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DYNAMICAL JURISPRUDENCE: LAW AS A COMPLEX SYSTEM

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Vast flocks of English starlings gather over the roost at dusk and glide through the air in a spectacular display of spatial coherence.[1] Both the evolutionary, or ultimate cause, of flocking behavior, and the proximate mechanisms that makes this performance possible are still relatively poorly understood.[2] Flocking, along with schooling in fish[3] and swarming in insects,[4] was until recently believed to be driven by one or more leaders, whose followers percolated the behavior through the group. We are now beginning to discover that this collective behavior results not from leadership, but emerges from individuals following simple sets of local rules.[5]

Highly multidisciplinary teams of scientists from anthropology, biology, computer science, ecology, economics, physics, political

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1. 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 http://angel.elte.hu/starling/index.html (last visited Mar 23, 2008).

2. *See generally*, Michele Ballerini, et al., *An Empirical Study of Large, Naturally Occurring Starling Flocks: A Benchmark in Collective Animal Behaviour*, ANIMAL BEHAVIOUR (forthcoming, 2008), available at http://arxiv.org/ftp/arxiv/papers/0802/0802.1667.pdf (last visited Mar 23, 2008).

3. *See generally*, Yoshinobu Inada & Keiji Kawachi, *Order and Flexibility in the Motion of Fish Schools*, 214 J. OF THEOR. BIOL. 371 (2002).

4. *See generally*, ERIC BONABEAU, SWARM INTELLIGENCE: FROM NATURAL TO ARTIFICIAL SYSTEMS (1999).

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

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

For a web site that 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, *see* http://www.red3d.com/cwr/boids/ (last visited mar 23, 2008). For another simulation of this behavior, with access to the underlying code, *see* URI WILENSKY, NETLOGO FLOCKING MODEL, CENTER FOR CONNECTED LEARNING AND COMPUTER-BASED MODELING, NORTHWESTERN UNIVERSITY, EVANSTON, IL. (1998), http://ccl.northwestern.edu/netlogo/models/Flocking.

science, psychology, mathematics, sociology, and numerous other fields have begun to recognize that large systems of interacting heterogeneous agents often display very complex behaviors that cannot be easily deduced by studying the behaviors of the individual agents. Lessons from these emergent collective behaviors are now being applied to help us rethink the dynamics of human behavior.

> *Wouldn't it be worthwhile if we could identify and understand individual human behaviors that result in dramatic human group behavior*[6]*– and use this understanding to optimally design institutions*[7] *that constrain this behavior in ways that promote social welfare?*

A close examination of the dynamics of forest fires reveals that the extent of damage is closely related to the density of the trees.[8] This is not particularly surprising. However, computer simulations reveal that this observation offers more nuance.[9] Holding other variables such as combustibility, rainfall, etc. constant, computational 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.[10] The same artificial forest with 60% density would result in more than 75% of the forest destroyed.[11]

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6. *See generally*, Robert A. Stallings, *On Theory in Collective Behavior and Empirical Patterns in a Riot Process*, 41 AM. SOCIOLOGICAL REV. 749 (1976); Mark Granovetter, *Threshold Models of Collective Behavior*, 83 A. J. S. 1420 (1978).

7. *See generally*, Marcel Fafchamps, *Spontaneous Market Emergence*, 2 TOPICS IN THEORETICAL ECONOMICS 1 (2002) *available at* http://www.bepress.com/bejte (last visited Mar 23, 2008).

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

9. *See generally*, Barbara Drossel & Franz Schwabl, *Self-Organized Critical Forest-Fire Model*, 69 PHYS. REV. LETTERS 1629 (1992). For a simulation of these dynamics, with access to the underlying code, see URI WILENSKY, NETLOGO FIRE MODEL, CENTER FOR CONNECTED LEARNING AND COMPUTER-BASED MODELING, NORTHWESTERN UNIVERSITY, EVANSTON, IL. (1998), http://ccl.northwestern.edu/netlogo/models/Fire.

10. These models are stochastic and results reported are typical averages over a series of simulation runs.

11. Clearly, there are many more variables that may affect outcomes and these damage percentages are not intended to be accurate estimates. The simulations are intended to show differences in outcomes relative to each other and to demonstrate the isolated non-linear effect of density.

What this exercise demonstrates, that may not be immediately obvious, is that a very small increase in density results in a dramatic increase in forest burned. The relationship between density and destruction is a highly non-linear one.

Wouldn't it be worthwhile if we could understand this non-linearity and take its possibility into account when designing regulation?

Thomas Schelling, the 2005 Nobel Laureate in Economics, and one of the first to apply emergence and nonlinear dynamics to questions of public policy, used a checkerboard to demonstrate that a small preference for similarity with neighbors could lead to disproportionately large levels of segregation.[12] Today, we are fortunate to have computers to replicate Schelling's studies and, much like the forest fires described above, simulations demonstrate a non-linear relationship between preference for similarity and emergent segregation.[13] And much like the flocking starlings discussed above, Schelling's systems of interacting heterogeneous agents display segregation behavior that cannot be derived from the individual preferences for similarity.[14]

Some of our recent work in the Consortium on Negotiation and Conflict Resolution's Computational Laboratory for Complex Adaptive Systems takes agents from Schelling's chessboard and presents them with a cooperative task in a complex social network.[15]

12. Thomas C. Schelling, *Models of Segregation*, 59 AM. ECON. REV. 488 (1969). For a simulation of these segregation dynamics, with access to the underlying code, see URI WILENSKY, NETLOGO SEGREGATION MODEL, CENTER FOR CONNECTED LEARNING AND COMPUTER-BASED MODELING, NORTHWESTERN UNIVERSITY, EVANSTON, IL. (1998), http://ccl.northwestern.edu/netlogo/models/Segregation.

13. *Id.*

14. *Id.*

15. See Figure One. Complex social network architectures allow for agents with a wide range of interaction partners, not artificially limited by the adjacent squares on a checkerboard, a toroidal, two-dimensional, non-bordered space. Our simulations also differ from Schelling's in that agents are engaged in a cooperative task rather than being limited to merely making decisions about moving to satisfy preferences for similarity. *See* Gregory Todd Jones & Travis Lloyd, *Parents Involved in Community Schools v. Seattle School District No. 1 et al.: Computational Models of Prejudice and the*

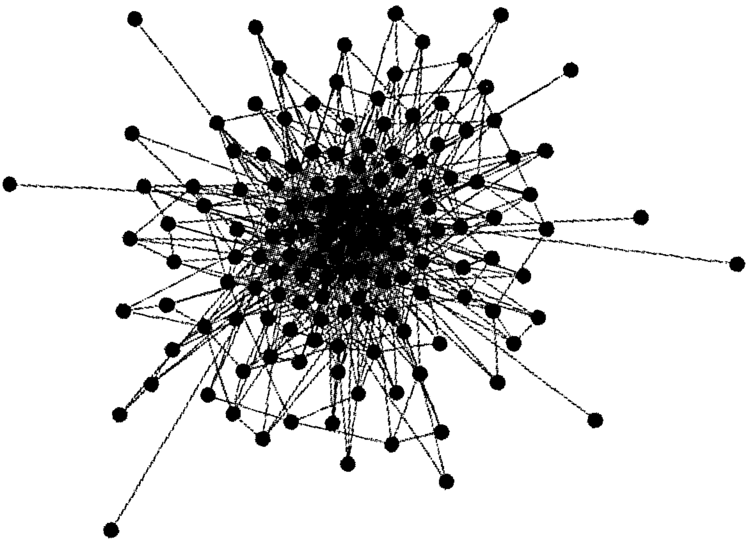

Figure One: Segregated Agents in a Complex Social Network (full color diagram available at: http://www.gregorytoddjones.com/publications.htm).

Because agents can be identified by some arbitrary tag (here, their color), it is possible for agents to employ prejudicial strategies – treating agents with a different color differently than they treat agents with their same color.

We have shown that when the level of segregation is controlled exogenously, by an institution such as the law, the success of prejudicial strategies increases – and social welfare decreases – as segregation increases. More precisely, the success of prejudicial

Contact Hypothesis (unpublished working paper, available from authors); Gregory Todd Jones & Travis Lloyd, *Computational Models of Prejudice Reduction: Spatial Robustness and the Contact Hypothesis* (unpublished working paper, available from authors).

strategies increases sharply, in a steep, nonlinear relationship to increasing segregation.[16]

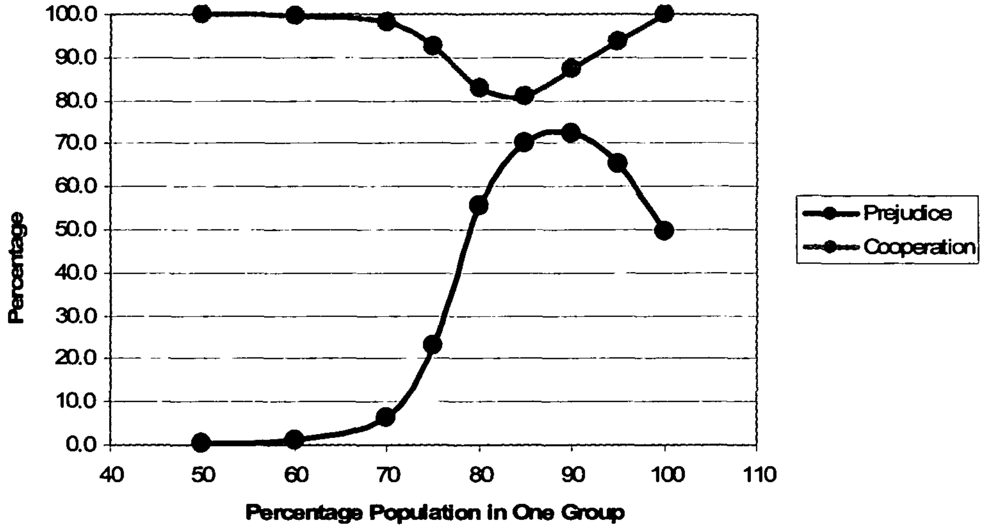

Figure Two: The Relative Success of Prejudicial Strategies (Percentage) and Cooperation (Percentage) as a Measure of Social Welfare as Functions of Levels of Segregation (full color diagram available at: http://www.gregorytoddjones.com/publications.htm).

One possible consequence of these characteristics is that decisions such as the Supreme Court's *Seattle School District v. Parents Involved*,[17] while expressly seeking to merely limit segregation plans may essentially eviscerate *Brown v. Board of Education*[18] by virtue of emergent nonlinearities.

16. See Figure Two. These steep s-shaped curves often indicate what is known as "phase transitions," where small changes, or perturbations, to system variables can bring about large scale changes in system properties.

17. Parents Involved in Cmty. Sch. v. Seattle Sch. Dist. No. 1, 551 U.S. ___, 127 S.Ct. 2738, (2007).

18. Brown v. Bd. of Educ. of Topeka, 347 U.S. 483 (1954).

Wouldn't it be worthwhile if law makers and the courts understood emergence and nonlinearity well enough to consider their possible consequences in their decision making?

There is a small, but growing cadre of legal scholars who do think that it would be worthwhile to consider the implications of networks, complex systems, and nonlinear dynamics to the future of the law.[19] The breadth of current substantive applications is impressive, including jurisprudence,[20] law and economics,[21] torts,[22] criminal law,[23] environmental law,[24] regulatory law,[25] bankruptcy,[26] mediation

19. We would be in good company—it has been suggested that the study of networks, complex systems, and nonlinear dynamics has pervaded all of science. *See* Steven H. Strogatz, *Exploring Complex Networks*, 410 NATURE 268 (2001).

20. *See* Thomas Earl Geu, *The Tao of Jurisprudence: Chaos, Brain Science, Synchronicity, and the Law*, 61 TENN. L. REV. 933, 934–35 (1994); Oona 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 Post, *"Chaos Prevailing on Every Continent": A New Theory of Decentralized Decision-Making in Complex Systems* 73 CHI.-KENT L. REV. 1055 (1999); 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).

21. Mark J. Roe, *Chaos and Evolution in Law and Economics*, 109 HARV. L. REV. 641, 643–65 (1996).

22. Edward S. Adams et al., *At the End of Palsgraf, There Is Chaos: An Assessment of Proximate Cause in Law and Chaos Theory*, 59 U. PITT. L. REV. 507 (1997); Jeff L. Lewin, *The Genesis and Evolution of Legal Uncertainty About "Reasonable Medical Certainty"*, 57 MD. L. REV. 380, 389–93 (1998).

23. 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).

24. 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. & POL'Y FORUM 167 (1996); Daniel A. Farber, *Probabilities Behaving Badly: Complexity Theory and Environmental Uncertainty*, 37 U.C. DAVIS L. REV. 145 (2003); William H. Rodgers, Jr., *Where Environmental Law and Biology Meet: Of Pandas' Thumbs, Statutory Sleepers, and Effective Law*, 65 U. COLO. L. REV. 25, 46–48 (1993); 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); J. B. Ruhl, *Sustainable Development: A Five-Dimensional Algorithm for Environmental Law*, 18 STAN. ENVTL. L.J. 31 (1999).

and other forms of alternative dispute resolution,[27] administrative law,[28] capital markets,[29] telecommunications,[30] legislative[31] and judicial decision making,[32] discrimination and equal opportunity,[33] constitutional law,[34] business law,[35] land use law,[36] intellectual

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25. 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, *Regulatory Traffic Jams*, 2 WYO. L. REV. 253 (2002).

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

27. 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 (1997).

28. Donald T. Hornstein, *Complexity Theory, Adaptation, and Administrative Law*, 54 DUKE L.J. 913 (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 (2001–2002); 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); 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.C. DAVIS L. REV. 405 (1997).

29. 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); Lawrence A. Cunningham, *Capital Market Theory, Mandatory Disclosure, and Price Discovery*, 51 WASH. & LEE L. REV. 843, 854–59 (1994).

30. Barbara A. Cherry, *The Telecommunications Economy and Regulation as Coevolving Complex Adaptive Systems: Implications for Federalism*, 59 FED. COMM. L.J. 369 (2006); Susan P. Crawford, *The Biology of the Broadcast Flag*, 25 HASTINGS COMM. & ENT. L.J. 603 (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 (2005); Kevin Werbach, *Supercommons: Toward a Unified Theory of Wireless Communication*, 82 TEX. L. REV. 863 (2004).

31. Vincent Di Lorenzo, *Complexity and Legislative Signatures: Lending Discrimination Laws as a Test Case*, 12 J.L. & POL. 637 (1996); Vincent M. Di Lorenzo, *Equal Economic Opportunity: Corporate Social Responsibility in the New Millennium*, 71 U. COLO. L. REV. 51 (2000); Vincent Di Lorenzo, *Legislative Chaos: An Exploratory Study*, 12 YALE LAW & POL'Y REV. 425, 432–35 (1994).

32. 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 (2000); David G. Post & Michael B. Eisen, *How Long is the Coastline of the Law? Thoughts on the Fractal Nature of Legal Systems*, 29 J. LEGAL STUD. 545 (2000); Glenn Harlan Reynolds, *Chaos and the Court*, 91 COLUM. L. REV. 110, 112–15 (1991).

33. Daria Roithmayr, *Barriers to Entry: A Lock-In Model of Racial Inequality*, 86 VA. L. REV. 727 (2000).

34. Michael J. Gerhardt, *The Role of Precedent in Constitutional Decision Making and Theory*, 60 GEO. WASH. L. REV. 68, 114–15 (1991).

35. 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 (1998).

36. Alistair M. Hanna, *The Land Use System*, 13 PACE ENVTL. L. REV. 531, 538 (1996).

property,[37] and political theory[38] – and this is surely not a complete list.[39]

In this Symposium edition of the *Georgia State University Law Review*, we are fortunate to have contributions from many of the pioneers in the application of complex systems and dynamical systems theory to the law. J.B. Ruhl, one of the first legal scholars to apply complexity theory to his work, sets the stage by inviting us to think about the law as a complex system.[40] To aid those for which this is a new enterprise, Ruhl provides a primer of complex systems principles and suggests how certain characteristics of the law may be complex, in the technical definition of the term. Particularly valuable is Ruhl's taxonomy of complex systems principles paired with tangible examples from legal systems. Finally, Ruhl considers what the implications may be for legal system design when the law is conceived as a complex adaptive system.

Next, along with collaborators Doug Yarn, Reidar Hagtvedt and Travis Llyod, I use evolutionary game theoretic simulation models to explore the influence of structure in complex social networks where pro-social, welfare optimizing behavior is possible, but not assured.[41] It has been widely demonstrated that social capital, or social "connectedness," matters in these contexts. We show that the distribution of social capital also matters by exerting a negative influence on pro-social behavior that is shown to be statistically independent from average social capital. We conclude by suggesting that institutions, including legal institutions, designed to promote

37. Andrea M. Matwyshyn, *Organizational Code: A Complexity Theory Perspective on Technology and Intellectual Property Regulation*, 11 J. TECH. L. & POL'Y 1 (2006).

38. 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 (1997); Glenn Harlan Reynolds, *Is Democracy Like Sex?*, 48 VAND. L. REV. 1635, 1639–40 (1995).

39. I am grateful to J.B. Ruhl for his web site, *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 http://law.vanderbilt.edu/seal/resources/readingscomplex.htm (last visited Mar 23, 2008).

40. J.B. Ruhl, *Law's Complexity: A Primer*, 24 GA. ST. U. L. REV. 883 (2008).

41. 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. 929 (2008).

homogeneity in social capital may produce increases in social welfare overall, and as such, is properly thought of as a collective good.

Daniel Katz and Derek Stafford, political scientists from the University of Michigan, employ a subset of tools from complexity science, those of network analysis, to examine how the decision making of individual judges may map to the judiciary's aggregate doctrinal output.[42] Katz and Stafford hypothesize that the decision making framework used by any particular jurist to interpret and apply sets of legal rules is impacted by a combination of jurists who are socially prominent and socially proximate. Their work is at once an excellent introduction to network architecture and analysis and an eerie look into the doctrinal connections within the federal judiciary. Using the path of judical clerks as a proxy for proximity, they paint a picture of complex networks that make sense on their face and make former law clerks anxious to discover their own place in the links of federal jurisprudence. The real power of the network approach is revealed when they reorganize the networks by demographics such as the party of the appointing president revealing sometimes surprising relationships that may have otherwise remained hidden.

In general, complexity theory principles call for the emergence of co-evolved institutions from the interactions of agents following simple local strategic rules. Relying on micro-level mechanisms similar to Adam Smith's "invisible hand" which produces optimal prices from the bottom up merely from the interactions of individuals pursuing their own interests, proponents of deregulation argue that top-down intervention is unnecessary to create efficient markets. Barbara Cherry brings decades of telecommunications policy expertise to bear in crafting her warning that the sustainability of critical communications infrastructures will depend on the existence of specific top-down legal rules.[43] Framing her discussion with the

42. Daniel M. Katz, Derek K. Stafford, & Eric Provins, *Social Architecture, Judicial Peer Effects and the "Evolution" of the Law: Toward a Positive Theory of Judicial Social Structure*, 24 GA. ST. U. L. REV. 975 (2008).

43. Barbara A. Cherry, *Maintaining Critical Rules to Enable Sustainable Communications Infrastructures*, 24 GA. ST. U. L. REV. 945 (2008).

principles of complex systems, Cherry sets out certain institutional boundary conditions that will be necessary to maintain emergent properties of widespread availability, affordability and reliability.

Bernard Trujillo leads us on a deeply philosophical exploration of the nature of modeling in the social sciences.[44] He is critical of what he sees as a long standing reliance on linear models with a stochastic term added as a place holder for our ignorance. Trujillo advocates replacing these conventional random terms with others that may be supplied by the mathematics of complexity. He suggests that nonlinear chaotic systems may be used to successfully model complex social forms, like the diffusion of legal doctrine, and brings his theory to bear on two examples that define much of his other substantive scholarship: finance and bankruptcy law.

Finally, Ted Blumoff, an ethicist and legal philosopher, employs a social network analysis to examine the nature of the action-omission network in the criminal law.[45] Blumoff begins with Hume's understanding that humans have a feeling of obligation to others that radiates outward from themselves resembling a network with valence that tends to attenuate as the connections become more remote. He argues that omission accountability is a function of relationally proximate networks with proximity being a function both of biology and fiduciary relationships.

These papers embody significant breath both in analytical tools and substantive application and as suggested earlier represent but a small sample of the growing cadre of legal scholars putting complexity science principles to work in their research. As J.B. Ruhl concludes, the goal shared by this work is to make visible legal system machinery that remains hidden when examined through the dominant lens of linearity.[46] The recognition of complex attributes, such as nonlinearity and their consequences, is a start, but much

44. Bernard Trujillo, *Randomness and Complexity in Social Explanation: Evidence from Finance and Bankruptcy Law*, 24 GA. ST. U. L. REV. 911 (2008).

45. Theodore Y. Blumoff, *On the Nature of the Action-Omission Network*, 24 GA. ST. U. L. REV. 1001 (2008).

46. J.B. Ruhl, *Law's Complexity: A Primer*, 24 GA. ST. U. L. REV. 883 (2008).

remains to be done before complex systems theory can offer tangible guidance for institutional designers. Within the institution of the law, we hope this Symposium edition is seen as a step in that direction.