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A DEFAULT-LOGIC PARADIGM FOR LEGAL FACT-FINDING

Vern R. Walker*

ABSTRACT: Unlike research in linguistics and artificial intelligence, legal research has not used advances in logical theory very effectively. This article uses default logic to develop a paradigm for analyzing the reasoning behind legal fact-finding. The article provides a formal model that integrates legal rules and policies with the evaluation of both expert and nonexpert evidence—whether the fact-finding occurs in courts or administrative agencies, and whether in domestic, foreign, or international legal systems. This paradigm can standardize the representation of fact-finding reasoning, guide empirical research into the dynamics of such reasoning, and help prepare such representations and research results for automation through artificial intelligence software. This new model therefore has the potential to transform legal practice and legal education, as well as legal theory.

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Legal scholarship and practice have made too little use of logical theory,[1] and as a result are making too little progress in understanding the formal structure of legal fact-finding, in developing effective methods of searching legal information, and in automating legal reasoning through artificial intelligence (AI). Although legal theorists have long acknowledged the relevance of traditional

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1. Logical theory studies those patterns of reasoning that ought to be persuasive to a reasonable person seeking knowledge. Logic therefore studies reasonable inference, even when it is performed by artificial agents. Logical research is distinct from research into the patterns of reasoning that *are in fact* persuasive to human beings—research in such fields as psychology, rhetoric, and cognitive science. *See, e.g.*, DOUGLAS WALTON, LEGAL ARGUMENTATION AND EVIDENCE 347 (2002) (contrasting logical uses of argument with psychological or rhetorical uses).

deductive logics,[2] they have seldom used developments in many-valued logics[3] and nonmonotonic logics.[4] By contrast, other fields of study are using logical theories to their advantage. The field of linguistics, for example, uses logical theory to study the knowledge possessed by native speakers about the meaning of ordinary language.[5] The field of artificial intelligence uses logical theory to capture human knowledge in particular domains and to model human reasoning patterns.[6] Judging from results in these other fields, the cost to legal theory and practice from failing to use developments in logic may be very high.

This article uses advances in the study of default reasoning to develop a paradigm for modeling the reasoning that supports legal fact-finding.[7] Default

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2. *See, e.g.*, TERENCE ANDERSON & WILLIAM TWINING, ANALYSIS OF EVIDENCE: HOW TO DO THINGS WITH FACTS BASED ON WIGMORE'S SCIENCE OF JUDICIAL PROOF 63–69 (1991) (showing that for Wigmore the principle utility of the deductive form of inference was "to force into prominence the generalization upon which the inference rests," and thereby "to discover the real points of weakness of inference"); Mark L. Movsesian, *Rediscovering Williston*, 62 WASH. & LEE L. REV. 207, 241–43 (2005) (describing Williston's view that the use of "analytic logic" in law has pedagogical benefits, "promotes predictability and stability in law," and "makes the legal system more acceptable to the general public").

3. *E.g.*, SIEGFRIED GOTTWALD, A TREATISE ON MANY-VALUED LOGICS (2001); GRZEGORZ MALINOWSKI, MANY-VALUED LOGICS (1993).

4. *E.g.*, GERHARD BREWKA ET AL., NONMONOTONIC REASONING: AN OVERVIEW (1997); HENRY E. KYBURG, JR. & CHOH MAN TENG, UNCERTAIN INFERENCE 117–51 (2001); ISAAC LEVI, FOR THE SAKE OF ARGUMENT: RAMSEY TEST CONDITIONALS, INDUCTIVE INFERENCE, AND NONMONOTONIC REASONING 120–59 (1996); HENRY PRAKKEN, LOGICAL TOOLS FOR MODELLING LEGAL ARGUMENT 67–100 (1997). In its broadest sense, nonmonotonic reasoning is reasoning to plausible conclusions on the basis of incomplete information. BREWKA ET AL., *supra*, at ix.

5. For applications of logical analysis to semantic theories about the meaning of ordinary language, see, for example, GENNARO CHIERCHIA & SALLY MCCONNELL-GINET, MEANING AND GRAMMAR: AN INTRODUCTION TO SEMANTICS 53–193 (2d ed. 2000); RICHARD LARSON & GABRIEL SEGAL, KNOWLEDGE OF MEANING: AN INTRODUCTION TO SEMANTIC THEORY 25–359 (1995); JOHN I. SAEED, SEMANTICS 86–115, 292–341 (2d ed. 2003).

6. For applications of logical analysis to the design of artificial intelligence systems, see, for example, RONALD J. BRACHMAN & HECTOR J. LEVESQUE, KNOWLEDGE REPRESENTATION AND REASONING (2004) (using logic to provide formal symbols to represent knowledge and to provide a computational architecture for reasoning procedures); ERIK T. MUELLER, COMMONSENSE REASONING (2006) (using logic to represent knowledge about everyday events); STUART J. RUSSELL & PETER NORVIG, ARTIFICIAL INTELLIGENCE: A MODERN APPROACH 194–374, 523–28 (2d ed. 2003) (discussing logical agents and knowledge representation); Munindar P. Singh et al., *Formal Methods in DAI: Logic-Based Representation and Reasoning*, *in* MULTIAGENT SYSTEMS: A MODERN APPROACH TO DISTRIBUTED ARTIFICIAL INTELLIGENCE 331, 331–76 (Gerhard Weiss ed., 1999) (discussing logic-based methods for describing and reasoning about artificial agents).

For discussions of default reasoning within the research on AI and law, see, for example, BART VERHEIJ, VIRTUAL ARGUMENTS: ON THE DESIGN OF ARGUMENT ASSISTANTS FOR LAWYERS AND OTHER ARGUERS 97–122 (2005); Henry Prakken & Giovanni Sartor, *The Three Faces of Defeasibility in the Law*, 17 RATIO JURIS 118 (2004).

7. For discussions of the logic of default reasoning, see, for example, PHILIPPE BESNARD, AN INTRODUCTION TO DEFAULT LOGIC (1989); BRACHMAN & LEVESQUE, *supra* note 6, 205–33; BREWKA ET AL., *supra* note 4, at 2–3, 40–51; KYBURG & TENG, *supra* note 4, at 121–34; LEVI, *supra* note 4, at 200–33; MUELLER, *supra* note 6, at 225–38; JOHN L. POLLOCK, NOMIC PROBABILITY AND THE FOUNDATIONS OF INDUCTION (1990); PRAKKEN, *supra* note 4; STEPHEN TOULMIN ET AL., AN INTRODUCTION TO REASONING (2d ed. 1984); DOUGLAS N. WALTON, ARGUMENTATION SCHEMES FOR PRESUMPTIVE REASONING (1996); WALTON, *supra* note 1, at 105–08.

reasoning uses inference rules, together with the available evidence, to warrant presumptive conclusions, which are then subject to future revision.[8] Such reasoning patterns possess four important characteristics. First, default reasoning is *practical*, because reasonable decision makers rely on the conclusions to justify their decisions and guide their actions.[9] Such reasoning is also *dynamic* because the degree of support from the evidence and analysis to the conclusion can change over time, and multiple parties can participate in the reasoning process. Third, default reasoning is *defeasible*, meaning that new evidence or a reanalysis of old evidence can defeat an earlier conclusion or undermine its evidentiary support.[10] Nevertheless, in the absence of such defeating considerations, default reasoning is *presumptively valid* if the reasoning behind it is sound—that is, it is reasonable to treat the (provisional) conclusion as being probably true.[11] The default-logic paradigm introduced here builds these four characteristics into its model of legal fact-finding.

The practical nature of the fact-finding process results from its instrumental role in achieving the policy objectives of law itself. Those policy objectives are both epistemic and nonepistemic.[12] The epistemic objective is to produce findings of fact that are as accurate as possible and that are warranted by the evidence that is legally available to the fact finder.[13] Some nonepistemic objectives are common across many governmental institutions (such as procedural fairness to parties and administrative efficiency), while others vary by institution and by area of law (such as protecting public health from unsafe food or deterring criminal activity within securities markets).[14] The fact-finding processes found in law are designed to balance the epistemic objective against the applicable nonepistemic objectives, and to produce findings of fact that are as accurate as possible given that pragmatic balance. If logical analysis is to be useful within law, and help solve legal problems, then logical formalism must help advance those same

8. Legal scholars have long recognized the presumptive nature of legal reasoning. *See, e.g.*, Movsesian, *supra* note 2, at 244 (documenting that for Williston, "[l]egal logic ... is a matter of '[p]resumptions and probabilities;' it indicates the likely result, at least in the absence of serious practical difficulties").

9. *See* WALTON, *supra* note 7, at 11 (defining practical reasoning as "a kind of goal-directed, knowledge-based reasoning that is directed to choosing a prudent course of action for an agent that is aware of its present circumstances"). To ensure that logical theory remains practical, the default-logic paradigm of this article adopts the strategic policy that no logical concepts are introduced unless they are useful in solving an actual legal problem.

10. *See* JOHN L. POLLOCK & JOSEPH CRUZ, CONTEMPORARY THEORIES OF KNOWLEDGE 36–37 (2d ed. 1999); PRAKKEN, *supra* note 4, at 47–49, 52–53, 56–61; WALTON, *supra* note 1, at 6, 52.

11. WALTON, *supra* note 1, at 52.

12. Vern R. Walker, *Epistemic and Non-Epistemic Aspects of the Factfinding Process in Law*, AM. PHIL. ASS'N NEWSL., Fall 2003, at 132, 132 (arguing that "any factfinding process in a governmental institution is designed to balance the epistemic objective against relevant non-epistemic objectives"). The importance or priority placed on achieving the epistemic objective, in competition with various nonepistemic objectives, might vary from one area of law to another, and from one policy objective to another. It would be difficult, however, to imagine an area of law in which the epistemic objective had no importance whatsoever.

13. *Id.* at 132.

14. *Id.*

policy objectives by making the law's reasoning transparent, but without pursuing logical formalism for its own sake. The default-logic paradigm works explicitly within this practical legal context.

While the default-logic paradigm represents the logical elements of fact-finding in ways that make the reasoning more amenable to automation, the primary focus of this article is not on the field of artificial intelligence and law.[15] Some AI researchers have attempted to model, for example, the decision making in legal cases that is warranted by analogies to case precedents, using the AI approach called "case-based reasoning" (CBR).[16] Other AI research takes a modeling approach to legal decision making called "rule-based reasoning" (RBR).[17] Other AI and law researchers have tried to develop hybrid systems incorporating both case-based and rule-based reasoning.[18] This article does not enter the AI debate about which approach to software programming will best automate different aspects of legal fact-finding. That debate involves such critical implementation questions as which software architectures to use to represent the elements of fact-finding, which software algorithms are tractable or computable in practice, and how best to validate computer models against actual human reasoning.[19] While this article does refer in a number of places to recent work in AI that might provide fruitful approaches to automating aspects of the default-logic paradigm, it focuses on the underlying logic of legal fact-finding, rather than on AI automation of that analysis. Legal theorists must provide an accurate and

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15. For surveys of the research in AI and law, see, for example, Kevin D. Ashley & Edwina L. Rissland, *Law, Learning and Representation*, 150 ARTIFICIAL INTELLIGENCE 17 (2003); Prakken & Sartor, *supra* note 6; Edwina L. Rissland, *Artificial Intelligence and Law: Stepping Stones to a Model of Legal Reasoning*, 99 YALE L.J. 1957 (1990); Edwina L. Rissland et al., *AI and Law: A Fruitful Synergy*, 150 ARTIFICIAL INTELLIGENCE 1 (2003); VERHEIJ, *supra* note 6, at 97–122.

16. *See, e.g.*, L. KARL BRANTING, REASONING WITH RULES AND PRECEDENTS: A COMPUTATIONAL MODEL OF LEGAL ANALYSIS 6 (2000) (discussing the research goal of using rule-based reasoning and case-based reasoning "as complementary processes for classification and explanation in legal analysis"); Ashley & Rissland, *supra* note 15, at 33–54 (surveying "the HYPO family of case-based reasoning (CBR) models," including HYPO, CABARET, and CATO); Rissland, *supra* note 15, at 1968–78 (surveying early developments in AI and law that used case-based reasoning).

17. *See, e.g.*, BRANTING, *supra* note 16, at 6 (discussing the research goal of using rule-based reasoning and case-based reasoning "as complementary processes for classification and explanation in legal analysis"); Rissland, *supra* note 15, at 1965–71, 1975–78 (surveying early developments in AI and law that used rule-based reasoning).

18. *See, e.g.*, BRANTING, *supra* note 16, at 63–109 (examining the Generator of Recursive Exemplar-Based Explanations (GREBE) software system as integrating rule-based and case-based reasoning); Henry Prakken & Giovanni Sartor, *Reasoning with Precedents in a Dialogue Game*, 6 INT'L CONF. ARTIFICIAL INTELLIGENCE & L. PROC. 1, 1 (1997) (stating that the authors attempt "to build a bridge between AI & Law research on case-based reasoning and recent more logic-oriented AI & Law research on defeasible argumentation"); *see* Rissland, *supra* note 15, at 1968–71, 1975–78 (surveying early developments in AI and law that used both case-based and rule-based approaches).

19. *See* Rissland, *supra* note 15, at 1957 (stating that the goal of understanding and modeling legal arguments requires that we know how to represent the elements of legal knowledge, how to reason with them, and how to program a computer to perform tasks using them).

useful analysis of legal fact-finding before researchers in AI can design software that validly automates aspects of legal decision making.[20]

This article lays out the default-logic paradigm in three major parts. Part I introduces "implication trees" and three-valued logic, as well as additional logical structures needed to model legal rules and policies. This rule-based framework integrates statutes, regulations, and case law with fact-finding, and makes fact-finding more efficient. Part II introduces "plausibility schemas," many-valued logic, and theories of uncertainty, together with other logical concepts needed to evaluate evidence. Rational fact-finding extends the rule-based tree structure into the realm of evidence evaluation and integrates expert and lay evidence into single patterns of reasoning. Part III uses the logical structures introduced in Parts I and II to model legal rules about procedure and evidence and to evaluate decisions that apply those rules to particular cases. The complete default-logic paradigm provides an "inference tree" that can formalize the legal reasoning found in any actual case (including the rules, policies, evidence, rulings, and findings in the case), suggest how such reasoning could be improved, and provide the structure needed to automate important segments of that reasoning. The article therefore provides a paradigm for modeling any instance of legal fact-finding.

20. Although research on legal reasoning today involves many fields (for example, law, logic, psychology, rhetoric, cognitive science, and computer science), those fields generally employ different methods and try to solve different sets of problems. Law, for example, uses reasoning expressed in natural, legal, and other specialized languages when approaching such questions as fair compensation for personal injuries caused by food products (applying the law of torts and products liability) or when trying to make food products safe prospectively (applying food safety regulations). Logicians, by contrast, develop formal logic systems to solve problems of interest to logicians, and AI researchers design software programs to solve representational and computational problems of concern to them. While this is an exciting time of rapid convergence among these fields, and no field should ignore advances in the others, it remains true that new logics and software systems are not necessarily useful tools to courts in deciding torts cases or to regulatory agencies in regulating food safety. The default-logic paradigm attempts to analyze legal fact-finding in a way that is useful in solving legal problems, while at the same time more amenable to automation than natural-language reasoning is.

I. LEGAL RULES AND IMPLICATION TREES

An essential characteristic of fact-finding is its rule-based nature.[21] Rules of law identify the conditions under which governmental action is legitimate. Governmental institutions adopt legal rules in a variety of ways (for example, by means of statutes, regulations, executive orders, and judicial judgments), and those rules govern other governmental decisions. The default-logic paradigm models the role of such rules in the fact-finding process. This part of the article introduces "implication trees"—the default-logic structure used to capture legal rules. Part II will add logical structures for modeling the application of such rules to particular cases.

A. Implication Trees as Models of Legal Rules

In the default-logic model, a legal rule is a universally applicable, conditional proposition.[22] A proposition is the meaning or informational content of an assertion, usually expressed in ordinary language by a sentence or clause.[23] A rule is a conditional proposition of the form "if *p*, then *q*," where *p* and *q* stand for two constituent propositions. A rule states that finding proposition *p* (the condition) to be true warrants finding *q* (the conclusion) to be true also. Moreover, a rule is universal in application—it warrants making the inference in all situations described by the condition in the "if" clause. If there are any exceptions to the rule, other rules should identify those exceptions and govern the reasoning in those exceptional cases. A legal rule, therefore, identifies an acceptable line of legal reasoning to a conclusion in all similar cases, where the relevant similarity is specified by the rule's condition.

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21. For a discussion of the advantages of rule-based reasoning in the context of the "new formalism" in contract theory, see Movsesian, *supra* note 2, at 224–29 (stating that new formalists advocate formalism "because it advances important pragmatic values like certainty, stability, and efficiency"; that "the new formalists believe that legal rules have merely presumptive force," and "pragmatic or ethical considerations" can overcome that presumption; and that they seek to give formalism a theoretical and empirical foundation).

22. *See* Scott Brewer, *Exemplary Reasoning: Semantics, Pragmatics, and the Rational Force of Legal Argument by Analogy*, 109 HARV. L. REV. 923, 972 (1996) (defining "rule" in a "logically spare manner" as "a prescriptive proposition that has a logical structure the most abstract form of which is reflected in the standard conditional proposition, either propositional ('if P then Q') or predicate ('for all x, if x is an F then x is a G')"). For a discussion of rules in the research on AI and law, and the related concept of rule-based reasoning (RBR), see *supra* notes 17–18.

23. Distinctions should be made between sentences and propositions, and between linguistics and logic. A sentence is a linguistic unit consisting of words, phrases, clauses and other grammatical elements, while a proposition is the logical content of a statement or assertion, which is capable of being true or false. IRVING M. COPI & CARL COHEN, INTRODUCTION TO LOGIC 4–6 (11th ed. 2002); MARK SAINSBURY, LOGIC FORMS: AN INTRODUCTION TO PHILOSOPHICAL LOGIC 25–28 (1991). Different sentences, either in the same language or in different languages, can express the same proposition. COPI & COHEN, *supra*, at 5–6. Linguistics studies the grammatical structure of ordinary languages, while logic studies the reasoning structure expressed in those languages. *See, e.g.*, LARSON & SEGAL, *supra* note 5, at 1, 9–11, 22–24, 67–76 (distinguishing semantic and syntactic theory from logical theory).

The default-logic paradigm reflects the dynamic nature of fact-finding by assigning to the propositions of legal rules one of three truth-values: true, false, or undecided.[24] When fact-finding begins in a particular situation, the truth-values of the conditions and conclusions of the applicable legal rules are undecided. The evidence and reasoning may change the truth-values of conditions (or "factual triggers") for rules, which may in turn change the truth-values of conclusions. Traditional two-valued logic paid insufficient attention to the dynamics of truth-value change and constructed static models for only the end results of reasoning. The default-logic paradigm, by contrast, incorporates dynamic reasoning into the logical structure and can therefore provide an understanding of the flow of rule-based reasoning.

The condition of a legal rule normally has a complex logical structure. It is usually a set of propositions that are connected by one or more of three logical operators: AND, OR, and UNLESS. Rules with conditions connected by "AND" are called conjunctive rules, and each constituent proposition of the condition is called a conjunct.[25] An example of a conjunctive rule is the tort rule identifying the factual elements of a plaintiff's prima facie case for battery:[26]

> **If** the defendant performed a voluntary act, AND
>
> the defendant acted intending to cause a harmful or offensive contact with a person, AND
>
> the defendant's act caused a harmful or offensive contact with the plaintiff,
>
> **then** the defendant is subject to liability to the plaintiff for battery.

A conjunctive rule requires the proof of all of its conjuncts before it warrants drawing the conclusion.[27] Rules may also be disjunctive, with the constituent

24. A system of legal rules based on more than three truth-values would be very complicated and probably largely unprincipled. It would be complicated because it would require rules for the different truth-values of an antecedent condition. For example, the legal implication of a condition that is very likely to be true could be different than the implication if the condition is only probably true. But if there is a difference between two such rules, then there should be policy reasons for treating the two cases differently, and it might be very difficult to give such reasons to cover all permutations in a many-valued system. This lack of policy justification means that many rules would lack justification. Moreover, as discussed *infra* in Part II, a three-valued system in the rule-based portion of reasoning allows a basis for harmonizing fact-finder evaluation of the evidence, without imposing on the fact finder any particular truth-value system to use in evaluating that evidence.

25. Logical conjunction models part of the meaning of many ordinary-language words and phrases, including "and," "also," "moreover," "but," "yet," "nevertheless," and "although." For discussions of using conjunction to model the propositions expressed by English sentences, see, for example, COPI & COHEN, *supra* note 23, at 301–03; ROBERT E. RODES, JR. & HOWARD POSPESEL, PREMISES AND CONCLUSIONS: SYMBOLIC LOGIC FOR LEGAL ANALYSIS 17–27 (1997); SAINSBURY, *supra* note 23, at 62–65.

26. *See, e.g.*, RESTATEMENT (SECOND) OF TORTS, §§ 2, 13, 18 (1965); DAN B. DOBBS, THE LAW OF TORTS 47–63 (2000).

27. The following table defines the truth-function for three-valued conjunction in an implication tree. In the table, the three truth-values are: F = false, U = undecided, and T = true. The top row and left column list the possible truth-values of the two conjuncts, while the cells in the table specify the resulting truth-value of the conclusion.

propositions of the condition (disjuncts) connected by the logical connective "OR."[28] With a disjunctive rule, proving any one or more of the disjuncts is sufficient for proving the conclusion.[29] For example, the tort causes of action in battery and in negligence are two alternative ways to prove that the defendant is liable to the plaintiff for compensatory damages. The third type of default-logic connective is "defeater," denoted by "UNLESS."[30] With a defeater rule, if the condition (defeater proposition) is true, then the rule warrants the conclusion to be false.[31] An example of a defeater is an affirmative defense to a cause of action. A prima facie case for battery can be defeated by the privilege to use reasonable force under certain conditions, such as when the defendant is making a lawful arrest or defending herself from intentionally inflicted bodily harm.[32]

Conjunctive, disjunctive, and defeater connectives are truth functional in operation—that is, the truth-value of the conclusion is entirely a function of the truth-values of the constituent propositions in the condition. The truth-function for each connective determines the truth-value of the conclusion based on the truth-values of the constituent propositions in the condition.[33] Their truth-functional nature makes it straightforward to capture their operation completely

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AND	F	U	T
F	F	F	F
U	F	U	U
T	F	U	T

See the definition of the many-valued connective "et_1", GOTTWALD, *supra* note 3, at 66.

28. Logical disjunction models part of the meaning of the ordinary-language words "or" and "either . . . or . . . ." For discussions of using disjunction to model the propositions expressed by English sentences, see, for example, COPI & COHEN, *supra* note 23, at 304–06; RODES & POSPESEL, *supra* note 25, at 59–73; SAINSBURY, *supra* note 23, at 65–68.

29. The following table defines the truth-function for three-valued disjunction in an implication tree. In the table, the three truth-values are: F = false, U = undecided, and T = true. The top row and left column list the possible truth-values of the two disjuncts, while the cells in the table specify the resulting truth-value of the conclusion.

OR	F	U	T
F	F	U	T
U	U	U	T
T	T	T	T

See the definition of the many-valued connective "vel_1", GOTTWALD, *supra* note 3, at 90.

30. Logical defeater can model part of the meaning of such words and phrases as "unless," "provided that," and "except when." For logical discussions of the defeater connective, see BREWKA ET AL., *supra* note 4, at 2–3, 16; POLLOCK, *supra* note 7, at 79. *See also infra* notes 76–80. For discussions in the field of AI and law, see Henry Prakken et al., *Argumentation Schemes and Generalisations in Reasoning About Evidence*, 9 INT'L CONF. ARTIFICIAL INTELLIGENCE & L. PROC. 32, 37–38 (2003); Prakken & Sartor, *supra* note 6, at 120–24; Prakken & Sartor, *supra* note 18, at 3.

31. Unless a defeater proposition is true, the truth-value of the conclusion remains what it would have been in the absence of a defeater proposition.

32. *See, e.g.*, RESTATEMENT (SECOND) OF TORTS §§ 63–76, 112–39 (1965); DOBBS, *supra* note 26, at 159–70, 190–204.

33. On the concept of truth-functional connectives generally, see, for example, COPI & COHEN, *supra* note 23, at 302; RODES & POSPESEL, *supra* note 25, at 96–104; SAINSBURY, *supra* note 23, at 49–51.

within artificial intelligence software.[34] The default-logic paradigm constructs "implication trees" to model complex legal rules and chains of such rules.[35] Implication trees start with the ultimate conclusion at the top and branch downward, making an inverted tree. For example, the implication tree in Figure 1 models the plaintiff's prima facie case for battery.

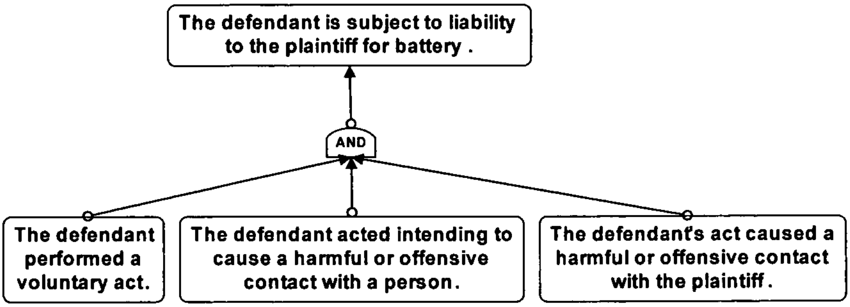

Figure 1. Implication Tree for a Prima Facie Case of Battery

Such a logic diagram shows that, according to this rule, the upper-level proposition is warranted to be true if all three lower-level propositions are true. An implication tree models a legal rule as two adjacent levels, with the upper level stating the conclusion of the rule, a logical connective between the two levels

34. *See* RUSSELL & NORVIG, *supra* note 6, at 206–10, 524.

35. A number of legal theorists have analyzed portions of legal reasoning as having a tree-like structure. *See, e.g.*, ANDERSON & TWINING, *supra* note 2, at 108–55 (concluding that "Wigmorean charts are a species of what today are sometimes described as 'directed acyclic graphs'"); JOSEPH B. KADANE & DAVID A. SCHUM, A PROBABILISTIC ANALYSIS OF THE SACCO AND VANZETTI EVIDENCE 66–74 (1996) (developing inference networks as directed acyclic graphs with the root node—the ultimate issue to be proved—at the top, and the chains of reasoning extending from the evidence at the bottom upward to the root node); DAVID A. SCHUM, EVIDENTIAL FOUNDATIONS OF PROBABILISTIC REASONING 169 (1994) (interpreting Wigmorean evidence charts as "directed acyclic graphs whose nodes indicate propositions and whose arcs represent fuzzy probabilistic linkages among these nodes"); WALTON, *supra* note 1, at 338–48 (discussing argument diagramming). For a discussion of the tree-like inference structure developed by Schum and Kadane, see Vern R. Walker, *Language, Meaning, and Warrant: An Essay on the Use of Bayesian Probability Systems in Legal Factfinding*, 39 JURIMETRICS J. 391, 392–404 (1999).

Within formal logic, tableau structures are sometimes used to analyze truth-values of complex formulae. *E.g.*, GOTTWALD, *supra* note 3, at 16, 138–39 (discussing, for many-valued logics, the use of a "tableau tree" to indicate "the conditions which have to be met to give some wff [well-formed formula] the truth value").

Within research on AI and law, tree structures are commonly used, but with varying interpretations for the nodes and arcs (arrows) of the tree. *See, e.g.*, BRANTING, *supra* note 16, at 9–15, 36–52 (discussing "warrant-reduction graphs" and "goal-direction graphs" as models of the "*ratio decidendi*" of a legal decision or case); Ashley & Rissland, *supra* note 15, at 33–47 (discussing case-based systems in which "claim lattices" and "factor hierarchies" connect "dimensions," "factors," or "issues" with cases contained in the case database); Prakken et al., *supra* note 30, at 33, 36–37 (discussing Wigmore's charting method and the Araucaria software's graphical representation of argumentation schemes).

specifying the truth-function involved, and the lower level identifying the constituent propositions of the condition.[36] Each proposition in the lower level might then become the conclusion of another rule, whose condition would add yet a lower level to the implication tree. This logical structure constitutes an inverted "tree" because the branches from upper-level propositions to lower-level propositions never loop back to a higher level, but continue to expand downward.[37]

In principle, the substantive legal rules of tort law that can justify compensatory damages can be modeled as one large implication tree. For example, the implication tree for battery might begin as shown in Figure 2.

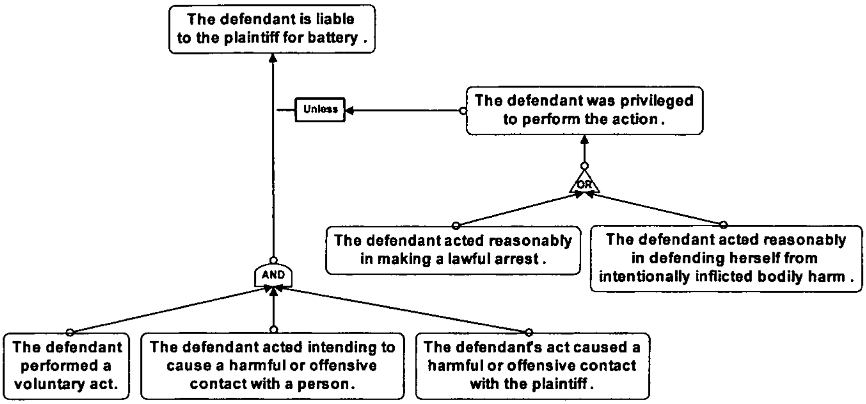

Figure 2. High-Level, Partial Implication Tree for Battery

According to the rules in Figure 2, a court is justified in entering a judgment for the plaintiff if the defendant is found to be liable to the plaintiff for battery. If the plaintiff proves all three of the conjuncts at the bottom, then the defendant is liable to the plaintiff for battery, unless the defendant proves that she was privileged to perform the action she did. The defendant can establish a privilege by proving either that she acted reasonably in making a lawful arrest or that she acted reasonably in defending herself from harmful contact. This logic diagram also displays how the defeater connective operates. A defeater functions as a kind of switch that can, under the specified condition, override the inference that would otherwise occur.

The goal in constructing an implication tree is to model *all* the legally acceptable lines of reasoning that can prove or disprove the ultimate issue stated by the conclusion at the top of the tree. The three logical connectives model all

36. In the terminology of inverted trees, the upper or "root" node is sometimes called the "parent," the lower nodes called the "children," and the two-level unit a "family." *See, e.g.*, GLENN SHAFER, THE ART OF CAUSAL CONJECTURE 386 (1996).

37. *See* KADANE & SCHUM, *supra* note 35, at 71 (constructing evidence charts that are directed acyclic graphs and "resemble *trees* whose branches seem to converge to a single trunk or root"); SCHUM, *supra* note 35, at 169–73 (discussing directed acyclic graphs).

the ways that lower-level propositions can combine to prove or disprove upper-level propositions. At the bottom level of each branch of an implication tree, where the legal rules end, the constituent propositions in the conditions of those last rules are the "terminal" propositions of the tree. The truth-value for a terminal proposition cannot be determined by lower rules in the tree, for by definition there are no further legal rules. Taken together, the set of all the terminal propositions for a tree is the set of all possible findings of fact that are relevant for proving or disproving the ultimate issue at the top. The terminal propositions are the issues of fact to be determined by the fact finder. Part II of this article examines the reasoning of the fact finder in making such findings. The implication-tree structure, however, shows the role of legal rules in elaborating the single ultimate issue at the top into a potentially large set of terminal propositions at the bottom.[38]

Implication trees display graphically many features of legal rules. First, implication trees make every step of the reasoning transparent, by showing the conditions that are relevant to warranting the conclusion and the logical connectives within that inference. Second, implication trees that model *all* the acceptable lines of reasoning that can warrant a particular conclusion can be said to capture the legal meaning or significance of the conclusion. A complete implication tree for battery, for instance, shows what the law of torts means by "battery." Third, a graphical representation can present a large amount of information at one time. It can show how all relevant reasoning "fits together," while retaining detailed information within the branches of the tree.

Implication trees also display the dynamics of the reasoning. The implication tree for battery, for example, suggests the dynamic structure of a prima facie case, a rebuttal, and an exception or affirmative defense. The main conjunctive branch of the tree shows what the plaintiff must prove in order to establish a prima facie case. The defendant, in response, has three options for defending against the plaintiff's claim. First, the defendant can rebut the truth of one or more of the constituent propositions of the plaintiff's prima facie case. Second, the defendant can assert an affirmative defense and prove the truth of one or more defeater propositions. Third, the defendant can argue for a change in the legal rules—that is, argue for a change in the shape of the implication tree itself. Thus, implication trees can suggest possible strategies for proving or warranting intermediate and ultimate conclusions.

38. An important corollary is that adopting a new legal rule not only expands the implication tree downward, but almost always expands it horizontally as well, increasing the number of terminal propositions. Adopting new legal rules almost always adds new issues of fact and increases the complexity of the legal cases brought using the implication tree.

An implication tree applies to particular cases through the logical subjects contained in the tree's propositions. Traditional predicate logic analyzes propositions into a logical predicate and one or more logical subjects.[39] A logical predicate is the component of a proposition that expresses what is being affirmed or denied about one or more logical subjects. A logical subject is a component of a proposition that names, denotes, or refers to one or more objects, situations, or events that the proposition is about.[40] For example, the proposition "the defendant's act caused a harmful or offensive contact with the plaintiff" refers to several logical subjects: "the defendant's act," "a harmful or offensive contact," and "the plaintiff."[41] The logical predicate is the causal relationship asserted about these subjects. Within the propositions of an implication tree, the logical subjects are variables that range over the names of the particular objects, situations, or events that are the subjects of particular cases. For example, the phrase "the plaintiff" in a rule can refer to any plaintiff in any case, and can be replaced in a particular case by the name of any particular plaintiff (for example, Jennifer Jones). Similar substitutions or specific identifications would occur for "the defendant's act" (for example, driving the automobile) and "a harmful or offensive contact" (for example, hitting someone with an automobile). Supplying specific values or referents for logical subjects in rules converts general rules into propositions about specific cases. Those converted propositions, consisting of logical predicates supplied by the rules and logical subjects supplied by the particular case, play an important logical role in the evaluation of evidence, as discussed in Part II below.[42]

39. For general discussions of predicate logic, see, for example, COPI & COHEN, *supra* note 23, at 385–420; RODES & POSPESEL, *supra* note 25, at 113–206; SAINSBURY, *supra* note 23, at 133–219.

For applications of predicate logic to semantic theories about the meaning of sentences, see, for example, CHIERCHIA & MCCONNELL-GINET, *supra* note 5, at 53–193 (developing a referential or denotational approach to meaning, based on predicate logic); LARSON & SEGAL, *supra* note 5, at 115–226, 319–59 (discussing the meaning of verbs and predication, proper nouns, pronouns, demonstratives, and definite descriptions); SAEED, *supra* note 5, at 292–341 (discussing a formal or logical semantics based on predicate logic).

For AI research based on predicate logic, see, for example, BRACHMAN & LEVESQUE, *supra* note 6, at 15–47 (using first-order predicate logic to represent knowledge).

40. In English, the grammatical subject of a sentence usually identifies a subject of the proposition expressed by the sentence. Grammatical and logical form, however, are not necessarily identical. An English sentence may have a single grammatical subject, but the proposition that it expresses might have multiple logical subjects. For example, the sentence "Jones leases the property from Smith" has a single grammatical subject (Jones), but asserts a relationship among three logical subjects (Jones, the particular property, and Smith).

41. The decision about which subjects to select for separate analytical treatment is a practical one, and depends upon which subjects have legal significance. *See supra* text accompanying notes 12–14, and 20.

42. Some legal rules employ predicate logic in a different manner. While an implication tree is designed to capture all of the legal rules that are applicable in proving a particular conclusion, some legal rules state entailments among concepts employed within logical predicates and subjects. Concept entailments exhibit the logical property of "locality"—that is, the truth-value of the conclusion is determined by the truth-values of a specifiable (and usually small) set of conditions. *See* RUSSELL & NORVIG, *supra* note 6, at 524 (discussing locality as a desirable

Using implication trees to model legal rules can help the legal system to achieve its epistemic objective. Such models can make transparent the exact rules that are in play and identify with precision the triggering conditions for those rules.[43] Such transparent precision allows criticism and refinement of those rules, and can increase consistency of application, predictability of outcome for potentially affected parties, and reviewability by other legal institutions. These formal models can also suggest optimal proof strategies for those parties producing evidence. In addition, as Part II of this article will discuss, the models can help fact finders identify relevant evidence, organize it, and evaluate its probative value. Part II demonstrates how legal rules turn the available evidence into warrant for drawing the ultimate conclusions. By providing a standardized method of modeling rules, the default-logic paradigm enables more effective comparisons between different legal rule-structures and may suggest more efficient designs. Finally, as the default-logic paradigm successfully models the reasoning structure of fact-finding, it can facilitate the automation of those models—and therefore the automation of important parts of fact-finding.

B. Policy-Based Reasoning About Implication Trees

Legal rules provide part of the deductive structure for fact-finding about the world, but they are also the subject matter of legal reasoning about whether particular rules are justified. The justification for adopting or not adopting particular legal rules generally takes the form of policy-based reasoning. In the default-logic framework, policies are not constituent elements within implication

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property of logical rule-based systems). Such entailments can play a useful role in warranting inferences between propositions within different implication trees.

For example, some entailments identify class-subclass relationships among concepts, such that any attribute of members of the class is necessarily an inherited attribute of members of the subclass. If a specific individual Jones is a defendant, then the class-subclass relationship "party/defendant" warrants that Jones is also a party, and has all the attributes of being a party (such as having a right to be notified about proceedings that determine his rights and obligations). *See* FLEMING JAMES, JR. ET AL., CIVIL PROCEDURE § 2.10, at 72–73 (4th ed. 1992).

Other entailments state definitions. A definition supplies words, phrases, or expressions that have the same meaning as the word, phrase, or expression to be defined, and equivalent propositions about a subject can use either expression. *See* BARUCH A. BRODY, LOGIC: THEORETICAL AND APPLIED 21–27 (1973); COPI & COHEN, *supra* note 23, at 99–135; LARSON & SEGAL, *supra* note 5, at 319–59.

For examples of semantic theories using a rule-based approach to specifying truth-conditions for the meaningful use of ordinary words, see CHIERCHIA & MCCONNELL-GINET, *supra* note 5, at 75 (setting the goal of providing "a fully explicit, that is, fully formalized, specification of truth conditions for sentences" having propositional structures); LARSON & SEGAL, *supra* note 5, at 25–42 (adopting the approach of studying knowledge of word meaning by developing deductive theories about truth conditions for ordinary sentences); SAEED, *supra* note 5, at 293 (exploring a formal semantics in which "the listener who understands the sentence is able to determine the truth conditions of the uttered sentence, that is, know what conditions in the world would make the sentence true" (emphasis removed)).

43. This article does not discuss how to craft the appropriate default-logic model for capturing a particular instance of fact-finding. The art of logical modeling requires the skills needed to model accurately the rules, policies, evidence and reasoning that appear in particular statutes, regulations, administrative adjudications, and judicial decisions.

trees, but rather guides for the construction of implication trees.[44] Institutions empowered by law to adopt legal rules (for example, legislatures, administrative agencies, and courts) may decide what rules to adopt by evaluating possible rules against the policy objectives that are applicable: epistemic policies primarily designed to achieve the epistemic objective (producing accurate findings warranted by the legally available evidence) and nonepistemic policies primarily pursuing such objectives as procedural fairness and administrative efficiency.[45] Because the applicable policies are often diverse and competing, modeling such policy-based reasoning within the default-logic paradigm poses several major problems. The first is how to represent symbolically the content of policies, using a formalism that expresses all of the attributes of policies that play a role in legal reasoning. A second problem is how to model the reasoning that connects a particular policy to any particular rule. A third problem is how to balance many lines of such reasoning within a single justification for a particular rule. It is no surprise, therefore, that the field of AI and law has made very limited progress in modeling policy-based reasoning (PBR).[46]

This article does not present a formal model for policy-based reasoning. It does present, however, a model for evaluating or weighing evidence to arrive at a warranted finding of fact—a model that Part II addresses in detail. Such a default-logic structure for organizing and weighing relevant evidence may also provide insight into the types of structure that may be useful for organizing and balancing policy rationales. For example, many policy-based rationales, such as those based on efficiency and deterrence, take the form of means-to-end relationships warranted by causal theories. Efficiency rationales compare the costs and benefits of alternative rules, and definitions and measures of efficiency would allow the question of comparative efficiency among particular rules to become an empirical question.[47] The plausibility of the available evidence on efficiency, therefore, could then be modeled by the formal structures discussed in Part II below. In other words, many aspects of policy-based reasoning involve (or should involve) fact-finding based on evidence.

Moreover, using the default-logic paradigm to model legal process rules (the topic of Part III of this article) provides a method for clarifying policy-based reasoning. The formal adoption of a legal rule is itself a kind of governmental

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44. Policy-based reasoning is about whether to adopt rules that, if adopted, can be modeled within implication trees. For purposes of this article, there is no reason to distinguish "policies" from "principles" or to distinguish different types of policy rationales. The phrase "policy-based reasoning" is intended to cover all principled reasoning about rule adoption.

45. *See supra* text accompanying note 12–14.

46. *See, e.g.*, Ashley & Rissland, *supra* note 15, at 55 (stating that "more study is needed to determine how legal experts evaluate analogical arguments in light of principles and policies. It is not yet clear how to represent principles and policies at the top of the argumentation pyramid, nor how to develop algorithms for integrating them into realistic arguments."). Nevertheless, the AI and law literature contains some very interesting research on the logic behind rule change. *See, e.g.*, *id.* at 18 (discussing two ways in which rules can change: by changing the rule's structure, for example by adding conditions or exceptions, and "by changing the meaning of the rule's constituent concepts").

47. *See, e.g.*, EDITH STOKEY & RICHARD ZECKHAUSER, A PRIMER FOR POLICY ANALYSIS 134–58, 291–319 (1978) (discussing benefit-cost analysis and market efficiency).

action that requires justification, and there are several areas where documented reasoning about rule justification can be studied empirically. Administrative rulemaking is an example of rule adoption, and judicial review ensures that both agencies and courts discuss how process and substantive rules affect particular instances of rule adoption.[48] In addition, statutory interpretation requires courts to elaborate new rules out of statutory language, and the judicial canons of interpretation provide examples of policy-based reasoning about rule adoption.[49] Finally, common-law courts sometimes announce new legal rules in explaining their judgments in particular cases, and many courts have reasoned at length about how they balance policy rationales.[50] Research on such examples of policy-based reasoning, using the tools developed within the default-logic paradigm, should lead to better formal models of the interplay among rule application, rule adoption, and evidence evaluation.[51]

Policies are particularly important in analyzing principled changes in legal rules or implication trees over time. The goal of a "synchronic" logic model is to capture all of the rule-based deductions that are acceptable at a single point in time. A complete implication tree would capture all of the accepted legal rules that are relevant to proving the ultimate conclusion of the tree at that point in time. It is also possible, however, to model how legal rules and implication trees change over time, thus furnishing a "diachronic" model of legal reasoning. Legislatures and regulatory agencies might adopt new rules, or amend or rescind old ones. Courts might adopt new interpretations of statutory provisions, adopt new common-law rules, or overrule prior cases. The default-logic paradigm provides synchronic models of rule systems at different times and therefore allows a precise picture of how implication trees change over time. Diachronic models of change within legal rule systems would allow research into the policy-driven aspect of that change. As Part II explores the default logic of evidence evaluation, therefore, there is in the background the possibility of similar investigations into the policy-based reasoning behind rule change.

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48. *E.g.*, Cmty. Nutrition Inst. v. Young, 773 F.2d 1356, 1357–60, 1362–67 (D.C. Cir. 1985) (reviewing a final rule issued by the Food and Drug Administration approving the artificial sweetener aspartame for use in liquids, under the process and substantive rules of the Federal Food, Drug, and Cosmetic Act, 21 U.S.C. § 348 (1982) (current version at 21 U.S.C. § 348 (2000).

49. For leading cases on interpreting statutes administered by federal agencies, see Whitman v. Am. Trucking Ass'ns, Inc., 531 U.S. 457, 462–71 (2001) (holding that § 109(b) of the Clean Air Act "unambiguously bars cost considerations" from the process of setting national ambient air quality standards); Chevron U.S.A., Inc. v. Natural Res. Def. Council, Inc., 467 U.S. 837, 842–45 (1984) (establishing rules for a two-step process of interpretation).

50. *E.g.*, Hymowitz v. Eli Lilly & Co., 73 N.Y.2d 487 (1989) (establishing a market share doctrine for diethylstilbestrol (DES) cases).

51. An alternative and complementary approach to rule justification has been to argue by analogy to precedents. For leading work on this approach, see, for example, EDWARD H. LEVI, AN INTRODUCTION TO LEGAL REASONING (1949); Brewer, *supra* note 22; Cass R. Sunstein, *On Analogical Reasoning*, 106 HARV. L. REV. 741 (1993).

II. EVIDENCE EVALUATION, PLAUSIBILITY SCHEMAS, AND INFERENCE TREES

The default-logic paradigm models rule-based deductions and evidence evaluation as parts of a single continuum. Within the paradigm, fact-finding is the process of "linking" admitted evidence to those terminal propositions (issues of fact) of a legal implication tree to which the evidence is relevant; evaluating the probative value of the total evidence that is relevant to any particular terminal proposition; and using that evaluation to assign a truth-value to that terminal proposition. Legal fact-finding as a whole, therefore, has two major components: rule-based reasoning within the implication tree and the evaluation of evidence linked to the end nodes of the branches of the implication tree.[52] Part I of this article examined rule-based, three-valued deductions, modeled by implication trees. Part II extends the default-logic framework to evidence evaluation by formalizing patterns of reasoning in which propositions are plausible, and therefore presumptive, but defeasible.[53] The resulting inference tree, which includes an implication tree of rules at the top and evidence evaluations at the lower ends of the branches, is able to model the substantive reasoning behind the fact-finding in a particular case.[54] Part III will examine process rules and the

52. The traditional taxonomic divisions of logic (deduction, induction, and abduction) are not particularly useful in the default-logic paradigm. While deduction occurs within the rule-based portion of an implication tree, the tree itself is embedded in a broader reasoning context that includes both inductive and abductive aspects. *See* WALTON, *supra* note 7, at 42–43 (stating that in his treatment "presumptive reasoning is neither deductive nor inductive in nature, but represents a third distinct type of reasoning of the kind classified by Rescher (1976) as *plausible reasoning*, an inherently tentative kind of reasoning subject to defeat by the special circumstances (not defined inductively or statistically) of a particular case") (citing N. RESCHER, PLAUSIBLE REASONING (1976)).

Wigmore apparently regarded induction as an inference from an evidentiary assertion about a particular individual to a conclusion about that same individual, while he regarded deduction as supporting the same conclusion syllogistically, using an "implied law or generalization" as a major premise. *See* JOHN HENRY WIGMORE, THE SCIENCE OF JUDICIAL PROOF §§ 9–10 (1937), *reprinted in* ANDERSON & TWINING, *supra* note 2, at 63–66 (asserting that the form of inference in court is usually inductive, but that "every inductive inference is at least capable of being transmuted into and stated in the deductive form, by forcing into prominence the implied law or generalization on which it rests"). For a discussion of terminological confusion surrounding induction and abduction, see, for example, John R. Josephson & Michael C. Tanner, *Conceptual Analysis of Abduction, in* ABDUCTIVE INFERENCE 5 (John R. Josephson & Susan G. Josephson eds., 1994).

53. For other approaches to evidence evaluation, see generally ANDERSON & TWINING, *supra* note 2, at 105–72, 329–84 (discussing and extending Wigmore's methods of evidence evaluation); KADANE & SCHUM, *supra* note 35, at 116–75 (discussing the use of Bayes' Theorem and likelihood ratios to grade the "probative force of evidence"); SCHUM, *supra* note 35, at 200–69 (discussing various methods for grading the "force of evidence" and "evidential support").

54. The default-logic paradigm is a framework for representing or modeling the reasoning used in particular legal cases, but it is not a theory about which particular rules should be adopted or which particular lines of reasoning are plausible. For example, the default-logic paradigm is necessarily neutral on what the rules should be concerning the legal sufficiency of statistical evidence in tort cases. *See, e.g.*, Charles Nesson, *The Evidence or the Event?: On Judicial Proof and the Acceptability of Verdicts*, 98 HARV. L. REV. 1357, 1378–90 (1985) (posing and discussing the "blue bus" hypothetical, based on *Smith v. Rapid Transit, Inc.*, 58 N.E.2d 754 (Mass. 1945));

process conditions that warrant fact-finding, using the logic models developed in Parts I and II.

A. The Plausibility of Evidence as Warrant

In general, the task of the fact finder is to determine the truth-values of the terminal propositions of an implication tree by evaluating the relevant portion of the legally available evidence.[55] The terminal propositions of an implication tree are the lowest propositions in every branch of the tree,[56] and they represent all of the possible findings that are relevant to proving or disproving the ultimate issue at the top of the tree. Relevance is a logical relationship between evidentiary assertions and a terminal proposition in an implication tree.[57] A particular evidentiary assertion is relevant if, but only if, a reasonable fact finder would rely upon it in determining the truth-value of a terminal proposition.[58] The problem for logical theory is modeling the probative value or weight of individual evidentiary assertions, formally combining such values into a single probative value for the totality of relevant evidence, and determining the truth-value of a terminal proposition as a function of that probative value.

1. *Plausibility-Values of Evidentiary Assertions*

While propositions in an implication tree have a three-valued truth-value, evidentiary assertions are propositions that are assigned a "plausibility-value."[59] Evidentiary assertions include testimony by witnesses, statements from documents admitted into evidence, descriptions of evidentiary exhibits, or other

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see also Tracey L. Meares, *Three Objections to the Use of Empiricism in Criminal Law and Procedure—And Three Answers*, 2002 U. ILL. L. REV. 851, 857–66 (2002) (discussing the reasoning behind the "blue bus" hypothetical).

55. Truth-values of terminal propositions can also be determined by stipulation of the parties or decided "as a matter of law" by a court or an administrative agency. However, the most challenging method from the standpoint of modeling is evidence evaluation by a fact finder.

56. *See* SHAFER, *supra* note 36, at 386 (stating that in the terminology of directed graphs, "[a] node with no children is called *terminal*").

57. Federal Rule of Evidence 401 defines "relevant evidence" as "evidence having any tendency to make the existence of any fact that is of consequence to the determination of the action more probable or less probable than it would be without the evidence."

58. If legal fact-finding has the epistemic goal of producing knowledge, in the sense of "warranted true belief," then the notion of a proposition's being "probably true" reflects the degree to which a reasonable fact finder is warranted, on the basis of the evidence that is legally available, in believing that the proposition accurately describes its subject. *See* Vern R. Walker, *Preponderance, Probability, and Warranted Factfinding*, 62 BROOK. L. REV. 1075, 1079–97 (1996). Usually, such a reasonable belief is only presumptively valid, and is defeasible if new evidence or a reanalysis of old evidence warrants a change in the belief.

59. *See* WALTON, *supra* note 1, at 103–50 (distinguishing plausibility from probability and discussing the history of the concept of plausibility). For a discussion of plausibility as a useful concept for evaluating evidence and weighing hypotheses, see John R. Josephson, *Plausibility*, *in* ABDUCTIVE INFERENCE, *supra* note 52, at 266, 268 (arguing that "coarse-scale" measures of plausibility "seem to be all we can usually get from experience" and "are almost always sufficient to decide action," while little may be gained by interpreting plausibility as mathematical probability, and it may be misleading to do so).

relevant descriptions (such as descriptions of a witness's demeanor). The informational content of some evidentiary assertions may be taken directly from the evidence (for example, from the testimony of witnesses), while the content of other assertions may be provided by the fact finder (for example, a fact finder's own description of a witness's demeanor). A plausibility-value is the classification on a scale of plausibility that a fact finder assigns to an evidentiary assertion.[60] A fact finder can use scales of plausibility having different numbers of possible values, and scales that are either ordinal or cardinal.[61] For example, a plausibility scale might be ordinal and have five values (such as very plausible, plausible, undecided, implausible, and very implausible) or seven values (such as highly plausible, very plausible, slightly plausible, undecided, slightly implausible, very implausible, and highly implausible).[62] By contrast, conventional mathematical probability is an infinite-valued cardinal scale using as values the real numbers between zero and one.[63] A reasonable fact finder would select a plausibility scale that is suitable to the circumstances, and would assign to evidentiary assertions plausibility-values on that scale.

The decision about which plausibility scale to employ should balance nonepistemic and epistemic objectives.[64] An important nonepistemic considera-

60. On measurement or classification generally, see Vern R. Walker, *The Siren Songs of Science: Toward a Taxonomy of Scientific Uncertainty for Decisionmakers*, 23 CONN. L. REV. 567, 580–88 (1991).

61. Researchers in AI and law have used various systems for evaluating evidence. *See, e.g.*, VERHEIJ, *supra* note 6, at 72 (discussing the evaluation algorithm in his ARGUMED 3.0 software program, which "computes the dialectical interpretations of the available assumptions, in accordance with the formal definitions of DEFLOG," the logical system underlying the software); Prakken et al., *supra* note 30, at 32–33 (listing researchers who have studied evidentiary reasoning, but stating that "[i]n AI & Law evidential reasoning is a little studied topic").

62. *See* Josephson, *supra* note 59, at 266–67 (stating that a "seven-step scale" using such values as "very likely" and "ruled out" was used in designing a medical diagnostic system, because "all available evidence supported the view that seven confidence grades are more than sufficient to represent physician reasoning during diagnosis"). In empirical studies of human risk perception, researchers measure the perceived risk of hazards using scales with a small number of classification categories. *See, e.g.*, Michael A. Diefenbach et al., *Scales for Assessing Perceptions of Health Hazard Susceptibility*, 8 HEALTH EDUC. RES. 181, 188–89 (1993) (finding that in measuring susceptibility or likelihood of harm, a seven-point verbal category scale performs at least as well as a 100-point numerical scale); Michael Siegrist & George Cvetkovich, *Perception of Hazards: The Role of Social Trust and Knowledge*, 20 RISK ANALYSIS 713, 715 (2000) (using a seven-point scale ranging from "not at all risky" to "very risky"); Paul Slovic et al., *Evaluating Chemical Risks: Results of a Survey of the British Toxicology Society*, 16 HUM. & EXPERIMENTAL TOXICOLOGY 289, 290, 293 fig.1 (1997) (using the categories "almost no health risk," "slight health risk," "moderate health risk," "high health risk," and "don't know").

Cf. John Henry Wigmore, *The Problem of Proof*, 8 ILL. L. REV. 77 (1913), *reprinted in* ANDERSON & TWINING, *supra* note 2, at 108–17 (grading the "probative effect of an evidential fact" as "provisional credit" and "strong credit," while grading the supported conclusion as "believ[ed] . . . to be a fact" and "particularly strong belief").

63. *See* L. JONATHAN COHEN, AN INTRODUCTION TO THE PHILOSOPHY OF INDUCTION AND PROBABILITY 70–74 (1989). For an introduction to mathematical probability within the context of legal reasoning, see, for example, Philip Dawid, *Probability and Proof: Some Basic Concepts*, *in* ANDERSON & TWINING, *supra* note 2, app. B at 389.

64. *Cf.* Vern R. Walker, *Restoring the Individual Plaintiff to Tort Law by Rejecting "Junk Logic" About Specific Causation*, 56 ALA. L. REV. 381, 389–95 (2004) (arguing that within a legal

tion is the pragmatic context for the fact-finding.[65] If the legal decision making does not require a high level of precision in evaluating plausibility, then there may be no reason for using a scale with a large number of values. Moreover, from an epistemic standpoint, using an ordinal, qualitative scale with a small number of values often reduces the potential for classification error, especially when the concepts in the evidentiary assertion are themselves qualitative. Inconsistency in classification is good evidence of the existence of error.[66] Scientists often manage to employ very precise, quantitative plausibility scales, yet achieve acceptable consistency of results, when the subject matter lends itself to quantitative measurements, researchers refine and test precise measurement instruments, and they train investigators to achieve reliable and valid measurements with those instruments. But ordinary-language concepts are often "fuzzy," or vague in their application,[67] and highly quantitative plausibility scales would yield inconsistent evaluations. Moreover, ordinary legal fact finders, who are usually untrained in scientific measurement, must assign degrees of plausibility to the everyday assertions of lay witnesses. Legal rules therefore seldom require fact finders to employ any particular plausibility scale when evaluating evidence. Generally, the fact finder is free to use any plausibility scale, so long as the fact finder is able to apply the appropriate standard of proof in making the findings or verdicts.[68] The epistemic objective is better served, however, when the plausibility scale

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context, decisions about what levels of precision and accuracy are acceptable are inherently pragmatic).

65. *See, e.g.*, Josephson & Tanner, *supra* note 52, at 14 (stating that in abductive reasoning, besides the "judgment of . . . likelihood" (plausibility) associated with the conclusion, the "willingness to accept the conclusion should (and typically does) depend on . . . pragmatic considerations, including the costs of being wrong and the benefits of being right," as well as "how strong the need is to come to a conclusion at all").

66. The potential for classification error can be divided into two important categories: the potential for *random error* (making the classifications "unreliable") and the potential for *systematic error* or *bias* (making the classifications "invalid"). For discussions of the concepts of reliability and validity in science, see generally EDWARD G. CARMINES & RICHARD A. ZELLER, RELIABILITY AND VALIDITY ASSESSMENT 11–13, 29–51 (1979); DAVID FREEDMAN ET AL., STATISTICS 90–101, 395–411 (2d ed. 1991); EDWIN E. GHISELLI ET AL., MEASUREMENT THEORY FOR THE BEHAVIORAL SCIENCES 184, 191, 266 (1981); HERMAN J. LOETHER & DONALD G. MCTAVISH, DESCRIPTIVE AND INFERENTIAL STATISTICS: AN INTRODUCTION 15, 34 (4th ed. 1993); Robert M. Groves, *Measurement Error Across the Disciplines*, *in* MEASUREMENT ERRORS IN SURVEYS 1 (Paul P. Biemer et al. eds., 1991); David H. Kaye & David A. Freedman, *Reference Guide on Statistics*, *in* REFERENCE MANUAL ON SCIENTIFIC EVIDENCE 83, 102–04 (Federal Judicial Center, 2d ed. 2000); Walker, *supra* note 64, at 389–95. The reliability of a classification process for plausibility would characterize the random variability in results when the same fact finder repeatedly classifies the same asserted proposition. Reliability is a measure of same-evaluator inconsistency. The validity of a classification process for plausibility would characterize the systematic divergence when two different fact finders or evaluators classify the same asserted proposition. Validity measures inter-evaluator inconsistency. Both reliability and validity are generally matters of degree, and this is particularly so as the number of possible values in the plausibility scale increases.

67. *See* CHIERCHIA & MCCONNELL-GINET, *supra* note 5, at 482–89; SCHUM, *supra* note 35, at 261–69.

68. The process rules about standard of proof are discussed *infra* text accompanying note 180.

produces the level of precision and the potential for error that are acceptable under the circumstances.[69]

2. *Plausibility Schemas*

"Plausibility schemas"[70] are logical patterns of evidentiary assertions that use the plausibility-values of those assertions to assign a plausibility-value to the conclusion of the schema.[71] They are inference schemas that explain why the plausibility of the evidence warrants default reasoning up the implication tree.[72]

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69. There is usually a cost associated with increasing precision without increasing the potential for error, or with decreasing the potential for error while retaining the same degree of precision. In a default-reasoning context, there is always more evidence to be obtained or there are always more ways to evaluate the available evidence. Such costs must be weighed against the possible benefits involved in producing more accurate conclusions, more warranted decisions, and more justified actions.

70. The word "schema" refers to a linguistic pattern that contains variables, together with a rule for replacing linguistic elements for those variables, so that one can use the schema to generate an indefinite number of instances. In logic, schemas are used to specify sets of permissible axioms or inferences. *See* JOHN M. ANDERSON & HENRY W. JOHNSTONE, JR., NATURAL DEDUCTION: THE LOGICAL BASIS OF AXIOM SYSTEMS 20–21 (1962); GERALD J. MASSEY, UNDERSTANDING SYMBOLIC LOGIC 139–40, 147–48 (1970). In semantics, schemas are used to specify conditions for assigning a truth-value to a sentence, see, for example, SAEED, *supra* note 5, at 89, 305–09, or more generally, to organize cognitive domains such as language, see *id.* at 353–57. In the field of artificial intelligence, the concept of a schema is often generalized to the concept of a "model" or "possible world" used to define when a sentence is true, *see, e.g.*, RUSSELL & NORVIG, *supra* note 6, at 201, but the notion of a schema also finds more particular uses, *see, e.g.*, *id.* at 118–19 (describing schemas in genetic search algorithms), 809 (describing rules schemas in augmented grammars).

71. The same evidentiary assertion could be relevant to (link to) many different terminal propositions. The plausibility-value of any particular evidence assertion must remain the same (be invariant), regardless of where the evidence is relevant in the tree. Plausibility reflects the evaluation of that evidence assertion relative to the support *for it*. By contrast, the degree of support that an evidentiary assertion can provide *to* a terminal proposition (the evidence's probative value relative to that proposition), given the other available evidence relevant to that proposition, can vary from issue of fact to issue of fact. The same piece of testimony, possessing the same plausibility, can be highly probative for proving one terminal proposition, but only slightly probative for proving some other terminal proposition. *Cf.* WALTON, *supra* note 1, at 294 (stating that an "argument is evaluated on the basis of (a) how plausible the premises are, and (b) how strong is the inference from the premises to the conclusion").

72. A literature has developed on "argumentation schemes," WALTON, *supra* note 7, at 2–3, which bear a family resemblance to plausibility schemas as defined here. As Walton uses the phrase, an argumentation scheme is "presumptive and plausibilistic in nature," supporting a conclusion that is "a reasonable presumption." *Id.* at 13. However, "[d]rawing conclusions from premises using these argumentation schemes is a kind of presumptive guesswork" because "the basis of their support is subjective" and "attaching some numerical values, truth-values, or whatever, to the propositions is not, by itself, much help." *Id.* at 13–14. The function of the argumentation scheme is to orchestrate a dialogue by use of "appropriate critical questions," the asking of which shifts "a burden or weight of presumptions to the other side in a dialogue." *Id.* at 13–14, 46. While the study of argumentation schemes can therefore provide valuable information for developing plausibility schemas, the two structures are clearly not identical.

For examples of researchers in AI and law using argumentation schemes, see, e.g., Prakken & Sartor, *supra* note 6, at 124–26, 129–30 (discussing "a model of legal reasoning as the dialectical interaction of competing inferences"); Prakken et al., *supra* note 30, at 32–40 (using argumentation schemes to model legal reasoning about evidence).

Like implication trees, plausibility schemas have an inverted tree structure, composed of propositional nodes and logical connectives. The propositional nodes represent evidentiary assertions, while the logical connectives operate on the plausibility-values of those evidentiary assertions. Plausibility connectives determine the plausibility-value of the conclusion on the upper level as a function of the plausibility-values of the evidentiary assertions on the lower level. In a many-valued plausibility logic, it is possible to define a large number of different plausibility connectives, based on different functions for combining plausibility-values. While this article cannot examine plausibility connectives comprehensively or systematically, it is possible to illustrate such connectives with several that are common in everyday reasoning. One pair of plausibility connectives consists of generalized functions of the conjunctive and disjunctive truth-value connectives used in implication trees.[73] The "MIN" plausibility connective assigns to the conclusion the *lowest* plausibility-value possessed by any of its conditions, just as the "AND" truth-value connective assigns to the conclusion the lowest truth-value of its conjuncts.[74] The "MAX" plausibility connective assigns to the conclusion the *highest* value of any of its conditions, just as the "OR" truth-value connective assigns to the conclusion the highest truth-value of its disjuncts.[75]

As a counterpart to the truth-value connective "UNLESS," it is useful to distinguish at least two kinds of plausibility defeaters, based on a distinction drawn by Pollock.[76] A "rebutting" defeater (represented by a "REBUT" connective) operates like UNLESS in the sense that it uses the plausibility-values of the rebutting evidentiary assertion to change the plausibility-value of the conclu-

73. Defining the three-valued truth connectives as special cases of the many-valued plausibility connectives creates an important feature of the default-logic paradigm: the patterns of deductive reasoning within the rule-based implication tree exhibit the same connective logic as the patterns of reasoning within the generalization-based plausibility schemas.

74. Within many-valued logic, Łukasiewicz and Gödel studied this conjunction connective formally. *See* GOTTWALD, *supra* note 3, at 65–66. This definition of the connective function is independent of "the number of truth degrees of the particular system of many-valued logic they belong to." *Id.*; *see* WALTON, *supra* note 1, at 109–13 (contrasting "linked arguments," in which "the conclusion should be at least as plausible as the least plausible premise"—the "least plausible premise rule"—with "convergent arguments," for which he thinks the least plausible premise rule does not work).

One advantage of the MIN connective that makes it useful in everyday reasoning is that it does not require knowledge about the degree of independence among the premises or children nodes of the schema. Because the plausibility of the conclusion is set equal to the plausibility of the least-plausible premise node, any entailments, implications, or statistical associations among premises have no effect on the plausibility of the inference. This permits plausible default reasoning on the basis of limited information, while allowing more precise analysis to occur in the future, if additional information becomes available that is helpful in solving a particular problem.

75. For a formal definition of this many-valued disjunction connective, see GOTTWALD, *supra* note 3, at 90.

76. POLLOCK, *supra* note 7, at 79 (distinguishing "rebutting defeaters" that warrant the falsehood of the conclusion from "undercutting defeaters" that "attack the connection between the prima facie reason and its conclusion rather than attacking the conclusion itself"). For examples where researchers in AI and law have employed Pollock's distinction, see Prakken & Sartor, *supra* note 6, at 120–24; Prakken & Sartor, *supra* note 18, at 3; Prakken et al., *supra* note 30, at 37–38.

sion.[77] By contrast, an "undercutting" defeater (represented by an "UNDERCUT" connective) merely defeats the line of reasoning leading to the conclusion, without changing the plausibility-value of the conclusion.[78] The operational rules for REBUT and UNDERCUT make this distinction clearer. If a rebutting assertion is plausible to any degree, then the REBUT connective assigns to the conclusion a degree of implausibility inverse to that of the defeater assertion. That is, as the degree of plausibility of a plausible rebutting assertion increases, the degree of plausibility of the conclusion decreases (in other words, the *im*plausibility of the conclusion *in*creases). Some examples: on the five-point scale above, if the plausibility-value of the defeater is "plausible," then the plausibility-value of the conclusion is "implausible"; on the seven-point scale above, if the defeater is "highly plausible," then the conclusion is "highly implausible"; on the scale of mathematical probability, if the defeater's plausibility-value is 0.56, then the conclusion's plausibility-value is 0.44 (that is, 1 – 0.56).[79] The plausibility defeater UNDERCUT operates differently. If an undercutting assertion is plausible to any degree, then the conclusion's plausibility-value remains whatever it would have been in the absence of the branch of reasoning to which the UNDERCUT connective is attached. In sum, rebutting assertions defeat the conclusion, while undercutting assertions defeat the line of support for the conclusion.[80]

If fact finders are free to adopt different plausibility scales for different evidentiary assertions,[81] then these plausibility functions will require a rule for handling a mixture of scales—for example, where one conjunct or disjunct has a plausibility-value on a seven-point ordinal scale and another conjunct or disjunct has a quantitative value on a real-number scale. These connectives require knowing only whether a particular value on one scale is lower (for conjunction) or higher (for disjunction) than a value on another scale. Then the conclusion can be evaluated on a scale appropriate to its content, context, and support, but the scale could be as precise as the scale of the decisive evidentiary assertion—the

77. From a formal standpoint, a many-valued defeater combines the functions of a many-valued conjunction ("AND") and a many-valued negation ("NOT") into a single connective ("AND-NOT"). For formal definitions of many-valued negation connectives, see GOTTWALD, *supra* note 3, at 84–85.

78. Logicians have also studied a weaker kind of defeater connective that may prove useful in plausibility schemas. *E.g.*, BREWKA ET AL., *supra* note 4, at 2–3, 16 (explaining a Type II defeater as "undermin[ing] the justification for a default without contradicting its conclusion; the conclusion may still hold, but we cannot use the default to justify it").

79. For the calculus of mathematical probability, see Dawid, *supra* note 63.

80. This is not the place for a full discussion of why legal rules seem to employ only rebutting defeaters (represented by UNLESS in three-valued implication trees), while plausibility schemas may contain both rebutting and undercutting defeaters. One suggestion is that legal authorities, when they adopt legal rules, generally employ a strong sense of defeat when they establish affirmative defenses or exceptions to a rule, and that they intend the adopted set of legal rules to represent *all possible* lines of accepted reasoning. By contrast, plausibility schemas are not usually adopted by authority, but generally reflect common-sense or logical patterns of default reasoning. Moreover, any particular plausibility schema generally represents *only one possible* line of support for a conclusion, and it is more likely to employ only undercutting defeaters.

81. *See supra* text accompanying notes 59–69.

one with the lowest plausibility-value (for conjunction) or the highest plausibility-value (for disjunction).

Like truth-functional connectives, plausibility connectives determine the conclusion's plausibility-value entirely as a function of the plausibility-values of the schema's evidentiary assertions. This is a desirable property from both a theoretical and an automation standpoint. The derivation of the inferential value is completely transparent and formal. Moreover, software can determine the plausibility-value of the conclusion of a schema entirely from the plausibility-values at lower levels of the schema.

Part II.B *infra* provides an illustration of a plausibility schema. Schematically, however, a plausibility schema is an inference tree, of the kind shown in Figure 3.[82]

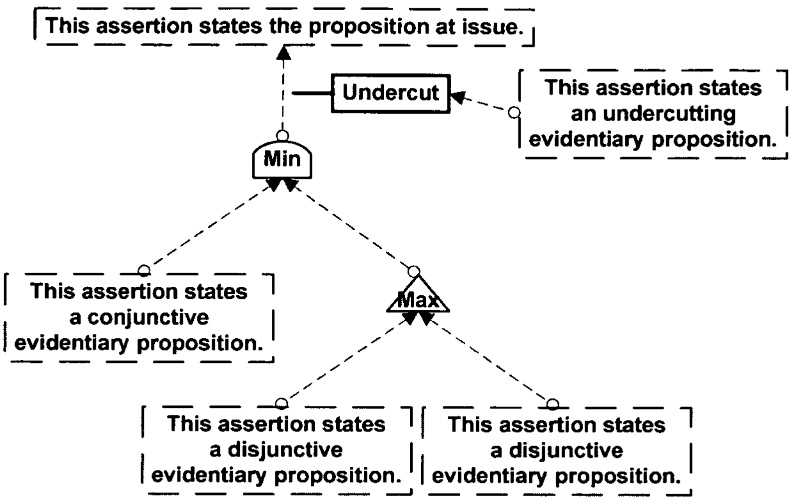

Figure 3. Illustrative Schematic of a Plausibility Schema

The interpretation of such a schema is that if the evidentiary assertions on the lower level are plausible, then the conclusion is also plausible (or implausible) in the manner determined by the plausibility connectives MIN, MAX, and UNDERCUT. Plausibility schemas model default reasoning to conclusions that are presumptively plausible or implausible, but defeasible.

Because plausibility schemas supply the warrant for a default inference to a presumptively true conclusion, a major strategy for designing a plausibility

82. In the plausibility region of a logic diagram, the assertion shape has a dashed line around it instead of a solid line to indicate that the proposition uses a plausibility-value instead of a truth-value. In addition, the arrows and plausibility connectives that connect evidentiary assertions within a plausibility schema operate on plausibility-values, instead of representing a three-valued inference of an implication tree. The complete model of the reasoning behind an instance of fact-finding therefore constitutes an "inference tree," which includes both rule-based and plausibility-based inferences.

schema is to develop a "theory of uncertainty" for the type of inference.[83] When the available evidence is incomplete, a good theory of uncertainty can warrant drawing a presumptive but defeasible conclusion precisely because the fact finder understands not only what evidence is missing and why the missing evidence is relevant, but also why it is nevertheless reasonable to make a finding without that missing evidence.[84] A theory of uncertainty explains how the available evidence could be plausible but the conclusion could still be false (or in the case of defeater, how the conclusion could still be true). It identifies the possible sources of error in a type of inference and explains how that error can come about.[85] A theory of uncertainty therefore helps a fact finder identify the sources, types, and degrees of uncertainty associated with drawing the conclusion[86] and can suggest strategies for obtaining new evidence.[87] Theories of uncertainty, incorporated into the inference structures of plausibility schemas, therefore play a critical role in default reasoning.[88] Just as epistemic policies play a role in justifying the adoption of particular legal rules, theories of uncertainty supply the epistemic justification for adopting particular plausibility schemas as constituting warrant for default fact-finding.

Plausibility schemas commonly contain one or more propositions with the logical form of a "generalization," and the presumptive force of the schema depends in part on the plausibility of its generalizations.[89] A generalization

83. For the concept of a "theory of uncertainty" generally, see Vern R. Walker, *Theories of Uncertainty: Explaining the Possible Sources of Error in Inferences*, 22 CARDOZO L. REV. 1523, 1525, 1538–41 (2001) (suggesting that "theories of uncertainty have an explanatory function in inference that is roughly parallel to the role played by theories of causation in the empirical sciences").

84. *See, e.g.*, Josephson & Tanner, *supra* note 52, at 15 (stating that when an abductive justification is challenged, a proper answer is "in terms of what is wrong with alternative explanations and what is the evidence that all plausible explanations have been considered"); *cf.* Prakken et al., *supra* note 30, at 34 (stating that "[o]ne very important aspect of Wigmore's method" of charting evidence is that Wigmore saw "charting not primarily as an attempt to express reasons for belief but to express reasons for doubt").

85. Theories of uncertainty often consider three broad sources of error: linguistic, logical, and causal. Walker, *supra* note 83, at 1532–38. Error might arise because the fact finder misunderstands the meanings of the words used (the linguistic dimension), the logical relationships among the propositions asserted (the logical dimension), or the causal relationships among the objects or events involved (the causal dimension).

86. *Id.* at 1525–26, 1538–43.

87. *Id.* at 1526.

88. For a recognition of this critical role within AI and law, see Prakken et al., *supra* note 30, at 40 (stating that when the authors' general theory is applied to "real cases, it must be supplemented with detailed knowledge-engineering research on sources of doubt of evidential arguments").

89. For general discussions of the role of generalizations within legal reasoning, see ANDERSON & TWINING, *supra* note 2, at 63–69, 367–79; SCHUM, *supra* note 35, at 81–83, 101–02, 109–12, 209–10, 261–69, 472; WALTON, *supra* note 7, at 46, 51–53, 151–54. Some logical theorists have treated generalizations, as defined here, as being a species of propositions that they call "warrants." *See, e.g.*, STEPHEN EDELSTON TOULMIN, THE USES OF ARGUMENT 97–107 (1958) (giving the example of a possible warrant as "A Swede can be taken almost certainly not to be a Roman Catholic"); TOULMIN ET AL., *supra* note 7, at 45–59, 219–29 (discussing generalizations based on samples or signs and causal generalizations as kinds of backing for warrants).

usually asserts that its description is true in some situations but not all situations.[90] When a generalization is analyzed into its logical predicate and one or more indefinite subjects,[91] it asserts that the predicate accurately describes some portion of the members of the subject class.[92] Examples of generalizations are: "most witnesses testifying under oath tell the truth," "one-third of Americans are overweight," and "60% of the test group in the study developed the disease." These generalizations have the following logical forms (respectively): "most As are Bs," "X/Y of As are Bs," and "X% of the members of group A are (also) members of group B." In these propositions, logicians call group A the "reference class" or "reference group" for the generalization.[93] The content of a generalization includes an asserted degree of "quantification" over the reference class—that

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The logical structure of warrant for an inference is distinct from the cognitive process of producing possible generalizations on which to base an inference. For one analysis of the latter process, see, for example, JEROME P. KASSIRER & RICHARD I. KOPELMAN, LEARNING CLINICAL REASONING 2–46 (1991) (analyzing the process of generating, refining, and verifying medical hypotheses for diagnosing diseases of specific patients in a clinical setting).

90. Logicians often call propositions asserted to be true about all members of a group "generalizations," for example, COPI & COHEN, *supra* note 23, at 389, but less-than-universal generalizations are far more common in assessing plausibility of evidence. In the default-logic paradigm, therefore, the term "generalization" refers to a less-than-universal generalization, unless the proposition is expressly stated to be universal.

91. Logical subjects are divided into definite and indefinite subjects. *See, e.g.*, CHIERCHIA & MCCONNELL-GINET, *supra* note 5, at 55–68, 105–08 (discussing, within semantic theory, the concepts of proper names and definite descriptions, as contrasted with general terms and common nouns); LARSON & SEGAL, *supra* note 5, at 286–301, 319–59 (discussing the "definiteness effect" and "definite descriptions" within semantic theory); RODES & POSPESEL, *supra* note 25, at 114–20 (discussing "singular terms" and "general terms"). Definite subjects are specific individuals that are denoted by proper names ("John Jones"), definite descriptions ("the plaintiff in Civil Case No. 2006-234"), or pronouns taking their denotations from proper names or definite descriptions. Indefinite subjects are individuals identified entirely by their general characteristics. Indefinite subjects can be denoted by common nouns ("plaintiffs"), indefinite descriptions ("a party to a lawsuit"), and other grammatical phrases that name groups or classes of individuals. In ordinary language, the same phrase might be used to name either a definite subject or an indefinite subject (e.g., "a justice of the United States Supreme Court"), depending upon whether the speaker intends to name a specific individual or merely an indefinite member of a class or group.

92. This concept of "generalization" is that employed by logicians. *See, e.g.*, CHIERCHIA & MCCONNELL-GINET, *supra* note 5, at 113–17; COPI & COHEN, *supra* note 23, at 389; RODES & POSPESEL, *supra* note 25, at 119–20. This concept is very close to that employed by Wigmore, Anderson, and Twining, *see* ANDERSON & TWINING, *supra* note 2, at 43–44, 63–69, 367–84 (giving numerous examples of generalizations), and at least consistent with the hypothetical concept of generalization employed by Toulmin and Schum, *see* TOULMIN, *supra* note 89, at 98 (calling "general, hypothetical statements" that authorize inferences "warrants"); SCHUM, *supra* note 35, at 81–82 (calling generalizations "assertions about what happens *in general*," intended to state "why we believe we are entitled to reason from one stage to another"). The more formal concept of generalization employed by logicians and in the default-logic paradigm is more conducive to capture in artificial intelligence software.

For a discussion of generalizations within the research on AI and law, see Prakken et al., *supra* note 30, at 38–40 (modeling both generalizations and argumentation schemes).

93. *See, e.g.*, HENRY E. KYBURG, JR., SCIENCE & REASON 41 (1990); BRIAN SKYRMS, CHOICE AND CHANCE: AN INTRODUCTION TO INDUCTIVE LOGIC 201 (2d ed. 1975).

is, the size of the portion of A that is asserted to be B.[94] The degree of quantification that is asserted can obviously affect the plausibility-value that a fact finder will assign to the generalization. Moreover, the expression of a generalization in a natural language such as English often contains an explicit modal "hedge" qualifying the entire assertion, which can influence the plausibility-value compared to an unhedged generalization.[95] Examples of modal hedges are expressions of frequency (for example, "sometimes" or "often"), typicality (for example, "typically" or "normally"), temporal limitation (for example, "in the past" or "at least for the immediate future"), or degree of confidence of the speaker (for example, "perhaps" or "almost certainly").[96] The degree of quantification asserted and the modal hedge employed can together change the content of the generalization and influence its plausibility. As Part II.B of this article illustrates, these attributes of generalizations can influence in turn the degree of warrant that a plausibility schema provides for a conclusion.

Plausibility schemas also commonly contain one or more assertions about "definite subjects." Definite subjects are one or more specific individuals, who can be denoted by proper names (for example, "John Jones"), definite descriptions ("the plaintiff in Civil Case No. 2006-234"), or pronouns taking their denotations from a proper name or a definite description ("she"). By contrast, indefinite subjects are individuals identified entirely by their general characteristics or properties and denoted by common nouns ("plaintiffs"), indefinite descriptions ("a party to a lawsuit"), and other grammatical phrases that name groups or classes of individuals. Legal rules often contain placeholders or variables for names that refer to definite subjects (such as "the plaintiff" and "the plaintiff's injury"), with the intention that the name of a specific individual will be substituted in any particular lawsuit. A plausibility schema that attaches to a terminal proposition about a definite subject, therefore, must also have a definite subject in the conclusion of the schema. Moreover, assertions admitted as evidence in a legal case are often about specific individuals (such as the specific plaintiff John Jones). Plausibility schemas, therefore, combine generalizations about groups with definite assertions about specific individuals into a coherent pattern of default reasoning that can warrant making a finding of fact.

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94. Traditional predicate logic has studied extensively the formal properties of two important quantifiers: the universal quantifier ("all A's ...") and the existential quantifier ("some A's ..." or "at least one A ..."). *E.g.*, COPI & COHEN, *supra* note 23, at 387–91; RODES & POSPESEL, *supra* note 25, at 124–34; SAINSBURY, *supra* note 23, at 141–47, 182–90.

95. *See* SCHUM, *supra* note 35, at 81–83, 101–02, 110–12 (giving as examples of "hedges" the adverbs "sometimes," "frequently," "often," and "usually"); TOULMIN, *supra* note 89, at 100–01, 108–13 (discussing "modal qualifiers," such as "presumably" and "almost certainly," as "indicating the strength conferred by the warrant" on an inference from evidence to conclusion). It is not always clear in legal writings, however, whether the hedge term is about frequency (how often the asserted description is true), fuzzy set membership (how definitively individuals can be placed in a class or given a description), degree of warrant (how good the evidential support is), or subjective confidence (how convinced the speaker is). *See* Walker, *supra* note 83, at 1560–62.

96. *See* SCHUM, *supra* note 35, at 81–82; TOULMIN, *supra* note 89, at 100–01 (discussing "modal qualifiers" like "presumably" as expressing a "degree of force"); Josephson & Tanner, *supra* note 52, at 23.

3. *Findings of Fact and Complete Inference Trees*

The purpose of using a plausibility schema is to structure the evidence in such a way as to warrant a finding that a terminal proposition is either true or false. The function of a schema is to organize the relevant evidence so that the presumptive nature of the reasoning becomes transparent. Primary factors in selecting a schema to use for a particular terminal proposition are therefore the logical form of the terminal proposition and the nature of the legally available evidence. For example, whether the terminal proposition is a generalization about groups or a proposition about a specific individual will determine what kind of schema is needed. And evidence that is scientific and statistical should be organized differently than eyewitness testimony. While this article cannot present a complete catalog of possible plausibility schemas or explore their properties in a formal way, it does provide an extended illustration focusing on one type of important terminal proposition (in Part II.B *infra*).

Plausibility schemas are not implication trees, and linking schematized evidence to an implication tree does not extend that tree. First, as noted above, the evidentiary assertions within a plausibility schema have plausibility-values on variable scales of plausibility, not truth-values on a three-valued scale. Moreover, the fact finder selects schemas and plausibility scales to fit the evidence in the particular case, whereas authoritative institutions adopt the legal rules represented by the implication tree. This means that the schematized evidence is specific to the particular case and to the particular fact finder, whereas the implication tree is generic to all cases within the legal jurisdiction. There are many plausibility schemas that might warrant a particular terminal proposition, depending upon the nature and probative value of the available evidence and how a particular fact finder chooses to organize the evidence. The fact that one line of evidentiary reasoning provides sufficient warrant in a particular case does not mean that no other line of reasoning could warrant that finding as well, or that no other line of reasoning would provide stronger warrant. An entire "inference tree," composed of an implication tree at the top and schemas of evidence attached to terminal propositions toward the bottom, can model the entire reasoning behind the fact-finding in the particular case—which includes rules, policies, findings, and evidentiary bases for those findings.

In order for plausibility schemas to provide a transparent and principled inference from plausible evidence to a finding, there must be a rule for determining the truth-value of a terminal proposition as a function of the plausibility-value of the evidence relevant to that proposition. In legal terminology, this rule is the applicable "standard of proof."[97] For example, the standard of proof for most issues of fact in civil cases is preponderance of the evidence.[98] Under this rule, if the fact finder evaluates the relevant evidence as having any plausibility-value other than "undecided," then the fact finder must assign the corresponding truth-

97. *See* JAMES ET AL., *supra* note 42, §§ 7.5, 7.14 (discussing the "three generally recognized standards of proof . . . : preponderance, clear and convincing, and beyond a reasonable doubt").

98. *See id.*; 2 MCCORMICK ON EVIDENCE § 339, at 438 (John W. Strong ed., 4th ed. 1992); J.P. McBaine, *Burden of Proof: Degrees of Belief*, 32 CAL. L. REV. 242, 247, 261 (1944).

value to the terminal proposition—that is, find the terminal proposition to be true if she evaluates the evidence as plausible to any degree and find the terminal proposition to be false if she evaluates the evidence as being implausible to any degree. The use of the preponderance standard of proof in law has a number of policy-based rationales.[99] Part III.B of this article discusses standards of proof generally, as a type of process rule, but such standards are essential to warranting inferences from evidence that is merely plausible to rule-based deductions and ultimate conclusions. Standards of proof are the warrant links between the output of plausibility schemas and the input to the implication trees to which the schemas attach.

B. An Extended Illustration: The Statistical-Syllogism Plausibility Schema

This section illustrates the use of plausibility schemas to evaluate evidence and help warrant findings of fact, by briefly considering a statistical-syllogism schema for categorizing definite subjects. This schema can help organize the warranting evidence for a finding about an unobserved property of a definite subject or specific individual. Examples of such findings are: "the tire that caused the accident had a manufacturing or design defect,"[100] "the defendant was driving under the influence of marijuana,"[101] and "the claimant contracted pneumoconiosis."[102] These findings are about a specific tire, a specific defendant, and a specific claimant. Such findings would establish (respectively) the truth of the following terminal propositions within legal implication trees: "the product [identified in the case] was defective"[103]; "the person [driving a motor vehicle] was under the influence of a controlled substance"[104]; and "the claimant suffers

99. *See* Walker, *supra* note 58, at 1083–92, 1113–20 (discussing, besides the epistemic objective, three policy rationales for the preponderance standard of proof: creating an incentive for all parties to produce an adequate amount of relevant evidence; treating all parties to a proceeding in an unbiased and nearly equal manner, despite the fact that one party bears the burden of persuasion; and producing findings that are likely to enjoy a fairly wide scope of agreement, at least among reasonable people weighing the same evidence).

100. *See, e.g.*, Kumho Tire Co. v. Carmichael, 526 U.S. 137, 142–45 (1999) (judicial civil case).

101. *See, e.g.*, State v. Klawitter, 518 N.W.2d 577, 578 (Minn. 1994) (judicial criminal case).

102. *See, e.g.*, Greenwich Collieries v. Dir., Office of Workers' Comp. Programs, 990 F.2d 730, 731 (3d Cir. 1993), *aff'd*, 512 U.S. 269 (1994) (administrative case involving judicial review of a decision of the Benefits Review Board).

103. *See, e.g.*, RESTATEMENT (THIRD) OF TORTS: PRODUCTS LIABILITY § 1 (1998); Carmichael v. Samyung Tires, Inc., 923 F. Supp. 1514, 1516–17 (S.D. Ala. 1996), *rev'd on other grounds*, 131 F.3d 1433 (11th Cir. 1997), *rev'd on other grounds sub nom.* Kumho Tire Co. v. Carmichael, 526 U.S. 137 (1999) (applying the products liability law of Alabama).

104. *See* MINN. STAT. § 152.02 (2005) (controlled substances); *id.* § 169A.20 (driving while impaired).

from pneumoconiosis."[105] The logical problem is modeling patterns of default reasoning that can warrant the plausibility of such findings of fact.[106]

1. *The Statistical-Syllogism Schema in General*

There may be several possible patterns of reasoning that could provide the needed warrant,[107] but logicians have called the particular pattern discussed here a "statistical syllogism" or a "direct inference."[108] They give the statistical syllogism the following basic form:[109]

Most things in category A are also in category B.

The definite subject S is in category A.

Therefore, the definite subject S is probably (also) in category B.

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105. *See, e.g.*, Peabody Coal Co. v. Hill, 123 F.3d 412, 415–16 (6th Cir. 1997) (enumerating the factual elements of a claimant's prima facie case to establish entitlement to benefits under the Black Lung Benefits Act).

106. A parallel pattern of reasoning in medicine is "evidence-based medicine" (EBM), in which physicians evaluate the best available scientific information and apply it to specific patients. David L. Sackett et al., *Evidence Based Medicine: What It Is and What It Isn't*, 312 BRITISH MED. J. 71, 71 (1996) (defining EBM as "the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients"); *see* DAN MAYER, ESSENTIAL EVIDENCE-BASED MEDICINE 9–15 (2004) (discussing six steps of EBM).

107. It is an underlying principle of the default-logic paradigm that empirical research together with logical analysis might uncover many patterns of sound presumptive reasoning. Theories of uncertainty could then be the bases for converting them into plausibility schema. This optimism runs counter to the pessimism of some theorists. *E.g.*, SCHUM, *supra* note 35, at 472 (concluding that "[t]here is no general standard according to which we may grade the plausibility of generalizations that we may assert" and that "there are no rules showing us which generalizations to invoke as we attempt to link evidence to hypotheses").

108. The inference is called a "statistical syllogism" because a statistical premise (such as "X percent of A's are B") is used instead of a universal generalization ("All A's are B"). POLLOCK, *supra* note 7, at 75–77; WESLEY C. SALMON, LOGIC 88–91 (2d ed. 1973). When the portion of A asserted to be B is identified statistically (using, for example, a mathematical proportion or percentage), then logicians often call the generalization a "statistical generalization." *See, e.g.*, POLLOCK & CRUZ, *supra* note 10, at 229–30; SALMON, *supra*, at 87–91; Josephson & Tanner, *supra* note 52, at 23. For early recognition of the difficulty such inferences pose for legal theory, see George F. James, *Relevancy, Probability and the Law*, 29 CAL. L. REV. 689 (1941).

For discussions of the inference as "direct inference," see, for example, POLLOCK, *supra* note 7, ch. 4; Henry E. Kyburg, Jr., *The Reference Class*, 50 PHIL. SCI. 374 (1983); Isaac Levi, *Direct Inference and Confirmational Conditionalization*, 48 PHIL. SCI. 532 (1981); Isaac Levi, *Direct Inference*, 74 J. PHIL. 5 (1977). Toulmin has referred to direct inferences as "quasi-syllogisms." *See* TOULMIN, *supra* note 89, at 108–11, 131–34, 139–40.

For research on this inference pattern in AI and law, see Henry Prakken, *Analysing Reasoning About Evidence with Formal Models of Argumentation*, 3 LAW, PROBABILITY & RISK 33, 38–40 (2004) (formalizing the statistical syllogism); Prakken et al., *supra* note 30, at 39 (stating that if certain argumentation schemes are regarded as "empirical generalizations," then "applying the schemes boils down to applying the (qualitative) statistical syllogism").

One type of direct inference is sometimes called "abduction," when abduction is defined as "inference to the best explanation" or as "a process of reasoning from effect to cause" to explain the data in a specific case. Josephson & Tanner, *supra* note 52, at 5, 17. However, some authors explicitly exclude direct inference from the definition of abduction. *See id.* at 23–24.

109. *See* Walker, *supra* note 64, at 386–89 (discussing direct inference in warranting conclusions about specific causation in tort cases).

This statistical syllogism consists of two premises leading to a conclusion about the categorization (in category B) of a specific individual or definite subject (S). The first or major premise is a generalization that asserts that most things identified as being in category A are in fact also in category B. The second or minor premise is an assertion that the definite subject S is in category A.[110] A preliminary plausibility schema of this statistical syllogism would be the schema shown in Figure 4.

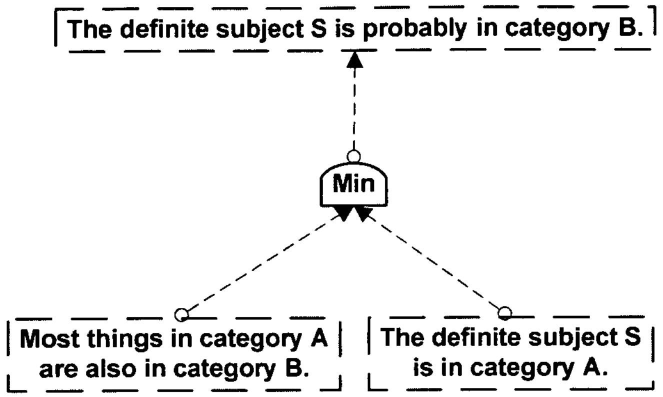

Figure 4. Preliminary Plausibility Schema for the Statistical Syllogism

Because a statistical syllogism uses a generalization about a reference group to warrant inferences about specific individuals in that group,[111] this pattern of reasoning is particularly useful when the individual's membership in category B is not directly observed by a witness.

While such statistical reasoning has intuitive appeal, an examination of each of the two premises clarifies the uncertainties inherent in such reasoning. The first or major premise is a generalization asserting that most of the members of reference class A are also in category B. The plausibility of this premise rests in turn upon the plausibility of the evidence upon which it is based. One possible type of evidence for a generalization is statistical data.[112] Generalizing from statistical data runs the risk of incorporating at least two types or sources of uncertainty: measurement uncertainty and sampling uncertainty.[113] First, the

110. Ayer defined a distinct class of judgments that he called "judgements of credibility." A.J. AYER, PROBABILITY AND EVIDENCE 27–29, 53–61 (1972). As he said: "the judgement that such and such an individual smoker will probably die of lung cancer, if it is genuinely a judgement about this individual, and not just about the class of smokers to which he belongs, is a judgement of credibility." *Id.* at 28.

111. For a direct-inference analysis of reasoning to a warranted finding about causation of a specific plaintiff's injury in a tort case, see Walker, *supra* note 64, at 452–60.

112. For a general discussion of reasoning involving the backing for generalizations, see TOULMIN ET AL., *supra* note 7, at 219–29.

113. For extended discussions of measurement and sampling uncertainty, see Walker, *supra* note 60, at 580–98; Walker, *supra* note 64, at 389–405; *supra* note 66 (discussing measurement uncertainty); and *infra* notes 117–19 (discussing sampling uncertainty).

plausibility of the statistical generalization depends upon how much measurement uncertainty there is in classifying individual things as being A and being B.[114] The asserted proportion of A's that are B's can be warranted as accurate only if the classifications of individuals into groups A and B have acceptable accuracy.[115] If individuals are misclassified as being A or being B, then the asserted proportion of A's that are B's will be inaccurate to some extent. Unless the data classifying individuals as A and B have acceptable measurement accuracy, the generalization about A's being B's is itself unwarranted.[116]

Second, the plausibility of the statistical generalization depends upon whether the sampling uncertainty is acceptable.[117] The sample is the collection of individuals that were actually measured in order to obtain the empirical data. Sampling uncertainty is the potential for error introduced precisely because the reasoning proceeds from statistics about a sample of measured individuals to a conclusion about a more general population.[118] Whether sampling uncertainty is acceptable depends upon how representative (with respect to the association of A with B) that sample is relative to the population described in the generalization. The plausibility of the statistical generalization depends not only on the uncertainty inherent in the measurement processes, but also on the uncertainty created by measuring the members of one sample as opposed to another.[119]

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114. For discussion and references on measurement or classification uncertainty, see *supra* note 66; Walker, *supra* note 64, at 389–95.

115. The degree of precision asserted in the generalization can also affect its plausibility. A generalization asserting that a precise percentage of A's are B's may require stronger support than a generalization asserting merely that "most" A's are B's.

116. Of course, more precise statements of uncertainty may come into play in warranting that the measurement uncertainty is acceptable. Measurement uncertainty rests in turn on reliability and validity, each of which can reduce the plausibility of the generalization. *See supra* note 66. Reliability describes the degree of variability in outcome when reclassifying the same subject using the same measurement process. Validity characterizes the inaccuracy resulting from a measurement process when the results are compared to the results from another measurement process for the same property or characteristic. Researchers can improve reliability and validity by different methods—by improving the measurement instruments or measurement process, or by improving the analysis of the data. Walker, *supra* note 64, at 394–95. Moreover, as discussed above in the context of classifying evidentiary assertions, *supra* text accompanying notes 59–69, the degrees of unreliability and invalidity that are acceptable in a particular situation depend upon the pragmatic purpose for which the inference is being made. Walker, *supra* note 64, at 395. Acceptable reliability and validity in the measurements of A and B are therefore necessary conditions for finding a statistical generalization to be plausible.

117. For discussion and references on sampling uncertainty, see Walker, *supra* note 64, at 396–405.

118. *Id.* at 396.

119. The reasoning behind sampling uncertainty has two subbranches, depending upon whether the possible lack of representativeness can cause either biased error or random error when generalizing a sample ratio B/A to the population. Walker, *supra* note 64, at 396–405. Researchers address sample representativeness in two ways: by explicitly taking into account in the sampling process any variables thought to be important in the target population, and by building randomization into the sampling process. *Id.* at 396–98. They have also developed analytical techniques for characterizing sampling uncertainty. The conventions about "statistical significance" help guard against the potential for error due to variations among samples attributable to chance alone, and the conventions about "statistical power" help guard against the potential for error due to small sample size. *Id.* at 399–403.

While the major premise in a statistical syllogism about a definite subject (Figure 4) is a generalization about groups of A's and B's, the minor premise identifies a definite subject S and classifies that specific individual as being a member of group A. One possible type of evidence for such a premise is another direct inference, based on another statistical syllogism. The minor premise of one direct inference might be warranted in a particular case by another direct-inference schema, and this chaining of direct inferences might continue down the inference tree. An alternative line of reasoning, however, to the same kind of conclusion is the report of an eyewitness, based upon her own perceptual observation. Using the analysis of Schum,[120] the plausibility of the eyewitness report depends on three conditions: the observational capability of the eyewitness, the witness's memory about what she perceived, and the witness's veracity in accurately reporting what she remembers.[121] Taken together, these three conditions constitute the credibility of the witness herself in asserting that she observed the subject S as being an A.[122] Additional conditions for the plausibility of the witness's assertion might be whether the assertion is consistent with the concept of "being an A" (for example, whether S possesses the other properties entailed by being an A) and whether the assertion is plausible in light of what else is known about S.[123]

The major and minor premises in Figure 4, however, do not adequately address all of the uncertainty or potential for error in a direct inference. The generalization (the major premise) could have a high degree of plausibility, as could the categorization of S as an A (the minor premise), but the support for the inference would be very weak unless we take into account what else we know about the specific individual S.[124] Unless the definition of reference group A

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120. *See* SCHUM, *supra* note 35, at 100–09; *see also* KADANE & SCHUM, *supra* note 35, at 53–60; Walker, *supra* note 83, at 1559–68. For a general analysis of Schum's system, see Walker, *supra* note 35, at 392–404.

The plausibility of an assertion warranted by personal perception depends in part on whether an act of perception actually occurred. For example, the plausibility of a witness's claim to have seen a man leaving the crime scene depends upon the witness's having a clear line of sight to the man, upon the witness's visual capability, upon the lighting conditions, and so forth. An act of perception is itself a specific causal occurrence between the thing perceived and the perceiver, and the plausibility that it occurred depends in turn on generalizations about human perceptual abilities.

121. SCHUM, *supra* note 35, at 100–09 (dividing observational capability into the "observational sensitivity or accuracy" of the witness's sensory evidence and the "objectivity" of the witness in interpreting her sensory evidence).

122. *Id.*; KADANE & SCHUM, *supra* note 35, at 55–58.

123. Alibi evidence is a good example. If the fact finder believes that S was in California on a particular date, then it is implausible that S was also in New York on the same date, absent S's taking some fast mode of transportation.

124. The statistical-syllogism schema also suggests how plausibility schemas can integrate scientific or other expert evidence with lay, nonexpert evidence. Expert knowledge domains supply evidence for legal decision making, often in the form of generalizations, and those generalizations become evidentiary assertions within plausibility schemas. But those generalizations alone, no matter how well established, cannot warrant a conclusion about a specific individual S. Doubts about S's being in category A or how well the members of category A represent S may seriously undermine the probative value of the generalization in the particular case.

incorporates enough information about S, so that A is acceptably representative of S, then there may be little logical support for the conclusion that S is also a member of category B.[125] For example, most residents of the United States might be women, and S might be a resident of the United States, but that alone might not warrant a finding that S is (probably) a woman. The warrant for such a finding depends upon what else we know about S, and upon the completeness of that information. For example, we may have more information about S that is relevant to predicting gender. In short, whether the direct inference is warranted depends in part upon whether the reference group A adequately represents the specific individual S, with respect to enough of the attributes or variables that are relevant to predicting whether S is a B.[126] This condition of being "adequately representative" could lead in turn to more elaboration of its meaning and the conditions under which it is a plausible premise.[127]

The revised plausibility schema for a statistical syllogism categorizing a definite subject therefore includes the major and minor premise in Figure 4, together with this additional condition, as shown in Figure 5.

125. Schum uses the notion of "ancillary evidence" to test whether a generalization applies in a particular instance. SCHUM, *supra* note 35, at 109–20, 187–92; KADANE & SCHUM, *supra* note 35, at 52–53.

126. *See* Walker, *supra* note 64, at 439–48 (arguing that in torts cases, reference group A must adequately represent the particular plaintiff before a direct inference is warranted). *Cf.* Peter Tillers, *If Wishes Were Horses: Discursive Comments on Attempts to Prevent Individuals from Being Unfairly Burdened by Their Reference Classes*, 4 LAW, PROBABILITY & RISK 33, 37–47 (2005) (discussing, in the context of a criminal case, epistemic and nonepistemic aspects of the "reference class problem").

A parallel problem in clinical medicine is whether to treat a patient's condition using a diagnosis based on incomplete information or whether to await the results of additional tests. *See* KASSIRER & KOPELMAN, *supra* note 89, at 24–27 (stating that "[t]he trade-offs between the risks and benefits of tests and treatments are embodied in the threshold concept," and analyzing medical decision rules for testing and treating particular patients in a clinical setting).

127. For example, in some contexts the process of randomly selecting S from A is sufficient warrant that A adequately represents S for purposes of inferring that S is a B. In a lottery-type drawing, for example, the probability of drawing a particular type of object (such as an even-numbered ball, category B) is equal to the proportion of such objects in the lottery pool (category A), provided each object in the pool has an equal chance of being selected on that particular draw. *See* Walker, *supra* note 64, at 448–52 (discussing lottery mechanisms in which the proportions of items to be drawn are known, as well as the probabilities for drawing them).

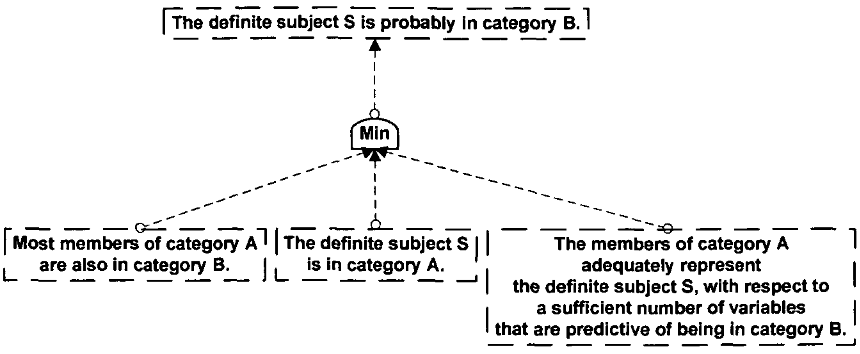

Figure 5. Revised Plausibility Schema for the Statistical Syllogism

The plausibility connective MIN joining the branches makes the plausibility-value of the conclusion, insofar as it is warranted by this direct inference, equal to the lowest plausibility-value among these three conditions. The next section provides an extended illustration of an application of this plausibility schema.

2. *Applying the Statistical-Syllogism Schema in Particular Cases*

The application of the statistical-syllogism schema in particular cases can be illustrated by claims under the National Childhood Vaccine Injury Act of 1986 (the Vaccine Act), which provides an administrative compensation system for individuals who have suffered vaccine-related injuries.[128] The Vaccine Act provides that, in order to be successful, a claimant must establish a *prima facie* causal relationship between a vaccination and the claimant's injury, and can do so in one of two alternative ways.[129] First, the claimant can trigger a statutorily prescribed presumption of causation by showing (1) that the claimant's type of injury is one of those listed on the "Vaccine Injury Table" (provided by the Vaccine Act) as being associated with the particular vaccine the claimant received (that is, it is a "table injury"); and (2) that the claimant experienced the first "symptom or manifestation" of the table injury within the "table time period" following the vaccination (that is, the time period specified in the Vaccine Injury Table).[130] Under the second, alternative method of proof, for "off-table injuries" the claimant must establish "causation in fact" between the vaccination and the injury.[131] This second alternative requires the claimant to establish three conjoined conditions: (i) that there is "a medical theory causally connecting the vaccination and the injury"; (ii) that there was "a logical sequence of cause and effect showing that the vaccination was the reason for the injury"; and (iii) that

128. Pub. L. No. 99-660, 100 Stat. 3743 (codified as amended at 42 U.S.C. §§ 300aa-1 to -34 (2000)).

129. *See, e.g.*, Althen v. Sec'y of Health & Human Servs., 418 F.3d 1274, 1278 (Fed. Cir. 2005); Whitecotton v. Sec'y of Health & Human Servs., 81 F.3d 1099, 1102 (Fed. Cir. 1996).

130. 42 U.S.C. §§ 300aa-11(c)(1)(C)(i), -13(a)(1)(A), -14 (2000); *Whitecotton*, 81 F.3d at 1102.

131. *Althen*, 418 F.3d at 1278.

there was "a proximate temporal relationship between vaccination and injury."[132] Under either method of proving causation, the government can defeat the claimant's prima facie case by proving that the injury was in fact caused by "factors unrelated" to the vaccine.[133] All of these issues are subject to proof by a preponderance of the evidence.[134] An implication tree for these alternative methods of proving causation is shown in Figure 6.

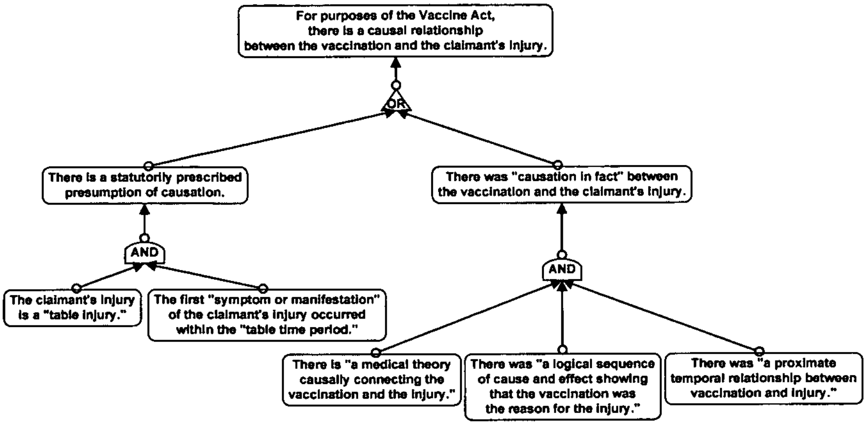

Figure 6. Partial Implication Tree for Proving Causation under the Vaccine Act

A case under the Vaccine Act, *Huber v. Secretary of the Department of Health and Human Services*,[135] illustrates the reasoning modeled by the statistical-syllogism plausibility schema. The case involved a claim that Garrett Huber's "condition of tuberous sclerosis was significantly aggravated by" a diphtheria-pertussis-tetanus (DPT) vaccination, a vaccine on the Vaccine Injury Table.[136] The special master found that Garrett was born on January 10, 1985, was vaccinated on May 3, 1985, became unusually fussy during the next two days, had a seizure on May 5 ("approximately 48 hours after the vaccination"), and had two more seizures, on May 9 and May 10.[137] A CAT scan performed after the seizures established that Garrett had tuberous sclerosis, "a congenital familial disease characterized pathologically by tumors on the surfaces of the lateral ventricles and sclerotic patches on the surface of the brain and marked clinically by progressive mental deterioration and epileptic convulsions."[138] The

132. *Id.*

133. 42 U.S.C. § 300aa-13(a)(1)(B); *Whitecotton*, 81 F.3d at 1102 (stating the defeating condition for table injuries); *Althen*, 418 F.3d at 1278 (stating the defeating condition for off-table injuries).

134. *See* 42 U.S.C. § 300aa-13(a)(1).

135. No. 89-72V, 1990 WL 293881 (Cl. Ct. Aug. 6, 1990), *remanded* 22 Ct. Cl. 255 (1991), *on remand* 1991 WL 62124 (Cl. Ct. Apr. 5, 1991).

136. *Huber*, 1990 WL 293881, at *1–*2; *Huber*, 22 Cl. Ct. at 256.

137. *Huber*, 1990 WL 293881, at *1.

138. *Id.* at *1, *3 n.2.

special master found this to be an "on table" case,[139] and in such cases a petitioner must show that he or she "suffered the first symptom or manifestation of the significant aggravation of a table injury within the table time period" following his or her vaccination.[140] The statute defines "significant aggravation" as "any change for the worse in a preexisting condition which results in markedly greater disability, pain, or illness accompanied by substantial deterioration of health."[141] On the evidence, the special master found that Garrett was eligible for compensation under the Vaccine Act and awarded compensation totaling $2,574,786, which covered special care and facilities for Garrett based on a life expectancy of 72.8 years.[142] The compensation award took into account that by age 5½, Garrett had seizures "several times a day," despite medication; was classified as "moderately mentally retarded"; was "essentially non-verbal"; and was "hyperactive with a short attention span, no safety awareness and inappropriate aggressive behavior, all of which require constant supervision."[143]

In a case alleging significant aggravation of tuberous sclerosis, the preexisting condition can be a relevant factor both to liability (whether the vaccine or the preexisting condition caused the seizures) and to the amount of damages (whether the vaccine or the preexisting condition would cause life-long harm, and the nature and extent of such harm). The expert testimony on these issues in Garrett Huber's case, as reported by the special master, can be organized in part using the statistical-syllogism schema. The applied schema is shown in Figure 7, using the following substitutions for Garrett's case: "the definite subject S" is Garrett Huber; "category A" is the category of people who have tuberous sclerosis and who develop seizures early in life; and "category B" is the category of people who have life-long serious mental disabilities.

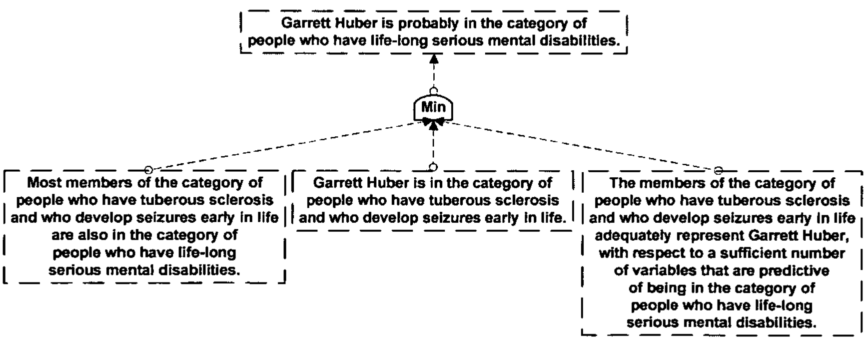

Figure 7. The Statistical-Syllogism Schema as Applied in the *Huber* Case

139. *Id.* at *2.

140. 42 U.S.C. § 300aa-11(c)(1)(C)(i) (2000); Whitecotton v. Sec'y of Health & Human Servs., 81 F.3d 1099, 1103 (Fed. Cir. 1996).

141. 42 U.S.C. § 300aa-33(4); *Whitecotton*, 81 F.3d at 1107; *Huber*, 1990 WL 293881, at *2.

142. *Huber*, 1990 WL 293881, at *2–*5; *Huber*, 22 Cl. Ct. at 256.

143. *Huber*, 1990 WL 293881, at *3.

The schema organizes the available relevant evidence under three conditions or premises. In the *Huber* case, the evidence in support of the second premise was the CAT-scan evidence that Garrett had tuberous sclerosis and the expert's testimony that "within 48 hours after the vaccination he [Garrett] developed seizures, [and] that the seizure heralded the beginning of a seizure pattern that later became characteristic of an underlying process called tuberous sclerosis."[144] Also clearly relevant was "the parents' testimony as to his [Garrett's] condition both before and after the shot, [and] medical records relating to those times."[145] The plausibility of Garrett's being a member of this reference class rests both on scientific tests and on the credibility of personal observations by both expert and lay witnesses.

The evidence for the first premise, the statistical generalization, was entirely medical. The expert testified that "most people that have tuberous sclerosis have normal intelligence and function normally," while "some may have a seizure disorder."[146] Of those who experience seizures, those "who have seizures that start late or after two years of age usually function with normal intelligence."[147] However, "[c]hildren whose seizures begin much earlier than that usually have decreasing intelligence and ability to master their surroundings."[148] The reference group for Garrett, therefore, was children who have tuberous sclerosis and who experience seizures before two years of age. The generalization about that reference group was that *most* have lifelong mental disabilities (such children "usually" have such disabilities).[149] Such a generalization is not about Garrett specifically, but asserts a proposition about most people in the reference category.

The third condition or premise requires a judgment about the representative adequacy of that reference group, with respect to classifying Garrett in category B. It requires the fact finder to consider all of the variables that are predictors for being in category B, consider the profile of values for Garrett's case on those factors, and determine whether the reference group is sufficiently like Garrett on enough of those variables.[150] For example, a reference group of people who have tuberous sclerosis, most of whom (according to the testimony) have normal intelligence and function normally, would not be representative of Garrett, because there is good evidence that having seizures and the timing of those

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144. *Id.*

145. *Id.* at *2.

146. *Id.*

147. *Id.*

148. *Id.*

149. *Id.* The expert also testified that "there is support for the idea that DPT is a frequent triggering mechanism which might provoke the first seizure in children with tuberous sclerosis," that "[w]here seizures are triggered at an early age as happened in this case then the outcome for mental development is going to be much worse than had seizures naturally occurred at a much later state in the child's development," and that "tuberous sclerosis, in the absence of the seizures, would not have been expected to adversely impact his mental development but in the presence of seizures is well known to adversely impact his mental development . . . ." *Id.* at *2–*3.

150. For a detailed discussion of this premise as applied to inferences about specific causation in torts cases, see Walker, *supra* note 64, at 439–48 (arguing that "[t]he appropriate reference group to use for a direct inference about a specific individual is a function of which additional characteristics of that individual are causally relevant to being in subgroup B").

seizures are also predictors of lifelong serious mental disabilities. Using any reference group that is not like Garrett on those two additional variables would not warrant drawing the direct inference. Likewise, if there are additional variables known to be predictors for lifelong serious mental disabilities, then the reference group used should also be sufficiently like Garrett on those variables.[151] As this example illustrates, using a plausibility schema to organize the evidence and the fact finder's evaluation of that evidence does not obviate the need for judgment, or turn difficult qualitative concepts (such as "adequately represent" and "sufficient number of variables") into precise quantitative concepts. The primary function of a plausibility schema is to make the logic behind the default reasoning more transparent by identifying the critical conditions under which the default inference becomes plausible. A plausibility schema incorporates those conditions that address enough of the principle sources of uncertainty in making the inference. Of course, it is also possible that, once those conditions are clearly stated, additional theories, concepts, and schemas can be developed that will help clarify our reasoning further.[152]

Finally, the evidence in the Garrett Huber case helps illustrate the logic of the MIN connective in the statistical-syllogism schema. The schema reflects the theory that the three stated conditions, if plausible, address enough of the uncertainty inherent in the inference, such that the resulting conclusion is reasonable as a presumptive inference, even if a defeasible one. The default conclusion supported by such a line of reasoning, however, is only as plausible as the least plausible of the three conditions. No reasonable person would base such an inference on statistics for reference groups of which Garrett is *not* a member (the second condition). Likewise, to the extent that the fact finder considers a reference group inadequately representative of Garrett, with respect to a sufficient number of predictive variables (the third condition), any inference based on that reference group should be similarly lacking in plausibility. In such a case, the mere fact that most people with tuberous sclerosis lead normal lives should not persuade that fact finder to put Garrett in the latter category. Finally, a fact finder might evaluate the second and third conditions as having high plausibility-values, with a great deal of information about Garrett on a number of predictive variables, but there may be insufficient data on people with the same risk profile as

151. It is also possible for a fact finder to conclude that so many predictor variables are *unknown* that the fact finder is unable to find any particular reference group to be adequately representative of a specific individual. *See, e.g.*, Walker, *supra* note 64, at 460–68 (describing the fact finder's reasoning in *XYZ v. Schering Health Care, Ltd.*, [2002] E.W.H.C. 1420 (Q.B.) and arguing that "[i]n a case such as *Schering Health Care*, where it is demonstrable that no available causal model even approaches the completeness needed to explain or predict individual cases, assigning *any* probability of *specific* causation on the basis of such evidence cannot be epistemically warranted").

152. For example, for extended discussion of the principle sources of uncertainty underlying statistical generalizations such as those in the first premise of the statistical-syllogism schema, as applied to inferences about specific causation in torts cases, see Walker, *supra* note 64, at 389–437 (elaborating the logic behind the concepts of measurement uncertainty, sampling uncertainty, modeling uncertainty, and causal uncertainty) and *supra* notes 66, 112–119.

Garrett.[153] For example, Garrett might possess a genetic marker, have a family history, or have suffered an injury *in utero* that is causally linked to developing serious mental disabilities, but there may be no scientific studies with sufficient data about Garrett's *combination* of risk factors. The fact finder might then assign a low plausibility-value to the proposition that *most* people in that reference group have *any* predictable prognosis: we may not be able to generalize plausibly about such a group of people. Thus, any conclusion about Garrett would have a correspondingly low plausibility-value, with any positive finding of fact being unwarranted.[154] The statistical-syllogism schema formalizes the above reasoning by setting the plausibility-value of the conclusion equal to the lowest plausibility-value within the set of three conditions. To the extent that the conclusion is based on this line of reasoning, it can be no more plausible than the least plausible premise.

This discussion of the statistical-syllogism schema illustrates a number of logical features of plausibility schemas. First, the appropriate schema to use in evaluating the plausibility of evidence depends upon the logical nature of the conclusion being drawn and upon the type of evidence offered to warrant that conclusion. The logical nature of the conclusion is determined by the terminal proposition to which the evidence is linked. The evidence, however, might be eyewitness testimony, or a direct inference based on a scientific generalization, or some other type of plausible reasoning. This means that, although the range of appropriate schemas is narrowed by the content of the terminal proposition, plausibility schemas can seldom be "hard wired" onto implication trees.[155]

Second, the branches within a plausibility schema can themselves generate a chain of plausibility schemas, with lower schemas providing the plausibility-values for evidentiary assertions higher in the branch. This process generates lower branches of the complete inference tree in a particular case, which has a three-valued implication tree for the top levels and plausibility schemas of evidence for the lower levels.

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153. For example, an adequately representative reference group may have so few subjects within existing scientific studies that the "statistical power" is lacking to draw any generalizations about that reference group. *See supra* note 119; Walker, *supra* note 64, at 396–405 (discussing sampling uncertainty).

154. This does not mean that all plaintiffs should lose their lawsuits in the presence of such uncertainty, simply that the logic of fact-finding cannot warrant the outcome. *See* Walker, *supra* note 64, at 467 (concluding that in tort cases "where it is demonstrable that no available causal model even approaches the completeness needed to explain or predict individual cases," "specific causation cannot be a factual or scientific issue" and "whether any particular plaintiff ever prevails must be a matter of common sense, fairness, and policy").

155. There are instances, however, when legal authorities might seem to attach plausibility schemas to terminal propositions as a matter of legal rule, as when a statute or regulation creates a substantive legal presumption. *See, e.g.*, Dir., Office of Workers' Comp. Programs v. Greenwich Collieries, 512 U.S. 267, 280–81 (1994) (discussing both statutory and administrative presumptions applicable in adjudications under the Black Lung Benefits Act and the Longshore and Harbor Workers' Compensation Act). Such substantive rules are probably better modeled, however, as defeaters incorporated within the implication tree.

Third, the goal of developing an adequate default logic for legal fact-finding (and eventually for policy balancing[156]) requires research into the variety of plausibility schemas that are acceptable. Such research is partly empirical (to identify how legal fact finders actually reason) and partly logical (to critique actual reasoning from the epistemic perspective). Such research is particularly needed about schemas that combine quantitative and qualitative scales of plausibility, and expert evidence with nonexpert evidence. Moreover, as the conclusion of this article will suggest, research is needed into the dynamic between the rule-based reasoning in the top portion of an inference tree and the generalization-based plausible reasoning in the bottom portion of an inference tree. It is a hallmark of a true paradigm, however, that it creates promising research programs by structuring the logic of the inquiry and providing criteria for success.

III. LEGAL PROCESS RULES AND SUBSIDIARY INFERENCE TREES

Parts I and II above discuss the default-logic paradigm for analyzing substantive legal rules and evaluating the evidence that applies those substantive rules to particular cases. Many of the decisions in legal fact-finding, however, are not about applying the substantive rules of law to the evidence, but about complying with the rules governing the process of fact-finding. Legal process rules govern the dynamics of default reasoning in a legal fact-finding process.[157] This part of the article discusses how the default-logic paradigm represents the reasoning that warrants such process decisions, and how the paradigm incorporates that reasoning into the broader model of legal fact-finding.

The fundamental notion is that, because decisions about legal process are *rule-based* and *evidence-based*, implication and inference trees can model the reasoning using the same logical elements used to model reasoning based on substantive legal rules. A balance of legal policies can justify adopting legal process rules, just as they can justify adopting substantive rules. The decision maker links relevant evidence to the terminal propositions of the process implication tree, structures and evaluates that evidence with plausibility schemas, and uses the plausibility-values of evidentiary assertions to determine the truth-values of those terminal propositions. Therefore, in order to model the default reasoning that warrants a finding about the legal process, no new logical structures are needed—only new content for the structures developed in Parts I and II of this article.

In many legal contexts, fact-finding is legitimate only if both substantive and process rules are satisfied. For example, the court or agency must afford due notice of the proceedings, the judge must decide all issues raised about the

156. *See supra* Part I.B.

157. *Cf.* Walker, *supra* note 12, at 135 (concluding that "[t]he strategy behind factfinding in law is . . . to maintain a dynamic process of rule-governed decision-making, through which (it is hoped) reasonable decision makers will come close enough to achieving the epistemic objective over time").

admissibility of evidence, and the jury must be correctly instructed. Inference trees can model the legal rules and evidentiary reasoning that warrant decisions about such issues. And because process determinations and substantive findings have similar warranting structures, the default-logic paradigm can sometimes integrate substantive and process reasoning by treating the process conditions as though they were conjunctive branches of the substantive inference model. Sometimes such a process tree connects to the substantive tree at a very high level and states process requirements for the decision as a whole. An example of such a high-level process condition is whether a court or administrative agency has jurisdiction to conduct the fact-finding at all. Section III.A below will discuss this example. At other times, a process implication tree connects to the substantive implication tree at a very low level and prescribes conditions for only the low-level decision involved. Examples of such low-level process conditions are rules about the admissibility of evidence or a rule that certain types of evidence are relevant or irrelevant to a particular terminal proposition in the substantive implication tree. Such rules govern decisions about admitting evidence at all or linking admitted evidence to terminal propositions of a substantive implication tree. Section III.B will discuss these examples and provide an extended illustration. The complete inference tree for warranting a governmental finding, therefore, often consists of primary substantive branches to which process branches attach at various levels using three-valued logical connectives.[158]

There are various perspectives from which to understand the relationship between process reasoning and substantive reasoning. It is an advantage of the default-logic paradigm that its representation of reasoning about process decisions accommodates all of these perspectives. First, from the perspective of inference trees, the inference trees that model the reasoning of process decisions can be viewed as subsidiary to the primary substantive tree. Constitutions, statutes, regulations, and judicial decisions provide the informational content of the ultimate conclusion or finding, in the form of the ultimate substantive issue to be decided. They may also provide additional substantive rules that branch down to the relevant issues of fact. But they also provide rules to govern the process of making those particular findings. The substantive rules provide the primary findings to be made, while the process rules add conditions for drawing those conclusions lawfully.

158. This notion of conjoining substantive and process trees with a logical connective is not always the appropriate model. For example, a motion arguing that a court should overrule a precedent and thereby rescind an existing common-law rule is an argument that certain propositions should be removed from the substantive implication tree. It is not an argument that is simply conjoined to some portion of the existing tree. Similarly, a motion arguing that a proffered evidentiary assertion should be excluded from the case as inadmissible is not an argument that is simply conjoined by a logical connective to the evidentiary assertion or other proposition in the substantive inference tree. Such motions have propositional elements of inference trees as their logical subjects, and they require decisions about what to do with such propositional elements, but the reasoning supporting those decisions is not simply conjoined to the inference tree that models the substantive reasoning in the case. They are arguments about what propositions should *not* be included in the reasoning behind the ultimate finding of fact.

Second, from a practical standpoint, it makes sense to model process rules separately from substantive rules because the same process implication tree can be applicable to many substantive trees (for example, a process tree for deciding jurisdiction) or can connect to many branches in the same implication tree (for example, a process tree for deciding the admissibility of evidence). Moreover, process rules may be evaluated using a distinct set of policies that are common to process rules (for example, policies about adequate notice).

Third, from a logical perspective, process rules often have as their logical subject a rule or proposition in the primary inference tree. For example, a motion to dismiss for failure to state a claim or cause of action questions the plaintiff's understanding of the applicable substantive rules, and requires a judicial decision about the existence or structure of the substantive implication tree upon which the plaintiff wishes to rely.[159] A motion to exclude expert witness testimony questions the admissibility of a proffered evidentiary assertion.[160] The ultimate conclusion of an implication tree for a process rule often has as its logical subject a proposition or evidentiary assertion of the primary, substantive inference tree. The variables within the process rules can take as values the propositions and assertions of the substantive reasoning.

Fourth, from the standpoint of automating legal fact-finding, separate knowledge models can be developed for process rules, which can operate independently of any particular substantive tree. For example, researchers can develop a knowledge model for the admissibility of expert opinions under the Federal Rules of Evidence, and such knowledge models can be constructed in a modular fashion.[161]

This part of the article discusses and illustrates several major types of process rules. The traditional distinction between rules of procedure and rules of evidence also forms a useful subdivision for process rules. The default-logic structure is the same, however, for procedural and evidentiary decisions, so classifying any particular rule correctly is of little importance from the standpoint of the model. This part of the article, however, uses familiar examples from both the law of civil procedure and the law of evidence to illustrate this application of the default-logic paradigm. In addition, Section III.B provides an extensive illustration of how complex process reasoning can be modeled within the default-logic paradigm.

A. Procedural Process Rules

The jurisdiction of a federal court illustrates a procedural condition branching at a high level from the implication tree for any federal court judgment. The principal general bases for federal district court jurisdiction include diversity

159. *E.g.*, FED. R. CIV. P. 12(b)(6); JAMES ET AL., *supra* note 42, § 4.2, at 192.

160. *E.g.*, FED. R. EVID. 103; JAMES ET AL., *supra* note 42, § 7.20, at 365–69.

161. For other examples of such modularity in research for AI and law, see, for example, Prakken & Sartor, *supra* note 6, at 126–31 (discussing "process-based defeasibility," including decisions about admissibility and legal sufficiency of evidence).

jurisdiction,[162] general federal question jurisdiction,[163] admiralty jurisdiction,[164] and actions in which the United States is a party.[165] Such provisions, as well as numerous statutes dealing with specific types of jurisdiction,[166] provide the legal process rules governing decisions about jurisdiction. For example, under federal diversity jurisdiction, the rule of "complete diversity" is that "all plaintiffs properly joined must have state citizenship different from that of all the defendants."[167] Another rule is that, for purposes of diversity jurisdiction, a corporation is considered a citizen of the state of its incorporation and of the state in which it has its principal place of business.[168] Implication trees can model these rules and elaborate the conditions that must be satisfied in any case brought in federal district court under diversity jurisdiction.

As with any implication tree, findings on the issues stated in the terminal propositions should rest upon an adequate evaluation of the available, relevant evidence. Some issues, such as the state of incorporation of a corporate party, might be decided by stipulation of the parties or by judicial notice.[169] Other issues might be contested and raise triable issues of fact. For example, under Article III of the United States Constitution, as interpreted by case law, a plaintiff must have standing to bring the lawsuit for the court to have jurisdiction.[170] While a particular plaintiff's standing might be decidable on summary judgment, it is also possible that in an appropriate case a trial is needed to decide the issue of standing.[171] As with any issue stated in a terminal proposition of an implication tree, in a particular case the nature of the evidence might require the fact finder to

162. 28 U.S.C. § 1332 (2000). On jurisdiction generally, see JAMES ET AL., *supra* note 42, §§ 2.24–2.31.

163. 28 U.S.C. § 1331 (authorizing actions "arising under the Constitution, laws, or treaties of the United States").

164. *Id.* § 1333.

165. *E.g.*, *id.* § 1345 (authorizing the United States to bring civil actions in federal courts).

166. *E.g.*, 21 U.S.C. § 371(f) (2000) (conferring jurisdiction on the United States courts of appeals to review and affirm or set aside certain orders of the Secretary of Health and Human Services entered under the Federal Food, Drug, and Cosmetic Act).

167. JAMES ET AL., *supra* note 42, § 2.24, at 98.

168. 28 U.S.C. § 1332(c).

169. *See, e.g.*, FED. R. EVID. 201 (providing that "[a] court shall take judicial notice if requested by a party and supplied with the necessary information," and that "[a] judicially noticed fact must be one not subject to reasonable dispute in that it is . . . capable of accurate and ready determination by resort to sources whose accuracy cannot reasonably be questioned").

170. *E.g.*, Vt. Agency of Natural Res. v. United States *ex rel.* Stevens, 529 U.S. 765, 771 (2000) (addressing "the jurisdictional question whether respondent Stevens has standing under Article III of the Constitution to maintain this suit"); Lujan v. Defenders of Wildlife, 504 U.S. 555, 559–66 (1992) (setting out the three issues constituting "the irreducible constitutional minimum of standing": a concrete and particularized "injury in fact" to a legally-protected interest, a "causal connection between the injury and the conduct complained of," and a likelihood that the injury will be "redressed by a favorable decision").

171. *Lujan*, 504 U.S. at 561–62 (stating that each factual element "must be supported in the same way as any other matter on which the plaintiff bears the burden of proof, i.e., with the manner and degree of evidence required at the successive stages of the litigation"—namely, at the pleading stage, in response to a summary judgment motion, and at trial).

decide the issue, or it might allow the court to decide the issue as a matter of law.[172]

Procedural rules are able to govern the dynamics and timing of default reasoning by authorizing or requiring decisions that are warranted only at specified periods of time.[173] In a civil proceeding in federal court, for example, a defendant is able to move successfully to dismiss for lack of jurisdiction on the basis of the pleadings,[174] whereas a party successfully seeking summary judgment often relies on depositions and other products of discovery obtained before trial,[175] and motions for directed verdict or for judgment as a matter of law are decided after evidence has been produced at trial.[176] Types of motion vary by the nature of the issue raised by the motion and by the nature of the evidence needed to decide that issue.[177] From a logical perspective, the timing aspect of a procedural motion originates from the content of the rule governing the motion, which is modeled by an implication tree containing terminal propositions that can be true only at certain times or stages of the proceeding. The dynamics and timing of the process of fact-finding, therefore, are controlled by the content of the applicable process rules, not by new types of logical elements or structures.

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172. For the rule when the fact finder is a jury, see FED. R. CIV. P. 50(a)(1) (providing that "[i]f during a trial by jury a party has been fully heard on an issue and there is no legally sufficient evidentiary basis for a reasonable jury to find for that party on that issue, the court may determine the issue against that party and may grant a motion for judgment as a matter of law against that party with respect to a claim or defense that cannot under the controlling law be maintained or defeated without a favorable finding on that issue").

173. Certain conditions of a rule governing the decision on a motion must be true before the motion is properly *made* (for example, the condition for a motion for summary judgment that it can be made "at any time after the expiration of 20 days from the commencement of the action," FED. R. CIV. P. 56(a)), while other conditions must be true before the motion is properly *granted* (for example, for summary judgment, that "there is no genuine issue as to any material fact and . . . the moving party is entitled to a judgment as a matter of law," FED. R. CIV. P. 56(c)).

174. FED. R. CIV. P. 12(b).

175. *See* FED. R. CIV. P. 56(c) (providing that summary judgment shall be rendered "if the pleadings, depositions, answers to interrogatories, and admissions on file, together with the affidavits, if any, show that there is no genuine issue as to any material fact and that the moving party is entitled to a judgment as a matter of law").

176. *See* FED. R. CIV. P. 50(a); JAMES ET AL., *supra* note 42, §§ 7.19, 7.21.

177. Although administrative efficiency is a major policy objective for process rules, and applying those rules often results in greater efficiency, there is no guarantee that process rules will make legal proceedings more efficient. It is not always possible to decide even a high-level process rule early in the case. For example, fact-finding might be needed to decide whether the statute of limitations has been satisfied. *E.g.*, Cipollone v. Liggett Group, Inc., 893 F.2d 541, 579 (3d Cir. 1990), *aff'd in part and rev'd in part on other grounds*, 505 U.S. 504 (1992) (holding that, in litigation that had begun in 1983, the district court's grant of summary judgment against the defendants on their statute of limitations defense was inappropriate and that the issue would need to be tried). The creation of any process rule usually means the addition of new branches to implication trees, and the elaboration of new rules under those additional branches ensures an inexorable growth in complexity. A good example is the increase in complexity due to Federal Rule of Evidence 702 and the Supreme Court's trilogy elaborating rules under that rule of evidence. *See infra* Section III.B.

B. Evidentiary Process Rules

Within the default-logic paradigm, evidentiary process rules cover much more than the traditional law of evidence. Evidentiary process rules are those rules that structure the evaluation of evidence and the process of making findings on terminal propositions. Examples are rules about relevancy (linking evidentiary assertions to terminal propositions); rules about admissibility (either excluding some proffered evidence from the case altogether, or admitting particular items of evidence provided they are linked to certain terminal propositions);[178] rules about sufficiency of evidence (deciding whether the totality of evidence linked to a terminal proposition can reasonably warrant a finding that the proposition is true);[179] rules about standards of proof (establishing the probative value of evidence required to assign a truth-value to a terminal proposition);[180] and rules allocating the burden of persuasion (determining what finding to make when the totality of linked evidence evaluates precisely on the threshold degree of plausibility established by the standard of proof).[181] All of these rules constrain the fact finder's discretion in evaluating the evidence and making findings, by allowing the presiding legal authority to oversee the fact-finding process. From a logical perspective, evidentiary process rules supply implication trees for deciding certain issues of law involved in the evaluation of evidence.

As with any implication tree, the appropriate findings to be made on the terminal propositions of an evidentiary implication tree depend on evaluating the available evidence that is relevant. An illustration is decision making in federal court about the admissibility of expert opinion testimony. In order to admit an expert opinion under Federal Rule of Evidence 702, federal district courts must find that the opinion represents "scientific, technical, or other specialized knowledge" and that it "will assist the trier of fact."[182] The opinion may be admitted only "if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case."[183] Evidence relevant to deciding these issues is produced pursuant to Federal Rule

178. *E.g.*, FED. R. EVID. 407 (excluding evidence of "subsequent remedial measures" to prove negligence or a defect in a product, but not requiring exclusion of such evidence "when offered for another purpose, such as proving . . . feasibility of precautionary measures, if controverted").

179. *See* JAMES ET AL., *supra* note 42, § 7.19.

180. *See* JAMES ET AL., *supra* note 42, §§ 7.5, 7.14 (discussing the "three generally recognized standards of proof. . . : preponderance, clear and convincing, and beyond a reasonable doubt"); 2 MCCORMICK ON EVIDENCE § 339, *supra* note 98, at 438; Walker, *supra* note 58, at 1075–78, 1097–1120 (discussing possible interpretations of the preponderance standard of proof, in light of the policies behind the rule).

181. *See* JAMES ET AL., *supra* note 42, § 7.13, at 338 (discussing the "risk of nonpersuasion" as a "default rule" and as a concept "inseparable from any system in which issues of fact are to be decided through rational deliberation on the basis of incomplete knowledge").

182. Another conjoined condition is that the witness must be "qualified as an expert by knowledge, skill, experience, training, or education." FED. R. EVID. 702.

183. *Id.*

of Evidence 104(a), either in written form or at an evidentiary hearing.[184] The trial court evaluates the relevant evidence and determines by a preponderance of the evidence whether these conditions are satisfied.[185] On appellate review, the standard of review for the district court's evidentiary rulings is the deferential "abuse-of-discretion" standard.[186] A motion to exclude proffered expert testimony therefore triggers a decision-making process governed by procedural and evidentiary process rules.[187]

The default-logic paradigm would use implication trees and plausibility schemas to model a district court's reasoning about the admissibility of an expert opinion under Federal Rule of Evidence 702.[188] The ultimate issue to be decided (the top node of the implication tree) would be "the expert's opinion is admissible," where the definite-subject variable "the expert's opinion" takes as its value a specific proffered opinion (proffered evidentiary assertion) in a specific case. For example, in the case decided by the Supreme Court under the name *General Electric Company v. Joiner*,[189] one contested opinion was Dr. Arnold Schechter's assertion that "more likely than not . . . Mr. Joiner's lung cancer was causally linked to cigarette smoking and PCB exposure."[190] The question before the

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184. *See also* Kumho Tire Co. v. Carmichael, 526 U.S. 137, 152 (1999) (stating that "[t]he trial court must have the same kind of latitude in deciding *how* to test an expert's reliability, and to decide whether or when special briefing or other proceedings are needed to investigate reliability, as it enjoys when it decides *whether or not* that expert's relevant testimony is reliable"); William W. Schwarzer & Joe S. Cecil, *Management of Expert Evidence*, *in* REFERENCE MANUAL ON SCIENTIFIC EVIDENCE 39, 53–54 (Federal Judicial Center, 2d ed. 2000) (stating that the trial court "has broad discretion to determine what briefing and evidentiary proceedings are needed for it to rule on admissibility of expert evidence").

185. *See* Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 593 n.10 (1993); *Kumho Tire Co.*, 526 U.S. at 152.

186. Gen. Elec. Co. v. Joiner, 522 U.S. 136, 141–43 (1997).

187. The trial court has considerable flexibility in tailoring the "reliability" proceedings to the opinion and evidence proffered, so that it can balance both epistemic and nonepistemic policy objectives. *See Kumho Tire Co.*, 526 U.S. at 152–53 (stating that the Federal Rules of Evidence "seek to avoid 'unjustifiable expense and delay' as part of their search for 'truth' and the 'jus[t] determin[ation]' of proceedings" (alteration in original)).

188. The reported cases that involve admissibility determinations for expert testimony provide extensive data for an empirical study of plausibility schemas. Because the trial court rulings on the terminal propositions of Federal Rule of Evidence 702 are mandated and subject to appellate review, lower court opinions contain voluminous examples of careful reasoning about the plausibility of inferences based on complex scientific evidence. Indeed, each case "in the Supreme Court's trilogy involved the proof of causation in either a toxic tort or product liability case." Margaret A. Berger, *The Supreme Court's Trilogy on the Admissibility of Expert Testimony*, in REFERENCE MANUAL ON SCIENTIFIC EVIDENCE 9, 32 (Federal Judicial Center, 2d ed., 2000). For the complex reasoning discussed in the three cases, see *Kumho Tire Co.*, 526 U.S. at 137 (involving the evaluation of physical evidence allegedly relevant to proving causation of a tire blow-out); *Gen. Elec. Co.*, 522 U.S. at 136 (involving the evaluation of epidemiologic and animal-study evidence allegedly relevant to proving causation of small cell lung cancer); Daubert v. Merrell Dow Pharms., Inc., 43 F.3d 1311 (1995) (judgment after remand from the Supreme Court) (involving the evaluation of epidemiologic, statistical, and other types of evidence allegedly relevant to proving causation of limb reduction birth defects).

189. 522 U.S. 136 (1997).

190. *Gen. Elec. Co.*, 522 U.S. at 143; *see also* Joiner v. Gen. Elec. Co., 864 F. Supp. 1310, 1320–21 (N.D. Ga. 1994).

district court was whether that specific opinion by Dr. Schechter was admissible in Joiner's tort suit.

At the time the district court decided that issue, Federal Rule of Evidence 702 required that Dr. Schechter be qualified, that he testify regarding "scientific knowledge," and that his opinion "assist the trier of fact."[191] With regard to the second condition, "scientific knowledge," and specific causation, the district court found that "[p]laintiffs' experts erred in relying on the mice studies to opine that PCBs caused Joiner's lung cancer."[192] In reviewing the district court's finding under the "abuse of discretion" standard, the Supreme Court upheld the district court's reasoning, citing the following factors as making that reasoning acceptable:

- "The studies involved infant mice," whereas "Joiner was an adult human being."
- "The infant mice in the studies had massive doses of PCBs injected directly into their peritoneums or stomachs," whereas Joiner's "alleged exposure to PCBs was far less."
- The mice were injected with PCBs "in a highly concentrated form," whereas "[t]he fluid with which Joiner had come into contact generally had a much smaller PCB concentration."
- "The cancer that these mice developed was alveologenic adenomas; Joiner had developed small-cell carcinomas."
- "No study demonstrated that adult mice developed cancer after being exposed to PCBs."
- "No study had demonstrated that PCBs lead to cancer in any other species."[193]

By holding that the district court had not abused its discretion, the Supreme Court officially approved a pattern of reasoning that is acceptable as a matter of law under Federal Rule of Evidence 702.[194] By creating an officially sanctioned safe haven for district court reasoning about the "scientific" use of animal studies, the Supreme Court created what could be called a "soft rule." A "soft rule" is a pattern of reasoning, which can be generalized to other cases, that has some persuasive authority—either because it has been affirmed as reasonable (not an "abuse of discretion" or "clearly erroneous") or because it was not appealed. Such

191. *See supra* text accompanying notes 182 and 183. The three conditions enumerated in the text at note 183 were added by the 2000 Amendments in response to the Supreme Court's trilogy of cases cited in *supra* note 185 and 188. FED. R. EVID. 702 advisory committee's note.

192. *Joiner*, 864 F. Supp. at 1324.

193. *Gen. Elec. Co.*, 522 U.S. at 144.

194. In addition, the Supreme Court in effect recognized a list of relevant factors for evaluating animal studies under the "scientific evidence" condition of Federal Rule of Evidence 702. In *Daubert v. Merrell Dow Pharmaceuticals*, the Supreme Court enumerated a more general list of factors relevant to concluding that an opinion represents "scientific knowledge": that the opinion "can be (and has been) tested"; that "the theory or technique has been subjected to peer review and publication"; that "the known or potential error rate" is acceptable; that "standards controlling the technique's operation" exist and are maintained; and that there is "general acceptance" of the technique within the "relevant scientific community." 509 U.S. 579, 593–94 (1993).

soft rules provide an incentive for more courts to adopt the same pattern of reasoning, and they can develop over time into normal rules of law.

One hypothesis about the pattern of reasoning found acceptable in *Joiner* is shown in the abbreviated diagram in Figure 8. The proposition at the top is the terminal proposition of one branch of the legal rules of admissibility under Federal Rule of Evidence 702, as interpreted in the *Daubert* case.

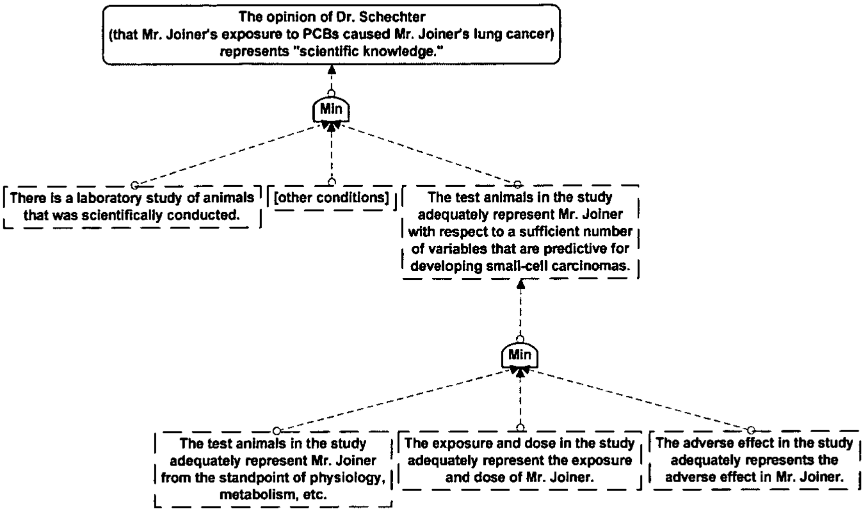

Figure 8. Partial Inference Tree for Reasoning in the *Joiner* Case

The evidentiary assertions shown with dashed outlines model the conditions for applying the *particular* animal study involved in the case to the plaintiff Joiner. Under this reasoning, the animal study would be a scientific basis for an expert opinion about toxic effects in Joiner if the study was scientifically conducted and "the test animals in the study adequately represent Joiner, with respect to a sufficient number of variables that are predictive for developing small-cell carcinomas." This condition is very similar to the third condition in the statistical-syllogism plausibility schema, shown in Figure 5, because the reasoning is similar—the question is whether the test animals of the study are adequately representative of Joiner with respect to developing Joiner's type of cancer. The reasoning in *Joiner* was that the latter assertion is plausible if three other conditions are plausible: (1) the young mice in the study adequately represent Joiner from the standpoint of physiology, metabolism, and so forth; (2) the exposure and dose used in the study adequately represent the exposure and dose of Joiner; and (3) alveologenic adenomas (the adverse effect in the study) adequately represent small-cell carcinomas (the adverse effect in Joiner). Arguably, this might provide sufficient warrant for a presumptive inference, even if no other study demonstrated the same adverse effect in other species. The MIN connecting these three conditions to their conclusion indicates that the plausibility of the default inference can be no greater than that of the least plausible condition.

It is easy to see how courts might generalize this pattern of reasoning to other cases and to understand why other district courts would avail themselves of this pattern of reasoning when facing similar cases. Appellate courts might eventually adopt a rule stating that such reasoning is a sufficient basis for finding that a particular use of an animal study is scientific. These are, of course, empirical questions, but the default-logic paradigm provides the logical tools for empirically investigating the reasoning in other cases.

The inference trees of the default-logic paradigm are designed to model the reasoning that warrants the findings of fact of any governmental institution.[195] The upper portion of any inference tree consists of an implication tree that models all of the legal rules that could apply in reaching an ultimate finding of fact. When those rules are applied in a particular context or case, the logical subjects of those rules denote the particular objects, situations, or events involved in the case. Policy-based reasoning aims at justifying the legal rules (that is, the form of the implication trees) by using principles, goals, and objectives that are outside the trees themselves. Although the legal rules modeled by implication trees should be the same for all cases in the jurisdiction at any point in time, those rules and trees can also change over time.

When an implication tree is applied to a particular case, the lower portion of the inference tree consists of evidentiary assertions that are linked to the terminal propositions of the implication tree. Plausibility schemas organize those evidentiary assertions and extend the inference tree downward. Such schemas formalize theories of uncertainty about the potential for error in default reasoning and therefore make the evidentiary warrant for default reasoning more transparent. Plausibility schemas can also integrate into single patterns of reasoning both expert and nonexpert evidence. As the fact finder evaluates the plausibility of individual evidentiary assertions, the plausibility schemas warrant assigning plausibility-values to higher-level evidentiary conclusions, which in turn warrant truth-values for the terminal propositions of the implication tree, which in turn determine the truth-values of propositions further up the implication tree.

The overall structure of an inference tree shows the continuity and parallelism between rule adoption and evidence organizing, between policy balancing and evidence evaluation, and between making legal rulings and finding facts. Inference trees can also model the application of legal process rules to particular cases. Procedural and evidentiary rules control the dynamics of fact-finding in a principled way and balance the epistemic objective with such nonepistemic

195. Because the paradigm is based on logic, and not on any particular set of rules or legal system, the models can capture the reasoning of any type of governmental institution for any type of action, including court judgments and orders, administrative adjudications and rulemakings, and legislative and executive determinations. They can capture the reasoning of state and federal institutions in the United States, of national and European Community institutions in Europe, and of international institutions such as the World Trade Organization. The use of a single paradigm for analysis therefore creates the possibility of extensive comparative research.

objectives as fairness and administrative efficiency. The default-logic paradigm shows how substantive and process reasoning are similar and together structure the fact-finding in any particular legal case.

The value of any paradigm lies in its ability not only to model and explain its subject matter, but also to guide productive research into that subject matter. The default-logic paradigm provides a universally applicable model for mapping fact-finding.[196] Implication trees for legal rules and plausibility schemas for fact-finding patterns allow researchers to model legal cases and legal areas incrementally, while adding automatically to a cumulative logic model of legal knowledge. The single framework for modeling legal rules allows comparative analyses of different sets of rules—whether the comparison is between different sets of rules in the same jurisdiction at a given time, between stages in the development of the same set of rules over time, or between different sets of rules in different legal jurisdictions. A single framework for modeling fact-finding also allows comparative analyses of different fact-finding institutions, as well as comparative research into the effectiveness and efficiency of those institutions. Finally, the paradigm allows all of this research to be based empirically on actual rule systems and actual cases, not merely on abstract concepts and accounts of the law. Such empirical research should also lead to testable theories about patterns of legal fact-finding.[197]

The default-logic paradigm also makes the results of such research more amenable to automation. This article has suggested the many points of congruence between the default-logic paradigm and ongoing research in artificial intelligence and law.[198] Artificial intelligence software can incorporate the inference trees of particular cases into a coordinated system of "smart" legal "objects."[199] Such software should allow searches not merely for legal documents that contain specified words, but also for legal decisions that contain specified reasoning patterns. Such "smart searches" could make more efficient use of the vast legal databases that are now available. Intelligent software would also allow

196. The mapping metaphor is particularly apt in this context. Like the system of latitude and longitude, which allowed explorers to map local coastlines in a way that automatically added the local map to the evolving map of the globe, the default-logic paradigm allows legal researchers to map the reasoning and fact-finding found in any particular case in a way that automatically adds that reasoning to the evolving model of legal rules or to the growing set of plausibility schemas.

197. For example, legal researchers can test hypotheses about how new legal rules evolve out of established fact-finding patterns or about how new plausibility schemas evolve within institutions that conduct reasoned and transparent fact-finding. Some areas of law are especially suited to such empirical research, such as the evolution of legal rules and plausibility schemas under the Supreme Court's trilogy of cases interpreting Federal Rule of Evidence 702 (*see supra* text accompanying notes 182–94).

198. For the principle notes discussing these points of congruence, see *supra* notes 15–20, 30, 35, 39, 46, 61, 72, 76, 88, 92, 108, 161.

199. In the field of artificial intelligence and object-based programming, an "object" is a self-contained programming structure that can act as a unit within its environment. *See, e.g.*, RUSSELL & NORVIG, *supra* note 6, at 322–28 (discussing categories and objects within computing environments); Michael Wooldridge, *Intelligent Agents*, in MULTIAGENT SYSTEMS, *supra* note 6, at 28–36 (comparing computing objects and agents). Implication trees, plausibility schemas, and inference trees are themselves suitable for programming as objects.

more efficient management of the law and the evidence within single complex cases, or among a large number of similar cases. It could help provide high-quality legal services to more people at a lower cost, thus helping to achieve the rule of law in society. Finally, these same attributes of transparency and usefulness could transform the teaching of legal knowledge and skills, both during law school and after. The default-logic paradigm, especially when incorporated into intelligent software, is above all a framework to help legal systems improve the reasoning and fact-finding in the next legal case.