e.g., members of a single-species social group or species in a multispecies ecosystem) follow adaptive strategies which evolved through selection, but those strategies will typically not result in functional organization at the level of the whole system.

Examples of biological systems that qualify as CAS1 and CAS2 are provided below to put some empirical flesh on these theoretical bones. As will be seen, even though complex systems do not self-organize into functional units in the absence of selection, they do provide the raw material that selection operates upon in environments that are also complex. Hence, it is essential to study complex systems theory and evolutionary theory in conjunction with each other, rather than separately.

Biological Systems That Qualify as CAS1

Properties of individual organisms (e.g., the brain, the immune system, the cell, and the process of multicellular development) are miracles of functional organization. No evolutionary biologist would contest the fact that the source of this functional organization is selection at the level of individual organisms. Every generation produces mutations and products of genetic recombination that are poorly adapted to the environment. Unless these are eliminated, individual-level functional organization will become degraded by entropy.

The physical mechanisms that cause organisms to develop, survive, and reproduce are complex and self-organizing. Economists might debate the merits of centralized governments versus self-organizing processes (e.g., the market), but everything that appears centralized in an individual organism (e.g., making a decision about where to move) becomes a decentralized process when studied in enough mechanistic detail (Seeley et al. 2012). Individual organisms are a highly refined subset of self-organizing systems, winnowed by natural selection from a much larger set of self-organizing systems.

The distinction between an individual organism and a single-species social group might seem obvious: an individual is a physically bounded entity whereas members of a social group are not physically connected to each other. Physical boundedness, however, is not a deciding criterion for functional organization and is illusory for individual organisms. Nerve cells do not touch each other but instead communicate across small distances called synapses. The

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many specialized cell types that comprise the immune system are physically dispersed throughout the body and must communicate across even greater distances. Parasites and infectious diseases disrupt the functional organization of an organism even though they dwell within the same body.

The deciding criterion for functional organization is not physical boundedness but the degree to which the parts work together to achieve some common purpose as a whole. By this criterion, at least some single-species social groups deserve to be called organisms, despite the fact that their members are physically dispersed (Holldobler and Wilson 2008). The most famous examples are eusocial insect colonies (e.g., bees, wasps, ants, and termites). When a honeybee colony splits, the queen leaves with some of the workers and forms a mass on a tree branch called a swarm. Scouts leave the swarm in search of the next new cavity. Typically a number of cavities are found and the swarm has an impressive ability to decide upon the best one based on factors such a size, height, orientation toward the sun, size, and location of the opening (Seeley 2010; Seeley et al. 2012). The social process whereby the swarm makes a decision is distributed, with individual bees functioning more like neurons than decision makers in their own right. Research on collective decision making in eusocial insects and other social species has taken the concept of a group mind out of the realm of science fiction and into the realm of established fact.

When a single-species social group qualifies as an organism, it is because the group is a potent unit of selection. For example, the reason that honeybee swarms make good house-hunting decisions is because swarms that made better decisions survived and reproduced better than other swarms. They did not evolve by virtue of individuals responsible for the decision surviving and reproducing better than other individuals within the same swarm. If anything, within-swarm selection would favor free riders who leave the work of house hunting to others. Accounts of social insect evolution framed in terms of inclusive fitness theory offer a different perspective but do not contradict the account framed in terms of multilevel selection theory.

Another distinction that seems obvious is between a single-species social group and a multispecies community, yet this is also not salient when it comes to functional organization. In one of the most important major transitions of evolution, nucleated cells originated as multispecies communities of bacterial cells that were selected as collectives (Margulis 1970; Maynard Smith and Szathmáry 1995, 1999). It is the unit of selection that counts, not the composition of the unit (e.g., single species vs. multiple species).

With William Swenson, I was among the first biologists to investigate ecosystem-level selection in the laboratory (for a computer simulation model, see Wilson 1992; Swenson et al. 2000a, b). In one experiment, we grew a fast-growing plant, *Arabidopsis*, in pots with sterile soil, to which we added 6 grams of unsterilized soil from a well-mixed slurry. After a period of weeks, we measured the biomass of each plant. If we had selected seeds from the largest (or smallest) plants to grow the next generation, it would be a standard

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artificial selection experiment at the level of individual plants. Instead, we selected the soil from underneath the largest (or smallest) plants and used it to colonize the soil for the next generation, drawing the plants from the same seed source as the previous generation. In other words, we were selecting whole soil ecosystems for the phenotypic property of plant growth. Other than treating the soil community as the unit of selection rather than plant genes, we conducted a standard artificial selection experiment. There was a response to selection over the course of several generations: plants became larger in the line selected for large plants and smaller in the line selected for small plants: This proved that phenotypic variation at the ecosystem level is heritable. In a second set of experiments, we selected aquatic microbial communities for their ability to alter the acidity of their medium and for their ability to break down a toxic substance. Our demonstration of the efficacy of ecosystem-level selection was recently replicated by another laboratory, using soil microbial ecosystems and plant floral development as the phenotypic trait under selection (Panke-Buisse et al. 2014).

It is worth describing these experiments in more detail to illustrate the essential role that complex interactions play in the process of ecosystem selection. The slurry of nonsterilized soil added to each pot contained millions upon millions of microbes and other small life forms comprising hundreds of species. Since the 6 g added to each pot came from a single well-mixed source, the initial variation among pots in the composition of the soil communities, due to sampling error, was negligible. Nevertheless, after a period of weeks the soil communities had become sufficiently different from each other to cause substantial variation in plant biomass. This illustrates the phenomenon of sensitive dependence on initial conditions which is the hallmark of some complex systems. Small differences between replicate systems do not stay small but become larger over time. The same "butterfly effect" that causes complex physical systems (e.g., the weather) to become variable caused the species composition of our pots to become variable.

Let us now examine the part of the experiment where soil from the pots at the tails of the phenotypic distribution (either the largest or smallest plants, depending upon the selected line) was used to inoculate the next generation of pots. If the butterfly effect operates too strongly, then the phenotypic variation in plant biomass during the next generation would be no different than during the previous generation, which would mean a lack of heritability. What actually happened was that the mean plant biomass during the next generation was different than during the previous generation in the selected direction, which means (by definition) that phenotypic variation at the ecosystem level is partially heritable. Over the course of generations, the soil community becomes functionally organized to grow large (or small) plants.

In complex systems terms, the experiment can be seen as a way to explore a very large parameter space (combinations of many hundreds of species that also vary in their genetic composition) for regions with two properties: (a) the

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phenotypic trait that is being selected and (b) enough local stability so that "offspring" ecosystems resemble "parent" ecosystems. Complex interactions do not lead to functional organization in the absence of selection; they lead to phenotypic variation and heritability, thereby providing the raw material upon which natural or artificial selection acts.

The literature on microbiomes provides examples of natural ecosystem selection comparable to the artificial ecosystem selection experiments. Every multicellular organism contains a teeming community of microbes and other small life forms whose cells can number over ten times the number of host cells (Dethlefsen et al. 2007). The phenotypic properties of the host can be influenced by its microbiome in addition to its genes. The differential survival and reproduction of the host results in the differential survival and reproduction of its microbiome, although there is also potential for selection among species and genes within the microbiome, not necessarily to the benefit of its host. Between-host selection operating over eons has been strong enough for microbiomes to become mutualistic partners with hosts. Some species of multicellular organisms need their microbiomes as much as they need their own cells and genes.

Biological Systems That Qualify as CAS2

The claim that higher-level selection is invariably weaker than lower-level selection has been thoroughly refuted. Nevertheless, it remains true in many individual cases. In other words, traits frequently evolve by virtue of increasing the fitness of individuals, compared to other members of their groups, resulting in a breakdown of group-level functional organization. Between-group selection, if it takes place at all, is not sufficiently strong to oppose within-group selection. The groups remain functionally impaired indefinitely and there is no invisible hand to save the day.

Sexual reproduction is especially prone to disruptive within-group selection. If you are a woman, imagine someone breaking into your home, slaughtering your husband and children, forcing you to have his children, and having to repeat the experience five or ten years later with the next thug. There is nothing you can do about it because all of your other options are even worse (e.g., setting out on your own which could increase the likelihood of exploitation and abuse).

Most people would regard such a human society as a total breakdown of order to be avoided at all costs. However, in certain animal societies, this is normality, and has been for untold generations. Nothing will change it except a shift in the balance between levels of selection.

Although many primate examples could be cited, including some in which males are the single largest source of infant mortality (Strier 2011), I will use an insect example to illustrate this point because it has been exceptionally well studied from a multilevel perspective. Water striders (*Aquarius remigis*) are insects that live on the surface of water, where they prey and scavenge upon other insects. Sexual conflict has been an evolutionary force for so long that it is reflected in the morphology of the genitalia. The penis is designed to shoehorn its way into the female's genital opening and expand into a spiny balloon so that the male cannot be dislodged. Males differ greatly in their aggressiveness toward females. Some would be regarded as psychopaths in human terms, hunting females and attempting to mate with them against their will. Others are more passive, waiting to be approached by females before copulating.

In a series of experiments, Eldakar and colleagues examined the consequences of aggressive and docile male mating behavior in a multigroup population of water striders (Eldakar et al. 2009a, b, 2010). Within any group, aggressive males mated more frequently than docile males. However, groups composed primarily of docile males were much more productive than groups composed mostly of aggressive males, because females could forage more freely in the presence of docile males and therefore lay more eggs. This situation is exactly as Darwin imagined: an antisocial behavior is favored by within-group selection and a prosocial behavior is favored by between-group selection. In this case, the balance between levels of selection results in a mix of solid citizens and exploiters being maintained in the population. This mix is not adaptive at the group level because groups would function even better without any aggressive males. It is simply the outcome of multilevel selection in which within-group selection favoring an antisocial behavior is a potent evolutionary force.

Although multispecies communities can be units of selection, in many cases they are not. Ecosystems dominated by beavers provide a good example (Bailey et al. 2004). When beavers move into an area, they flood streams, displacing many species of plants and animals and providing a habitat for many other species. As smart foragers, they eat the most palatable trees, leaving those that are protected by tannins and other protective secondary plant compounds. When these compounds leach into the water, they are toxic to many aquatic animal species. Leaves and wood protected by tannins decompose slowly, retarding the recycling of nutrients. Beavers do not behave for the good of their ecosystem. They behave for the good of themselves, resulting in a cascade of effects that can be good or bad for other species and the ecosystem as a whole. Beavers do not even act in a way that benefits their own long-term survival. After they overexploit their food source in one location, they leave to repeat the process in another location, much like humans who practice slash and burn agriculture.

These examples, one for a single species society (water striders) and another for a multispecies community (beavers), are illustrations of CAS2: complex systems composed of agents which individually employ adaptive strategies. Accordingly, three general observations can be made: First, CAS2 systems qualify as complex systems by exhibiting properties such as sensitive dependence on initial conditions, multiple basins of attraction, and being frequently out of equilibrium.

Second, it is very difficult to understand the dynamics of CAS2 systems without taking the adaptive strategies of the lower-level units into account. In the water strider example, the adaptive strategies of males and females makes it possible to predict that aggressive males will occupy the most food-rich areas, that females will be forced into food-poor areas, that females fleeing from aggressive males and gathering in the vicinity of docile males will increase variation among groups, and so on. In the beaver example, knowing the optimal foraging behavior of beavers enables us to predict the ecosystem-level consequences of harvesting the palatable trees and leaving the better-protected trees, regardless of whether the net effects are good or bad at the ecosystem level. The fact that systems composed of elements that follow simple rules (e.g., Game of Life; Gardner 1970) exhibit a diversity of behaviors at the system level is interesting and important, but the study of CAS2 systems must account for the adaptive strategies of the lower-level units.

Third, in the absence of higher-level selection, there is nothing about the complexity of CAS2 systems to cause them to become functionally organized at the level of the system except by chance—the same kind of chance that causes a random mutation to be beneficial now and then. The general rule that emerges from a proper understanding of evolutionary theory is that *system-level functional organization requires a process of selection at the level of the system*. That is precisely what sets CAS1 and CAS2 systems apart from each other.

Human Social Systems from a Multilevel Evolutionary Perspective

The three generalities listed earlier can be modified so that they apply to human social systems:

1. Functional organization in human social systems requires a process of selection.
2. In a multitier hierarchy of units, functional organization at level X typically requires a process of selection at the same level and is frequency undermined by selection at lower levels.
3. There is nothing about complex systems theory, economics, or any other branch of the human social sciences that contradicts the first two points.

These statements should be acknowledged front and center by all branches of the human social sciences, but this is far from the case. Each branch has its own history, and many of them preserve essentially pre-Darwinian notions concerning the harmony and order of whole social and economic systems. Complex systems theory has not been clear on the distinction between CAS1 and CAS2. Beneath the formalism of neoclassical economic theory,

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three ancient cosmologies of Western thought can be recognized: (a) "natural man" exists as a rational, self-sufficient, egotistical individual; (b) competition among individuals leads to a well-functioning society; and (c) there is an ideal, optimal state of nature with which one should not tamper (Gowdy et al. 2013).

One step toward achieving a more widespread consensus is to show how much human genetic and cultural evolution can be understood as a multilevel selection process, in the same terms as the biological examples described above. Human genetic evolution qualifies as a major transition. Mechanisms evolved in our species that made it difficult for individuals to bully or otherwise exploit other members of their own groups. With disruptive forms of within-group selection suppressed, constructive forms of within-group selection and between-group selection became the strongest evolutionary forces. Teamwork became the signature human adaptation (Boehm 2012).

Teamwork included physical activities such as child care, food acquisition, predator defense, as well as trade with and warfare against other groups. It also involved mental activities such as a shared inventory of symbolic relations (including, but not restricted to, language) and an enhanced ability to transmit learned information across generations. These forms of mental teamwork became an inheritance system in its own right, enabling our ancestors to adapt to their environments far more rapidly than through genetic evolution alone. As a result, humans spread over the planet, inhabiting all climatic zones and hundreds of ecological niches (Pagel and Mace 2004).

With the advent of agriculture (along with high concentrations of natural resources in some areas), larger groups became possible, but our genetic adaptations for suppressing disruptive forms of competition within small groups did not necessarily scale up accordingly. New culturally derived mechanisms of social control were thus required to interface with older genetic and cultural mechanisms. Human history provides a detailed fossil record of the process of multilevel cultural evolution leading up to the mega societies of today (Turchin 2005, 2010). For example, the nation-states of Europe are the product of centuries of between-group military and economic competition. Evolution is a path-dependent process, and the European nations might or might not serve as viable models for other regions of the world (e.g., the Middle East or Africa).

Much is made of the fact that human behavioral and cultural processes are often directed toward a goal (in contrast to genetic variation) that is not random in the strict sense of the word but is said to be arbitrary with respect to the traits that are selected. The terms Lamarkian and Darwinian are often used to make this comparison, but it is important to avoid historical revisionism. Darwin also invoked the inheritance of acquired characters in his effort to explain the nature of heritable variation. Moreover, as Jablonka and Lamb (2006) explain, if Lamark had been correct, the outcome of evolution would be much the same: there would, for example, still be giraffes with long necks. At least some forms of genetic variation are proving to be directed after all.

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Theoretically, there is nothing heretical or "non-Darwinian" about goal-directed evolutionary processes because their directed aspects evolved through undirected heritable variation in the past. Moreover, human goal-directed processes typically include undirected components. Consider intentional decision making, one of the most goal-directed forms of behavioral and cultural change, which involves explicitly selecting among alternative options with set criteria in mind. The search for options can be either directed or undirected, and the most creative options often come out of nowhere—in other words, brainstorming and thinking out of the box. Evolutionary algorithms have become important engineering tools because having a computer randomly generate options can identify potential solutions better than more narrow goal-directed algorithms.

If we regard decision making as an explicit variation-and-selection process, the variation part often benefits from an undirected component. The selection part is goal-directed by definition, but many selection criteria are possible. Some individuals might select options to maximize their relative advantage within their groups. Others might select the options to maximize world peace or the sustainability of the planet. Which selection criteria come to be employed in any particular decision-making process? Another selection process must be invoked to answer this question. In this fashion, current variation-and-selection processes must be explained in terms of past variation-and-selection processes, like peeling away the layers of an onion. In addition to conscious decision making, other-directed selection processes take place subliminally, such as our tendency to copy the behaviors of high-status individuals. Then there is the raw process of undirected cultural evolution—many inadvertent social experiments, a few that succeed. Even intentional decisions result in variation that is arbitrary with respect to what is selected when they produce unintended consequences or collide with each other.

The most important common denominator for variation-and-selection processes, whether directed or undirected, is that they are open ended. They are capable of producing new properties of social systems (phenotypes, in evolutionary parlance) in response to current environmental conditions. This contrasts with what evolutionists call closed phenotypic plasticity, which selects among a fixed repertoire of phenotypes in response to current environmental conditions (West-Eberhard 2003). To summarize, all variation-and-selection processes—from intentional decision making to selection among alternative cultural forms that no one intended—fall under the umbrella of cultural evolutionary theory.

Implications

Complexity theory and evolutionary theory need to become better integrated before a new paradigm for economics can be envisioned. The classification of

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complex systems at the beginning of this chapter provides one example. Some complex systems are composed of elements that follow simple rules of behavior, which are not a product of selection. Other complex systems are composed of elements that follow adaptive strategies (CAS2). Still others are adaptive at the level of the whole system (CAS1). What are the relations among these three categories of complex systems, and which are most relevant to the formulation of wise public policy?

Evolutionary theory can address these questions in a way that is surprisingly definitive. The first category of complex systems might produce a dazzling variety of patterns at the level of the whole system, but these patterns are no more likely to adapt the system to its environment than a random mutation. When the adaptive strategies employed by elements of CAS2 systems are products of lower-level selection, the system as a whole is unlikely to become well adapted to its environment. The lower-level strategies are much more likely to undermine functional organization at the level of the whole system. Functional organization at the level of the whole system (CAS1) requires selection at the level of the whole system.

These generalities emerged from evolutionary theory in two stages. The first stage occurred in the 1960s and sensitized evolutionary biologists to the problem of naïve group selectionism. The cardinal rule is to never invoke adaptation at level X of a multitier hierarchy without demonstrating a selection process at the same level. Unfortunately, this stage was accompanied by a consensus that higher-level selection is invariably weaker than lower-level selection so that "group-level adaptations do not, in fact, exist" (Williams 1966:93).

Decades were required for the second generality to become established, which is that higher-level selection is not invariably weaker and can even dominate lower-level selection. Traits do evolve by virtue of benefiting groups of various sorts, despite being selectively disadvantageous within the groups. These traits can be accepted at face value as group-level adaptations. Why this conclusion was resisted for so long, when it became plain to some people as early as the 1970s, is becoming a lively branch of historical scholarship (e.g., Borrello 2010; Harman 2010). For purposes of this discussion, let us accept it as an issue that has been resolved and needs to be part of the new synthesis for economics.

These generalities need to become common knowledge among complex systems theorists before they can be synthesized into economics and public policy. My own reading of the complex systems literature is that this is not yet the case. Some complex system theorists are closely attuned to developments in evolutionary theory while others are not and have not independently converged upon the need to distinguish between CAS1 and CAS2 and how they relate to each other. Once a consensus is reached that CAS1 systems require a process of system-level selection, this core insight can be applied to economics and public policy. To this end, the following points are highlighted to further future discussions.

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Revising the Concept of the Invisible Hand

Throughout its history, economics has focused on whether economic systems are able to run themselves (laissez-faire) or whether they require active intervention.[2] Adam Smith's metaphor of the invisible hand, even though he invoked it only three times and it does not represent the full corpus of his work, has come to represent the concept of laissez in the economic literature and popular imagination.

The conditions required for the evolution of CAS2 systems leads to foundational changes in the concept of the invisible hand, as outlined in a recent article (Wilson and Gowdy 2015). The two conditions for the invisible hand metaphor are: (a) society functions well as a unit and (b) members of the society do not have its welfare in mind. From an evolutionary perspective, the first condition is met only when a society is a unit of selection; otherwise it does not function well as a unit. When the first condition is met, then members of the society do not necessarily need to have its welfare in mind; they merely need to respond to their local environments in ways that are good for the group. This is obvious for biological units of selection, whose members (e.g., genes, cells, and social insects) do not possess minds in the human sense of the word. Put another way, higher-level selection *is* the invisible hand, winnowing a small set of behaviors that contribute to the welfare of the group from the much larger set that do not. This view contrasts the version of the invisible hand in economics and public discourse, which imagines that the unregulated pursuit of self-interest, usually conceptualized as financial wealth, robustly benefits the common good. In popular discourse this is called greed is good. In formal economic theory it is called the first fundamental theorem of welfare economics and agency theory.

Revising the Concept of Regulation

It is interesting to compare the concept of regulation from the perspectives of economists and biologists. For an economist, regulation is something imposed by governments, and self-organizing processes (e.g., the market) are regarded as an absence of regulation. For a biologist, all of the metabolic processes that keep organisms alive and all of the social processes that coordinate social insect colonies are regulated, and all of the regulations are self-organizing. The absence of regulation means dysfunction and death. At the same time, for every regulatory process that works there are hundreds which do not. The concept of regulation in economics and public policy needs to be better aligned to the biological concept of regulation. The idea of no regulation should be regarded

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[2] Details of laissez-faire economics are available in an online interview; see https://evolution-institute.org/article/everything-you-need-to-know-about-laissez-faire-economics/?source=tvol (accessed June 21, 2015).

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as patently absurd, whereas determining the proper kind of regulation and the role of formal government in regulatory processes are central topics of inquiry.

Formulating Economic and Public Policy with Complex Systems in Mind

My use of the word “selection” in this chapter spans the gamut from the raw process of unintended variation and selection to conscious decision-making processes. It is clear that unmanaged cultural evolutionary processes are not going to solve the problems of modern human existence at the scale and timeframe required. We must become “wise managers of evolutionary processes” (Wilson et al. 2014). This does not necessarily imply centralized planning and control; it can mean the selection of self-organizing regulatory processes. The idea that effective self-organizing processes must be selected from among a much larger number of ineffective self-organizing processes is not a contradiction of terms. It is how all adaptive self-organizing processes emerge.

Selecting complex systems for group-beneficial outcomes is especially fraught with difficulties because interventions are likely to produce unintended consequences. According to some estimates, over half of change efforts in the business world make things worse rather than better (Schaffer and Ashkenas 2007). Given the pervasiveness of unintended consequences and cascading effects of interventions in complex social systems, there is no alternative to conducting careful experiments and scaling up practices that work (Colander and Kupers 2014).

An important insight from evolutionary theory is that some dysfunctions are caused by a mismatch between adaptations that evolved in an ancestral environment and the current environment. As one example, the vertebrate immune system evolved in the presence of a diverse ecosystem of microbes, worms, and other species that inhabited the interior and exterior of vertebrate bodies. These species were not always beneficial to the host, but they were always there. In modern times, it is possible for humans to cleanse themselves of many of these species. This might seem like an unambiguous blessing, but it turns out that some of the species are required for the normal development of the immune system, which goes haywire in their absence (Rook 2012). Solving mismatch problems requires a detailed understanding of the adaptation, the ancestral environment, and the modern environment. This understanding is beginning to emerge for immune system dysfunction, but the concept of “cultural system dysfunction,” comparable to immune system dysfunction, is not yet widely appreciated. It is difficult to understand and solve mismatch problems except from an evolutionary perspective.

Creating a Science-to-Narrative Chain

I have been thinking hard about evolution in relation to economics and public policy since 2007, when I helped to create the Evolution Institute, and have been struck by the disconnect between economic concepts at the professional and public levels of discourse. Portrayals of major figures such as Adam Smith and Friedrich Hayek bear almost no resemblance to actual people or their work. I have been repeatedly told by professional economists that they and their colleagues would never be so naïve as to think that laissez-faire economics actually leads to the common good without the need for regulations. Yet it is at the level of public discourse that elections are won, legislation is passed, and policies are implemented. Hardin (1968:1244) described this well in his classic article on the tragedy of the commons:

> In economic affairs, *The Wealth of Nations* (Smith 1776/2014) popularized the "invisible hand," the idea that an individual who "intends only his own gain," is, as it were, "led by an invisible hand to promote…the public interest." Adam Smith did not assert that this was invariably true, and perhaps neither did any of his followers. But he contributed to a dominant tendency of thought that has ever since interfered with positive action based on rational analysis, namely, the tendency to assume that decisions reached individually will, in fact, be the best decisions for an entire society.

Based on this experience, the Evolution Institute has formulated a communication strategy that we call the science-to-narrative chain, which describes science as being necessary but not sufficient to solve the problems of modern existence. Ways must be found to communicate information to large numbers of people who do not have expert knowledge. These narratives must be connected to science through a chain of material that provides increasing depth, so that those who become engaged with the narrative, either as proponents or skeptics, can find their way to the science.

What this means is that a new economic paradigm based on complexity and evolution needs to be communicated to the general public as well as to experts across a range of academic disciplines. Hardin's idea that "decisions reached individually will be the best decisions for an entire society" must be exposed as wrong at a foundational level. In addition, a chain of intermediate material must be provided so that the narrative of the new economic paradigm is connected to expert knowledge more responsibly. Communicating only at the professional level is not good enough. The Evolution Institute's three websites (This View of Life, Social Evolution Forum, and Evonomics.com) are dedicated to this end.[3]

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[3] http://www.thisviewoflife.com, https://evolution-institute.org/social-evolution-forum/, http://evonomics.com (accessed April 15, 2016).

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