

THE BLIND LAWMAKER

by

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DEDICATION

This is dedicated to my wife who has put up with me being in school for almost our entire life together and to the animals that add a welcomed element of chaos into our lives.

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I would like to thank the members of my committee; their guidance and support were critical components of what went into this dissertation. Also, I would like to thank my family and friends for all the support they have shown me over the years and without whom I would never have finished this dissertation. Finally, I cannot overlook all the help and support provided by Karen Underwood. This document has been publicly released by the MITRE Corporation, distribution unlimited, case number: 13-4197.

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ABSTRACT

THE BLIND LAWMAKER

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George Mason University, 2013

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Many have written about how the Common Law should evolve. The few attempts to demonstrate this empirically, however, have not found evidence that this evolution takes place. This study uses a representation of the Article III United States Federal Courts and an agent-based model to demonstrate that a judicial system may evolve while simultaneously emitting signals to the contrary by evolving via a punctuated equilibrium dynamic. The study then proceeds to demonstrate that agent-based modeling is a viable method for understanding the performance of judicial institutions. After reviewing concepts of jurisprudence and computational social science, the development of the model is discussed followed by a presentation of the results of the aforementioned experiments.

INTRODUCTION

Law pervades our lives. It is a complex system made up of humans and is rife with interactions and positive and negative feedbacks. There are aspects of it that are formal, such as statutes and the Constitution. Some aspects of it are informal, such as cultural norms and other social mores. This study is about the formal legal system that is part of the Federal Government of the United States, specifically the limited jurisdiction Article III Federal Courts. Many aspects of the Federal Courts have already been thoroughly examined: What the courts should be for society, what judges should do, what judges should not do, how judges do what they do, why judges do what they do, and so on. This study is not another one of those. Instead, it will focus on the structure of the “judicial system,” and how the structure of the judicial system impacts its ability to find answers to hard problems. In this regard it is akin to Farmer’s [2005] analysis of markets, which examined the impact of the structure of the market rather than the sophistication of the traders, a focus that helped make clear the importance of an order book when one studies a market. Similarly, it is my contention that what judges do, why, and how are functions not only of the humans involved but also of the system within which they find themselves embedded and this structure can lead to very interesting system dynamics. In order to examine this question this work makes use of a largely unused analytic technique—generative analysis from computational social science—within the field of jurisprudence.

Use of this new technique opens entirely new avenues of inquiry to those interested in judicial systems. With these tools and techniques the system as a *whole*, with all of its components and interactions, can be examined. Entirely new institutional systems can be created and carefully examined in ways not otherwise possible. Traditional social science has trouble with such questions. It is difficult and expensive to design and test completely whole new “real” systems. When this has been achieved the effect is sometimes dramatic (as observed in the famous prison simulation run by Hanley, et al. [1973]). Recently, an alternative to the study of real systems has become available, the agent-based model (ABM). ABMs are a specific flavor of model. An ABM is a model in which all “relevant” portions of a system are explicitly represented and, perhaps most importantly, the interactions among the components are represented, as well [Axtell 2000]. This type of model gives researchers a new way to explore social systems and test hypotheses about how these systems function and change over time. The work presented here centers on a set of ABMs that represent the Article III Federal Courts, a genetic algorithm, and a particle swarm optimization (how these all relate will be dealt with *infra*). It is the ultimate goal of this study to explore how a system structured like our Federal Courts can, or cannot, solve problems.

This dissertation will focus on the Article III U.S. Federal Courts as a problem solving system. How well a judiciary can solve problems when presented with limited information will be the overall motivation. Many have argued that a judiciary solves problems in an evolutionary manner; overtime the laws created by the judiciary should become more efficient. However, none have found evidence of this dynamic. This

dissertation will approach this problem from a new, complexity science-based, perspective and will demonstrate that *both* findings may be correct. This is the case, as modeled here, because the judicial systems become more efficient via the evolutionary dynamic known as punctuated equilibrium. In so doing, I also show that a judicial system, when treated as a heuristic search algorithm, performs in a manner comparable to traditional genetic algorithms and particle swarm optimization.

The discussion will proceed in the following way: First, I will describe the logical foundation for this approach. Second, I will discuss the salient aspects of the U.S. Article III Federal Courts and present the, seemingly inconsistent, findings of the Courts' evolutionary dynamics. Next, I will turn to complex systems and the use of it to analyze a judicial system. Finally, the models will be developed and analyzed. Through execution of these models I will demonstrate that a judicial system can evolve to more optimal problem solutions while creating signals to contrary. It will be shown that movement toward optimal solutions occurs episodically and, therefore, signals indicating no movement toward optimality may actually predominate.

Jurisprudence, Logic, and Generative Science

This section will discuss the jurisprudential and logical foundations for this approach to analyzing a judicial system. It is important to create this foundation so that the strengths and weakness of this approach and how it relates to more traditional approaches is clear. First, jurisprudence and how the analytic techniques used here will be discussed. This

will be followed by a discussion of the logical foundations for the work, which is not strictly deductive or inductive.

Black's Law Dictionary defines jurisprudence as: "The philosophy of law, or the science which treats of the [sic] principles of positive law and legal relations" [Black's Law Dictionary 1991]. Shapiro [2011] further divides jurisprudence into normative jurisprudence and analytical jurisprudence. Normative jurisprudence is comprised of two subcategories: interpretive and critical. Interpretive normative jurisprudence is concerned with the analysis and discovery of the moral and philosophical underpinnings of our legal system (e.g., what social norms lead a judicial system to be structured in a particular way). Critical normative jurisprudence is concerned with what should be the moral and philosophical underpinnings of our legal system. On the other hand, analytic jurisprudence is interested in studying the objects of law (such as statutes, constitutions, and judicial behavior) as they exist rather than the foundational elements found in normative jurisprudence.

For the purposes of the present discussion I will add a few categories to this framework to more clearly situate this work and generative methods within the field of jurisprudence. Hopefully, this will make clear the utility of generative methods and the fact that they are complementary to existing methods. I will divide jurisprudence into three basic categories: narrative, descriptive, and generative. Narrative is "philosophical jurisprudence." This is the jurisprudence that most are familiar with and is further subdivided into interpretive normative and critical normative by Shapiro [2011]. Descriptive jurisprudence is very similar to Shapiro's analytic jurisprudence however I

include within descriptive jurisprudence an additional subcategory: computational descriptive jurisprudence. In this way there are two elements to descriptive jurisprudence: the first is analytic, as described by Shapiro and is traditionally narrative in nature. The second is computational. This is an emerging field taking advantage of newly available large datasets that allow for the analysis of the network of laws [Bommarito II and Katz 2010], the network among judges [Katz and Stafford 2010] and so on. Finally, I will include generative jurisprudence as a new category. This type of jurisprudence uses generative methods for the analysis of law. Generative jurisprudence is further divided into computational methods, such as agent-based modeling; and “other.” Here other includes such methods as experimental economics and behavioral game theory [see generally, Camerer 2003] and, possibly, other methods such as moot courts, methods where human subjects interact to *generate* a norm or behavioral pattern. Increasing the specialization of jurisprudence by adding additional categories does more than make the topic seem more exciting, it also helps to highlight the tools, techniques, and assumptions of a particular study. Here we are using generative methods to address an abductive challenge. Knowing that, allows those examining the work to know more about it, its strengths and its weaknesses, and the method’s appropriateness to the topic under study (see *infra*).

Clearly, these categories are not mutually exclusive, nor are they meant to be. In fact, these categories should build upon one another to create a completely transdisciplinary jurisprudence. In this sense “traditional” narrative jurisprudence calls upon computational methods to characterize the current state of the legal system and uses

generative methods to test its theories about the underlying rules and morality that led to our current system and experiment with other foundations. The basic structure of what was discussed above can be found in Figure 1.

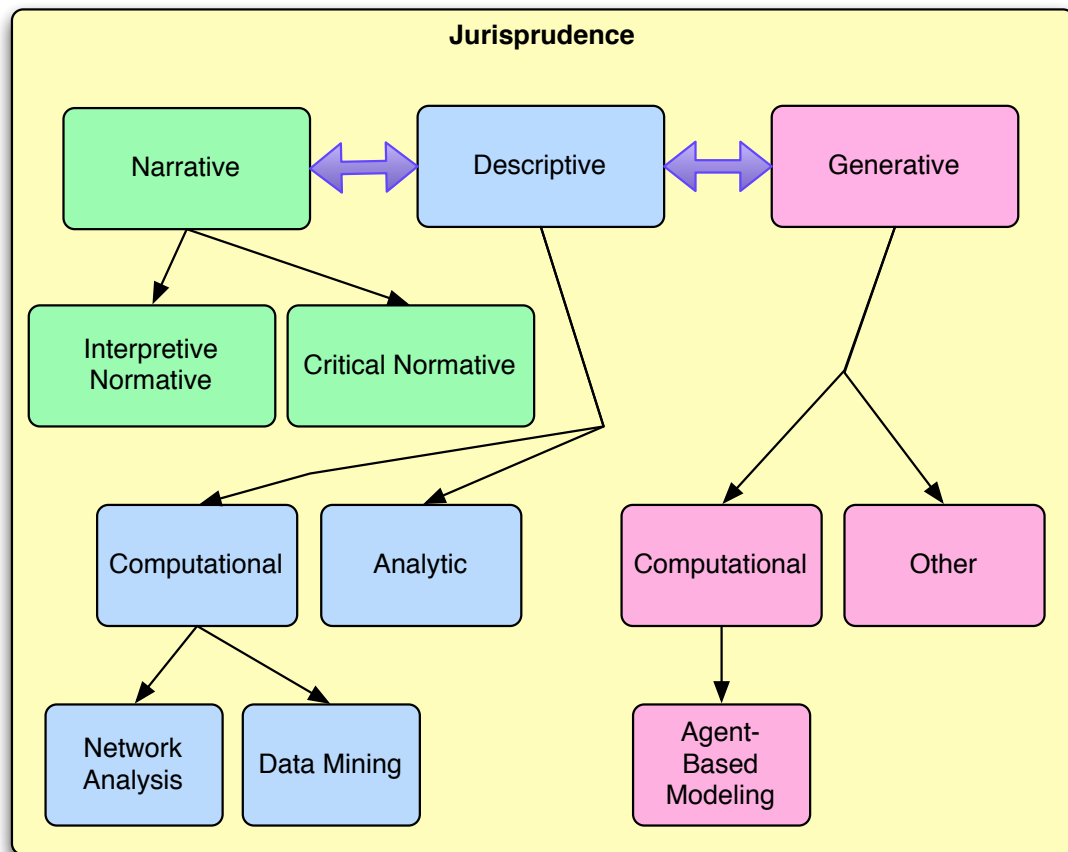


Figure 1. The components of jurisprudence.

The study discussed here will focus on computational generative jurisprudence. It will make extensive use of agent-based models to explore the dynamics of a legal system. What is computational generative jurisprudence (CGJ)? CGJ uses computation to

experiment with conditions that are sufficient to generate the dynamics seen in a system in question. Of course, this presupposes that the system in question exists and is measurable. Another use of generative methods is to explore the potential dynamics of systems that do not exist. Both aspects of agent-based computational generative jurisprudence will be discussed here.

A Formal Statement of Computational Generative Jurisprudence

This section will spend some time developing the logical foundations for this generative investigation. As this work espouses a relatively new way to approach jurisprudential problems, I feel it is important to establish a firm foundation for the approach and clearly articulate what the, well established, logical foundation is for the use of these tools in this situation. Epstein [2005] articulated a motto for generative social science: “If we did not generate x, we did not explain x” (shown in (1.1)):

$$\forall x(\neg Gx \supset \neg Ex) \tag{1.1}$$

This motto can be augmented with the ideas of sufficiency theorem generation discussed by Axtell [2005]. This, in turn, can be thought of as a type of computational abduction. Abduction, in its simplest form, is: “with inputs A, C is generated,” essentially C follows from A as a matter of course (1.2) [Aliseda 2006].

$$A \models C \quad (1.2)$$

This is completely consistent with sufficiency as described by Axtell [2005]:
Output R if Input A. Further, if one has a theory about a system, the abductive argument takes the form [the following characterization draws upon Aliseda 2006]:

$$\theta \cup \alpha \Rightarrow \varphi \quad (1.3)$$

$$\theta \not\Rightarrow \varphi \quad (1.4)$$

$$\theta \not\Rightarrow \neg\varphi \quad (1.5)$$

The system as currently conceptualized (Θ), with an additional theory (α), implies the existence of the, initially, surprising dynamic (φ) (1.3). One other condition on the argument begins to make abduction look a lot like a way to think about emergent phenomena, φ and its negation should not logically follow from Θ (1.4 and 1.5). Given our current thinking about a system, the phenomena that we see it producing should be surprising. Often an Occam's razor-like condition is added to α , stating that it should be simple, brief, or minimal. Of course, novelty is relative, what is surprising to one individual may not be to another. This implies that Θ may be unique to each individual. Occasionally, the third constraint above is used as a prior condition on the use of abduction; meaning, the current theory of the system should preclude the observation φ .

Using Schelling's [1978] famous segregation model as an example, we have:

$\theta_i \in \Theta$: Individuals living within a city self report to prefer integrated neighborhoods and have only very weak homophilic preferences.

φ : Individuals living within a city tend to live in highly segregated neighborhoods.

Our overall theory of the system (here the basis for a model), Θ , could be characterized (briefly and incompletely) as being comprised of:

θ_1 : Cities are made up of discrete spatial units where distance is meaningful.

θ_2 : Individuals live within these discrete spatial units and use distance to define neighborhoods.

θ_3 : Individuals have weak homophilic preference within their neighborhood.

This satisfies abduction: we have novelty, $\theta \not\Rightarrow \varphi$, and we have abductive anomaly in that $\theta \Rightarrow \neg\varphi$. Schelling postulated that by including an α a system could be created that makes φ follow from $\theta \cup \alpha$ as a matter of course. This α was that individuals are initially heterogeneously distributed and move around in an uncoordinated manner. Now, $\theta \cup \alpha \Rightarrow \varphi$ and we have a sufficiency theorem for the dynamics that are observed. When dealing with these sorts of complex systems it is often necessary to run a model as a simulation to understand that φ will follow as a matter of course. This provides the sufficiency theorem as discussed by Axtell.

The " \Rightarrow " operator can represent a number of different inferential operators depending upon the domain in question. Interestingly, the proper search for "useful" α s is

often an open question. Within a computational perspective of this work, the search is accomplished iteratively via the development and execution of a simulation or set of simulations.

Abduction, though a very significant motivation for agent-based modeling, is only part of the story. The process of agent-based modeling (at least as construed here) makes use of deduction, induction, and abduction. As observed by Epstein [2005], assuming one has adequately controlled for the stochasticity typically found in an ABM, every run of the model is a strict deduction: Given these rules encoded in this software, these initial conditions, and this random number stream, this output *must* occur. One runs the model a number of times to generate a distribution of outcomes. This may (should?) include sensitivity analysis around the significant parameters, as well. Now, at this point one uses this collection of observations to draw inductive conclusions about the system as a whole. Here the ABM takes on the Proof and the Discovery uses of simulation in the Social Sciences as discussed by Axelrod [1997].

$$o \rightarrow r \wedge i \wedge s \quad (1.6)$$

Where o is a particular, though not necessarily unique, outcome from the set of all possible simulation outcomes, O . It is an outcome generated if:

$r \subseteq$ all possible rules, R (included here is the model's parameter space that impacts the functioning of the rules)

$i \subseteq$ all possible initial conditions, I

$s \subseteq$ all possible random number streams, S

As the number of model runs increases, more of the “O space” is filled in. This, inductively, is then used to create our theory of the system, Θ . This is then used as our foundation for abductively explaining emergent or surprising dynamics or patterns, ϕ . This is, of course, a cycle. The α used to explain ϕ *may* then be incorporated into a new Θ and form the foundation for yet another abductive explanation for a new ϕ .

Finally, the process of computational social science (used here to create Computational Generative Jurisprudence) via the use of agent-based models may proceed as a variant of abduction. Specifically, once the system is created, here the Θ , a surprising outcome, ϕ , may be observed. Then the process is to find the α that is *already* part of Θ that made ϕ a matter of course. Here the process of abduction is not additive as the “world” is completely contained in silico; therefore, the relevant α has already been incorporated in to Θ and need only be identified as such.

The preceding section discussed the logical foundation for this study, abduction. It also provided a simple example derived from the well known Schelling segregation model. With this background we can now turn to the specific question at hand, in a precise, logically grounded manner. In the sections that follow we will build up an agent-based model of a judicial system, eventually creating the Article III U.S. Federal Courts. We will then use this model to offer an explanation for the seemingly contradictory findings, namely that a judicial system can simultaneously find better solutions to a problem while producing evidence to the contrary, of a recent study about the efficiency of the Common Law.

This framework also provides a very specific way to think about the empirical relevance of the model and how to perform any necessary verification and validation. The specificity of the initial system, Θ , and the specificity of the surprising dynamic, ϕ , will constrain the potential new components, α , and also dictate the needed data. If the system, Θ , is reasonably abstract as it was in the Schelling example above and the surprising dynamic, ϕ , is a general macroscopic observation of the system; then, too, the new sufficient feature, α , can be fairly abstract, also. Using Axtell's Levels of Empirical Relevance [Axtell 2005] what would be produced under these conditions is, likely, an agent-based model of Level 1 (macro-level qualitative correspondence to the referent) Empirical Relevance. As the specificity of the system, Θ , and the surprising dynamic, ϕ , increase, it is likely that the specificity of the new feature, α , will need to increase, as well. Now, the ABM is likely trying to achieve Level 2 Empirical Relevance (macro-level quantitative correspondence). There are two additional Levels in Axtell's framework: Level 0 (micro-level qualitative correspondence—agents that behave plausibly for a given system), and Level 3 (micro-level quantitative correspondence—agents that behave identically to their “real-world counterparts”).

The correspondence with the referent system can be characterized using the Docking Framework created by Axtell, et al [1996]. In their Docking Framework there are three levels of correspondence: Identity (where the simulation produces identical results to the referent (typically another simulation)), Distributional (where the simulation produces results that are statistically indistinguishable from the referent), and Relational (where the simulation produces results that are statistically distinguishable from the

referent but are qualitatively similar) (additional discussion of the use of Docking and the Empirical Relevance Framework for ABM evaluation can be found in Koehler [2006] and Barry et al. [2009]).

Is it valid to approach jurisprudence with such an alien set of tools? Simply put, yes, it is consistent with concepts of jurisprudence to use tools and techniques from outside the legal discipline to study the law. Posner [1987] commented on the decline of law as an autonomous discipline as the field of economics grew in importance within jurisprudence. This was further stressed a few years later when Posner articulated an approach to jurisprudence that is consistent with the approach taken here:

“By ‘jurisprudence’ I mean the most fundamental, general, and theoretical plane of analysis of the social phenomenon called law. For the most part it deals with problems, and uses perspectives, remote from the daily concerns of legal practitioners: problems that cannot be solved by reference to or by reasoning from conventional legal materials; perspectives that cannot be reduced to legal doctrines or to legal reasoning” [Posner 1990 at xi].

Central to the issues dealt with by jurisprudence, when seen as a pursuit to create a science of the law, is the meaning of “conformity to reason,” “uniformity,” and “certainty” [Pound 1908]; the sense that law must find solutions that focus on the “root of controversies,” treat all parties equally, and allows for predictable outcomes [Pound 1908]. To Pound a scientific law is a means to an end, the goal of the law is as stated above, not for the “arbitrary” application of structured decision making framework. “Law has the practical function of adjusting every-day relations so as to meet *current* ideas of

fair play [emphasis added]” [Pound 1908 at 606]. A key concept used by Posner *supra* is the need for, and use of, nonconventional legal materials for jurisprudential analysis.

Both Posner and Pound articulate a need for the law to be practical and for jurisprudence to create meaningful insights into the structure and function of law. This work proposes “generative jurisprudence,” or “computational jurisprudence” as a new tool to use in the analysis of the law and a new way to gain meaningful insight into the dynamics of judicial systems and the law as a whole. This is not unique to jurisprudence, more generally, computational social science is showing utility in many fields.

Further, this work is not concerned with what Tur describes as “particular concrete issues” of law, but rather with legal philosophy [Tur 1978], raising the question of the utility of this discourse. In this regard, Tur argues that one of the uses of jurisprudence is to build up a framework and a vocabulary for specific analysis within the law [Tur 1978]. That is the purpose of this work, the creation of a new way to conceptualize and discuss the law and the institutions that have grown up around it. Also this work will serve to link ‘legal philosophy’ to ‘concrete issues’—possibly the only formally logical way to do this, because it involves no logical ‘jumps’, since the framework requires a full set of definitions.

Moreover, Schubert [1968] explained the need for “behavioral jurisprudence.” By characterizing it as an approach that “seeks to relate what we think we know, and what we can learn, about how persons behave in adjudicatory roles and institutional relationships, to a general body of theory about human decision-making behavior.” He also stresses the particular importance of four areas that distinguish behavioral

jurisprudence from traditional jurisprudence, namely: the use of theory, data, subjects of study, and culture. Thus, inquiry should focus on “what human beings, cast in socially defined roles in certain characteristic types of decision-making sequences which traditionally have been identified as ‘legal,’ do in their interactions and transactions with each other” [Schubert 1968 at 409]. The importance Schubert attributes to socially and institutionally defined roles, culture, and behavior is an essential aspect of Schubert’s notion of behavioral jurisprudence. It is the refinement of (or formalism of) behavioral jurisprudence that calls for generative social science methods that allow one to explicitly represent humans and how they ‘work’ [see generally Epstein 2006].

Motivation for the Current Study

Jurisprudence has a long and rich literature. Notions of law and justice have occupied many academics and philosophers over the years. Some of this literature has focused on whether or not judge made law (Common Law) evolves to produce an “efficient” solution for society. Most of the work on this topic, save one notable exception, has been theoretical, including game theoretic, providing rich narrative and logical discussions about how judges and litigants think and behave [see generally, Elliott 1985]. The general conclusion is that the Common Law evolves and will produce an efficient solution for society. The one analytic study that tackles this question [Niblett 2010], however, found no evidence of a general convergence to efficient outcomes.

As discussed above, this juxtaposition, logical arguments concluding that the law must evolve and an analytic finding that it does not, now creates an ideal situation for

simulation-supported abductive investigation. Our current model, Θ , about the U.S. Courts is quite detailed and includes many ideas about how and why the Common Law should evolve (discussed more fully below) to more efficient states. But now we have a surprising dynamic, ϕ , one that is counter-indicated by our theory of the Courts ($\Theta \Rightarrow \neg\phi$). Now the challenge becomes, can we build up a generative representation of the Courts that will allow us to find an additional feature, α , that makes the surprising dynamic, ϕ , follow from our current model, Θ , as a matter of course ($\Theta \cup \alpha \Rightarrow \phi$)?

Could both sides be correct? In the 1970's Thomas Schelling [1978] demonstrated how a social system could generate seemingly mutually exclusive signals. With a very simple agent-based model Schelling showed that a social system could produce segregated settlement patterns, with a population of citizens that would prefer more integration. Regarding the evolution of Common Law, could a similar dynamic be at work? Could the Common Law actually evolve while at the same time produce signals that seem to indicate that it does not? A judicially focused agent-based model may be the bridge between these two camps, the logic that indicates the Common Law should evolve and the evidence that indicates that it does not. Moreover, given the growing evidence that the "rules of the game" often have as much or more impact on the dynamics of the system than do the players, it is an open question as to the relative importance of the judges vs. the rules and structure of the judiciary in determining its performance. If we want to change the legal system's dynamics do we need to change the judges, the system, or both? The work presented here is an initial step toward creating representative models and providing the foundation for additional work to explore these types of questions.

BACKGROUND

This section discusses the U.S. Article III Federal Courts, the use of *stare decisis* and precedent, and evolutionary change within a common law system.

The U.S. Article III Federal Courts

The Federal Courts of the United States are created in Article III of the U.S. Constitution (Supplementary Information Section B¹ contains the full text of Article III). Given the importance of the legal system, Article III is remarkably short, only 758 words. In Article III Section 1 the U.S. Supreme Court is created and Congress is given the power to create lower courts as deemed necessary. Moreover, judges shall be compensated for their service and shall continue to hold their position during periods of good behavior.

Section 2 spells out the jurisdiction of the courts. Essentially, the Article III courts have jurisdiction over cases and controversies between/among the States and its citizens; between/among the States and its citizens and foreign entities; and where the U.S., its representatives, or its actions are a subject. This section also describes under what circumstances the U.S. Supreme Court has original vs. appellate jurisdiction. Finally, this section articulates the use of juries and the location of trials.

¹ Supplementary Information can be found at: <http://css.gmu.edu/mkoehler>.

Section 3 contains some details about the crime of Treason and how it may be tried and punished.

The Common Law

Though a somewhat vague term, for our purposes the Common Law can be thought of as judge-made law, in contrast to constitutions and legislative acts [Friedman 2000]. The Common Law is somewhat unique to the English legal tradition (which the U.S. draws from heavily). Much of the world has a civil law system, which is thought to have started in 450 B.C. with the publication of the XII Tablets of Rome. In a civil law system the sources of law are statutes, regulations and customs [Merryman 1985]. It should be noted, also, that that list of sources is in order of authority and that judges are not seen as a source of legal rules. In fact, judges are precluded from examining legal works other than statutes, regulations, and customs when deciding a case. Moreover, judges are not allowed to use previous cases as a source of legal rules [Merryman 1985]; meaning, there is no common (judge made) law in a civil law system.

The civil law system stands in contrast to the Common Law system where judges are seen as a source of law. The Common Law tradition is thought to have started in 1066 A.D. when the Normans conquered England [Merryman 1985]. In the Common Law, the expression of “unwritten” general custom by judges is seen as an extremely important component of law [Friedman 1973]. “Common law was judge-made law—molded, refined, examined, and changed in the crucible of actual decision, and handed down from generation to generation in the form of reported cases” [Friedman 1973, at 17]. This

brings us to one of the central principles of the Common Law, the notion of precedent or *stare decisis*, essentially the principle of letting the previous decisions stand. This means judges are “bound” by the decisions they and their colleagues have made over time. This is not a “hard” rule, of course. Previous rules can be overturned if they are egregiously wrong or no longer applicable. However, the tool used by judges far more frequently is that of distinguishing a current case from the previous line of precedent; thus, allowing the judge the freedom to make a new decision [Friedman 1973].

Precedent

Precedent is the embodiment of the “relative importance” of a judge’s opinion. When a judge renders an opinion it becomes a precedent on the legal issues in the case. Adding the legal tradition of *stare decisis* (let the decision stand), earlier cases become binding precedent on subsequent cases (to a greater or lesser degree, see *infra*). Posner [1998] has a very interesting perspective on precedent. He describes precedent as a capital stock of information. With a single decision carrying little weight, as additional decisions cite the original and follow suit, then the collection of cases becomes a stronger precedent. This is because a single case holds for a particular set of facts and is, by tradition, interpreted narrowly. In order to create a broad Common Law holding one must have a large number of decisions that come to the same conclusion from a wide variety of fact patterns [Landes and Posner 1976].

However, as with any capital stock, precedent can depreciate over time and must be replenished with new cases [Posner 1998, and Landes and Posner 1976]. This is

especially true for case law in highly dynamic areas. This dynamism can come from legislative activity or social and technologic change [Landes and Posner 1976]. This appears to create a proportional attachment-like [Simon 1955] dynamic within the case citation network. The Simon proportional attachment is a “rich get richer” dynamic for network creation. When a new node or entity enters the system the likelihood of it connecting with other elements in the system is proportional to the connections each existing element has already. If this dynamic is the case, then one would expect to find a power law distribution in the citation counts.

This may, in fact, be the case. Smith [2007] found strong indications of power law distributions [Clauset, et al. 2009] in the citation count of State and Federal cases. In the current study, this dynamic should be seen as increased standard deviations and decreased rates of convergence as a problem becomes more difficult. It should be noted, however, that a key component of the Landes and Posner study is missing in the model created here: namely, that of citizens to bring a suit before the court. In the Landes and Posner analysis citizens make up an initial filter, if the legal outcome is clear or the alternative is not substantially preferable to the current state of the law, then the suit will not be brought before the court. In the model created here the role of the citizenry is abstracted as random draws to determine which case will be heard and the nature of the counter “argument.”

The Efficiency of the Common Law

There is an enormous literature about the efficiency of the Common Law (rules created by judges as they decide cases). There is also an enormous literature dealing with the Common Law's inefficiency due to biases within the system (usually centered around judges' decision-making). Much of this literature has been influenced by Coase's article: The Problem of Social Cost [Coase 1960], in which he introduced the now famous "Coase Theorem." In a nutshell, this theorem states that if neoclassical assumptions hold (rationality, no transaction costs, etc.) and actors have exclusively alienable rights, then, regardless of the legal rules, resources will be allocated efficiently. Basically, with no transaction costs the parties to a lawsuit will allocate resources efficiently. The law is important only to give the parties a place to start bargaining [Coase 1960 and generally, Cooter and Ulen 2000].

However, there does seem to be some confusion about the Coase Theorem in the legal literature. Many appear to interpret Coase as saying the law should have a bright-line rule, the outcome should be clear. However, Coase actually argues against a single bright-line rule. In fact, Coase states that Common Law should *not* converge to a single bright-line rule and argues that this result would, in fact, not be desirable from an economic perspective. "The objection to the rule in *Boulston's* case is that [...the plaintiff] can *never* be liable. It fixes the rule of liability at one pole: and this is as undesirable, from an economic point of view, as fixing the rule at the other pole..." [Coase 1960, at 38]. So, ideally, what the Common Law should converge to is a standard *process* for weighing the economic and welfare impacts of activities, not a bright-line rule of liability. While I certainly take no issue with the perspective of Niblett et al.

(discussed fully *infra*) that predictability is important within the law, what Coase argues is that this predictability is in the process and method, not in a particular rule of liability. To Coase, the utility of law is to clearly articulate how decisions about property rights should be made and intervene where transaction costs are not zero. It should be stressed that the intervention should come in the form of a process to determine the outcome of, ideally, what would be a negotiation between the two parties to the case if transaction costs were low enough.

The predictability of the process is consistent with earlier jurisprudential thought, as well. “The substitution of efficient for final causes as explanations of natural phenomena has been paralleled by a revolution in political thought. We do not base institutions upon deduction from assumed principles of human nature; instead, we require them to exhibit practical utility, and we rest them upon a foundation of policy and established adaptation to human needs” [Pound 1908, at 609]. From Pound’s perspective a *jus naturale* jurisprudence, or a natural law from first principles, forms a static legal system, one where legal concepts are static and taken for granted and the rules deduced from them tend to “decay” [Pound 1908]. He continues by espousing the virtues of German legal reform, “It lays down principles from which to deduce, not rules, but decisions; and decision will indicate a rule only so long as the conditions to which they are applied cause them to express the principle [...]. This, [...] is the true way to make rules fit cases instead of making cases fit rules” [Pound 1908, at 613]. Though Pound is interested in process, it should be noted that Germany is a civil law jurisdiction and not a

Common Law jurisdiction, which limits the utility of this particular example in the present argument.

There is a tension here, of course. One does not want a legal system that is static, however one does not want a legal system that is constantly and quickly changing, either. These concepts were articulated by Cover [1983] as jurisgenerative systems (those that produce new legal rules) and jurispathic systems (those that remove legal rules). For example, a judge is presented with, at least, two arguments about a case (one from the plaintiff and one from the defendant), and assume for the moment that each is premised on existing case law. The judge can find one compelling and find for that theory while dismissing the other. This does not create any new legal rules and may end the use of the losing argument. On the other hand, if the judge finds elements of each side's theory compelling h/she may create a hybrid solution to the case. This will create a new legal rule and, likely, not remove either side's original theory of the case. Now the legal system has gained complexity. This dynamic is exacerbated when one, or both, of the sides present a theory not currently part of the legal system (see *infra* for a counterargument).

More recently there is an expansive and growing literature on the economic analysis of the law, or Law and Economics [see generally: Posner 1998, Cooter and Ulen 2000, and Mercuro and Medema 2006]. There is rich literature on the use of game theory and the law [see generally Baird et al. 1994]. There is even a small literature on Behavioral Law and Economics drawing from the growing field of experimental and behavioral game theory and economics [Sunstein 2000]. However, with the exception of Behavioral Law and Economics, these analytic techniques are based largely on the

assumptions inherent in neoclassical microeconomics, many of which are unrealistic with respect to human capabilities, such as infinite computing power and perfect rationality.

Evolution and the Common Law

Much of what we do as humans involves problem solving. Some problems are important: should we invade this or that country?, some are less important: do I want banana cream pie or coconut cream pie for dessert? This suggests that social systems are, to some extent, information processing systems [see generally, Hayek 1978 and Schelling 1978]. Interestingly, this information processing is highly sensitive, at least in an individual sense, to how the problem is presented and the order in which it is solved [see generally, Page 2006, and Thaler and Sunstein 2009]. From the complexity sciences, these topics almost inevitably lead to a discussion of emergence, the idea that the behavior of a system is not easily discerned from a reductionist study of that system's components [see generally, Holland 1995 and Simon 2001].

Many have explored such topics and it is beyond the scope of this study to deal with all of them. Rather, this study will focus on an as yet underrepresented subject of complexity study; namely, the legal system of the United States. More specifically, this is an examination of the Federal courts of the U.S. as a computational system. It is my belief that treating the courts as a computational system will provide many new insights into their dynamics, potential failings, and suggest new ideas for improving their performance.

The work presented here explicitly concerns understanding the legal system as a way to solve society's hard problems. Human society is a classic complex adaptive system and has been the subject of a great many publications. As H. L. A. Hart stated in his celebrated jurisprudential work: "Few questions concerning human society have been asked with such persistence and answered by serious thinkers in so many diverse, strange, and even paradoxical ways as the question 'What is law?'" [Hart 1961, at 1]. Hart goes on to make a key distinction. Law is different than convergent social behavior. For example, many individuals go to the movies each week. It is also true that many individuals pay their taxes each year. The former is a social convention or convergent behavior, such as the El Farol problem [Arthur 1994] or some other instance of synchrony found in a social system [see generally, Strogatz 2003]. In contrast, law has coercion associated with it, typically the power of a sovereign. Hart's expression of an informal notion of what is included in a system of Laws included a set of courts that: "determine what the rules are and when they have been broken, and to fix the punishment or compensation to be paid..."[Hart 1961, at 3]. Another important distinction made by Shapiro is between "the law" and "law" [Shapiro 2011]. "The law" refers to a specific law while "law" refers to the concept of law rather than to a specific rule or statute. A key piece of research used to motivate this work is that of Niblett, Posner, and Shleifer [2010]. Though they discuss "law," the evidence used to support their findings is about "the law," here, "the law" of economic loss. I bring up these distinctions to highlight what the present work is attempting to be and what it is not. The present study is an attempt to create an experimental platform to understand the implications of how

decisions are made within “law.” This work is not trying to understand a specific rule, or line of reasoning. It very well may form the foundation for such an inquiry in the future, but at present this is not the focus.

As such, the development of any judicial system will be very abstract. This approach is necessary because our legal system is, by our Constitution (Article III), charged with solving problems and disputes. Moreover, much ink has been spilled over the years debating whether or not the judge-made law, or Common Law, evolves to a more efficient state. However, none, save Niblett, have attempted any experimental or evidentiary work to refute or confirm the hypothesis that the Common Law can, and does, evolve. The work presented here can be seen as an initial attempt at filling this experimental gap. Arguably this work could be thought of as Generative Computational Jurisprudence (as introduced above). One should also note, the Niblett work built up a dataset from *state courts*. The model created here uses data from *federal courts*. I chose to use federal courts here based upon the availability of data; however, there is no reason state courts could not be modeled here should the data be available. The model and the simulation that implements it, are designed to be very general and any court structure and judicial network can be used.

As will be seen below, efficient will be defined in a highly constrained manner: as moving the mean “score” of the population towards a single, potentially globally optimal, number (as discussed below optimal is a particular minimum value depending upon the problem). This is in contrast to the typical usage of the term efficiency as introduced by Posner back in the 1970s when he started the economic analysis of the law [Marciano and

Khalil 2012]. Efficiency as defined by Posner [1979] was centered on wealth, the dollar value of items individuals wanted to purchase or the amount of money it would take for someone to part with an item.

Is it reasonable to think of the legal system as a system that evolves and tries to solve problems to make society function more efficiently? Posner has argued that this is the case because efficient rules are litigated less often than are inefficient rules. Therefore even if courts decided cases randomly the Common Law should become more efficient over time [Posner 1998]. Is that all that is necessary for a system to exhibit Darwinian dynamics? For example, most statements of Darwinian evolution include the notion of fitness. Marciano and Khalil [2012] rightly point out that a meaningful notion of fitness requires scarcity. If there is no scarcity then all things/decisions are equally fit.

In a review of the literature that discusses the evolutionary tradition in jurisprudence, Elliot [1985] found four categories of its use: social, doctrinal, economic, and sociobiological. In the social use of evolutionary theory, it is not that the law evolves *per se* but rather that law is part of society and society is evolving, and, so too, must the law. The doctrinal view expands the social category, claiming that not only does society evolve but so too do specific legal doctrines. Elliot argues that the economic perspective of legal evolution is where Darwinian dynamics come into play. From the economic viewpoint society is trying to minimize costs (maximize welfare); which, in turn, cause the law to adapt and evolve. Finally, the sociobiological view stresses Darwinian forces as the manner in which law has and continues to develop.

Godfrey-Smith [2010] has proposed a minimal concept of what constitutes a Darwinian population: “A *Darwinian population in the minimal sense* is a collection of causally connected individual things in which there is variation in character, which leads to differences in reproductive output (differences in how much or how quickly individuals reproduce), and which is inherited to some extent” [Godfrey-Smith 2010]. Godfrey-Smith takes a very “hard line” view of Darwinian dynamics, but he does not preclude Darwinian evolutionary dynamics outside of biology.

Godfrey-Smith cites a very insightful example about Polynesian canoes due to the French philosopher Emile-Auguste Chartier, which will be helpful when determining if the Common Law can evolve. Here Chartier claims that every boat is a copy of another boat. Boats that function well are copied and badly designed boats sink and are, thus, not copied. For Godfrey-Smith this human system has the necessary components for Darwinian evolution. The important point for him being that there is a causal relationship between the “parent boat” and the “child boat.” The structures of the parent boats, and how well they function in the open water, directly influences the structures that appear on the child boats. For Godfrey-Smith it is not important that the child boats are created by human craftsmen and not by the boats themselves. What is key is the direct relationship between the presence and function of structures on the parent and the presence of structures on the child.

When humans become more than the replicator, however, the Darwinian connection starts to breakdown. As humans, or any intelligence, begin to take a hand in moving characteristics and structure from a previous generation to a subsequent

generation, in Godfrey-Smith's eyes the Darwinian dynamic is lost as the causal relationship between parent and child is lost. In essence, for Godfrey-Smith it seems that trial and error boat design is Darwinian, but CAD boat design is not. Where does this leave the Common Law?

If we think about the Common Law as depicted in Figure 2, at time t there exists some number of Common Law principles (labeled as "CL 1 – 8"). Some Common Law principles already exist (colored green); others are developed during that time period (colored purple). As the Common Law system moves forward to time $t+1$ some Common Law principles move forward by default (they exist and continue to exist); while others, shown in Figure 2, move forward via adjudication (labeled J 1 – 5 in Figure 2) or are culled. When Common Law principles move forward in time via adjudication this could constitute "classic" Darwinian evolution. However, judges actively create the child of the Common Law principles that come before them. Judges think about the principles, what is justice regarding the case before them, what other judges decide, and so on. This active participation in deciding what the next generation of Common Law principles should be destroys the causal relationship between parent and child, from the perspective of Godfrey-Smith; therefore, the Common Law cannot evolve in a strict Darwinian sense.

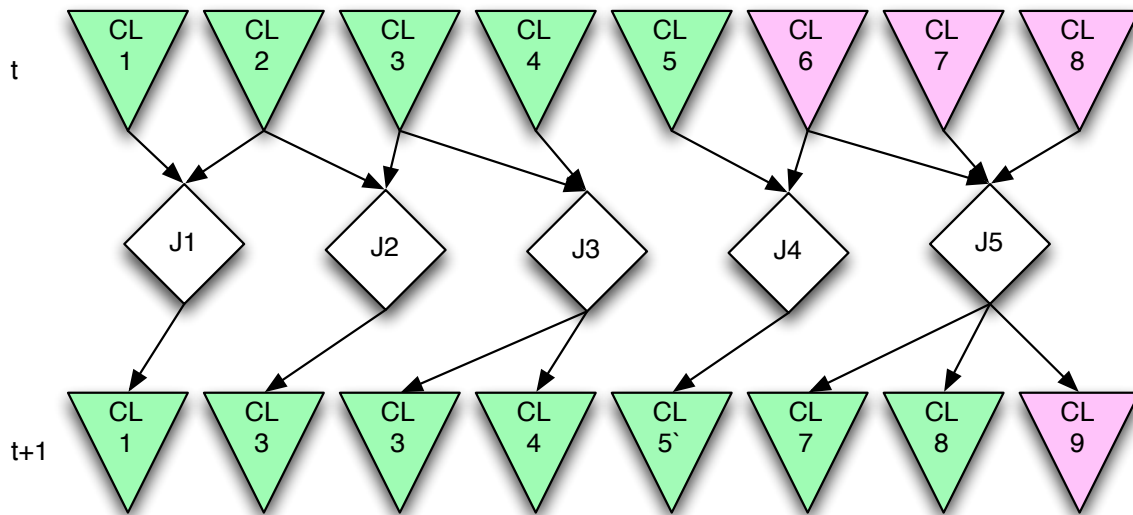


Figure 2. A simple depiction of the movement of the Common Law through time via adjudication.

Given this and all the work that has been done to date discussing how the Common Law should evolve, does the use evolutionary concepts and principles not provide insight in to the structure and function of the Common Law? Evolutionary concepts do provide insight into the dynamics of the Common Law. Perhaps Common Law does not progress and develop through time in a strictly Darwinian sense, but, as many have argued, it does change over time and respond to current conditions. The Common Law may not be a true “Darwinian Population” but it is certainly is a biologically inspired search heuristic for discovering and applying solutions to social problems and changing over time to accommodate changes to the society in which it is embedded. To use the categories of Elliot, this falls into the doctrinal or economic perspective of legal evolution, where evolution is more metaphoric in mechanism rather than strictly Darwinian.

Mathematical and Analytical Approaches to Evolution and the Common Law

Many have commented on the question of the evolution of the Common Law, much of it being narrative in structure [see generally Elliott 1985]. A few have used formal methods to analyze Common Law evolution or gathered specific data sets, however. Of particular interest in this regard are the works of Niblett et al. [2010] and work by Cooter and Kornhauser [1980] (see below).

Cooter and Kornhauser modeled the courts as a Markov process to explore the impact of legal evolution with ignorant judges. Their findings are not unexpected: 1) blind evolution will not create an optimal set of legal rules, 2) in a stable state all legal rules regardless of fitness will exist for some period of time, 3) if “worse” legal rules are litigated more often than “better” legal rules then the resulting stable state is better [Cooter and Kornhauser 1980]. These findings are interesting but they are based on a number of strong assumptions about the Common Law and judges, four of which will be discussed here. First, all laws can be cardinally ordered. Second, there is no purposiveness to the behavior of judges, they simply change an existing law with some probability. Third, when a judge changes a law they are equally likely to make it worse as make it better. Fourth, the ranking of the laws does not change over time, meaning, in essence, that the society around the Common Law is static. This work presents a reasonable summary of the arguments about how and why the common law should evolve, this becomes a major component of our current model of the system, Θ .

Uniquely, Niblett et al. tested the idea that the Common Law will evolve to an efficient state by gathering a dataset comprised of 461 state court appellate decisions regarding the economic loss rule (ELR) in construction disputes (an issue of commercial contract law) [Niblett et al. 2010]. What Niblett et al. concluded from their analysis was that the Common Law did not evolve to a stable state and evolved differently in different jurisdictions (the data contained cases from many States). This finding now becomes our surprising system dynamic, ϕ .

Though not entirely clear from their published findings, the authors appeared to be expecting this branch of commercial law to converge to a single, bright-line rule in a monotonic way. This is contrary to the Coase Theorem, which states that Common Law should converge to a predictable method for making allocation choices. Moreover, the findings reported by Niblett et al. are reasonably consistent with some of the dynamics reported by Cooter and Kornhauser [1980].

Niblett et al. clearly views jurispathic judicial decision-making as the preferred method, and they expected to find the law converge to a single outcome. Gennaioli and Shleifer [2007], take a contrarian position. They argue, among other things, that jurispathic judicial decision-making actually makes the law less precise and, therefore, less predictable [Gennaioli and Shleifer 2007]. To Gennaioli and Shleifer jurisgenerative (see *infra* for a brief discussion of jurispathic and jurisgenerative judicial decision-making) judicial decision-making makes the law more precise which, in turn, makes the law more predictable [Gennaioli and Shleifer 2007]. Also of note in the Gennaioli and Shleifer work is their finding that heterogeneity among the judges within a Common Law

system is an important aspect for evolution to cause improvement. So long as there is diversity within the judiciary, the biases of individual judges tends to washout and, on average, the evolution of the legal system tends toward improvement [Gennaioli and Shleifer 2007]. Interestingly, these findings are consistent with work on diversity and decision-making by Hong and Page [2004], potentially with Couzin et al. [2011] and certainly with the basic ideas of particle swarm optimization [see Kennedy and Eberhart, 1995].

A GENERATIVE, MODEL-BASED APPROACH

“...the future of legal studies belong[s] to the economist and statistician rather than the ‘black-letter’ man.” ~Posner (paraphrasing O. W. Holmes), 1987

This section introduces the idea that judicial systems are Complex Adaptive Systems and the use of generative methods to examine a judicial system.

Why? Courts as Complex Adaptive Systems

To this point we have established both a crisp abductive problem and that tools beyond traditional jurisprudence are valid here. But, is it reasonable to use complexity science, in particular, to study the law? In order to determine if the tools and techniques of complexity science are appropriate for the present analysis of the U.S. Article III Federal Courts one must establish that these courts are, in fact, a complex system. More specifically: Are the U.S. Article III Federal Courts a complex adaptive system?

First, of all, what is a complex adaptive system? Complex adaptive systems (CAS) have received a great deal of attention the recent years, typically under the moniker of Complexity. For our purposes here the basis of CAS derives from two foundational works and one more recent work. These are Holland [1995] and Simon [2001], and more recently Miller and Page [2007].

A CAS is a system “composed of interacting agents described in terms of rules. These agents adapt by changing their rules as experience accumulates. In *cas* [sic], a major part of the environment of an given adaptive agent consists of other adaptive agents, so that a portion of any agent’s efforts at adaptation is spent adapting to other adaptive agents” [Holland 1995, at 10]. This leads to the idea of “near decomposability” discussed by Simon [2001]. In essence, nearly decomposable systems are systems of systems in which the subsystems have more interactions within themselves than with other subsystems. In its “strong form” these systems can be represented by an $n \times n$ interaction matrix where the diagonal is comprised mainly of high numbers representing strong interactions among components of subsystems and small numbers off the diagonal representing limited interaction among subsystems. Simon states that these are strong assumptions for a social system, however the concepts and representation can still be used, here the $n \times n$ matrix becomes a sort of influence matrix among the humans [Simon 2001].

Turning back to Holland’s articulation of CAS, there are a small number of key components to CAS, including:

Aggregation: entities that are part of the CAS in question can be placed in one or more categories and treated as similar *and* the micro-structures or dynamics of the system map into a macro-structure or dynamic.

Tagging: this is a way for the components of a CAS to distinguish what might otherwise not be distinguishable and allows for aggregation and structure formation.

Nonlinearity: this is the basic property that the behavior of the system as a whole is not a simple weighted sum of the components.

Flows: CAS are inherently network based. The term network may be loosely applied to a given CAS, however. Flow, here, refers mainly to the characteristic that “things” flow around a CAS and may have various impacts on the sending or receiving entities (e.g., positive or negative feedback or externalities).

Diversity: CAS are made up of many heterogeneous components; moreover, this heterogeneity is often a function of the system as a whole and will attempt to be conserved as individual components are lost or changed.

Internal Models: the entities that make up the CAS must have some sort of internal representation of the relevant parts of the CAS that actively shapes the behavior of the entity.

Building Blocks: internal models are made up reusable elements that can be used to represent parts of the CAS. It is the combination of a relatively small number of different types of building blocks that allows a entity within a CAS to represent what is, essentially, a system that can generate perpetual novelty.

This by no means fully characterizes a CAS. Miller and Page articulate CAS as an “Eightfold Path”: Information and connections, Goals, Communication among the agents, Interaction, Payoffs, Strategies and actions, Cognition, and Model focus and heterogeneity [Miller and Page, 2007, Table 7.1]. The Miller and Page Eightfold Path is not incompatible with the seven characteristics articulated by Holland. In fact, in dealing with a definition of what CAS are Miller and Page eventually turn to the Justice Stewart

quote regarding obscenity: “I shall not today attempt further to define the kinds of material I understand to be embraced within that shorthand description; and perhaps I could never succeed in intelligently doing so. But I know it when I see it...” (Jacobellis v. Ohio, 378 U.S. 184, 1964, Justice Stewart, concurring).

Ruhl has made a strong case to use a complex adaptive systems perspective for legal analysis [Ruhl 2008]. Ruhl discusses a number of reasons why jurisprudential scholars and lawyers, and policy makers should be conversant with the ideas of CAS. First, if what the law is trying to govern is a CAS then one must understand CAS to appropriately craft laws to govern them. Second, if the law is a CAS, then one must understand CAS to understand the dynamics of the law. Finally, if the law and what is being governed are both CAS, then understanding their interactions will likely require knowledge of CAS.

Courts and Judges as a Complex Adaptive System

As discussed above there are a number of key components necessary to claim a system is a CAS. I will now turn to a discussion of how well the legal system fits the paradigm of CAS.

Aggregation: the entities within the legal system can be placed in to a finite number of bins and treated as similar. The bins include such categories as: appellate judges, Supreme Court justices, plaintiffs, and defendants. Furthermore, the microbehavior of these entities aggregates to macro-level dynamics such as settlement rates, dockets, precedence, and citation networks among others.

Tagging: clearly this is a very important feature of the legal system. Tagging is used to identify plaintiffs, defendants, and judges each of whom would otherwise be tagged as lawyers. This tagging has a profound impact on what would otherwise be a symmetrical system. In the present example, tagging is used to determine, *inter alia*, who is the finder of fact, who is the finder of law, and who has the burden of proof.

Nonlinearity: the dynamics of the legal system have clear indications of nonlinearity as evidenced by the citation network (which is clearly power law distributed, at least over certain regions [Smith 2007]), which implies that there exists no “mean impact” of a court case. Some cases have very little impact while others can have very large impact.

Flows: the legal system is made up of a large number of flows that have significant impact on its dynamics. Information flows in the form of precedent and holdings can have a significant impact on the behavior of the system. Flows of resources will impact who can enter the legal system and how. As a final example, the flow of judges from law school to courts and then movement among the courts can have a significant impact on what information is used when deciding a case, and even the flow of law clerks have been a source of study [Katz and Stafford 2010].

Diversity: there is a great amount of diversity within the legal sector. Not only are there lawyers, citizens, and judges, but also judges are further divided into different jurisdictions, appellate levels and competencies. Furthermore, laws are divided into titles that deal with particular topics and differentially impact citizens, themselves falling into many different types.

Internal Models: the entities within the legal system must have representations of winning arguments and the likely behaviors of their adversaries in order to create the legal arguments. Furthermore, each individual has a representation of the court process and the role that various parties play.

Building Blocks: the entities within the legal system use building blocks contracts and legal briefs are all comprised of standard language and structure. The same holds for the creation of law, regulations, and procedures. Legal concepts can be reconfigured to continually create new theories of a case and of the law.

Finally, how does the legal system map to concepts of near decomposability? The legal system fits this concept very well. For example, courts within a state jurisdiction have many more interactions with each other than they do with other states. Similarly, Federal Circuit Courts have more interaction within a circuit than between circuits. This is the case as courts and decisions within a jurisdiction are controlling precedent unlike decisions that come from outside of a jurisdiction which are merely persuasive precedent.

Although there is an impressive amount of literature on law and complexity, as discussed above, it exists largely at the metaphorical or descriptive level. In a number of articles Ruhl makes a strong case for approaching law as a complex system [Ruhl 2006 and 1996]. The Antitrust Bulletin devoted an issue to looking at antitrust law from a complexity perspective [see generally, Gundlach and Foer 2006] for an introduction to the issue, and Wilkinson [2006] for a general discussion of complex adaptive systems and antitrust, mainly drawing comparisons between ecosystems of species and ecosystems of firms and elements of path dependency. Interestingly Wilkinson advocates for the use of

agent-based modeling for the analysis of the dynamics of markets when being examined for antitrust issues, but does not appear to create a model to do so. These previous works make important points about the law and judicial system being a complex system.

Moreover, they advocate strongly for the use of the tools of complexity science, however, they do not create the tools or apply them. Two exceptions do exist: one is Picker [1997], who created a cellular automata system to explore the evolutionary dynamics of norms. This effort was a single step beyond the traditional two-by-two games that are typically used on legal analysis [Picker 1997, at 1226]. The other is work I completed [Koehler 2007] examining judicial decision making to explore the utility of jurisgenerative (as opposed to jurispathic) decision making on the efficiency of resource extraction within a population of artificial agents.

Many have examined the U.S. Courts analytically. For example, given newly available electronic databases of cases and powerful text processing tools, many have examined and described the citation network of cases and statutes. Fowler, et al. [2007] undertook an analytic analysis of the citation network of U.S. Supreme Court majority opinions (26,681) and the cases that cite them from 1791 to 2005. This was done to create network-based importance scores to measure the relative precedent importance of the Supreme Court cases. Katz et al. has explored a number of network relationships among the U.S. Code, the U.S. Courts, and the judiciary and legal education system [for example: Katz, et al. 2008, Bommarito II and Katz 2010]. Others have looked for statistical evidence of bias in judicial decision making [for example, Shayo and Zussman

2011, and Gazal-Ayal and Sulitzeanu-Kenan 2010]. To date these efforts have been analytic and have not included the generative aspect advocated here.

Given the above, is an agent-model the most appropriate tool for analyzing the dynamics of the Federal judiciary? First, the legal system is made up of a number of interacting autonomous entities that depend on interactions with each other to create their future state. When dealing with these sorts of systems, except in very trivial cases, the most efficient way to understand its future state is to iterate forward in time—simulate it [Buss, et al. 1991]. Moreover, the legal system is made up of moderate numbers of actors [Ruhl 2008]. Other tools (such as game theory) would be appropriate if the interactions were bilateral or “n” in number [Miller and Page 2007]. The system may be susceptible to outliers and may exhibit scale-free dynamics [Ruhl 2008] reports anecdotal evidence of significantly skewed behavior: 0.025% of cases account for 80% of all citations). “Average agent” is likely not a meaningful term, as there are many different kinds of agents within the judicial system. Even if one limits the type of agent to judges, judges sit on different courts, have different backgrounds, and hear different cases in different orders. The path dependency of the law (*stare decisis* explicitly creates path dependency within the U.S. Federal judicial system [see generally, Hathaway 2001] also creates difficulties for other analytic methods. Finally, law is a system that exhibits emergence (macroscopic order that is difficult to predict from microscopic characteristics) [Picker 1997, and especially as it relates to the Common Law, Ogus 1989 and Hayek 1973]. Emergence in social systems such as those being studied here (moderate in scale, high degrees of meaningful heterogeneity, and composed of agents that can learn/adapt) can

be difficult to study with traditional tools. Finally, a generative approach is also consistent with the perspective articulated by Alchain [1950], who stressed the importance of uncertainty in economic decision-making and that economic decisions were made iteratively (evolutionarily) based on experience rather than an *a priori* maximization. Using an ABM we can easily explore these sorts of dynamics.

Therefore, agent-model appears to be a reasonable way to explore the dynamics of the U.S. Federal Courts. Moreover, given the particular characteristics outlined above, an ABM appears to be the most natural way to represent the U.S. Courts system. The use of generative methods provides very powerful tools for understanding complex adaptive systems, however generative methods have their limitations. Creating a simulation does not produce a mathematical proof. Once the model is created, each run becomes a simulation that produces a deduction or sufficiency theorem (assumptions and rules + these initial conditions yield this outcome) [see generally, Epstein 2006, Axtell 2000, Epstein and Axtell 1996]. Though not mathematical proofs, this method provides ways to test our hypotheses about the dynamics of a system and understand the sufficiency of our theories about what causes their dynamics.

As powerful as generative methods can be in this space, I am aware of only two studies utilizing them: Picker [1997] and Koehler [2007]. Picker reported the first application of generative methods to jurisprudence of which I am aware. In this work he created a simple symmetric game played by adjacent automata in a 2D grid. Picker's initial example is the spatial prisoner's dilemma. His second example is of a coordination game. He demonstrates that with certain payoff structures one can show a sharp transition

point in eventual outcome as one varies the initial strategy distribution, and with learning/imitation the population can settle on the best strategy if the payoffs for coordination are sufficiently high. He goes on to show how varying agent decision-making and payoff structure can change the shape and location of the transition points from coordination on one strategy to coordination on another. He concludes by articulating lessons that policy makers can draw from the results about how to change a social norm.

In previous work, Koehler [2007], I created a model to better understand the effects of two classes of judicial decision making: jurispathic decision making and jurisgenerative decision making. Jurispathic decision making “trims” legal theory by finding only for one side in a suit. Jurisgenerative decision making, on the other hand, creates legal theory by crafting a compromise solution among parties to a suit and not, unlike the jurispathic method, find one side incorrect. In the jurisprudential literature there was a strong bias towards jurisgenerative decision-making but nothing other than rich narrative to support that claim. I created an agent-based model to test the hypothesis that jurisgenerative decision making was, in fact, better than jurispathic. This model was a simple society of agents extracting resources from an environment. If two agents were very close together they had to use the same method of resource extraction. In order to decide what that method would be the two agents would “sue” each other. The method of decision-making by the judge was varied (jurispathic or jurisgenerative with no, partial, or full information about what good extraction strategies were) and the overall welfare of the society was measured. The results of his simple model indicated that only if a judge

had full information did jurisgenerative decision making become clearly superior to jurispathic decision-making.

In following on the simple models created by Picker and myself, the questions presented here are addressed with a simple agent-based model of the U.S. Article III Federal Courts. We attempt here to create a model that is as simple as possible while capturing the relevant features of the U.S. Courts. Now we turn to the details of that model.

Having defined our abductive problem and having established a foundation for the utility of the tools of complexity science, specifically agent-based models in this jurisprudential space we now turn our attention to the development of an initial agent-based model of a judicial system. Using this initial model the goal will be to create a simulation that allows us to explore the dynamics of the most basic or minimum components of the system to achieve Level 1 Empirical Relevance and Relational correspondence to the referent, here the dynamics of the U.S. Courts.

AN INITIAL MINIMAL MODEL

We now turn to the models that will form the core of the analysis of this work. First, a very basic model will be discussed. It was created to demonstrate the potential utility of the method. Next, a model will be built to explore the possibility that a judicial system may be evolving toward better solutions while emitting signals to the contrary. Finally, a more complex model will be discussed that allows one to examine specific institutional types and compare different structures for a judicial system and understand how these structures may impact performance.

The Basic Model and Simulation

All the simulation work discussed herein was implemented within NetLogo 5.0.4. NetLogo is an open source agent-based modeling framework being developed and maintained by the Center for Connected Learning at Northwestern University by Uri Wilensky, et al. [Wilensky 1999]. NetLogo is a Java program and will run on any machine that can run the Java virtual machine. NetLogo has its own scripting language based upon Lisp and Logo.

NetLogo is made up of two basic components: a 2D torodial landscape segmented into an arbitrary number of square cells called the patches, and a set of agents called turtles (also known as agents) (there is a three dimensional version of NetLogo but it was

not used here). The major difference between turtles and patches is that patches are fixed in space and do not move around, whereas turtles can move around.

Both patches and turtles were utilized in this work. The 2D De Jong test set was implemented within the patches. The De Jong test set is a standard set of 5 minimization problems used to test heuristic search algorithms. Additional detail on the De Jong test set can be found in Supplementary Information Section C².

Initial Ground Work

This initial work was undertaken to build the simplest possible representation of the potential dynamics of a hierarchical legal system and how such a system might converge to a single value. Smith [2005] articulated three principles for a minimal, sustainable legal system: “(1) it must produce a final decision; (2) that will be viewed as legitimate; and (3) that is predictable on some scale” [Smith, 2005, at 54]. Furthermore, as pointed out by Shavell [2010], all legal systems have an appellate process. Assuming this is a minimal specification for something that can be termed a legal system, what must the model have? First of all, legitimacy is a perception of a population rather than a feature of the “thing.” If no population is included then the legitimacy requirement goes away. Essentially, we will assume a population that views this legal system as legitimate. Secondly, it must have a set of rules for producing an outcome, this will satisfy the predictability constraint. Finally, it must produce a final decision and include an appeals process.

² Supplementary Information can be found at: <http://css.gmu.edu/koehler>.

This initial judicial model, involving a population of agents coalescing on a single number in five different processes, were used to represent the actual dynamics of hierarchical judicial problem solving system while being, arguably, the simplest possible representation of it. If this representative system fails to show promise then there would be little hope for the full system. Clearly, this specification is too simple to capture all of the relevant components of an actual judicial system. However, in following in Einstein's footsteps ("A model should be as simple as possible, but no simpler"), we will start with this very simple case and see how far it can get us.

Initial Representation of the Legal Environment

Cases and controversies (issues) in this simulated world were represented by integers between 0 and 99 (consistent with the representation of Cooter and Kornhauser). Each agent (of 500 total) was given one, completely arbitrary, integer drawn from $U(0,100]$. Agents existed on a torus. At each time step one agent was chosen, (with replacement, to interact). When agents interact they select another agent at random, also with replacement and then, using their numbers, decide on a single number for each of them to "use."

Two methods are used for deciding on a single number. One method, "mean-it," simply takes the average of the two agents' numbers and assigns that average value back to each agent. The other method, "pick-it," picks one of the two interacting agents' numbers at random and then assigns it to the two interacting agents.

When courts were involved, the case is referenced by a court by the concatenation of the integers of the parties. For example, if two agents came before a court with the

numbers 45 and 6, the case would be “filed” in a hash table under the key “4506.” The court then stores the decision that they make under that key which might be, for example, the average of 45 and 6: 25.5. That decision will be used any time that court hears a case with the ID 4506. It should be noted that the way in which cases are identified and recorded can result in rehearing the same issues if the plaintiff and defendant are switched. If the plaintiff and defendant switch the case would have a new ID and will be treated as a different case, with the ID: 0645 and may have a different outcome (see *infra*).

If the court system is tiered, once the trial court renders a decision, the case will be immediately sent to an appellate court for review. The appellate court will utilize the same decision-making process as the lower court. In the case of the mean-it method the outcome will not change, and such cases were not tested. If the method used is pick-it, the outcome could be different, given the random choice. In this case the outcome is then assigned to the agents and the lower courts are informed of the decision. If necessary, the lower courts update their hash table with the controlling precedent. The case is then sent for review by the Supreme Court, which performs the same process as the appellate court. The Supreme Court’s decision is then sent to all lower courts, which then update their hash tables as necessary. The relevant court networks (appeal and precedent) of this simple proof-of-concept study are shown in Figure 3.

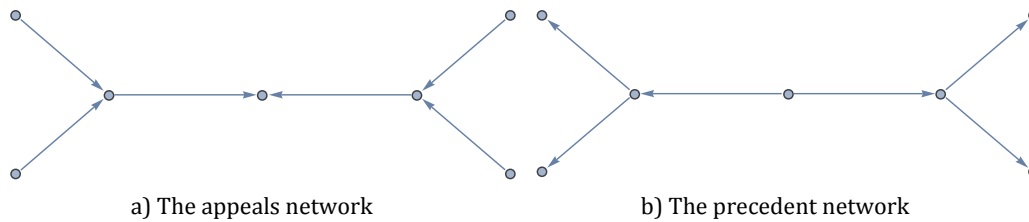


Figure 3. The networks of the model's courts.

In the model the population of agents coalesce upon a single number. As stated previously, all agents start with a number between 0 and 99 inclusive. Once the run starts, the agents have one million time steps to attempt to converge on a single value. This convergence occurs via highly stylized lawsuits or negotiated settlement, described above. As described above, the process is either pick-it (a very simple representation of jurispathic judicial decision making), or mean-it (a very simple representation of jurisgenerative judicial decision-making) (see generally, *supra* or [Cover 1983]) for a discussion of jurispathic and jurisgenerative judicial decision-making).

Initial Results

Our basic hypotheses for this minimal model include: both mean-it and pick-it should converge; the mean-it method should, on average, converge to a value close to 50; the numbers that the pick-it method converges to should be more diffuse than the mean-it method; and the mean-it method should converge more quickly than the pick-it method. There are four basic modes to a model run: mean-it or pick-it to choose between agent numbers, and using bilateral negotiations or a hierarchical, or not, judiciary for decision-making. The judiciary is made up of three tiers: a trial level, an appellate level, and a

Supreme Court. In order to test the effects of hierarchy and appeals on the convergence process, two cases were tested, one with no appeals and one with automatic appeals (akin to automatic review of death penalty cases). When the decision process utilized is mean-it, the appeal version would have no impact, as discussed above, and was not tested. The basic design of experiments used is described in Table 1.

Table 1. The Basic design of experiments used for this simple proof-of-concept.

Decision Method	Decision “Maker”		
	Bilateral Negotiation	With Courts	With Appeals
Average Numbers	100 runs, max time steps = 10^6	100 runs, max time steps = 10^6	N/A
Pick a Number	100 runs, max time steps = 10^6	100 runs, max time steps = 10^6	100 runs, max time steps = 10^6

The stopping condition for the convergence is defined as the population variance that is approximately zero. As expected, the population is readily able to meet the stop condition when averaging values; however the number of unique agents rises dramatically as a result of the decimalization of the initial set of integers. This could be analogous to Common Law converging to a particular outcome while still maintaining a great deal of “nuance.”

On the other hand, when the pick-it strategy is implemented, the population may not converge to a (very) low variance state within the one million time-step limit.

Moreover, as it converges the strategies used by the agents monotonically decrease rather than expanding, as observed in the averaging case. Something to note from these dynamics are that, although a jurispathic system decreases the legal theories used over time, it will **not** necessarily converge to a solution more quickly than jurisgenerative systems. This is an interesting finding by itself, and also provides guidance for the more complex models discussed below, namely convergence rates will not necessarily be solely a function of how jurispathic or jurisgenerative a particular institution may be.

Table 2 collects summary statistics of the runs. Figure 4 shows the dynamics of each run.

Table 2. Summary statistics of the runs.

Decision Method	Decision “Maker”		
	Without Courts, <i>mean(standard deviation)</i>	With Courts, <i>mean(standard deviation)</i>	With Appeals, <i>mean(standard deviation)</i>
Average Numbers	Always Converged: 49.5(1.2) @ 3681(131.7) time steps	Always Converged: 49.6(0.94) @ 7367(186.9) time steps	N/A
Pick a Number	Always Converged: 50.2(31.7) @ 228,506(123,487) time steps	Sometimes Converged: 51.4(26.7) @ 517,555(307,956) time steps	Sometimes Converged: 51.7(28.9) @ 488,281(306,378.9) time steps

In Figure 4, the averaging method behaves exactly as expected with the population coalescing to a value close to 49.5. Largely, the pick-it method behaved as expected, although it is somewhat surprising that it always converged within the one

million time-step limit in the bilateral negotiation case. Once the courts become involved, the system failed to converge in some cases. Fundamentally, there is nothing about the court cases that would preclude convergence to a single number, but there is one particular aspect that could make convergence very difficult, especially when appeals are allowed. The “pick-it with appeals” represents a potential extreme case. For example, if the population was down to only two numbers, say 45 and 78, the high court could force the following decision logic on the rest of the courts: in cases 4578 find for 45, in cases 7845 find for 78. In this case, while it would not be impossible for the population to coalesce on either 45 or 78, it could take a very long time. Finally, Figure 5 shows that this simple model, using the pick-it decision-making process, can produce surprisingly complex time series (as measured by current average value of the number among the population).

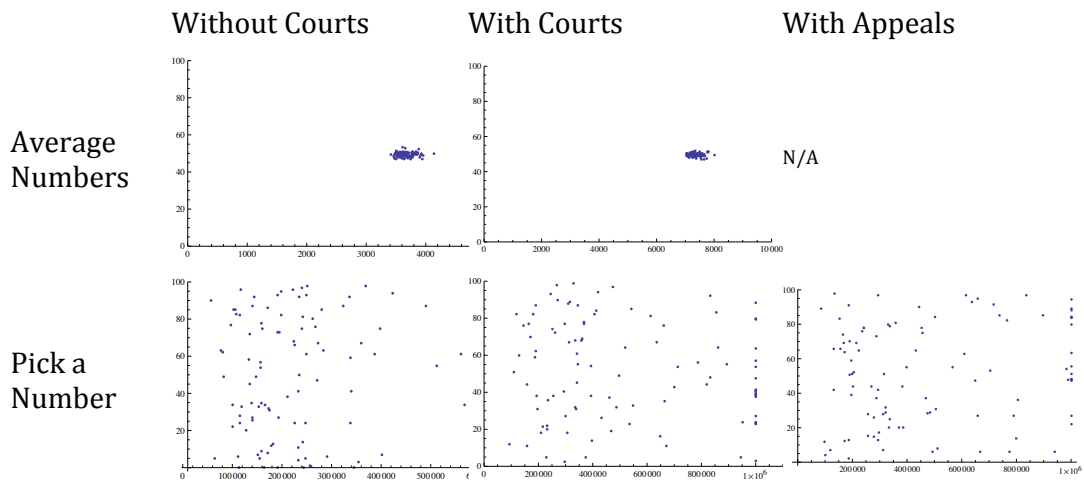


Figure 4. The individual outcomes of each run of the study (x-axis is time steps to completion, y-axis is average number of the population).

Since the maximally simple prototype, discussed above, generated promising dynamics, a more detailed version of the judicial system model was developed (described below.)

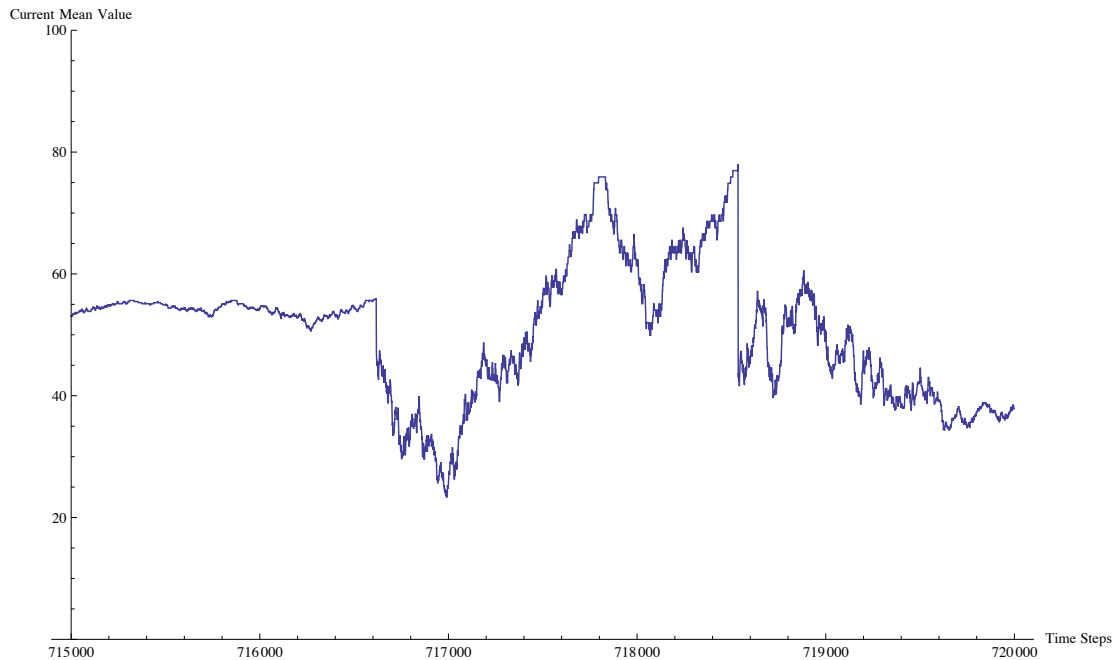


Figure 5. As can be seen in the time series of the current average value of the numbers held by the population, it can show very complex dynamics (x-axis is time steps, y-axis is current average value of the number within the population).

This initial minimal model was able to generate very interesting dynamics. However, it is too simple to account for the dynamics and drivers required to answer the question posed above: can the Common Law both evolve and appear not to? What we can say is that even this minimal model shows very interesting dynamics as the system converges on a single value. This suggests that it is conceivable for a judicial system to evolve while displaying very “chaotic” dynamics. In the present case, although we know

the system will converge to a single value, when viewed in finite chunks it is not at all clear that this is, in fact, the case as can be seen in Figure 5. A richer model will be necessary to answer that question. We will now turn our attention to building up that model.

A RICHER MODEL OF THE U.S. COURTS

What are some of the features of courts that the initial model lacked? Obviously, a complete list is too long to articulate here but the key features seem to be: scale, jurisdictions, a social network, and problems that actually have a correct answer. Why scale? As discussed above courts are a complex adaptive system. As such, the system may change its behavior as its scale changes [Anderson 1972]. Therefore, to have faith in our results we must create and run the model as closely to the scale of interest as possible. Likely, jurisdictions are important, as they will form a source for increasing the diversity of opinions within the system. This is akin to isolating populations of a species, eventually the variation may increase to a point that these subpopulations actually speciate. That eventual outcome is not an issue here, obviously as there is a top-down control scheme (precedents and *stare decisis*) but different jurisdictions will have different views of the problems (as discussed below) and, therefore, will inject diversity into the court system. This is important, as it is this diversity that seems to be at the heart of Niblett's critique of the evolutionary dynamics of the Common Law. A social network will be added as another source of diversity and convergence. As judges are human there is a social network among them, judges do not find all other judges equally influential, in order to represent that in the model we need to add a social network. Finally, evolution typically (but not always) requires a sense of fitness. To have fitness for the Common

Law there must be better and worse answers for judges to make. Therefore, we will need to add a set of problems for the judges to try and solve that have a very well formed solution and better and worse solutions. Although much will be added to create this richer model of a judicial system, one feature will be removed. The thought experiment included both jurispathic and jurisgenerative decisions. This richer model, based upon how the problems will be structured (see *infra*), judicial decision making will only occur via jurispathic methods.

Also of note, the landscape was the same in all cases: A torus made up of 1001 by 1001 patches for a total of 1,002,001, meaning there was a space of 1,002,001 potential solutions for the judges to “search” through. In all cases 774 judges were implemented; thus, solving any issue there may have been with scale (there were agents used to represent each court but they were not used for search or evaluation, but rather only bookkeeping). This means that there were approximately 1,295 potential answers per judge. In all cases the judges only had 500 “tries” to find the right answer; therefore, an exhaustive search was not feasible. This means that changes to the structure of the judicial institution should have an impact on its overall performance as the system would be very unlikely to simply stumble onto the correct answer through a brute force search (that would not be related to the structure and function of the judicial system being simulated).

A Richer Model of a Judicial System

The relative utility of the more complicated model will become evident through a set of computational experiments. Importantly, if one were to create a model of the U.S. courts that included all of the nuances and idiosyncrasies of judges, lawyers, how decisions are made and so on, the model would become so complex that it would be difficult to gain serious insights from the working model.

Starting with a minimal model discussed above, we next add a small set of additional functionality to more closely represent the U.S. Federal Courts, distilled to its essence. The basic components of the courts that are included explicitly in the next model are:

- Judges
- Courts
- Social Networks and Persuasive Precedent
- Hierarchical Networks and Controlling Precedent
- Spatially Defined Jurisdiction

The Cases and Controversies Clause is not explicitly included. It is included in a very limited sense by only allowing appellate courts to find solutions based upon the case being appealed. Together, these features define a system that is recognizably the U.S. Federal judicial system.

Here the model is defined for a three tiered hierarchical court system. At the top there is a single Supreme Court. Immediately below the Supreme Court is some number of Appellate Courts. Finally, below the Appellate Courts is some number of District Courts. Each court has at least one judge assigned to it. In addition to judges each court has a jurisdiction assigned to it. The jurisdiction is a portion of the problem space that it

“oversees.” In the present case, this problem space maps into a toroidal space of solutions. Shown in Figure 6 is the torus as well as an “unrolled” depiction showing the jurisdictions that exist in the NetLogo implementation. Not explicitly represented in this initial implementation is a population to actually present the courts with the requisite case or controversy. How this is handled is discussed below.

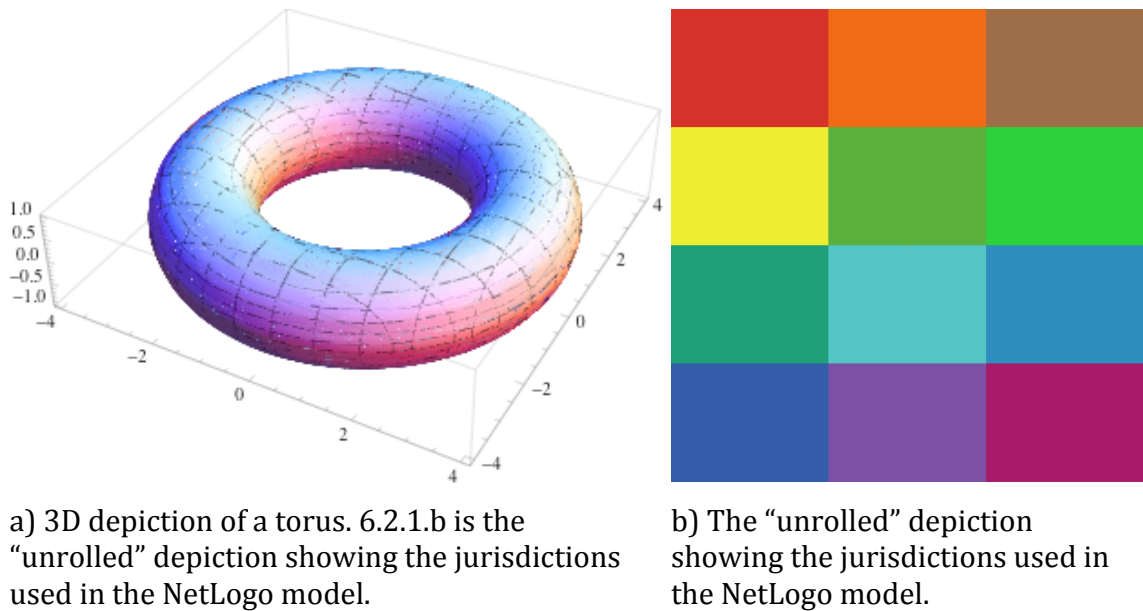


Figure 6. Visualizations of the NetLogo landscape.

District Court Decision Making

When a District Court judge is presented with a case it is made up of two potential solutions to the problem at hand. As with other heuristic search algorithms the judge knows that smaller is better, but has more trouble determining which is better as the

solutions converge on a single value. As the difference between the two potential solutions increases to the maximum possible for the problem at hand the probability of choosing the potential solution with the smallest answer approaches 1. This is accomplished using the following sigmoidal function equation (5.1):

$$probability = \left(\frac{1}{1 + e^{-slope(-mean+x)}} \right) \quad (5.1)$$

where slope and mean parameters are used to control the shape of the line and tuned for each De Jong problem (see *infra*), and x is the difference between the two potential solutions. Figure 7 shows the behavior of the equation when slope is set at 0.2, the mean is set at 10 and x varies from -50 to 50. A sigmoidal function was chosen for simplicity and that it produces dynamic consistent with the argument by Tribe [1971]. Tribe argues that mathematics, even if more precise, would cause more harm than good in a trial. Mathematics, he argues, could be misapplied to facts and give poor argumentation unwarranted credibility. As Tribe's argument against mathematics proved influential [Lempert 1988], it is assumed here that as the necessary precision increases to determine which argument is better the likelihood of making the correct choice should decrease. Finally, the sigmoid function is consistent with Weber's Law from psychophysical research demonstrating that as differences decrease humans' ability to perceive the difference also decreases [Hunt 2007].

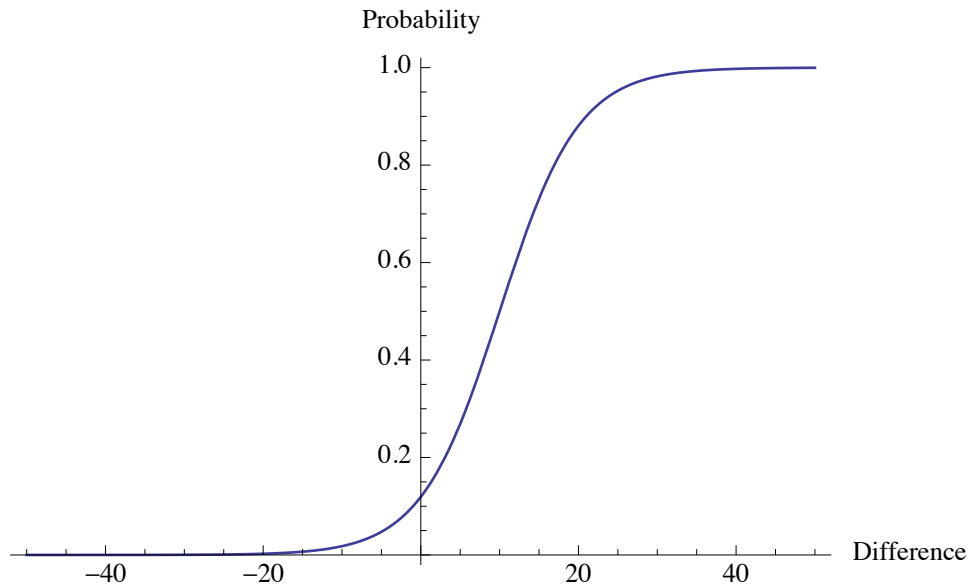
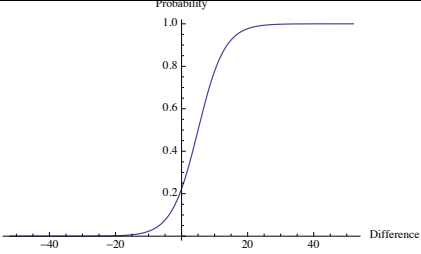
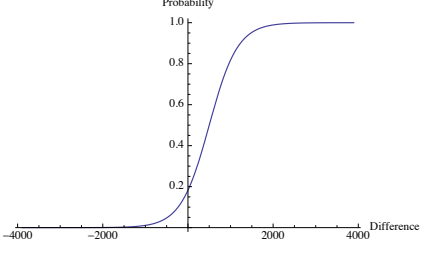
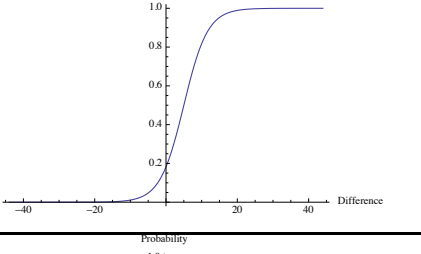
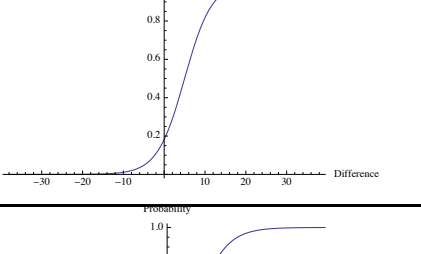
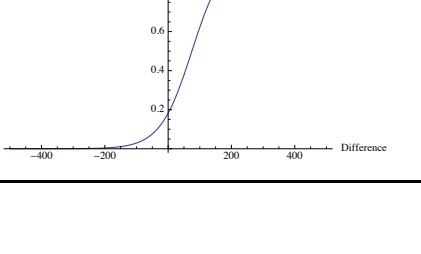


Figure 7. An example of using equation 1.1 to map the difference between two potential solutions and the probability of picking the potential solution with the lowest number.

At instantiation each District Court judge chooses, at random, a potential solution within its jurisdiction. This serves as the “current legal theory” for the problem at hand for that judge (one of the problems within the De Jong test set). The calculation is performed in the following way: The new potential solution is subtracted from the current potential solution. As can be seen in Figure 7, as the difference approaches 0 and becomes negative (meaning the current solution is better than the new one) the probability that a judge will overrule the existing solution becomes less and less likely. Table 3 contains the parameter values used for the sigmoidal function for each of the problems in the De Jong test set.

Table 3. The parameter values used for the sigmoidal functions to calculate the probability of overruling a solution.

De Jong Problem	Spread	Sigmoid Function Slope	Sigmoid Function Mean	Picture
1	~104.6	0.25	5	
2	~7786	0.003	500	
3	~44	0.3	5	
4	~38	0.3	5	
5	~1000	0.02	75	

The Appellate Courts

A similar dynamic is used for the Appellate Court level. With some probability the Appellate Court chooses two district courts to review. This immolates the desire for an Appellate court to maintain consistency within its jurisdiction. When reviewing the holdings of the two District Courts, the Appellate Court uses the same decision logic as the District Court. The Appellate system described here is very similar to that created by Shavell [2006], however it should be noted that Shavell's system is premised upon rational actors; therefore, in his canonical model there are no appeals. By relaxing the restrictive assumptions of the Shavell model via simulation we can examine a judicial system with much more plausible human actors and, hopefully, gain additional insight in to the likely function of the system.

The Supreme Court

As with the Appellate Court level, the Supreme Court chooses two Appellate Courts at random to review. Again, it uses the same decision logic as the District Courts when choosing between potential solutions.

The appellate courts can behave in one of two ways. Each judge on the court can act independently and hear cases by themselves, or each court can perform *en banc* reviews. This means all the judges on the court will hear the case and the holding will come from the majority.

Once an Appellate Court decides a case it is pushed out via the precedent network as controlling precedent. The probability that a case will be decided against that

controlling precedent is proportional to how much closer to optimal the new solution is given a random number draw based upon the sigmoid functions described above. In this regard precedent is implemented in a manner consistent with the theories of Common Law evolution discussed *supra*.

Network and Jurisdictions

Network and Flow among Courts and Judges

Not surprisingly, the performance of a networked system is affected by the structure of the network that connects the components. Optimization of the Common Law is certainly a difficult problem, especially as its fitness is dependent upon the changing society in which it is embedded. In this case, the fitness of the Common Law is coupled to the actions of the population as well as the environment in which the population is embedded [see generally Miller and Page 2007, and Kauffman 1999]. This seems to indicate that the courts would need a fairly complex network connecting them. The courts, however, have a hierarchical network structure (Figure 8 a and b). Given the particular problems that the courts face this may not be an optimal network structure. Of course there are other networks at play here, including educational, prior work, etc. This social component of the courts has been explored by Katz and Stafford [2010] who find that its social network is highly skewed and consistent with a power law distribution. This social feature could significantly complicate determining the impact of a hierarchical precedent network, as the persuasive precedents from external sources could have more or less impact.

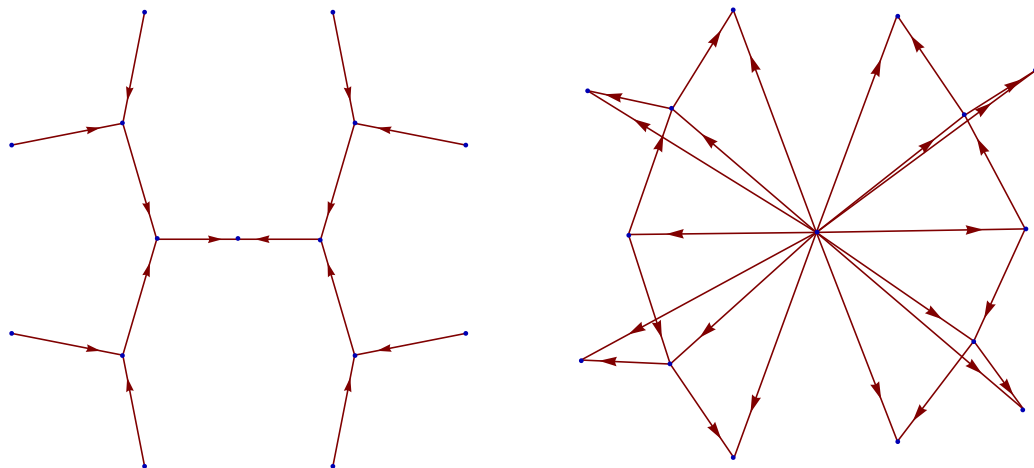
Thus, there are three basic networks of interest within the courts: the Appellate Network, the Controlling Precedent Network, and the Social Network among the judges. The Appellate Network (AN) is the directed network created from courts with original jurisdiction over a case to courts with appellate jurisdiction. For example, in cases between citizens of different states the U.S. Supreme Court does not have original jurisdiction, therefore the case cannot start there it must start in a Federal District Court. In between the District Court and the Supreme Court are the U.S. Federal Appeals Courts. Therefore, this creates a three-tiered appellate network with a directed edge from the District Court to the Appellate Court and another directed edge from the Appellate Court to the Supreme Court.

The Controlling Precedent Network (CPN) is somewhat different from the AN. This network is made up of directed edges, as is the AN, however the flow is from the Supreme Court down to the lower courts. Moreover, the Appellate Court is not a necessary intermediary as it often is with appeals. In the CPN there is an edge from the Supreme Court directly to all lower courts. There are also directed edges from the Appellate Court to all District Courts over which that Appellate Court has jurisdiction.

Finally, there is the social network among the judges. The social network is important as it may reveal what a judge considers “persuasive precedent.” Persuasive precedents are court opinions, law review articles, and other materials that may influence a court’s decision but do not dictate an outcome. What materials are found persuasive and how they are used is completely up to an individual judge. This is occasionally referred to as *dictum*, *gratis dictum*, *simplex dictum*, or *obiter dictum*. However, there is a distinction

to be made. *Dictum* refers to a statement made by a judge in a ruling that is not directly related to the issue(s) before the court [see generally, Black's Law Dictionary 1991].

Dictum is material that is not controlling within a ruling that is otherwise controlling on the examining court. This is somewhat narrower than the category of persuasive precedent. Persuasive precedent does not, necessarily, contain any material that is controlling on the examining court.



a) Appeals Network

b) Controlling Precedent Network

Figure 8. Appellate and controlling precedent networks of a simple three-tiered hierarchical court.

The Network Structure Used Here

Data on the networks of the U.S. Article III Federal Courts used here was derived from data obtained from the U.S. Courts (<http://www.courts.gov>). This data included the

hierarchical structure of the Article III Courts, the judges assigned to each court, and biographical data about each judge.

Creating the hierarchical network structure of the courts was a direct port of their actual structure. The current models instantiates 104 of the Article III Courts (some specialized courts were excluded such as, *inter alia*, the Court of International Trade and the Court of Federal Claims). The U.S. Supreme Court is at the top, followed by the various Appellate Courts; lastly, at the bottom of the hierarchy are the U.S. District Courts. Figure 9 shows this hierarchical network.

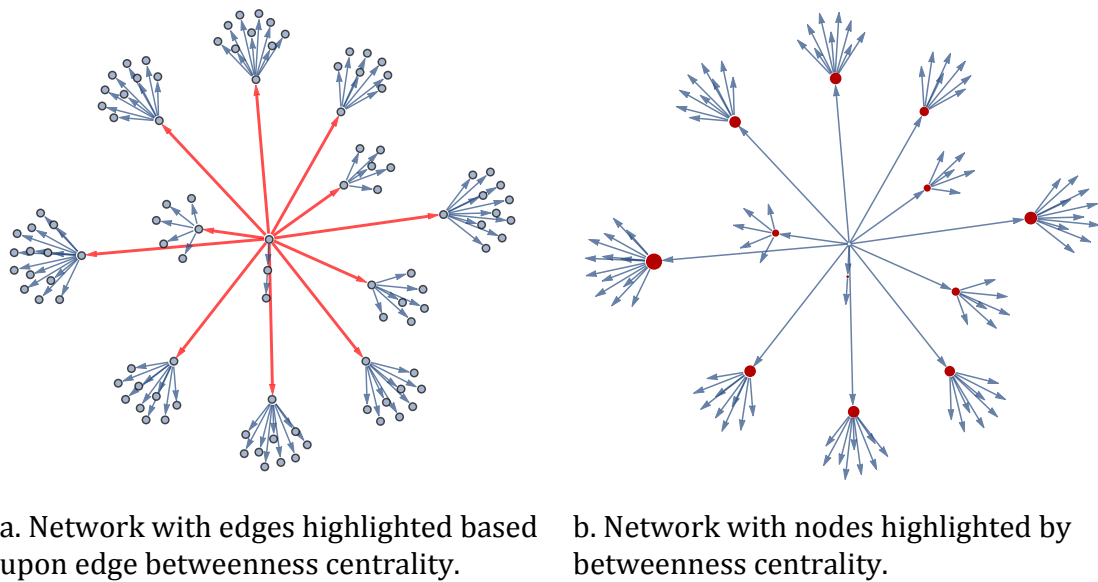


Figure 9. The hierarchical network of the Article III U.S. Federal Courts used in the model.

The social network among the judges had to be inferred based upon biographical data on the judges obtained from the U.S. Courts website. Creating a plausible

representation of the social network is important as network structure can impact the dynamics of social problem solving [Kennedy and Mendes 2002]. Biographical information on every Federal judge that has ever served on the Federal bench is available as a downloadable spreadsheet. This spreadsheet contains a large number of fields. A fully enumerated list can be found in Supplementary Information Section A³.

From this raw data, first all judges that are not currently on the Federal bench were removed (this could be due to death, retirement, resignation, or termination). Then all sitting judges that were not on a court being represented in the model were removed. This left 774 judges to explicitly represent in the model. It should be noted that this is less than the total number of judges' seats on the Article III Courts, 849 total positions. This is due to vacancies that have not yet been filled.

Building the social network

The social network among the judges was built with the following fields:

- Birth year
- Place of Birth (City)
- Place of Birth (State)
- Gender
- Race or Ethnicity
- Court Name
- Court Type
- President name
- Party Affiliation of President
- Name of School
- Degree
- Degree year
- Name of School (2)

³ Supplementary Information can be found at: <http://css.gmu.edu/koehler>.

- Degree (2)
- Degree year (2)
- Name of School (3)
- Degree (3)
- Degree year (3)
- Name of School (4)
- Degree (4)
- Degree year (4)
- Name of School (5)
- Degree (5)
- Degree year (5)

To build the social network an $N \times N$ comparison of each field was done if there was a match then the pair was linked; if there was no match then the pair was not linked. Some fields were matched with a fuzzy criterion, school as considered a match if it was the same school and the degree year was within 4 years of each other. The same is true of birth year. This collection of matrixes could then be used to build the social network for the model. Summing across each characteristic provided a score for each pair. Figure 10 shows a depiction of the $N \times N$ judge matrix. A threshold was then set as the criteria for whether or not there should be a link created between the pair in the model. A simple threshold was chosen as it created a network that has statistical characteristic similar to those found by others [Katz and Stafford 2010], and other techniques were found unsatisfactory (such as Carely [1991], which produced vanishingly small link probabilities, the highest probability that it generated was 0.995%). The judges are grouped by court in Figure 10; interestingly there is structure to the network when viewed this way (lighter and darker bands). As one follows the diagonal one does see an expansion of light moving away from the diagonal. This is expected as all judges on the

same court share at least one attribute. If each court was perfectly insular then one would expect to see very clear white squares moving across on the diagonal, instead one sees a more diffuse structure suggesting more inter-court connections and fewer intra-court connections.

Using a high threshold of 7 or more shared attributes necessary for a link to be created in the model produced a network that had general statistical properties that were similar to the findings of Katz (Table 4).

Table 4. Judge degree distributions from Katz (2010) and the results derived from the biographical data used here.

	Katz	7+ Shared Biographical Attributes
Degree 0	50.04%	44.7%
Degree 1	24.16%	25.3%
Degree 2	11.73%	13.6%
Degree 3	5.61%	8.4%
Degree 4	3.28%	3.5%
Degree 5	1.56%	2.3%
Degree 6-10	1.90%	4.3%
Degree >10	1.73%	.1%

Depictions of the social network created with the biographical data is shown in Figure 10-13.

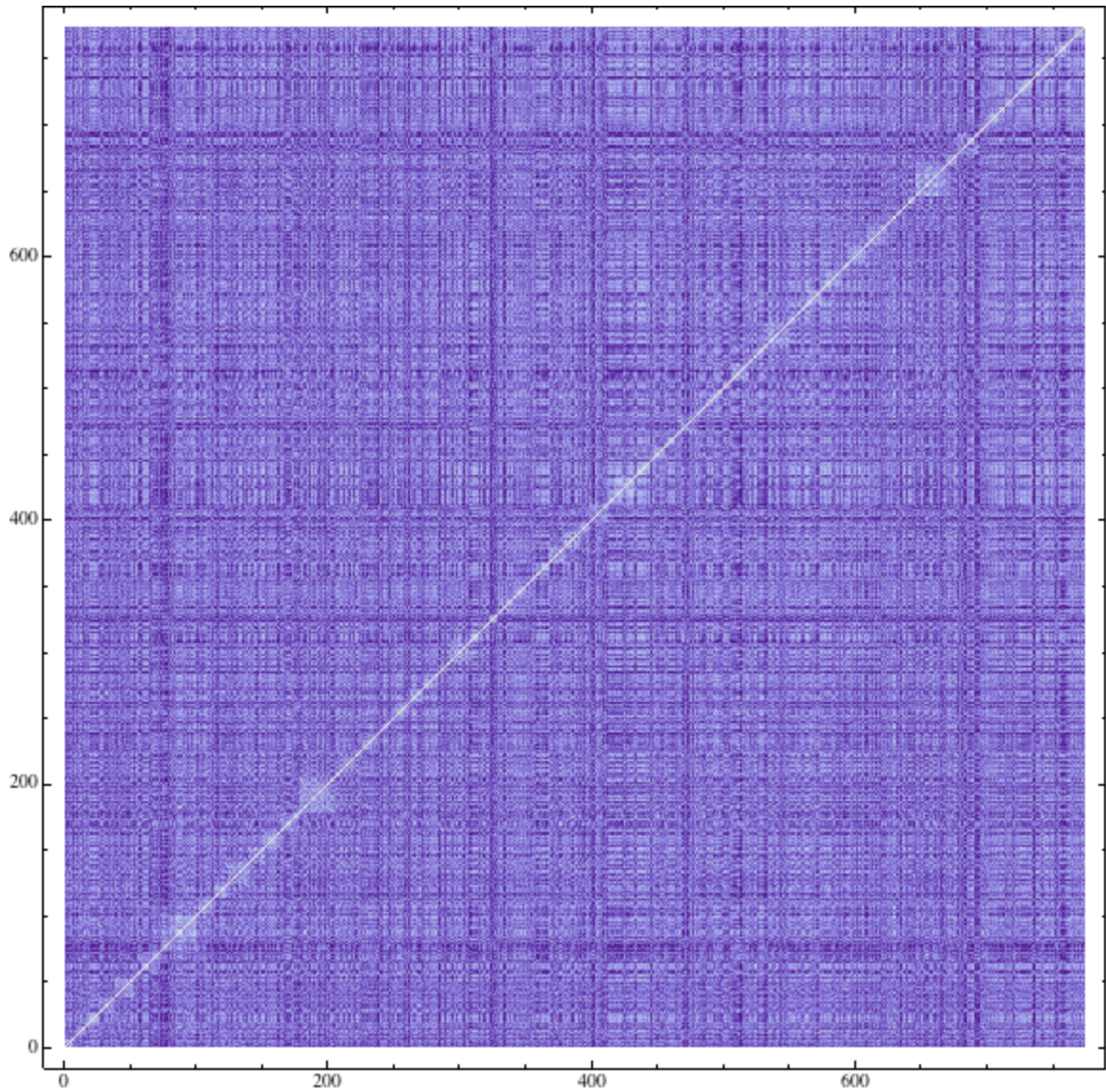


Figure 10. A depiction of the $N \times N$ matrix showing the sum of the shared attributes. The lighter the color the more attributes are shared (for a maximum of 8 attributes). Here the judges are organized by court.

Using the input file visualized in Figure 10, the simulation instantiates all the sitting judges and then creates the social network among them. Code for creating the social network can be found in Table 5. Figure 14 shows histograms of various centrality measures.

Table 5. Code used to create judges and their network.

```
to createJudges
  file-open "judgeNetwork_75_04.jid"
  while [not file-at-end?]
  [
    create-judges 1
    [
      set shape "person"
      set myNetList []
      set myJudgeID file-read
      set myCourt file-read
      set myCourtID one-of courts with [myName = [myCourt] of myself]
      set myJurisdictionID [myCircuit] of myCourtID
      set myPatchList []
      let t 1
      repeat 774
      [
        if file-read > 0
        [
          set myNetList fput t myNetList
        ]
        set t t + 1
      ]
      set myNetList remove myJudgeID myNetList
      set xcor random-xcor
      set ycor random-ycor
    ]
  ]
  file-close

end
to makeYourNetwork
  foreach myNetList
  [
    create-socialLinks-with judges with [myJudgeID = ?]
  ]
  create-precedent-from one-of courts with [myName = [myCourt] of myself]
end
```

The social network that is created is fragmented. There is one reasonably large component and many smaller components ranging in size from 2 to about 10 judges.

There is only one singleton judge. The basic network is shown in Figure 11. Based upon

the density of connectivity and the fragmentation of the network, the communities of judges can be found and visualized. Figure 12.a shows the network with community shown via node colorations. Figure 12.b redraws the network and circles the communities. Of particular interest is how the community structure relates to court's structure, as this will impact the way in which the conformity dynamic propagates. Given the weak structure seen in Figure 12, one may anticipate a weak correlation between community structure and court structure; this is what is seen when only building the network with biographical data (Figure 13.a.). However, when one adds connections based upon sitting on the same court the clustering changes dramatically (Figure 13.b.) In Figure 13 judge nodes are colored by community membership. As expected, one does not see definite clusters of similar color around each court when using only biographical data. The clustering around courts increases dramatically when one explicitly incorporates "common courts" into the network. Interestingly, in both cases, the network appears to build a near-decomposable system [Simon 2001]. To understand the social and precedent forces influencing a judge, one cannot look only at the court on which they sit and the controlling precedent around them. This is interesting because it implies that perfect decomposition regarding the functioning of the judicial system may provide misleading results. Understanding a judge is important, but their behavior will be influenced by the whole system and so to understand what the dynamics of the Common Law are one must study the system as a whole.

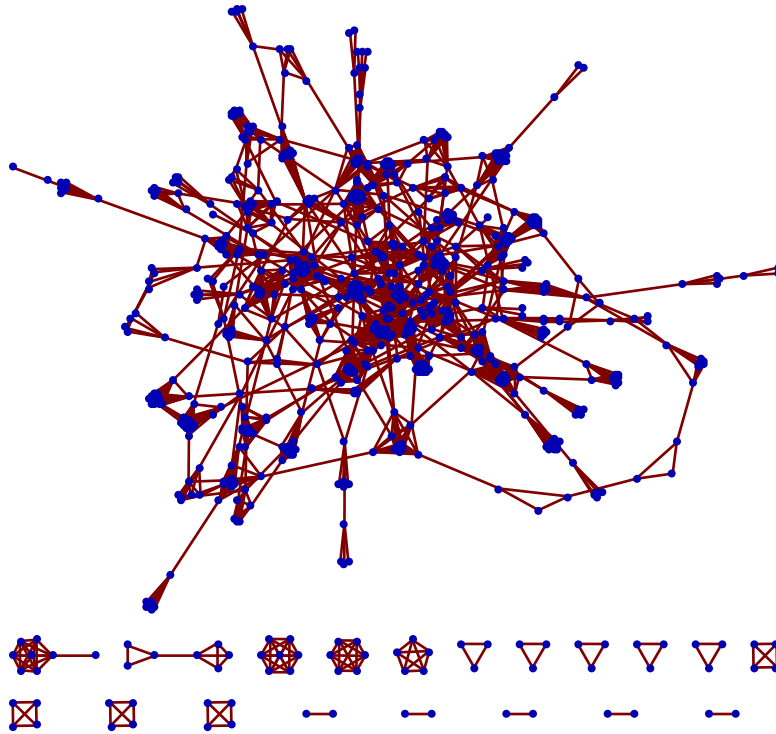
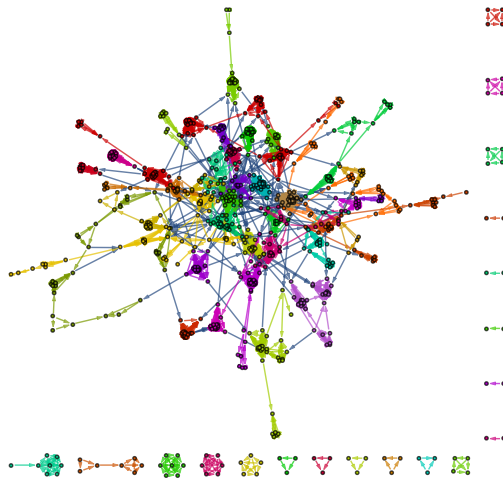
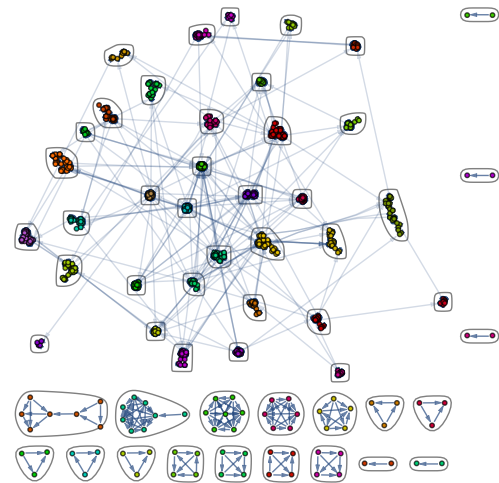


Figure 11. The basic social network among judges.

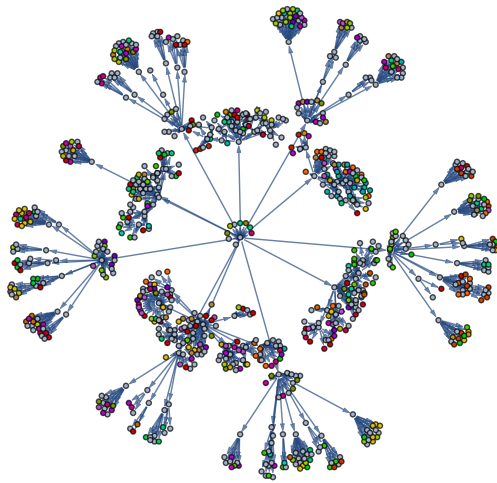


a. The judge network highlighted by community.

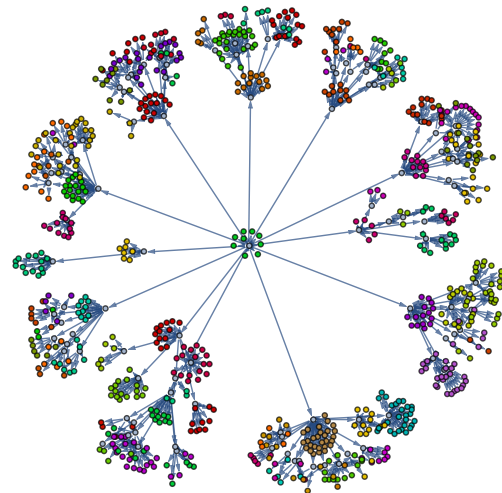


b. The judge network redrawn to highlight the community structure.

Figure 12. The social and influence network of the judges in the simulation.



a. The social network among the judges only using the biographical data.



b. The social network among the judges using both the biographical data and court structure.

Figure 13. The court hierarchical network, judges highlighted by community (Figure 12).

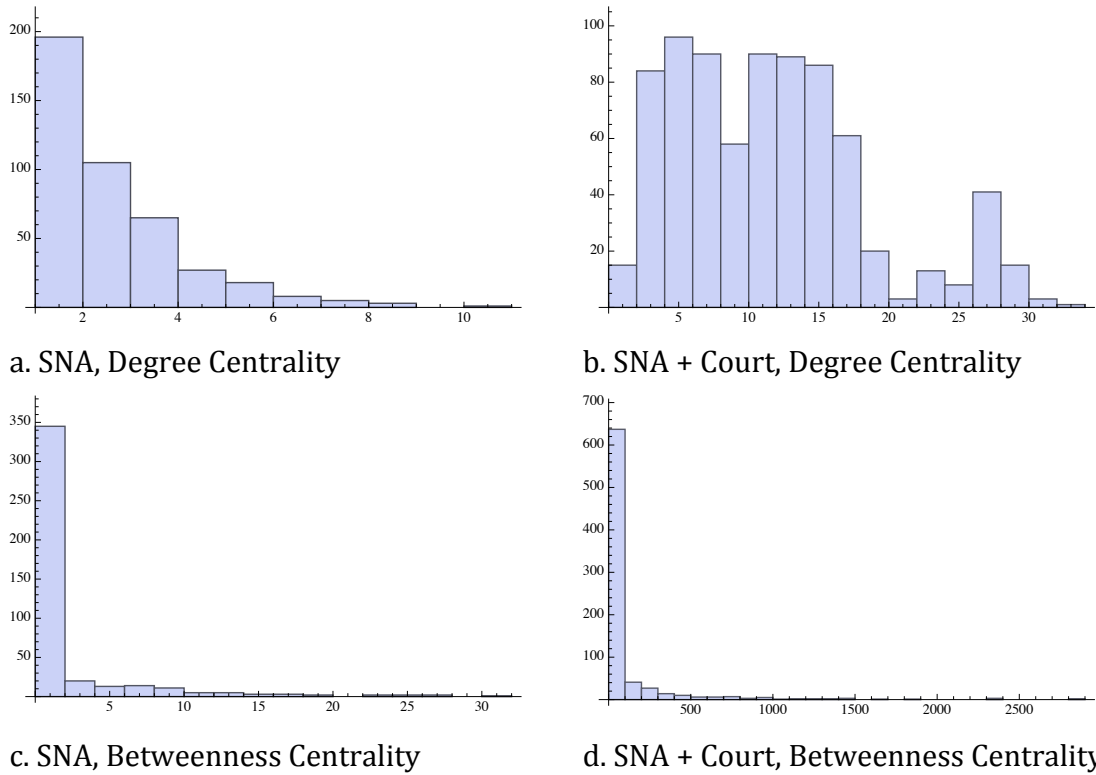


Figure 14. Histograms of basic centrality measures. SNA is the network created with only the biographical data, SNA+Courts is the network created with the biographical data and linking all judges that sit on the same court.

Initializing and Running the Model

The De Jong Test Set Problems

In order to create a system that has a well-defined measure of fitness a standard set of machine learning test problems was used. This test set is known as the De Jong test set and is made up of five different minimization problems each with a single, unique minima. Therefore all judge decisions can be compared against these minima to determine decisions that are better or worse. In this current implementation judges do know that all problems are minimizations. Therefore, judges are much more likely to pick

answers that are smaller rather than larger. Details of the De Jong test set can be found in Supplementary Information Section C. When initialization begins, the De Jong test set is created on the landscape first. As such, each of the twelve roughly equal jurisdictions will only “possess” a small portion of the De Jong solution space. Figure 15 shows these jurisdictions and the courts and judges associated with them.

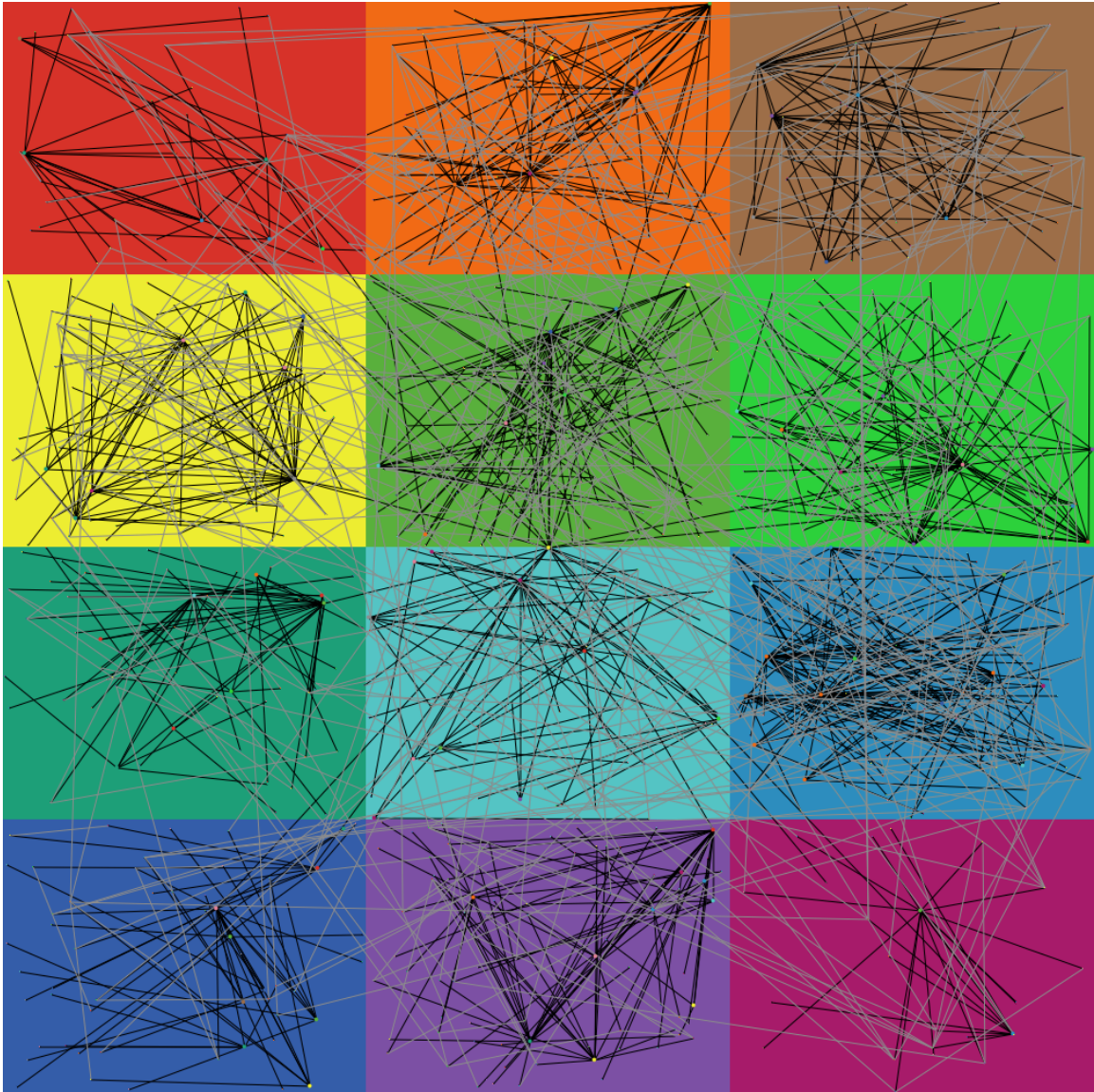


Figure 15. The twelve jurisdictions within the system and the courts and judges that are a part of it. The dark lines are precedent networks, the grey lines are social network ties among the judges. Each edge shown here is an explicit connection in the model.

Initially, the model instantiates the courts. This is accomplished via an input file created from data obtained from the U.S. Courts (www.uscourts.gov). This file contains information on all the courts: the hierarchical level of the court (0 = Supreme Court, 1 =

Appellate Courts, 2 = District Courts), and a number indicating the court's jurisdiction.

Table 6 contains a sample of the input file.

Table 6. A sample of the input file used to create the courts.

"SupremeCourt" 9 0 0
"DistrictofColumbiaCircuit" 11 1 12
"FirstCircuit" 6 1 1
"SecondCircuit" 13 1 2
"ThirdCircuit" 14 1 3
"FourthCircuit" 15 1 4
"FifthCircuit" 17 1 5
"SixthCircuit" 16 1 6
"SeventhCircuit" 11 1 7
"EighthCircuit" 11 1 8
"NinthCircuit" 29 1 9
"TenthCircuit" 12 1 10
"EleventhCircuit" 12 1 11
"DistrictofColumbia" 15 2 12
"Maine" 3 2 1
"Massachusetts" 13 2 1
"NewHampshire" 3 2 1
"RhodeIsland" 3 2 1
"PuertoRico" 7 2 1
"Connecticut" 8 2 2
"NewYorkNorthern" 5 2 2
"NewYorkEastern" 15 2 2
"NewYorkSouthern" 28 2 2
"NewYorkWestern" 4 2 2

The code used to create the courts is quite simple and contained in Table 7.

Table 7. Code used to create the courts.

```
to setupJudgesAndCourts
file-open "CourtInputData2.csv"
while [not file-at-end?]
[
create-courts 1
[
set xcor random-xcor
set ycor random-ycor
set myName file-read
set myNumJudges file-read
set myLevel file-read
set myCircuit file-read
set shape "circle"
set size 4
createCourt
]
]
file-close
```

In addition to creating the courts, the precedent network is also created. This is a directed graph emanating from the Supreme Court to the Appellate Courts and finally to the District Courts. Figure 16 shows this three-tiered hierarchical network. This network is created via the attributes of the courts, their hierarchical level and their jurisdiction.

The code used to create this network can be found in Table 8.

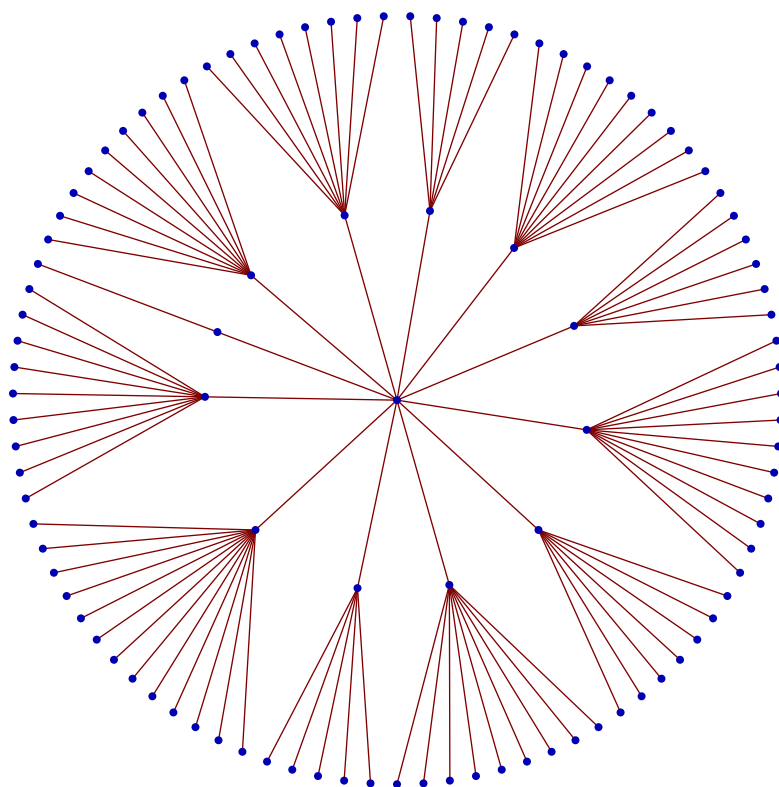


Figure 16. The network of courts, the Supreme Court is in the middle, the Appellate Courts are in the second ring, and the District Courts are in the outer most ring.

Table 8. The code used to create the precedential network.

```
ask courts with [myName = "SupremeCourt"]
[
  let r sort courts with [myLevel = 1]
  foreach r [create-precedent-to ?]
]
end
and from the process "createCourt"
to createCourt
  let t one-of courts with [myLevel = ([myLevel] of myself - 1) and myCircuit =
[myCircuit] of myself]
  if is-turtle? t [create-precedent-from t]
end
```

Now that the court structure is complete, the judges are added. In order to address any potential scaling issues, all of the currently sitting Federal Judges are instantiated. This, too, is accomplished with an input file of biographic information obtained from the U.S. Courts at www.uscourts.gov). For those interested, the input file can be obtained here: www.css.gmu.edu. However, due to its size (774 rows by approximately 776 columns) a sample is not included here. The data this file contains is the judges ID number, the court on which they sit, and a series of 774 0's and 1's that defines the judge's social network (each row corresponds to a single judge).

The final step of initialization is creating an existing "legal theory" for each judge. Here a legal theory is simply a potential solution to the De Jong test set. This is accomplished by having each judge pick a potential answer at random from a patch in their jurisdiction. The one exception are the judges on the Supreme Court who have

jurisdiction over the entire system, they choose a potential solution from any patch. The code used to do this is found in Table 9.

Table 9. Code used to create an initial legal theory for all judges.

```
to setInitialHolding
  ifelse myJurisdictionID > 0 ;and myLevelID = 2
    [set myCurrentHolding [item whichProblem myAnswerList] of one-of my]]
    [set myCurrentHolding [item whichProblem myAnswerList] of one-of patches]
end
```

This concludes the initialization steps (for esthetic purposes the judges also move to their jurisdiction but this has no impact on the functioning of the code or the conceptual model).

In this most basic implementation the runtime procedures are equally simple. For each of 500 time steps the District Court judges compare a patch within their jurisdiction chosen at random with their current legal theory. With some probability this newly chosen patch is used to replace the judge's existing legal theory. The probability increases as the difference between the two competing theories increases (and the new theory is smaller than the current theory). The code for this is contained in Table 10. The reporter "overruleProb" is the implementation of the sigmoidal curve discussed in section above.

Table 10. Code used by the judges to compare their current solutions with a new one.

```

to checkForBetterSolution
  let temp [item whichProblem myAnswerList] of one-of myJ
  if random-float 1.0 < overruleProb globalSlope globalMean (myCurrentHolding -
temp)
  [
    if debug? [show (word "myCurrentHolding--> " myCurrentHolding " and temp--> "
temp)
    if temp > myCurrentHolding [show (word "temp > myCurrentHolding!! the
overruleProb is: " overruleProb globalSlope globalMean (myCurrentHolding -
temp)) ]]
    set myCurrentHolding temp
  ]
end
to-report overruleProb [s m d]
  set s s * -1
  let t 1 / (1 + e ^ (s * (d - m)))
  if debug? [show t]
  report t
end

```

In addition to the District judges’ activities the Appellate and Supreme Courts handle “appeals.” In this simplest case, appeals occur at a rate of 13%. The rate was determined by examining data on caseload available at uscourts.gov. For an appeal, an appellate body picks a judge within their jurisdiction and compares that judge’s current theory to their current theory. Using the same sigmoid function, with some probability they will “overrule” the judge with their legal theory. When this occurs all lower court judges within the jurisdiction of the appellate body are “given” the winning legal theory. It should also be noted that, with the initial implementation, all appellate judges act *independently*. There are no en banc reviews or judicial panels. The code for this simple appellate review can be found in Table 11.

Table 11. Code implementing the appellate dynamics.

```

to doAppellateAppeal
  let temp [myCurrentHolding] of one-of judges with [myJurisdictionID =
[myJurisdictionID] of myself and myLevelID > [myLevelID] of myself]
  if random-float 1.0 < overruleProb globalSlope globalMean (myCurrentHolding -
temp)
  [
    if debug? [show (word "myCurrentHolding--> " myCurrentHolding " and temp--> "
temp)]
    set myCurrentHolding temp
  ]
  ask judges with [myJurisdictionID = [myJurisdictionID] of myself][set
myCurrentHolding [myCurrentHolding] of myself]
  if debug? [show "I did something"]
end
to doSupremeAppeal
  let temp [myCurrentHolding] of one-of judges with [myLevelID = 1]
  if random-float 1.0 < overruleProb globalSlope globalMean (myCurrentHolding -
temp)
  [
    if debug? [show (word "myCurrentHolding--> " myCurrentHolding " and temp--> "
temp)]
    set myCurrentHolding temp
  ]
  ask judges [set myCurrentHolding [myCurrentHolding] of myself]
  if debug? [show "supreme court did something!"]
end

```

The above implements the most basic structure of the court system. There are other meaningful components to how courts solve problems. Appellate courts may review a case *en banc*, meaning all the judges that sit on an appellate court's bench will, as a group, hear a case. When a court hears a case *en banc* the case is decided by majority

rules among the judges (this is how the U.S. Supreme Court hears and decides cases, for example).

To add this to the model required adding a GUI element to allow users to turn this dynamic off or on. This Boolean is called “majorityRule?”. Example code for the implementation of *en banc* can be found in Table 12.

Table 12. Code used to implement *en banc* review.

```
ifelse majorityRule?
[
  let t sort other judges with [myLevelID = [myLevelID] of myself and
myCourtID = [myCourtID] of myself]
  if debug? [show t]
  let i random 5
  let u 0
  let p one-of judges with [myJurisdictionID = [myJurisdictionID] of
myself and myLevelID > [myLevelID] of myself]
  let q item i [myPatchList] of p
  let temp [item i myAnswerList] of q
  if random-float 1.0 < overruleProb globalSlope globalMean (item i
myCurrentHolding - temp) i [set u u + 1]
  if length t > 0
  [
    foreach t
    [
      if random-float 1.0 < overruleProb globalSlope globalMean ([item i
myCurrentHolding] of ? - temp) i [set u u + 1]
    ]
  ]
  if u > (.5 * length t)
  [
    if debug? [show "u is greater than 1/2 my judge buddies!!"]
    set myPatchList replace-item i myPatchList q
    updateScores
    ask judges with [myJurisdictionID = [myJurisdictionID] of myself]
    [
      set myPatchList replace-item i myPatchList [item i myPatchList] of
myself
      updateScores
    ]
  ]
  [
    Individual decision-making methods (see Figure 22)
  ]
]
```

When a judge is called on to make a decision and majorityRules? is set to true, then the judge:

1. Creates a list of all the other judges on their bench
2. Iterates through the list asking each one to decide (random draw based upon the sigmoid function)
3. If the judge decides to change his/her mind, then increment a counter

4. Finally, check to see if the counter is greater than .5 times the number of judges on the bench then a majority changed their minds and so the new answer wins
5. Push out the precedent to the lower courts

Additionally, as discussed *supra*, there is the social network in which judges are embedded and the need for conceptual consistency. Both of these forces have influence on a judge's worldview and how they make decisions. Implementing this dynamic required a slightly larger modification to the simple implementation discussed above. To implement the Bednar-Page conformity-consistency dynamics the judges need to think about more than one problem at a time. Therefore, the initial modification to the model was to allow the courts to address all five De Jong problems at once. This functionality was added to the model. One should note, that the judges know, with certainty, which problem they are trying to solve. The code that implements the consistency and conformity dynamics is contained in Table 13.

Table 13. Code used to implement the Bednar-Page consistency and conformity dynamics.

```
to consist
  if random-float 1.0 < consistProb
  [
    let i random 5
    let u random 5
    set myPatchList replace-item i myPatchList item u myPatchList
  ]
  updateScores
end
to conform
  if random-float 1.0 < conformProb and length myNetList > 0
  [
    let i random 5
    let r random length myNetList
    let t one-of judges with [myJudgeID = r]
    if is-turtle? t [set myPatchList replace-item i myPatchList [item i
myPatchList] of t]
  ]
  updateScores
end
```

The consistency dynamics are simple. The code that implements the consistency dynamics is contained in the “to consist” procedure found in Table 13. Essentially, when called a judge will draw a uniform random number between 0 and 1 (not including 1). If that random draw is less than the user set probability that the consistency dynamic will occur (a number between 0 and 1 inclusive), then the judge picks two random locations within their answer list (with replacement) and copies the value of one into the location of the other. This value is the location of the patch rather than the numeric answer of that location for a given problem. One way to think about this as a form of consistency is that a judge wants his/her answer to come from the same general “answer region.” For example, a liberal judge may use answers from a “liberal decision space” regardless of the applicability or overall impact on efficiency in any particular case. In the current

model a judge may use a particular region of the space for all of the decisions he/she may make. For some test problems that may efficient but for others it may not.

The conformity dynamics are very similar to the consistency dynamics except that rather than pick two problems within the judges own worldview, the judge picks a partner from their social network and a single problem within their worldviews and copies the patch location from the partner to their worldview. This is also controlled by a user-specified probability. As each is controlled by its own probability the model can be run with both, neither, or either dynamic occurring.

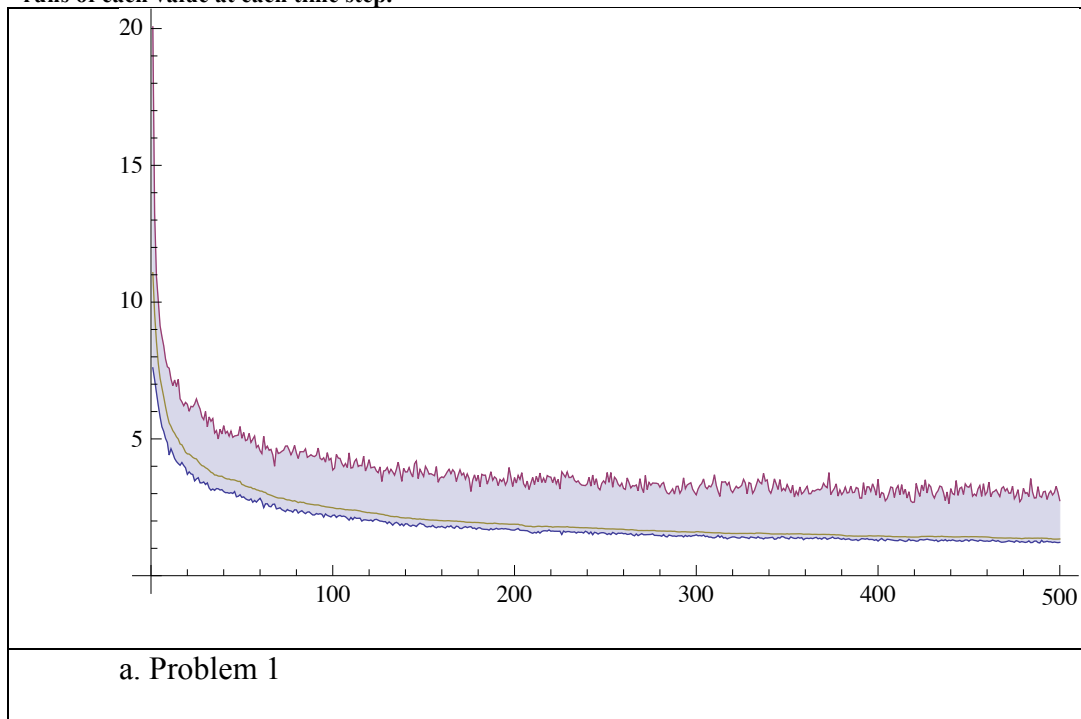
Results

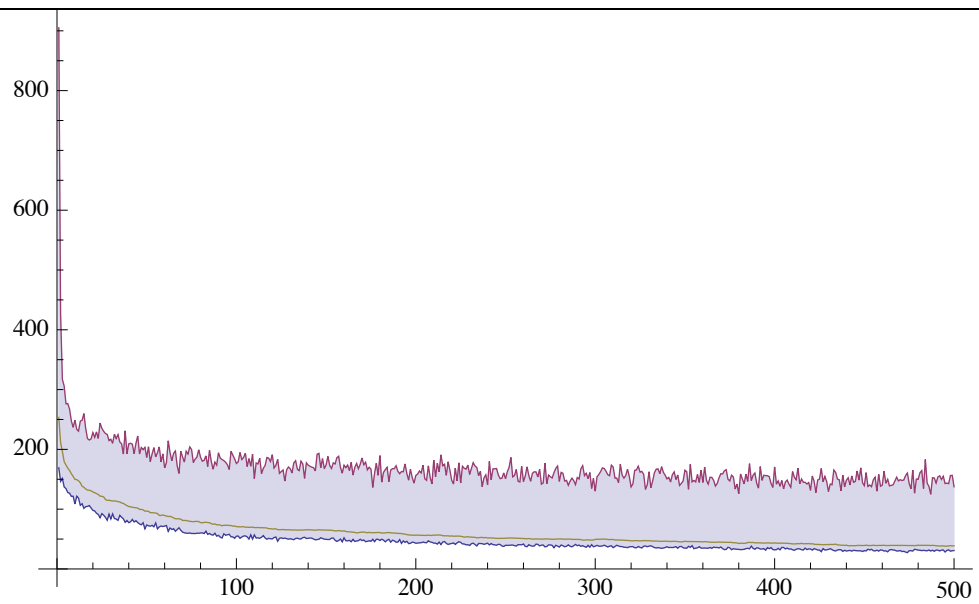
This section contains the results obtained when running the aforementioned model run 500 times for 500 time steps on each De Jong problem. At each time step the following values were recorded: the current time step, the population minimum, the population maximum, the population mean, and the population standard deviation.

Table 14 shows the min, max, and mean of the simulated judicial system for each of the five De Jong problems. As can be seen in Table 14, the judicial system converged very quickly on problems 1 and 2 (relatively simple basins). Problem 4, the basin with random noise, caused more trouble but the mean score did monotonically decrease over the course of the 500 time steps, indicating that the population continued to improve but more slowly (as hypothesized above). Table 15 shows the raw data (min, max, mean, standard deviation) from each time step of the 500 runs. Interestingly, problems 3 and 5,

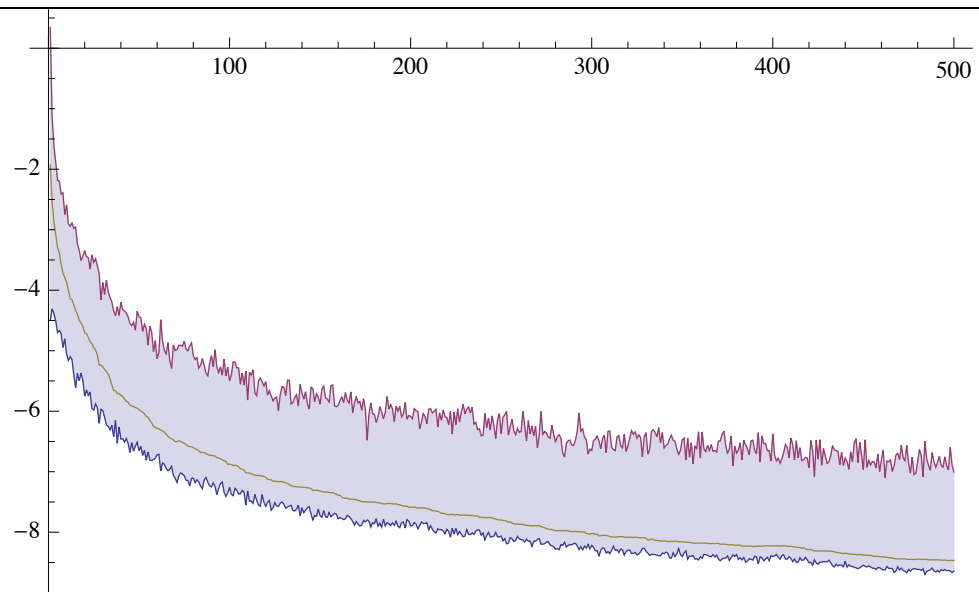
seemed to cause the judicial system less trouble than it did to the other tested heuristic search algorithms (see *infra*).

Table 14. A plot of the min, max, and mean for each test problem. Each point was created by averaging all 500 runs of each value at each time step.

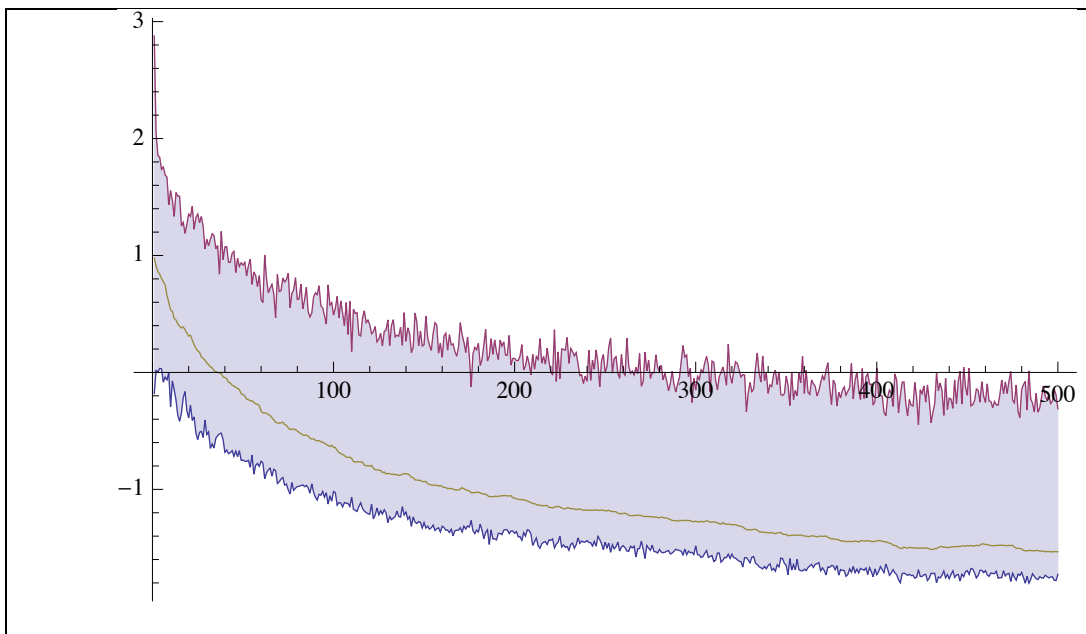




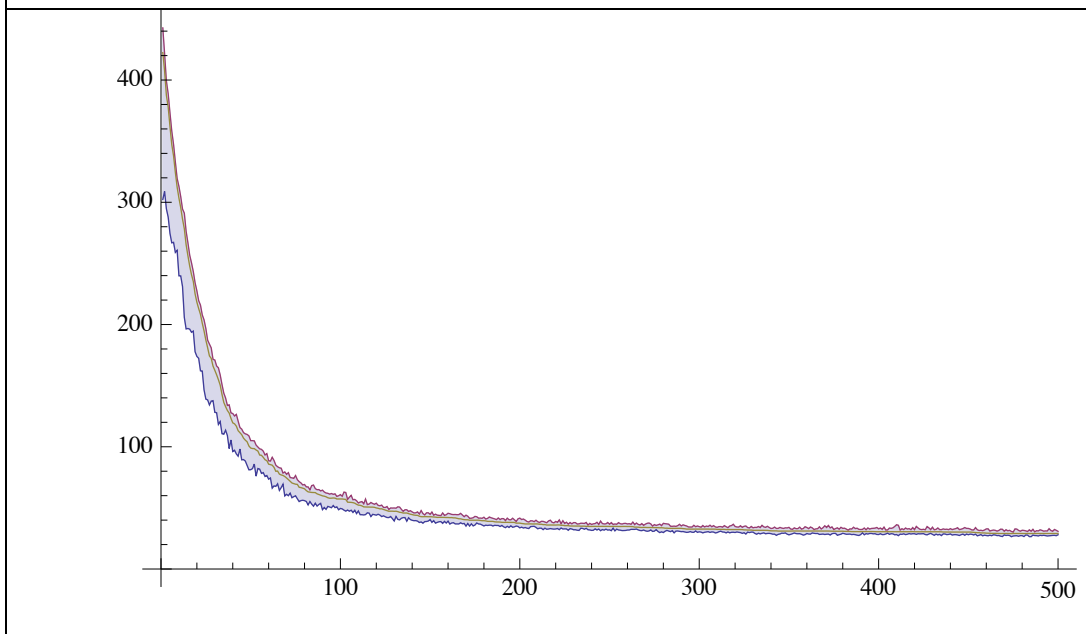
b. Problem 2



c. Problem 3



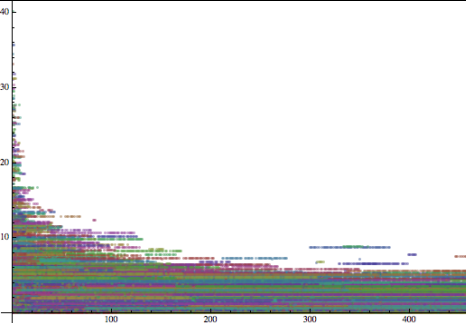
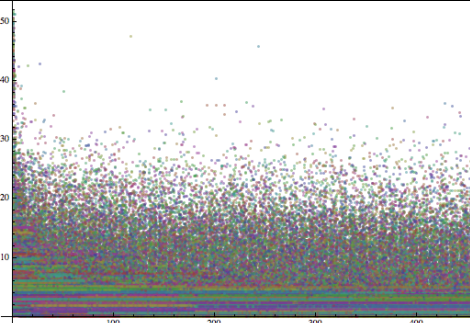
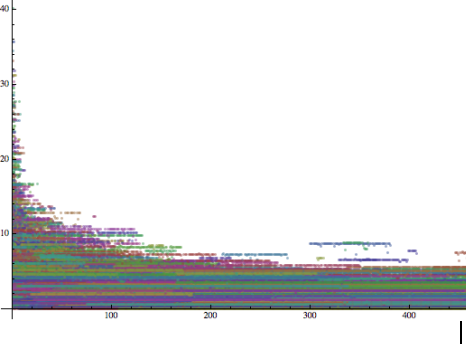
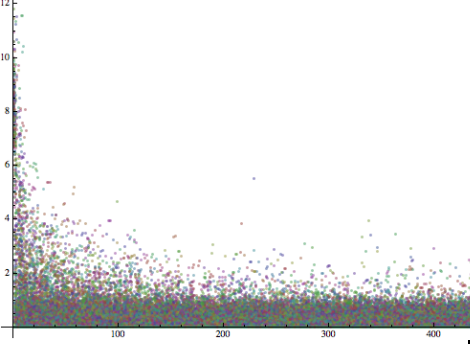
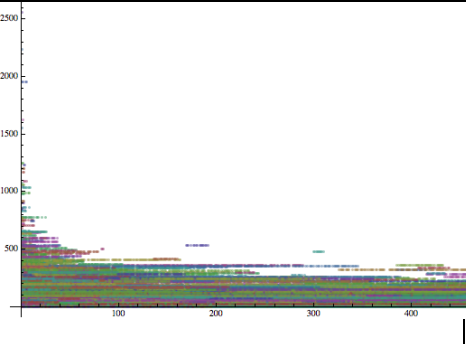
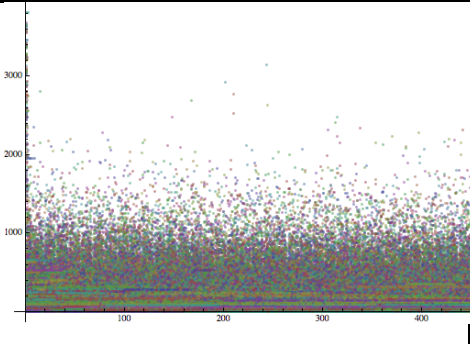
d. Problem 4

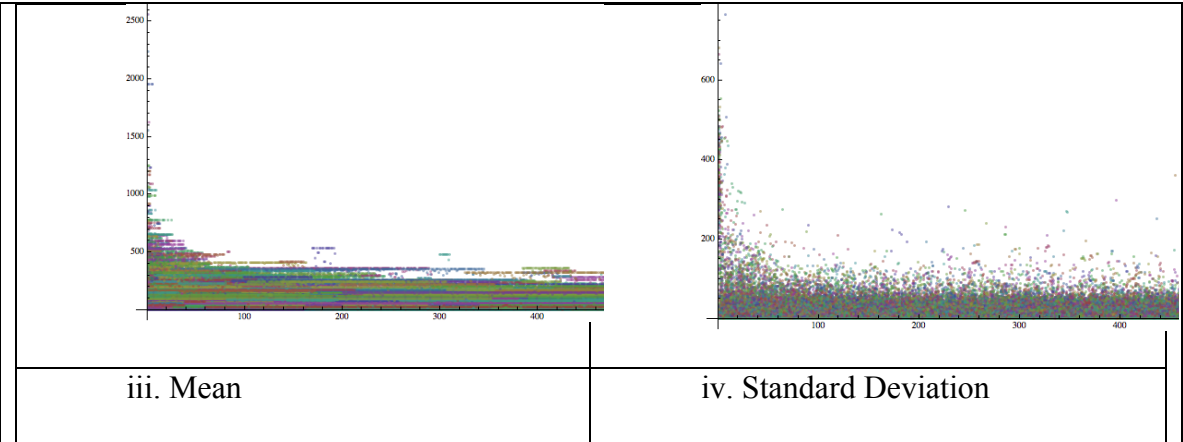


e. Problem 5

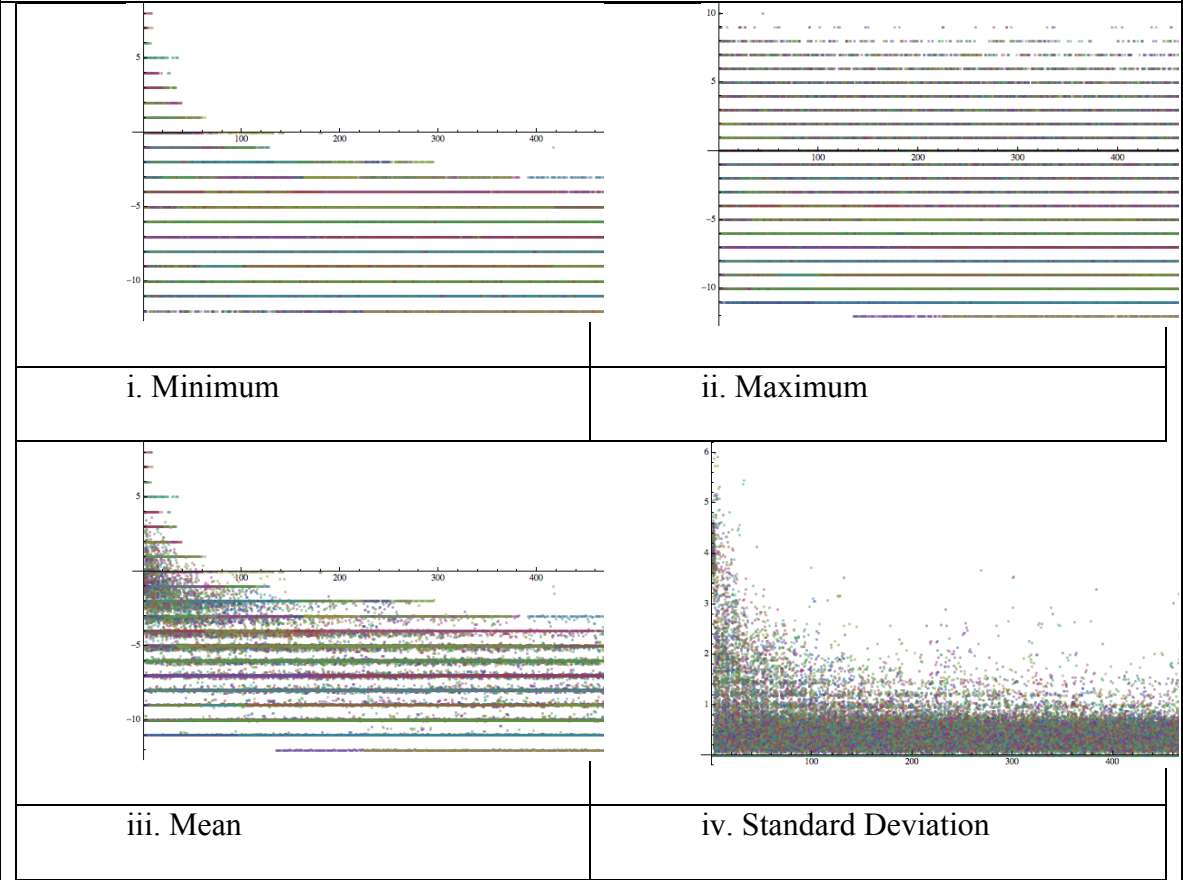
When looking at the raw data, the judicial system was able to find the global minimum in many cases. However, this global minimum rarely percolated up to the Supreme Court level where it could be pushed back down to all judges. This is an important point that speaks to the difficulty for an institution such as a judiciary to not only find socially beneficial solutions but also for the system to then converge on those solutions. This, in turn, may highlight the need for additional automation tools to help judges increase their awareness of the scope and breath of holdings on similar legal issues to the ones currently before them.

Table 15. Raw judicial system simulation data.

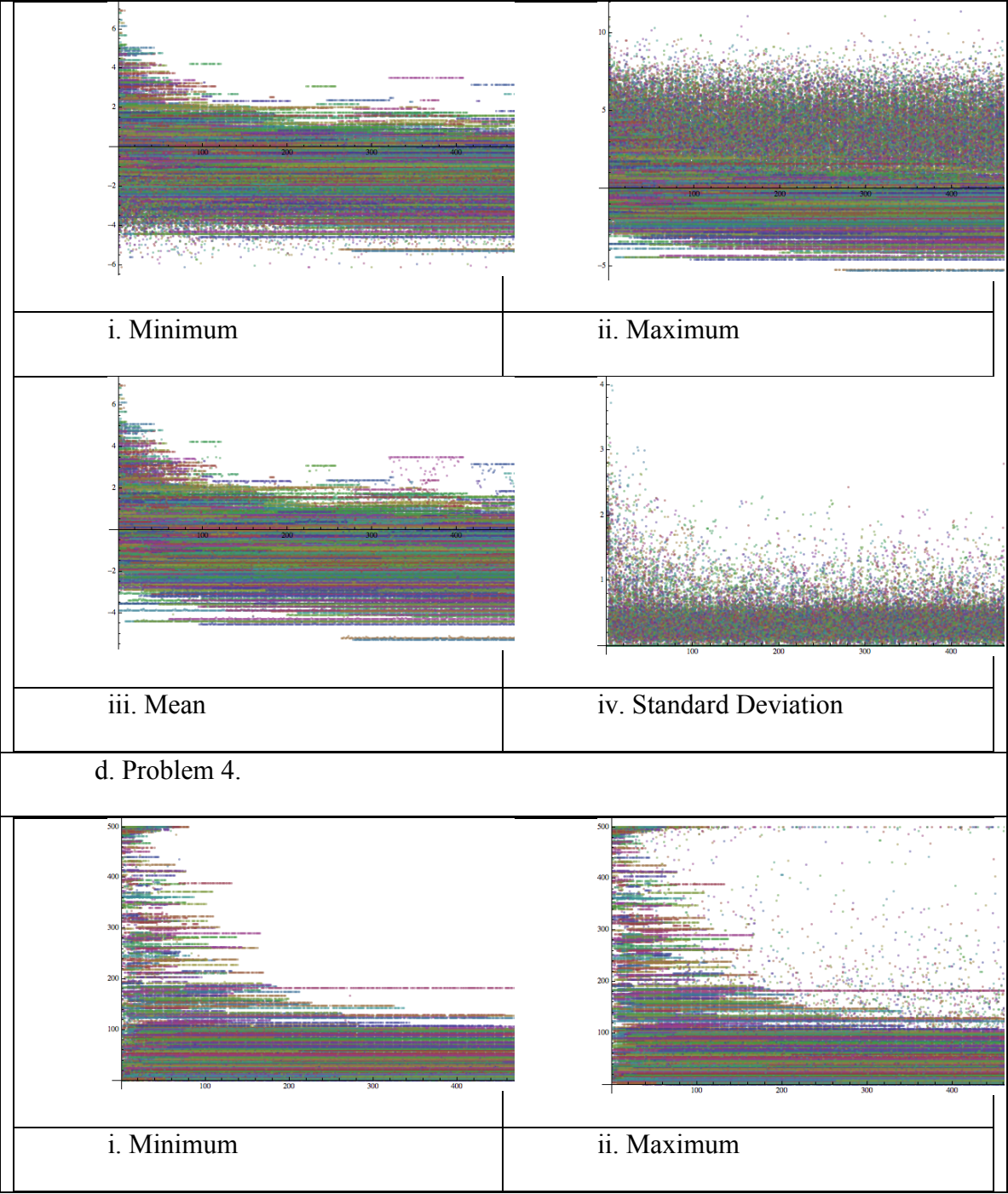
	
i. Minimum	ii. Maximum
	
iii. Mean	iv. Standard Deviation
a. Problem 1.	
	
i. Minimum	ii. Maximum



b. Problem 2.



c. Problem 3.



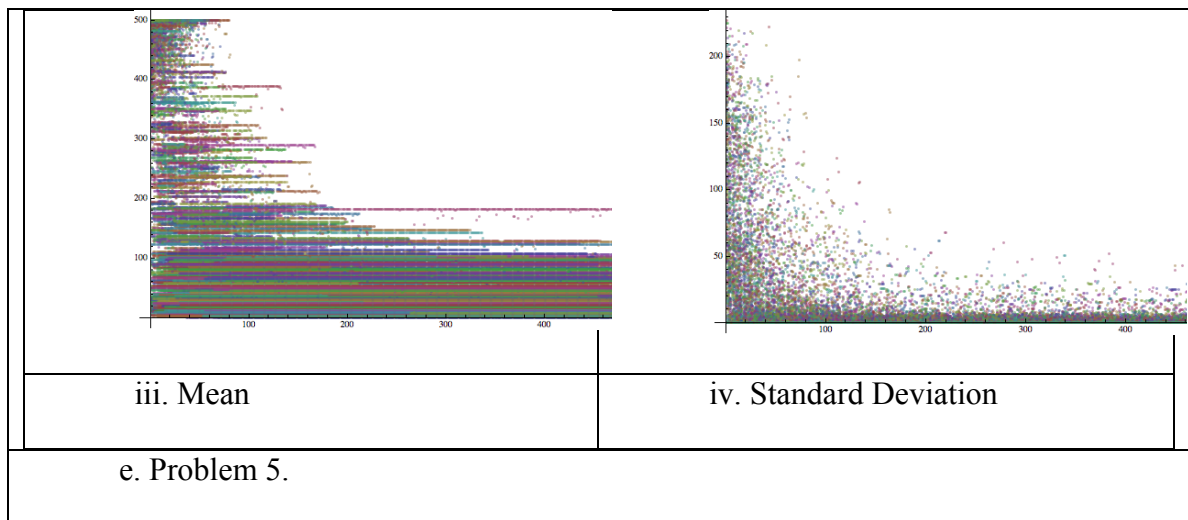
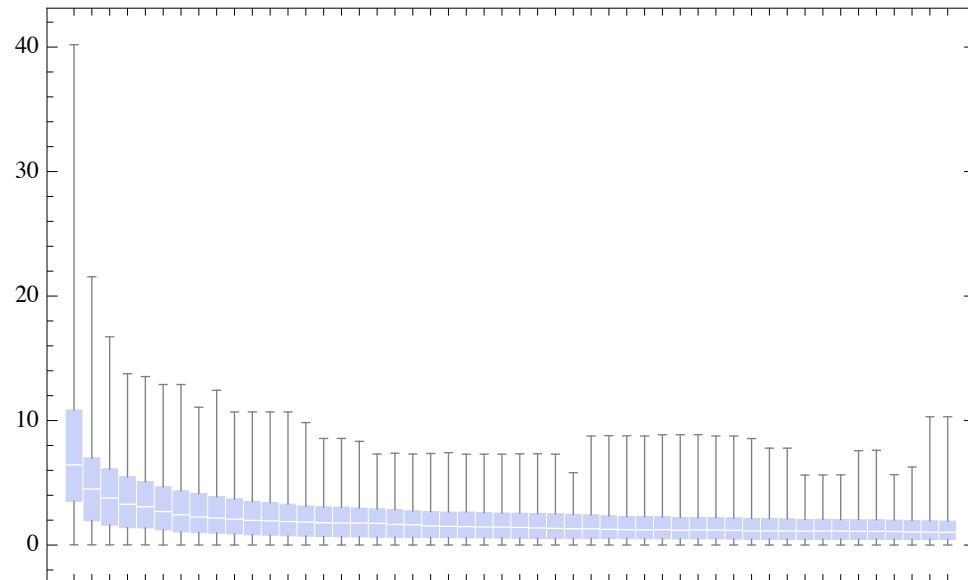
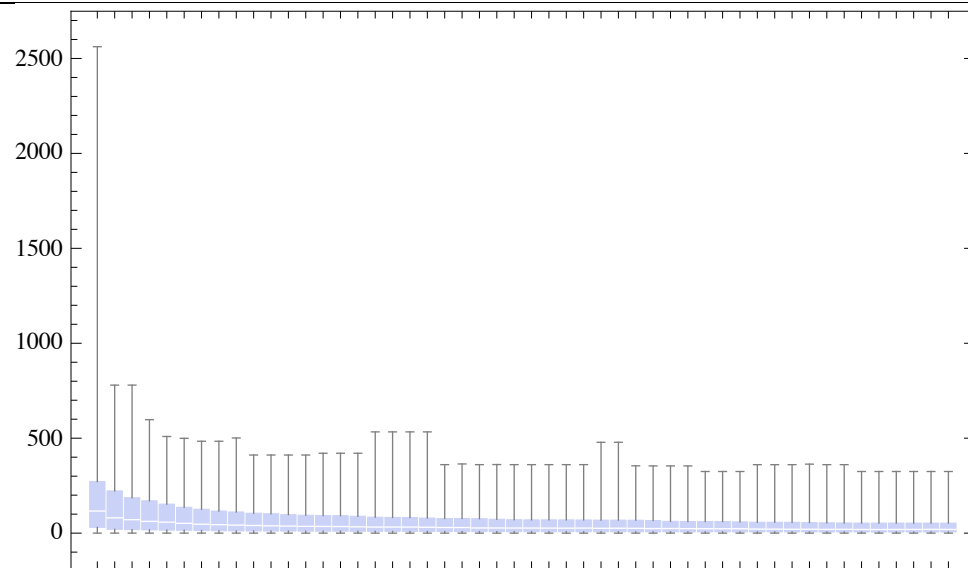


Table 16 shows the aggregated box and whisker plots of mean score over time (each box and whisker plot shows the distribution of mean scores for all 500 runs aggregated to sets of ten time steps per box and whisker plot). Unlike the other heuristic search algorithms tested, the judicial system shows *no* statistically significant improvements from one set of box and whiskers to the next (with larger jumps one can see significant change (e.g., jumping 100 time steps or ten box and whiskers)). Meaning, the courts made incremental improvements rather than dramatic shifts in many cases.

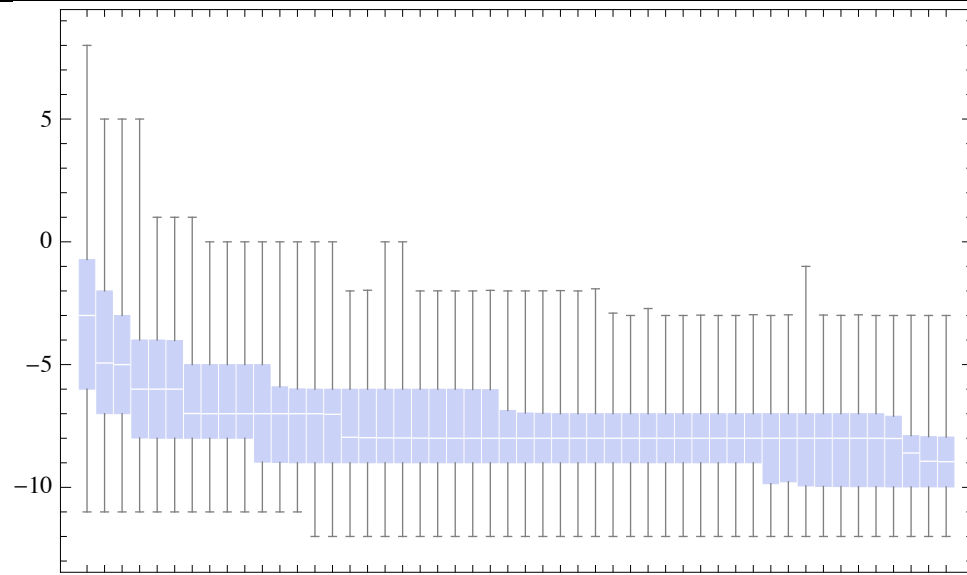
Table 16. Box and whisker plots of the mean judicial system score aggregated into groups of ten time steps.



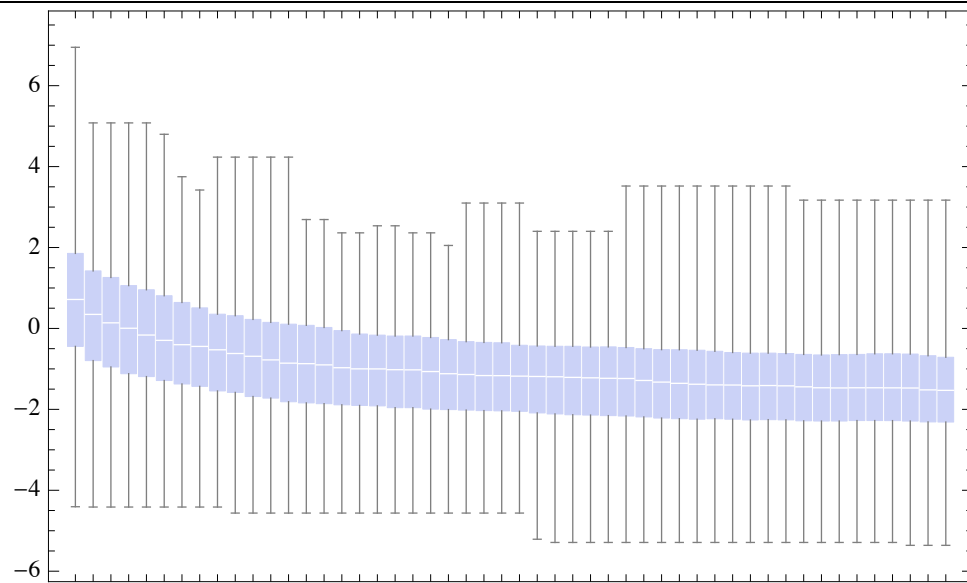
a. Problem 1.



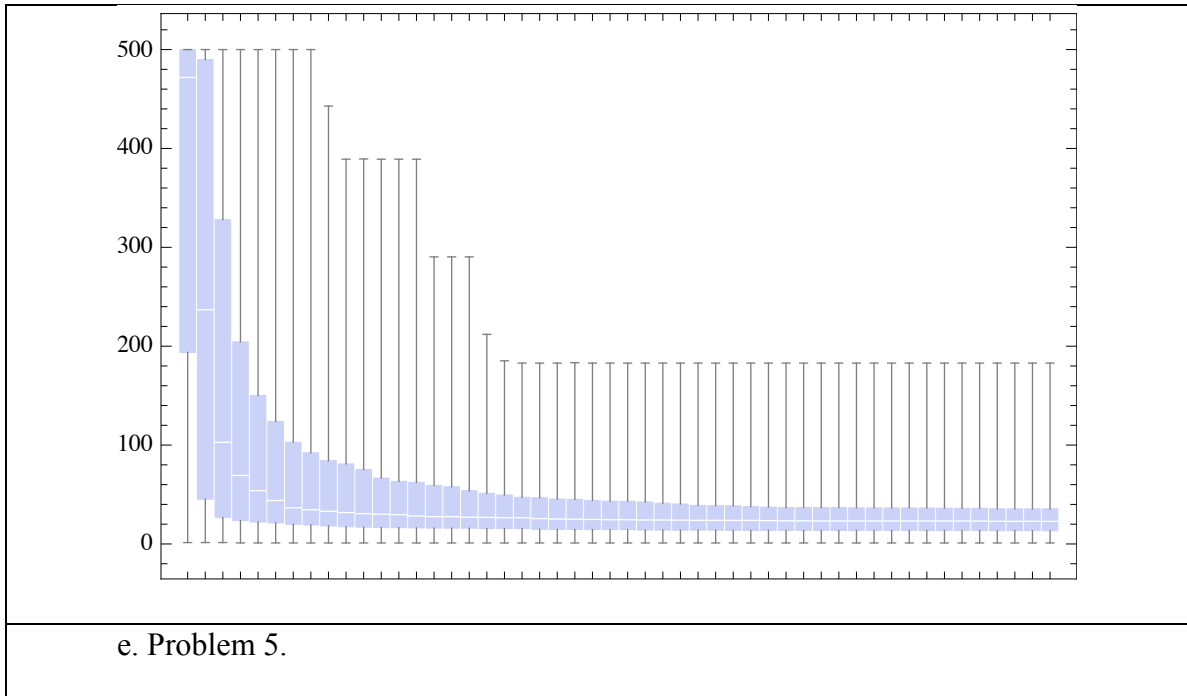
b. Problem 2.



c. Problem 3.



d. Problem 4.



Now we turn to the impact of adding *en banc*, and conformity/consistency dynamics to the courts. These results are not directly comparable to the results discussed above as all five De Jong problems were addressed by the courts in a single run. This was handled probabilistically; therefore, on average, over the 500 time steps each judge will examine each problem 100 times. This is, obviously, only 20% as often as the runs discussed above; however, as can be seen in the histograms contained in Table 16 much of the significant improvements in solution discovery occur in the first 100 time steps. Therefore, it is not expected that this change in court decision-making will have a significant impact on the ultimate ability of the courts to find a solution to the De Jong problems. These runs were performed in the same way as the first set: each design point was run 500 times (each initialized with the same 500 random seeds as previous runs)

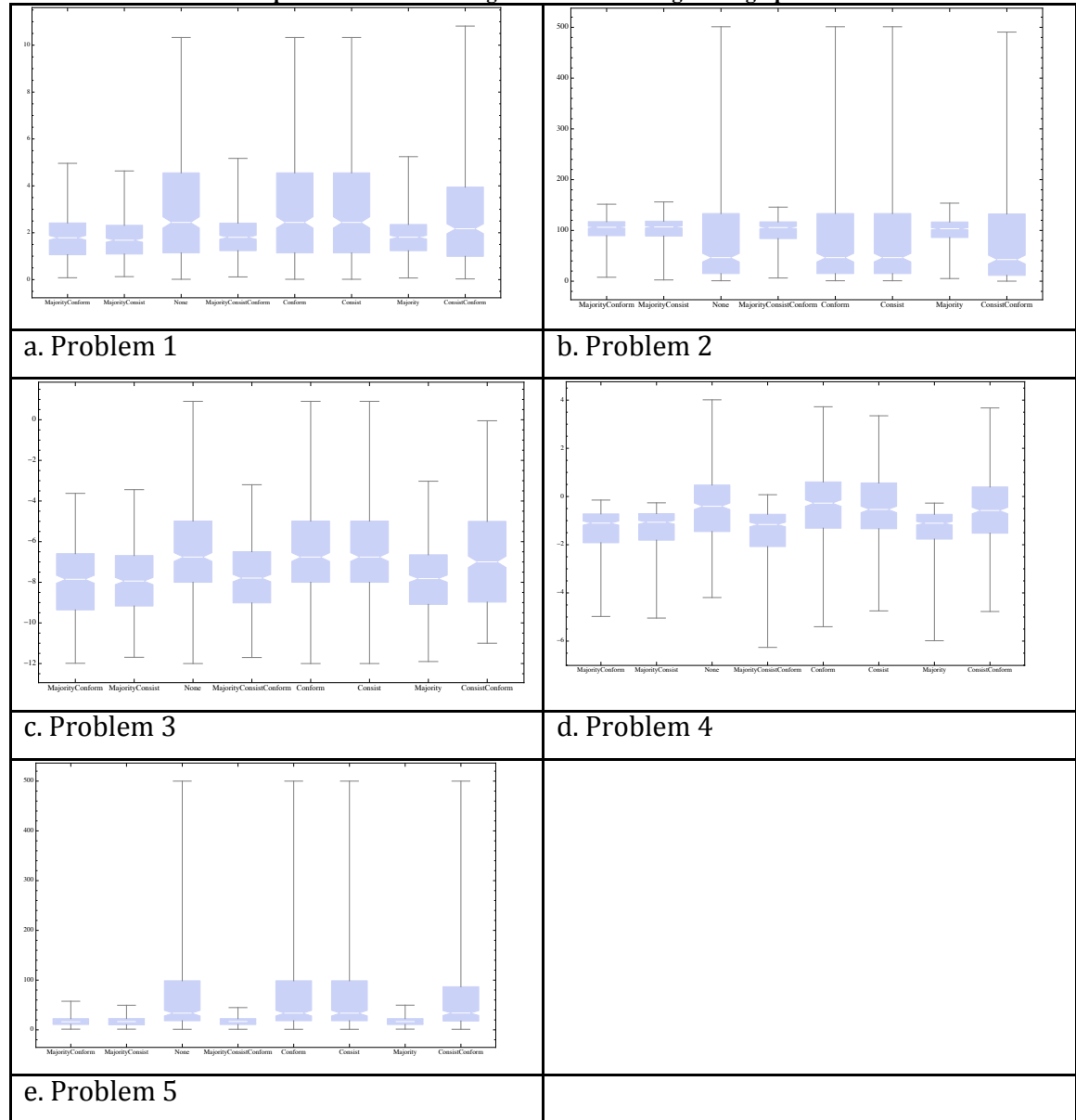
and was iterated for 500 time steps. Table 17 shows box and whisker plots for the average solution found for each problem at the end of the run (each box and whisker plot depicts the distribution of 500 runs).

This next set of runs consisted of eight design points:

1. None (base case all setting as above, however judges dealt with all five problems simultaneously)
2. Consistency (as with None, except the consistency dynamic is turned on)
3. Conformity (as with None, except that conformity dynamic is turned on)
4. Majority (as with None, except that the majorityRule? is set to true)
5. Consistency-Conformity (as with None, except both the conformity and the consistency dynamics are turned on)
6. Consistency-Majority (as with None, except both the consistency dynamic is turned on and the majorityRules? is set to true)
7. Conformity-Majority (as with None, except both the conformity dynamic is turned on and the majorityRules? is set to true)
8. Consistency-Conformity-Majority (as with None, except that the conformity and consistency dynamics are turned on and the majorityRules? is set to true)

In all cases, if the majorityRule? Boolean was set to true then *all* the appellate cases were heard *en banc* (with a 13% chance of an appeal based upon data from the U.S. Courts). Moreover, when the consistency or the conformity dynamics were run they were run with a probability of 1. This means that each time step each judge will go through the conformity or consistency dynamics. Given these settings, this design represents the corner cases of the space, not necessarily realistic values for how human judges may behave. This particular design was created to highlight the potential impact of these dynamics.

Table 17. Box and whisker plots of the final average answer for the eight design points.



One is immediately struck by the fact that the distributions of average solution fall into two distinct groups. These groupings are statistically distinct as shown in Table 18.

Table 18. Kruskal-Wallis analysis of significant difference among the eight design points.

	P-Values		
Problem	Overall Design	MajorityRule True	MajorityRule False
Problem 1	8.16×10^{-30}	0.206	0.053
Problem 2	2.52×10^{-68}	0.184	0.533
Problem 3	2.06×10^{-57}	0.288	0.043
Problem 4	2.69×10^{-115}	0.779	0.173
Problem 5	9.14×10^{-196}	0.998	0.882

Given the extremely small p-values for the overall design, the null hypothesis that there is no difference among the means of the design points can be rejected. On the other hand, when one examines the design points split by *en banc* decision-making one is unable to reject the null hypothesis that the means are equal (with the exception of majorityRule false, problem 3, where design point Conformity true, Consistency true does have a slightly lower mean than the other non-*en banc* design points).

Not only are the differences between runs with and without *en banc* review statistically distinct, the runs with *en banc* review have, in all cases, lower medians than do the runs without *en banc* review. Why would this be the case? Likely, for the same reason that real courts have *en banc* reviews. Namely, it decreases error. The sigmoid curves used for decision-making in the model in all cases will allow for some probability that the judge will err in their decision-making and pick a solution that is not better than their current solution. However, the likelihood of this occurring with *en banc* review decreases dramatically.

Comparison Heuristic Search Algorithms

The comparison of the simulated judicial system's problem solving performance compared with a simple genetic algorithm and a simple particle swarm optimization can be found in Supplementary Information Section Section D.

DO WE HAVE OUR α ?

Based upon the above it is reasonable to conclude that (abstracted) judicial systems can solve problems. Moreover, they can search a space and find better and better solutions. This is consistent with the proponents of the idea that Common Law can evolve to states of higher efficiency. Where does that leave the evidence compiled, and the conclusions drawn, by Niblett et al.? I believe that the model created and discussed here demonstrates that a judicial system can be consistent with both perspectives. Namely, that it can evolve to states of greater efficiency and for discrete portions of time generate signals that tend to indicate that it is, in fact, not becoming more efficient. Niblett et al. appear to have based their conclusion on the assumption that a judicial system would monotonically improve its efficiency. If not truly monotonic then Niblett et al. at least assume a self-similar, or fractal, structure in judicial dynamics that would allow one to draw conclusion about the overall dynamics when only examining a small portion. Given the results described here, even in a very simple hierarchical system trying to converge on a single number, it is unlikely that monotonicity is a feature of judicial systems. This is shown in Figure 17, which depicts the average value over time for De Jong problem 1, the simplest problem, with no *en banc* or conformity and consistency dynamics for 5 runs picked at random.

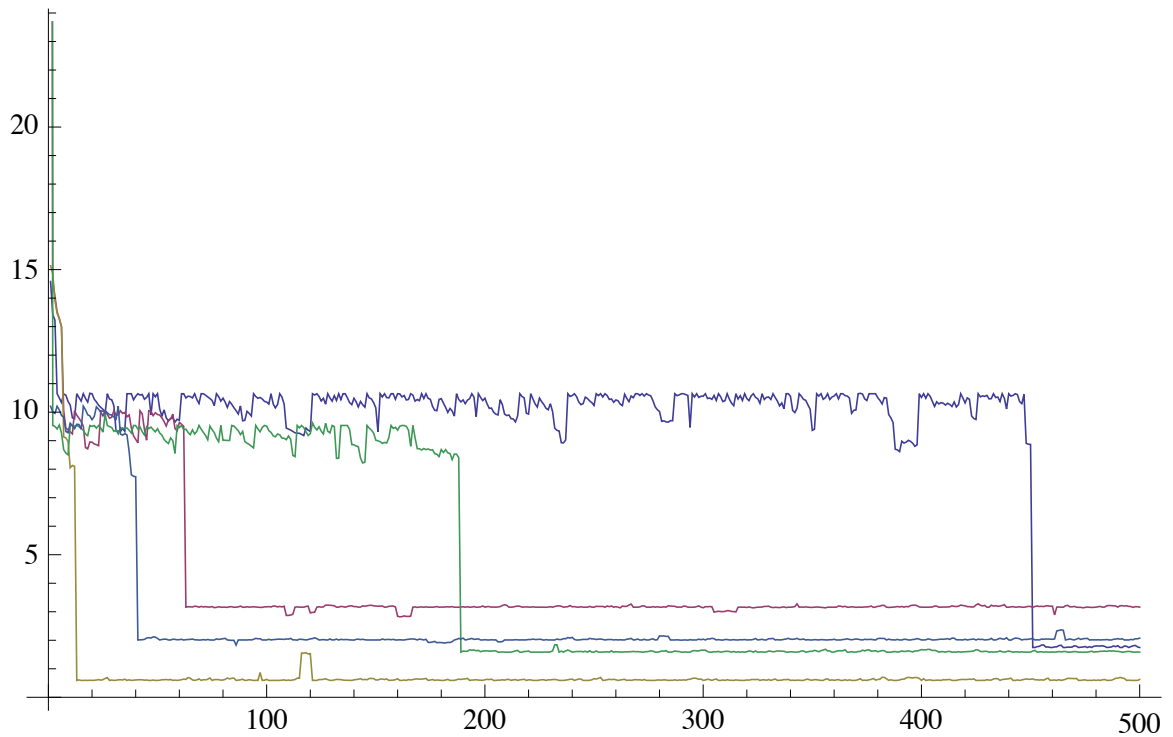
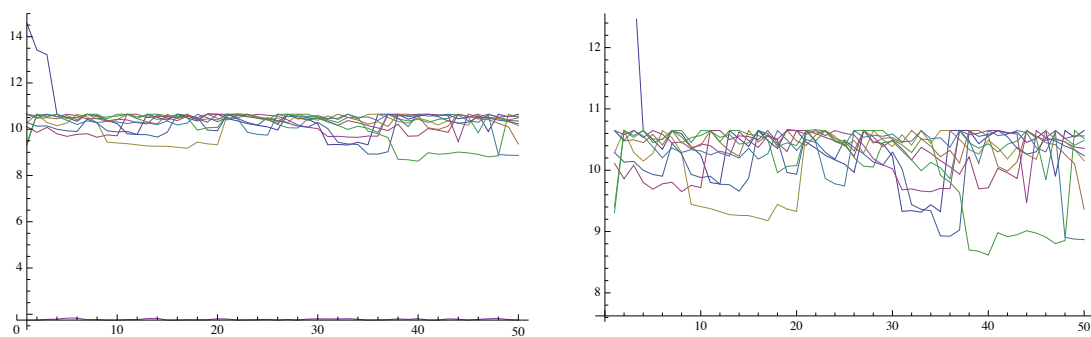


Figure 17. A plot of five randomly chosen runs of the judicial system model, De Jong test set problem 1, without *en banc*, consistency, or conformity dynamics.

Now if we pick one run of the five and break it up into 50 time step portions to emulate the data set that Nibblet et al. created (a snapshot of the overall time series), that produces a set of very ambiguous signals. Picking any one of these portions of the overall dynamic it would be very difficult to determine that the system as a whole was becoming more efficient, even though, when viewed as a whole, it clearly does (this is shown in Figure 17 and Figure 18).



a. Plot of 50 time step portions of the overall dynamic.

b. Zooming in on the plot in a.

Figure 18. Plots of one of the time series shown in Figure 17, split into 50 unit portions and plotted together.

What about a more complicated system, one that has *en banc* review, and the consistency and conformity dynamics turned on? Very similar dynamics are seen in this case, as well. Dramatic improvements are seen as cases are decided on appeal followed by slow losses in fitness. Once again, if a single run is split into 50 unit pieces and plotted together it is very difficult to conclude that the system is actually improving its performance (save the one segment that contains the early sharp drop). In fact, this view of the system may lead one to conclude that the system is actively trying not to find the right answer (Figure 19 and Figure 20).

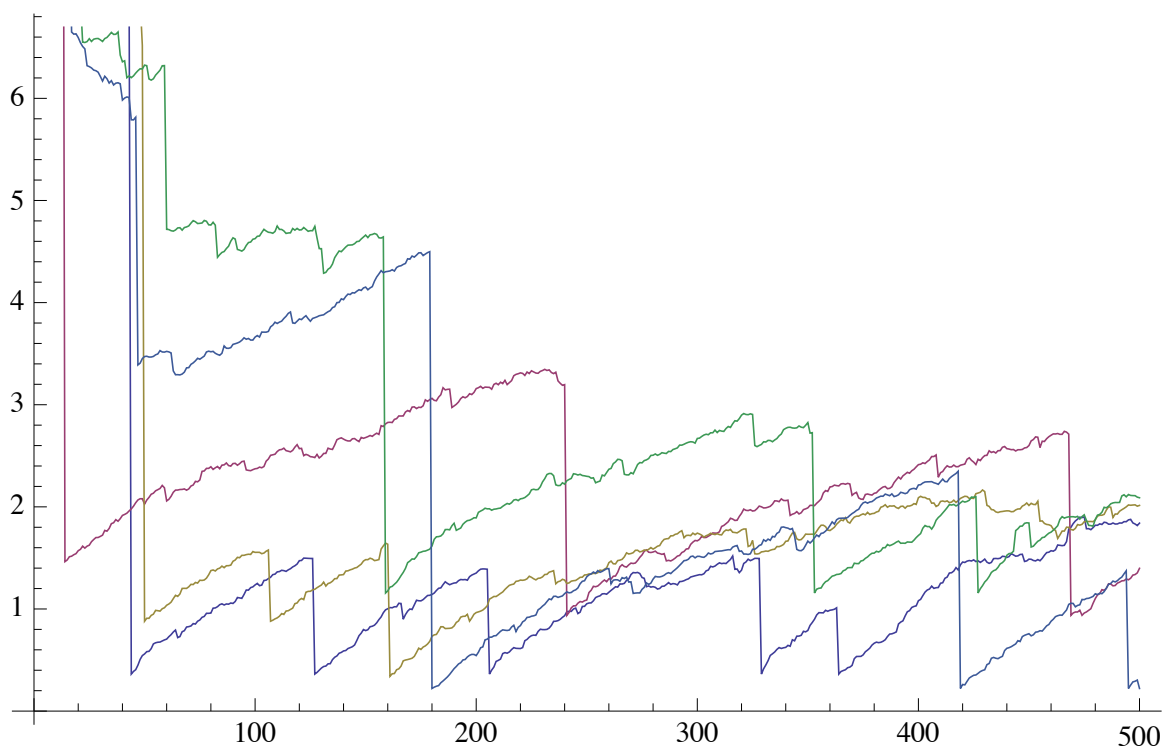


Figure 19. A plot of five randomly chosen runs of the judicial system model, De Jong test set problem 1, with *en banc*, consistency, and conformity dynamics.

It should be noted that these dynamics are seen even in a system as simple as the one created here, where judges know what better answers look like and the problem does not change over time. Likely, in reality judges may not know what an objectively better answer looks like and, more problematically, everything is dynamic (society, technology, laws, etc.).

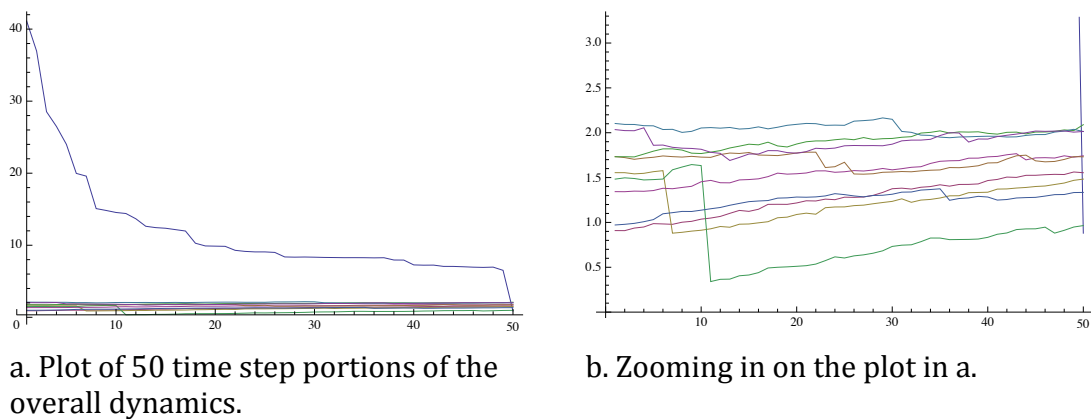


Figure 20. Plot of one of the time series shown in Figure 19, split into 50 units portions and plotted together.

The mechanism that produces these dynamics is the combination of information flow across the two networks that are present in the model. Jumps in the efficiency of the solution occur when an appellate court makes a decision and pushes controlling precedent down to lower courts (the sharp drops seen in Figure 19), then the social influence driving conformity among judges and the desire of judges to have a consistent world view slowly introduces increased heterogeneity (and typically lower efficiency solutions, the slow upward creep seen in Figure 19 that follows a sharp drop) until another appellate decision is made and pushed down. The dramatic change that occurs in this example could be thought of as an example of the dynamic articulated by Sunstein [1996] of a legal system coupling with a “norm cascade” to cause a rapid shift in social and legal structure [Sunstein 1996]. This is akin to a significant case being decided by a high court such as *Miranda v. Arizona* 384 U.S. 436 (the large drop in Figure 19), then over time nuances to its application are developed (the creeping up seen in Figure 19). This is also consistent with many of the dynamics found in the Economic Loss Rule as reported by

Niblett (again with the caveat of Niblett's data was compiled from state courts and the work presented here is based upon a model of the Article III U.S. Federal Courts).

To summarize, our model of the system, Θ , is as described above—a hierarchical judicial system with *stare decisis* and influence networks trying to solve De Jong Problems. Furthermore, this model or Θ includes the philosophical and game theoretic arguments that Common Law should evolve to more efficient states. Our surprising dynamic, ϕ , is the evidence gathered by Niblett et al. that, on their face, appear to contradict the idea that Common Law should evolve. What additional component, α , could be added to Θ such that ϕ would follow as a matter of course? In this case it appears to be that the structure of the judicial system creates a punctuated equilibrium-like [Gould 1989] dynamic to the evolution of the Common Law. This being the case, there should be long periods of relative stasis followed by abrupt changes. This is precisely what is shown in Figures 17 – 20. Therefore, our abduction ($\Theta \cup \alpha \Rightarrow \phi$) is complete (or at least plausible). Where α is the knowledge that the Common Law does not evolve via gradualism, but rather via punctuated equilibrium. This implies that any finite sample of the overall system dynamics is likely to show little improvement.

ADDING A BIT MORE DETAIL

The addition of scale, jurisdiction, social networks, and real problems appears to be adequate to produce a system that demonstrates that a real court system can be consistent with all the logical arguments espousing evolutionary pressure on the Common Law and the finding from a finite sample that the Common Law does not monotonically move to states of increased efficiency. In this way, this abductive investigation appears to have been successful. However, this does not end the utility of such a model. As additional key features are added to the model it can be used to explore and understand other dynamics of a judicial system. For example, in the above model judges acted independently or en banc, essentially, corner cases for a judicial system. What about a more typical three judge panel for appellate courts? Moreover, all judges acted independently to pick cases. Typically a court has a docket. Does that have any impact on the overall dynamics of the system?

In the next section we will add these two features to the model and explore their impact on the dynamics. In addition, we will undertake a simple sensitivity analysis on the impact of the conformity and consistency dynamics added above.

Adding a Docket

In order to create a docket in a simple manner, I provided each court agent with a list data structure in which to store “cases” that were appealed. Each court’s docket is set up as a “FIFO” queue (first in, first out). At the District Court level the docket is created by randomly populating the court’s docket with cases equal to the number of judges on the court (the assumption being that District courts are never case constrained). This is consistent with the Rubin [1977] model of common law evolution, where parties with an interest in precedent will have an incentive to litigate inefficient laws. Therefore, even if judges decided cases randomly eventually a decision would create an efficient law and said law would no longer be litigated. This is also consistent with arguments by Alchian [1950] about how an economy can become efficient when populated by boundedly rational actors subjected to uncertainty.

However, it should be noted that in the model presented here, due to the fact that parties to a case are not currently part of the model, a case is added to a court’s docket at random and the judge deciding the case determines whether or not to appeal (using the judge in this manner was **simply** an implementation convenience and is **not** used as part of the institutional structure under review). Cases to be appealed were determined by the lower court judge that heard the case originally. Appeals from the District Courts are very simple. Examining statistics available from the U.S. Courts (www.uscourts.gov) shows that approximately half the cases heard by the District Courts are appealed. Therefore, after a District Court judge hears a case there is a 50% chance that it will be appealed. If appealed, the case is added to the relevant Appellate Court’s docket. Once an Appellate Court hears a case there is some chance that it will be appealed to the Supreme Court.

Again, examining U.S. Court statistics reveals that approximately 13% of cases heard at the Appellate level are appealed. The Supreme Court is most likely to step in when there is disagreement among the lower Courts [Ulmer 1984]. Therefore, the algorithm used by Appellate Judges to decide whether or not a case is appealed takes into account the standard deviation in solutions among Appellate Judges divided by the overall standard deviation for the problem in question. As an example, the logic used for the appeals to the Supreme Court can be found below (7.1). The value of 2.25 was used to tune the appeal rate based upon data obtained from www.uscourts.gov.

$$IF\left(rand(2.25) < \left(\frac{standardDeviation(AppellateJudges)}{maxPossibleStandardDeviation}\right), Appeal, NoAppeal\right) \quad (7.1)$$

This was used as part of a random draw that resulted in approximately 13% of cases being appealed; with the added feature that cases involving high disagreement among judges were heard more often than were cases with little disagreement. It should be noted that this is a simplification of the actual dynamics of the appeals process within the U.S. Federal Courts. The system used in the model includes intra-Circuit as well as inter-Circuit splits. In the judicial institutions of the Federal Court intra-Circuit variation is typically dealt with via an en banc review of a case, rather than through appeal to a higher court. In the simplified appeals process used here this distinction was not made [see generally, George 1999 and Ulmer 1984]. As before, if the case was appealed to the Supreme Court it was added to the Supreme Court's docket. The appeals process was

tailored in this manner as we have no litigants in the current model who would decide whether or not to pursue an appeal.

When making use of the docket, judges are limited in the cases that they can hear to those that have been added to their court's docket. This should make a difference to the model's dynamics. When judges are not using a docket all judges on a court may pick a case to hear. Therefore, using a docket will dramatically decrease the throughput of the Appellate Courts and partially address the issue that empanelled judges produce as many decisions as non-empanelled judges.

Adding Three Judge Panels

Adding three judge panels to the model was relatively straightforward. The same “machinery” used for the en banc was used here, but rather than making use of all judges on a court, the judge that “calls” the case only chooses two other judges from the court to join in the ruling. This should make a difference when compared to the one-judge-per-case institution, as it will decrease the chance of error. For example, if there is a 10% chance that one judge will make a mistake (here choose an answer that is higher), then the chance that a three judge panel would make the same mistake is 2.8% ($.1^3 + 3*(.1^2*.9)$). This is a dramatic decrease. However dramatic this decrease is, in practical terms three judge panels should not be significantly worse than an en banc panel as once the probability of mistake gets small enough mistakes are vanishingly rare. This is, essentially, the Condorcet Jury Theorem. In the model developed here we have a number of independent decision-makers that have imperfect abilities to choose an objectively

correct answer, but the probability that they will choose the correct answer is greater than .5, and who are aggregating their choice via majority rules. Therefore, as the number of independent decision-makers grows so too does the probability of the majority rules decision choosing the correct answer [Berend and Paroush 1998].

Our hypotheses for these new features in the model include:

H1: Using a docket will *decrease* the throughput of the system.

H₀1: Docket use will cause no change to, or increase, the throughput of the system.

H2: Using more than one judge above the District level will *increase* the performance of the system.

H₀2: Using more than one judge above the District level will not improve the performance of the system.

H3: Given H2, en banc review should do *better* than three judge panels.

H₀3: Given H2, en banc review will not do better than three judge panels.

Results and Sensitivity Analysis

A simple design of experiments (DOE) was completed to exercise this next version of the model. Specifics of the DOE can be found in Table 19, below. The DOE consisted of 54 parameter combinations (3x3x3x2). Each design point (unique parameter combination) was run 250 times, each with a specific random seed. This produced 13,500 runs of the simulation (and produced more than 74,000 output files).

Table 19. The design of experiments used for this version of the judicial model.

Parameter	Low Value	Medium Value	High Value
Probability of Conforming	0	25%	50%
Probability of Increasing Consistency	0	25%	50%
Use of the Docket	False	N/A	True
Institution	Individual	Three Judge Panels	En Banc

Basic dynamics of the system can be seen in Tables 20 – 24. Tables 20 – 24 shows a judge level visualization of the dynamics of a single representative run. What is shown in these Tables is an array or percolation plot. Each pixel is a judge (Supreme Court justices are on the far left, followed by Appellate Court justices and lastly the District Court justices). Each row is a time step in the model, each column shows the activities of a particular judge over time. Each problem’s solution space is normalized to have its minimum value occur at zero. The lighter the color, the closer to zero is the particular judge’s solution. Blocks of color change represent the impact of precedent. When an Appellate Court decides a case that decision is “pushed” down to lower courts within the Appellate Court’s controlling precedent network. There is a transience period of approximately 10 time steps that are removed from the visualization as the solutions the judicial system contains are particularly bad and these extremely high values wash out the changes seen later.

Structures to notice in the visualizations include: Horizontal “lines,” these are caused by the Supreme Court deciding cases. Thick columns on the left with a number of thinner columns towards the right, these are caused by Appellate Courts deciding a case that is then pushed down to the lower courts in its jurisdiction. There are some very interesting dynamics in the simulation. Looking at Problem 3 and 4, which caused the courts some trouble, there are times where the Supreme Court makes a decision that makes things worse; however, as can be seen, this poor choice is followed quickly by an increase in diversity as many cases that come before District and Appellate Courts will be better solutions to the problem. However, when the Supreme Court makes decisions that improve the solution held by the judicial system diversity creeps in more slowly (as it is largely a function of how much room is left for improvement and the error rate).

Table 20. Visualizations of sample runs of De Jong Problem 1 by judge grouping (rows) and institution (column).

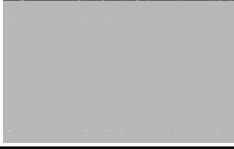
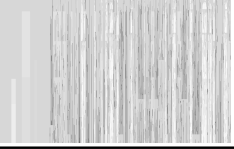
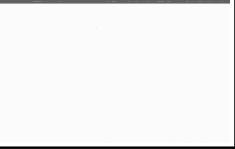


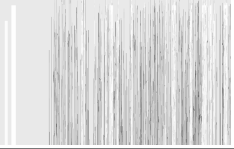


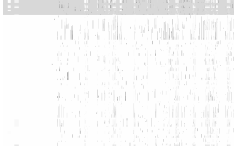



Problem 1	Without conformity or consistency dynamics		With conformity and consistency dynamics	
	Docket False	Docket True	Docket False	Docket True
Individual				
Three Judge				
En Banc				

Table 21. Visualizations of sample runs of De Jong Problem 2 by judge grouping (rows) and institution (column).





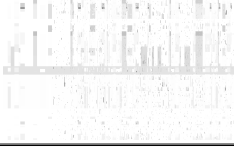





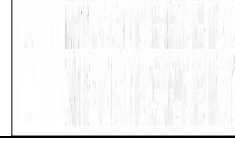
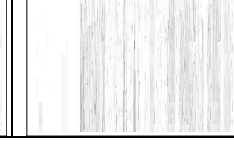
Problem 2	Without conformity or consistency dynamics		With conformity and consistency dynamics	
	Docket False	Docket True	Docket False	Docket True
Individual				
Three Judge				
En Banc				

Table 22. Visualizations of sample runs of De Jong Problem 3 by judge grouping (rows) and institution (column).

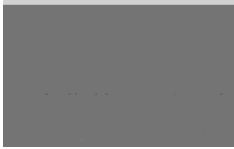



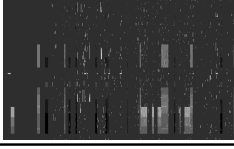
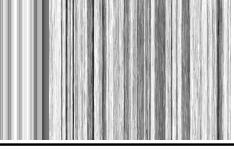
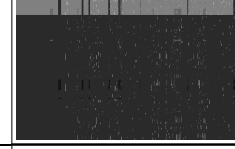

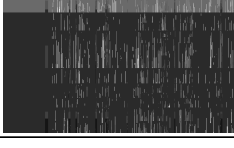

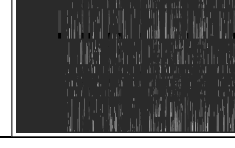

Problem 3	Without conformity or consistency dynamics		With conformity and consistency dynamics	
	Docket False	Docket True	Docket False	Docket True
Individual				
Three Judge				
En Banc				

Table 23. Visualizations of sample runs of De Jong Problem 4 by judge grouping (rows) and institution (columns).

Problem 4	Without conformity or consistency dynamics		With conformity and consistency dynamics	
	Docket False	Docket True	Docket False	Docket True
Individual				
Three Judge				
En Banc				

Table 24. Visualizations of sample runs of De Jong Problem 5 by judge grouping (rows) and institution (columns).

Problem 5	Without conformity or consistency dynamics		With conformity and consistency dynamics	
	Docket False	Docket True	Docket False	Docket True
Individual				
Three Judge				
En Banc				

Looking at individual runs can be informative for basic model functionality but to understand system dynamics often it is more informative to look at a large number of runs. In **Error! Reference source not found.**, below, box and whisker plots are shown that show the distribution of “solution volumes” created by sets of 250 runs. The solution volume was created by calculating the area under the plane created by the answers of each judge over time. If the judges all had the best answer for the entire run of the simulation then the volume would be zero. A visualization of this can be found in Figure 21 in which you can see that the system steps down twice, and there are a number of individual instances when a judge finds a better answer before they are overruled again. Essentially, the volume calculation amounts to slicing this surface up into a 774 (the number of judges) by 500 (the number of time steps) units and measuring each one’s distance from the best answers. Each of these ~385,000 measurements are then summed to a single value of total volume. This was done for each of the 250 runs completed for each design point of the design of experiments. The box and whisker plots below are built from these 250 points.

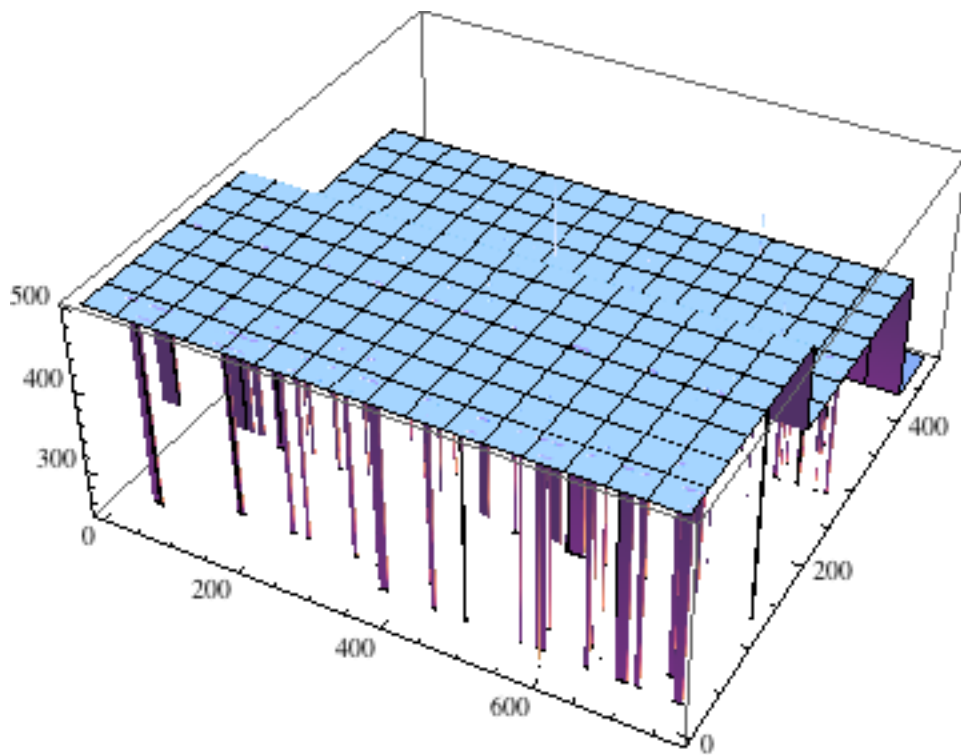


Figure 21. A graphical depiction of the “surface” created by the judicial system’s current state. This surface is created by first normalizing the minimum to zero and then height of the system by recording the holding of every judge at every time step. This creates a surface made up of 387,000 points (500 time steps x 774 judges). The purple columns see extending down from the surface are a feature created by diversity of solution among the judges. If a judge has a better solution to the problem that will be shown as a column. These columns are transitory due to the precedent network.

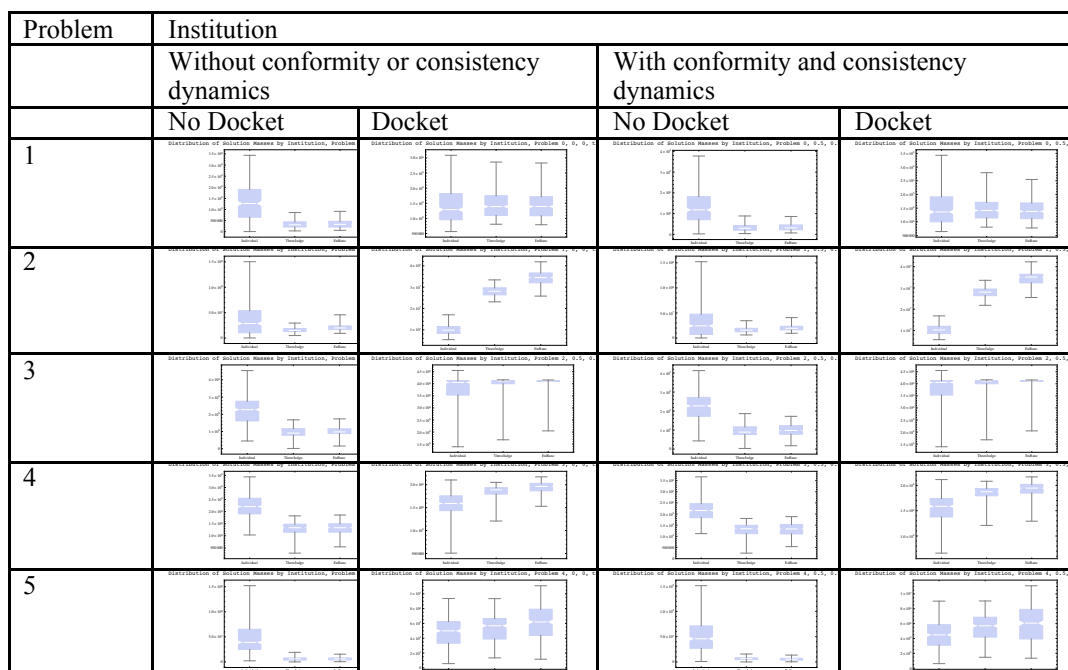


Figure 22. Notched box and whisker plots of the distribution of solution masses by problem (rows) and institution (columns).

As can be seen, in almost all cases the Institutions that use group decision-making (three judge panels or en banc review) out perform institutions in which all judges act independently. This is not a surprise, as discussed above with probability of mistakes decreasing so dramatically as decision-makers are added. What is of interest is that there is almost no statistically significant performance difference between the institution that uses a three judge panel and the institution using the en banc review. This is interesting because if there is no performance penalty between the two then the three judge panel is cheaper and can have higher throughput than can en banc review.

As discussed above, it was anticipated that adding a docket should decrease the throughput of the judicial system. That can be seen in the following Figures (23 – 26). In

all the cases above the District Court level, the inclusion of a docket decrease the number of cases heard and, therefore, the number appealed to the next higher court. It should also be noted that there is, essentially, no effect on the flow of cases based upon changes in the conformity or consistency dynamics. This is not surprising as, in the model, these two mechanisms are entirely separate. This is not to say that there is no way one could impact the other, simply that the expected, and as can be seen, the realized, impact is minor.

Figures 23 – 26 show these conclusions.

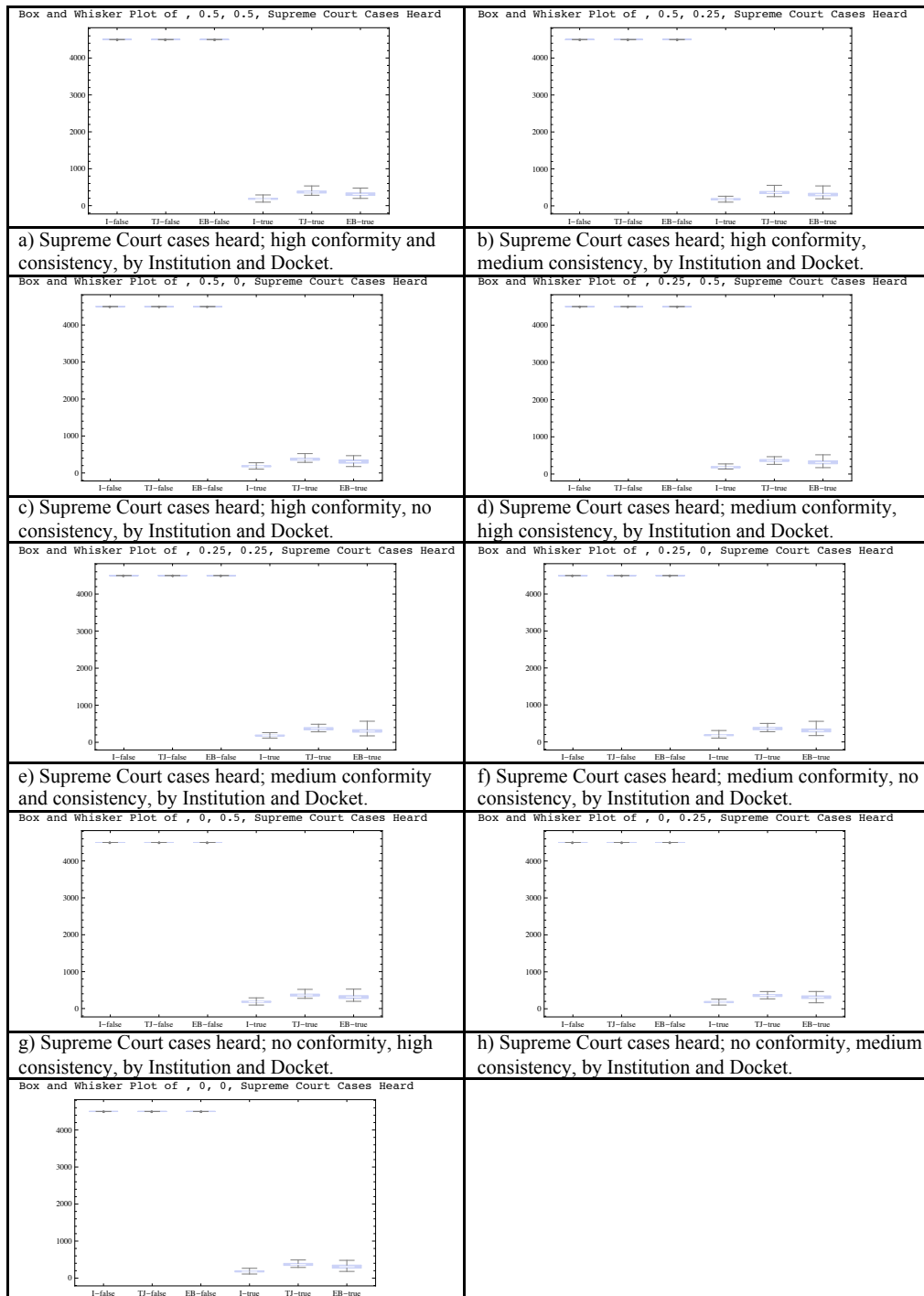


Figure 23. Supreme Court cases heard.

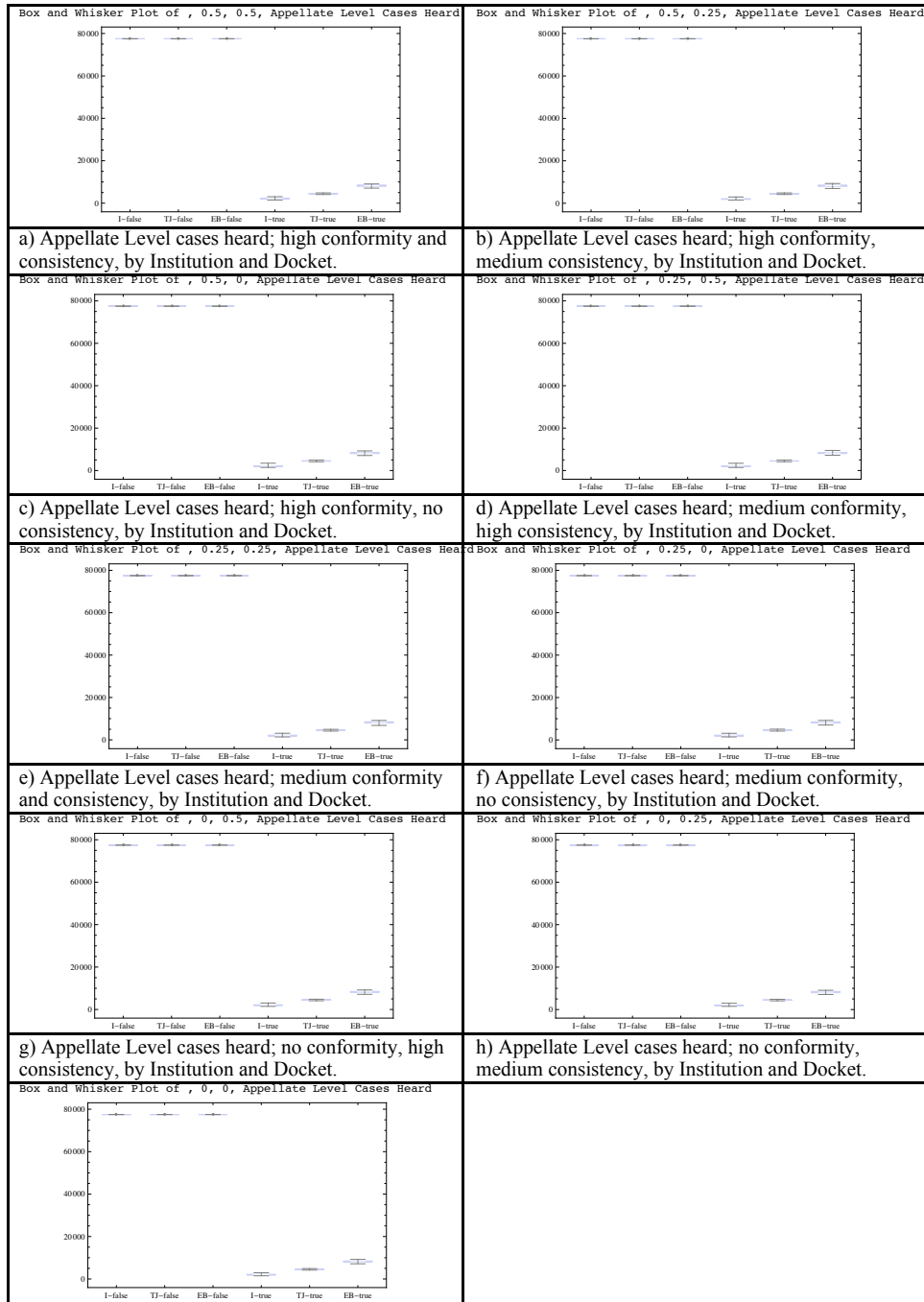


Figure 24. Appellate Level cases heard.

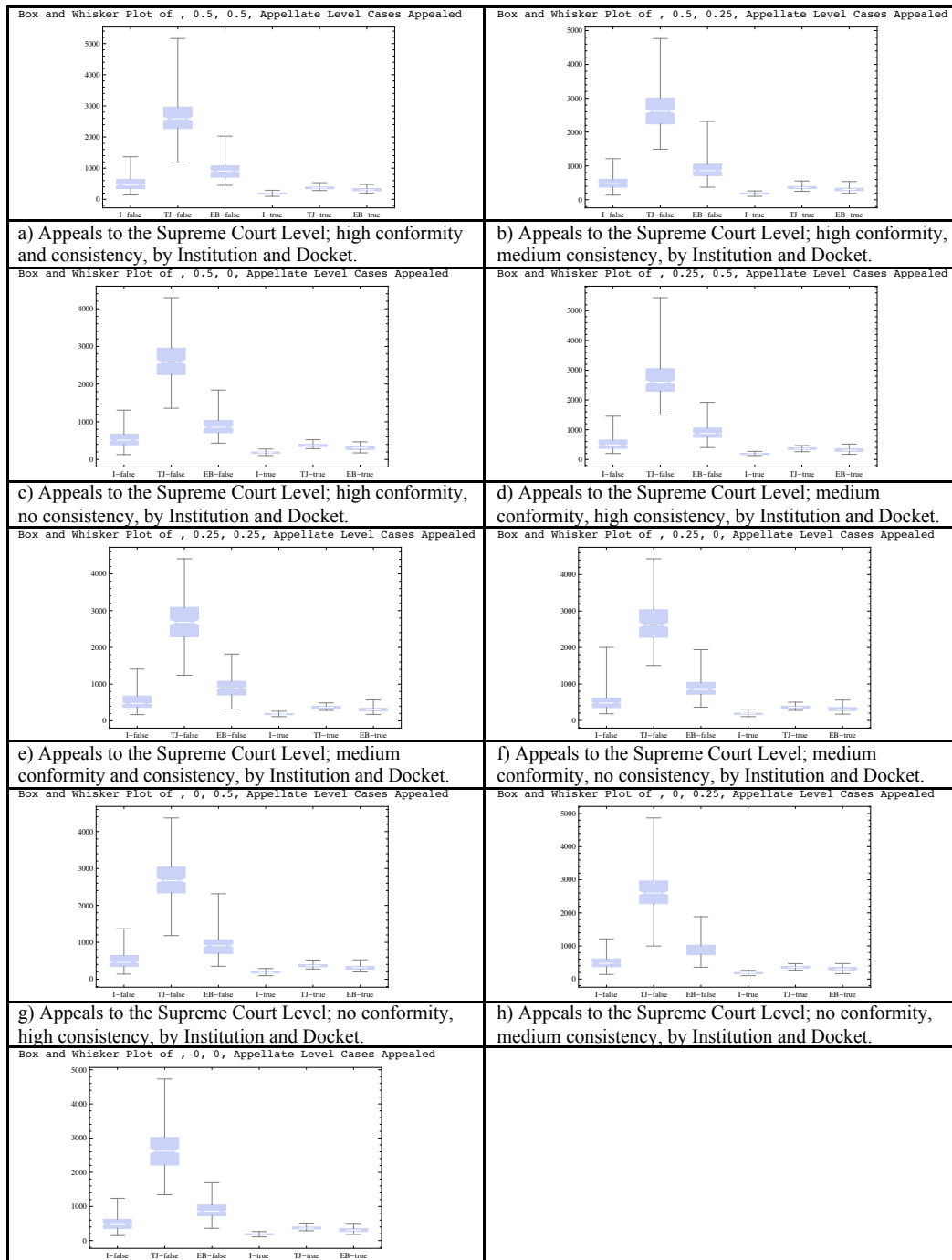


Figure 25. Appeals to the Supreme Court.

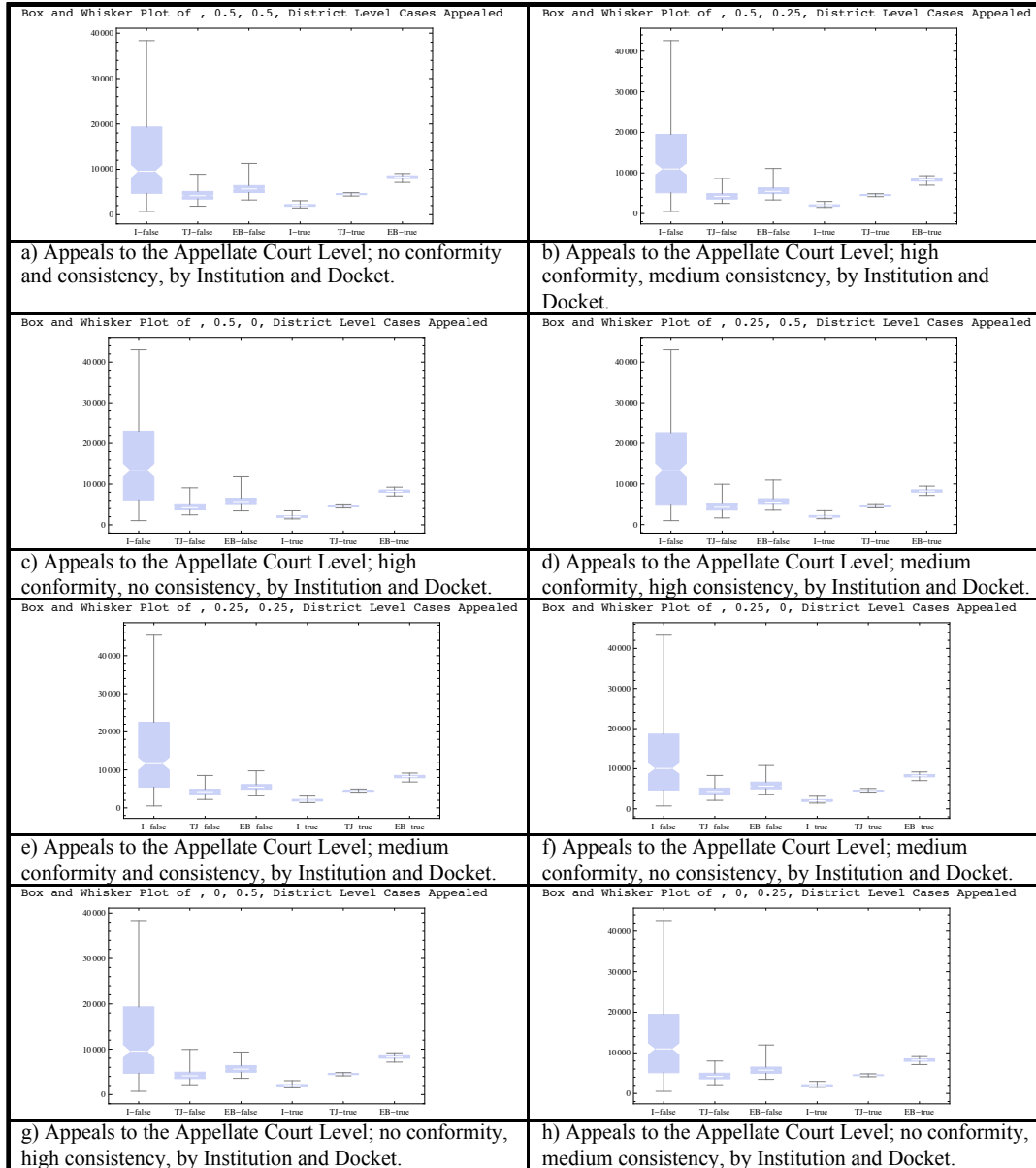


Figure 26. Appeals to the Appellate Court level.

Impact of Agent Activation

Agent activation regime was also tested. The activation regime used in the sensitivity analysis discussed above used was Structured Randomized. Every time step the district judges were activated in random order (a different random order each time), then the appellate judges were activated in random order (a different random order each time), and finally the Supreme Court justices were activated in random order (a different random order each time). Other regimes that were tested included:

Structured Fixed: District court judges activated first in a fixed order, then appellate level judges activated in a fixed order, finally Supreme Court justices activated in a fixed order.

Fully Randomized: All judges activated in a random order (a different random order each time) without regard to court.

Fully Fixed: All judges activated in a fix order without regard to court.

Changes to activation regime had little impact on the overall outcome of a run. Although for some De Jong problems and institutions there were statistically significant differences, the “practical” different in terms of mean/median outcome was not large. Furthermore, activation regime did not wash out the differences seen in the use of a docket. Additional details and figures can be found in the Supplementary Material⁴.

Regarding the hypotheses:

The original hypotheses:

H1: Using a docket will *decrease* the throughput of the system.

⁴ Supplementary Information can be found at: <http://css.gmu.edu/koehler>.

H₀1: Docket use will cause no change to, or increase, the throughput of the system.

H₂: Using more than one judge above the District level will *increase* the performance of the system.

H₀2: Using more than one judge above the District level will not improve the performance of the system.

H₃: Given H₂, en banc review should do *better* than three judge panels.

H₀3: Given H₂, en banc review will not do better than three judge panels.

Holdings:

H₀1: This was slightly **mixed** but basically rejected. The use of the docket dramatically decreased the number of Appellate cases heard. It also dramatically decreased the number of cases heard by the Supreme Court. The number of Appellate cases heard decreased dramatically. At the District level the impact is less clear. The variance decreased with the use of the docket. The docket caused a dramatic decrease in the number of appeals in the Individual Judge Institution. Interestingly, the impact of the docket on Three Judge and En Banc Institutions was mixed. Likely, this is due to the increased performance of the system as there were fewer erroneous decisions passed down from the Supreme and Appellate levels.

H₀2: **Mixed**, often three judge panels and en banc panels perform better than do independent judges. However, this is somewhat tempered by the fact that fewer cases are examined, so, although the system makes a better decision it has fewer chances to make the best decision.

H₀3: **Mixed**, often we fail to reject. There are few statistically significant differences between three judge panels and en banc panels. As this model only includes bipartite choices the probability of error decreases very quickly as each judge makes their decision independently.

FUTURE WORK

Where are these models with respect to empirical relevance? At the agent level we have well functioning code that describes appropriate behavior for the agents. That places these models solidly in Level 0 (see *supra* for a brief discussion of the Axtell Levels of Empirical Relevance). Some aspects of these models generate appropriate macro dynamics (e.g., percent appealed and degree distribution among the judicial social network (to the extent that is understood)). That indicates that portions of the models have reached Level 1. Here, due to the fact that a society was assumed away, some of the potentially Level 1 results, such as rates of appeals, are more likely the result of tuning rather than an emergent phenomena. This brings us to what must be done next to begin to make these dynamics endogenous.

Like all models many features of the system being represented by the model were not included. As shown, a relatively simple model was adequate to produce a plausible hypothesis to explain the Niblett et al. finding. However, that simple model would not be adequate to answer all questions related to a judicial system. For example, one could not examine the impact of changes in a judge's clerk staff with any model presented here. Moreover, changes to society cannot be examined with the models created here. Some of the simplifications that should be addressed will be discussed next.

One significant simplification in the models described here is that the judges are not, specifically, time-constrained and do not have an inherent “skill level” or attention to detail. All the decisions that start in a time step finish in that time step and how careful a judge is has no impact on the time required to decide a case. Having said that, the “time step” is, therefore, defined as the period of time it takes a judge to make a decision. (However, it should be noted that this definition fails to highlight the “free” work judges undertake in the simulation when *en banc* or three judge panels are used; in these cases each judge on a court will call a panel, therefore the judges will make the same number of decisions whether they are empanelled or not.) So, the simplification actually becomes one of homogeneity. Namely, that all judges can make a decision in the same period of time. Although, it is unlikely to make a significant difference to the ultimate result, relaxing this assumption should slow the time to convergence on a solution. Where this might make a significant difference is with the litigants. Where this could make a difference is when it is coupled with a judge’s skill level or attention to detail. Adding that would allow one to examine the impact of judges that have higher rates of incorrect conclusions but can decide cases very quickly versus judges that often make the correct decision but it takes them a long time to do so. Two judges on the Ninth Circuit, Kozinski and Reinhardt, have actually dealt with this issue by discussing (<http://www.nonpublication.com/don't%20cite%20this.htm>) the utility of having unpublished memorandum dispositions, which can be created very quickly, versus published opinions which take much more time to create.

Which brings us to the next major simplification that will need to be addressed in future work: the absence of litigants. Much of the literature on the evolution of Common Law includes the litigants as a non-trivial component. Given the Cases and Controversies clause the judicial system is subject to the whims of society regarding what gets litigated. That being the case, the dynamics of society are an extremely important component to the judicial system and one that is largely ignored in the current models. Further, as stressed by Smith (2005), not only are litigants a critical part of the legal system (and the lawyers that represent them) but so are the narratives used to argue a case. The addition of litigants will allow for a more endogenous treatment of the appellate process. Moreover, litigants would provide an experimental medium for testing of Behavioral Biology and Law espoused by Jones and Goldsmith [2005]. A related issue is the use of *en banc* review. In the current model, *en banc* is used as a method for appellate courts to decide cases. In reality it is often used as another “vertical” step to review an appellate court’s decisions before it is appealed to the U.S. Supreme Court. It would be interesting to see what, if any, impact this additional layer of review might have to the performance of the judicial system modeled here.

There are two other issues with the current model that should be addressed in the next developmental steps. The first is to explore the impact of judicial bias. This is coupled with the final issue: Problem discovery and jurisgenerative decision-making. In the current model the judges all “know” they face a minimization problem (not to mention these minimization problems are static); therefore, smaller numbers are better. This is a very stylized and, arguably, unrealistic assumption. Many problems faced by a

judicial system are not so obvious. This is a simplification that should be addressed. The other related issue is that judges in the current system do not make law. All decision-making is jurispathic, the judges are presented with two options and they pick one, they never create a third solution. This, too, is an over-simplification that should be dealt with in subsequent version of the model.

CONCLUSION

The utility of Computational Generative Jurisprudence (CGJ) was discussed. An example, abductive problem was defined and then dealt with using the tools of CGJ. The utility of this approach comes from its ability to handle the messiness of real human systems. It allows one to relax the restrictive assumptions necessary for closed form mathematical treatments from fields such as Game Theory and Neoclassical Economics. As such, CGJ represents, potentially, the only viable option for an experimental underpinning to many problems facing our society today, as very large-scale human experiments are too costly or fraught with ethical issues to be truly viable options. As nations' governments change and new judicial systems are created, GCJ is, likely, the only way one may be able to experiment with new or different judicial systems and the potential impact changes may have. As a system created by humans to help solve disputes, how must the legal system deal with these challenges? The law and the judicial system within it must be willing to change. As Dworkin rightly pointed out, an optimal (here, in his example, train speed) will depend upon technology, which changes, and on other values that fluctuate such as the price of grain and the price of freight [Dworkin, 1986, at 281]

Given these initial findings what conclusions can be drawn about the judicial system and the statements made about its ability (or inability) to evolve towards more

efficient states and adapt to changing conditions? The main point seems to be one suggested by the box and whisker plots of the increasing optimization over time. As can be seen in Table 16 improvement within a judicial-like system seems to come more from “shrinking” the tails than from finding a new, disruptive solution to a problem. This being the case, it would be possible to collect data that would tend to indicate that the system was not tending towards better answers (as Niblett, et al. did). However, this can be misleading, as one needs to look more to what the system is doing to the tails. Are the obviously less efficient answers being culled? This is not an argument for strict jurispathic behavior. Rather it is an argument for pruning legal theory that has become inefficient or socially difficult to manage. The legal system should be willing to try new ideas, as one may prove much more efficient than what is currently available. Finally, a hierarchical judicial system is capable of finding, and then adopting, new and better solutions, and doing so in a manner that is not wholly different or less efficient than other heuristic search methods.

However, society will need to be willing to deal with convergence that is unlikely to be smooth and monotonic. A system showing smooth and monotonic convergence would have to be much less dramatic than the system we observe. If smooth and monotonic, overruling a case would, typically, only involve a tweak to the decision logic. Even in the simplified system presented here the courts were unable to generate smooth convergence. If smooth convergence is not possible here how can it be expected in the real world where judges may misunderstand the problem before them and society and technology continue to change?

Furthermore, these models suggest that a system based upon single judges acting independently will not make decision as well as a system that uses groups of judges. However, there is little improvement between three judge panels and en banc review. This is important to understand, as a system based upon en banc review would be much slower and, potentially, much more expensive. These models also highlight the tension between a judicial system that is slow to make good decisions and one that is much faster at making okay decisions. Along the lines of Shavell [2006 and 2007], judicial systems need a way to triage cases, “clear” cases can be quickly dispatched by single judges, then more complex cases or ones decided in error can be appealed to a higher level authority, and here we move to multiple judges hearing cases. It would be interesting to use the tools and techniques discussed here to begin to examine issues of group think and other problems with small group decision-making that may take place within a judicial panel.

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