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Sustainability, Complexity, and the Negotiation of Constraint

Gregory Todd Jones

SUSTAINABILITY, COMPLEXITY, AND THE NEGOTIATION OF CONSTRAINT

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We are living in a moment of unprecedented complexity, when things are changing faster than our ability to comprehend them. This is a time of transition betwixt and between a period that seemed more stable and secure and a time when, many people hope, equilibrium will be restored. Awash in a sea of information that seems to have no meaning and bombarded by images and sounds transmitted by new media, many people have lost a sense of direction and purpose and long for security and stability. Stability, security, and equilibrium, however, can be deceptive, for they are but momentary eddies in an endlessly complex and turbulent flux. In the world that is emerging, the condition of complexity is as irreducible as it is inescapable. While the moment of complexity inevitably generates confusion and uncertainty, today's social, economic, political, and cultural transformations are also creating possibilities for apprehending ourselves in new ways. To understand our time, we must comprehend complexity, and to comprehend complexity, we must understand what makes this moment different from every other.[1]

We live in an increasingly complex world—not just complex in the common meaning of the word, that is "complicated," but also complex in the sense intended when we speak of complex systems theory. In this sense, a *complex system* is one that is made up of a large number of interdependent parts that together display properties that would not be obvious from an examination of the individual parts. A complex system is *adaptive* to the extent that its diverse parts have the capacity to learn and to adapt behavior in response.[2]

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1. Mark C. Taylor, *The Moment of Complexity: Emerging Network Culture* 3 (U. Chi. Press 2001).

2. For general introductions to the field of complex adaptive systems, see Eric D. Beinhocker, *The Origin of Wealth: Evolution, Complexity, and the Radical Remaking of Economics* (Harv. Bus. Sch. Press 2006); John L. Casti, *Complexification: Explaining a Paradoxical World through the Science of Surprise* (HarperCollins Publg. 1994); Jack Cohen & Ian Stewart, *The Collapse of Chaos: Discovering Simplicity in a Complex World* (Viking 1994); Murray Gell-Mann, *The Quark and the Jaguar: Adventures in the Simple and the Complex* (W.H. Freeman & Co. 1994); Brian Goodwin, *How the Leopard Changed Its Spots: The Evolution of Complexity* (Charles Scribner's Sons 1994); John Gribbin, *Deep Simplicity: Bringing Order to Chaos and Complexity* (Random H. 2004); Claudius Gros, *Complex and Adaptive Dynamical Systems: A Primer* (Springer 2008); John H. Holland, *Emergence: From Chaos to Order* (Helix Bks. 1998); John H. Holland, *Hidden Order: How Adaptation Builds Complexity* (Addison-Wesley Publg. Co. 1995); Stuart Kauffman, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* (Oxford U. Press 1995); Stuart A.

Multidisciplinary teams of scientists from diverse fields such as anthropology, biology, computer science, ecology, economics, physics, political science, psychology, mathematics, and sociology have begun to recognize that these large systems of interacting heterogeneous parts are all around us. Examples of complex systems include ant colonies, honey bees, the economy, energy and telecommunication networks, the weather, living things, including humans, and the ecological systems on which we depend for our survival.

Complex systems are bottom-up systems. System behavior in the aggregate arises from the interaction of lower-level parts (or agents) following simple rules which evolve based on the adaptive success of those rules. The more successful a given agent's set of rules within the system environment, the more likely that agent is to survive to pass on these rules to other agents by means of genetic evolution or learning. Because seemingly inconsequential decision rules can percolate through a complex system triggering cascades of system-wide change, complex systems often exhibit discontinuous change and nonlinearity. Sensitivity to initial conditions can bring about effects that are disproportionate to their causes. While often thought to be indeterminate, complex systems can be fully determinate—their lack of predictability derives from an inability to precisely identify a complete set of initial conditions. The ideas of discontinuous change, nonlinearity, disproportionate causation, and unpredictability are prone to create discomfort for most of us. While basic values and foundational beliefs may provide temporary succor, return to the simple, linear world characterized by most policy agendas of the twentieth century is an aspiration no longer reasonable to entertain. The idea that we can somehow assess the importance of complexity and reject its consequence now borders on absurd. Complexity must be dealt with.

Ecologists to a great extent have been frontrunners in the recognition that complex systems theory has important consequences for their field. Conflict resolution theorists have been substantially more reticent. The central theme of this article is that many of the elements of complex systems theory that help us to understand ecology and sustainability are also extremely helpful in understanding and designing the negotiations

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Kauffman, *The Origins of Order: Self-Organization and Selection in Evolution* (Oxford U. Press 1993); R. Keith Sawyer, *Social Emergence: Societies As Complex Systems* (Cambridge U. Press 2005); M. Mitchell Waldrop, *Complexity: The Emerging Science at the Edge of Order and Chaos* (Touchstone 1993). For introductions to the application of complex systems theory to social systems, see David Byrne, *Complexity Theory and the Social Sciences: An Introduction* (Routledge 1998); Joshua M. Epstein, *Generative Social Science: Studies in Agent-Based Computational Modeling* (Princeton U. Press 2006); John H. Miller & Scott E. Page, *Complex Adaptive Systems: An Introduction to Computational Models of Social Life* (Princeton U. Press 2007). For introductions to the application of complex systems theory to ecology and sustainability, see *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change* (Fikret Berkes, Johan Colding & Carl Folke eds., Cambridge U. Press 2003); *Panarchy: Understanding Transformations in Human and Natural Systems* (Lance H. Gunderson & C.S. Holling eds., Is. Press 2002); Graham Harris, *Seeking Sustainability in an Age of Complexity* (Cambridge U. Press 2007); Simon A. Levin, *Fragile Dominion: Complexity and the Commons* (Helix Bks. 1999); Brian A. Maurer, *Untangling Ecological Complexity: The Macroscopic Perspective* (U. Chi. Press 1999); Bryan G. Norton, *Sustainability: A Philosophy of Adaptive Ecosystem Management* (U. Chi. Press 2005); Peter J. Taylor, *Unruly Complexity: Ecology, Interpretation, Engagement* (U. Chi. Press 2005); Brian Walker & David Salt, *Resilience Thinking: Sustaining Ecosystems and People in a Changing World* (Is. Press 2006). For the relative dearth of applications of complex systems theory to negotiation and conflict resolution, more generally, see Edwin E. Olson & Glenda H. Eoyang, *Facilitating Organization Change: Lessons from Complexity Science* (Jossey-Bass/Pfeiffer 2001); Michael A. Wheeler & Gillian Morris, *Complexity Theory and Negotiation* (Harv. Bus. Sch. Note 902-230, June 18, 2002) (copy on file with author).

of constraint necessary if sustainability is to be possible in the complex environmental, social, and economic context in which we live.

The article proceeds in three parts. First, an introduction to several elements of complex systems theory is provided along with applications in ecology and sustainability for purposes of illumination. Interdependency and its consequence for emergent behavior, nonlinearity and the jagged adaptive landscapes it produces, disproportionality and the significance of phase transitions, determinism and predictability, and the effect of diversity on adaptation are considered. Next, the same elements are applied to the context of negotiation, highlighting the similarity of concerns for the two contexts where complexity is the common denominator. Finally, the article concludes with a discussion of the need to understand complexity in both contexts—conceiving of strategies for ecological sustainability and designing procedural mechanisms for reaching consensus about these strategies. Prescriptions and suggestions for first steps are offered. Recognizing that the way forward is going to be difficult, the article recognizes the importance of trust and social capital as well as the need for careful institutional design in achieving sustainability. Ultimately, sustainability is about collective action, and clever interventions are necessary but not sufficient for success. A significant change in the way we think about conflict and conflict resolution will be necessary. And even then, success is not guaranteed.

I. COMPLEXITY AND SUSTAINABILITY

> *"Ecological complexity poses challenges to conventional scientific ways of knowing. Ecology is not like thermodynamics, in which complexity can be simplified through statistical averaging of large numbers of identically behaving components."*[3]

A. *Interdependency and Emergence*

The flocking behavior of English starlings is an amazing spectacle to watch. Thousands of birds routinely sail through the air in a spectacular display of spatial coherence,[4] the sources of which are still poorly understood.[5] Flocking, along with schooling in fish[6] and swarming in insects,[7] was until recently thought to derive from individual leaders, whose directions radiated out through networks of visual, auditory, or chemical signaling. It is becoming clear, however, that much of collective animal behavior results not from leadership but is said to *emerge* from individuals following simple sets of local rules.[8] A group of interdependent agents acting upon largely local

3. Taylor, *supra* n. 2, at 1.

4. For an excellent resource summarizing an European Union study of starling flocking for the purpose of employing complex systems principles to shed light on collective animal behavior, including dramatic video footage and still photographs, see Eötvös U., Dept. Biological Physics, *EU FP6 Project Starling in Flight: STARFLAG*, http://angel.elte.hu/starling/index.html (last modified Mar. 18, 2008).

5. Michele Ballerini et al., *Empirical Investigation of Starling Flocks: A Benchmark Study in Collective Animal Behaviour* 76 Animal Behaviour 201 (2008).

6. *See generally* Yoshinobu Inada & Keiji Kawachi, *Order and Flexibility in the Motion of Fish Schools*, 214 J. Theoretical Biology 371 (2002).

7. *See generally* Eric Bonabeau, Marco Dorigo & Guy Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems* (Oxford U. Press 1999).

8. Indeed, recent work has demonstrated that three simple local rules can capture essential flocking

information produces emergent system behavior that could not be anticipated by examination of the local agents.[9]

Charles Darwin recognized the dependence of all living things on other living things and on natural resources in the concluding paragraph of *On the Origin of Species*:

> It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent on each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being Growth with Reproduction; Inheritance, which is almost implied by reproduction; Variability, from the indirect and direct action of the conditions of life, and from use and disuse; a Ratio of Increase so high as to lead to a Struggle for Life, and as a consequence to Natural Selection, entailing Divergence of Character and the Extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved.[10]

Along with this highly complex interdependence comes the possibility of emergence—the possibility of unanticipated consequences. Ecological examples abound. Take the sea otter, the sea urchin, and kelp forests. Sea urchins are herbivores, feeding largely on kelp forests. Should the sea urchins become overly abundant, the health of the kelp forests would be threatened. Fortunately, sea otters feed on the sea

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behavior:

> [1] **Separation**: steer to avoid crowding local flockmates
>
> [2] **Alignment**: steer towards the average heading of local flockmates
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> [3] **Cohesion**: steer to move toward the average position of local flockmates.

Craig Reynolds, *Boids: Background and Update*, http://www.red3d.com/cwr/boids (last updated Sept. 6, 2001). This web site includes a simulation allowing experimentation with these rules, an excellent summary of the relevant theory, and an exhaustive catalog of resources related to collective group movement. For another simulation of this behavior, with access to the underlying code, see NetLogo, *NetLogo Models Library: Flocking*, http://ccl.northwestern.edu/netlogo/models/Flocking (accessed Mar. 21, 2009).

9. The idea of emergence is not a new one. *See* George Henry Lewes, *The Problems of Life and Mind* vol. 2, 369 (James R. Osgood & Co. 1875) ("Every resultant is either a sum or a difference of the co-operant forces: their sum, when their directions are the same; their difference, when their directions are contrary. Further, every resultant is clearly traceable in its components, because these are homogeneous and commensurable. It is otherwise with emergents, when, instead of adding measurable motion to measurable motion, or things of one kind to other individuals of their kind, there is a co-operation of things of unlike kinds. . . . The emergent is unlike its components in so far as these are incommensurable, and it cannot be reduced either to their sum or their difference."). A more modern definition suggests that

> [t]he common characteristics [of emergence] are: (1) radical novelty (features not previously observed in the system); (2) coherence or correlation (meaning integrated wholes that maintain themselves over some period of time); (3) [a] global or macro "level" (i.e., there is some property of "wholeness"); (4) it is the product of a dynamical process (it evolves); and (5) it is "ostensive"—it can be perceived.

Peter A. Corning, *The Re-Emergence of "Emergence": A Venerable Concept in Search of a Theory*, 7 Complexity 18 (2002).

10. Charles Darwin, *On the Origin of Species: By Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life* 440–41 (Grant Richards 1902).

urchins and keep the population in check. But past over-hunting of the sea otter for the fur trade allowed the sea urchin population to become over abundant causing serious damage to the kelp forests, which put downward pressure on the populations of remaining urchins and otters.[11] Over-harvesting can cause the collapse of entire coastal ecosystems. By way of another example, it may seem innocuous enough to take down dead pine trees from forests. But taking down these dead trees in some parts of the world disturb the woodpeckers that feed on the insects that damage the trees. If the woodpeckers leave, then insects like the bark beetle can proliferate. And the bark beetle carries the pine pitch canker which, without woodpeckers to keep the beetles in check, can spread quickly wiping out entire forests.[12]

With interdependence and emergence comes the possibility of surprise. Complex ecologies demand that we embrace this uncertainty—management decisions must be made in spite of incomplete knowledge.[13] High levels of interdependence also result in nonlinearity, which we turn to now.

B. Nonlinearity and the Adaptive Landscape

Interactions between the various agents that make up any ecology and their interactions with the external environment produce systems that are nonlinear and hard to predict. In a *nonlinear system*, the system behavior of interest cannot be expressed as a linear function of independent components. A practical example may be helpful. It comes as no surprise that the damage to forests caused by fire is related to the density of the trees.[14] But computer models of forest fires reveal a more subtle, nonlinear relationship. In a typical simulation, in holding other variables such as combustibility, rainfall, etc. constant, results show that a fire started on one end of an artificial forest with 57% density would typically result in about 10% of the forest burning before the fire burned itself out. The same artificial forest with 60% density would result in more than 75% of the forest destroyed. A very small change in density results in a very large change in the amount of forest burned; the relationship between density and destruction is a highly non-linear one.[15]

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11. *See generally* James A. Estes & John F. Palmisano, *Sea Otters: Their Role in Structuring Nearshore Communities* 185 Sci. 1058 (1974).

12. *See generally* Matthew P. Ayres & María J. Lombardero, *Assessing the Consequences of Global Change for Forest Disturbance from Herbivores and Pathogens*, 262 Sci. Total Env. 263 (2000).

13. For an approach to this problem of uncertainty in the context of California water and ecosystem management, see David E. Booher & Judith E. Innes, *Complexity and Adaptive Policy Systems: CALFED As an Emergent Form of Governance for Sustainable Management of Contested Resources* 4 (July 2006) (available at http://www.csus.edu/ccp/publications/ISSS_Complexity_and_adaptive_policy_systems.pdf) (Proceedings of the 50th Annual Meeting of the International Society for the Systems Sciences) ("[T]he complexity of contemporary society has created an increasing sense of uncertainty. To some extent policymaking has always been constrained by uncertainty. However, the failures of traditional government agencies have created a new awareness among the public of the unintended, sometimes perverse consequences of large scale planning and the limits to centralized hierarchical control by government agencies . . . . Not only is the public uneasy about this uncertainty, but also public officials are more aware of the impact of this uncertainty on the public. Yet policy must be made despite the lack of complete knowledge.").

14. *See generally* Siegfried Clar, Barbara Drossel & Franz Schwabl, *Forest Fires and Other Examples of Self-Organized Criticality*, 8 J. Physics: Condensed Matter 6803 (1996).

15. *See generally* B. Drossel & F. Schwabl, *Self-Organized Critical Forest-Fire Model*, 69 Physical Rev. Ltrs. 1629 (1992). For a simulation of these dynamics, with access to the underlying code, see NetLogo, *NetLogo Models Library: Fire*, http://ccl.northwestern.edu/netlogo/models/Fire (accessed Mar. 21, 2009).

Plot the relationship between forest density (an independent or explanatory variable) and forest destroyed (a dependent variable) and you would end up not with a straight line, but a curved line. Plot the relationship between two hypothetical explanatory variables and a hypothetical dependent variable, and you would end up with an "adaptive landscape"[16] like the example shown in Figure One. It is absolutely possible to add additional explanatory variables to the landscape—the only consequence is the loss of the ability to visualize the relationships in three dimensions. The more interdependent explanatory variables that are included, the more bumpy or jagged the surface of the landscape becomes.

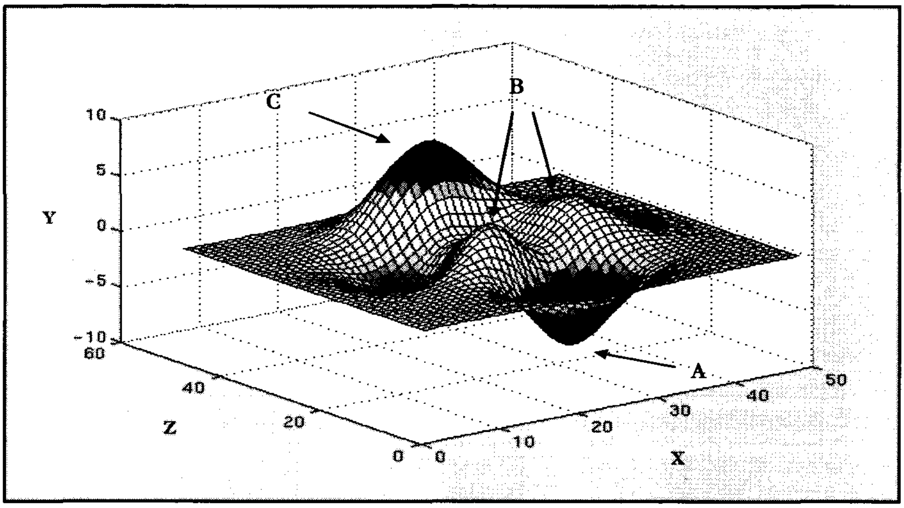

Figure One—An Adaptive Landscape

As a result, nonlinear systems present some significant challenges when making management decisions about intervening in such systems, and in the real world there are many, many explanatory variables and no chart like Figure One to provide a roadmap. If the goal in Figure One is to move the system from the "basin[] of attraction"[17] around point A to the maximum peak at point C, it will be hard to predict how much of a response in the Y-axis will result from changes in the X-axis or the Z-axis. Further, if the criterion for success is the height on the Y-axis, then once the system is at one of the points B, then any further small adjustment of the X-axis or the Z-axis would result in a decline on the Y-axis, leading to a possible misperception that the maximum peak has

16. George R. McGhee, Jr., *The Geometry of Evolution: Adaptive Landscapes and Theoretical Morphospaces* 1 (Cambridge U. Press 2007) ("An adaptive landscape is a very simple—but powerful—way of visualizing the evolution of life in terms of the geometry of spatial relationships, namely the spatial relationships one finds in a landscape. Consider an imaginary landscape in which you see mountains of high elevation in one region, towering mountains separated by deep valleys with precipitous slopes. In another region these mountains give way to lower elevation rolling hills separated by wide, gently sloping valleys, and that these further give way to broad flat plains in the distance. Now replace the concept of 'elevation' (height above sea level) with 'degree of adaptation' and you have an adaptive landscape.").

17. Helena E. Nusse & James A. Yorke, *Basins of Attraction*, 271 Sci. 1376, 1379–80 (1996). Generally speaking, dynamical systems will have one or more subsets of state space, known as attractors, toward which the system tends over time, like point A in Figure One. The area of state space which tends toward a given attractor, like the areas in Figure One that are sloped down toward point A, are known as its basin of attraction. *See generally id.*

been found. These intermediate peaks, known as "local optim[a],"[18] are more numerous as more interdependent system variables become relevant. Thus, in highly complex ecosystems, the likelihood of being trapped by local optima and failing to identify system states that are optimal overall, known as *global optima*, is very significant. Still, thinking in nonlinear terms helps to at least take these difficulties into account,[19] and should prepare interventional designers for the possibility that their efforts may produce disproportionate results, a concern that we consider in more detail next.

C. Disproportionality and the Significance of Phase Transitions

The most abundant molecule on the Earth's surface, water, is a liquid at one degree centigrade and a solid a zero degrees centigrade. The general success of scientific reductionism aside, examination of single water molecules offers no insight into why a collection of water molecules undergo this rather sudden change in state. Indeed, this transformation, or *phase transition* from liquid to solid, involves no change whatsoever in the molecules themselves, but instead a transformation in the network of their interactions.[20] Further, while a change from two degrees centigrade to one degree centigrade does not produce much of a change in the state of this network, the change from one degree centigrade to zero degrees centigrade produces a highly *disproportionate* change.

More generally, Figure Two, Panel A, illustrates a system that is drawn to attractor 1 when the system is in any state within the basin of attraction defined by the surface of the curve between the two peaks. As a consequence, any intervention that moves the system to a state anywhere within the basin of attraction will produce a result in which the system, in time, settles back down to attractor 1. Such interventions produce no long-term results.

18. *See generally* Marc Mangel & Colin W. Clark, *Dynamic Modeling in Behavioral Ecology* 6 (Princeton U. Press 1988).

19. Gregory A. Daneke, *Systemic Choices: Nonlinear Dynamics and Practical Management* 1 (U. Mich. Press 2002) (In response to "an era of increasing turbulence and surprises, nonlinearity—which is *the science of surprise*—should be a vital element of any social inquiry, particularly those which purport to improve practical policy and management." (emphasis in original)).

20. Mark Buchanan, *Nexus: Small Worlds and the Groundbreaking Science of Networks* 15 (W.W. Norton & Co. 2002).

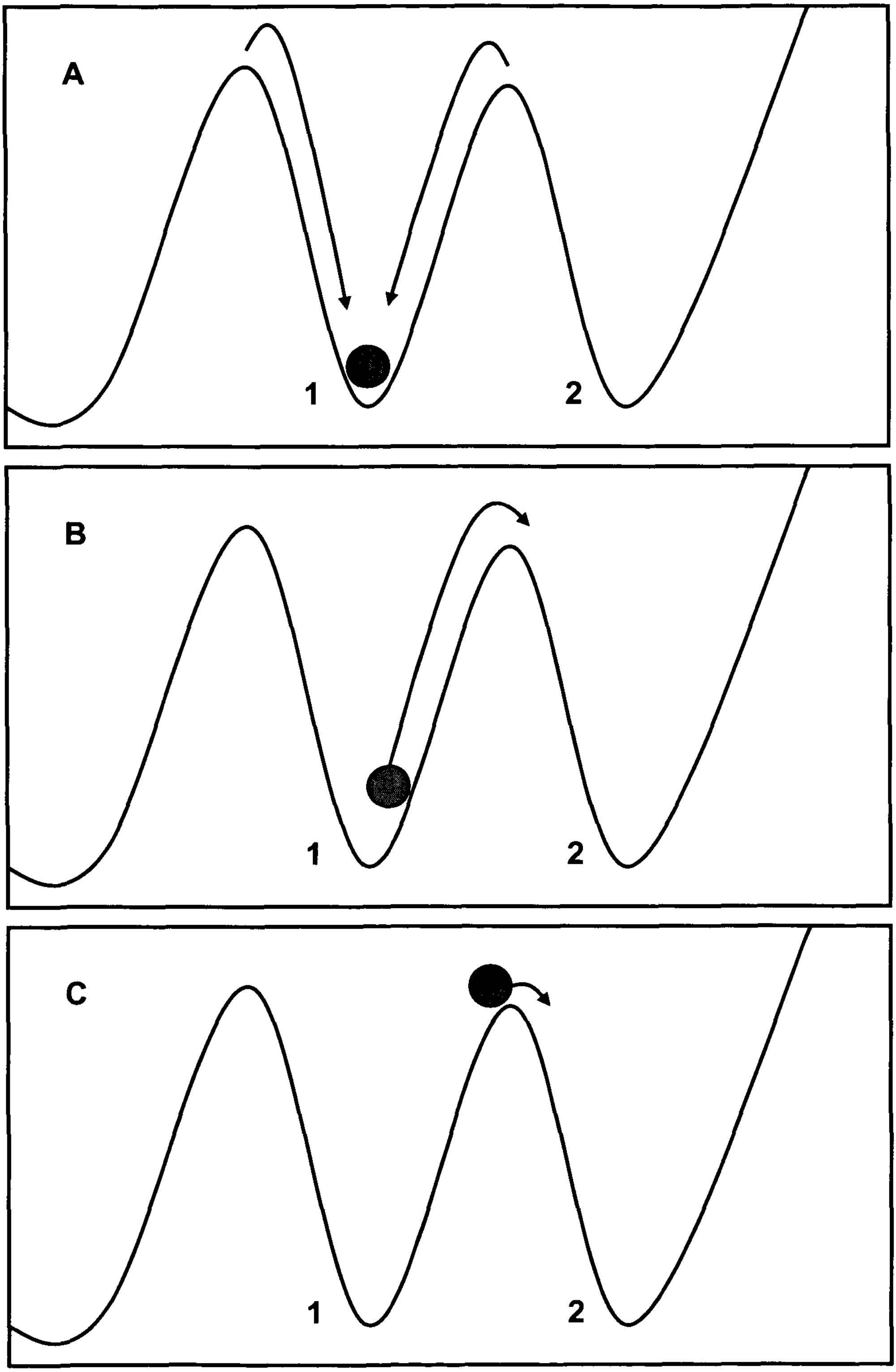

Figure Two—The Significance of Phase Transitions

Further, if the goal of the intervention is to move the system to attractor 2, the necessary strength of the intervention will depend highly on the current state of the system. As is illustrated by Panel B, if the system is near attractor 1, then a herculean effort will be necessary to push the system free of the pull exerted by attractor 1 and over the peak into the new basin of attraction for attractor 2. If the intervention moves the system just past the peak, it may appear that the intervention has not been successful, when in fact, in time, the system will settle into attractor 2. On the other hand, if the system is as illustrated by Panel C, then a very light-handed intervention will readily bring about the desired phase transition. "[A] small nudge at a critical time may be better than a large intervention."[21]

Such disproportionality makes the planning of interventions difficult. Indeed, as increasing complexity and interdependence makes the multi-dimensional adaptive landscape all the more jagged, it becomes a challenge not only to predict whether a phase transition will take place, but to predict which phase transitions are possible in current system states.

D. Determinism and Predictability

Francis Crick once said: "The ultimate aim of the modern movement in biology is in fact to explain *all* biology in terms of physics and chemistry,"[22] underscoring the traditional reliance of science on a reductionist approach. While reductionism has proven to be an extremely powerful analytical methodology, it may be that we are reaching the limits of this approach. In fact, E.O. Wilson recently made an ardent appeal for the importance of the complex systems approach, emphasizing the need to reassemble systems in order to examine key properties of the whole:

> The greatest challenge today, not just in cell biology and ecology but in all of science, is the accurate and complete description of complex systems. Scientists have broken down many kinds of systems. They think they know most of the elements and forces. The next task is to reassemble them, at least in mathematical models that capture the key properties of the entire ensembles.[23]

This shift to more holistic ways of thinking brings with it some consequences for our traditional view of determinism. Systems of micro-level agents can bring about emergent macro-level behavior that cannot be reduced to the individual agents—and this emergence can occur at many different levels of organization. Certain states on highly complex landscapes can present very steep basins of attraction that result in very large, unexpected changes in response to relatively small system adjustments.[24]

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21. Harris, *supra* n. 2, at 22.

22. Francis Crick, *Of Molecules and Men* 10 (Prometheus Bks. 2004) (emphasis in original).

23. Edward O. Wilson, *Consilience: The Unity of Knowledge* 85 (Alfred A. Knopf 1998).

24. Fulvio Mazzocchi, *Complexity in Biology: Exceeding the Limits of Reductionism and Determinism Using Complexity Theory*, 9 EMBO Rpts. 10, 10–11, 14 (2008) ("Complex systems exist at different levels of organization that range from the subatomic realm to individual organisms to whole populations and beyond. They include, for example, molecules, cells, organisms, ecosystems and human societies. Despite their differences, these all share common features, such as emergent properties. In addition, randomness and order are both relevant for the behaviour of the overall system. They are, in fact, neither typified by complete determinism, such as the phenomena that are investigated by Newtonian mechanics, nor by total randomness, such as the subjects of statistical mechanics . . . . Complex systems exist on the 'edge of chaos'. They might

In the context of fishery depletion, for example, reductionist thinking has repeatedly been shown to be counterproductive. The Canadians have attempted to blame reduced catches of Northwest Atlantic cod on the aggressiveness of the harp seal.[25] Ignoring a complex food web in which the seals not only ate more than one hundred other species that were direct competitors of cod, but also ate species that were predators of cod themselves, the government killed a half million seals annually in an attempt to restore the cod population. It didn't work.[26] Will selective removal of a predator help to support endangered prey populations? It is simply impossible to predict due to the complexity of the typical ecosystem where they would live.[27]

That is not to say that this lack of determinism is a cause for ecological nihilism.[28] On the contrary, complex systems can and do exhibit regularity and predictability within bounds.[29] Diversity of approach is one means for leveraging this regularity and confronting the complexity, that is, like it or not, characteristic of the real world.

E. Diversity and Its Effect on Adaptation

Diversity is important for the management of complex systems in two closely related ways. First, genetic diversity, or variation, provides the basis for selection to do its work. The more jagged the adaptive landscape is, the more important diversity is in order to find the global optima. With declining diversity comes the increased risk of becoming trapped in local optima. Imagine the ball in Figure Two being bounced around, or perturbed, so little that it can never escape the basin of attraction where it is currently found, even if the attractor associated with that basin is suboptimal. Of course, too much diversity can also present a challenge by making it difficult for the system to settle down into any basin of attraction at all. Imagine the ball in Figure Two being

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show regular and predictable behaviour, but they can undergo sudden massive and stochastic changes in response to what seem like minor modifications.").

25. David M. Lavigne, Invited Paper Presentation, *Seals and Fisheries, Science and Politics* (11th Biennial Conf. Biology of Marine Animals, Dec. 15, 1995) (copy on file with author).

26. *See* Jeffrey A. Hutchings & Ransom A. Myers, *What Can Be Learned from the Collapse of a Renewable Resource? Atlantic Cod,* Gadus morhua, *of Newfoundland and Labrador*, 51 Canadian J. Fisheries & Aquatic Sci. 2126 (1994).

27. Buchanan, *supra* n. 20, at 141 ("Indeed, considering chains involving only eight species or less, ecologists estimate that more than ten million distinct chains of cause and effect would link the seal to the cod. In the face of this overwhelming complexity, it is clearly not possible to foresee the ultimate effect of killing seals on the numbers of some commercial fish. With fewer seals off the Canadian coast, the number of halibut and sculpin might grow, and since they both eat cod, there may well end up being fewer cod than before. This kind of reasoning applies just as well to whales, which not only eat commercial fish but often eat the predators of those fish. So no one can honestly claim to know what the effect of resumed commercial whaling might be—other than a dangerous depletion of already endangered species. Will there be more fish? Or fewer fish? Politics and public-relations propaganda to one side, it is anyone's guess." (emphasis omitted)).

28. Daniel B. Botkin, *Discordant Harmonies* 7 (Oxford U. Press 1992) ("We are accustomed to thinking of life as a characteristic of individual organisms. Individuals are alive, but an individual cannot sustain life. Life is sustained only by a group of organisms of many species—not simply a horde or mob, but a certain kind of system composed of many individuals of different species—and their environment, making together a network of living and nonliving parts that can maintain the flow of energy and the cycling of chemical elements that, in turn, support life.").

29. Martha J. Groom, Gary K. Meffe & C. Ronald Carroll, *Principles of Conservation Biology* 18 (3rd. ed., Sinauer Assocs. Inc. 2006) (stating "our emphasis on nonequilibrial processes does not imply that species interactions are ephemeral or unpredictable, and therefore unimportant. Communities are not chaotic assemblages of species; they do have structure. . . . Change at some scale is a universal feature of ecological communities.").

bounced around so vigorously that it never settles into any basin of attraction before being perturbed out of that basin. Too much diversity can result in chaos that would threaten system stability.

Second, biodiversity provides system structure that promotes a return to system stability after the system is perturbed.[30] Keep in mind that in a nonlinear system, the removal of a single species can have disproportionate effects, possibly even producing ripple effects, or network effects, which involve the entire ecosystem. As such, even marginal declines in diversity can often be an early warning sign of impending collapse.

II. COMPLEXITY AND NEGOTIATION

> *[O]nce the world was large enough that it was always possible to find another forest to cut down, or another fish population to exploit in even deeper water. If we could not live off the interest from the local natural capital we could always live off the capital itself and then move somewhere else and repeat the trick. Now we have explored and altered the far*

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30. Levin, *supra* n. 2.

> The central environmental challenge of our time is embodied in the staggering losses, both recent and projected, of *biological diversity* at all levels, from the smallest organisms to charismatic large animals and towering trees. Largely through the actions of humans, *populations* of animals and plants are declining and disappearing at unprecedented rates; these losses endanger our way of life and, indeed, our very existence. *Biodiversity* loss provides immediate evidence of environmental change, and it also threatens the very structural and functional integrity of the Earth's systems, and ultimately the survival of humanity.
>
> Undergirding the dynamic Earth—its atmosphere, its physical and chemical fabric, and its biological essence—is a prototypical *complex adaptive system* (CAS), one that we call the *biosphere*. It has, over ecological and evolutionary time, spawned increasing biological diversity, but simultaneously it has evolved patterns of arrangement and interaction of its pieces. The result is an integrated network, with characteristic flows of materials, energy, and information that exhibit regularity in dynamics over long periods of time. Understanding the essential features of the biosphere's internal organization, and what maintains it, is fundamental to developing a rational and effective strategy for preserving the environment with quality sufficient to sustain us, our children, and our children's children.

Id. at 1–2. The role of complexity and diversity in stability and sustainability has not always been the focus of agreement. *See* Kevin Shear McCann, *The Diversity-Stability Debate*, 405 Nat. 228, 228–33 (2000) (Charles Elton was one of the first to argue the commonsense idea that less diverse, simpler ecologies would be "'more easily upset than that of richer ones; that is, more subject to destructive oscillations in populations, and more vulnerable to invasions.'"). Later, Robert May constructed mathematical models that seemed to show that as ecological networks became increasing complex and diverse, they would be less likely to return to stability after being perturbed. *See* Robert M. May, *Stability and Complexity in Model Ecosystems* 13–36 (Princeton U. Press 1973). But May's models relied upon random networks, and Peter Yodzis later questioned whether real ecosystems could be adequately represented this way. Using empirical data to construct what turned out to be highly nonrandom ecosystem webs, Yodzis demonstrated that increasing diversity and associated complexity supported stability after all. P. Yodzis, *The Stability of Real Ecosystems*, 289 Nat. 674, 674–76 (1981). Recent field experiments have provided additional support for Yodzis's findings. *See e.g.* David Tilman & John A. Downing, *Biodiversity and Stability in Grasslands*, 367 Nat. 363, 363–65 (1994). Perturbations that remove species, reducing diversity as well as complexity, will therefore threaten the entire ecosystem. McCann, *supra* n. 30.

> [W]e should . . . expect an increase in frequency of successful invaders as well as an increase in their impact as our ecosystems become simplified. The lessons for conservation are obvious: (1) if we wish to preserve an ecosystem and its component species then we are best to proceed as if each species is sacred; and (2) species removals (that is, extinction) or species additions (that is, invasions) can, and eventually will, invoke major shifts in community structure and dynamics.

Id. at 233.

corners of the Earth . . ., dominion must give way to negotiation and constraint.[31]

Sustainability is about negotiating constraints on the burden that we place on the environment so that current needs can be met, but that renewable resources have the opportunity to meet needs for the indefinite future. Negotiating these constraints in the complex world in which we live presents a substantial challenge, but this challenge may be more effectively met by viewing the negotiations themselves as complex adaptive systems.

A. *Interdependency and Emergence*

The negotiation of even the most straightforward agreements are quite complex. Indeed even a simplistic agreement with 25 distinct issues, each with only two alternatives, presents the parties with more than 33 million possible agreements[32]—far too many to evaluate in an effort to optimize the outcome. At the same time, while most research related to negotiation analysis treats issues as independent, it is more typical that issue sets exhibit high levels of interdependence that result in highly nonlinear utility functions with the possibility of multiple local optima.[33]

As an example, imagine that you are seeking to limit fishing in order to reestablish the population of Northwest Atlantic cod. This intervention would offer a certain amount of independent utility, but it would be even better if restrictions on the slaughter of the harp seal were also put in place. Protecting the harp seal would be an independent step in the right direction, but the intervention's impact would be maximized if fishing limitations were imposed as well. Aware of the complex ecosystems of pine forests in many parts of the world, you may be interested in agreements that would reduce the culling of dead trees where woodpeckers make their home. These agreements would be most effective, however, where certain protections were put in place for the woodpeckers, including the preservation of their insect food supplies. Across all of the possibilities for environmental intervention, there would likely be many such interdependencies and that makes arriving at agreement about how to allocate limited institutional resources much more complex. As a consequence, even simple negotiations frequently result in sub-optimal, Pareto-inferior agreements.[34] Awareness of this interdependence and its associated nonlinearity can bring about the emergence of possible agreements that may have otherwise gone unnoticed.

B. *Nonlinearity and the Adaptive Landscape*

As was noted above with ecosystems, negotiations that involve many interdependent issues have possible agreement spaces characterized by nonlinearity and highly jagged landscapes. This exponential complexity of multi-issue negotiations can

31. Harris, *supra* n. 2, at 8–9 (footnote omitted).

32. The actual number is $2^{25} = 33{,}554{,}432$.

33. Mark Klein, Peyman Faratin & Yaneer Bar-Yam, *Using an Annealing Mediator to Solve the Prisoners' Dilemma in the Negotiation of Complex Contracts* (2002) (available at http://www.ana.lcs.mit.edu/peyman/pubs/amec-02.pdf).

34. *See generally* Howard Raiffa, John Richardson & David Metcalfe, *Negotiation Analysis: The Science and Art of Collaborative Decision Making* (Belknap Press 2002).

defy an agreement in at least two ways. First, when pre-existing circumstances or preliminary negotiations (Contract 1 in Figure Three) place one party (B) at a optima that is above her reservation utility while the other party (A) remains below his reservation utility, and where the first party (B) will only consider alternative proposals that are strictly better than the current proposal, a protocol known as "hill climbing," there is no opportunity to reach alternative agreements (Contract 2) that would be acceptable to both parties. Second, where both parties find themselves at local optima and both are above their respective reservation utilities (Contract 1 in Figure Four), if even one of the parties engages in hill climbing, Pareto superior agreements (Contract 2) can never be reached.[35]

Avoiding these local optima traps in negotiations is very much like avoiding local optima in the design of ecological intervention, or more generally like avoiding local optima in the process of optimization across complex adaptive landscapes, although in the negotiation context, there are explicitly two or more sets of utility functions that may present conflicts of interest. The standard approach to addressing these challenges is the controlled exploration of greater portions of the agreement landscape, which increases the likelihood of identifying global optima while still insuring the stability necessary for the system to settle into a basin of attraction associated with these optima.[36] While full treatment of these approaches is quite technical and beyond the scope of this article, prescriptions such as "be willing to consider new, radically different proposals, even if sub-optimal in comparison to current proposals, early in the negotiations, and less willing later in the negotiations" and "once a proposal has been considered and rejected, be willing to table this proposal, while considering alternative proposals" have this effect of selectively considering more of the agreement landscape while maintaining necessary stability.[37]

35. Gregory Todd Jones, *Designing Heuristics: Hybrid Computational Models for the Negotiation of Complex Contracts*, in *Rethinking Negotiation Teaching: Innovations for Context and Culture* (DRI Press forthcoming 2009).

36. *Id.*

37. These proposed methods are based on optimization techniques such a simulated annealing and tabu lists. For more detail, *see id.*

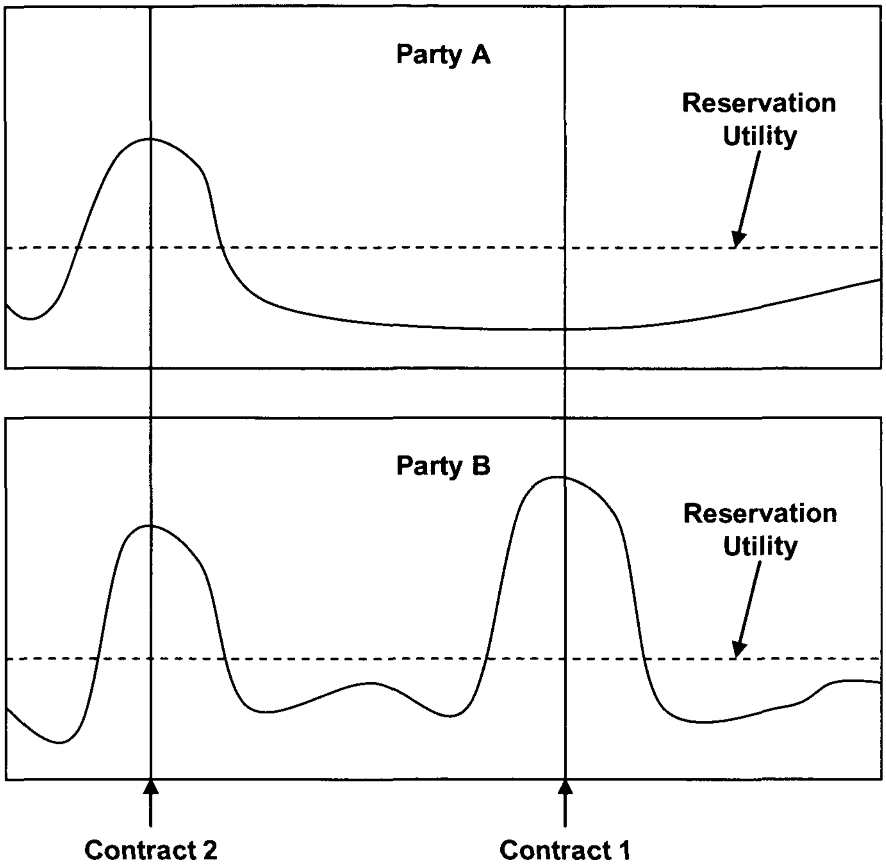

Figure Three—Failure to Reach Agreement

Further, due to natural cognitive limits on the number of issues that humans can consider at any given time, it may very well be that parties to a given negotiation are attempting to optimize across different areas of the issue space. While this reality adds to the complexity of the negotiations, it also offers opportunity, where the different considerations are not at odds.[38]

38. Indeed, it is these differences that are the basis for the interest-based, integrative bargaining popularized by Roger Fisher & William Ury, *Getting to Yes: Negotiating Agreement without Giving in* 40–55 (Bruce Patton ed., 2d ed., Houghton Mifflin Co. 1991). The classic story involves two sisters who have to share a single orange. One sister wants the juice to drink and the other wants the peel to make a cake. The distributive solution results in each getting half of the orange—a small glass of orange juice and a small cake. The integrative solution would have been for one sister to squeeze out all the juice and the other to take all of the peel. Max H. Bazerman, *Why Negotiations Go Wrong* in *The Negotiation Sourcebook* 219, 219 (Ira G. Asherman & Sandra Vance Asherman eds., 2d ed., HRD Press 2001).

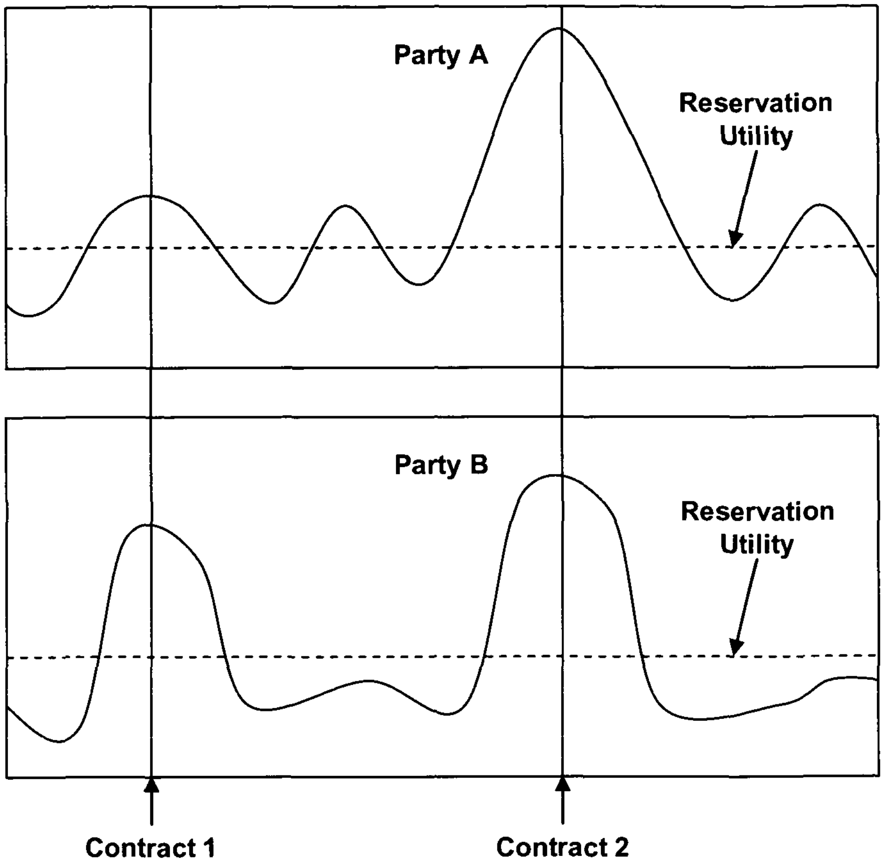

Figure Four—Pareto Inferior Agreement

C. Disproportionality and the Significance of Phase Transitions

Just as seemingly minor ecological interventions can produce extreme, highly disproportionate effects, small, seemingly irrelevant compromises can produce very large concessions from the other side. But this is a two edged sword. Just as the removal of dead pine trees can cascade through the ecosystem ultimately causing the collapse of the entire forest, small decisions during the course of a negotiation can cause the other side to become entrenched and bring the negotiations to a stalemate.

Keeping the image of the phase transition in mind can be useful. When a negotiation dynamic is in a state like that illustrated in Panel B of Figure Two, it may seem like no amount of discussion or concession could bring about the phase transition to attractor 2 where an agreement might be reached. At other times, system dynamics may be like that illustrated in Panel C where very small compromises can bring about disproportionately large shifts towards an agreement attractor. Ripeness of the dispute for settlement is critical, but again, the state of the system and the impact of intervention are difficult to predict.

D. Determinism and Predictability

Negotiation and conflict resolution is about multi-party, multi-attribute decision making under uncertainty. Given nonlinearity and a complex, jagged landscape, and given that it is often difficult to tell which issues comprise those of concern for other parties, it is often difficult to anticipate how other parties will react to changes in proposed agreements. For stakeholders in such negotiations as well as third-party mediators, the most well-intentioned interventions can plunge discussion into intractability. But small interventions can also bring about surprise agreements. Staying with the conflict while producing a diversity of viewpoints can often be an effective hedge against this uncertainty.

E. Diversity and Its Effect on Adaptation

Collective wisdom frequently exceeds the sum of its parts. Diversity of viewpoints allows solutions to emerge out of group effort that would not have been possible through the efforts of any of the individuals working alone.[39] A negotiation environment that supports and encourages diversity tends to function as a natural selection of ideas. Further, diversity helps to avoid the traps of local optima by guiding the investigation of larger areas of the adaptive landscape directed by the preferences of interested parties.

III. DISCUSSION, PRESCRIPTIONS, AND WAYS FORWARD

Negotiating ecological constraint presents very difficult public good dilemmas. The benefit that accrues from constraint is largely nonexcludable—it will be enjoyed by everyone—even those who do not bear the costs of controlling the burdens placed on the environment. The challenge is made all the more difficult by the fact that some stakeholders, those not yet born, cannot be present at the table. Theory suggests that there is no endogenous solution and the standard answer for this quandary is the creation of exogenous institutions, but this alone will not be enough.[40] Profound uncertainty makes the negotiations themselves a complex endeavor—complex decision-making about complex systems.

39. Scott E. Page, *The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies* 22–51 (Princeton U. Press 2007) (As Kenneth J. Arrow wrote in praise of Page's book, "diversity of viewpoints is of the greatest importance in solving the problems that face us individually and collectively. Diversity among a group of problem solvers is more important than individual excellence." (found on back cover)).

40. Harris, *supra* n. 2, at 5 ("Ideas are changing rapidly, long-standing theories and practices are being overturned and new concepts are being developed. The rising concern over sustainability merely adds to the complexity of our daily decision making, so we can add environmental factors to the social and economic challenges of the 'third way'. Above all we must now accept and cope with greatly increased complexity at all levels in our lives: individually, at the level of the community, nationally and even internationally. Do we as individuals and institutions have the capacity to adapt and grow under these circumstances? For that to happen there must be a strong dialogue between institutions and individuals in a changing world.").

A. This Isn't Going to Be Easy

"This isn't rocket science—it is much harder."[41]

The possibility exists that we have already entered the sixth great extinction, where more than fifty percent of all species may cease to exist due to impact on the environment of a single species—humans. Complexity science may offer some hope for turning back the progression of events that some now see as inevitable.[42] But this promise does not involve the ability to "manage" the ecosystem in the traditional sense. All we can hope for is to create the right conditions for positive change—an exceedingly difficult task without a crystal ball.[43]

One approach proposed in the context of intractable conflict by conflict resolution scholar, Daniel Druckman, that increases the likelihood of achieving these conditions, is designing institutions that employ scenario planning—the development of dynamic sets of solutions that probabilistically balance uncertainty with concerns for efficiency.[44]

B. Institutions

"[I]n the end sustainability will depend on the decisions that individuals take in the context of signals received and incentives provided by markets, government policies and global interactions."[45]

Institutions can be seen as one means of producing limitations on and incentives for desired behavior. The best known such institution is the law.[46] Legal systems as a means of regulation of complex systems have been studied in a wide variety of substantive areas, including not only environmental law,[47] but also jurisprudence,[48] law

41. *Id.*

42. Buchanan, *supra* n. 20, at 16–18 ("Through geological history there have been at least five great episodes of mass extinction, in each of which more than 50 percent of all species worldwide were suddenly eradicated. In recent years, some scientists have suggested that we may now be in the midst of a sixth great extinction, this one being triggered by our own perturbation of the earth's environment. To judge the likelihood of such a tragic scenario, and to learn more about how we might avoid it, scientists need a better handle on the workings of complex networks.").

43. *A Case for Nurture: Innovation Is a Complex Ecosystem That Requires Careful Cultivation*, 454 Nat. 918, 918 (2008) ("A more accurate picture is that of a nonlinear 'ecosystem', in which innovation is driven by multiple players, forces and feedback loops working simultaneously. Such an ecosystem cannot be managed—at least, not in the conventional sense of top-down control. But it can be cultivated, in the way that a gardener can try to create the right conditions for plants to grow, while accepting that unforeseen elements ultimately dictate the outcome.").

44. *See e.g.* Daniel Druckman & Paul C. Stern, *Evaluating Peacekeeping Missions*, 41 Mershon Intl. Stud. Rev. 151 (1997). I am grateful to Sanda Kaufman for pointing out this idea.

45. Harris, supra n. 2, at 4.

46. *See* Tom R. Tyler, *The Psychology of Cooperation* in *Cooperation: The Political Psychology of Effective Human Interaction* 105, 105 (Brandon A. Sullivan, Mark Snyder & John L. Sullivan eds., Blackwell Publg. 2008) ("Law is concerned with how to effectively regulate behavior so as to prevent people from engaging in actions that are personally rewarding but destructive to others and to the group—actions ranging from illegally copying music and movies to robbing banks.").

47. *See* Jim Chen, *Webs of Life: Biodiversity Conservation as a Species of Information Policy*, 89 Iowa L. Rev. 495 (2004); Gerald Andrews Emison, *The Potential for Unconventional Progress: Complex Adaptive Systems and Environmental Quality Policy*, 7 Duke Envtl. L. & Policy Forum 167 (1996); Daniel A. Farber, *Probabilities Behaving Badly: Complexity Theory and Environmental Uncertainty*, 37 U. Cal. Davis L. Rev. 145 (2003); William H. Rodgers, Jr., *Where Environmental Law and Biology Meet: Of Pandas' Thumbs,*

and economics,[49] torts,[50] criminal law,[51] regulatory law,[52] bankruptcy,[53] mediation and other forms of alternative dispute resolution,[54] administrative law,[55] capital markets,[56] telecommunications,[57] legislative[58] and judicial decision making,[59] discrimination and

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Statutory Sleepers, and Effective Law, 65 U. Colo. L. Rev. 25, 46–48 (1993); J.B. Ruhl, *Sustainable Development: A Five-Dimensional Algorithm for Environmental Law*, 18 Stan. Envtl. L.J. 31 (1999); J.B. Ruhl, *Thinking of Environmental Law As a Complex Adaptive System: How to Clean up the Environment by Making a Mess of Environmental Law*, 34 Hous. L. Rev. 933 (1997).

48. See Thomas Earl Geu, *The Tao of Jurisprudence: Chaos, Brain Science, Synchronicity, and the Law*, 61 Tenn. L. Rev. 933, 934–35 (1994); Oona A. Hathaway, *Path Dependence in the Law: The Course and Pattern of Legal Change in a Common Law System*, 86 Iowa L. Rev. 601 (2001); Eric Kades, *The Laws of Complexity and the Complexity of Laws: The Implications of Computational Complexity Theory for the Law*, 49 Rutgers L. Rev. 403, 452–54, 476 (1997); Lynn M. LoPucki, *The Systems Approach to Law*, 82 Cornell L. Rev.479, 480–82 (1997); Randal C. Picker, *Simple Games in a Complex World: A Generative Approach to the Adoption of Norms*, 64 U. Chi. L. Rev. 1225 (1997); David G. Post & David R. Johnson, *"Chaos Prevailing on Every Continent": Towards a New Theory of Decentralized Decision-Making in Complex Systems*, 73 Chi.-Kent L. Rev. 1055 (1998); John M. Rogers & Robert E. Molzon, *Some Lessons about the Law from Self-Referential Problems in Mathematics*, 90 Mich. L. Rev. 992 (1992); J.B. Ruhl, *The Fitness of Law: Using Complexity Theory to Describe the Evolution of Law and Society and Its Practical Meaning for Democracy*, 49 Vand. L. Rev. 1407 (1996); Robert E. Scott, *Chaos Theory and the Justice Paradox*, 35 Wm. & Mary L. Rev. 329, 329–31 (1993).

49. *See* Mark J. Roe, *Chaos and Evolution in Law and Economics*, 109 Harv. L. Rev. 641, 643–65 (1996).

50. *See* Edward S. Adams, Gordon B. Brumwell & James A. Glazier, *At the End of* Palsgraf, *There Is Chaos: An Assessment of Proximate Cause in Light of Chaos Theory*, 59 U. Pitt. L. Rev. 507 (1998); Jeff L. Lewin, *The Genesis and Evolution of Legal Uncertainty about "Reasonable Medical Certainty"*, 57 Md. L. Rev. 380, 389–93 (1998).

51. *See* Erica Beecher-Monas & Edgar Garcia-Rill, *Danger at the Edge of Chaos: Predicting Violent Behavior in a Post-*Daubert *World*, 24 Cardozo L. Rev. 1845 (2003); Susan W. Brenner, *Toward a Criminal Law for Cyberspace: Distributed Security*, 10 B.U. J. Sci. & Tech. L. 1 (2004).

52. *See* J.B. Ruhl & James Salzman, *Mozart and the Red Queen: The Problem of Regulatory Accretion in the Administrative State*, 91 Geo. L.J. 757 (2003); James Salzman, J.B. Ruhl & Kai-Sheng Song, *Regulatory Traffic Jams*, 2 Wyo. L. Rev. 253 (2002).

53. *See* Bernard Trujillo, *Patterns in a Complex System: An Empirical Study of Valuation in Business Bankruptcy Cases*, 53 UCLA L. Rev. 357 (2005).

54. *See* Robert A. Creo, *Mediation 2004: The Art and the Artist*, 108 Penn St. L. Rev. 1017, 1031–45 (2004); Scott H. Hughes, *Understanding Conflict in a Postmodern World*, 87 Marq. L. Rev. 681 (2004); J.B. Ruhl, *Thinking of Mediation as a Complex Adaptive System*, 1997 BYU L. Rev. 777.

55. *See* Donald T. Hornstein, *Complexity Theory, Adaptation, and Administrative Law*, 54 Duke L.J. 913, 917–19 (2005); Thomas R. McLean, *Application of Administrative Law to Health Care Reform: The Real Politik of* Crossing the Quality Chasm, 16 J.L. & Health 65, 71–73 (2001–02); J.B. Ruhl, *Complexity Theory As a Paradigm for the Dynamical Law-and-Society System: A Wake-Up Call for Legal Reductionism and the Modern Administrative State*, 45 Duke L.J. 849, 906–16 (1996); J.B. Ruhl & Harold J. Ruhl, Jr., *The Arrow of the Law in Modern Administrative States: Using Complexity Theory to Reveal the Diminishing Returns and Increasing Risks the Burgeoning of Law Poses to Society*, 30 U. Cal. Davis L. Rev. 405, 452–67 (1997).

56. *See* Lawrence A. Cunningham, *Capital Market Theory, Mandatory Disclosure, and Price Discovery*, 51 Wash. & Lee L. Rev. 843, 854–59 (1994); Lawrence A. Cunningham, *From Random Walks to Chaotic Crashes: The Linear Genealogy of the Efficient Capital Market Hypothesis*, 62 Geo. Wash. L. Rev. 546, 581–92 (1994).

57. *See* Barbara A. Cherry, *The Telecommunications Economy and Regulation as Coevolving Complex Adaptive Systems: Implications for Federalism*, 59 Fed. Commun. L.J. 369, 379–85 (2006); Susan P. Crawford, *The Biology of the Broadcast Flag*, 25 Hastings Commun. & Ent. L.J. 603, 636–40 (2003); Daniel F. Spulber & Christopher S. Yoo, *On the Regulation of Networks As Complex Systems: A Graph Theory Approach*, 99 Nw. U. L. Rev. 1687, 1687–93 (2005); Kevin Werbach, *Supercommons: Toward a Unified Theory of Wireless Communication*, 82 Tex. L. Rev. 863, 877–81 (2004).

58. *See* Vincent M. Di Lorenzo, *Equal Economic Opportunity: Corporate Social Responsibility in the New Millennium*, 71 U. Colo. L. Rev. 51, 69–78 (2000); Vincent Di Lorenzo, *Complexity and Legislative Signatures: Lending Discrimination Laws As a Test Case*, 12 J.L. & Pol. 637, 641–45 (1996); Vincent Di Lorenzo, *Legislative Chaos: An Exploratory Study*, 12 Yale L. & Policy Rev. 425, 432–35 (1994).

59. *See* Andrew W. Hayes, *An Introduction to Chaos and Law*, 60 UMKC L. Rev. 751, 764–73 (1992); Jeffrey G. Miller, *Evolutionary Statutory Interpretation: Mr. Justice Scalia Meets Darwin*, 20 Pace L. Rev. 409, 409–12 (2000); David G. Post & Michael B. Eisen, *How Long is the Coastline of the Law? Thoughts on*

equal opportunity,[60] constitutional law,[61] business law,[62] land use law,[63] intellectual property,[64] and political theory[65]—and this is surely not a complete list.[66] In addition, law has been considered not only as a means to regulate complex systems, but as a complex adaptive system itself.[67]

Other institutions for conflict resolution, like negotiation and third party intervention or mediation, can be viewed in a similar light, and the lessons are surprisingly general. Adaptive landscapes and the associated potential for abrupt phase transitions that make ecologies unpredictable also make the calibration of institutional response easier said than done. Quite often, light-handed approaches are preferred to strong-armed intervention.[68] Additionally, empirical studies suggest that institutions are not enough[69]—individuals still matter, and perhaps matter most.

C. *Trust, Social Capital*

> *Finally, the issue of the dynamics of trust has changed. Trust has always been a factor in politics. For traditional government, trust and confidence by the public originates in the legitimacy of agencies established by law. In the new context though, in which actors must collaborate across institutional boundaries, they can no longer assume trust. . . . Creating the dynamics of trust for these practices becomes a critical challenge. Policymaking is not simply about finding solutions but also creating processes for collective action and*

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the Fractal Nature of Legal Systems, 29 J. Leg. Stud. 545, 559–77 (2000); Glenn Harlan Reynolds, *Chaos and the Court*, 91 Colum. L. Rev. 110, 112–15 (1991).

60. *See* Daria Roithmayr, *Barriers to Entry: A Market Lock-In Model of Discrimination*, 86 Va. L. Rev. 727, 729–38 (2000).

61. *See* Michael J. Gerhardt, *The Role of Precedent in Constitutional Decisionmaking and Theory*, 60 Geo. Wash. L. Rev. 68, 114–15 (1991).

62. *See* Thomas Earl Geu, *Chaos, Complexity, and Coevolution: The Web of Law, Management Theory, and Law Related Services at the Millennium*, 65 Tenn. L. Rev. 925, 961–77 (1998).

63. *See* Alistair M. Hanna, *The Land Use System*, 13 Pace Envtl. L. Rev. 531, 538 (1996).

64. *See* Andrea M. Matwyshyn, *Organizational Code: A Complexity Theory Perspective on Technology and Intellectual Property Regulation*, 11 J. Tech. L. & Policy xiii (2006).

65. *See* Hope M. Babcock, Democracy's Discontent *in a Complex World: Can Avalanches, Sandpiles, and Finches Optimize Michael Sandel's Civic Republican Community?* 85 Geo. L.J. 2085, 2102–03 (1997); Glenn Harlan Reynolds, *Is Democracy Like Sex?* 48 Vand. L. Rev. 1635, 1639–40 (1995).

66. I am grateful to J.B. Ruhl for his website, *Complex Adaptive Systems Literature for Law and Social Sciences*, hosted by the Society for Evolutionary Analysis in Law, where many of the above citations were discovered. His bibliography is regularly updated and can be found at Socy. Evolutionary Analysis L., *Complex Adaptive Systems Literature for Law and Social Sciences*, http://law.vanderbilt.edu/seal/resources/readingscomplex.htm (accessed Mar. 24, 2009).

67. *See* J.B. Ruhl, *Complexity Theory As a Paradigm for the Dynamical Law-and-Society System: A Wake-Up Call for Legal Reductionism and the Modern Administrative State*, 45 Duke L.J. 849 (1996); *see also* Gregory Todd Jones, *Dynamical Jurisprudence: Law as a Complex System*, 24 Ga. St. U. L. Rev. 873 (2008).

68. I am grateful to Christoph Engel for exploring this idea with me at great length.

69. Tyler, *supra* n. 46, at 107 ("[I]t is important to distinguish . . . reasons for cooperating. One reason is that people's self-interest is linked to cooperative behavior. Groups create organizational frameworks within which desired forms of cooperation are rewarded, so that cooperation is linked to incentives, and in which undesirable forms of cooperation are punished, so that the failure to cooperate is linked to sanctions. The literature on cooperation suggests that the use of incentives and sanctions can effectively shape cooperative behavior. However, while effective, rewards and punishments are not a particularly efficient mechanism for shaping behavior. First, their impact on behavior is marginal. Further, these effects are costly to obtain, since organizations must commit considerable resources to the effective deployment of incentive and sanctioning systems. For these reasons, the adequacy of instrumental approaches to motivating cooperation has been questioned within law, political science, and management." (citation omitted)).

problem solving that generate trust among the actors.[70]

Notwithstanding the importance of institutions, the majority of collective action can be attributed to interactions between individual actors. An environment of trust is imperative and the creation of such environments may be the most important role for institutions.[71] In addition, recent work is demonstrating that the structure of social capital is important—both inclusion of a full range of stakeholders and egalitarianism in the distribution of connections within the social network are important for the promotion of prosocial behaviors.[72]

D. Changing the Way We Think about Conflict

We also need to change the way we think about prosocial behaviors—about how we approach conflict. Even among conflict resolution scholars and practitioners, we have an obsession with resolving conflict leading to denial, passivity, premature problem solving, or other conflict avoidance behavior. In complex systems terms, this leads to premature convergence to local optima and instability. Staying with the conflict[73]—engaging in ongoing conflict constructively, respectfully, and honestly—can not only provide opportunities to selectively investigate more of the solution space, but provide robustness in the face of ongoing changes to the landscape. Embracing uncertainty and promoting diversity will provide the adaptability necessary for individuals and institutions to appropriately respond to these changes.[74]

E. Our Success Is Far from Guaranteed

> *It is not the critic who counts; not the man who points out how the strong man stumbles, or where the doer of deeds could have done them better. The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood; who strives valiantly; who errs, and comes short again and again, . . . who knows the great*

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70. Booher & Innes, *supra* n. 13, at 5; *see also* Harris, *supra* n. 2, at 5 ("Relationships, collaboration, trust and social capital are the keys to success in this more complex technological, social, environmental and economic context in which we all live." (footnote omitted)).

71. *See* R. William Ide, III & Douglas H. Yarn, *Public Independent Fact-Finding: A Trust-Generating Institution for an Age of Corporate Illegitimacy and Public Mistrust*, 56 Vand. L. Rev. 1113, 1120–24 (2003) (exploring some innovative institutions for trust building); *see also* Gregory Todd Jones, *Trust, Institutionalization, & Corporate Reputations: Public Independent Fact-Finding from a Risk Management Perspective*, 13 U. Miami Bus. L. Rev. 121 (2005).

72. *See* Gregory Todd Jones, Douglas H. Yarn, Reidar Hagtvedt & Travis Lloyd, *Homogeneity of Degree in Complex Social Networks as a Collective Good*, 24 Ga. St. U. L. Rev. 931 (2008).

73. Bernie Mayer, professor of conflict resolution at the Werner Institute for Negotiation and Dispute Resolution, Creighton University, has significantly developed these ideas in many public talks with titles like "Staying with Conflict: Facing Our Fundamental Challenge" and "Staying with Conflict: The Challenge of Working with Long Term Disputes" and a forthcoming book with a similar title planned. These ideas have also appeared elsewhere in the organizational development literature. *See e.g.* Joan M. Roberts, *Alliances, Coalitions and Partnerships: Building Collaborative Organizations* 129 (New Socy. Publishers 2004).

74. Harris, *supra* n. 2, at 30 ("As we move into a world of complexity and surprises then the required attributes are adaptability, teamwork, collaboration and flexibility; this is a major challenge for individuals, communities and institutions. Dialogue, consensus, negotiation and adaptability are the requisite skills but these raise important issues of personal and institutional sovereignty. We suffer too much from public and institutional sclerosis; our institutions, policies and planning tend to be too slow to change as new information and concepts come to hand.") (footnote omitted).

> *enthusiasms, the great devotions; who spends himself in a worthy cause; who at the best knows in the end the triumph of high achievement, and who at the worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who know neither victory nor defeat.*[75]

It is sometimes difficult to discern order that is obscured by the accidents of history.[76] The path dependence that is a consequence of these historical accidents implies that we cannot "wind up" this history, or the contingencies that this history produces. As Steven Jay Gould warned:

> I am not speaking of randomness . . . but of the central principle of all history—*contingency*. A historical explanation does not rest on direct deductions from laws of nature, but on an unpredictable sequence of antecedent states, where any major change in any step of the sequence would have altered the final result. This final result is therefore dependent, or contingent, upon everything that came before—the unerasable and determining signature of history.[77]

Nonetheless, "striking order can emerge even in the face of history and its contingencies,"[78] and we have the relatively new advantage of virtual ecologies[79] from which to learn a new way of thinking about cooperation, policy creation, and institutional intervention. Dynamic environments call for dynamic thinking. To paraphrase David Guston in his recent opinion piece about innovation policy, maybe we can come to understand that "ecological policy" is an oxymoron, like "'jumbo shrimp'" or George Carlin's version of "'military intelligence.'"[80]

If we embrace uncertainty and respond with light-handed institutional design that considers ranges of solutions borne from diverse networks of trust—if we practice inclusiveness while being willing to stay with conflict rather than obsess on its resolution—and if we strive to identify order in the otherwise paralyzing consequences of path dependence, we may be fortunate enough to find those momentary eddies in the endlessly complex and turbulent flux—momentary eddies to offer a brief repose before

75. Theodore Roosevelt, *Citizenship in a Republic*, in *Theodore Roosevelt: Letters and Speeches* 778, 781–82 (Louis Auchincloss ed., Lib. Am. 2004) (Address delivered at the Sorbonne, Paris, April 23, 1910).

76. Edward Hallett Carr, *What Is History? The George Macaulay Trevelyan Lectures Delivered in the University of Cambridge January–March 1961* 133 (Random H. 1962) ("The entire historical process is a refraction of historical law through the accidental. In the language of biology, we might say that the historical law is realized through the natural selection of accidents." (quoting Leon Trotsky, *My Life: An Attempt at an Autobiography* 422 (Charles Scribner's Sons 1930)).

77. Stephen Jay Gould, *Wonderful Life: The Burgess Shale and the Nature of History* 283 (W.W. Norton & Co. 1989) (emphasis in original). *See also* Buchanan, *supra* n. 20, at 97 ("[C]ountless unorchestrated historical events have left their traces all over our social and ecological networks . . . . When Amazon.com started selling books over the Web, they not only launched a site that soon developed into a hub to which many hundreds of thousands of other sites have links, but also set loose an idea that has stimulated many others to start online bookselling services. Had Amazon.com never existed, the Web would be dramatically altered in many of its details. The biochemistry of the bacterium *Escherichia coli* has similarly been affected by a long string of genetic mutations, every one accidental and all of which have left their distinct traces on the structure of its present biochemistry. In the evolution of networks, history is tremendously important.").

78. Buchanan, *supra* n. 20, at 97.

79. Bernardo A. Huberman et al., *Strong Regularities in World Wide Web Surfing*, 280 Sci. 95, 97 (1998) ("[T]he sheer reach and structural complexity of the Web makes it an ecology of knowledge, with relationships, information 'food chains,' and dynamic interactions that could soon become as rich as, if not richer than, many natural ecosystems.").

80. David H. Guston, *Innovation Policy: Not Just a Jumbo Shrimp*, 454 Nat. 940, 940 (2008) ("How does one predict and direct something that is by nature unpredictable and, by necessity, often undirected?").

presented with the next challenge to the sustainability of our species and our planet.