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The Complexities of Global Systems History*

Only connect! That was the whole of her sermon. Only connect the prose and the passion and both will be exalted, and human love will be seen at its height. Live in fragments no longer.

—E.M. Forster

INTRODUCTION

WE LIVE IN a complex world. Each of us adapts in response to the actions of those connected to us to produce emergent aggregate phenomena: cities expand and contract, social groups form and dissolve, and things we enjoy (money, oil, good company, fine wine) wax and wane in availability over time. Our interactions produce phenomena in multiple domains—diseases spread over our social networks, species with whom we share our environment become extinct, and wars break out across our borders.

Increased connectedness has led to greater cooperation. In less than half a century, Europe transitioned out of centuries of bloodshed over national borders into a region of unprecedented international cooperation. Connectedness has also led to more competition. Ideas thought up in San Francisco today can be turned into products in Kunming, China, tomorrow.

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No single event tipped Europe into a zone of cooperation, yet we believe it was not purely an accident, either. We want to explain outcomes, to predict what is coming, and, in light of the many challenges facing the entire globe—terrorism, climate change, poverty, deforestation, financial collapse, and more—we also want to be able to change things. Standard tools of analysis that focus on equilibrium outcomes—snapshots of the world at particular moments—have gotten us far in our efforts to understand our world. But we can go further in our understanding. As Professor Alan Wood writes in “Fire, Water, Earth, and Sky,” complex systems thinking about global history can help us get there.¹

Global systems history characterizes the world as a complex system, with diverse, connected, interdependent parts whose actions have global impact. Whereas much of previous history, whether of the French Revolution or the Crimean War, could be identified geographically, much of the history of the present day (the Green Revolution, the War on Terrorism) transcends place. Cities, states, and nations may still be the pieces on the chessboard, but their local interactions, through the genius of modern technology, now have global impacts.

Saying that something, be it human history or the ecology of a small pond, is a complex system has implications for what we expect to transpire—and for how we explain what’s already there. In a global system outcomes won’t all just be one damn thing after another. Nor will they all be mechanistic and linear. Outcomes could be either, or they may lie in between, forming emergent, dynamic patterns, of which we can explain and possibly predict parts, if not the whole. As historians have long recognized, it is rare that we can identify one event as having been caused by just one other. Rather, it is a collection of interacting parts—actors in a system—affecting and reacting to each other that causes new events.

The word systemic, and its cousin holistic, implies a form of closure. A systems approach closes loops. It recognizes that toxic chemicals dumped into waterways accumulate in the flesh of fish and eventually enter our

¹Alan T. Wood, “Fire, Water, Earth, and Sky: Global Systems History and the Human Prospect,” *Journal of the Historical Society* 10:3 (September 2010): 287–318.

bloodstreams. This way of looking at the world echoes the emphasis on unity and connection between all things that characterizes much of Eastern philosophy. It can also, if one takes an optimistic enough view, translate into a hope that we will be able to think through the logical steps and attain a more perfect, more cooperative future. Applied to history, complex systems thinking may be folded into existing methods of analysis that already appreciate both the ambiguity and the richness that result from thinking about multiple causes and conditionality.

In this paper we comment on Wood's approach to global systems history from the perspective of complexologists. We make five main points. We first offer up some general comments about the difference between systems and complex systems. Not all systems produce complexity. In addition, regardless of whether a system produces complex phenomena, it may be subject to laws that make some outcomes unavoidable. Understanding does not necessarily mean freedom from helplessness. Even if we fully understand how a complex system functions, we may not be able to do much about the outcomes it produces. But that may be too hopeful a perspective, anyway. Often complex systems generate outcomes that are unexpected and even emergent.²

Second, we distinguish between the attributes of complex systems and the types of outcomes that they produce. In so doing, we emphasize that not all complex systems produce outcomes that are "good." True, complex systems can produce emergent cooperative regimes, but they're also capable of self-organized criticality. By this we mean they can self-configure to states that produce large events—financial crises, epidemics, and wars. We also discuss what exactly is meant by complexity. Surprisingly, for all the work on complexity, we often have a clearer idea of what complexity is not than of what it is.

The fact that complex systems produce emergence—the possibility of unexpected and unpredictable outcomes, not all of which will be good—has

²Emergence is another concept that tends to defy definition. We refer to emergence as the production of new, unexpected, and usually unpredictable outcomes from parts that look quite unlike the resulting whole. See John H. Holland, *Emergence: From Chaos to Order* (Oxford: Oxford University Press, 1999).

important policy implications. From the perspective of complex systems thinking, it no longer makes a lot of sense to have as a policy goal a “good outcome,” as there is no guarantee we can generate it in the first place, much less preserve it if it is reached. Instead, the implication is that we ought to think about how to design systems so that they are less likely to generate or tip into undesirable outcomes. We’d like systems that are robust in the face of large events, but that also produce fewer such events in the first place. If we want to explain events that have already taken place, complex systems thinking suggests we ought to be prepared for the possibility that our causes may look very, very different from our effects.

Third, we focus on just one particular aspect of complex systems to illustrate how close study of even just part of a complex system yields insights that can offer a lot of traction in understanding social, ecological, and physical outcomes. We select connectedness, specifically networks, and examine their logic, structure, and function. It turns out that not only is understanding each element of a network useful, but also understanding one element (e.g., structure) helps us say things about another (e.g., function).

We then turn to the big “so what?” If the world is complex, why does it matter? Here we agree strongly with Wood that it means we need more global thinking. More specifically, it means that the adage “think globally, act locally” should be reframed as “act locally with an eye toward global consequences.”³ Our long-term viability may well depend on such an approach, but does it mean that by adopting such a mindset, we should expect outcomes in the political, economic, and social realms to be robust, beautiful, efficient, and fair?

Here we take a less sanguine view than Wood. Even if we do learn to “harness” complexity, we must keep in mind that even our best results won’t always be pretty.⁴ The best of all possible complex worlds are messy and inefficient. We need look no further than ecosystems, which, for all their decentralization and bottom-up activity, suffer plenty of undesirable

³Or from a policy perspective, perhaps, “get people to act locally in ways that can improve what happens globally”—but that might be stretching it.

⁴On harnessing complexity, see Robert Axelrod and Michael D. Cohen, *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (New York: Free Press, 2000).

processes and outcomes. To be sure, political systems are also perfectly capable of producing outcomes like war, ethnic conflict, and the collapse of nation-states.⁵

Finally, we cannot forget the tradeoff between exploration (looking for new solutions) and exploitation (using existing ones) within complex systems.⁶ Too much exploration and outcomes suffer, but too much exploitation sacrifices robustness. If we accept the complexity paradigm, we must accept the frictions brought about by experimentation and testing of the status quo. We need to keep disagreeing. The balance between yin and yang will not be one of equilibrium, but one of churning.

SYSTEMS, COMPLEX SYSTEMS

In this essay, we distinguish between systems thinking and complex systems thinking. Systems thinking refers to a way of understanding the world by considering the whole, i.e., by considering the parts as well as how they are connected. For example, a non-systems thinker might believe that by increasing the penalties for speeding on highways, fewer people will exceed the speed limit. A systems thinker will recognize that if fewer people speed, then the police will be less inclined to monitor highways and will focus their limited resources elsewhere. This reduced police presence will decrease the likelihood that a speeder gets caught and will create an incentive for people to drive faster. The direct effect—the higher penalty—and the indirect effect—the lower probability of receiving a ticket—may well balance out and have little or no impact on the number of motorists exceeding the speed limit.

This simple example is important because it drives home (no pun intended) a key point. A system may include feedbacks and interdependencies, but that does not mean that it produces complex outcomes. Initially, the system had an equilibrium number of speeders, and after the penalty was increased, it

⁵For two collections of examples of complex systems models that produce these phenomena, see Lars-Erik Cederman, *Emergent Actors in World Politics: How States and Nations Develop* (Princeton: Princeton University Press, 1997), and Ian S. Lustick, “Agent-Based Modelling of Collective Identity: Testing Constructivist Theory,” *Journal of Artificial Societies and Social Simulation* 3:1 (2000).

⁶For the seminal work on the exploration/exploitation tradeoff, see James C. March, “Exploration and Exploitation in Organizational Learning,” *Organization Science* 2:1 (1991): 71–87.

had a new equilibrium number of speeders that was slightly lower than the initial number. This outcome is not a particularly complex one.

What do we mean by that? What makes an outcome complex? Stephen Wolfram characterizes four types of outcomes of systems: equilibrium, cycles, complexity, and chaos.⁷ Each of these could be associated with a way of seeing the world. Some of us—economists, for example—may tend to look for equilibria: snapshots of outcomes poised in balance like a modern art installation of hinges and levers. Others might notice cycles or other repeating patterns over history. After all, we do tend to repeat ourselves over time, both in our personal habits and in our behavior as groups.⁸ Finally, the cynics among us may believe that all of this is just chaotic.

Complexologists locate themselves in the middle: the world may not be perfectly predictable or repeating, but it is also not completely unpredictable or unintelligible. Instead, interactions between parts can give rise to a kind of order—what John Holland calls “hidden order.”⁹ Sometimes we see patterns that give way to large events. Other times we might observe exponential growth followed by stasis. We might see it coming, or we might be surprised, but we always see it as worth trying to understand.

The connectedness and interdependencies in complex systems contribute to their unpredictability. We cannot separate a complex system into simple parts, analyze the effects of those parts independently, and then combine them to discern the aggregate effect.¹⁰ In systems with only two parts or actors, be they entities in a physical system or strategic players in a game theory model, mathematicians can deduce closed form solutions using mechanistic arguments. In systems with millions of parts or actors, such as a gas or a simplistic model of an economy, it is possible to use statistics and

⁷Stephen Wolfram, *A New Kind of Science* (Champaign, IL: Wolfram Media, 2002).

⁸For psychological evidence of habits see Wendy Wood and David T. Neal, “A New Look at Habits and the Habit-Goal Interface,” *Psychological Review* 114:4 (2007): 843–863. Note also that policymakers might be somewhere in between equilibrium and cyclical worldviews: they might imagine the world as a machine with multiple levers that generates a patterned outcome. Change the pressure on one of the levers, and you change the outcome.

⁹John H. Holland, *Hidden Order: How Adaptation Builds Complexity* (New York: Helix Books, 1995).

¹⁰See Robert Jervis, *System Effects: Complexity in Political and Social Life* (Princeton: Princeton University Press, 1998).

statistical mechanics to derive limiting distributions. Complex systems lie between mechanistic small number problems and probabilistic large number problems.¹¹ We have the mathematics to solve both very simple systems and systems with large numbers of independent entities, but we lack the mathematics to characterize complex systems.

COMPLEX SYSTEMS: ATTRIBUTES AND OUTCOMES

Wood identifies five concepts as characteristics of systems theory that yield synergy when applied to global history. They are emergence, feedback, interconnectivity, self-organization, and cooperation. While all five concepts are related to complex systems, we suggest it is useful to make a distinction between those that are *attributes* of complex systems, and those that are *outcomes* of complex systems. Feedback and connectivity are attributes—they are things that make a complex system complex. Cooperation and self-organization, on the other hand, are phenomena that can be produced by complex systems. Below is a list of the four core attributes of any complex system:

- Diverse Agents
- Connectivity
- Nonlinear, Meaningful Interactions
- Adaptive, Rule-Based Behaviors

Given this attributional approach to definition, an ecosystem, an economy, and a political system would be complex, but a subwoofer would not. The subwoofer has parts, but they don't adapt in interesting ways. Therefore, the subwoofer is complicated, but not complex. Note also that the performance of the subwoofer, at least one hopes, is also predictable. Turn the bass dial from four to six and the bass level increases in a linear fashion. This predictability need not hold for a complex system: a few more kilotons of carbon in the atmosphere or a few hundred more defaults on mortgages can cause a system to shift from stable to cataclysmic.

¹¹See, e.g., Gerald Weinberg, *An Introduction to General Systems Theory* (New York: Wiley, 1975), and also see Warren Weaver, "Science and Complexity," *American Scientist* 36 (1948): 537–544.

All of the above attributes must be present in a system in order for it to be complex. A system of connected, interacting, and adaptive *identical* agents will not give rise to outcomes we associate with complex systems, and neither will a system of diverse agents that are adaptive but never interact meaningfully with one another. All four attributes must be present in order for complex systems to generate phenomena that are of interest, such as emergence.

As Wood points out, complex systems are capable of producing much more than just emergence. Below is a (nonexhaustive) list of some major phenomena we might expect to be produced by a system that is complex:

- Robust outcomes
- Self-organization
- Emergence/Levels
- Phase transitions
- Large events
- Novelty
- Path dependence
- Lever points
- Cooperative outcomes

The range of possible behaviors produced by complex systems is unimaginably large. To say that they can produce linear or nonlinear effects understates the vastness of possibilities. To wit, John Von Neumann, one of the founders of complexity theory, once referred to the study of nonlinear functions as akin to the study of nonelephants. Despite this breadth of outcomes, we should keep in mind that complex systems are subject to mathematical and physical constraints. If the entities within a complex system are subject to selective pressures, then those entities will be subject to efficiency constraints. Efficiency may then drive the emergent order we see. For example, West, Brown, and Enquist explain power law relationships across a host of biological phenomena (heart rates, white matter to gray matter ratios, etc.) based on efficiency arguments.¹²

¹²Geoffrey West, James H. Brown, and Brian J. Enquist, "A General Model for the Origin of Allometric Scaling Laws in Biology," *Science* 276 (1997): 122–26.

This research in no way contradicts the findings by Wolfram, Kauffman, and others who show that even extremely simple models and rules can generate emergent order, patterns, and computation.¹³ The Wolfram and Kauffman models are stylized models that demonstrate the potential for simple systems of interacting parts to produce complex phenomena. West et al. show that in the real world, the ability to compute evolved in such a way that the solution satisfies efficiency constraints. In this case, the amount of white matter (connections) and gray matter (processors) must satisfy a certain relationship.

Overall, complex systems can produce a variety of types of outcomes, some of which we can understand, some of which we can affect, and some of which we can neither comprehend nor manipulate.¹⁴ We will discuss some of these—large events, robustness, cooperation, etc.—in more detail in the next section. Before we can move on, though, we must focus on what is still left unsaid: namely, what the heck is complexity? Complexity has an abundance of definitions, which, like Whitman, sometimes contradict themselves owing to largeness. As mentioned, there exist even more definitions of what complexity *is not* (random, chaotic, periodic, predictable, or static) than what exactly it *is*.

To paint with a wide brush, we can distinguish between two primary types of definitions that Page refers to as BOAR and DEEP.¹⁵

BOAR: Complexity lies between order and randomness.

DEEP: Complexity cannot be easily described, evolved, engineered, or predicted.

The DEEP definition is intuitive, but rather challenging in the details. The BOAR approach requires some clarification. A system that produces

¹³Wolfram, *A New Kind of Science*; Stuart A. Kauffman, *The Origins of Order: Self-Organization and Selection in Evolution* (New York and Oxford: Oxford University Press, 1995). See also Stuart A. Kauffman, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* (New York and Oxford: Oxford University Press, 1995).

¹⁴Jervis, *System Effects*.

¹⁵On BOAR and DEEP, see Scott E. Page, *Diversity and Complexity* (Princeton: Princeton University Press, forthcoming, 2010). See also Melanie Mitchell, *Complexity: A Guided Tour* (Oxford: Oxford University Press, 2009), for more on defining complexity.

regular patterns or equilibria is not complex. It is ordered. One might think, then, that complexity means a lack of order. That logic only extends so far. If a system becomes random, then it is no longer complex. To see why, we turn to the second definition. A random process is easily described and engineered, and if it is stationary, then it is also easily predicted, at least at the distribution level. A complex process cannot be easily described. It produces an endless stream of structures and patterns that may or may not be seen again.

In light of these definitions, we find Professor Wood's position uncontroversial. We do live in a complex world. In fact, we go even further and suggest that over the past one hundred years, the human experience has become more complex. This is not to say we haven't previously had global effects (deforestation in medieval Europe affected the climate then, too). Nor is it to say that individuals have necessarily become more sophisticated. That need not be the case. Systemic complexity depends less on the characteristics of the components than on their connections and interdependencies. A human brain, for example, is extremely complex, but its parts—the neurons, axons, and dendrites—have fewer capabilities than your average paramecium. Our modern complexity stems from the fact that new technology allows our actions to influence and be influenced by more people. And those interactions have meaningful, possibly immediate, repercussions at multiple levels. In the next section we consider just that.

NETWORKS: LOGIC, STRUCTURE, AND FUNCTION

Rather than attempt a survey of all attributes of complex systems and how they might produce the various outcomes we list above, we focus here on a single attribute: connectedness. Our aim is to demonstrate how careful analysis of just one attribute can earn us substantial mileage in terms of understanding complex systems processes and outcomes, and how we might do something to affect them. We hope to encourage historians to embrace complexity theory, not just to employ it as a convenient collection of metaphors and insights.

Research in complex systems has begun to show how connectedness matters. How people, ideas, and species are connected influences how events play out. One powerful example suffices to make this point. Models of epidemics that rely on mathematics used to assume random mixing of people. This effectively assumes away any social structure. Random mixing may not be a terrible assumption for the spread of a flu virus, but it makes absolutely no sense to imagine HIV-AIDS or any other sexually transmitted disease spreading randomly. Sexual contacts are not random. People do not randomly fly to Chicago, have sex with some random person without regard to gender, and fly home. The lack of randomness in contact structure affects how the disease spreads.

To say that agents in a complex system are connected in some way should immediately bring to mind a network. Wood gives networks a great deal of attention in his paper, and rightly so. Networks provide the foundation of interaction patterns in any system. They are the channels across which information, behaviors, and effects travel.

We can also say much more about a system than just notice that it is connected in some way. If we think of financial institutions, world monetary systems, international political alliances, or trade partnerships in terms of networks, then this opens a whole world for study.¹⁶ There is a logic to how these networks are formed that gives rise to their structure, and that structure has functions. We are then able to ask questions like: Why did a particular network break apart? Would a different structure be more stable? To what kinds of shocks was it particularly vulnerable?

Over the past two decades, the field of network science has made tremendous advances on two fronts. First, we are better equipped with tools for describing and analyzing networks.¹⁷ Second, we are getting better at using

¹⁶On the world monetary system as a system—and as a network—that lends itself to stability analysis, see the 2009 report by the International Monetary Fund (IMF): *World Economic and Financial Surveys Global Financial Stability Report: Responding to the Financial Crisis and Measuring Systemic Risk* (Washington, DC: International Monetary Fund, 2009).

¹⁷See Mark E. J. Newman, Albert-László Barabási, and Duncan J. Watts, *Structure and Dynamics of Networks* (Princeton: Princeton University Press, 2006), and Matthew O. Jackson, *Social and Economic Networks* (Princeton: Princeton University Press, 2008).

these tools to discover important things about ourselves—for example, that our health, happiness, and even our tastes in music are influenced considerably by those with whom we interact regularly.¹⁸

We now have ways to discover the logic, structure, and function of many types of networks. Specifically, we can understand the rules by which a network forms, we can characterize its structure, and we can explain functional attributes of that structure, such as robustness to node failure or the rate at which diseases or information spread across it. We can use this knowledge to inform policy decisions, extrapolate lessons from the past, and even affect our own lives. As we will see in a moment, one very powerful way to change outcomes in our lives is to change the micro-level rules that guide with whom we interact.¹⁹

Networks form when actors interact in some way. People who give each other business cards form a network of professionals to contact for business matters. A set of friends who send one another e-mail form a different social network. Neurons that frequently send signals to one another form neural networks. How networks form depends on the microrules of the agents in the network for interaction. An example of a simple microrule is: at a party, introduce yourself to people randomly. A more complicated rule is: most of the time, introduce yourself to people who are already talking to people you know, and only some of the time introduce yourself to random people. The first rule would produce a random network, which is (not surprisingly) a network where the connections (or “edges”) between people (“nodes”) are randomly scattered across the network. The second microrule would produce what is known as a small world network, where each node has many local connections and a few random distant ones.²⁰

¹⁸On health and happiness see James Fowler and Nicholas A. Christakis, *Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives* (New York: Little, Brown, and Company, 2009). On musical tastes, see Matthew J. Salganik, Peter Sheridan Dodds, and Duncan J. Watts, “Experimental Study of Inequality and Unpredictability in an Artificial Cultural Market,” *Science* (February 10, 2006): 854–56.

¹⁹Parents, here’s even more reason to be worried about your children’s friends!

²⁰For a pioneering study of small world networks, see Duncan J. Watts and Steven H. Strogatz, “Collective Dynamics of ‘Small-World’ Networks,” *Nature* (June 1998): 440–42. For a more general treatment, see Duncan J. Watts, *Small Worlds: The Dynamics of Networks between Order and Randomness* (Princeton: Princeton University Press, 1999).

Random networks and small world networks are different. They are different in the processes that formed them, as we just saw. They are also different in how they look, which affects their functionality—i.e., the properties of the network that we care about. We'll say more about functionality in a moment. First, we have a few important points to make about structure and where it comes from.

Structure is an emergent property of networks. The agent in our example above did not attend the party in order to contribute to the generation of a small world network (or so we hope); he or she went to meet new people and hopefully have a good time. Network science has classified many network structures and has devised rules by which we can characterize them. In addition to small world and random networks, other common structures include power law, hierarchical, and hubs and spokes networks.²¹

Different types of networks tend to take on different forms. Ground traffic networks tend to look like random networks, while air travel networks are hubs and spokes. Most social networks are small world, while academic citation networks and networks of websites that link to one another are almost always power law networks. In a power law network, almost all nodes have very few connections but a handful of nodes have a great many connections.

The reason these networks look different from each other is due less to the fact that they have different components and more to the fact that these different components use different rules, or processes, for connecting with one another. Humans tend to connect with one another using a rule of mostly meeting people like themselves, which produces a small world network. Alternatively, scientific papers that are cited more are more likely to get still more citations, which means a few papers host the majority of the citations, and most papers receive fewer than two or three citations. This process is *preferential attachment*—or “the more, the more.” If papers receive citations in proportion to the number of citations they already have, then this results in a power law. The World Wide Web is also a power

²¹For an overview of types of networks and their properties, see Albert-László Barabási, *Linked: The New Science of Networks* (New York: Basic Books, 2002).

law: websites with more sites linked to them are more likely to receive more links.

Because structure emerges from these microrules—“pick the one with the most,” “pick randomly,” or “pick others like you”—this means that changes in network structure can be brought about by changes in microrules. Changes in network structure affect the network’s performance—thus finally bringing us to functionality. We discuss two functionalities, robustness and speed of diffusion, and explain how each is influenced by structure.

By robustness we specifically mean resiliency in the face of node failure. How many nodes can be knocked out in a network before the network splits apart, that is, breaks into two pieces such that one can’t travel from just any node to any other node? The more node knockouts a network can sustain without breaking apart, the more robust it is. Here is where structure matters: networks with power law distributions are robust to random attacks, but very fragile to targeted ones (knock out the node with the most edges and the whole thing crumbles). Random networks, on the other hand, are robust against targeted attacks, but they are more vulnerable than power law networks to random knockouts. This type of analysis—looking at the network structure and asking whether the knockout of a single node will lead to catastrophic failure—has been used by the International Monetary Fund in exploring the stability of the world financial system.²²

Another important functionality is how quickly something, such as a disease or a new idea, spreads through a population. If we want a new good idea to spread quickly through a population, then we would like that population to be connected according to hubs and spokes or a power law. If we want a disease to spread slowly through a population, we might prefer a random network or a small world network with very few random long-distance connections.

From just this brief overview of network theory, we can see implications for how understanding networks can help us think not just about how networks form and what they do, but how we can use them to solve problems

²²IMF, *World Economic and Financial Surveys Global Financial Stability Report*.

and generate positive change. From a policy perspective, it is immediately clear that changing incentives locally can lead to real global change. If changing the form of the network can change its functionality, this means it is possible to shift a system from fragility into robustness, or vice versa, with just a few changes to local interaction rules. Of course, even this rule need not always hold: sometimes it may turn out that just a few small changes in local interaction rules can produce tremendous global changes. Other times, we might be surprised by how resilient a network is to many changes. Understanding the properties of networks and the rules that gave rise to them can help us predict what kinds of interventions will be most effective to achieve our desired outcomes.

Having just preached the benefits of thinking in terms of networks, we now offer a word of caution. It is possible to get carried away with network thinking. Almost any information can be represented as a network. We could represent each unique word in this article as a node and draw a link between any two words that appear next to each other in the text. That would certainly be a network, but it wouldn't provide much useful information.

Scholars have used networks to analyze how and whether people vote and what goods they purchase. These studies show that while networks of friends matter, they do not explain behavior as much as income, ideology, education, and other variables.²³ So, though networks matter, they don't always matter that much. As is the case with most methods of scientific inquiry, knowing when to apply a networks lens to our analysis is at least as important as knowing how to understand information about a network once we have it.

A LESS ROSY VIEW

The feature of complex systems that most animates Wood seems to be the robustness of human society—the continuation of the human experiment.

²³On the factors that influence voting behavior, see such foundational and influential works as John Zaller, *The Nature and Origins of Mass Opinion* (Cambridge: Cambridge University Press, 1992), and V. O. Key, Jr., *Public Opinion and American Democracy* (New York: Knopf, 1964). On purchasing decisions, see, e.g., James R. Bettman, *An Information Processing Theory of Consumer Choice* (Reading, MA: Addison-Wesley, 1979).

Wood takes a rather rosy view of the potential for complexity thinking. He envisions a world in which our recognition of complexity results in a more cooperative global society. That may well be true. And, more to the point, greater cooperation may be necessary to cope with our growing complexity. Yet, wishing for cooperation won't make it so. In addition, achieving it may be difficult. Finally, complexity thinking actually suggests that full cooperation is not ideal anyway.

We take up each of these three points: complex systems need not produce emergent cooperation; controlling complex systems often is not possible; and, actually, we shouldn't want full cooperation after all. As for the first concern, there is no end of models that produce emergent cooperation.²⁴ Cooperation can emerge even with the simplest agent rules. For example, Axelrod found that a simple rule of reciprocity was sufficient to generate and sustain cooperation in a community of interacting agents.²⁵ Nowak and May have shown that, over time, evolutionary pressures on spatially arranged agents lead to cooperation even in the Prisoner's Dilemma game, a game in which noncooperative behavior is optimal in the one-shot setting.²⁶

Before we just sit back and wait for the cooperation to come about, we must keep in mind that complex systems also organize themselves into undesirable states. Most notably, a substantial body of research suggests that many systems have organized themselves into *critical states*. A critical state is one in which small disturbances can lead to large events, such as earthquakes or stock market crashes.²⁷ In systems that self-organize to a critical state, tensions build until the entire system is poised on the verge of collapse. The potential danger of self-organized criticality warns us against just letting complex systems run. Recent events in financial markets support this claim.

Despite the risks to just letting systems run, there is abundant evidence of the benefits from decentralization and bottom-up processes. What then is to

²⁴Robert Axelrod, "On Six Advances in Cooperation Theory," *Analyse & Kritik* 22 (2000): 130–151.

²⁵Robert Axelrod, *The Evolution of Cooperation* (New York: Basic Books, 1984).

²⁶Martin A. Nowak and Robert M. May, "The Spatial Dilemmas of Evolution," *International Journal of Bifurcation and Chaos* 3:1 (1993): 35–78.

²⁷See Per Bak, *How Nature Works: The Science of Self-Organized Criticality* (New York: Copernicus, 1996).

be done? If decentralization and bottom-up processes are so great, should we just leave all systems to work themselves out and cross our fingers against criticality? On the one hand, Wood argues for leaving the Leviathan out of this. On the other, we think Wood would disagree with a full laissez-faire policy towards complex systems.

In addition to being “red in tooth and claw,” ecosystems can suffer mass extinctions.²⁸ For many reasons, few would agree that we should just let ‘er rip and see what emerges in ecosystems. Instead, policy makers talk of ecosystem management.

In social systems, emergent outcomes can be very beneficial. In political systems, democracy can emerge. And plenty of good things, like innovation along points of high connectedness, could take place long before we had any complex systems thinking to explain it. But pervasive inequality, disease epidemics, and nuclear weapons can also emerge. Wood’s main premise is that we need better understandings of global history from a complex systems perspective so that we can intervene and affect outcomes for the better. But when do we intervene, and when do we let things run their course?

In contemplating interventions from a complexity standpoint, we must avoid thinking in terms of comparative statics: “the world is in state X now, and if we choose policy Y, the world will move to state Z.” Such logic may work in an equilibrium system, but it doesn’t make sense in a complex system. The same holds for explaining outcomes we already see in the world. We must instead think in terms of features of the system itself. For this reason, Axelrod and Cohen advocate trying to *harness* complexity.²⁹

Policies geared toward harnessing complexity focus on the attributes of complex systems: diverse agents, connectivity, nonlinear interactions, and adaptation. We can think of each one of these attributes as a dial, and we can explore what happens as we turn those dials. As might be expected, as we turn those dials, we do not see simple linear effects. Taking a system that is not at all connected and making it more connected typically increases complexity. However, if the system becomes too connected it can collapse into

²⁸See Doug Erwin, *Extinction: How Life on Earth Nearly Ended 250 Million Years Ago* (Princeton: Princeton University Press, 2006).

²⁹See Axelrod and Cohen, *Harnessing Complexity*.

stasis. The same is true of the other attributes. No adaptation leads to stasis. Too much adaptation leads to a random mess.³⁰ Too much interaction leads to a tangled mess, while too little leads to no complexity. Complexity arises when the dials for connectedness, diversity, adaptation, and nonlinearity are set in between the extremes. For this reason, Miller and Page, in their survey of complex adaptive social systems, describe complexity as the “interesting in between.”

As discussed above, the phenomena produced by a complex system can run the gamut—from emergence to phase transitions. Here’s where knowledge and understanding become important. Models of disease transmission show that there exists a threshold after which a disease outbreak becomes an epidemic. That threshold depends on levels of connectedness. Turn connectedness up a little and the system might produce a mass epidemic. Dial it back down and only a few suffer. This implies there is something that can be done about many systems we care about. Happily, the tools available to understand them are also undergoing regular improvement.³¹

The possibility of harnessing complexity by adjusting dials becomes challenging and may surpass our collective capabilities. This doesn’t mean that we shouldn’t try—only that we must be realistic in what we hope to achieve. A fully cooperative world may exceed our powers. Wood is correct that success in generating desirable outcomes will require a new reality—a new way of thinking and behaving.³² But we doubt that this will take the fully cooperative form that Wood foresees. It will instead be messier and constantly under attack from new ideas. But this is good!

³⁰John Miller and Scott E. Page, *Complex Adaptive Systems: An Introduction to Computational Models of Social Life* (Princeton: Princeton University Press, 2008).

³¹One important tool for analyzing complex systems that Wood doesn’t mention is agent-based modeling, a computational approach to understanding outcomes in systems of diverse, connected, interacting, and adaptive agents. Other tools include increasingly sophisticated software for network analysis, dynamical mathematical models, and genetic algorithms. In addition to actual physical tools, there have also been tremendous conceptual innovations. Just a few of the conceptual tools that give us leverage in our challenging complex systems problems include new ways to measure attributes of complex systems (like connectedness), new ways to classify different types of adaptation, and new theories of when diversity is helpful (see Page, *Diversity and Complexity*).

³²For more on the need for new mindsets to understand our world, see also Eric Beinhocker, *The Origin of Wealth: Evolution, Complexity, and the Radical Remaking of Economics* (Cambridge: Harvard University Press, 2006).

In predicting the lack of a fully cooperative future, we do not want to be seen as throwing a wet blanket on Wood's fire. On the contrary, complexity theory tells us that we would not want full cooperation if we want a robust global system.³³ As Bednar et al. show, system level robustness requires a balance between exploration and exploitation.³⁴ Thus, our economic, political, and social institutions must allow for new ideas and approaches to percolate.³⁵ That means they must permit challenges to the status quo. Often those challenges will be uncooperative and inefficient. And when that happens, those challenges must be put down. But other times, challenges to the "cooperative" status quo will reveal new opportunities or signal calamities. In doing so, they will help to ensure robustness. In other words, we are going to need to have some conflict in order to get to new solutions. We have to prepare to disagree—to defend our ideas while considering others, even if they are starkly different from our own.

We do not mean to suggest that suicide bombers at the local level preserve stability at the global level. Far from it, we mean instead to say that what constitutes a cooperative act in the collective interest depends on an individual's model of how the world works.³⁶ In addition, given that no one person can make complete sense of something as complex as the modern world, any hope for collective understanding will depend on diverse understandings of reality.³⁷ And in order to get anywhere with all our diverse understandings—some of which will be complex systems thinking, and many of which won't be—we need not just to accept, but to encourage our differences.

³³See Jenna Bednar, Aaron Bramson, Andrea Jones-Rooy, and Scott E. Page, "Emergent Cultural Signatures and Persistent Diversity: A Model of Conformity and Consistency," *Rationality and Society* (forthcoming, 2010), for a model that produces both differences between communities and diversity within groups.

³⁴March, "Exploration and Exploitation in Organizational Learning."

³⁵On designing robust institutions that still allow new ideas to percolate and an expansion of the ideas put forth in this paragraph, see Jenna Bednar, *The Robust Federation* (Cambridge: Cambridge University Press, 2009).

³⁶For more on mental models and the advantages for populations with diverse mental models, see Scott E. Page, *The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies* (Princeton: Princeton University Press, 2008).

³⁷See Hélène Landemore, *Democratic Reason: Politics, Collective Intelligence, and the Rule of the Many* (forthcoming).

We are left with a balancing act. Cooperation requires common understandings of what is good. Understanding what is good requires diversity—and not too much and not too little. Making this all the more challenging, the appropriate balance may well be contingent on the current state of the system. At times, we may need to encourage discontent. At others, we may need to look past our differences and forge agreement. Complex systems thinking is itself one way of thinking about the world in a wide system populated by other ways of thinking. It can offer up lots of solutions to lots of our problems, but it is not the only way. In fact, it is a matter of our own survival that it not be the only way.

CONCLUSION: WHERE NEXT?

Where does all of this leave us? We are left with three agendas. First, the world has become more complex. That should be indisputable. It follows that complex systems thinking should prove useful to historians. Having an appropriate set of concepts would seem a prerequisite for competent historical analysis. So, though we take a more tempered view, we agree with what Wood has described—that complexity thinking is needed to help us tackle our most challenging global problems. At the same time, for all our work on complex systems, we need to keep in mind that other ways of thinking are necessary and must simultaneously be encouraged.

Second, it is not a minor point to say that we need a new mindset. Policy analysis has long been conducted from the perspective of equilibrium—doing X creates more Y. Changing our thinking about outcomes from an equilibrium standpoint to one that incorporates complexity means more than just considering that pulling the X lever can have rippling consequences of potentially unexpected magnitudes through a system. It means considering that the institutions that generate policies in the first place may tend to produce outcomes that are more or less robust. How can we structure institutions so they do not produce undesirable large events, like financial crises? For example, Bednar shows that diverse but complementary institutions in political systems can simultaneously provide safeguards against massive shock (due to diversity), but also sustain dynamic performance over time (due to

complementarity).³⁸ This way, a political system need not be fragile, nor will it be completely rigid and unchanging.

Third, historical scholarship and complex systems thinking can form a powerful partnership. For all the new tools and models that have been developed in recent decades, complex systems thinking is still new compared to other ways of thinking. There remains a lot of ground yet to be broken. The currently widely used stylized social science models would be enriched considerably by careful consideration of history and context.³⁹ For example, John Padgett and colleagues, in their work on social networks in Renaissance Florence, found that the Medici formed networks that were robust to shocks.⁴⁰ We ought to take lessons from such findings in the past and incorporate them into what we know now about our current, more complex, social world.

We believe these kinds of historical perspectives on social problems are key to our understanding of how we got where we are. This is not news to historians. Still, adding a complex systems perspective may help both historians and social scientists. Combining historical knowledge of past successes, such as in sustainable resource extraction or disease containment, with complex systems logic should produce very powerful explanations. These explanations can offer insight on our current global system. As much as complex systems can help our understanding of the past, so, too, we believe history can help us understand complex systems. To put it another way: If we combine complex systems thinking with historical analysis, we believe the outcome will be greater than the sum of its parts.

³⁸ Bednar, *The Robust Federation*.

³⁹ The examples of stylized social science models in Cederman, *Emergent Actors in World Politics*, and Lustick, "Agent-Based Modelling of Collective Identity" (see Note 5 above), are excellent cases where much insight was generated from extremely simple models. Imagine how far we might get on particular problems if we could embed these in rich context, or adjust the assumptions with an eye to real cases!

⁴⁰ Christopher Ansell and John Padgett, "Robust Action and the Rise of the Medici, 1400–1434," *American Journal of Sociology* 98 (1993): 1259–1319. John Padgett's entire collection of research on this subject is an excellent case of exactly what we describe in the above footnote on the value to be gained from deep understanding of context.