

1-1-2015

Measuring, Monitoring and Managing Legal Complexity

Daniel Katz

IIT Chicago-Kent College of Law, dkatz3@kentlaw.iit.edu

J.B. Ruhl

Vanderbilt University Law School

Follow this and additional works at: http://scholarship.kentlaw.iit.edu/fac_schol



Part of the [Law Commons](#)

Recommended Citation

Daniel Katz & J.B. Ruhl, *Measuring, Monitoring and Managing Legal Complexity*, 101 Iowa L. Rev. 191 (2015).

Available at: http://scholarship.kentlaw.iit.edu/fac_schol/865

This Article is brought to you for free and open access by the Faculty Scholarship at Scholarly Commons @ IIT Chicago-Kent College of Law. It has been accepted for inclusion in All Faculty Scholarship by an authorized administrator of Scholarly Commons @ IIT Chicago-Kent College of Law. For more information, please contact dgersberg@kentlaw.iit.edu.

Measuring, Monitoring, and Managing Legal Complexity

J.B. Ruhl & Daniel Martin Katz***

ABSTRACT: The American legal system is often accused of being “too complex.” For example, most Americans believe the Tax Code is too complex. But what does that mean, and how would one prove the Tax Code is too complex? Both the descriptive claim that an element of law is complex and the normative claim that it is too complex should be empirically testable hypotheses. Yet, in fact, very little is known about how to measure legal complexity, much less how to monitor and manage it.

Legal scholars have begun to employ the science of complex adaptive systems, also known as complexity science, to probe these kinds of descriptive and normative questions about the legal system. This body of work has focused primarily on developing theories of legal complexity and positing reasons for, and ways of, managing it. Legal scholars thus have skipped the hard part—developing quantitative metrics and methods for measuring and monitoring law’s complexity. But the theory of legal complexity will remain stuck in theory until it moves to the empirical phase of study. Thinking about ways of managing legal complexity is pointless if there is no yardstick for deciding how complex the law should be. In short, the theory of legal complexity cannot be put to work without more robust empirical tools for identifying and tracking complexity in legal systems.

This Article explores legal complexity at a depth not previously undertaken in legal scholarship. First, the Article orients the discussion by briefly reviewing complexity science scholarship to develop descriptive, prescriptive, and ethical theories of legal complexity. The Article then shifts to the empirical front, identifying potentially useful metrics and methods for studying legal complexity. It draws from complexity science to develop methods that have

* David Daniels Allen Distinguished Chair of Law, Vanderbilt University Law School.

** Associate Professor of Law, Chicago-Kent College of Law; External Affiliated Faculty, CodeX: The Stanford Center for Legal Informatics.

We are thankful for comments from participants in workshops conducted by Lancaster University, the University of San Diego’s Center for Computation, Mathematics, and Law; the Society for Evolutionary Analysis in Law; and the German Law and Society Association. We also are grateful to our respective institutions for research support. Please direct comments or questions to jb.ruhl@vanderbilt.com and dkatz3@kentlaw.iit.edu.

been or might be applied to measure different features of legal complexity. Next, the Article proposes methods for monitoring legal complexity over time, in particular by conceptualizing what we call Legal Maps—a multi-layered, active representation of the legal system network at work. Finally, the Article concludes with a preliminary examination of how the measurement and monitoring techniques could inform interventions designed to manage legal complexity by using currently available machine learning and user interface design technologies.

| | |
|---|-----|
| I. INTRODUCTION | 193 |
| II. THE COMPLEXITY SCIENCE THEORY OF LEGAL COMPLEXITY | 201 |
| A. <i>DESCRIPTIVE THEORIES</i> | 203 |
| B. <i>PRESCRIPTIVE THEORIES</i> | 207 |
| C. <i>ETHICAL THEORIES</i> | 210 |
| III. MEASURING LEGAL COMPLEXITY..... | 211 |
| A. <i>COMPLEXITY AND SYSTEM STRUCTURE</i> | 212 |
| 1. Agents and Agent Sets: Composition, Classification, and Diversity..... | 212 |
| 2. Formal Architecture: Trees and Other Formal Hierarchies | 213 |
| 3. Network Architecture: Emergent Hierarchies | 216 |
| 4. Information Storage and Computation..... | 222 |
| B. <i>COMPLEXITY AND SYSTEM BEHAVIOR</i> | 224 |
| 1. Networks, Trees, Diffusion, and System Behavior | 226 |
| 2. Emergence, Feedback, Laplace’s Demon, and System Prediction | 228 |
| <i>i. Feedback</i> | 229 |
| <i>ii. Emergence</i> | 229 |
| IV. MONITORING LEGAL COMPLEXITY | 231 |
| A. <i>DESIGNING “LEGAL MAPS” FOR NETWORK BEHAVIOR MONITORING</i> | 232 |
| B. <i>TESTING SYSTEM PERFORMANCE</i> | 234 |
| 1. Synchronization Monitoring | 234 |
| 2. Stress Tests..... | 237 |
| 3. Interdependent Systems Analysis..... | 237 |
| C. <i>COMPARATIVE DESIGN STUDIES</i> | 238 |
| V. MANAGING LEGAL COMPLEXITY | 238 |
| A. <i>DEFINING TOO MUCH COMPLEXITY</i> | 238 |

| | |
|--|-----|
| B. MANAGING TOO MUCH COMPLEXITY..... | 240 |
| 1. Real-Time Monitoring Leveraging Learning Algorithms | 240 |
| 2. Designing Legal User Interfaces | 242 |
| VI. CONCLUSION | 243 |

I. INTRODUCTION

Do you believe the U.S. Tax Code is too complex? If so, you are in good company—most Americans believe the Tax Code is too complex.¹ Many legal scholars believe the Tax Code is too complex.² Even the Internal Revenue Service’s own National Taxpayer Advocate Service believes the Tax Code is too complex.³ And this is not a new sentiment in society—“[s]ince the inception of the federal income tax, commentators have viewed complexity as virtually inevitable.”⁴ But prove it! That’s right, prove the Tax Code is too complex.

How would you do that? How would you prove the Tax Code—or any other statute or regulation—is too complex? Making such a claim about some element of law requires proof of two related hypotheses. The first is descriptive: the law is *complex*. The second is normative: the law is *too* complex. Both are, in theory, empirically testable hypotheses. The claim that a body of law is complex requires some convention for defining legal complexity and

1. Surveys routinely find the vast majority of American taxpayers believe the Code is too complex. See, e.g., Courtney Coren, *Tax Poll: Most Americans Say Tax Code Is Too Complicated*, NEWSMAX (Apr. 11, 2013, 9:27 AM), <http://www.newsmax.com/Newsfront/quinnipiac-poll-irs-tax/2013/04/11/id/498974>. Google searches for “U.S. tax code too complex” and “tax code is too complex” yield millions of sites.

2. For a small slice, see Michelle Arnopol Cecil, *Toward Adding Further Complexity to the Internal Revenue Code: A New Paradigm for the Deductibility of Capital Losses*, 99 U. ILL. L. REV. 1083 (1999); Steven A. Dean, *Attractive Complexity: Tax Deregulation, the Check-the-Box Election, and the Future of Tax Simplification*, 34 HOFSTRA L. REV. 405 (2005); Samuel A. Donaldson, *The Easy Case Against Tax Simplification*, 22 VA. TAX REV. 645 (2003); James S. Eustice, *Tax Complexity and the Tax Practitioner*, 45 TAX L. REV. 7 (1989); Stanley A. Koppelman, *At-Risk and Passive Activity Limitations: Can Complexity Be Reduced?*, 45 TAX L. REV. 97 (1989); Susan B. Long & Judyth A. Swingen, *An Approach to the Measurement of Tax Law Complexity*, 8 J. AM. TAX ASS’N 22 (1987); Edward J. McCaffery, *The Holy Grail of Tax Simplification*, 1990 WIS. L. REV. 1267; John A. Miller, *Indeterminacy, Complexity, and Fairness: Justifying Rule Simplification in the Law of Taxation*, 68 WASH. L. REV. 1 (1993); and Deborah L. Paul, *The Sources of Tax Complexity: How Much Simplicity Can Fundamental Tax Reform Achieve?*, 76 N.C. L. REV. 151 (1997).

3. 1 TAXPAYER ADVOCATE SERV., INTERNAL REVENUE SERV., NATIONAL TAXPAYER ADVOCATE 2012 ANNUAL REPORT TO CONGRESS 3 (2012), <http://www.taxpayeradvocate.irs.gov/2012-Annual-Report/downloads/Most-Serious-Problems-Tax-Code-Complexity.pdf> (“The most serious problem facing taxpayers—and the IRS—is the complexity of the Internal Revenue Code (the ‘tax code’).”).

4. 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, 408 (1997) (citing commentary from the early 1900s).

then some way of measuring whatever that is. Further, the claim that a body of law is too complex requires identifying an optimal legal complexity and some way of comparing a particular law's complexity to that standard. With all the arm-waving about the excessive complexity of the Tax Code, one would think these two sets of metrics are well established and routinely applied across a wide berth of the legal domain. That would be a mistake. Law's complexity, while often invoked in rhetorical policy debates, is in fact one of the least understood and measured features of law. Thus, making the legal system less complex, or "simpler," remains a popular but elusive remedy for "too much complexity," with prescriptions often appearing more complex than the problem.⁵

As intuitive as it is to any lawyer that the law is complex, getting a handle on exactly what that means and what to do about it is no simple matter. First, one needs a theoretical foundation to describe complexity in terms relevant to legal systems. What is legal complexity, and what attributes and variables go into making legal systems complex? Then one must develop metrics and methods to measure and monitor those attributes in the legal system. Armed with such data, legal theorists, politicians, and citizens can begin an evidence-based debate regarding how complex the law should be. And, if it were determined that the law is too complex or not complex enough, it would be useful to have the means to adjust and manage the law's complexity. Of course, none of these is a small task.

Legal scholars have begun to employ complexity science (also known as complexity theory) as one lens through which to probe these descriptive and normative questions about law's complexity.⁶ The focus of complexity science

5. See, e.g., CASS R. SUNSTEIN, SIMPLER: THE FUTURE OF GOVERNMENT (2013) (arguing that the regulatory state can be made more simple through cost-benefit analysis, regulatory "nudges" of behavior, information disclosure, eliminating red tape, and other measures).

6. For an overview of complexity science and how scholars in the social sciences, including law, have integrated it, see generally J.B. Ruhl, *Law's Complexity: A Primer*, 24 GA. ST. L. REV. 885 (2008). Further details on complexity in the legal system are provided *infra* Parts II–III. We need to stress at the outset that the use of complexity science in legal systems theory is distinct from other systems models that have been used in legal applications. In particular, the famous German sociologist Niklas Luhmann developed an "autopoiesis" systems model that has had tremendous influence in European legal theory. See generally Jakob Arnoldi, *Niklas Luhmann: An Introduction*, 18 THEORY, CULTURE & SOC'Y, Feb. 2001 (introducing a special issue devoted to Luhmann); Niklas Luhmann, *Law as a Social System*, 83 NW. U. L. REV. 136 (1989) (outlining the model). There is some disagreement over the distinctions between the complexity science and autopoiesis models, however, as the two bear similarities and distinctions. Most legal scholars who have explored the two models consider them related but distinct forms of systems theory. See Lynn M. LoPucki, *The Systems Approach to Law*, 82 CORNELL L. REV. 479, 483–84 nn.13–17 (1997); Thomas E. Webb, *Exploring System Boundaries*, 24 L. CRITIQUE 131, 131–32 (2013) [hereinafter Webb, *Exploring System Boundaries*]. Others describe autopoiesis as "a significant branch of complexity theory." See, e.g., Julian Webb, *Law, Ethics, and Complexity: Complexity Theory & the Normative Reconstruction of Law*, 52 CLEV. ST. L. REV. 227, 227 n.3 (2005) [hereinafter Webb, *Law, Ethics, and Complexity*]. Going further, some legal scholars have employed systems models purportedly or impliedly different from both the autopoiesis and complexity science models, see, e.g., LoPucki,

is complex adaptive systems, systems “in which large networks of components with no central control and simple rules of operation give rise to complex collective behavior, sophisticated information processing, and adaptation via learning or evolution.”⁷ Thus far, legal scholars using this discipline to study law’s complexity focus primarily on describing legal systems as complex adaptive systems to understand the origins of legal complexity and on exploring theoretical ways of managing it. In other words, legal scholars have largely skipped the hard part—developing quantitative metrics and methods for measuring and monitoring law’s complexity.⁸ But the theory of legal complexity will remain stuck in theory until it moves to the empirical phase of study; thinking about how to manage legal complexity is pointless if there is no yardstick for deciding how complex the law should be. In short, we cannot put the theory of legal complexity to work without robust empirical tools.

To put this problem in practical terms, consider again the Tax Code. Exactly how complex is the Tax Code, and how complex should it be compared to, say, securities laws or environmental protection laws? American individuals and businesses in 2012 spent 6.1 billion hours and \$168 billion complying with the Tax Code’s nearly 4 million words of text, a text which Congress has changed over 5000 times between 2001 and 2012.⁹ Are those figures proof of the Tax Code’s excess complexity? Tax Code “simplification” is often associated with reducing these compliance costs.¹⁰ But is the best measure of Tax Code complexity the hours and dollars spent complying with it? After all, knowing how much time and money is spent on tax compliance might tell us more about “tax morality” than about the Tax Code’s

supra, at 488–509 (sketching out what is described as a distinct, empirically oriented “systems approach” for legal design), while others have cherry-picked concepts from complexity science to construct a legal systems model without explicitly calling it a complexity science model. *See, e.g.*, ADRIAN VERMEULE, *THE SYSTEM OF THE CONSTITUTION* (2011) (developing a “systems theory” model of constitutional dynamics using many concepts from complexity science); Thomas E. Webb, Book Note, 75 *MOD. L. REV.* 1182, 1182–83 (2012) [hereinafter Webb, Book Note] (reviewing VERMEULE, *supra*) (showing that the concepts Vermeule uses, “taken collectively, indicate that the theory under discussion is complexity theory, although this is not clearly stated”). We are not making any claims in this Article about these or any other legal systems models and do not cover them in any further detail. Our interest is in how the concept of complexity as developed specifically in complexity science can be applied and tested in legal systems.

7. MELANIE MITCHELL, *COMPLEXITY: A GUIDED TOUR* 13 (2009). The term “complex adaptive system” is often used to distinguish between complex systems that are highly adaptive (such as an ecosystem) versus nonadaptive (such as a hurricane).

8. Significant exceptions are discussed in more detail in Part III *infra*.

9. 1 TAXPAYER ADVOCATE SERV., *supra* note 3, at 5–6.

10. *See* Joel Slemrod & Nikki Sorum, *The Compliance Cost of the U.S. Individual Income Tax System* 1 (Nat’l Bureau of Econ. Research, Working Paper No. 1401, 1984), <http://www.nber.org/papers/w1401.pdf> (noting that at the time of the study in 1984 there was “an almost complete absence of quantitative information about the magnitude and characteristics of the cost of the current system”).

complexity. People and businesses in Greece reportedly devote little time and money to tax compliance,¹¹ but that does not prove that their tax laws are less complex than our Tax Code.

A less obvious measure of Tax Code complexity could be the complexity of popular tax compliance software programs such as TurboTax. Tax software companies are essentially selling the simplification of the Tax Code for the user, yet they must provide a product that accurately calculates the user's tax liability under any scenario and thus must somehow pack all of the Tax Code's substance into the software program. The program itself, however, has its own internal coding complexity, which software developers measure through various technical metrics and which software companies seek to control for business-cost purposes.¹² If the software is too complex, for example, it may be very difficult to update the program as Congress changes the Tax Code, as a change in one provision cascades in effect to other provisions.¹³ It would be in a tax software company's interests, therefore, to develop a program that is no more complex than needed to produce accurate user tax liability calculations. Perhaps a good measure of Tax Code complexity would then be the complexity of reliable tax compliance software.

These are just two of the many possible ways of measuring Tax Code complexity; others that have been proposed focus on attributes such as the text's "readability"¹⁴ or the number of tax rates and special provisions.¹⁵ The point is that people speak freely and passionately about the Tax Code's complexity, yet there is no standard set of metrics for measuring Tax Code complexity, no agreement on precisely how complex the Tax Code should be (other than less complex than it is now), and little agreement on how to achieve such a target if there were one. If everyone agreed that the Tax Code should be no more complex than to require 2.7 billion hours and \$45 billion in compliance efforts; no more complex than to require half the software complexity needed to code today's tax compliance software; or no more complex than to require a fifth-grade reading level, how would Congress know what to do to the Tax Code? Which provisions should Congress tweak to weed out the complexity? And what possible costs could reducing complexity have on the Tax Code's effectiveness in meeting tax policy goals?

11. *Tax Evasion in Greece: In Flagrante*, ECONOMIST (Sept. 4, 2012, 4:13 PM), <http://www.economist.com/blogs/freexchange/2012/09/tax-evasion-greece>.

12. For an article that is considered one of the classic early reviews of software complexity measurement, see Joseph K. Kearney et al., *Software Complexity Measurement*, 29 COMM. ACM 1044 (1986).

13. See Rajiv D. Banker et al., *Software Complexity and Maintenance Costs*, 36 COMM. ACM 81 (1993) (confirming that software maintenance is significantly affected by software complexity).

14. See, e.g., Andrew Stumpff Morrison, *Case Law, Systematic Law, and a Very Modest Suggestion*, 35 STATUTE L. REV. 149, 163 (2014).

15. See George Warskett et al., *The Complexity of Tax Structure in Competitive Political Systems*, 5 INT'L TAX & PUB. FIN. 123, 123 (1998) ("The complexity of a tax system is usually associated with the numbers of tax rates, tax bases and special provisions it includes.").

One reason it is difficult to approach these questions is that the metrics currently proposed for measuring Tax Code complexity turn the problem on its head. The Tax Code is not complex because of its costs of compliance, difficult readability, number of rates and special provisions, or the complexity of tax compliance software. Rather, the Tax Code imposes costly compliance burdens, is difficult to read, has lots of rates and special provisions, and poses a challenge to software developers *because it is complex*. These attributes are *consequences* of Tax Code complexity, not its *causes*. They do not get at the heart of why the Tax Code is complex and what makes it, allegedly, too much so. And while these attributes undoubtedly are useful metrics for evaluating whether the Tax Code is complex, they are of little help in determining how to solve the Tax Code's complexity problem (if it has one). Taking the temperature of an ill patient may show how ill the patient is but not why the patient is ill or what to do about it.

The Tax Code in this respect is a microcosm of legal complexity in general and an example of how little we understand its causes, consequences, and cures. The same questions could be asked of environmental law, securities law, health law, and dozens of other legal fields; answers would be wanting in those fields, too.¹⁶ In short, there is very little empirically robust understanding of the causes of legal complexity,¹⁷ which reduces the normative debate over legal complexity and how to "simplify" law largely to scholarly theory and political rhetoric.¹⁸

One might argue that, even accepting the foregoing, the complexity of law is extraneous to the challenge of designing legal measures to achieve policy goals.¹⁹ So long as a law or doctrine is performing effectively in meeting its intended purposes, the argument would go, it must be "just right" in terms of complexity.²⁰ But this argument would rely on the assumption that for each

16. See, e.g., Thomas O. McGarity, *When Strong Enforcement Works Better Than Weak Regulation: The EPA/DOJ New Source Review Enforcement Initiative*, 72 MD. L. REV. 1204, 1205-06 (2013). Environmental law is an example of "mature regulatory environments where the underlying statutes remain static and complexity increases over time." *Id.*

17. See Daniel Martin Katz & M.J. Bommarito II, *Measuring the Complexity of the Law: The United States Code*, 22 ARTIFICIAL INTELLIGENCE & L. 337, 338-41 (2014) (reviewing legal scholarship on measurement of legal complexity).

18. See, e.g., RICHARD A. EPSTEIN, *SIMPLE RULES FOR A COMPLEX WORLD* (1995) (proposing measures to simplify legal systems without defining empirical metrics for measuring legal complexity); SUNSTEIN, *supra* note 5 (outlining reforms claimed to simplify and thus improve governance).

19. Generally, "[a]n effective regulatory design is one that achieves the identified regulatory goals." Alejandro E. Camacho & Robert L. Glicksman, *Functional Government in 3-D: A Framework for Evaluating Allocations of Government Authority*, 51 HARV. J. LEGIS. 19, 27 (2014).

20. According to law and economics theory:

Once lawmakers list all the relevant costs and benefits of complexity, optimizing the amount of complexity in the law becomes a straightforward exercise in economic marginalism. One continues to add incremental precision to a rule as long as the sum of the benefits of the new twist exceed the sum of its costs.

policy goal there is a fixed amount of legal complexity required to fulfill it—any more or less would throw the law or doctrine off its optimal performance in achieving its goals. Yet there is no a priori reason to believe this is true. There could be multiple alternative legal designs, each with different levels of legal complexity (however measured) but all equally effective at fulfilling a prescribed policy goal.

Still, when choosing between such alternative legal constructions, one could argue that complexity should only matter in the design phase if there is reason to believe complexity matters in the performance phase as a factor influencing not only efficiency and effectiveness, but also equity, legitimacy, transparency, and other important normative features of legal systems.²¹ But if the Tax Code debate is any indication, many observers firmly believe that legal complexity has important practical policy implications. The Tax Code complexity debate also suggests that legal complexity is not a novel or controversial claim—it is a mainstream concern about the legal system. Legal complexity matters.

What is more likely to strike readers as “out there” is our claim that complexity science, with its origins in physics and ecology, provides a useful framework for studying *legal* complexity. Most lawyers are likely unfamiliar with complexity science, and some legal scholars have even expressed skepticism that it has much to offer the study of law.²² Legal scholarship, however, is seldom at the forefront of innovation in the social sciences. Complexity science has had tremendous influence already in other social science disciplines, including most prominently economics,²³ political

Kades, *supra* note 4, at 419 (offering an alternative using computational theory).

21. See Camacho & Glicksman, *supra* note 19, at 27–31 (identifying these other factors as important normative considerations in regulatory design).

22. See VERMEULE, *supra* note 6, at 8 (claiming that some applications of systems theory in law “reek of pseudoscience, as practitioners offer mysterious utterances about ‘complexity’ and ‘chaos’” and that “there is a core of genuine insight to systems theory that is not at all obscurantist or bogus”); LoPucki, *supra* note 6, at 483–84 (claiming that complexity science is unlikely to help advance understanding of legal systems beyond “levels of broad generality”); John Martinez, *The Dynamic Cycle of Legal Change*, 9 TENN. J.L. & POL’Y (SPECIAL EDITION) 10, 13–14 (2013) (claiming that “scholars have applied variants of complex adaptive systems theory—such as game theory and chaos theory—to the study of the legal system, but such efforts have foundered on the shoals of indeterminacy that such variants produce”).

23. See, e.g., ERIC D. BEINHOCKER, *THE ORIGIN OF WEALTH: EVOLUTION, COMPLEXITY, AND THE RADICAL REMAKING OF ECONOMICS* (2006); PAUL KRUGMAN, *THE SELF-ORGANIZING ECONOMY* (1996); Brian Arthur, *Competing Technologies, Increasing Returns, and Lock-In by Historical Events*, 99 ECON. J. 116 (1989); Neil Johnson & Thomas Lux, *Financial Systems: Ecology and Economics*, 469 NATURE 302 (2011); Robert M. May et al., *Complex Systems: Ecology for Bankers*, 451 NATURE 893 (2008); Didier Sornette & Ryan Woodard, *Financial Bubbles, Real Estate Bubbles, Derivative Bubbles, and the Financial and Economic Crisis*, in *ECONOPHYSICS APPROACHES TO LARGE-SCALE BUSINESS DATA AND FINANCIAL CRISIS* 101 (Misako Takayasu et al. eds., 2010).

science,²⁴ sociology,²⁵ and international affairs,²⁶ and it has been applied in the study of a wide variety of policy challenges such as terrorist networks,²⁷ healthcare,²⁸ organized crime,²⁹ transportation systems,³⁰ urban growth,³¹ and national security.³² This does not mean complexity science will necessarily have the same utility when applied to legal systems, but if one believes legal complexity is a concern, it is probably worth exploring whether anything can be gained from applying a scientific discipline singularly devoted to the study of complexity in social and physical systems.

Building on that theme, this Article explores the theoretical and empirical dimensions of legal complexity at a depth not previously undertaken in legal scholarship, but in terms we hope are accessible and of practical value to lawyers and legal scholars not already familiar with complexity science. Part II orients the discussion by briefly reviewing the core concepts of complexity science and legal scholars' application of these theories to the law. There have been three major themes in this body of

24. See generally ROBERT AXELROD, *THE COMPLEXITY OF COOPERATION: AGENT-BASED MODELS OF COMPETITION AND COLLABORATION* (1997); SCOTT DE MARCHI, *COMPUTATIONAL AND MATHEMATICAL MODELING IN THE SOCIAL SCIENCES* (2005); ROBERT JERVIS, *SYSTEM EFFECTS: COMPLEXITY IN POLITICAL AND SOCIAL LIFE* (1997); HERBERT SIMON, *THE SCIENCES OF THE ARTIFICIAL* (1969); Michael J. Ensley et al., *District Complexity as an Advantage in Congressional Elections*, 53 AM. J. POL. SCI. 990 (2009); Ken Kollman et al., *Political Parties and Electoral Landscapes*, 28 BRIT. J. POL. SCI. 139 (1998); Scott E. Page, *Path Dependence*, 1 Q.J. POL. SCI. 87 (2006).

25. See, e.g., R. KEITH SAWYER, *SOCIAL EMERGENCE: SOCIETIES AS COMPLEX SYSTEMS* (2005); Elizabeth E. Bruch & Robert D. Mare, *Neighborhood Choice and Neighborhood Change*, 112 AM. J. SOC. 667 (2006); Elinor Ostrom, *Collective Action and the Evolution of Social Norms*, 14 J. ECON. PERSP. 137 (2000).

26. See, e.g., WALTER C. CLEMENS, *COMPLEXITY SCIENCE AND WORLD AFFAIRS* (2013); Robert Axelrod, *The Dissemination of Culture: A Model with Local Convergence and Global Polarization*, 41 J. CONFLICT RESOL. 203 (1997); Lars-Erik Cederman, *Modeling the Size of Wars: From Billiard Balls to Sandpiles*, 97 AM. POL. SCI. REV. 135 (2003).

27. See, e.g., E. Ahmed et al., *On Complex Adaptive Systems and Terrorism*, 337 PHYSICS LETTERS A 127 (2005); Antoine Bousquet, *Complexity Theory and the War on Terror: Understanding the Self-Organising Dynamics of Leaderless Jihad*, 15 J. INT'L REL. & DEV. 345 (2012); Vito Latora & Massimo Marchiori, *How the Science of Complex Networks Can Help Developing Strategies Against Terrorism*, 20 CHAOS, SOLITONS & FRACTALS 69 (2004).

28. See, e.g., YANEER BAR-YAM ET AL., *NEW ENG. COMPLEX SYS. INST., A COMPLEX SYSTEMS SCIENCE APPROACH TO HEALTHCARE COSTS AND QUALITY* (2012).

29. See, e.g., Paul A.C. Duijn et al., *The Relative Ineffectiveness of Criminal Network Disruption*, 4 SCI. REP. 4238 (2014).

30. See, e.g., A. Aw & M. Rascle, *Resurrection of 'Second Order' Models of Traffic Flow*, 60 SIAM J. APPLIED MATHEMATICS 916 (2000); Debashish Chowdhury, *Statistical Physics of Vehicular Traffic and Some Related Systems*, 329 PHYSICS REP. 199 (2000); Petter Holme, *Congestion and Centrality in Traffic Flow on Complex Networks*, 6 ADVANCES COMPLEX SYSTEMS 163 (2003); Bosiljka Tadić et al., *Traffic on Complex Networks: Towards Understanding Global Statistical Properties from Microscopic Density Fluctuations*, 69 PHYSICAL REV. E 036102 (2004); Bosiljka Tadić et al., *Transport on Complex Networks: Flow, Jamming and Optimization*, 17 INT'L J. BIFURCATION & CHAOS 2363 (2007).

31. See, e.g., Robert H. Samet et al., *Complexity, the Science of Cities and Long-Range Futures*, 47 FUTURES 49 (2013).

32. See, e.g., Jürgen Scheffran, *The Complexity of Security*, 14 COMPLEXITY 13 (2008).

scholarship. First, a descriptive body of work has focused on mapping complexity science concepts onto legal systems to enable explanation of legal systems as complex adaptive systems. Second, a prescriptive thrust has moved from mapping concepts towards developing principles for structural design and normatively acceptable operation of legal systems given their complex adaptive system properties. Finally, an ethical focus in the literature explores what it means to be an actor in a complex legal system.

Parts III–V then shift to the empirical front, identifying potentially useful metrics and methods for studying legal complexity. Part III draws from complexity science to develop methods that have or might be applied to measure aspects of legal complexity, including metrics for agents, trees, networks, computation, feedback, and emergence. Part IV proposes methods for monitoring legal complexity over time by conceptualizing what we call Legal Maps—a multi-layered, Google Maps-style active representation of the legal system network at work. Part V concludes with a preliminary examination of how these measurement and monitoring techniques could inform interventions by applying currently available machine learning and user interface design technologies. While there is no possibility of attaining full (or even near full) management control of a complex social system such as law, techniques used in other complex adaptive system environments—such as financial- and transportation-systems management and software development—could prove adaptable to and useful in the long-term design, evaluation, and operation of legal systems.

To be clear, we are not claiming that we can finely measure and tune legal complexity using current data management and computational capacities. Rather, this Article establishes an agenda for identifying the empirical questions and methodological approaches ripe for study. From there, we plan in future work to test our proposed approaches through applied empirical studies. We recognize that existing technology will support only relatively crude metrics and computational methods for exploring legal complexity, and we suffer from no delusion that we can fully describe and regulate legal complexity today, if ever. We and other researchers must study legal complexity in small increments to begin with, hoping over time to build improved theoretical foundations that will lead to refined and expanded research agendas designed to advance our practical understanding of legal complexity. This Article is our opening contribution to that research agenda.

Law would not be the first domain to ask these questions about itself—it is a latecomer to complexity science, network analysis, machine learning, and other highly computational approaches to system assessment and management. Indeed, as important as the legal system is to social sustainability, it is a mystery to us why so much data and computational capacity is devoted in the business and finance sectors to monitoring financial system structure (not always successfully!) while legal scholars seldom use

these computational techniques to understand and evaluate the legal system *as a system*. This is what we hope to change.

II. THE COMPLEXITY SCIENCE THEORY OF LEGAL COMPLEXITY

The key premise in applying complexity science to legal systems is that there is a difference between complexity in the sense of “complicatedness” and complexity in the sense of system structure and behavior. That distinction, which goes to the essence of complexity science theory, is aptly described as follows:

In a complicated world, the various elements that make up the system maintain a degree of independence from one another. Thus, removing one such element (which reduces the level of complication) does not fundamentally alter the system’s behavior apart from that which directly resulted from the piece that was removed. Complexity arises when the dependencies among the elements become important. In such a system, removing one such element destroys system behavior to an extent that goes well beyond what is embodied by the particular element that is removed.³³

Few dispute that law is complicated; whether it is complex in the systems context is another matter.

To be sure, the complicatedness of law should not be discounted. Law can be vast, dense, vague, and intricate, making compliance a daunting undertaking. Complexity as used in our project, however, is getting at something different. Even in a world where all individual rules are perfectly clear and cost-efficient, knowing how to comply could still be burdensome. An *effort burden* would be associated with learning all the rules, and an *information burden* would be associated with compiling the evidence needed to test for and comply with the rules.³⁴ But beyond that, the *system* of rules could be difficult to navigate and predict because of the interactions between the multitude of rules and institutions administering them.³⁵ Complying with one rule could require actions that make complying with another rule more difficult.³⁶ Similarly, because legal rules often are interrelated through techniques such as cross-referencing and *stare decisis*, how one rule is interpreted and applied could affect the meaning or operation of other

33. JOHN H. MILLER & SCOTT E. PAGE, *COMPLEX ADAPTIVE SYSTEMS: AN INTRODUCTION TO COMPUTATIONAL MODELS OF SOCIAL LIFE* 9 (2007). Thus, “work is needed on distinguishing the complex . . . from the just complicated in the presence of many possible explanatory models and imperfect data.” Nicholas W. Watkins & Mervyn P. Freeman, *Natural Complexity*, 320 *SCI.* 323, 324 (2008).

34. 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, 798–800 (2003) (developing the concepts of effort and information burdens).

35. See *id.* at 800–23 (developing the concept of system burdens).

36. See *id.* (providing examples).

rules.³⁷ These kinds of *system burdens* are usually overlooked in legal scholarship that addresses ways of measuring and managing legal complicatedness—even when referred to as “complexity”—where the focus is primarily or exclusively on effort and information burdens.³⁸

Complexity science emphasizes these systems effects, studying inter-agent connections and the system-wide effects they produce. In the context of social systems, complexity science offers a different approach from that taken in small-number agent models (such as in bilateral game theory) and large-number agent models (such as the rational actor in law and economics). The problem with these inter-agent modeling approaches is that “most economic, political, and social interactions involve moderate numbers of people.”³⁹ To elaborate:

Most social science models require either very few (typically two) or very many (often an infinity) agents to be tractable. When an agent interacts with only a few other agents, we can usually trace all of the potential actions and reactions. When an agent faces an infinity of other agents, we can average out . . . the behavior of the masses and again find ourselves back in a world that can be easily traced. It is in between these two extremes—when an agent interacts with a moderate number of others—that our traditional analytic tools break down.⁴⁰

In other words, traditional models of inter-agent behavior do not work well when there are too many interacting agents to fit neatly into bilateral models, but not enough agents to ignore idiosyncratic behavior by averaging-out to an infinite-numbers “rational actor” model. Throughout the legal system, agents in legal institutions and instruments interact in ways suggesting that the differences between agents matter. Thus, mean-field approximations do not always capture useful or relevant dynamics. The number of judges, lawyers, agencies, laws, or regulations is neither small nor infinite, and we can find no legal scholarship claiming that the differences between, say, judges or regulations, do not matter.

37. See J.B. Ruhl, *Managing Systemic Risk in Legal Systems*, 89 IND. L.J. 559, 587–88 (2014) (examining cascade effects in legal rule systems).

38. See Kades, *supra* note 4, at 416–21 (examining several different proposed metrics of legal complexity); see also Louis Kaplow, *A Model of the Optimal Complexity of Legal Rules*, 11 J.L. ECON. & ORG. 150, 150–51 (1995) (defining legal complexity as “the number and difficulty of distinctions the rules make” and arguing that “[a]ctors seeking to comply with more complex rules may need to expend resources to learn how the rules apply to their contemplated acts”); Morrison, *supra* note 14 (proposing a linguistic “readability” metric, acknowledging that it will register more complexity the more “systematic” the regime of legal rules); Peter H. Schuck, *Legal Complexity: Some Causes, Consequences, and Cures*, 42 DUKE L.J. 1, 3 (1992) (“[A] legal system [i]s complex to the extent that its rules, processes, institutions, and supporting culture possess four features: density, technicality, differentiation, and indeterminacy or uncertainty.”).

39. MILLER & PAGE, *supra* note 33, at 221.

40. *Id.*

Complexity science is about building models for contexts in which agent heterogeneity and interrelatedness can and usually do influence outcomes. Legal scholars have developed descriptive, prescriptive, and ethical models of what this approach means for law.

A. DESCRIPTIVE THEORIES

Thus far, applying complexity science to legal systems has focused on mapping key concepts of complexity science onto legal systems.⁴¹ Consider the general definition of a complex adaptive system mentioned above: a large network of components, with no central control and simple rules of operation, giving rise to complex collective behavior, sophisticated information processing, and adaptation via learning or evolution. Anyone with training in law can easily map this framework onto the legal system. The legal system's components comprise a broad diversity of institutions—the organizations of people who make, interpret, and enforce laws—and of instruments—the laws, regulations, cases, and related legal content the institutions produce.⁴² These components are interconnected and interactive. Institutions are interconnected through structures and rules such as hierarchies of courts and legislative creation and oversight of agencies; institutions interact in forums such as judicial trials, legislative hearings and debates, and agency rulemakings. The instruments also are interconnected through mechanisms such as code structures, and they interact through cross-references and other devices.

The highly interconnected architecture of such a system drives the way it behaves over time. An agency adopts a rule, which prompts another agency to enforce a different rule, which leads to litigation before a judge, who issues an opinion overruled by a higher court, which prompts a legislature to enact a new statute, and so on. The institutional agents follow procedural rules (e.g., notice and comment), and even the instrumental agents have rules for rules (e.g., canons of statutory construction), but there is no central controller pulling all the strings. There are hierarchies for various institutions (e.g., courts) and instruments (e.g., federal preemption). Yet there is no master agent controlling *the system*.

41. The discussion and examples of legal complexity in this Subpart draw from Ruhl, *supra* note 37, at 565–69.

42. There are, of course, many different ways and terms used to describe the legal system, but for our purposes, what matters is the components, and it is quite common for legal scholars to speak of legal institutions and instruments in the way we use the terms to describe and discuss the legal system. Searches for the two terms in Westlaw's Law Review and Journals library turn up thousands of documents. For our purposes, we can put aside the question of what institutions and instruments are in or out of the legal system; what is important for now is that there is a collection of such components society calls "the legal system." See LoPucki, *supra* note 6, at 488–92, 497–502 (describing a systems analysis method for defining legal system boundaries); Webb, *Exploring System Boundaries*, *supra* note 6, at 133–35 (comparing complexity science and autopoiesis models of legal system boundaries).

The descriptive branch of legal complexity theory has focused on this kind of mapping exercise to demonstrate the legal system's complexity by examining how each attribute of complex adaptive systems described in complexity science research finds close parallels in legal system structure and behavior.⁴³ One dominant attribute of a complex adaptive system is feedback between the system components—the connections among which information flows to trigger responses.⁴⁴ Another important property, driven largely by intercomponent feedback, is emergence, the core idea of which is that the system exhibits macroscopic behavior that could not be predicted by examining the system components, interconnections, and interactions at microscopic scales.⁴⁵ In more technical terms, emergence is defined as “complicated global patterns emerging from local or individual interaction rules between parts of a system.”⁴⁶ A third central property of complex adaptive systems is self-organized structure, such that, as system scale grows, the system organizes spontaneously (with no central controller or plan) around a set of deep structural rules that lend stability to the system behavior.⁴⁷ These three key system attributes produce complex systems' adaptive capacity and promote their evolution over time,⁴⁸ which is at least in

43. See, e.g., Ruhl, *supra* note 6, at 898–901 (depicting a chart showing general features of complex adaptive systems and how each is found in legal systems); see also PAUL CILLIERS, COMPLEXITY AND POSTMODERNISM: UNDERSTANDING COMPLEX SYSTEMS 119–23 (1998) (listing complex adaptive system attributes found in social systems generally); Webb, *Law, Ethics, and Complexity*, *supra* note 6, at 232–38 (mapping six features of complex adaptive systems onto legal systems). See generally Thomas E. Webb, *Tracing an Outline of Legal Complexity*, 27 *RATIO JURIS* 477 (2014) [hereinafter Webb, *Tracing an Outline of Legal Complexity*] (relating complexity science principles to legal systems from the perspectives of inside the system, the boundary with the external environment, the external environment, and the coevolving system of systems as a whole).

44. Feedback loops allow the system to “restructure, or at least modify, the interaction pattern among its variables.” JOHN L. CASTI, COMPLEXIFICATION: EXPLAINING THE PARADOXICAL WORLD THROUGH THE SCIENCE OF SURPRISE 271 (1994). Such feedback loops can become exponential in effect and thus dominate the system in which they operate. See Douglas S. Robertson & Michael C. Grant, *Feedback and Chaos in Darwinian Evolution*, 2 *COMPLEXITY* 10, 12–14 (1996). For more on feedback as a complexity metric, see *infra* Part III.B.

45. MITCHELL, *supra* note 7, at 12–13.

46. P.-M. Binder, *Frustration in Complexity*, 320 *SCI.* 322, 322 (2008). For more on emergence as a complexity metric, see *infra* Part III.B.

47. Self-organized structure is “a generic pattern of self-organized nonequilibrium behavior in which there are characteristic long-range temporal and spatial regularities.” PETER COVENEY & ROGER HIGHFIELD, *FRONTIERS OF COMPLEXITY: THE SEARCH FOR ORDER IN A CHAOTIC WORLD* 432 (1995). For some of the foundational work on self-organization properties in physical, biological, and social complex adaptive systems, see generally PER BAK, *HOW NATURE WORKS: THE SCIENCE OF SELF-ORGANIZED CRITICALITY* (1996); STUART KAUFFMAN, *AT HOME IN THE UNIVERSE: THE SEARCH FOR THE LAWS OF SELF-ORGANIZATION AND COMPLEXITY* (1995); and KRUGMAN, *supra* note 23. For more on self-organization as a complexity metric, see *infra* Part III.B.

48. Adaptation is associated with the feedback and feedforward loops made possible by multiple paths of interactions between system components and thus “is an emergent property which spontaneously arises through the interaction of simple components.” JAMES GLEICK, *CHAOS: MAKING A NEW SCIENCE* 339 n.314 (1987).

part a product of coevolution with other complex adaptive systems in its environment.⁴⁹ The legal system, for example, does not operate in a vacuum—it influences, and is influenced by, other social, technological, physical, and biological systems.

Legal complexity scholars have argued that these properties can be found throughout legal systems, such as in the common law's development of foundational doctrinal rules over time.⁵⁰ Indeed, Stuart Kauffman, one of the leading thinkers in complexity science since its early development in the 1990s, used the common law as an example of complex adaptive system behavior.⁵¹ The judiciary's hierarchical structure and practice of stare decisis link courts with courts and opinions with opinions in ways that produce complicated *and* complex (as we define it) feedback connections.⁵² The “substantive jurisprudence” emerges from this system through a process of gradual development and evolution of doctrine based on bedrock principles, some of which were set down centuries ago. Although one must read the cases to know the common law of, say, property, the common law of property is something more than just the sum of the cases. The *Restatement of Property*, for example, is more than a case reporter—it is the product of tremendous effort by property law experts working over many decades to synthesize and compress case law into emergent, macro-scale doctrinal themes and structures, as well specific micro-scale rules and principles.

Notwithstanding claims to the contrary,⁵³ there have been numerous accounts of complex adaptive system attributes in a broad range of legal systems including administrative law,⁵⁴ mediation and alternative dispute

49. See Mikhail Prokopenko et al., *An Information-Theoretic Primer on Complexity, Self-Organization, and Emergence*, 15 COMPLEXITY 11, 23–24 (2008) (describing adaptation and evolution in complex adaptive systems). See generally KAUFFMAN, *supra* note 47 (outlining a theory of coevolution of complex adaptive systems).

50. See Daniel Martin Katz et al., *Reproduction of Hierarchy? A Social Network Analysis of the American Law Professoriate*, 61 J. LEGAL EDUC. 76, 97 (2011); 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, 1469–72 (1996).

51. KAUFFMAN, *supra* note 47, at 169.

52. See generally Jonathan F. Mitchell, *Stare Decisis and Constitutional Text*, 110 MICH. L. REV. 1 (2011).

53. See VERMEULE, *supra* note 6, at 8 (“Political scientists have made some use of systems theory, but legal applications are few and far between.”); Joost Pauwelyn, *At the Edge of Chaos? Foreign Investment Law as a Complex Adaptive System, How It Emerged and How It Can Be Reformed*, 29 ICSID REV. 372, 375 n.27 (2014) (“Few studies have applied complexity theory to law.”).

54. See, e.g., Donald T. Hornstein, *Complexity Theory, Adaptation, and Administrative Law*, 54 DUKE L.J. 913 (2005).

resolution,⁵⁵ bankruptcy law,⁵⁶ environmental law,⁵⁷ business law,⁵⁸ international law,⁵⁹ land-use regulation law,⁶⁰ intellectual property law,⁶¹ international development law,⁶² regulation of the internet,⁶³ the law of war,⁶⁴ health law,⁶⁵ and telecommunications regulation,⁶⁶ as well as in more general accounts of legal systems.⁶⁷ It is beyond this Article's scope to articulate all such examples—the point is that these scholarly contributions have established a robust descriptive model of legal systems as complex adaptive systems.

It is appropriate to pause here and ask the critic's question: So what? Accepting for now that the attributes of complex adaptive systems map well onto legal systems, what is the value of having a robust descriptive model of

55. See, e.g., Robert A. Creo, *Mediation 2004: The Art and the Artist*, 108 PENN. ST. L. REV. 1017 (2004).

56. See, e.g., Bernard Trujillo, *Patterns in a Complex System: An Empirical Study of Valuation in Business Bankruptcy Cases*, 53 UCLA L. REV. 357 (2005); Bernard Trujillo, *Self-Organizing Legal Systems: Precedent and Variation in Bankruptcy*, 2004 UTAH L. REV. 483.

57. See, e.g., Gerald Andrews Emison, *The Potential for Unconventional Progress: Complex Adaptive Systems and Environmental Quality Policy*, 7 DUKE ENVTL. L. & POL'Y 167 (1996).

58. See, e.g., 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).

59. See, e.g., Mark D. Belcher & James W. Newton, *International Legal Development: A Complex Problem Deserving of a "Complex" Solution and Implications for the CAFTA Region*, 12 SW. J.L. & TRADE AM. 189 (2006); Rakhyn E. Kim & Brendan Mackey, *International Environmental Law as a Complex Adaptive System*, 14 INT'L ENVTL. AGREEMENTS 5 (2014); Pauwelyn, *supra* note 53.

60. See, e.g., John R. Nolon, *Champions of Change: Reinventing Democracy Through Land Law Reform*, 30 HARV. ENVTL. L. REV. 1 (2006).

61. See, e.g., Andrea M. Matwyshyn, *Organizational Code: A Complexity Theory Perspective on Technology and Intellectual Property Regulation*, 11 J. TECH. L. & POL'Y, at xiii (2006); Deborah Tussey, *Music at the Edge of Chaos: A Complex Systems Perspective on File Sharing*, 37 LOY. U. CHI. L.J. 147 (2005).

62. See, e.g., Belcher & Newton, *supra* note 59.

63. See, e.g., Susan P. Crawford, *Shortness of Vision: Regulatory Ambition in the Digital Age*, 74 FORDHAM L. REV. 695 (2005); 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).

64. See, e.g., Carla Crandall, *If You Can't Beat Them, Kill Them: Complex Adaptive Systems Theory and the Rise in Targeted Killing*, 43 SETON HALL L. REV. 595 (2013).

65. See, e.g., M. Gregg Bloche, *The Emergent Logic of Health Law*, 82 S. CAL. L. REV. 389 (2009).

66. See, e.g., Barbara A. Cherry, *The Telecommunications Economy and Regulation as Coevolving Complex Adaptive Systems: Implications for Federalism*, 59 FED. COMM. L.J. 369 (2007); Susan P. Crawford, *The Biology of the Broadcast Flag*, 25 HASTINGS COMM. & ENT. L.J. 603 (2003).

67. See, e.g., Thomas Earl Geu, *The Tao of Jurisprudence: Chaos, Brain Science, Synchronicity, and the Law*, 61 TENN. L. REV. 933, 942–75 (1994); 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) (discussing complexity theory); Mark J. Roe, *Chaos and Evolution in Law and Economics*, 109 HARV. L. REV. 641 (1996) (discussing chaos theory, path dependence, and modern evolution theory as applied to law and economics); 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); Ruhl, *supra* note 6; Webb, *Law, Ethics, and Complexity*, *supra* note 6, at 227–38; Webb, *Tracing an Outline of Legal Complexity*, *supra* note 43.

legal systems as complex adaptive systems? The value of such a model is that it changes perspective and leads to new questions. To paraphrase how Brian Arthur, a leading thinker in applying complexity science to economics, described the impact of complexity science in economics:

[T]his new approach is not just an extension of standard [legal theory], nor does it consist of adding agent-based behavior to standard models. It is a different way of seeing the [legal system]. It gives a different view, one where actions and strategies constantly evolve, where time becomes important, where structures constantly form and re-form, where phenomena appear that are not visible to standard equilibrium analysis, and where a meso-layer between the micro and the macro becomes important.⁶⁸

In other words, the descriptive model of legal systems as complex adaptive systems provides a different perspective on legal systems. Admittedly, thus far the model has been constructed based on intuition, analogy, and example, but that by no means makes it unusual in the world of legal theory. Either you are persuaded on that basis or not, but we will proceed for now on the assumption that there is theoretical coherence to the model. The obvious next question is what to do with it.

B. PRESCRIPTIVE THEORIES

If the legal system is a complex adaptive system, how should legal agents and society at large act in such a system? An important point—one that cannot be overemphasized—is that describing the legal system as a complex adaptive system assumes no normative position about complex adaptive systems or legal systems. Instead, describing the legal system as a complex adaptive system is merely an observation about the way the legal system is constructed and behaves. Assuming that as a given, however, the nature of the legal system as a social system means that, unlike complex physical and biological systems, humans have a say in how it is designed and operated. Hence, as legal theorists constructed the descriptive model of legal complexity, they also turned to normative questions about the model's implications for legal system structure and performance.

This inquiry is distinct from the separate but related question of how to design legal systems given that their target regulatory subject is often a complex adaptive system. Ecosystems, for example, are classic examples of a

68. W. BRIAN ARTHUR, *Complexity Economics: A Different Framework for Economic Thought*, in COMPLEXITY AND THE ECONOMY 1, 2 (2015) (explaining the significance of the development of what he calls the “complexity economics” model). We have replaced his references to economic terms with the analogous legal terms. *Cf. id.*

complex adaptive system.⁶⁹ Therefore, it makes sense to think that the design of legal regimes intended to manage human interaction with ecosystems should consider that property.⁷⁰ This may counsel in favor of certain kinds of legal regimes, such as market-based instruments or adaptive management procedures, which may mesh better with the dynamic properties of ecosystems.⁷¹ Similar prescriptive accounts have been made in a wide variety of legal fields.⁷² But both sides of the equation must be taken into account. Law itself is a complex adaptive system, and it necessarily influences and is influenced by the systems it is intended to regulate or manage.⁷³ Hence, a principal concern of legal theorists interested in legal complexity has been to develop some sense of how best to respond to the legal system's complexity, considering that the legal system is just one member of a "system of systems."⁷⁴

One consequence of understanding the "system of systems" nature of legal regimes is the appreciation that tinkering may open up a huge can of worms. Thinking by analogy, consider what can happen in a biological ecosystem if a nonnative species is introduced, as humans have often done for what were believed to be good reasons. Often the species does not survive. Sometimes, though, the introduced species takes hold in its new environment and all chaos breaks loose.⁷⁵ The lesson is that intervening in a complex adaptive system is a risky venture. Yet, with the legal system, sometimes there

69. See 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, 953-58 (1997) (surveying the science of ecosystem complexity).

70. See *id.* at 967-79.

71. See *id.* at 980-1000. For a sweeping history of legal scholarship on why and how environmental law must account for the complex adaptive system properties of the environment, see generally Robin Kundis Craig, *Learning to Think About Complex Environmental Systems in Environmental and Natural Resource Law and Legal Scholarship: A Twenty-Year Retrospective*, 24 FORDHAM ENVTL. L. REV. 87 (2013). For similar treatments in general and applied contexts, see Alejandro E. Camacho, *Transforming the Means and Ends of Natural Resources Management*, 89 N.C. L. REV. 1405 (2011); and Barbara Cosens, *Resilience and Law as a Theoretical Backdrop for Natural Resource Management: Flood Management in the Columbia River Basin*, 42 ENVTL. L. 241 (2012).

72. See, e.g., Lawrence G. Baxter, *Capture Nuances in Financial Regulation*, 47 WAKE FOREST L. REV. 537 (2012) (discussing how finance law regulates complex financial markets); Debra Gerardi, *The Culture of Health Care: How Professional and Organizational Cultures Impact Conflict Management*, 21 GA. ST. U. L. REV. 857 (2005) (discussing how health care law regulates complex health care organizations); Richard E. Myers II, *Complex Times Don't Call for Complex Crimes*, 89 N.C. L. REV. 1849 (2011) (discussing how criminal law regulates complex behaviors).

73. See, e.g., Cherry, *supra* note 66, at 371 (arguing "that if the telecommunications sector and the legal/policymaking institutions are viewed as coevolving and complex adaptive systems, then there are important implications for regulatory policy"); Crandall, *supra* note 64, at 608-14, 639-41 (arguing that war and the law are interdependent complex adaptive systems).

74. For a summary of systems theory study of systems of systems, see Mary Ann Allison et al., *The Characteristics and Emerging Behaviors of System of Systems*, NEW ENG. COMPLEX SYS. INST., <http://necsi.edu/education/oneweek/winter05/NECSISoS.pdf>.

75. So much so that an extensive legal regime has arisen devoted to the invasive species problem. See JOHN COPELAND NAGLE, J.B. RUHL & KALYANI ROBBINS, *THE LAW OF BIODIVERSITY AND ECOSYSTEM MANAGEMENT* 1197-284 (3d ed. 2013) (devoting full chapter to invasive species law).

is no choice given the external set of social norms the legal system should fulfill. If the legal system is producing normatively poor results, something should be done.

Hence, legal complexity theory has worked on designing legal institutions and instruments that seem to fit well with complex adaptive system attributes. The theoretical premise is not that complexity is necessarily normatively good and should be promoted, but that some structural designs are less likely to disrupt the complexity dynamics of the system and are more likely to work well within the system as a whole and, perhaps as important, to facilitate the legal system's interaction with other complex social systems. The operative principle is that the legal system should be designed with its complexity in mind.

The main thrust of this prescriptive branch of legal complexity theory is a deep skepticism that top-down, centralized regulation can avoid unintended consequences or keep up with the co-evolving systems, and that more flexible, decentralized forms of governance fit better with the legal complexity model. For example, administrative law expert Donald Hornstein argues that understanding regulatory law as a complex adaptive system counsels in favor of relying more on the distributed power of states for policy formulation and for making federal administrative agency governance more experimental, adaptive, and collaborative.⁷⁶ Similarly, telecommunications law expert Barbara Cherry argues that rapid technological, social, and economic change—systems co-evolving with law—demand a more adaptive governance structure.⁷⁷ Cherry also argues that wholesale deregulation as a means of “simplifying” legal regimes can lead to disastrous results due to complex system cascade effects. Instead, building regulatory resilience—the capacity to withstand shocks from technology and other systems—should be the priority.⁷⁸

The answer to legal complexity, in other words, is not to hack away at the legal system and declare victory in the campaign for legal simplification. Rather, these scholars and other legal complexity theorists focus on offering prescriptive advice to build adaptability and resilience into legal systems to keep pace with co-evolving social, technological, physical, and biological systems. The predominant view among legal complexity theorists is that law cannot deregulate its way there, nor can it command-and-control its way there.⁷⁹ There are no easy answers—how to put law's complexity to work will

76. Hornstein, *supra* note 54, at 915–16, 934–60.

77. See Barbara A. Cherry, *Institutional Governance for Essential Industries Under Complexity: Providing Resilience Within the Rule of Law*, 17 *COMMLAW CONSPPECTUS J. COMM. L. & POL'Y* 1, 19–31 (2008).

78. See *id.* at 3–18. For an overview of resilience theory as applied in legal systems, see generally J.B. Ruhl, *General Design Principles for Resilience and Adaptive Capacity in Legal Systems—with Applications to Climate Change Adaptation*, 89 *N.C. L. REV.* 1373 (2011).

79. See, e.g., Jonathan H. Adler, *Water Rights, Markets, and Changing Ecological Conditions*, 42 *ENVTL. L.* 93, 108–09 (2012) (arguing that climate change requires the adoption of complex

be quite the challenge for legal design, particularly if there are no reliable metrics for assessing how the legal system performs as a complex adaptive system.

C. ETHICAL THEORIES

Some legal complexity theorists have gone beyond descriptive and prescriptive accounts of legal system design to examine the ethical implications of viewing law as a complex adaptive system. As Julian Webb suggests, one might conclude from the descriptive and prescriptive theories that “we have little choice but to accept that the system will organize and adapt itself in the manner most likely to ensure its survival,” and thus “resistance to law is likely to achieve little or no immediate gain.” But Webb offers an alternative to this pessimistic view, arguing that “[c]omplexity . . . emphasizes the distributed nature of power; the inability of any person (or institution) to claim that it exerts control over society.” The upshot of this is that “we have to take responsibility for the effects of all our decisions.”⁸⁰

Exercising that responsibility, argues Webb, implicates three overarching principles. First, an appreciation of legal complexity confirms why “the law delivers justice as much by accident as by design,” but also “encourage[s] emancipatory movements to embrace the uncertainty this provides.”⁸¹ Second, complexity science reveals the interconnectedness of seemingly self-referentially closed social systems, meaning that “a failure to achieve normative consistency between systems will generate system-conflicts.”⁸² Lastly, Webb argues that activating certain ethical values consistent with complex adaptive system behavior, such as altruism, pluralism, and interdependence, will support the maintenance and development of the legal system.⁸³ In short, Webb’s take on the ethical implications of legal complexity calls for polity-wide responsibility and participation in the legal system and a deep reexamination of fundamental ethical notions of power, rights, and rules.⁸⁴ But the question remains: How, exactly, should such ethical principles

adaptive governance systems and that market-based, rather than centrally controlled regulation, will be more adaptive); Cherry, *supra* note 66, at 372 (“An important implication of the complexity theory perspective is that policies of complete federal preemption, and particularly full deregulation, must be approached with great caution.”).

80. Webb, *Law, Ethics, and Complexity*, *supra* note 6, at 238, 241; see also Palma Joy Strand, *Law as Story: A Civic Concept of Law (with Constitutional Illustrations)*, 18 S. CAL. INTERDISC. L.J. 603, 627 (2009) (noting legal complexity means “all the individuals in the society are responsible for the content of law”).

81. Webb, *Law, Ethics, and Complexity*, *supra* note 6, at 239.

82. *Id.*

83. *Id.* at 240; see also CILLIERS, *supra* note 43, at 111 (noting legal complexity requires altruistic and decentralized governance).

84. Webb, *Law, Ethics, and Complexity*, *supra* note 6, at 242 (“Complexity also begs a re-analysis of meta-concepts like ‘rights’ How do we regard (legal) rules that breach our expectations of moral legitimacy?”); see also CILLIERS, *supra* note 43, at 139 (noting in a complex

be operationalized in concert with legal complexity if there is no reliable way of measuring legal complexity?

III. MEASURING LEGAL COMPLEXITY

The descriptive, prescriptive, and ethical theories of legal complexity rely largely on intuition, analogy, and example for their persuasion. This approach has taken the legal complexity project far, but the path has come to an end. What else is there to say about legal complexity that derives from intuition, analogy, and example? Not much. Now that it is developed, the core theory of legal complexity can be used as a lens to examine different fields of law or legal problems, but this leads to little theoretical advancement. Rather, this technique maps the theory onto author-selected contexts and elaborates on why legal complexity is a useful model for understanding how the discrete legal context is operating. To be sure, it is essential when working out a theory to compare hypotheses to the real world by intuition, analogy, and example. If a theory does not cohere at that level, it is probably not worth pursuing. But we believe it is fair to conclude that the theory of legal complexity has been sufficiently tested at this level to confirm it is worth pursuing further. So, what is the next step in that cause?

As with any posited theory, the next step for legal-complexity theory is to respond to the critic's demand for empirical proof (e.g., prove the Tax Code is too complex). Asking that a theory withstand empirical testing is not an idle or obstructionist demand. Particularly when normative claims are based on a theory, those making the claims should be expected to offer support beyond mere elegance or intuitive appeal. If one believes legal complexity imposes constraints on the legal system or, conversely, that it opens up tremendous opportunities, one should want to know when, where, and by how much complexity activates those conditions. And if one believes legal complexity justifies using adaptive approaches to respond to those constraints, when, where, and through what means should the law be adaptive? If the quality and quantity of legal complexity matters for either of those questions, how are the quality and quantity of legal complexity measured and described? These are questions one should naturally ask of legal-complexity theorists making normative claims about what the theory means for legal-system design and behavior. If the theory is to produce answers to such questions, legal-complexity theorists must initiate an empirical phase of study.

The first step in such an undertaking is to design and field test a set of relevant system metrics and methods to measure legal complexity. Unfortunately, complexity science has arrived at no standard kit of metrics or

legal system, “[t]o behave ethically means not to follow rules blindly—to merely calculate—but to follow them responsibly, which may imply that the rules must be broken”).

methods, but a synthesis of various accounts by complexity scientists,⁸⁵ and by the few legal scholars (including one of us) that have explored legal complexity empirics,⁸⁶ suggests several dominant themes we believe will be most useful for studying legal complexity. We divide these into a system-structure set and a system-behavior set.

A. COMPLEXITY AND SYSTEM STRUCTURE

1. Agents and Agent Sets: Composition, Classification, and Diversity

Complex systems' development and evolution can be described as an "ecosystem."⁸⁷ This archetype is a useful descriptor of the rich and complex dynamics underlying law's evolution. However, in order to advance such statements beyond mere metaphor, it is necessary to retrofit and apply rigorous tools from appropriate intellectual domains such as systems ecology, physics, biology, and complex systems. One threshold step in the process of characterizing the broader landscape is to identify all potential agents whose individual behavior might impact the collective behavior of the broader system.

The law, like other complex adaptive systems, exhibits a diversity of agents and agent sets.⁸⁸ The set of all potential agents is vast and includes institutions (i.e., courts, legislatures, administrative agencies, corporations, public interest organizations, etc.); individual actors (i.e., judges, legislators, lobbyist, bureaucrats, etc.); and the law itself (i.e., rules, adjudications, decisions, etc.).

Individual agents often belong to agent sets and those agent sets can themselves be nested within broader agent sets. The nested nature of agent sets is an important complication that must be confronted in the process of deconstructing and measuring legal complexity. At the same time, such theoretic representations of the respective agent sets can be a useful manner through which to begin exploring the operation and dynamics of the respective complex adaptive system.

85. In addition to the numerous references cited in following footnotes, see generally MITCHELL, *supra* note 7, at 94–111; and Carlos Gershenson & Nelson Fernández, *Complexity and Information: Measuring Emergence, Self-Organization, and Homeostasis at Multiple Scales*, 18 COMPLEXITY 29 (2012).

86. See, e.g., Michael J. Bommarito & Daniel M. Katz, *A Mathematical Approach to the Study of the United States Code*, 389 PHYSICA A 4195 (2010); Katz & Bommarito, *supra* note 17; Daniel M. Katz & Derek K. Stafford, *Hustle and Flow: A Social Network Analysis of the American Federal Judiciary*, 71 OHIO ST. L.J. 457 (2010); see also Romain Boulet et al., *Network Analysis of the French Environmental Code*, in AI APPROACHES TO THE COMPLEXITY OF LEGAL SYSTEMS 39 (Pompeu Casanovas et al. eds., 2010).

87. See, e.g., Peter K. Yu, *Intellectual Property and the Information Ecosystem*, MICH. ST. L. REV. 1 (2005).

88. See *supra* Part II.A.

With the basic identification step in place, an agent-centric metric thus would classify the respective legal agent sets by segmenting them and placing them in a broader taxonomy of agents and agent sets. This classification step is itself complex because it requires the development of categories whose boundaries are typically difficult to cleanly segment. Additionally, the categories themselves usually require a researcher or other interested party to engage in some form of dimension reduction.⁸⁹

The set of agents may be (and often is) quite diverse. There is a variety of measures to assess the diversity of a particular set of agents and agent sets. Both an absolute and comparative question, an agent-centric diversity measure could illuminate a variety of interesting research questions. In addition to evaluating individual time slices, an agent diversity measure which identifies temporal changes in the diversity of the respective agent set could actually highlight other important changes in the evolution of the broader law or law-generating process.

2. Formal Architecture: Trees and Other Formal Hierarchies

The sheer number of agents offers just a partial characterization of the overall complexity of a given complex adaptive system. Agents are connected in a variety of ways, including by formal architectures that serve specific purposes and functions. Formal architecture is an important default proposition for any complex system, helping set some contours of its performance and offering a partial description of its behavior and topology.

Formal hierarchical architecture is typically represented in a structure known as a tree. Trees are a well-studied mathematical structure that can be “widely used as [graphs or] data structures in computer science.”⁹⁰ Trees are comprised of nodes which are connected by branches. Conceptualized as a graph, a tree is a connected, undirected graph with no simple circuits. Direction only flows one way; each node and branch is associated with a level, with levels starting at the root node and terminating at the leaf nodes. These are important features that distinguish a tree from other graphs (such as those typically studied in network science).

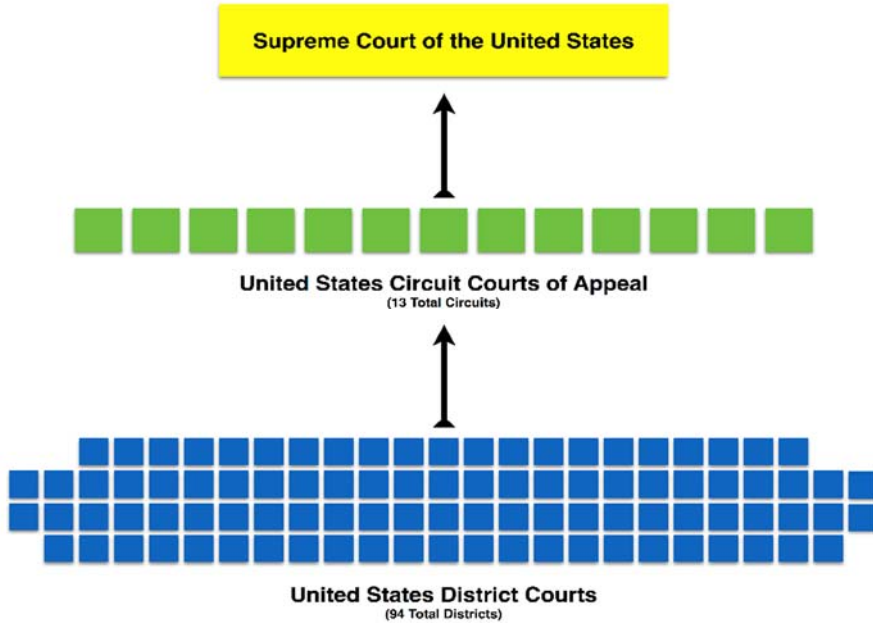
Typically the byproduct of system designers or instantiated by formal rules, tree-based architecture is designed to serve important functions. Those functions might be institutional or they might serve as a means to help make sense of a given system’s complexity.

89. For anything other than a trivial problem, the mapping from n dimensional space to a smaller dimensional space (typically 2D or 3D space) represents some loss of information. The question is, how much? This depends upon how much loading there is on the initial dimensions.

90. See Joe Malkevitch, *Trees: A Mathematical Tool for All Seasons*, AM. MATHEMATICAL SOC’Y: FEATURE COLUMN, <http://www.ams.org/samplings/feature-column/fcarc-trees> (last visited Sept. 14, 2015); see also Eric W. Weisstein, *Tree*, WOLFRAM MATHWORLD, <http://mathworld.wolfram.com/Tree.html> (last visited Sept. 14, 2015).

For an institutional example, consider the American federal judiciary. The federal judiciary features a formal hierarchy of judges and judicial staff whose collective behavior help shape “the path of the law.”⁹¹ The basic formal hierarchy is memorialized in the formal multi-tier structure that begins with federal magistrate judges and terminates with the United States Supreme Court. Figure 1 offers a simple version of this formal tree-based hierarchy.

Figure 1. The Federal Judicial Hierarchy

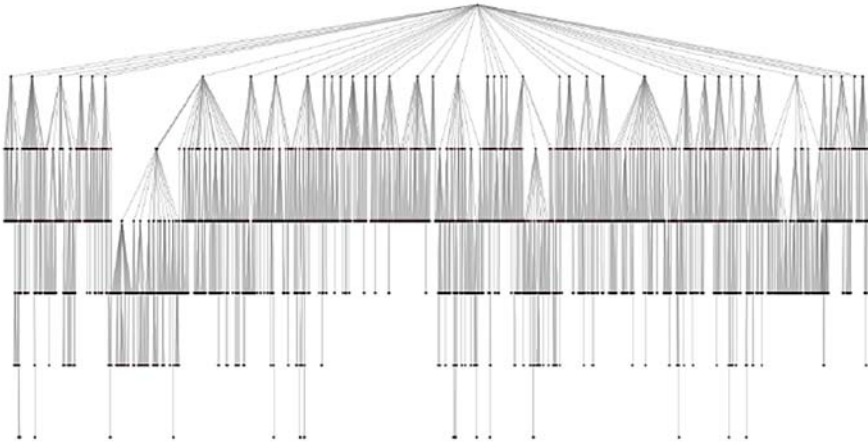


For a similar case, consider the well-known West Key Number System. As displayed in Figure 2, the West Key Number System is a tree-based architecture designed to categorize the space of legal concepts. This is a hierarchical method of organizing the law into categories that make it easier for actors inside the legal system to understand and navigate it. In Figure 2, higher-order legal concepts are located above lower level concepts. Those seeking to learn about a narrow question can both identify directly relevant information as well as learn about surrounding higher level ideas under which their discrete question is located. Like all taxonomies, these categories are obviously not hermetic, and an alternative structure could potentially be developed. However, the existing divisions in a taxonomy such as the West Key Number System point to the sort of latent organizational structure that many hold in their minds (even if it is never formalized). Although it is a proxy to the question, the complexity of this structure illustrates the

91. See generally Oliver Wendell Holmes, Jr., *The Path of the Law*, 10 HARV. L. REV. 457 (1897).

complexity of the conceptual space being modeled as more distinctions in the law generate greater and greater numbers of potential category distinctions.

Figure 2. West Key Number System



For both of these examples, as well as for other tree-based hierarchies, the goal is to develop appropriate measures that allow a researcher to characterize the complexity of the respective space.⁹² In terms of metrics, simple measures such as tree depth can highlight the level of intricacy present in a given architecture.⁹³ The ratio between the breadth (i.e., width) and depth (i.e., flatness) of a tree can illuminate the extent of hierarchy present in a given context. For example, the width of a tree might indicate the grouping of a highly diverse set of objects that cannot otherwise be combined in the nested categories. One potentially interesting set of measures would center upon the inequality and stratification within and across various agent sets. What is the average distance between each leaf node and the root node of the tree? One could also consider other moments (e.g., variance, skewness, and kurtosis) of that distribution as it would illuminate other properties of the nature of authority in the broader complex system.

92. In a real sense, taxonomies such as the West Key Number System help partially represent the law's phylogenetic structure. The complexity of such trees can also be leveraged in a variety of scientific inquiries. See, e.g., Louis J. Billera et al., *Geometry of the Space of Phylogenetic Trees*, 27 *ADVANCES APPLIED MATHEMATICS* 733 (2001); John P. Huelsenbeck & Fredrik Ronquist, *MRBAYES: Bayesian Inference of Phylogenetic Trees*, 17 *BIOINFORMATICS* 754 (2001); Hasan H. Otu & Khalid Sayood, *A New Sequence Distance Measure for Phylogenetic Tree Construction*, 19 *BIOINFORMATICS* 2122 (2003).

93. In principle, it could cut either way. However, in general, the distinctions might be helpful in understanding, or they may make it harder to understand the overall complex system.

3. Network Architecture: Emergent Hierarchies

Complex system architectures take on a variety of flavors and complex adaptive systems exhibit multi-scalar hierarchies, organizations, and other structural forms within which the agents are distributed.⁹⁴ As a matter of system evolution, there are two forces typically in constant operation—forces building up hierarchies and forces operating to tear those very hierarchies down. At any given moment, these countervailing dynamics operate to yield different kinds of observed structures.

The tree conception has some important limitations, but many limitations are overcome by considering the interconnectedness (network) that exists between respective objects. As recently noted, “hierarchies emerge and occur widely in self-organizing and evolutionary systems, such as food webs (ecological), neural networks (biological), open-source software (technological), and industrial production networks (economic).”⁹⁵ This is equally applicable to describing legal systems.⁹⁶ Hierarchy is a fundamental feature of legal systems, but the nature of that hierarchy is likely to vary across particular agents and agent sets.

Hierarchies are typically not the byproduct of a random process. Quite the opposite, their forms are the consequence of specific underlying generating dynamics. While hierarchies can be the byproduct of choices by system designers, they more commonly emerge as a result of actions undertaken by agents. Thus, observed system architecture is usually not the function of top-down choices made by a system designer, but rather the aggregate byproduct of bottom-up decisions offered by various agents and agent sets. Thus, in addition to the formal hierarchies discussed above, there are emergent hierarchies that develop through a series of micro-choices made by the respective actors. Such emergent hierarchies operate alongside any nominal hierarchy that might also exist, thereby confounding one’s ability to understand the dynamics and predict the behavior of a given system.

Consider again the federal judiciary. The formal tree-based hierarchy displayed in Figure 1 does not fully capture the true state of social and professional authority carried by the respective agents. Although judges at each level of the federal judiciary hierarchy would appear to possess equal

94. For various examples, see generally Stefano Boccaletti et al., *Complex Networks: Structure and Dynamics*, 424 PHYSICS REP. 175 (2006); Phillip Bonacich, *Power and Centrality: A Family of Measures*, 92 AM. J. SOC. 1170 (1987); David A. Lake, *Escape from the State of Nature: Authority and Hierarchy in World Politics*, 32 INT’L SECURITY 47 (2007); Joel M. Podolny & Karen L. Page, *Network Forms of Organization*, 24 ANN. REV. SOC. 57 (1998); and M. Puck Rombach et al., 74 SIAM J. ON APPLIED MATHEMATICS 167 (2014).

95. Jianxi Luo & Christopher L. Magee, *Detecting Evolving Patterns of Self-Organizing Networks by Flow Hierarchy Measurement*, 16 COMPLEXITY 53, 53 (2011).

96. See *supra* text accompanying note 91.

levels of authority, the social authority of these jurists is far from equal.⁹⁷ While each jurist's decisions are important to the individual litigators that appear before the judge, most judges cannot be said to have a lasting and prolonged effect on the development of the law. Indeed, "[e]ven a casual observer would recognize that although many jurists' views are quickly forgotten, the views of a selected few persist."⁹⁸ Whether one agrees with their particular decisions, it is difficult to deny the distinct and lasting legacies of federal judges such as Learned Hand, Jerome Frank, Henry Friendly, Richard Posner, Abner Mikva, and J. Skelly Wright as well as Supreme Court Justices such as Oliver Wendell Holmes, John Marshall, Earl Warren, Roger Taney, Louis Brandeis, and Joseph Story.

Figure 3 offers a partial picture of the informal, network-based hierarchy present in the federal judiciary. Consistent with the coloring offered in Figure 1 above, yellow nodes are members of the Supreme Court of the United States, green nodes are members of the United States Court of Appeals, and blue nodes are United States District Court judges. Edges are built from the flow of law clerks from one jurist to another.⁹⁹ A simple ocular review reveals a structure that is far from a random graph. This is a portrait of inequality, and that inequality is a function of several micro-level choices made by individual jurists. These choices yield a social structure where some jurists' social authority far outstrips their formal rank. As such, they may exert more social control than a jurist who is normally ranked above them. In other words, there are certain district court judges whose social authority appears to outstrip at least some of their circuit court counterparts. It also leads one to consider provocative questions such as whether well-known circuit court judges such as Richard Posner have more authority over the long term development of the law than some justices on the United States Supreme Court. Of course, Figure 3 offers only a snapshot of the social structure of the American federal judiciary at a given moment in time. The landscape is dynamic and the prestige hierarchy shifts. "[R]eputation effects, esteem, prestige, and influence are undoubtedly generated through dynamic processes that include negative and positive feedback."¹⁰⁰

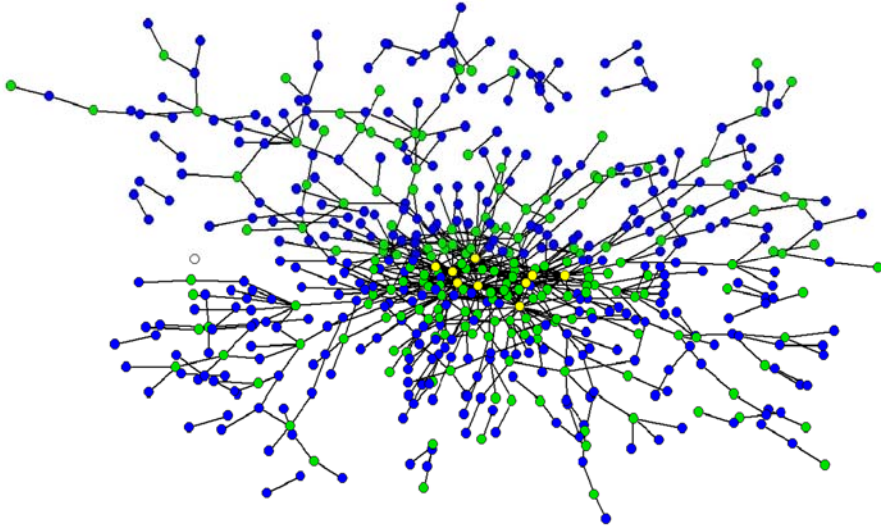
97. Our best understanding is that the authority follows some form of extremely skewed distribution (i.e., power, law, etc.).

98. See Katz & Stafford, *supra* note 86, at 461–62 n.10.

99. *Id.* at 461.

100. *Id.*

Figure 3. The Emergent Federal Judicial Social Structure



One way to formalize this emergent architecture is through the tools of network science (applied graph theory).¹⁰¹ Networks consist of nodes that can, for example, in the simple case represent actors, institutions, and documents. The connections between these nodes are represented by edges (bidirectional) or arcs (unidirectional). Such connections can memorialize simple binary {0, 1} connections or can be weighted to represent far more sophisticated types of relationships. Network science is among the fastest growing fields in all of science and includes scholarship in wide-ranging

101. See generally ALBERT-LÁSZLÓ BARABÁSI, LINKED: HOW EVERYTHING IS CONNECTED TO EVERYTHING ELSE AND WHAT IT MEANS FOR BUSINESS, SCIENCE, AND EVERYDAY LIFE (2003); DUNCAN J. WATTS, SIX DEGREES: THE SCIENCE OF A CONNECTED AGE (2003); David Lazer et al., *Life Computational Social Science*, 323 *SCI.* 721 (2009).

disciplines such as physics,¹⁰² sociology,¹⁰³ political science,¹⁰⁴ public health,¹⁰⁵ economics,¹⁰⁶ and law.¹⁰⁷

The application of network-science tools to legal systems has revealed some interesting and illuminating patterns. The law's most well-studied form of emergent architecture is a documented tendency of legal systems and agents to display self-similar, or fractal, properties.¹⁰⁸ This tendency extends

102. See, e.g., Albert-László Barabási, *Network Science*, 371 PHIL. TRANSACTIONS ROYAL SOC. 1 (2013); Albert-László Barabási & Reka Albert, *Emergence of Scaling in Random Networks*, 286 SCI. 509 (1999); Michael J. Bommarito, Daniel Martin Katz, Jonathan Zelner & James Fowler, *Distance Measures for Dynamic Citation Networks*, 389 PHYSICA A 4201 (2010); M. Girvan & M.E.J. Newman, *Community Structure in Social and Biological Networks*, 99 PROC. NAT'L ACAD. SCI. 7821 (2002); Duncan J. Watts & Stephen H. Strogatz, Letter, *Collective Dynamics of 'Small-World' Networks*, 393 NATURE 440 (1998).

103. See, e.g., RONALD S. BURT, STRUCTURAL HOLES: THE SOCIAL STRUCTURE OF COMPETITION (1995); Mark Granovetter, *The Strength of Weak Ties*, 78 AM. J. SOC. 1360 (1973); Stanley Milgram, *The Small-World Problem*, 1 PSYCHOL. TODAY 61 (1967); John Padgett & Christopher K. Ansell, *Robust Action and the Rise of the Medici, 1400–1434*, 98 AM. J. SOC. 1259 (1993).

104. See, e.g., Lada A. Adamic & Natalie Glance, *The Political Blogosphere and the 2004 U.S. Election: Divided They Blog*, 3 INT'L WORKSHOP ON LINK DISCOVERY 36 (2005); James H. Fowler, *Connecting the Congress: A Study of Cosponsorship Networks*, 14 POL. ANALYSIS 456 (2006).

105. See, e.g., Lisa F. Berkman & Thomas Glass, *Social Integration, Social Networks, Social Support, and Health*, in SOCIAL EPIDEMIOLOGY 137 (Lisa F. Berkman & Ichiro Kawachi eds., 2000); Nicholas A. Christakis & James H. Fowler, *The Collective Dynamics of Smoking in a Large Social Network*, 358 NEW ENG. J. MED. 2249 (2008); Jonathan L. Zelner et al., *Social Connectedness and Disease Transmission: Social Organization, Cohesion, Village Context, and Infection Risk in Rural Ecuador*, 102 AM. J. PUB. HEALTH 2233 (2012).

106. See, e.g., Daron Acemoglu et al., *Bayesian Learning in Social Networks*, 78 REV. ECON. STUD. 1201 (2011); Antoni Calvo-Armengol & Matthew O. Jackson, *The Effects of Social Networks on Employment and Inequality*, 94 AM. ECON. REV. 426 (2004); Benjamin Golub & Matthew O. Jackson, *How Homophily Affects the Speed of Learning and Best-Response Dynamics*, 127 Q.J. ECON. 1287 (2012); Sanjeev Goyal et al., *Economics: An Emerging Small World*, 114 J. POL. ECON. 403 (2006); Sanjeev Goyal & Fernando Vega-Redondo, *Structural Holes in Social Networks*, 137 J. ECON. THEORY 460 (2007); Dunia López-Pintado, *Diffusion in Complex Social Networks*, 62 GAMES & ECON. BEHAV. 573 (2008); Adalbert Mayer & Steven L. Puller, *The Old Boy (and Girl) Network: Social Network Formation on University Campuses*, 92 J. PUB. ECON. 329 (2008).

107. See, e.g., James Fowler et al., *Network Analysis and the Law: Measuring the Legal Importance of Precedents at the U.S. Supreme Court*, 15 POL. ANALYSIS 324 (2007); Katz & Stafford, *supra* note 86; Katz et al., *supra* note 50; Post & Eisen, *supra* note 67; Thomas A. Smith, *The Web of the Law*, 44 SAN DIEGO L. REV. 309 (2007); Katherine J. Strandburg et al., *Law and the Science of Networks: An Overview and an Application to the 'Patent Explosion'*, 21 BERKELEY TECH. L.J. 1293 (2007); Katherine J. Strandburg et al., *Patent Citation Networks Revisited: Signs of a Twenty-First Century Change?*, 87 N.C. L. REV. 1657 (2009).

108. See Daniel Martin Katz, *How Long is the Coastline of the Law: Additional Thoughts on the Fractal Nature of Legal Systems [Repost]*, COMPUTATIONAL LEGAL STUD. (May 13, 2011), <http://computationallegalstudies.com/2011/05/13/how-long-is-the-coastline-of-the-law-additional-thoughts-on-the-fractal-nature-of-legal-systems-repost>.

Fractal geometry was developed in a set of classic papers by the late mathematician Benoît Mandelbrot. The original paper in the field *How Long is the Coastline of Britain* describes the coastline measurement problem. In short form, the length of the coastline is a function of the size of measurement one employs. . . . As a first-order description of one important dynamic of the common law, we believe significant

to a wide variety of contexts, including cases, judges, law schools, and law review articles. The implications for legal theory are significant. One important implication is that distance between those cases, judges, law schools, and law review articles are highly nonlinear. Focusing upon the cases and judges, the distance between an emergent case or judge and the average case or judge is extremely large. Indeed, as documented in the literature, the social distance is actually exponential.¹⁰⁹

Consider the judicial decision-making and opinion-authorship process. Although formal hierarchies exist in the law such as the state or federal judicial hierarchy, day-to-day decision-making in legal systems is actually fairly decentralized. Individual actors can, in principle, reference whatever relevant cases and other sources they choose. Despite such broad discretion, actors tend to disproportionately gravitate to small numbers of cases that are consistently cited. This micro-tendency toward the familiar and the already well regarded yields a macro-prestige hierarchy that is extremely skewed (i.e., its degree distribution roughly follows a power law). Sometimes called the “Mathew effect,” the “80/20 rule,” or the “rich-get-richer phenomenon,” power laws as well as other related skewed distributions are indicative of highly uneven social processes. Those with initial resources are able to rapidly extend that advantage. As displayed in Figure 4, complex systems scholars have documented this trend across a variety of legal systems and associated legal institutions. Consider the case of judicial citations. While a small number of cases are consistently cited, roughly half of the written decisions in American law have never been cited more than once.¹¹⁰ Figure 4 offers evidence of a similar phenomenon across a variety of contexts.¹¹¹

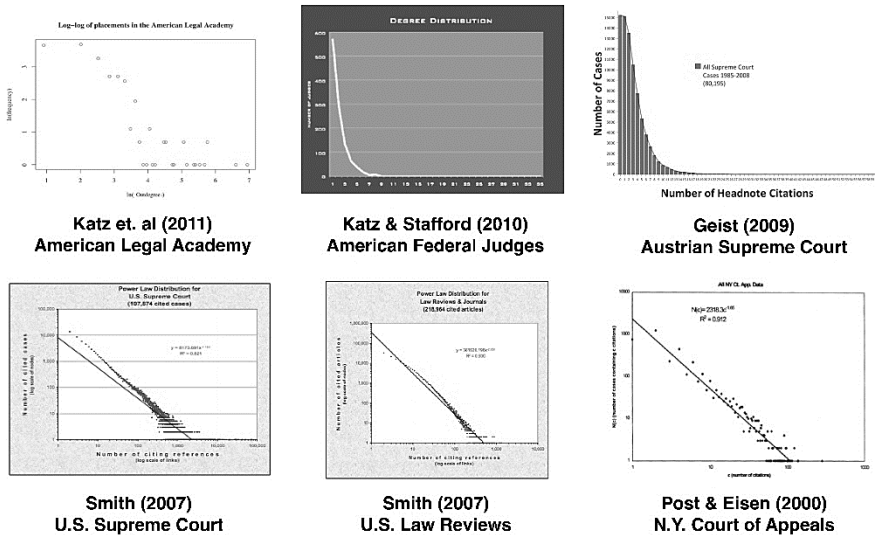
progress can be made by considering the conditions under which legal systems behave in a manner similar to fractals. [Indeed,] a number of important papers have discussed the fractal nature of legal systems.

Id.

109. See Katz & Stafford, *supra* note 86; Post & Eisen, *supra* note 67; Smith, *supra* note 107; see also *supra* note 108 and accompanying text.

110. See Smith, *supra* note 107.

111. In each of the plots in Figure 4, the *x*-axis plots the *quantity* (i.e., number of times cited) and the *y*-axis plots the *frequency* of that particular quantity throughout the data.

Figure 4. Skewed Distribution of Social Authority in Legal Systems¹¹²

Beyond the degree distribution, there are a large number of commonly used statistics used to characterize the properties of a given network (graph).¹¹³ These statistics include macro-level statistics, such as average path length, clustering coefficients, and density, as well as micro-level statistics such as degree, closeness, betweenness, and other related authority measures. Also interesting are the mesoscopic graph measures that allow for the identification and tracking of particular subgroups and subgraphs (loosely called communities). These measures, along with others, can help form the basis for more sophisticated composite measures of overall system complexity.

Legal-complexity theorists need more documentation and a far more extensive scientific exploration of these questions. The age of armchair theorizing must give way to a new reality with legal theorists applying appropriate metrics to help better substantiate their respective claims. The good news is that, with respect to measuring legal systems as complex systems, legal theorists do not have to go it alone. Scholars in the social, biological, and physical sciences have developed methods designed to measure the

112. Katz et al., *supra* note 50, at 95 fig.5; Katz & Stafford, *supra* note 86, at 498 fig.5; Post & Eisen, *supra* note 67, at 574 fig.11; Smith, *supra* note 107, at 329 fig.8, 335 fig.12; Anton Geist, Using Citation Analysis Techniques for Computer-Assisted Legal Research in Continental Jurisdictions 82 fig.4 (Sept. 2009) (unpublished LLM thesis, University of Edinburgh), <https://www.era.lib.ed.ac.uk/bitstream/handle/1842/3511/GeistLLM2009.pdf?sequence=2>.

113. See generally MATTHEW O. JACKSON, SOCIAL AND ECONOMIC NETWORKS (2008); M.E.J. NEWMAN, NETWORKS: AN INTRODUCTION (2010); THE STRUCTURE AND DYNAMICS OF NETWORKS (Mark Newman et al. eds., 2006).

extent of hierarchy present in a given context.¹¹⁴ The question properly posed is how one might retrofit these existing approaches to identify and measure the persistent and differentiable features present in legal systems. In that vein, there are a variety of potential measurement strategies or metrics one might employ depending upon the specific component or components of the legal system one is interested in studying.

4. Information Storage and Computation

Complex adaptive systems store and process information.¹¹⁵ The agents and architecture described above play an important role in characterizing the operation and flow of information undertaken therein. If trees and networks represent the architecture and agents are the nodes, then information would be the “electrical current” that flows across the respective institutional circuitry. The act of processing the information is computation (broadly construed). This is true whether the complex system is one’s cognitive architecture or the operation of a biological or physical system.

The strongest version of these ideas leads to a claim of universality (i.e., universal computation) whereby every cell, every brain, every person, every society, and even the universe itself can be conceptualized as engaging in computation. In one sense, this is a trivially true statement—every system is engaging in something that might be called computation. However, the nontrivial version of the idea is controversial. What is important to remember is that one need not assent to the concept of universal computation in order to observe the theoretical value of computation as a first-order descriptor of a complex system’s behavior.

In application, legal systems can be conceptualized as computational complex systems—systems that store and process information. As it concerns this storage and processing task, not all computational complex systems are equally complex. Even among otherwise complex systems, there is a spectrum. From the characterization above, two classes of information-centric metrics present themselves: (1) content measures; and (2) computation measures.

A content-centric information measure could consider the amount of information necessary to fully characterize the content stored in the legal

114. See, e.g., Andrea Lancichinetti et al., *Detecting the Overlapping and Hierarchical Community Structure in Complex Networks*, 11 NEW J. PHYSICS 033015 (2009); Enys Mones et al., *Hierarchy Measure for Complex Networks*, 7 PLOS ONE e33799 (2012); Marta Sales-Pardo et al., *Extracting the Hierarchical Organization of Complex Systems*, 104 PROC. NAT’L ACAD. SCI. U.S. 15224 (2007); Huawei Shen et al., *Detect Overlapping and Hierarchical Community Structure in Networks*, 388 PHYSICA A 1706 (2009).

115. See, e.g., HERMANN HAKEN, INFORMATION AND SELF-ORGANIZATION: A MACROSCOPIC APPROACH TO COMPLEX SYSTEMS (3d ed. 2010); DIRK HELBIG, QUANTITATIVE SOCIODYNAMICS: STOCHASTIC METHODS AND MODELS OF SOCIAL INTERACTION PROCESSES (2d ed. 2010); GREGOIRE NICOLIS & CATHERINE NICOLIS, FOUNDATIONS OF COMPLEX SYSTEMS: EMERGENCE, INFORMATION AND PREDICTION (2d ed. 2012); Guido Nolte et al., *Robustly Estimating the Flow Direction of Information in Complex Physical Systems*, 100 PHYSICAL REV. LETTERS 234101 (2008).

system. What is the information content contained in a particular body of legal rules? How complex is the resulting rules set?

Law's complexity is a long-standing social and political issue, and various technologies help lawyers and lay persons confront the sheer volume of information and overall attendant complexity of legal systems. As the saying goes, necessity is the mother of all invention, and the complexity of law has necessitated the development of legal information technology as a rational and necessary response to law's complexity. Even in a pre-computing era, the hornbooks, digests, restatements, and other related legal treatises can be thought of as an early form of legal information technology allowing various end users to better understand the law in a given area. In addition, various indexing systems and other legal taxonomies—such as the West Key Number System discussed above—also represent early forms of legal technology. Again, their use allowed an end user to more quickly assemble the relevant information content contained therein.

A related, but distinct, information measure is a computational measure. Again, the linkage between information technology and the complexity of the law stands ever present. Consider again TurboTax—the popular, consumer-facing tax preparation software mentioned in Part I. From a complexity perspective, TurboTax offers taxpayers a layer between the underlying legal rules and the lived experience on behalf of its users.

More recent developments in legal technology have a similar purpose—reverse-engineering complex legal processes. Consider, for example, the United States Tax Code (Title 26 and its surrounding regulations). As we suggested in Part I, to call the Tax Code “complex” is straightforward and hardly represents some sort of revelation. Indeed, there exists a cottage industry of commentary highlighting this point.¹¹⁶ However, the question is: how do its end users experience that complexity? For many end users, legal technology and its ability to mediate complexity further complicates the picture.

Complexity in the underlying object may or may not project into complexity as experienced by the relevant end user. TurboTax and other competing products offer a technology layer sandwiched between the Code and the experience of the end user. In a very serious sense, this software is a legal user interface. Much like internet browsers shield users from the underlying coding language (e.g., HTML and Java) and processes, tax preparation software shields users from the underlying complexity in the Tax Code. Given this complication, what is the best metric for measuring complexity?

One measure would be of the underlying object—the Tax Code—through methods discussed above. Another metric could evaluate the average experience of an end-user of the Code, such as time to complete, accuracy,

116. See sources cited *supra* note 2.

or satisfaction. Or, as suggested in Part I, one could measure the complexity of the rules and user interface that converts existing legal rules into some sort of an executable program used to perform meaningful functions. In other words, how complex is the software necessary to represent TurboTax? How does this compare to other forms of software that help automate legal knowledge? There exists a series of well-regarded software-complexity measures, including simple measures such as program size, computational complexity, and run-time measures, as well as more complicated measures such as Halstead's complexity measures or McCabe's cyclomatic complexity measures.¹¹⁷ A related measure might consider how much information one needs in order to execute the *average* task and whether that average characterization is informative (i.e., what are statistical properties of that distribution including its variance, skewness, and kurtosis)?

B. COMPLEXITY AND SYSTEM BEHAVIOR

Our interest in legal complexity is in part motivated by our interest in the behavior of the legal system and its predictability. Some basic level of predictability is an obvious and straightforward normative goal for any legal system. The difficulty arises in instances where predictability conflicts with other normative goals, such as fairness and various efforts to ensure that the law evolves to take account of changes in broader society. In the aggregate, various efforts to particularize the law to better distinguish various classes of conduct are one important source of legal complexity. In this context, complexity arguably serves a positive normative purpose. However, each increase in complexity can have unintended consequences including making the overall legal system less transparent and less understandable to lay persons.¹¹⁸

As highlighted herein and across the literature, legal systems are complex adaptive systems. Our desire to predict system-level behavior must be tempered by the realities that are attendant in working with complex adaptive systems. There are real limits in our ability to make forecasts. In the general case discussing the relationship between system complexity and prediction, scholars highlight the distinction between two famous complex systems—tides and weather. Both feature fairly complex dynamics, but from a prediction standpoint, one is easy and the other is hard (in some cases, perhaps, impossible).

For predicting tides, relevant variables include “the Earth’s rotation, the topography of the ocean, and the position of the Moon and the Sun relative

117. See generally Bill Curtis et al., *Measuring the Psychological Complexity of Software Maintenance Tasks with the Halstead and McCabe Metrics*, SE-5 IEEE TRANSACTIONS ON SOFTWARE ENGINEERING 96 (1979); Kearney et al., *supra* note 12.

118. See Katz & Bommarito, *supra* note 17.

to Earth.”¹¹⁹ Significant work by well-regarded mathematicians such as Kelvin, Poincare, and LaPlace yielded a set of rigorous predictions that have been shown to be highly accurate.¹²⁰ In addition, in many instances, tides patterns can be determined well in advance, such that they are printed and distributed in books such as tide tables and used by a variety of end users.

While tides are complex yet predictable, weather systems are complex and often unpredictable.¹²¹ The specific level of predictability depends the dynamics present at a given moment in time. For example, consider forecasting the temperature during the summer months in a desert climate. From a day-over-day perspective, the expected temperature is fairly stable. By contrast, temperate climates are typically more difficult to predict (particularly during seasonal transition periods). During the shift from winter to spring, such temperate climates can experience wide variations in temperature from 25 degrees one day to 75 degrees just a few days later.

The challenge of weather prediction extends beyond just temperature and includes predicting rainstorms and wind patterns. Many scientists have studied weather patterns in the hopes of trying to develop more accurate forecasts. The pioneering work of Edward Lorenz, however, offers a useful caution. Among other things, Lorenz identified how the complex dynamics underlying weather systems made longer term forecasting difficult or impossible.¹²² Indeed, outside a 7- to 14-day window, most weather predictions do not perform much better than an almanac.

Taken as a whole, and in many specific instances, legal systems exhibit properties that make them behave more like weather and less like tides. However, this is merely conjecture (albeit, perhaps, well founded and intuitive conjecture). To better evaluate that proposition requires greater scientific exploration, characterization, and measurement of legal systems and their complexity using appropriate tools.

Despite these real limitations along a variety of dimensions, it is possible to make forecasts about the future behavior of complex systems. Indeed, a core portion of lawyers’ professional judgment includes forecasting uncertain legal environments. In certain instances, complexity makes this task more challenging. The tools used by complex-systems scholars such as networks, trees, and computation, and terms such as emergence, path dependence, feedback, and diffusion can help those embedded in an environment better understand (and hopefully predict) relevant behavior.

119. See Daniel Martin Katz, *Quantitative Legal Prediction—or—How I Learned to Stop Worrying and Start Preparing for the Data Driven Future of the Legal Services Industry*, 62 EMORY L.J. 909, 961 (2013).

120. *Id.*; see also Duncan Watts, *The Dream of Prediction: Why You Should Be Skeptical*, 2011 YEAR REV. BLOG (Dec. 27, 2011, 9:00 PM), <http://2011.yearinreview.yahoo.com/2011/blog/8569/predictions-why-you-should-be-skeptical>.

121. See NATE SILVER, *THE SIGNAL AND THE NOISE: WHY SO MANY PREDICTIONS FAIL—BUT SOME DON’T* (2012); Watts, *supra* note 120.

122. See generally EDWARD N. LORENZ, *THE ESSENCE OF CHAOS* (1995).

1. Networks, Trees, Diffusion, and System Behavior

Complex adaptive systems exhibit information processing, feedback, and feedforward mechanisms producing structural interconnectedness and interdependence between agents throughout the system itself. As discussed earlier, a structural metric would construct a model of the legal system's networked agents and structure, showing all interconnections and interdependencies, and measure the strengths and directions of information feedback and feedforward channels.

From a behavioral standpoint, the structural properties of a given complex system aid in various forms of system prediction. Obviously, there are many scopes at which such a forecast might be offered with the high level (or coarse grained) properties being far easier than lower level (or fine grained) properties. Initially, one can examine the structural properties (trees, networks, information, etc.) and then offer an account of the evolutionary conditions giving rise to the system as observed at time *t*. Further, it is possible to offer a reasonable forecast of its future behavioral properties, as in many instances we care less about the structure of system than the information, signal, or pathogen being distributed across its architecture.

In the context of law, we are interested in the social spread of ideas and paradigms. The development of the common law, for example, is a distributed process. No individual jurist, academic, or lawyer is able to unilaterally impose his or her specific vision of what the law is or what the law ought to be. It is a process of prestige and persuasion—where prestige is a function of one's structural position within a network, and persuasion is about one's ability to use legal argumentation to convince his or her colleagues of the merit of their argument.¹²³ We are interested in the origin, persistence, and ultimate success of various legal ideas, doctrines, and paradigms. In law, as in many other pursuits, there exists a marketplace for ideas where most ideas do not persist. However, some do. An important question is why do some persist and others fade?¹²⁴

With a reasonable understanding of the current and future structure in place, it is possible to study the flow and spread of ideas and paradigms using the tools of social epidemiology.¹²⁵ Among other things, social epidemiology and social physics is the study of how various social structures impact the spread or persistence of various ideas.¹²⁶ Like very contagious pathogens,

123. These themes are explored in some recent work in political science. See, e.g., LAWRENCE BAUM, *JUDGES AND THEIR AUDIENCES: A PERSPECTIVE ON JUDICIAL BEHAVIOR* (2006).

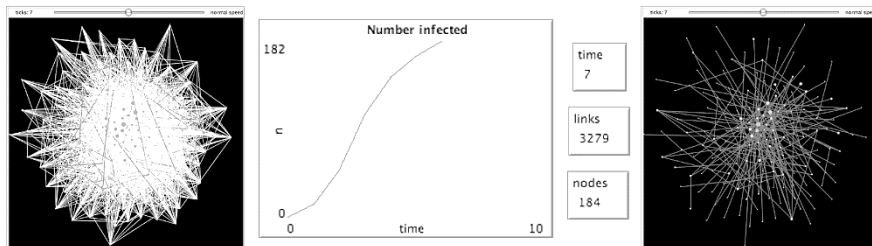
124. For an exploration of these questions, see Katz et al., *supra* note 50.

125. Obviously one must remain mindful of Laplace's Demon as described *infra* Part III.B.2.

126. See generally ALEX PENTLAND, *SOCIAL PHYSICS: HOW GOOD IDEAS SPREAD—THE LESSONS FROM A NEW SCIENCE* (2014); Luís M.A. Bettencourt et al., *The Power of a Good Idea: Quantitative Modeling of the Spread of Ideas from Epidemiological Models*, 364 *PHYSICA A* 513 (2006).

transformative ideas tend to win out while poor ideas rarely catch fire.¹²⁷ However, there is a large intermediate class of ideas whose fate can be said to be contingent. If those without social authority do not embrace the idea, it will not persist (even if it is superior to its alternatives). For those classes of ideas, structure matters. Structure drives system behavior in a way yet to be fully appreciated by legal theorists.¹²⁸

Figure 5. Diffusion of Paradigms on the American Law Professoriate



In order to offer a concrete implementation of these ideas, Figure 5 offers a hypothetical diffusion simulation across the American law professoriate where the displayed structure maps the relationship between where an individual professor attended law school and the institution where that individual now teaches.¹²⁹ Tracing across that structure is a hypothetical idea (pathogen) with some underlying level of infectiousness. High-infectiousness ideas always spread and low-infectiousness ideas do not spread, but the intermediate class of ideas are far more likely to succeed if they emanate or are quickly adopted by institutions with high social standing.

127. See generally ANDREW CHESTERMAN, MEMES OF TRANSLATION: THE SPREAD OF IDEAS IN TRANSLATION THEORY (1997); Susan Blackmore, *The Power of Memes*, 283 SCI. AM. 64 (2000). For application in law, see generally Thomas F. Cotter, *Memos and Copyright*, 80 TUL. L. REV. 331 (2005); Simon Deakin, *Evolution for our Time: A Theory of Legal Memetics*, 55 CURRENT LEG. PROBS. 1 (2003); Michael S. Fried, *The Evolution of Legal Concepts: The Memetic Perspective*, 39 JURIMETRICS 291 (1999); and Daniel Martin Katz et al., *Legal N-Grams? A Simple Approach to Track the 'Evolution' of Legal Language*, JURIX PROC. (2011).

128. There have been some case studies of this phenomenon documented by the “historical institutionalists.” They highlight various sociopolitical mechanisms responsible for the lock-in of historically questionable narratives. See, e.g., PAMELA BRANDWEIN, RECONSTRUCTING RECONSTRUCTION: THE SUPREME COURT AND THE PRODUCTION OF HISTORICAL TRUTH (1999); BARRY CUSHMAN, RETHINKING THE NEW DEAL COURT: THE STRUCTURE OF A CONSTITUTIONAL REVOLUTION (1998); HOWARD GILLMAN, THE CONSTITUTION BESIEGED: THE RISE AND DEMISE OF LOCHNER ERA POLICE POWERS JURISPRUDENCE (1993); MARK A. GRABER, TRANSFORMING FREE SPEECH: THE AMBIGUOUS LEGACY OF CIVIL LIBERTARIANISM (1991); Pamela Brandwein, *A Judicial Abandonment of Blacks? Rethinking the “State Action” Cases of the Waite Court*, 41 L. & SOC’Y REV. 343, 374-75 (2007). However, none of this work offers a rigorous and generalizable model for the underlying phenomenon.

129. This structure is an empirically derived snapshot drawn from Katz et al., *supra* note 50.

Similar approaches attempting to marry empirical phenomena to theoretical models would significantly advance our understanding of the complex socio-political ecosystem driving the development of the law. These would include the social spread of various legal ideas across the judiciary, the diffusion of policies in a legislative and executive context, and further work on the impact of law school socialization on the long-term development of the law.

2. Emergence, Feedback, Laplace's Demon, and System Prediction

With all we currently know and all we might know about the operation of any given system, it is all too tempting to overstate our ability to forecast its behavior. In his book, *A Philosophical Essay on Probabilities*, the renowned French mathematician Pierre-Simon Laplace fell victim to the trap of determinism, or what has been called by many "Laplace's Demon."¹³⁰ Loosely speaking, Laplace argued that, if someone knew the precise location and momentum of every atom in the universe, their past and future values for any given time could be precisely calculated using the laws of classical mechanics.¹³¹ In a sense, Laplace was offering a strong case of modernist thinking.

Of course, this specific line of thinking has been thoroughly discredited through the work of Heisenberg, Mandelbrot, Lorenz, and many others.¹³² As discussed earlier, what Lorenz demonstrated about weather is more broadly applicable to the behavior of other complex adaptive systems (including the law). In a real sense, complex systems is a discipline anchored to postmodern thinking. However, unlike much of the work done under the umbrella of postmodernism, it is actually rigorous. The discipline also has the benefit of actually building positive knowledge (as opposed to merely demonstrating what we do not know). Among other things, complex-systems scholars have

130. For a discussion of Laplace's Demon, see generally Michael Shermer, *Exorcising Laplace's Demon: Chaos and Antichaos, History and Metahistory*, 34 *HIST. & THEORY* 59 (1995); and Marcel Weber, *Determinism, Realism, and Probability in Evolutionary Theory*, 68 *PHIL. SCI.* 213 (2001).

131. See PIERRE-SIMON LAPLACE, *A PHILOSOPHICAL ESSAY ON PROBABILITIES* 4 (photo. reprinted 2007) (F.W. Truscott & F.L. Emory trans., 1901).

We ought then to regard the present state of the universe as the effect of its anterior state and as the cause of the one which is to follow. Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it—an intelligence sufficiently vast to submit these data to analysis—it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes.

Id.

132. See generally LORENZ, *supra* note 122; BENOIT B. MANDELBROT & RICHARD L. HUDSON, *THE (MIS)BEHAVIOR OF MARKETS: A FRACTAL VIEW OF RISK, RUIN, AND REWARD* (2006).

identified two major dynamics that frustrate our ability to predict system behavior: (1) feedback; and (2) emergence.

i. Feedback

There are two basic forms of feedback every system generates. *Negative feedback* systems tend toward stability over time as a change in the variable being considered brings about some sort of contrary response that moves that variable in the opposing direction.¹³³ For example, heat applied to a cup of coffee is not stable because it will slowly cool through a process of negative feedback until it reaches equilibrium at room temperature. Standard models of social, economic, and political sciences tend to emphasize the equilibrium properties of a given phenomenon. As a first-order description of the relevant dynamics, such characterizations tend to perform fairly well. However, they are missing an important source of system behavior—positive feedback.

In systems that display *positive feedback*, small changes get amplified because they run in the direction that the systems are already moving (or they are able to permanently push the system in that direction).¹³⁴ Positive feedback systems are sensitive to initial conditions where small changes get amplified. Herds, bubbles, avalanches, cascades, and network effects are empirically observable phenomena whose theoretical origins are linked to various forms of positive feedback. The skewed distribution of social authority displayed earlier in Figure 4 is the byproduct of positive feedback.

Understanding this dynamic informs future predictions of system behavior. On average, across all of its respective agents, the law is a system rapidly moving in the direction of social-authority inequality. Without a significant change in the underlying dynamics, law is a complex system that currently features (and will continue to feature) positive feedback and large amounts of social-authority inequality among cases,¹³⁵ judges,¹³⁶ law reviews,¹³⁷ law schools,¹³⁸ and other related social institutions.

ii. Emergence

Another important source of frustration is the tendency of complex systems to display emergent behavior. Complex adaptive systems produce emergent-scale behavior that is sometimes incapable of being understood

133. See *Feedback Loops*, STARTING POINT: TEACHING ENTRY LEVEL GEOSCIENCE, <http://serc.carleton.edu/introgeo/models/loops.html> (last visited Sept. 15, 2015).

134. *Id.*

135. See Smith, *supra* note 107, at 325–34. See generally Post & Eisen, *supra* note 67.

136. See Katz & Stafford, *supra* note 86.

137. See Smith, *supra* note 107, at 355.

138. See Katz et al., *supra* note 50.

except through system-wide study.¹³⁹ There is not complete agreement about the conditions giving rise to emergent phenomena. In general, however, systems display emergence when the micro-study of individual actors in a given system yields incomplete information about the entirety of the organization.¹⁴⁰ Instead, interactions between the components help structure the outputs of the given system. These themes are well articulated in classic treatments such as *Micromotives and Macrobehavior* by Thomas Schelling,¹⁴¹ and *Emergence: From Chaos to Order* by John Holland.¹⁴² As Peter Corning describes, “[a]mong other things, complexity theory gave mathematical legitimacy to the idea that processes involving the interactions among many parts may be at once deterministic yet for various reasons unpredictable.”¹⁴³

There is a variety of examples of emergent behavior in social and physical systems, including ecosystems, where order emerges from the interspecies interactions, the phase transition of various chemicals, and the rise of fads and other cultural cascades. Some such systems seem mundane but are nonetheless emergent:

Automobile traffic is another example of a complex system. To characterize the global properties of a traffic system, one could code a set of individual-level variables, including the horsepower of the respective vehicles, the disposition of the drivers, and a host of decisional rules employed by the driver, including the leave space and a driver’s ideal speed and lane. Even with an understanding of all of these properties, it is ultimately the interactions between actors that structure outputs for the overall system. Whether flow or bottleneck will emerge is a function of the intermingling of individuals, each of whom possesses a host of these attributes and decisional rules. Thus, it depends upon the precise spatial distribution of agents and the nature of their local interactions.¹⁴⁴

139. See, e.g., JOSHUA M. EPSTEIN & ROBERT AXTELL, *GROWING ARTIFICIAL SOCIETIES: SOCIAL SCIENCE FROM THE BOTTOM UP* 1–2 (1996). See generally STEVEN JOHNSON, *EMERGENCE: THE CONNECTED LIVES OF ANTS, BRAINS, CITIES, AND SOFTWARE* (2002).

140. See Tom De Wolf & Tom Holvoet, *Emergence Versus Self-Organisation: Different Concepts but Promising When Combined*, in *ENGINEERING SELF-ORGANIZING SYSTEMS: METHODOLOGIES AND APPLICATIONS* 3 (Sven A. Brueckner et al. eds., 2005) (“A system exhibits emergence when there are coherent emergents at the macro-level that dynamically arise from the interactions between the parts at the micro-level. Such emergents are novel [with respect to] the individual parts of the system.”); see also David J. Chalmers, *Strong and Weak Emergence*, in *THE RE-EMERGENCE OF EMERGENCE: THE EMERGENTIST HYPOTHESIS FROM SCIENCE TO RELIGION* 245 (Philip Clayton & Paul Davies eds., 2006).

141. See generally THOMAS C. SCHELLING, *MICROMOTIVES AND MACROBEHAVIOR* (1978).

142. See generally JOHN H. HOLLAND, *EMERGENCE: FROM CHAOS TO ORDER* (1998).

143. Peter A. Corning, *The Re-Emergence of “Emergence”: A Venerable Concept in Search of a Theory*, 7 *COMPLEXITY* 18, 21 (2002).

144. See Katz & Stafford, *supra* note 86, at 466 (footnote omitted).

Notwithstanding the difficult—and often emergent—flavor of traffic systems, there is actually a robust literature where scholars help provide insight regarding how to most robustly and safely manage traffic throughput.¹⁴⁵ In other words, even though the underlying system is a complex adaptive system, it is still quite possible to engage in appropriately applying scientific methods to the question.

As is the case with traffic systems, so too it is also the case for legal systems. The study of emergence in legal systems would help us better quantify the magnitude of the legal system's irreducibility and incompressibility. This would, in part, provide a representation of how much we are *unable* to know and predict about the system through the construction of theoretical and empirical models that might include various structural and performance metrics. To borrow from the framework articulated by former Secretary of Defense Donald Rumsfeld, our effort is in part focused upon converting the “unknown unknowns” into “known unknowns.”¹⁴⁶

IV. MONITORING LEGAL COMPLEXITY

Applying the measurement metrics outlined in Part III to a legal system or subsystem would provide a snapshot of the system's complexity. But important questions would remain: Compared to what? How much is too much? In which direction is the system moving? One way of enriching knowledge in this regard would be by repeating the measurements over time and over many subsystems to gain a deeper understanding of comparative complexity (e.g., tax versus environmental law) and complexity trends. But still, such exercises would provide a sense only of how the different metrics behave over time, not of how the system as a whole behaves over time.

Monitoring legal system complexity thus should operate at two levels. On the surface, comparative and trend analyses like those just described, including of user features such as compliance burdens, provide real-time assessments of how complex a legal system is and whether relative complexity

145. See, e.g., G.A. Mendes et al., *Traffic Gridlock on Complex Networks*, 391 PHYSICA A 362 (2012); Kai Nagel et al., *Still Flowing: Approaches to Traffic Flow and Traffic Jam Modeling*, 51 OPERATIONS RES. 681 (2003); Jason Sewall et al., *Virtualized Traffic: Reconstructing Traffic Flows from Discrete Spatiotemporal Data*, 17 IEEE TRANSACTIONS ON VISUALIZATION & COMPUTER GRAPHICS 26 (2011).

146. The full quote is as follows:

Reports that say there's—that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things that we know that we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know.

Defense Department Briefing, at 37:40 (C-SPAN television broadcast Feb. 12, 2002), <http://www.c-span.org/video/?168646-1/defense-department-briefing>. The quote is actually linked to the longstanding problem of induction and more recently has been popularized in research about so-called “black swan events.” See generally NASSIM NICHOLAS TALEB, *THE BLACK SWAN: THE IMPACT OF THE HIGHLY IMPROBABLE FRAGILITY* (2007).

is increasing or decreasing.¹⁴⁷ Extreme shifts in these metrics could raise red flags as to system performance. At a deeper level, however, monitoring changes in network interconnection and synchronization would allow more direct evaluation of system-wide behavior and a platform for testing system performance. This Part outlines a platform and methods for doing so.

A. *DESIGNING “LEGAL MAPS” FOR NETWORK BEHAVIOR MONITORING*

Measuring system content, structure, information, and computation is necessary to construct a network model of the system, but once that model is constructed, another set of metrics is necessary to assess what is happening inside the system. For example, a metric of network growth would measure how the network expands or contracts, and a metric of system intensity could measure the rate of information flow and orientation along different feedback and feedforward channels. To make such evaluations requires a platform representing the networked system in real time—what we call Legal Maps.

Legal Maps is the legal system equivalent of more familiar applications for geographic navigation, such as Google Maps. The building block of Google Maps is Geographic Information Systems (“GIS”) technology, which is a computer system for capturing, storing, checking, and displaying data related to positions on Earth’s surface.¹⁴⁸ By integrating many “layers” of data, such as rainfall, vegetation, roads, and so on, GIS can show many different kinds of data on one map, thus enabling people to more easily see, analyze, and understand patterns and relationships.¹⁴⁹ Assembling GIS maps requires data capture, conversion, and digitization of data from many sources into compatible formats, metrics, and scales; integration of the multi-sourced data into one projection; and manipulation of the data structures to allow mapping, modeling, and other methods to extract information about patterns and relationships, such as the effect of rainfall levels on vegetation near roadways.¹⁵⁰

Google Maps combines a highly layered GIS map of geographic and other details with sophisticated algorithms, allowing the user to search the map for directions, distances, points of interest, and so on. In addition, Google Maps feeds data from smartphones and other sources into the map on a continuous basis to provide a dynamic, real-time user interface to

147. See, e.g., Rakhyun E. Kim, *The Emergent Network Structure of the Multilateral Environmental Agreement System*, 23 GLOBAL ENVTL. CHANGE 980 (2013) (tracing the network structure of the world’s multilateral environmental agreements from 1857 to 2012).

148. See *GIS (Geographic Information System)*, NAT’L GEOGRAPHIC ENCYCLOPEDIA, <http://education.nationalgeographic.com/encyclopedia/geographic-information-system-gis> (last visited Sept. 15, 2015).

149. *Id.*

150. See *What Is GIS?*, U.S. GEOLOGICAL SURVEY, http://webgis.wr.usgs.gov/globalgis/tutorials/what_is_gis.htm (last visited Sept. 15, 2015).

communicate useful information, such as traffic density. For example, if a highway is closed due to an accident, drivers can use Google Maps to identify where traffic is at its worst and alternate routes carrying less traffic.¹⁵¹

Legal Maps would be built on the same kind of platform as Google Maps, starting with layers of data relevant to the legal system network. For example, the hierarchy network of the United States Code, as described above in Part III, would be represented as a discrete layer, as would the hierarchies of the Code of Federal Regulations, the federal courts, and the corollaries for states. Then the network's architecture would be represented. Cross-references within each layer, such as between sections of the Tax Code (nodes), would be represented as connections (edges) representing directionality and strength (e.g., one provision references another provision three times). Citation network visualizations like this already exist for judicial opinions in search engines, such as Ravel Law.¹⁵² Then references between layers, such as a regulation referencing a statutory provision and a court referencing the regulation, would also be mapped. Additional layers relevant to the system behavior could be added—such as provisions of the Constitution, citations in attorney briefs, administrative rulings, and so on—and the interconnections within and between each layer could be mapped. Search algorithms can then be devised to identify patterns such as clusters of tightly connected statutory and regulatory provisions, particular courts' and agencies' decisions, and so on.¹⁵³

Legal Maps, like Google Maps, would also operate as a real-time (or nearly real-time) representation of the legal system's dynamics. Events such as promulgation or repeal of a regulation or a new judicial opinion can be streamed into the map system with appropriate representations of cross-references and citations, and the system's information flow paths and rates could be observed (e.g., are certain regulations strong gatekeeper nodes between the statutory provisions they reference and judicial opinions referencing the regulation?). Streams from news and social media could also be fed into Legal Maps to observe how the legal system responds to rising social interest in a policy topic (e.g., how long before courts mention the trend and new regulations are promulgated around the trend?). Like Google Maps, layers could be selected or excluded to allow analysis of paired layers, and over time, a user's search history could be tracked to provide tailored maps, such that a practitioner of tax or environmental law could work within the sector and layers of the system most relevant to his or her practice. The

151. See Google Maps, GOOGLE+ (Feb. 4, 2014, 9:31 AM), <https://plus.google.com/+GoogleMaps/posts/UpBRC7BhXWj>.

152. RAVEL L., <https://www.ravellaw.com> (last visited Sept. 15, 2015).

153. See generally Carlo Garbarino, *A Model of Legal Systems as Evolutionary Networks: Normative Complexity and Self-Organization of Clusters of Rules* (Bocconi Univ., Legal Studies Research Paper No. 1601338, 2010), http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1601338 (describing legal systems as clustered networks of rules).

end result would be as close a representation of a map of the legal-system network as one could attain using current technology.

Indeed, what we describe can be achieved today. All of the data described are already available in digital form. Capturing them and converting them into compatible digital representations would be no more complicated than what Google Maps accomplishes for geographic data. Indeed, Koniaris et al. recently constructed a partial representation of such a model for European Union (“E.U.”) legislation, plotting over 250,000 legal documents (nodes) spanning 60 years of E.U. legislation.¹⁵⁴ Their model linked three layers—treaties, statutes, and judicial opinions—yielding almost one million connections (edges) within the network. Using this network representation, they performed a temporal analysis of the evolution of the legislation network, as well as a robust resilience test to assess its vulnerability under specific cases that may lead to possible breakdowns. Similarly, the search algorithms we anticipate Legal Maps using are no more sophisticated than those used in Google Maps. The only constraints to further development of such models for the legal system are time and money. But, even assuming the time and money were available, why build Legal Maps?

B. TESTING SYSTEM PERFORMANCE

Google Maps has obvious valuable uses, not the least of which is providing directions between two points. Of even greater value when out on the road are the traffic density and trip rerouting functions. And Google now provides an application program interface—a set of routines, protocols, and tools for building software applications—allowing other application builders to integrate Google Maps into their user interfaces.¹⁵⁵ Legal Maps could provide all of these functions as well, several of which would greatly enhance the capacity for monitoring legal system complexity and behavior. We provide a few examples below.

1. Synchronization Monitoring

The feedback mechanisms characteristic of a complex adaptive system are the source of both system resilience and systemic risk. The term “systemic risk” has become closely associated with the financial system collapse of 2008,¹⁵⁶ but the concept of systemic risk is not limited to financial systems—

154. See M. Koniaris et al., *Network Analysis in the Legal Domain: A Complex Model for European Union Legal Sources*, ARXIV (Jan 21, 2015), <http://arxiv.org/pdf/1501.05237.pdf>.

155. *Google Maps APIs*, GOOGLE DEVELOPERS, <https://developers.google.com/maps> (last visited Sept. 15, 2015).

156. The concept of systemic risk has gained prominence in legal scholarship primarily in connection with regulation of financial systems, for which it is widely asserted that “regulation has an important role to play in managing systemic risk.” Iman Anabtawi & Steven L. Schwarcz, *Regulating Systemic Risk: Towards an Analytical Framework*, 86 NOTRE DAME L. REV. 1349, 1352 (2011). This concern has been building since the 1980s. See, e.g., Helen A. Garten, *Regulatory*

it applies to all complex systems. Dirk Helbing of the Swiss Federal Institute of Technology defines systemic risk as

the risk of having not just statistically independent failures, but interdependent, so-called “cascading” failures in a network of N interconnected system components. That is, systemic risks result from connections between risks (“networked risks”). In such cases, a localized initial failure (“perturbation”) could have disastrous effects and cause, in principle, unbounded damage as N goes to infinity. . . . Even higher risks are implied by networks of networks, that is, by the coupling of different kinds of systems. In fact, new vulnerabilities result from the increasing interdependencies between our energy, food and water systems, global supply chains, communication and financial systems, ecosystems and climate.¹⁵⁷

As Helbing notes, the World Economic Forum has described this global environment as a “hyper-connected” world exposed to massive systemic risks.¹⁵⁸ Helbing identifies the drivers of systemic instability (such as tipping points, positive feedback, and complexity) and explains how they affect various global systems (such as finance, communications, and social conflict).¹⁵⁹ The upshot is that catastrophic damage scenarios are increasingly realistic, and that “[s]ome of the worst disasters have happened because of a failure to imagine that they were possible.”¹⁶⁰ Yet our political and economic systems simply are not wired with the incentives needed to imagine and guard against these outlier events.

Quite simply, we need to build systemic risk into our scenarios of the future, including for the legal system. Helbing suggests the development of a “Global Systems Science” discipline devoted to studying the interactions and interdependencies in the global techno-socio-economic-environmental system leading to systemic risk.¹⁶¹ It would be pointless to exclude the legal system from Helbing’s proposal, and it would be naïve to think that the legal system is exempt from the systemic risk problem. Hence the legal system must

Growing Pains: A Perspective on Bank Regulation in a Regulatory Age, 57 *FORDHAM L. REV.* 501, 560–61 (1989) (“[T]he goal of bank regulation, to prevent losses to the banking system as a result of bank failure, makes the regulatory system overinvested in particular banks whose failure poses systemic risks.”); Michael Gruson, *The Global Securities Market: Introductory Remarks*, 1987 *COLUM. BUS. L. REV.* 303, 308 (“What we should be concerned about is systemic risk—the risk arising from the systems of the international market as such—not the risk which relates to the individual investor or even an individual institution. Given the size of today’s predominant financial players, the failure of one could affect the whole market.”).

157. Dirk Helbing, *Globally Networked Risks and How to Respond*, 497 *NATURE* 51, 51 (2013) (footnotes omitted).

158. *Id.* (citing *Hyperconnected World*, *WORLD ECON. F.*, <http://www.weforum.org/projects/hyperconnected-world> (last visited Sept. 15, 2015)).

159. *See id.*

160. *See id.* at 57.

161. *See id.* at 51, 57–58.

(1) anticipate systemic failures in the systems it is designed to regulate, but also (2) anticipate systemic risk in the legal system as well.

Legal Maps could provide a platform for the second type of monitoring. Complexity scientists have identified a strong marker for systemic risk in the form of highly synchronized positive-feedback systems that give rise to the “networked risks” to which Helbing refers. When all feedback in the system has harmonized in the same self-reinforcing direction, a small, seemingly noncausal disruption to the system can lead to massive failure.¹⁶² As econophysicist Didier Sornette puts it: “[t]he collapse is fundamentally due to the unstable position; the instantaneous cause of the collapse is secondary.”¹⁶³ His assessment of the financial crash, for example, is that, like other financial bubbles, over time “the expectation of future earnings rather than present economic reality . . . motivate[d] the average investor.”¹⁶⁴ What pops the bubble might seem like an inconsequential event in isolation, but it is enough to set the collapse in motion. “Essentially, anything would work once the system is ripe.”¹⁶⁵

By tracking information flow and structure in the legal system over time, including the conduits across which it moves and their direction, strength, and timing, Legal Maps could help monitor for the buildup of highly synchronized information pathways that could open the door to cascade failures.¹⁶⁶ For example, if financial, environmental, and other regulators receive information along a tightly synchronized set of pathways and then move in the same direction based on information input (e.g., increase monitoring if information indicates a certain trend), interruption in the information flow or a surge in unreliable information can set the legal system up for a cascade of failures. Analyses of both the financial collapse of 2008 and the BP Deep Horizon oil spill suggest such forces were at play in the relevant regulatory systems and contributed to the cascade of failures within and outside the legal system.¹⁶⁷

162. See generally Xiyun Zhang et al., *Explosive Synchronization in a General Complex Network*, 88 PHYSICAL REV. E 010802(R) (2013).

163. Didier Sornette, *Dragon-Kings, Black Swans and the Prediction of Crises*, 2 INT’L J. TERRASPACE SCI. & ENGINEERING 1, 13 (2009).

164. *Id.*

165. *Id.*

166. The study of change in time of network structure is a focal point of network science. See, e.g., Petter Holme & Jari Saramäki, *Temporal Networks*, 519 PHYSICS REP. 97 (2012). Koniaris et al. traced the evolution of the European Union’s “Legislation Network” over a 60-year period. Koniaris et al., *supra* note 154, at 12–13.

167. See FIN. CRISIS INQUIRY COMM’N, THE FINANCIAL CRISIS INQUIRY REPORT, at xviii (2011) (assessing causes of the financial crisis and concluding that “widespread failures in financial regulation and supervision proved devastating to the stability of the nation’s financial markets”); NAT’L COMM’N ON THE BP DEEPWATER HORIZON OIL SPILL & OFFSHORE DRILLING, DEEP WATER: THE GULF OIL DISASTER AND THE FUTURE OF OFFSHORE DRILLING 122 (2011) (assessing causes of the oil spill including failures in regulation). Groups of legal scholars from the Center for Progressive Reform have also published two studies of the blowout reaching similar conclusions.

2. Stress Tests

Financial system models allow introduction of perturbations to assess what happens when the system is put under stress.¹⁶⁸ Similar stress testing could be applied in legal system models. For example, the rate of information flow (e.g., rate of variation in financial instruments or number of pollution violations) could be manipulated in the network Legal Maps model to see how the legal system handles high-flow rates and where flow jams occur under different stress conditions. Or, as Koniaris et al. performed on their E.U. legislation network model, pieces of network structure could be deleted (as in a proposed major deregulatory event) or added (as in a proposed enactment of a major new regulatory regime) to test how network structure and behavior would respond in terms of reconfigured synchronization patterns and information flow jams.¹⁶⁹ While there are always unforeseen circumstances (i.e., unknown unknowns) which any legal system must confront on a constantly evolving landscape, it is still possible to stress test a legal system model against a range of known or proposed scenarios in the effort to determine its robustness.

3. Interdependent Systems Analysis

Transportation disaster planning and assessment is turning to interdependent systems analysis (“ISA”) to move beyond single-disaster assessment (which usually focuses on identifying human error) to understand why disasters happen in general.¹⁷⁰ ISA uses network analytics and stress testing to link the system under study to its co-evolving systems over relevant time scales. ISA improves the ability of planners to identify the endogenous and exogenous conditions leading to systemic risk and, ultimately, to failure cascades.¹⁷¹ The legal system, in coevolution with the social systems it is intended to regulate and protect, is a perfect medium for ISA. From the

See generally ALYSON FLOURNOY ET AL., CTR. FOR PROGRESSIVE REFORM, THE BP CATASTROPHE: WHEN HOBBOLED LAW AND HOLLOW REGULATION LEAVE AMERICANS UNPROTECTED (2011); ALYSON FLOURNOY ET AL., CTR. FOR PROGRESSIVE REFORM, REGULATORY BLOWOUT: HOW REGULATORY FAILURES MADE THE BP DISASTER POSSIBLE, AND HOW THE SYSTEM CAN BE FIXED TO AVOID A RECURRENCE (2010). For a broad and thoughtful examination of regulatory failure, including whether it is in fact as responsible for the financial crisis, the oil spill, and other social and economic calamities as is often claimed retrospectively, see generally REGULATORY BREAKDOWN: THE CRISIS OF CONFIDENCE IN U.S. REGULATION (Cary Coglianese ed., 2012).

168. See Robert Weber, *A Theory for Deliberation-Oriented Stress Testing Regulation*, 98 MINN. L. REV. 2236, 2238–39 (2014).

169. See Koniaris et al., *supra* note 154, at 10–11.

170. See Lloyd Burton & M. Jude Egan, *Courting Disaster: Systemic Failures and Reactive Responses in Railway Safety Regulation*, 20 CORNELL J.L. & PUB. POL’Y 533, 558–61 (2011).

171. Cf. Chris Barrett et al., *Human Initiated Cascading Failures in Societal Infrastructures*, 7 PLoS ONE e45406, at 1–2 (2012) (discussing human-initiated “co-evolving cascades in interdependent infrastructures” such as failures in wireless communication networks and transportation networks during an evacuation).

sectors law regulates and protects, Legal Maps could be built out to include data feeds such as financial, manufacturing, environmental, and demographic data. When one system experiences failure, such as a financial crash, retrospective analysis of how the legal system responded prior to, during, and after the event can help identify where stress and failure were rising or falling in the legal system, such as by excessive synchronization or information flow jams.

C. COMPARATIVE DESIGN STUDIES

In a world where all of the above could be accomplished, it would then be useful to conduct cross-system comparisons, such as between common law and civil code systems, or across different bodies of law (e.g., tax versus environmental) and national law systems (e.g., U.S. versus China). Particularly as economic and social phenomena occur increasingly at global scales, nations' legal systems are increasingly interdependent, thus supporting the case for building out and linking Legal Maps for all nations.

V. MANAGING LEGAL COMPLEXITY

A. DEFINING TOO MUCH COMPLEXITY

Going back to the Tax Code example, most assertions regarding its excessive complexity focus on its impact on the taxpayer—it is too hard to comprehend, takes too much time, costs too much, and so on. These are, of course, valid concerns, and at some point, extreme conditions in these respects for a legal system could indicate that something has gone wrong and needs adjusting. But assuming a legal system is fulfilling the purposes it was designed to accomplish (e.g., in the case of the Tax Code, raising necessary revenue in an equitable and efficient manner), the compliance burdens it imposes may simply be an inevitable consequence of some minimum necessary complexity of the system.

Of greater concern, therefore, would be the possibility that complexity at some level could undermine the system's capacity to achieve its purposes. Indeed, as suggested above in connection with the feedback synchronization problem, one of the focal points of complexity science research is how system complexity contributes to both the system's robustness and its fragility. As complexity scientists David Alderson and John Doyle explain, the adaptive quality of complex adaptive systems contributes to overall system robustness in several senses:

Reliability involves robustness to component failures. *Efficiency* is robustness to resource scarcity. *Scalability* is robustness to changes to the size and complexity of the system as a whole. *Modularity* is

robustness to structured component rearrangements. *Evolvability* is robustness of lineages to changes on long time scales.¹⁷²

At its core, therefore, “robustness is a measure of feature persistence in systems where the perturbations . . . represent changes in system composition, system topology, or in the fundamental assumptions regarding the environment in which the system operates.”¹⁷³ Robustness can be thought of as the fitness of the system’s options in two respects—resistance to forces of change, and resilience to those effects not successfully repelled.¹⁷⁴ Robustness is built from the system’s organized complexity—the networked content and structure that allows information to flow and be processed through the system.¹⁷⁵ But even in robust legal systems that satisfy normative preferences, that network structure also exposes the system to fragility, as perturbations can cascade down the system’s feedback and feedforward chains—i.e., the kind of systemic system meltdown discussed above.¹⁷⁶

The response to such events in many human-controlled systems usually is to build more organized network structure into the system—to beef it up with new legal content and structure—which ironically also adds more risk of fragility.¹⁷⁷ This “robust yet fragile” dilemma has been identified in many contexts as the source of systemic risk.¹⁷⁸ The financial system crisis of 2008, for example, has been attributed to an overload of systemic risk, including risk generated by the growing complexity of the financial regulatory system itself as it worked to keep up with the regulated industry’s innovations.¹⁷⁹ A post-spill task force reached a similar conclusion regarding regulatory agency oversight of drilling in the Gulf of Mexico prior to the BP Deepwater Horizon oil spill. The report concluded that the regulatory complexity, built up by rounds of agency responses to prior spills and environmental injuries, had outstripped agency capacity.¹⁸⁰ A major thrust of legal-complexity monitoring and an advantage of having built out Legal Maps, thus, would be to improve

172. David L. Alderson & John C. Doyle, *Contrasting Views of Complexity and Their Implications For Network-Centric Infrastructures*, 40 IEEE TRANSACTIONS ON SYSTEMS, MAN & CYBERNETICS 839, 840 (2010). For a comprehensive review of their model and its application to systemic risk in the legal system, see generally Ruhl, *supra* note 37.

173. Erica Jen, *Stable or Robust? What’s the Difference?*, 8 COMPLEXITY 12, 13–14 (2003) (comparing stability and robustness).

174. *Id.* at 16–17.

175. See Alderson & Doyle, *supra* note 172, at 840–41.

176. See Ruhl, *supra* note 37, at 588 (describing failure cascades).

177. See Alderson & Doyle, *supra* note 172, at 841–42.

178. See *id.* at 839, 842–43.

179. Lawrence G. Baxter, *Betting Big: Value, Caution and Accountability in an Era of Large Banks and Complex Finance*, 31 REV. BANKING & FIN. L. 765, 863–64 (2012)

180. NAT’L COMM’N ON THE BP DEEPWATER HORIZON OIL SPILL & OFFSHORE DRILLING, *supra* note 167, at 78 (concluding the agency lacked “a formal, bureau-wide compilation of rules, regulations, policies, or practices” and had “no formal process to promote standardization, consistency, and operational efficiency” across its many district offices).

the capacity to monitor for sectors in the system experiencing creep towards greater complexity of structure, in particular the synchronization of networked positive feedback mechanisms.

B. MANAGING TOO MUCH COMPLEXITY

So, how complex should the legal system be to get its job done without undue risk of systemic failure? Our short answer is: we don't know. We don't even know how complex the legal system is, much less how complex it should be. But that, of course, is the point of this Article—to initiate a research agenda that will inform both of those questions. Some work has been done but much more remains ahead.

That said, we can offer impressions of how improved empirical understanding of legal complexity can inform its management. We say *management* rather than *reduction* because, as explained above, there is no a priori basis for asserting that all legal complexity is structurally or normatively bad. Therefore, this agenda is something of a management problem—i.e., how to get the most “good” out of the legal system while minimizing the “bad.” Any hope of doing so with even limited success will depend on developing and implementing the measurement metrics and monitoring methods outlined in Parts III and IV. From there, we anticipate two technology applications for approaching the management problem: (1) machine learning; and (2) user interface design.

1. Real-Time Monitoring Leveraging Learning Algorithms

Monitoring for system complexity, focused around the detection and prevention of cascade failures, will require that Legal Maps embed sensors to alert policy makers to the markers of impending system failure from internal complexity and external disturbances.¹⁸¹ Research on power grid networks has shown, for example, that disabling even a small number of network failure sensors can render the grid subject to new types of disturbances even when they remain robust to conventional disturbances.¹⁸²

The legal system already incorporates numerous instrumental sensors such as pre-decisional impact assessments and monitoring, reporting, and disclosure requirements, all of which fall under the theoretical domain of what is known as “reflexive law.”¹⁸³ The National Environmental Policy Act,

181. Alderson & Doyle, *supra* note 172, at 841–42.

182. See Yang Yang et al., *Network Observability Transitions*, 109 PHYSICAL REV. LETTERS, 258701, 258701-4 (2012).

183. See David Hess, *Social Reporting: A Reflexive Law Approach to Corporate Social Responsiveness*, 25 J. CORP. L. 41, 48–51 (1999) (explaining the theory and development of reflexive law); see also Eric W. Orts, *Reflexive Environmental Law*, 89 NW. U. L. REV. 1227 (1995) (developing and applying theory of reflexive law in environmental field); Richard B. Stewart, *A New Generation of Environmental Regulation?*, 29 CAP. U. L. REV. 21, 127–51 (2001) (defining reflexive law and reviewing its instruments).

which requires federal agencies to assess the environmental impact of their proposed actions, is an example of a legal system sensor protocol for pre-decisional impact assessment.¹⁸⁴ Similar pre-decision assessment measures apply in agency rulemaking as well. For example, the Regulatory Flexibility Act requires agencies to prepare an analysis for any rule that may have an important economic impact on a significant number of small businesses, and similar pre-decision review measures abound in administrative law.¹⁸⁵ Of course, whether these kinds of sensors work, and whether they are efficient even if they do work, are important (and currently unanswered) questions. The point made here is that our legal system has implanted many system sensors to evaluate itself internally, to detect changes in its environment, and to measure its interactions with other social systems.

Similarly, sensors can be embedded in Legal Maps to leverage learning algorithms that detect conditions found over time to be associated with cascade failure and other undesirable properties. This type of learning algorithm is called “machine learning.” Machine learning is “the systematic study of algorithms and systems that improve their knowledge or performance with experience.”¹⁸⁶ It is the technology behind your e-mail spam filter as well as, in a legal application, the electronic discovery process.¹⁸⁷ The program “learns” through algorithm-based heuristics designed to detect patterns in data as well as through interaction with the user.¹⁸⁸ For example, as an e-mail user repeatedly sends emails with “Earn Cash Fast” as the subject lines to the spam folder, the program begins to associate that subject text and other attributes associated with the e-mails—such as the origin of such e-mails and other text they contain—with junk status. Soon, that class of e-mails goes straight to the junk mail box even if the subject line text changes. At first the

184. 42 U.S.C. § 4332(2)(C) (2012). This provision also requires assessment of alternative actions, short- and long-term implications, and “any irreversible and irretrievable commitments of resources.” *Id.* § 4332(2)(C)(iii)–(v).

185. 5 U.S.C. §§ 601–612 (2012). The law was amended by the Small Regulatory Enforcement Fairness Act of 1996, 5 U.S.C. § 611. For thorough descriptions of this and related pre-promulgation review requirements, see Fred Anderson et al., *Regulatory Improvement Legislation: Risk Assessment, Cost-Benefit Analysis, and Judicial Review*, 11 DUKE ENVTL. L. & POL’Y REV. 89 (2000); Daniel Cohen, S. 981, *The Regulatory Improvement Act of 1998: The Most Recent Attempt to Develop a Solution in Search of a Problem*, 50 ADMIN. L. REV. 699 (1998).

186. PETER FLACH, MACHINE LEARNING: THE ART AND SCIENCE OF ALGORITHMS THAT MAKE SENSE OF DATA 3 (2012). For a sweeping overview of the current and potential use of machine learning in legal settings, see Harry Surden, *Machine Learning and Law*, 89 WASH. L. REV. 87 (2014). For an enjoyable survey of machine learning’s increasing application in a variety of settings, see LUKE DORMEHL, THE FORMULA: HOW ALGORITHMS SOLVE ALL OUR PROBLEMS . . . AND CREATE MORE (2014).

187. See Surden, *supra* note 186, at 90–91 (spam); *id.* at 112–13 (e-discovery).

188. See *id.* at 91–95.

process may make mistakes, but over time, the user and the algorithms train the program towards increasing accuracy.¹⁸⁹

Legal Maps could use the same machine-learning technology in the form of embedded algorithms to identify red-flag conditions of excessive legal complexity, such as synchronization and information-flow surges and blockages, the same way Google Maps shows the impacts of an interstate being shut down on surrounding roadway traffic. Had Legal Maps existed at the time of the financial collapse, for example, users could have rerun the historical record following the failure to identify the conditions within and outside the legal system that were experienced in the run-up to the failure.¹⁹⁰ This would allow Legal Maps to learn those conditions and alert the users when those conditions are detected once again, but this time in advance of an actual collapse. This sensor alert would allow regulators to intervene with measures designed to preempt the failure, and whether those measures are successful or not, Legal Maps could be trained with that information so that it could assist in designing interventions when sensors call the alert again. This technology could also be used to experiment with stress-test scenarios that users of Legal Maps could run to simulate a variety of disturbances, such as a surge in social-media trending, the repeal or promulgation of a major regulatory statute, or flurries of licensing, registrations, or other regulatory approval applications. Over time, regulators could begin to learn from Legal Maps' learning, the way Google Maps learns about driver responses to traffic situations, gaining important perspectives about when and where legal system complexity appears to be approaching conditions of high systemic risk, as well as lessons about legal institution and instrument design that can reduce such stress.¹⁹¹ For example, the prescriptive legal complexity theory assertion that decentralized regulatory systems are more resilient than centralized top-down structures could be tested by comparing the performance of different regime structures over time. Of course, because the legal system itself is dynamic and adaptive, no lessons could be thought of as permanent—the Legal Maps training process would run indefinitely and human intervention and oversight would remain important.

2. Designing Legal User Interfaces

Legal complexity is a challenge to the participants in many legal systems. Indeed, as noted above, most of the claims regarding excessive Tax Code complexity point to impacts on taxpayers, with cost and time as the alleged

189. Spam filters must be consistently tuned and updated as the techniques used by spammers evolve over time.

190. Of course, to the extent that a future failure is drawn from the set of “unknown, unknowns,” then Legal Maps or any models or tools would be of limited effectiveness.

191. For an example drawn from the banking sector, see Paul Lippe, Daniel Martin Katz & Dan Jackson, *Legal by Design: A New Paradigm for Handling Complexity in Banking Regulation and Elsewhere in Law*, 93 OR. L. REV. 833 (2015).

proof. While there are occasional efforts toward simplifying the law, one alternative is to build intermediary systems that translate and compile “raw law” into clearer forms. The “law as code” or computational law movement is one which is in part interested in reducing complexity by developing various forms of “legal user interfaces.”¹⁹² Much like web browsers such as Firefox or Internet Explorer shield end users from the raw code, such systems could attempt to generalize what TurboTax has done for the Tax Code. Emerging legal technology companies such as Neota Logic are devoted to building such “expert systems” user interfaces for legal compliance problems.¹⁹³

Improving user interfaces can be a second-best alternative to reducing the complexity of the law itself when either reducing complexity is not desirable or no means of reducing legal complexity is apparent. As described above, complexity builds resilience in complex adaptive systems—law being no exception—hence some level of complexity is desirable. However, while the optimal level of legal complexity can be determined once appropriate metrics are identified and studied, it is not clear from any theory of complexity science how to fine tune so that just the right amount of complexity can be added or removed. Given how intertwined systems are, it could be difficult (even with Legal Maps up and running) to remove only some of the cross-references in the Tax Code, or between the Tax Code and other fields, and know how much complexity had been removed and what the effects would be on the still highly cross-referenced components. Rather, it may be an in-for-a-penny-in-for-a-pound proposition, suggesting that a complete rebuild from scratch would be needed instead, which presents its own set of political and design challenges. Until more is known about legal system complexity through initiatives like Legal Maps and measures to seed the system with machine learning sensors, work should continue on simplifying user interfaces for navigating legal systems without having to navigate their complexity.

VI. CONCLUSION

Much of the foregoing would have seemed like sheer fantasy as recently as just a few years ago. But that was before massive advances in data storage and computational capacity and their use to promote robust complexity and network sciences. These advances challenge traditionalists’ claims that the legal system is so exceptional or impenetrable that it cannot, in some substantial degree, be measured and modeled through computational methods applied in other disciplines. The legal system, a phrase used

192. Computational law is “[t]he study of formal representations and automated reasoning with laws (governmental regulations, business rules, and contracts) in electronically-mediated domains.” STANFORD COMPUTATIONAL LAW, <http://complaw.stanford.edu> (last visited Sept. 15, 2015).

193. See NEOTA LOGIC, <http://www.neotalogic.com> (last visited Sept. 15, 2015).

ubiquitously in legal scholarship,¹⁹⁴ is just that—a system. As such, its description and assessment are open to the empirical approaches we have suggested. This goes well beyond mere extrapolation from the empirical techniques already in play, such as citation databases and judicial voting studies. This is about building computational models of the legal system, its complexity, and its systemic risks.

Early attempts to develop legal complexity metrics, build out a system model through Legal Maps, conduct stress tests, locate systemic risk, seed the system with machine learning sensors, and propose new legal designs will be rudimentary, coarse, and often wrong, and will be criticized for that. But succumbing to such critiques would have kept economists using the abacus and ecologists counting tree rings. It is time for lawyers to move beyond case studies, rhetoric, and conventional statistical methods—it is time to study the deep structure of legal complexity through the empirical and technological methods of complexity science.

194. Searching for the term “legal system” in Westlaw’s Law Reviews and Journals database yields almost 10,000 articles using the term in some way. *See supra* note 42.