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Making Complexity Your Friend: Reframing Social Theory for the Anthropocene

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ABSTRACT

This article uses the dilemma of climate change as an entry point to explore the utility of a complexity framework for a more comprehensive social science of environmental sustainability. A theory of complex adaptive systems (CAS) is especially appropriate for the Anthropocene, a newly proposed geological period defined around humanity's impact on the biosphere. Aspects of complexity theory have been entering public consciousness through popular accounts of climate "tipping points" and "emergent" change—the risk that Earth's climate could shift into a new pattern in a relatively short time period. Social structures, including capitalism, are complex systems, as are social movements. The paper reviews CAS research with special attention to applications in social ecology. It discusses two case studies of exemplary research on human management of environmental resources and one case study of the antiglobalization movement, all conceived within a complexity framework. The central argument is that complexity thinking will enhance social studies of sustainability and efforts to create a more resilient economy and biosphere.

1. Introduction

As a gregarious adolescent, riding ponies and climbing trees in the 1960s, summer was my favorite season. But things have changed. The year 2016 was the warmest year since modern recordkeeping began in 1880, and the third year in a row of record-breaking surface temperatures, according to both NASA and the U.S. National Oceanic and Atmospheric Administration (NASA 2017). So summer is now a deadly season: 70 000 people died from a 2003 heat wave in Europe (Robine et al. 2008), killer heat and drought are plaguing India, and the World Health Organization estimates that between 2030 and 2050 climate-related deaths from heat stress, malaria, malnutrition, and diarrhea will rise by an additional 250 000 per year (WHO 2015). The reinforcing feedback loops of warmer seas and arctic ice melt, combined with other new weather patterns, are likely to produce changes in growing seasons and shifts in habitable zones that last thousands of years. Human extinction is not ruled out.

But wait, that lobster-in-the-pot scenario of gradual warming could be too optimistic. A recent analysis of past climate change episodes suggests a reasonable likelihood of abrupt regional climate change occurring after only a 2°C rise in ocean temperature (Drijfhout et al. 2015), yet activists have often depicted the 2° level as the *safe zone* we do not want to exceed. Other debates now ensue over an average 11% reduction in CO_2 emission in the United States between 2007 and 2013, which prompted the White House and BP to credit new fracked gas and less coal use. But University of Maryland researchers report that most of that drop was due to lower consumption in the Great Recession, with the changing fuel mix a minor factor (Feng et al. 2015). The matter is further complicated by conflation of growth in profits with growth in production (which diverged in the era of financialization). Welcome to complex systems!

Far more than the information revolution of decades past, climate change has thrust system thinking and complexity into public consciousness, as officials and the public grapple with climate emergencies, dire predictions, and the uncertainty of computer climate models. A wave of popular books on emergence, wicked problems and black swans has expanded our lexicon, if not always our understanding, of complex systems. My recent research on petroleum and capitalism (informed by a decade of activism in sustainability education) has brought home to me the problems of lacking a common language and

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theoretical grounding for cross-disciplinary conversations on climate and energy. Revisionist histories of capitalism's fossil fuel dependence draw attention to the gross biases of economic and geopolitical systems built on expectations of endless growth of capital, with no effective feedback to mitigate reliance on limited stocks (key resources), pollution sinks, or impacts on human welfare (Mitchell 2011; Huber 2013; Smith-Nonini 2016).

Concurrent with new attention to climate change, scholars now debate our entry into the Anthropocene—an epoch of human-forced climate change signaling the end of the Holocene. It is perhaps no accident that during the last decade, as the notion of a pristine nature outside of humanity became demonstrably false, social theorists weighed in on complexity (e.g., Morin 2008; Espinosa and Walker 2011; Byrne and Callaghan 2014). But relatively few qualitative anthropologists and sociologists draw on this body of theory to date, often for good reasons, as writings on complexity are sometimes obscure or lack convincing examples of applications to social life. The theme for this special issue—Thinking the Earth: Ways of Knowing, Modes of Care—inspired this paper's exploration of complexity thinking, its application to socioecological problems, and its implications for sustainability research and activism.

Complexity is best thought of as a property of systems. Donella Meadows defined a system as a set of things—people, cells, antelope, etc.—interconnected in such a way that they produce their own pattern of behavior over time (Meadows 2008, p. 2). A complex system has multiple, confusing components, with feedback loops, and both the system and its components are evolving. This thwarts efforts to adequately describe a system using Newtonian laws or applications of linear mathematics or rational analysis that tend to emphasize reductionism and the search for simple causal relationships. Unlike a complicated machine, a complex system (e.g., a fishery, a city) cannot be simply taken apart, analyzed, and then reassembled from those parts (Byrne and Callaghan 2014, 3–4). This concept should resonate with anthropologists who routinely teach introductory students that human culture is holistic, with a whole greater than the sum of its parts. Yet many social scientists find complexity to be a confusing and irrelevant theory. One reason may be its origins in post–World War II cybernetics, a field that also inspired structural functionalism, which fell out of favor after heavy critique by social theorists. Another reason is the polyglot complexity literature that encompasses mathematics, physics, and computer modeling. Social scientists often seek to distinguish their fields from hard sciences—especially applied fields, and classical economics—which are often derided for embracing positivist, individualistic, and technologically determinist values.

This paper will be mainly concerned with complexity applied to social life, a relatively new field known as complex adaptive systems (CAS) theory, which addresses system transformation that results in part from the changing experiences of actors inside a system. Intriguingly, Byrne and Callaghan (2014, p. 38) suggest that CAS theory presents the possibility of a unified approach capable of integrating the so-called hard and soft sciences. More modestly, I have come to see CAS work as offering important integrated models for thinking that will be essential to the humanistic ecology that needs to shape our planetary future. A key goal of much CAS theorizing, and of this paper, is to highlight work of scholars who seek a metalanguage to better enable cross-disciplinary work in complexity, and to transcend sterile debates that inhibit inquiry across the material and social realms. While CAS theory is catalyzing new methodologies and collaborative research, it also signals a paradigmatic shift toward new models for thinking about social–environmental issues.

In asserting the potential for CAS theory, Morin (2008) emphasizes that the social sciences have themselves been shaped by influences of Cartesian dualism, reductionism, and abstraction, creating a ''paradigm of simplification'' and leaving Western thought hobbled with ''blind intelligence'' that isolates objects from their environments. This hyperspecialization, he argues, has truncated communication across the fields of physics, biology, and the human sciences and has ''fragmented the complex fabric of reality'' (p. 4). While our societies are increasingly managed by experts and specialists, their license to solve problems is based on respecting disciplinary boundaries. Morin argues ''we have thus come to scorn general ideas since, it is claimed such ideas are 'built in the air' or lack proof.'' Meadows (2008) viewed boundaries between systems (including academic fields) as having high diversity and argued that they should be considered permeable or temporal, depending on the questions being addressed. This cross-boundary blind spot is why Morin (2008, p. 86) asserts that experts fail more often than nonexperts when new problems arise. He relates this inclination toward narrowness to the tendency to treat politics as ''simple and Manichean'' instead of a process that requires complex thought and recursive feedback (p. 5), and suggests that development of a human science is impeded by adherence to nineteenth century thinking, shaped by an ''implicit ideology of Christianity and western humanism – the supernaturality of the human'' (p. 8).

Despite these disjunctures, complexity thinking increasingly influences research in fields that touch on climate and environment, including archaeology, urban studies, epidemiology, economics, geography, ecology, and resources and wildlife management. In a lucid example for our theme of climate change, Meadows (2008, 58–66) illustrated how a complexity mindset aids analysis of capitalist fossil fuel extraction. She demonstrated the reproducible patterns produced from flows of two kinds of "stocks" that interact in oil well dynamics, with stocks referring to changing capital investment (affected by market prices) and quantities of oil produced over time. Economists, she noted, have typically focused mainly on flows, ignoring the structure of the system and factors like the oil well depletion rate. In addition, changing exponential rates of investment/extraction tend to trick most observers into grossly underestimating how rapidly depletion will occur. She goes on to show different patterns of responses if the resource being extracted is renewable, using the example of a fishery (Meadows 2008, 66–71).

Some ethnographers, as illustrated in the case studies below, combine computer modeling with qualitative methods to examine complex social–environmental phenomena. Complexity is also making its way into wider popular literatures, although often in a piecemeal fashion, which offers opportunities for innovation but also leads to magical attribution, such as claims that Lovelock and Margulis's (1974) hypothesis of a self-regulating Earth implies an ecoconsciousness (e.g., Goerner 1999). But this is perhaps no worse than our current situation of magical realism, or what Morin (2008) calls our inability to separate the world from our systems of knowing. Recalling the difficulties early anthropologists had explaining why superstitious tribal peoples nevertheless showed admirable rationality in hunting, he writes, "we did not realize that magic and rationality coexisted in these societies. We did not see similarly, that there is magic as well as rationality in our society, and even within our rationality" (p. 91).

Section 2 below provides a brief primer on CAS theory, and section 3 situates systems theory and complexity within contemporary social sciences. The fourth section addresses computer modeling in CAS research, and the fifth asks if CAS is an ecological theory. Section 6 presents two exemplary case studies of research on human–environment interaction that combine qualitative data and computer simulations within a CAS framework, and the seventh section explores the possibilities of CAS as a paradigm for social activism. In conclusion, I briefly consider the relevance of complexity thinking for social science knowledge and leadership in the Anthropocene.

2. Complex adaptive systems theory in a nutshell

An appeal of CAS theory is that it helps elucidate phenomena in flux situated at the intersection of the natural and human sciences and involving both population and individual-level variation. Complexity thinking represents a break with positivism, a mindset that prioritizes knowledge gained empirically and interpreted through logical reasoning, and which has tended to favor Newtonian formalism and embrace hierarchy as the definition of order in both science and society.

Sometimes described as a middle-range theory, complexity is especially useful for phenomena that fall in between the extremes of a two-variable problem and phenomena best described via statistical probability. Complex systems are involved, for example, in the conduct of warfare, the spread of epidemics (Johnson 2009), regulation of pesticide use on farms, finding effective incentives for consumers to save energy (Meadows 2008), or in individual decisions about whether to support a public good like climate change mitigation (Milinski et al. 2008).

The rise of complexity thinking, according to Morin (2008), corresponded in part to breaches in the epistemological framework of physics that challenged Newtonian laws. At the microlevel, quantum theory revealed there is no objective viewpoint on phenomena and showed that particles can also act like waves, with locations only describable in terms of probabilities. At the macrolevel, general relativity showed that the experience of "reality" depends on the observer's orientation (as well as that of the object being observed) in space and time, both of which must be theorized in relation with each other (Morin 2008, 8–9, 20–21).

Living systems are open systems that temporarily reverse the flow of entropy by creating order, but depend for existence on external sources for energy and information (Espinosa and Walker 2011). The focus of early cybernetics on recursive loops or regulatory feedback as a component of system stability elucidated a key process of all complex systems, whether they involve atomic nuclei, solar systems, or organic life, which is their self-organizing or "autopoietic" nature. In short, systems continuously reproduce themselves, but depend for stability on exchanges of energy, matter and information within and across system borders. Since there is no way to conceive of life or "the social" except as in relationship with its environment, Morin (2008, p. 11) observes that a theory of evolution (involving self-organization) is implicit.

Emergence, a key property of complex systems, refers to change in a system's state or form that is disproportionate to changes in causal elements. Such change can take place rapidly and is often not predictable from information about elements of the prior system (Byrne and Callaghan 2014, 20–24, 356–357). Emergent change in systems might include formation of traffic jams, bird flocks, social insect colonies (Sawyer 2005, p. 4), how a Twitter video ''goes viral,'' or abrupt climate change. An emergent state is often described as having laws or properties at higher levels that cannot be easily reduced to lower levels or to basic sciences. A state toward which a system evolves over time is known as an ''attractor.'' Any system's attractor states may be multiple and shifting within a range known as its ''phase space'' (Byrne and Callaghan 2014, p. 30).

To better envision how a complex system might engage simultaneously in tasks of creative self-production and routine reproduction, recall that an organism, ecosystem, or social system, unlike a machine, must replace its more fragile parts on a routine basis, for example, through molecular interchange, cell death and reproduction, microbial decomposition, or people in a population giving birth and dying (Morin 2008, p. 17). Self-organization involves creation of boundaries by a system as it undergoes change. Such bounded entities have some autonomy – but remain always bound with their environmental niche (Morin 2008, 18–19).

A key question about any complex system is how its complexity is defined for a specific observation. Any given system's degree of complexity is measured by its ''variety,'' which refers to the repertoire of potential behaviors a system can exhibit in a particular context (Espinosa and Walker 2011, p. 29). Drawing an analogy to biodiversity in ecosystems, in social systems, this might mean that democratic politics and cultural diversity lend resiliency to the myriad of human–Earth systems that make up our niche.

3. Complexity and social theory

Contemporary theorizing on complexity dates to early work in cybernetics inspired in part by McCulloch's (1945) work on binary properties of neural nets in the brain, which influenced early computer technology. Talcott Parsons, a structural functionalist, saw McCulloch's findings as resonating with his ideas about homeostasis. His ''general theory of action'' was a (not wholly successful) attempt to explain the role of agency and dynamics (constant change over time) in ''self-organizing'' social systems (Capra 2002, p. 77). Niklas Luhmann, Parson's student, is credited with conceiving the concept of social autopoiesis. But cybernetics also inspired a proliferation of machine metaphors in biological and social theory. Morin (2008) sees the contemporary technocratic origins of complexity as regrettable, observing that early work on self-organization in 1959–61 ''made the fortune of cybernetics, but atrophied its theoretical development'' (p. 17).

At the height of U.S. power after World War II, the influence of space-age science, anticommunist geopolitics, and the official embrace of cornucopian capitalist ''progress'' led to widespread application of Walter Rostow's Modernization Theory in social development programs such as ''green revolution'' agriculture. The relentless positivist and determinist influence displaced approaches that respected native historical knowledge or sociocultural relationships. Social resistance grew in response to imperial overreach, often fed by the excesses of authoritarian regimes, inspiring the civil rights and antiwar movements. Early environmental movements, the 1970s energy crisis, the influential *The Limits to Growth* study (Meadows et al. 1972), and the 1960s counterculture all combined to spawn innovation in thinking about the human–Earth relationship, helping to fertilize cybernetics and systems research while also provoking new social science critiques of imperialist policies and technologies that ignored history, social change, and diversity.

The influential notion of resilience was a complexity concept developed by C. S. Holling (Holling 1973) in response to what he saw as overly circular and normative tendencies of equilibrium models for ecosystem change. Unlike equilibrium—the notion that natural systems returned to a state of balance after disruption—resilience described the emergent capacity of a system to absorb shocks or stress and adjust to new circumstances without losing its coherent functions. These ideas paralleled other dialectical ideas in the social sciences such as Habermas's concept of ''life world'' involving both empirical/analytic and hermeneutic knowledge and Gidden's view of agency as continuous and transformative (Capra 2002, 77–81). Systems theory also influenced archaeologists in the 1960s and 1970s, who sought a more dynamic analysis of cultural patterns in the interpretation of artifacts (Flannery 1968; Binford and Binford 1968). More recently, the rise of network theory has influenced social research on communications, economics and social movements (Castells 1996; Juris 2008). Ecological anthropologist Emile Moran (Moran 2010) argues that the discovery that complexity exists even in simple systems poses a challenge to biologists since it implies that evolution is not the only source of order. He sees the concept of emergence as challenging the very idea of social structure and the relationship of micro to macro.

Ironically, some of the same critiques social scientists levy against positivist science also are seen as weaknesses of systems theorists, including a tendency toward determinist accounts that understate power and agency and overreliance by computer modelers on simulations that ignore social adaptation and creativity (Morin 2008;

Byrne and Callaghan 2014). However, it should be said that many such critiques were more relevant directed at the limitations of game theory in the 1980s and less applicable to multi-agent modeling as it is being used by social scientists today (see section below; Bell 2012). I would argue that use of a systems/complexity orientation to better understand ecology and social life has built-in limitations, such as its normative framing, which must be held in tension with core social science concepts of agency, power, and social conflict, all of which remain more relevant than ever in the period of late capitalism (Olsson et al. 2015). The erroneous notion that CAS theory signals an embrace of equilibrium (which remains a common premise of neoliberal economics) continues to haunt complexity analysis. This arises because of the idea that complex systems internalize external challenges to their existence, a process that creates ambiguity about subjectivity (Walker and Cooper 2011, p. 157). Another risk is making unwarranted assumptions from modelers' data about representation, since meaning is a contingent, historical concept and is specific to culture and environment (Cilliers 1998).

For all these reasons, researchers will continue to face challenges as they shift between frameworks for analysis (e.g., system attributes versus political critique of elites) since many writers rightly fear reinforcing the economistic or technologically determinist views that hold sway in economics and geopolitics. To date, the field remains divided between those favoring quantitative and computer-based simulation of social complexity and those who use qualitative methods but theorize about complexity as a new social paradigm (Stichweh 2011). A small number of researchers, including those in the "Praxis I" case studies below, work across methods and disciplines, combining computer modeling with ethnography and other social methods for perhaps the richest application of CAS theory.

I would argue against the embrace of complexity theory as an exclusive world view in social science; rather, I see "complexity thinking" as a fertile compliment to other social analysis. Morin (2008, p. 15) distinguishes the complexity turn from romantic, metaphorical traditions of organic analogies, because CAS theory seeks to discover common principles of organization across social and material categories. Urry (2005) refers to this paradigm as a revival of neovitalism in social thought.

A cogent example of using complexity to rethink system organization is Carole Crumley's (Crumley 1995, 2005) critique of assumptions that order is synonymous with hierarchy, or based on ranked elements. In archaeological fieldwork on Roman-era settlements in Burgundy, France, she found that artifacts often appeared unranked or could be ranked in multiple ways. Crumley pointed out that many orderly structures are not organized hierarchically: for example, a monsoon, or an animal, or the Western tradition of democracy. She argued that heterarchy is a common, if overlooked, pattern for managing social power, and noted that horizontal linkages are found inside seemingly hierarchical systems. This flexibility in vertical versus horizontal relations likely contributes to structural and/or cultural stability when systems come under stress (Crumley 1995, 2005).

Crumley (2005, p. 41) evokes earlier traditions in anthropology, such as the discipline's variety of work on kinship and Elman Service's (Service 1962) writings on the roles of coalitions, unions and communities in managing power. She asserts that heterarchy meets three key criteria for social models: the concept helps relate micro and macro aspects of society, it relates conscious agency to social structure, and it helps explain change. As we see below in the section on networked social movements to reform corporate capitalism, heterarchy has become a key organizing concept for social change (Crumley 2005, p. 40).

Cross-disciplinary discourse on complexity has most often foundered on theoretical and communication differences between computer modelers and scholars trained in other methodologies. Some theorists intentionally bracket out quantitative modeling or "restricted complexity" in their writings on CAS (e.g., Morin 2008; Byrne and Callaghan 2014), on the grounds that they overrely on methodological individualism and ignore complex aspects of human agency and institutional or collective agency. Yet, Byrne and Callaghan (2014) also criticize a tendency among some postmodernists to seize on CAS theory to reinforce views that knowledge is always partial, delegitimizing comparative or macro analysis. The result, they note, is CAS theory providing one more excuse to ignore materiality (p. 63). This paper seeks to bridge that divide and embraces Meadows' (2008) suggestion that scholars work together to solve common problems, rather than our usual habit of talking past each other.

4. Simulating social emergence in multiagent systems

In a brief survey of the field, Stichweh (2011) distinguishes theorists who write about CAS (abstractly) as a social paradigm from those who are interested in updated versions of general system theory, which traces its origins through Parsons, cybernetics, and game theory, and more recently, a turn to multiagent systems (MAS) using "artificial society" computer programs, combined with other methodologies. The Santa Fe Institute is the best known center for this latter approach. (see https://www.santafe.edu/research/; Sawyer 2005; Mitchell 2009; Johnson 2009; Holland 2014).

Self-selection is no doubt a partial explanation for the divide. Some quantitative researchers eschew the squishy ground of social methods and many cultural anthropologists lack strong backgrounds or interests in mathematics (Lansing 2003). I would add that there are also strong effects from academic habitus (e.g., 40 years of American cultural anthropology privileging ethnography over other methodologies) and rational responses of scholars to publishing pressures of the neoliberal academy that favor individualism. Likewise, there have been few funding sources (until relatively recently) for interdisciplinary work.

Some social researchers mistakenly lump together MAS models with game theory, which uses iterated games between players to study decision-making. Game theory, still widely used in behavioral economics and political science, has been criticized for reliance on rational choice decisions (which fail to predict outcomes in real world scenarios) and for its assumptions of a predictable environment (when so much of life takes place in ''noisy'' changing environments), according to Bell 2012, who describes a gradual migration of complexity theorists from game theory to multiagent computer modeling precisely because of these problems.

Even Robert Axelrod (Axelrod 1997)—best known for his game theory work showing how social cooperation can evolve into a stable strategy—turned to MAS modeling in the 1990s to create scenarios based on real-world problems in which strategies can arise and evolve without external intervention. The new approaches modeled how agents, lacking full knowledge about a problem, often follow ''rules of thumb,'' more closely resembling how people make decisions (Bell 2012). The models allow agents to cope with misunderstandings and adapt their strategies based on interaction and knowledge of the expectations of other agents. Such cooperative approaches may offer alternatives to the dominant model of competitive economic exchange, which governs global economic planning and constrains efforts to envision a sustainable future.

Axelrod observed that cooperation takes many forms, including collaboration to build a joint project, to win a conflict, to form a coalition to impose a new standard (e.g., as in an industrial strategy), to build a new organization, and to build a shared culture (Axelrod 1997). He saw simulations to be most useful as ''thought experiments.'' One reason why so much social science modeling has been based on rational choice, Axelrod argued, is not because it is predictive (although I would add, that probably accounts for its appeal to many economists), but because it allows deduction. In contrast, adaptive behavior is hard to deduce, and the goal must be to understand the processes, not accurate representation. This is why simplicity in design of the model is important, since a researcher needs to be able to assess and change the model in response to outcomes (Axelrod 1997).

Sawyer (2005) extols the usefulness of MAS work based on ''artificial society'' programs, which involve hundreds of thousands of adaptive interactive agents. A MAS simulation applies simple rules to a network of components that lack any central control. In such a program, the programmer decides goals and internal states, the topology, and population size. But each agent is autonomous, has the capacity to communicate, and may change behavior based on experience during the simulation. Models are designed with a more or less competitive environment, simulating conditions that have consequences—analogous to the stress of changing environmental conditions under which evolutionary change takes place. The goal is to simulate emergence or macro changes that cannot be predicted. Examples of micro-to-macro emergence discussed by Sawyer (2005) include successful modeling of the emergence of (racial/ethnic) geographic segregation in agent groups based on minor preferences programmed into individuals (Schelling 1971). Simulations run by Mellars (1985, 151–153) using archaeological data on human foragers during a glacial maximum, showed a correlation between increasing scarcity of resources and the evolution of hierarchy. Computer models are also used to project the course of epidemics. While random models may suffice to describe spread of the common cold in elementary schools, Miller and Page (2007) emphasize the usefulness of network models that simulate patterns of social relations—for example, workplaces, travel, or sexual activity—which correlate with risks for infections such as SARS or HIV/AIDS.

Emergence should not be thought of as mainly a micro-to-macro phenomenon. Sawyer (2005) notes that in these models, the emergent macro state constrains the actions of agents, creating influences running also from macro to micro level. As a simulation is run, however, agents do not perceive the whole picture, but only their neighbor's actions (Sawyer 2005, p. 157). He gives a provocative example of a simulation demonstrating macro-to-micro causation developed by Macy and Skvoretz (1998), in which agents played an iterated ''prisoner's dilemma'' game first with familiar neighbors, and then with strangers, while grouped in ''neighborhoods.'' In the simulation, agents evolved trust and cooperation with strangers, a process that took place in neighborhoods of all sizes, as long as agents interacted more with their neighbors than with strangers. But when agents were not grouped in neighborhoods, trust did not evolve (p. 160). Such findings hold implications for urban planning and for studies of governance of common resource regimes.

Simulations can also assist the study of path dependence, in which agents learn from experience and adapt to a changing topography. Models have been created, for example, to show how opposing candidates interact to develop political platforms that appeal to voters and respond to the positions of their opponent. In addition, simulated networks can be created with multiple patterns of connectivity, each of which generates surprising outcomes. This can help researchers find generic patterns. Besides modeling epidemics, this has been applied to digital connectivity and to patterns of human communication. Also, agent-based modeling of how games are played has helped researchers understand how simple rules affect market outcomes. This can be used to show emergence of trading patterns or cooperation scenarios (Miller and Page 2007).

Sawyer points out that many simulations challenge views of interpretivists. He singles out Anthony Giddens' theory that macro structures come about through practical consciousness, since emergence of macro conditions in simulations does not depend on internal representations by the agents involved (Sawyer 2005, p. 159). Giddens, however, gets credit from Sawyer for being correct in his prediction that emergence and maintenance of social patterns operate through similar processes, a conclusion that the MAS data supports (Sawyer 2005, p. 156). Against the critique that computer models are blind to history, Sawyer notes that ''artificial society'' simulations model not only homeostasis, but also change. However, he cautions that MAS simulations do not wholly support either methodological individualists or social realists, but can be used for theory development by both schools (Sawyer 2005, p. 168).

5. Ecology and CAS

The subfields of social–ecological systems (SES) and sustainability science have roots in complexity perspectives and have done important work to bring social science perspectives to the study of human–environment relations. The concept of resilience is central to SES and draws on many complexity concepts, such as nonlinear dynamics, thresholds, uncertainty, emergence, alternating periods of gradual and rapid change, and interaction of these changes at varying temporal and spatial scales (Folke 2006). The related field of sustainability science engages with problems of meeting basic human needs while preserving Earth's life-support systems. Cross-disciplinary work in complexity may assist with a central task that researchers in sustainability face, which is restoring working relations between science/technical fields and the social sciences following the estrangement of the ''culture wars'' and the postmodern turn in the 1990s.

Another enormous challenge is to appropriately scale and link local/bioregional and global research and communication networks (Kates et al. 2001). For knowledge to be useful across such scales involves power dynamics familiar to researchers in sustainable development, such as anticipating stakeholder power struggles, facilitating interaction between researchers and stakeholders, supporting social learning processes, and ways to involve communities in research and knowledge production (Clark et al. 2016). Again, complex thinking about differing frameworks of knowledge and power may assist researchers in reconceptualizing these problems.

The popular sustainability literature draws on aspects of complexity to demonstrate the embeddedness of humans in nature. Fritjof Capra's book—*The Systems View of Life: A Unifying Vision*, coauthored with Pier Luigi Luisi—envisions both life and cognition as best conceptualized in terms of ''processes'' rather than structures, with a basis in networked connections, rather than machine metaphors (Capra and Luisi 2014). So at the risk of unleashing a critical hailstorm about environmental determinism, let us ask this question: Is systems thinking somehow ''natural?'' After all, the system is a ''quasi universal'' concept that is often used to describe all known reality. Atoms, organisms, social institutions, and solar systems can all be productively described as systems (Morin 2008).

It is helpful here to distinguish ''weak'' approaches to sustainability, in which nature is imagined as external to humans (Espinosa and Walker 2011, p. 16), from ''strong'' or ecocentric approaches that see nature and humans as coevolving. Ecocentric theory might include Gregory Bateson's (Bateson 1973) views that patterns of thought contribute to external problems, or Meadows' (2008) discussions of ''systems traps'' or reforms that fail when planners do not incorporate human behavior and a systems perspective into environmental management. Both anthropological and popular writings on sustainability speak of the potential for a ''theocentric'' view that incorporates wisdom from traditional cultures into a human science of ecology (Bell and Morse 2005).

As noted above, poorly grounded assumptions about equilibrium animate these debates. Systems are by definition recursive—cycles and feedback are constant—and complex systems fail or transform when feedback fails. But earlier versions of systems theory often assumed feedback was always regulatory, while more recent theory distinguishes balancing or negative feedback loops (which regulate a system) from reinforcing or positive feedback that can destabilize a system by fostering path dependence (Urry 2005). Examples include contemporary industrial societies' fossil fuel dependence, the tendency of corporate capitalism to exacerbate inequality, or increased solar absorption by the Arctic Sea as ice cover melts. When institutional factors are combined with technology patterns, ''lock in'' can occur, with very real deterministic properties (Urry 2005, p. 5).

Urry (2005) echoes other CAS theorists in emphasizing that most systems exist far from equilibrium, and there is no such thing as ''nature's balance'' (p. 6); it is more accurate to imagine ''islands'' of order, rather than states. Self-organizing systems, he reminds us, are most stable (and achieve their most intricate functions) operating at the boundary between order and chaos. Chaos here refers not to randomness, but to a state that, while sufficiently complex to thwart description, reflects initial conditions (Crumley 1995). But what appear to be chaotic flows—for example, of immigrants, migrating animals, or antibiotic resistance—may represent systemic bifurcations that develop their own coherent properties. Such flows initially may seem confusing, even potentially threatening. But adoption of new frameworks that recognize multiple perspectives and the arbitrary, necessarily permeable, attributes of borders may permit restoration of meaning across boundaries. Espinosa and Walker (2011) hypothesize a direct correlation between the degree of self-governance within a society and its capacity to regulate unsustainable behavior. Resilient systems seem to be those that incorporate both hierarchical and heterarchical modes of organization, and in which goal-directed behavior and creativity/diversity are both present (Byrne and Callaghan 2014, p. 20).

Complexity and systems thinking appear to be fundamental to the growing literature on sustainability and ecoliteracy, and to the permaculture movement. The systems perspective is able to incorporate the wisdom of precautionary principles, biomimicry, preservation of diversity, networked relationships, and endless cycles of communication—not as programmatic prescriptions, but as ways of aligning human social systems with those of our ecological niche. Good examples of books intended for systems-informed sustainability education include *Developing Ecological Consciousness: Path to a Sustainable World* by Christopher Uhl (2004) and *The Power of Sustainable Thinking* by Bob Doppelt (2008). There are also several exemplary sustainability websites drawing on systems theory, for example, http://ecoliteracy.org and http://educationforsustainability.info/.

CAS thinking—or the influence of adaptive complexity concepts—has spread widely in the social sciences, even among those who do not apply CAS theory in any formal way. For example, how complexity is defined for any system depends on the framework used for observation. Espinosa and Walker (2011) point out that the choice of how to frame the field is highly subjective and cannot be teased apart from cognition, since observations are always filtered by mental models. As Francisco Varela and colleagues (Varela et al. 1992) and contemporary theorists such as Donna Haraway (Haraway 2008) have argued, mental models are themselves shaped by one's experience of ''being'' in the world. Thus, the heuristic value of complexity ideas, including pervasive uncertainty, unknowability, emergence, and attractors have already infused social theory. A key example is the literature on ''new ecology'' that emphasizes the situated and partial knowledge of the natural world and is sensitive to the multisited and shifting relationships of power that pervade social relations with resources and environments (Scoones 1999).

6. Praxis I: Walking our talk (or what a community of science for living on a finite planet might look like)

One of the central dilemmas of climate change is the periodic and long-term threat that extremes such as drought and flooding pose to essential resources such as food, fisheries, and arable land. Preserving or achieving cooperation to manage common resources is a dilemma at the base of many environmental and social conflicts. In this section, I explore two interdisciplinary social research projects that incorporated complex system thinking and combined qualitative and quantitative approaches to study humans' relationship with the environment and each other.

a. A decentralized irrigation system guided by religious ritual

In the 1970s, J. Stephen Lansing conducted ethnography on the Balinese water temple system to understand the relationship of religious beliefs to rice irrigation. Local cooperative groups of farmers called subaks, each associated with a water temple on a mountain watershed, controlled planting and harvesting in a seemingly coordinated way. During initial fieldwork, Lansing witnessed problems that arose from Green Revolution strategies in Bali when modernization schemes using new dams, fertilizers, and pesticides resulted in failed harvests rather than the high yields predicted (Lansing 1991). By the early 1980s he reported that many farmers on mountain watersheds had rejected the government strategies and returned to the more reliable water temple system.

In 1986 Lansing partnered with James Kremer to develop a computer model of the system to reflect the actual hydrological and agricultural conditions farmers faced on a Bali watershed with 172 subaks. They used the model to test whether there was an optimum mode of regional coordination that could balance between two conflicting goals: efficient use of water and control of insect pests. They found that coordination among hundreds of subaks was the key to good harvests. When each simulated subak chose its own planting schedule, there were many crop losses due to pest damage. At the other extreme, if all subaks planted in synchrony, they could reduce pests due to the fallow period between crops, but water supplies would be inadequate for good yields. As it turned out, the simulation of an optimal compromise between pest and water risks corresponded closely with actual coordination by the democratically managed subaks in the network. Lansing (1991) shared these finding with farmers, water temple priests, and state agricultural agents.

A second round of research was kicked off in 1992 after Lansing was prompted by colleagues at the Santa Fe Institute to investigate whether the Bali water mountain was a self-organizing system—that is, whether the system could arise from the ground up, or was designed by a central authority. Although there was a religious hierarchy on water mountains, Lansing's ethnography showed that most decision-making took place in democratic subaks. To answer this question, Lansing and Kremer ran a new set of simulations that allowed the digital agents of each subak to learn and adapt their practices based on outcomes of crops for four neighboring subaks. The agents were programmed to copy the behavior of more successful subaks. Using this simple rule, within a decade of simulated rice crops, the subaks had organized themselves into cooperative, nested networks, closely resembling the real system in Bali (Lansing and Kremer 1995; Lansing 2006, p. 14).

Lansing, aware of the potential bias from tweaking computer models in the direction of a subconsciously desired outcome, returned to Bali to do ethnography on 14 subaks to examine how they functioned (Lansing 2006). He found great variation in subak governance, from strong to weak democracy, constantly in tension with authoritarian tendencies (in this case, male contestation over status that prevails in other aspects of Balinese society). Yet he also found a strong ethic favoring democracy and a tendency for episodes of dominant leadership to be short-lived (Lansing 2006, 88–121). In further fieldwork on Balinese cosmology, Lansing explored the complex, gender-inflected rituals and beliefs that promote self-mastery of emotions and balance, which he argued helped mitigate the tensions of ranked male status with heterarchical ideals of the water temple system (Lansing 2006, 122–152).

The findings also kicked off inquiry into the contradictory history of the water temple system. In contrast to Java, where broad river valley irrigation was associated with strong kingdoms, after the twelfth century in mountainous Bali, archaeological and historical accounts showed a tense dialectic between weak kingdoms (promoting ranked status) and the rising, heterarchic power of village officials who managed taxation and rice agriculture. This suggested that the hypothesis of subak self-organization was a plausible interpretation (Lansing 2006, 62–66).

b. *Characteristics of polycentric social models for managing common resources*

Throughout a long career, Elinor Ostrom's collaborative research challenged classic assumptions (based on simplistic, dualistic models) that groups of people could not organize themselves to manage resources (Ostrom 2010). Economists and political theorists had argued that public and private goods, or personal and group interests, were in conflict with each other. But when Ostrom reanalyzed data from such studies, based on the premise that actors are embedded in a complex system, she concluded that the dualistic, ''either/or'' viewpoint could be reframed as polycentric (with multiple perspectives coexisting) once the problem was recast in terms of joint interests and risks (Ostrom 2010).

After years of studying groups that managed a range of resources, from water to police services, land, and fisheries, Ostrom and her colleagues undertook a meta-analysis of existing case studies of common-pool resource systems around the world based on material gathered by the U.S. National Research Council. Of 25 farmer-managed irrigation systems studied, over 70% (n = 18) had high performance that far surpassed outcomes from government-managed systems (Tang 1994, p. 234). Likewise, 75% (or 33 out of 45) of fisheries studied that were managed by the users (as opposed to an outside authority) had adopted informal rules to define who was allowed to fish where and to regulate harvesting (Schlager 1994, p. 260).

Early in her career, Ostrom had come to question rational choice assumptions, since her informants in the field seemed to act within a realm of ''bounded rationality,'' developing common sense heuristics to guide them. Her research team found that the capacity to overcome dilemmas and govern effectively depended upon the structure of the resource itself and on linking a set of rules effectively to that structure. In all self-organized systems, they found that users created boundary rules to determine who could use the resource, rules about allocation of resources, and active systems to monitor and sanction rule breakers (Ostrom 2010).

The researchers designed simulations in the laboratory to test which variables affected decision-making. They discovered that simply allowing communication or ''cheap talk'' enabled participants to reduce overharvesting and increase joint payoffs, contrary to game-theory predictions. This communication issue lies at the heart of much interdisciplinary confusion. Often findings of iterated prisoner's dilemma games show social actors trapped in a situation and unable to change the structure. But Ostrom sees the trap as built into the model: ''Public investigators purposely keep prisoners separated so they cannot communicate. The users of a common-pool resource are not so limited,'' said Ostrom in her Nobel Prize lecture (Ostrom 2010, p. 648). Ostrom also reconceptualized property rights, which had previously been construed as tied to the right to sell a property. Based on ethnographic data, she proposed a new concept of *bundles* of property rights. Ostrom created a set of best practices that describe the management of resources in those systems that proved resilient over the long term (Ostrom 1990, 90–102).

The social problems in both the above case studies involved the management of jointly utilized environmental resources. The groups studied by Lansing and Ostrom (and their colleagues) were in settings threatened by capitalist encroachment with accompanying pressures to privatize land and commercialize resources and production. Meadows (2008, 116–130) refers to the so-called ''tragedy of the commons'' (Hardin 1968) as well as the problem of capitalist-driven ''competitive exclusion'' as classic system traps, which deprive a system of the diversity and feedback that allow it to function. Importantly, the researchers in both case studies adopted holistic perspectives and were open to suggestions that a different framework might help them interpret the initially confusing data on their complex system. Both drew on a combination of modeling and indigenous knowledge to validate alternative frameworks, and in both cases the etic synthesis that emerged was more comprehensive and coherent than the partial perspectives of their informants, and offered a richer knowledge base than any single methodology or researcher could have produced. Further, the new knowledge in both cases holds the promise of assisting grassroots efforts to improve and defend indigenous systems overlooked (or threatened) by governing authorities, capitalist development pressures, and episodes of extreme weather tied to climate change.

7. Praxis II: Movements for social and environmental justice as complex adaptive systems

The future of climate change, fossil fuels, deforestation and other environmental issues cannot be teased apart from the current debt–peonage relationship harnessing humanity to the machinery of capitalist growth. So social movement thinking begins with capitalism, and from a systems perspective, what better example of emergence than revolution or radical change? Capitalism is replete with systemic thinking, beginning with Adam Smith's magical claim that self-interest suffices to redistribute wealth (Smith 1976, p. 184). The high priesthoods enjoyed by economists derive from their claim (however tenuous post-2008) to understand ''systems'' of trade and finance, and a pretense that they will manipulate these to the benefit of populations. But as social scientists who study actual capitalist systems will testify, the public welfare aspects of capitalist states, to the degree they exist, are entirely designed, require the collaboration of states with their monopolies on violence, and are increasingly unstable. Perhaps another way to describe current capitalism is to evoke a Schumpeterian logic (Schumpeter 1943): as formerly cheap resources become scarce, the level of creative destruction necessary to stoke the fires of the capitalist iron horse grows ever more rapidly.

In a study of transitions in fossil fuel use by social systems, Joseph Tainter and T. W. Patzek (Tainter and Patzek 2011) invoked a spiral of increasing social complexity, in which technologies based on new fuels such as coal, and later oil, initially spur rapid economic growth, then mire the system in path dependence, ensuring future instability as costs of obtaining fuel and other key resources begin to exceed the benefits of the growth they enable. This provokes crises in which debt financing (borrowing on presumed future growth) becomes increasingly necessary to maintain current functioning. This conundrum is why Morin (2008, p. 66) asserts that the more complex a system becomes, the more it tolerates disorder (which is costly to manage).

Neoliberal globalization in the West can also be productively theorized as an emergent response to the oil—and related profit—crises that crippled Keynesian economics in the 1970s. Capitalist elites responded to the profit crisis (and simultaneous political crisis) through the Reagan reforms that deregulated corporations and incentivized financialization, while subsidizing new neocolonial expansion and reorganization to permit a new phase of unequal exchange (Harvey 2005). Castells (1996) described the ''networked'' nature of this new economy, structured around flows of (digitized) information, power, and wealth in global financial networks and suggested that understanding these interrelationships will assist in creating effective social movements for change (p. 4). Many ''new social movements'' since the 1970s, including liberation theology, identity-centered cultural struggles, environmental justice, union ''corporate campaigns,'' and Internet-centered strategies reflect this new terrain of resistance, which Gerlach (2001) described as more heterarchic (relying on socially linked actors with shared understandings and identities), segmentary (composed of diverse, changing groups), polycentric (with multiple, competing leaders, and centers of influence), and networked.

The antiglobalization movement studied by Jeffrey Juris (Juris 2008) reflected the new strategies of neoliberal capital, using flexible, distributed (Internet linked) networks that enabled protests to be coordinated in ''convergence spaces,'' circumventing or evading police tactics. Nonprofits aided in this coordination, which also entailed vertical command logistics. The process modeled a set of new cultural ideals, such as radical, direct democracy; rhyzomatic structures; shifting alliances; and a multiscalar, complex politics (Juris 2008, p. 299), which, combined with the goals of specific issue campaigns, served as ''attractors'' aiding both mobilization and creativity in specific locales. Chesters and Welsh (2006) speculate that the antiglobalization movement itself is an attractor. It is not difficult to find other signal concepts, such as local food, sustainability, and climate justice, that might function in a similar way to coalesce creative political activity around common strategies. Juris notes that like all social movements, this one operates on the domain of culture, generating new ideas, frameworks, and values while projecting new visions of the future, calling attention to conflicts over inequality and rendering power visible (Juris 2008, p. 291). The movement had real impacts: it damaged the reputation of the International Monetary Fund (IMF) and World Bank, helped provoke international debt-relief talks and the rethinking of IMF rules, and influenced leftist political parties in the European Union and Latin America (Juris 2008, 293–295). Besides the mobilizations in Seattle, Ottawa, Genoa, and other cities, there were emergent victories such as the decision in late 1997 by the Organization of Economic Cooperation and Development to drop the effort to establish the Multilateral Agreement on Investments, after the document was leaked on the Internet, leading to widespread criticism (Capra 2002, 220–21).

Juris (2008, 297–298) argued that digital networks were more than just a technical tool, but generated emergent practices that were political ends in themselves, which were scale-making in their effects (transcending local/global divides), with the discursive flows actually constituting the transnational networks they flowed through. But the networks that emerged from the movement were relatively unstable in the aftermath of a convergent action and relied heavily on more vertical guidance from a small number of regional and global nonprofits for long-term integrity. This problem became evident with the shift to place-based World Social Forums, which fostered the rise of more hierarchical actors, both lending stability and generating critique within the movement (Juris 2008, p. 300). This experience presaged the strengths and weaknesses of the Occupy movement of 2011, suggesting that movements with long-term goals, such as the ongoing movement for policies to limit climate change, will need to combine the strengths of centralized and heterarchical forms of leadership. Global justice activists might benefit from a more thorough grounding in complexity theory, including Meadows' (2008, p. 82) explanation of the stability associated with hierarchy, which derives from the ability of nested subassemblies within a hierarchical body to retain their structure when separated from the larger system.

8. Conclusion: CAS thinking as a tool for our emergen(cy)

The Anthropocene is a period in which unprecedented risks of climate change and other economic and environmental breakdowns pose an existential risk to human populations—in short, we face an emergency. Wider awareness of complexity, with its emphasis on iterative feedback and systemic adaptation, may improve our chances of ''emerging'' from this existential threat. Complexity thinking lends strength to critics who argue for process-oriented approaches to both education and social movements so as to incorporate the ''tacit knowledge'' of informants. Put more simply, knowledge should be seen as embedded in people and in living systems (Capra 2002, 114–115). Such praxis evokes Wenger's (1998) ''communities of practice'' in learning, characterized by self-generating social networks, and often experienced by participants as a culture that seems ''alive.'' Comprehensive, engaged research on social problems and sustainable, grassroots-based social development and social movements all call for forms of mutual engagement in joint enterprises, and through this process, the development of shared routines, rules, and knowledge. These processes form the basis for community and solidarity, which, once constituted, offers a sense of belonging and generates its own boundaries of meaning (Capra 2002, 108–109). Process and heterarchical networks also have their hierarchical and strategic/power aspects. But our particular challenge in this moment is to overcome the proclivities for authority and individualism that mark our time. These are the lessons we stumble over and the nexus where we chronically underestimate the potential for emergent forms of social activism and economic community.

Emergent social transformation (while still embedded in a capitalist world) can resolve a system's tensions in multiple ways, including creating new pockets of resilience, producing a wider coalition of resistance to accelerate the systemic crisis, and provoking either reforms that generate temporary stability or bifurcations that change the dynamics of the struggle. Morin (2008, p. 54) observed that, unlike a ''program'' in a hierarchical formation, social action in a complex system is equivalent also to strategy, meaning that it escapes our intentions and has inherent risk. The challenge remains to accomplish a merger of the strategies and tactics of the anticorporate globalization movement with new understandings about climate risk that are, at long last, rising to global attention. Networked politics is a politics of scale, and scaling must be ''glocal'' (simultaneously up and down) in order to transform new awareness into political capital and accelerate the cultural shift that we now know is inevitable.

Redefining wealth and value is the pivot on which the system will change. The banks and oil companies will circle their wagons (in alliance with state authorities) in an attempt to pass along the risks from their stranded assets. But people also have stranded assets—not least among them the potential for new forms of community. In moments when we come together around a wider circle of interests, we recapture those assets, and their uncut stones begin to catch the light and reflect our dreams and visions. It seems like chaos now, but there are tools we have not yet learned to use. We may yet emerge.

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