A DEFAULT-LOGIC PARADIGM
FOR LEGAL REASONING AND FACTFINDING

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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 reasoning and factfinding, in developing effective methods of searching legal information, and in automating legal reasoning through artificial intelligence. Although legal theorists have generally acknowledged the role of traditional 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

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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).

[2] For example, legal theorists have occasionally recognized the benefits of logical analysis in law. *See, e.g.*, 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"); 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").

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

[4] *E.g.*, GERHARD BREWKA, JÜRGEN DIX, & KURT KONOLIGE, NONMONOTONIC REASONING: AN OVERVIEW (1997); HENRY E. KYBURG, JR. & CHOH MAN TENG, UNCERTAIN INFERENCE 117-51 (2001); ISAAC LEVI, FOR THE SAKE OF ARGUMENT 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.

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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 all aspects of legal reasoning, including legal factfinding.[7] Default 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

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[5] For applications of logical analysis to semantic theories about the meaning of ordinary language, see, e.g., 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, e.g., 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, Anand S. Rao, & Michael P. Georgeff, *Formal Methods in DAI: Logic-Based Representation and Reasoning*, in MULTIAGENT SYSTEMS: A MODERN APPROACH TO DISTRIBUTED ARTIFICIAL INTELLIGENCE 331-76 (Gerhard Weiss ed., 1999) (discussing logic-based methods for describing and reasoning about artificial agents).

[7] For discussions of the logic of default reasoning, see, e.g., PHILIPPE BESNARD, AN INTRODUCTION TO DEFAULT LOGIC (1989); 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; JOHN L. POLLOCK, NOMIC PROBABILITY AND THE FOUNDATIONS OF INDUCTION (1990); PRAKKEN, *supra* note 4; STEPHEN TOULMIN, RICHARD RIEKE, & ALLAN JANIK, AN INTRODUCTION TO REASONING (2d ed. 1984); DOUGLAS N. WALTON, ARGUMENT SCHEMES FOR PRESUMPTIVE REASONING (1996); WALTON, *supra* note 1.

[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, 56 (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"). In order 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.

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can participate in the reasoning process. Third, default reasoning is *defeasible*, meaning that new evidence or a re-analysis 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 reasoning.

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 caselaw with factfinding, and makes factfinding more efficient. Part II introduces "plausibility schemas," many-valued logic, and theories of uncertainty, together with other logical concepts needed to evaluate evidence. Rational factfinding 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), can suggest how such reasoning could be improved, and can provide the structure needed to automate important segments of that reasoning. The article therefore provides a paradigm for modeling any instance of legal reasoning and factfinding.

I.   LEGAL RULES AND IMPLICATION TREES

An essential characteristic of legal reasoning is its rule-based nature.[12] Rules of law identify the conditions under which governmental action is legitimate. Governmental institutions adopt legal rules in a variety of ways (e.g., by means of statutes, regulations, executive orders, and judicial

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[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] 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 that "pragmatic or ethical considerations" can overcome that presumption; and that they seek to give formalism a theoretical and empirical foundation).

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judgments), and those rules govern other governmental decisions. The default-logic paradigm models the role of such rules in legal reasoning. 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. It is a conditional proposition of the form "if *p*, then *q*," where *p* and *q* stand for two constituent propositions. A legal rule states that finding proposition *p* (the condition) to be true warrants finding *q* (the conclusion) to be true also. A proposition is the meaning or informational content of an assertion, usually expressed in ordinary language by a sentence or clause.[13] Moreover, a legal 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.

The default-logic model reflects the dynamic nature of legal reasoning by assigning to the propositions of legal rules one of three truth-values: true, false, or undecided.[14] When legal reasoning begins in a particular situation, the truth-values of the conditions and conclusions of the

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[13] 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 5-6 (10th ed. 1998); 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).

[14] A system of legal rules based on more than three truth-values would be very complicated and 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 systems. As discussed *infra* in Part II, a three-valued system in the rule-based portion of reasoning allows a basis for harmonizing factfinder evaluation of the evidence, without imposing on the factfinder any particular truth-value system to use in evaluating that evidence.

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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.[15] An example of a conjunctive rule is the tort rule identifying the factual elements of a plaintiff's *prima facie* case for battery:[16]

> **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.[17] Rules may also be disjunctive, with the constituent propositions of the condition

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[15] 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, e.g., COPI & COHEN, *supra* note 13, at 345-47; ROBERT E. RODES, JR. & HOWARD POSPESEL, PREMISES AND CONCLUSIONS: SYMBOLIC LOGIC FOR LEGAL ANALYSIS 17-27 (1997); SAINSBURY, *supra* note 13, at 62-65.

[16] *See, e.g.*, RESTATEMENT OF TORTS, SECOND §§ 2, 13, 18; DAN B. DOBBS, THE LAW OF TORTS 47-63 (2000).

[17] 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.

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(disjuncts) connected by the logical connective "OR."[18] With a disjunctive rule, proving any one or more of the disjuncts is sufficient for proving the conclusion.[19] 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."[20] With a defeater rule, if the condition (defeater proposition) is true, then the rule warrants the conclusion to be false.[21] An example of a defeater is an affirmative defense to a

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

See the definition of the many-valued connective "et₁", GOTTWALD, *supra* note 3, at 66.

[18] 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, e.g., COPI & COHEN, *supra* note 13, at 348-50; RODES & POSPESEL, *supra* note 15, at 59-73; SAINSBURY, *supra* note 13, at 65-68.

[19] 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 "vel₁", GOTTWALD, *supra* note 3, at 90.

[20] 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. *Also see infra* note 64.

[21] 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.

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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.[22]

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.[23] Their truth-functional nature makes it straightforward to capture their operation completely within artificial intelligence software.[24]

The default-logic paradigm constructs "implication trees" to model complex legal rules and chains of such rules.[25] Implication trees start with the ultimate conclusion at the top and branch downward, making an inverted tree. For example, the following implication tree models the plaintiff's *prima facie* case for battery:

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[22] *See, e.g.*, RESTATEMENT OF TORTS, SECOND §§ 63-76, 112-39; DOBBS, *supra* note 16, at 159-70, 190-204.

[23] On the concept of truth-functional connectives generally, see, e.g., COPI & COHEN, *supra* note 13, at 345-46; RODES & POSPESEL, *supra* note 15, at 96-104; SAINSBURY, *supra* note 13, at 49-51.

[24] *See* RUSSELL & NORVIG, *supra* note 6, at 206-10, 524.

[25] 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 156-94 (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 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").

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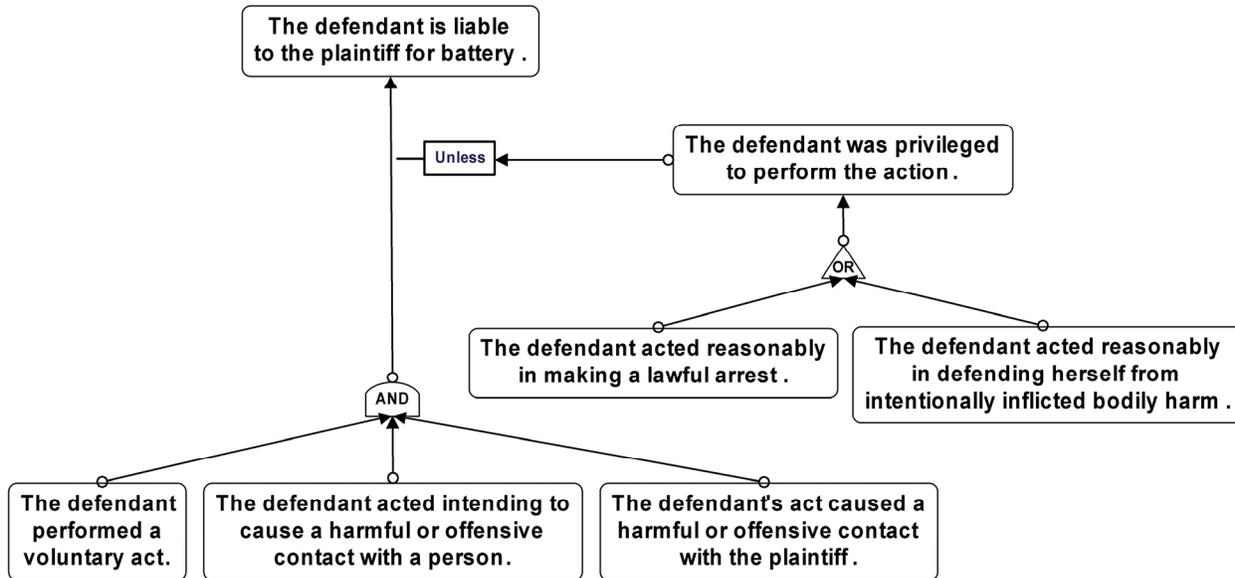CONFIDENTIAL DRAFT: PLEASE DO NOT QUOTE OR CITE
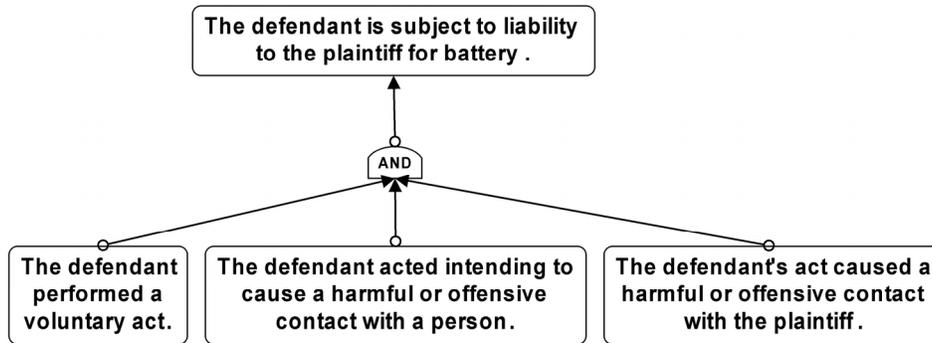
Such a logic diagram shows that, according to this rule, the upper-level proposition is warranted to be true if all three lower-level propositions are true. An implication tree models a legal rule as two adjacent levels, with the upper level stating the conclusion of the rule, a logical connective between the two levels specifying the truth-function involved, and the lower level identifying the constituent propositions of the condition. 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.[26] In principle, the substantive legal rules of tort law that can warrant compensatory damages can be modeled as one large implication tree. For example, the implication tree for battery might begin as follows:

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[26] *See* KADANE & SCHUM, *supra* note 25, 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 25, at 169-73 (discussing directed acyclic graphs).

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                    ┌──────────────────────┐
                    │ The defendant is liable│
                    │to the plaintiff for battery.│
                    └──────────────────────┘
                              ↑
                    ┌───────┐        ○──┌──────────────────────┐
                    │ Unless│◄──────────│ The defendant was privileged│
                    └───────┘           │  to perform the action.│
                                        └──────────────────────┘
                                                  ↑
                                                 OR
                              ○──────────────────────────○
          ┌──────────────────────┐        ┌──────────────────────┐
          │The defendant acted reasonably│ │The defendant acted reasonably│
          │ in making a lawful arrest.│   │  in defending herself from│
          └──────────────────────┘        │intentionally inflicted bodily harm.│
                                           └──────────────────────┘
              AND
   ○──────────┼──────────○
┌───────────┐ ┌──────────────────┐ ┌──────────────────┐
│The defendant│ │The defendant acted intending to│ │The defendant's act caused a│
│performed a │ │cause a harmful or offensive│ │harmful or offensive contact│
│voluntary act.│ │ contact with a person.│ │  with the plaintiff.│
└───────────┘ └──────────────────┘ └──────────────────┘
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According to these rules, 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. 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 of 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 the ways that lower-level propositions can combine to prove or disprove upper-level propositions. At the bottom level of each branch of a 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 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 factfinder. Part II of this article examines the reasoning of the factfinder in making such findings. The implication-tree structure, however, shows the role of legal rules in

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elaborating the single ultimate issue at the top into a potentially large set of terminal propositions at the bottom.[27]

Implication trees display graphically many default-logic 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* of 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 shows what the law of torts means by "battery." Third, implication trees suggest possible strategies for proving or warranting intermediate and ultimate conclusions. A graphical representation can present a large amount of information at one time. It can show how all possible 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.

In addition to implication trees, the default-logic paradigm uses concept-based entailments to model supplemental legal rules. Traditional predicate logic analyzes propositions into a logical predicate and one or more logical subjects, and those logical components can form the factual conditions for legal rules.[28] A logical predicate is the element of a proposition that indicates what is

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[27] 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.

[28] For general discussions of predicate logic, see, e.g., COPI & COHEN, *supra* note 13, at 428-65; RODES & POSPESEL, *supra* note 15, at 113-206; SAINSBURY, *supra* note 13, at 133-219.

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

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being affirmed or denied about one or more subjects. For example, the proposition "the plaintiff has developed cancer" classifies the plaintiff (the logical subject) as a member of the class of persons who have developed cancer ("… has developed cancer" being the logical predicate). A logical subject is an element of a proposition that names, denotes, or refers to one or more objects or events that the proposition is about.[29] Analyzed from a predicate-logic perspective, therefore, a proposition asserts something (expressed by the predicate) about one or more objects or events (named by the subject or subjects).

Logical predicates and subjects employ concepts (expressed by nouns, adjectives, adverbs, and other grammatical types) that can be linked by legal rules. Some rules identify class/sub-class relationships among concepts, such that any attribute of members of the class is necessarily an inherited attribute of members of the sub-class. For example, if a specific individual Jones is a defendant, then the class/sub-class relationship "party/defendant," warrants that Jones is also a party, and has all the attributes that attach to being a party (e.g., having a right to be notified about proceedings that determine his rights and obligations).[30] Other legal rules combine multiple concepts into a set of jointly sufficient conditions for applying a predicate to a subject. For example, being both a "party" to a lawsuit and a "corporation" means that citizenship for purposes of diversity jurisdiction in federal court is determined by the corporation's state of incorporation and its principal place of business.[31] A definition of a word or concept combines both types of relationship (necessary and jointly sufficient conditions) into a single statement of equivalence.[32]

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[29] 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).

[30] *See* FLEMING JAMES, JR., GEOFFREY C. HAZARD, JR., & JOHN LEUBSDORF, CIVIL PROCEDURE § 2.10, at 72-73 (4th ed. 1992).

[31] 28 U.S.C. § 1332(c).

[32] A definition supplies words, phrases or expressions that have the same meaning as the word, phrase or expression to be defined. *See* COPI & COHEN, *supra* note 13, Chapter 5; BARUCH A. BRODY, LOGIC: THEORETICAL AND APPLIED 21-27 (1973); LARSON & SEGAL, *supra* note 5, Chapter 4. When a definition equates the truth-conditions of two predicates, then using either predicate can assert an equivalent proposition about a subject. Identifying necessary and sufficient truth-conditions displays warrant, but does not necessarily exhaust the ordinary meaning of an asserted proposition.

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These kinds of rules are still conditional in logical form, but they identify entailments among concepts, not implications among unanalyzed propositions. Such rules tend to exhibit the logical property of "locality" – that is, the truth-value of the conclusion is determined by the truth-values of a specifiable set of conditions.[33] Concept-based entailments can play a useful role in warranting inferences between propositions in different branches of the same implication tree, or between propositions within different implication trees. They only supplement the strategic work of an implication tree, however, which is designed to capture all of the legal rules that are oriented toward proving a particular ultimate conclusion.

Using implication trees and concept-based entailments to model legal rules can help achieve the epistemic objective.[34] Such models can make transparent the exact rules that are in play, and identify with precision the triggering conditions for those rules. Such transparent precision allows criticism and refinement of those rules, as well as 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 factfinders to 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 structure of legal reasoning and factfinding, it allows the automation of those models – and therefore the automation of important parts of legal reasoning.

For examples of semantic theories using a rule-based approach to specifying truth-conditions for the meaningful use of ordinary words, see, e.g., 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); CHIERCHIA & MCCONNELL-GINET, *supra* note 5, at 73-81 (setting the goal of providing "a fully explicit, that is, fully formalized, specification of truth conditions for sentences" having propositional structures); SAEED, *supra* note 5, at 292-341 (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").

[33] *See* RUSSELL & NORVIG, *supra* note 6, at 230, 524 (discussing locality as a desirable property of logical rule-based systems).

[34] This article does not discuss how to craft the appropriate default-logic model for capturing a particular piece of legal reasoning. The art of logical modeling tries to elucidate the warrant and formalize the legal reasoning that appears in particular statutes, regulations, administrative adjudications, and judicial decisions.

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B.   Policy-Based Reasoning about Implication Trees

Legal rules provide the deductive structure for legal reasoning, but they are also the subject matter *of* legal reasoning about their justification. 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 trees, but rather guide the decisional process of constructing implication trees.[35] Moreover, legal policies are often diverse and competing: epistemic policies are primarily designed to achieve the epistemic objective (producing accurate findings warranted by the legally available evidence), while non-epistemic policies primarily pursue such objectives as procedural fairness and administrative efficiency.[36] Therefore, the modeling of policy-based reasoning within the default-logic paradigm poses two major problems. The first is how to model the content of the reasoning that connects a particular policy objective to any particular rule. The second problem is how to balance many lines of such reasoning, oriented toward diverse policy objectives, into a single justification for a particular rule.

This article does not present a formal model for policy-based reasoning. A promising approach, however, is one analogous to the model for evaluating evidence to arrive at a warranted finding of fact – a model that Part II addresses in detail. Just as there are default-logic structures for organizing and weighing relevant evidence, there may be analogous structures for organizing and balancing policy rationales.[37] Moreover, the success of the default-logic paradigm in modeling legal process rules (the topic of Part III of this article) gives additional reason to think that the paradigm can also clarify policy-based reasoning. The formal adoption of a legal rule is itself a kind of governmental action that requires justification, and there are several areas where reasoning about rule justification can be studied. Administrative rulemaking is an example of rule adoption, and its

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[35] Policy-based reasoning is therefore "second-order reasoning." It is reasoning about whether to adopt the legal rules that, if adopted, can be modeled within implication trees.

[36] Vern R. Walker, *Epistemic and Non-epistemic Aspects of the Factfinding Process in Law*, APA NEWSLETTER 03, no. 1, 132, 132 (Fall 2003) (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 non-epistemic 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.

[37] For example, if there are definitions and measures of efficiency, then a policy argument about whether a particular rule will or will not increase efficiency can become an empirical question. *See, e.g.*, EDITH STOKEY & RICHARD ZECKHAUSER, A PRIMER FOR POLICY ANALYSIS 134-58, 291-319 (1978) (discussing benefit-cost analysis and market efficiency).

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warrant consists of applying both process and substantive rules to particular issues.[38] Statutory interpretation is another example of explicit rule adoption, in which courts elaborate new rules out of statutory language, and the judicial canons of interpretation provide examples of policy-based reasoning.[39] Finally, common-law courts create new legal rules in the process of explaining their judgments, and many courts have reasoned at length about how they balance policy rationales.[40] Research on such examples of policy-based reasoning, using the tools developed within the default-logic paradigm, should be able to clarify formally the interplay among rule application, rule adoption, and evidence evaluation.

Policies are particularly important in analyzing principled changes in legal rules or implication trees. 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 should capture all of the applicable 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. This furnishes 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, or adopt new common-law rules or overrule prior cases. Policies not only justify new rule adoption, but they also help explain the course of past rule change. 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. Although diachronic models of legal rule systems can become quite complex, they allow research into the policy-driven aspect of that change. As Part II explores the default logic of evidence evaluation, it also suggests methods for evaluating the policy-based arguments behind rule change.

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[38] *E.g.*, Community Nutrition Institute v. Young, 773 F.2d 1356, 1357-60, 1362-67 (D.C.Cir. 1985), *cert. denied*, 475 U.S. 1123 (1986) (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).

[39] For leading cases on interpreting statutes administered by federal agencies, see Chevron, U.S.A., Inc. v. Natural Resources Defense Council, Inc., 467 U.S. 837, 842-45 (1984) (establishing rules for a two-step process of interpretation); Whitman v. American Trucking Associations, 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).

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

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II.   EVIDENCE EVALUATION AND PLAUSIBILITY SCHEMAS

The default-logic paradigm addresses a major flaw of the traditional approach to legal reasoning by modeling rule-based deductions and evidence evaluation as parts of a single continuum. Within the paradigm, factfinding is the process of "attaching" relevant evidence to a terminal proposition of a legal implication tree, evaluating the probative value of that evidence, and using that evaluation to assign a truth-value to the terminal proposition. Legal reasoning therefore has two major components: rule-based deduction within the implication tree, and the evaluation of evidence attached to the implication tree.[41] Part I of this article examined rule-based, three-valued deductions, modeled by implication trees and concept-based entailments among subjects and predicates. Part II extends the default-logic model to evidence evaluation by formalizing patterns of reasoning in which propositions are plausible, and therefore presumptive, but defeasible.[42] Part III will examine process rules in law, using the logic models developed in Parts I and II.

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[41] 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 42-3 (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, e.g., John R. Josephson & Michael C. Tanner, *Conceptual Analysis of Abduction,* in ABDUCTIVE INFERENCE 5-30 (John R. Josephson & Susan G. Josephson eds. 1996).

[42] 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 25, at 116-75 (discussing the use of Bayes' Theorem and likelihood ratios to grade the "probative force of evidence"); SCHUM, *supra* note 25, at 200-69 (discussing various methods for grading the "force of evidence" and "evidential support").

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A. The Plausibility of Evidence as Warrant

In general, the task of the factfinder is to determine the truth-values of the terminal propositions of an implication tree by evaluating the relevant portion of the available evidence.[43] The terminal propositions of an implication tree are the lowest propositions in every branch of the tree, 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 propositions and a terminal proposition in an implication tree.[44] A particular evidentiary proposition is relevant if, but only if, a reasonable factfinder would rely upon it in determining the truth-value of a terminal proposition.[45] The problem for logical theory is modeling the probative value or weight of individual evidentiary propositions, 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 Propositions

While propositions in an implication tree have a three-valued truth-value, evidentiary propositions are assigned a "plausibility-value."[46] Evidentiary propositions include assertions made

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[43] In practice, the truth-value may also be established by stipulation of the parties, or may be decided "as a matter of law" by a court ruling on a motion.

[44] 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."

[45] If legal factfinding 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 factfinder 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 BROOKLYN LAW REVIEW 1075, 1079-97 (1996). Usually, such a reasonable belief is only presumptively valid, and is defeasible if new evidence or a re-analysis of old evidence warrants a change in the belief.

[46] *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 41, at 266-72 (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).

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by witnesses, descriptions of things entered into evidence, or other relevant descriptions (such as descriptions of a witness's demeanor). A plausibility-value is the classification on a scale of plausibility that a factfinder assigns to an evidentiary proposition.[47] A scale of plausibility can have any number of possible values, and can be either qualitative or quantitative.[48] For example, a plausibility scale might be qualitative, ordinal, and have five values (such as "true / probably true / undecided / probably false / false") or seven values (such as "almost certainly true / highly likely / probably true / undecided / probably false / highly unlikely / almost certainly false").[49] By contrast, an infinite-valued quantitative scale is conventional mathematical probability, using the set of real numbers between zero and one, and having values such as 0.56.[50] A reasonable factfinder would select a plausibility scale that is suitable to the circumstances, and would assign to evidentiary propositions plausibility-values on that scale.

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[47] On measurement or classification generally, see Vern R. Walker, *The Siren Songs of Science: Toward a Taxonomy of Scientific Uncertainty for Decisionmakers*, 23 CONNECTICUT LAW REVIEW 567, 580-88 (1991).

[48] *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").

[49] *See* Josephson, *supra* note 46, 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.*, Paul Slovic et al., *Evaluating Chemical Risks: Results of a Survey of the British Toxicology Society*, 16 HUM. & EXPERIMENTAL TOXICOLOGY 289, 290 & fig. 1 (1997) (using the categories "almost no health risk," "slight health risk," "moderate health risk," "high health risk," and "don't know"); Michael Siegrist & George Cvetkovich, *Perception of Hazards: The Role of Social Trust and Knowledge*, 20 RISK ANALYSIS 713, 715 (2000) (using a 7-point scale ranging from "not at all risky" to "very risky"); 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 7-point verbal category scale performs at least as well as a 100-point numerical scale).

[50] *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, e.g., Philip Dawid, *Probability and Proof: Some Basic Concepts*, Appendix in ANDERSON & TWINING, *supra* note 2, at 389-441.

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The decision about which plausibility scale to employ should balance non-epistemic and epistemic objectives.[51] An important non-epistemic consideration is the pragmatic context for the factfinding.[52] 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 proposition are themselves qualitative. Inconsistency in classification is good evidence of the existence of error.[53] 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,[54] and highly quantitative

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[51] *Cf.* Vern R. Walker, *Restoring the Individual Plaintiff to Tort Law by Rejecting "Junk Logic" About Specific Causation*, 56 ALABAMA LAW REVIEW 381, 389-95 (2004) (arguing that within a legal context, decisions about what levels of precision and accuracy are acceptable are inherently pragmatic).

[52] *See, e.g.*, Josephson & Tanner, *supra* note 41, 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").

[53] 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, ROBERT PISANI, ROGER PURVES, & ANI ADHIKARI, STATISTICS 90-101, 395-411 (2d ed. 1991); EDWIN E. GHISELLI, JOHN P. CAMPBELL, & SHELDON ZEDECK, 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 1-25 (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 51, at 389-95. The reliability of a classification process for plausibility would characterize the random variability in results when the same factfinder 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 factfinders 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.

[54] *See* SCHUM, *supra* note 25, at 261-69; CHIERCHIA & MCCONNELL-GINET, *supra* note 5, at 482-89.

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plausibility scales would yield inconsistent evaluations. Moreover, ordinary legal factfinders, who are usually untrained in scientific measurement, must assign degrees of plausibility to the everyday assertions of lay witnesses. Legal rules therefore seldom require factfinders to employ any particular plausibility scale when evaluating evidence. Generally, the factfinder is free to utilize any plausibility scale, so long as the factfinder is able to apply the appropriate standard of proof in making the findings or verdicts.[55] The epistemic objective is better served, however, when the plausibility scale produces the level of precision and the potential for error that are acceptable under the circumstances.[56]

2.   Plausibility Schemas

"Plausibility schemas"[57] are patterns of evidentiary propositions that use the plausibility-values of evidentiary propositions to assign a truth-value to the terminal proposition.[58] They are

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[55] The process rules about standard of proof are discussed *infra* text accompanying notes 132-34.

[56] 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.

[57] 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* GERALD J. MASSEY, UNDERSTANDING SYMBOLIC LOGIC 139-40, 147-48 (1970); JOHN M. ANDERSON & HENRY W. JOHNSTONE, JR., NATURAL DEDUCTION: THE LOGICAL BASIS OF AXIOM SYSTEMS 20-21 (1962). In semantics, schemas are used to specify conditions for assigning a truth-value to a sentence, see, e.g., 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, *e.g., id.* at 118-19 (describing schemas in genetic search algorithms), 809 (describing rules schemas in augmented grammars).

[58] The same evidentiary assertion could be relevant to (attach 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 marginal support that an evidentiary assertion can provide *to* a terminal proposition, given the other available evidence relevant to that proposition, can vary from leaf node to leaf node. 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

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inference schemas that explain why the plausibility of the evidence warrants reasoning up the implication tree.[59] Like rule-based deductions, plausibility schemas have an inverted tree structure. One set of logical connectives bridging the levels of a schema consists of generalized functions of the three truth-value connectives used in implication trees.[60] These plausibility connectives determine the plausibility-value of the conclusion on the upper level as a function of the plausibility-values of the evidentiary propositions on the lower level. The "AND" plausibility connective assigns to the conclusion the *lowest* plausibility-value possessed by any of its conjuncts.[61] The "OR" plausibility connective assigns to the conclusion the *highest* value of any of its disjuncts.[62] If factfinders are free to adopt different plausibility scales for different evidentiary propositions,[63] then these plausibility functions will require a rule for handling a mixture of scales – for example, where

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basis of (a) how plausible the premises are, and (b) how strong is the inference from the premises to the conclusion").

[59] A recent 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.

[60] 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.

[61] 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).

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

[63] *See supra* text accompanying notes 48-56.

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

In the case of plausibility defeater, the "UNLESS" plausibility connective, if the defeater proposition is plausible, then this connective assigns to the conclusion a degree of plausibility inverse to that of the defeater proposition.[64] That is, as the plausibility of the defeater proposition increases, the plausibility of the conclusion decreases (alternatively, the *im*plausibility of the conclusion increases). Some examples: on the five-point scale above, if the plausibility-value of the defeater is "probably true," then the plausibility-value of the conclusion is "probably false"; on the seven-point scale above, if the defeater is "highly likely," then the conclusion is "highly unlikely"; on the scale of mathematical probability, if the defeater's plausibility-vaue is 0.56, then the conclusion's plausibility-value is 0.44 (1 − 0.56).[65]

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

Section II.B *infra* provides several illustrations of plausibility schemas. Formally, however, a plausibility schema is an inference tree, such as the following:[66]

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[64] 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"); 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").

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.

[65] For the calculus of mathematical probability, *see supra* note 50.

[66] In the plausibility region of a logic diagram, the proposition shape has a dashed line around it instead of a solid line, to indicate that the proposition takes a plausibility-value instead of a truth-value. In

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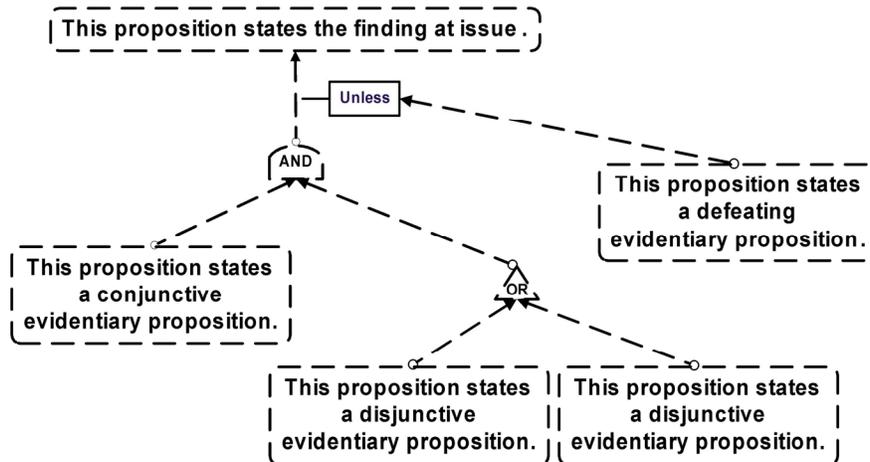
The interpretation of such a schema is that if the evidentiary propositions on the lower level are plausible, then the conclusion is also plausible (or implausible) in the manner determined by the plausibility connective. Plausibility schemas model default reasoning to conclusions that are presumptively 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 schema is to develop a "theory of uncertainty" for the type of inference.[67] When the available evidence is incomplete, a good theory of uncertainty can warrant drawing a presumptive but defeasible conclusion precisely because the factfinder understands what evidence is missing, why the missing evidence is relevant, but also why

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addition, the arrows connecting evidentiary propositions within a plausibility schema are dashed instead of solid, to indicate that the inference it represents operates plausibilistically (has "degrees of support"), instead of being the three-valued inference of an implication tree. The entire model of the complete reasoning is therefore an "inference tree," which includes both rule-based deductions and plausibility evaluations.

[67] 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 LAW REVIEW 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").

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it is nevertheless reasonable to make a finding without that missing evidence.[68] 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.[69] A theory of uncertainty therefore helps a factfinder to identify the sources, types, and degrees of uncertainty associated with drawing the conclusion,[70] and can suggest strategies for obtaining new evidence.[71] Theories of uncertainty, incorporated into the inference structures of plausibility schemas, therefore play a critical role in default reasoning. 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 factfinding.

A common component of most (if not all) plausibility schemas is a generalization, and the presumptive force of the schema depends in large part on the plausibility of that generalization.[72] A

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[68] *See, e.g.*, Josephson & Tanner, *supra* note 41, 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").

[69] Theories of uncertainty often consider three broad sources of error: linguistic, logical, and causal. Walker, *supra* note 67, at 1532-38. Error might arise because the factfinder 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).

[70] *Id.* at 1525-26, 1538-43.

[71] *Id.* at 1526.

[72] 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 25, 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 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).

The logical structure of warrant for a direct inference is distinct from the cognitive process of producing possible generalizations on which to base a direct inference. For one analysis of the latter process, see, e.g., 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).

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generalization usually asserts that a description is true in some situations but not all situations.[73] When a generalization is analyzed into its logical predicate and one or more indefinite subjects,[74] it asserts that the predicate accurately describes some portion of the subject class.[75] 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.[76] The content of a generalization includes an asserted degree of "quantification" over the reference class –

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[73] Logicians often call propositions asserted to be true about all members of a group "generalizations," e.g., COPI & COHEN, *supra* note 13, at 431-32, but less-than-universal generalizations are far more common in assessing plausibility of evidence.

[74] Logical subjects are divided into definite and indefinite subjects. *See, e.g.*, RODES & POSPESEL, *supra* note 15, at 114-20 (discussing "singular terms" and "general terms"); LARSON & SEGAL, *supra* note 5, at 286-301, 319-59 (discussing the "definiteness effect" and "definite descriptions" within semantic theory); 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). Definite subjects are specific individuals that are denoted by proper names ("John Jones") or by definite descriptions ("the plaintiff in Civil Case No. 2006-234"), or by pronouns taking their denotations from proper names or definite descriptions. Indefinite subjects are individuals that are 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.

[75] This concept of "generalization" is that employed by logicians. *See, e.g.*, COPI & COHEN, *supra* note 13, at 431-32; CHIERCHIA & MCCONNELL-GINET, *supra* note 5, at 113-17; RODES & POSPESEL, *supra* note 15, 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 72, at 98 (calling "general, hypothetical statements" that authorize inferences "warrants"); SCHUM, *supra* note 25, 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.

[76] *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).

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that is, the size of the portion of A that is asserted to be B.[77] Moreover, a generalization often contains an explicit modal "hedge" qualifying the entire assertion, which can influence the plausibility-value compared to an unhedged generalization.[78] Examples of modal hedges are expressions of frequency (e.g., "sometimes" or "often"), typicality (e.g., "typically" or "normally"), temporal limitation (e.g., "in the past" or "at least for the immediate future"), or degree of confidence of the speaker (e.g., "perhaps" or "almost certainly").[79] The degree of quantification asserted and the modal hedge employed change the content of the generalization, and therefore can 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.

3.   Findings of Fact

The purpose of using a plausibility schema is to warrant a finding that a terminal proposition is either true or false. The function of a schema is to organize the relevant evidence in such a way 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 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 Section II.B *infra*).

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[77] Traditional predicate logic has studied extensively the formal properties of two important quantifiers: the universal quantifier ("all As …") and the existential quantifier ("some As …" or "at least one A …"). *E.g.*, COPI & COHEN, *supra* note 13, at 431-59; RODES & POSPESEL, *supra* note 15, at 124-34; SAINSBURY, *supra* note 13, at 141-47, 182-90.

[78] *See* SCHUM, *supra* note 25, at 81-83, 101-02, 110-12 (giving as examples of "hedges" the adverbs "sometimes," "frequently," "often," and "usually"); TOULMIN, *supra* note 72, 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 67, at 1560-62.

[79] *See* Josephson & Tanner, *supra* note 41, at 22-23; SCHUM, *supra* note 25, at 81-82; TOULMIN, *supra* note 72, at 100-02 (discussing "modal qualifiers" like "presumably" as expressing a "degree of force").

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Plausibility schemas are not implication trees, and attaching schematized evidence to an implication tree does not extend that tree. First, as noted above, the evidentiary propositions within a plausibility schema have plausibility-values on variable scales of plausibility, not truth-values on a three-valued scale. Moreover, the factfinder selects schemas and plausibility scales to fit the evidence in the particular case, whereas authoritative institutions adopt the legal rules modeled by the implication tree. This means that the schematized evidence is specific to the particular case and factfinder, 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. 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 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, models the entire legal reasoning 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."[80] For example, the standard of proof for most issues of fact in civil cases is preponderance of the evidence.[81] Under this rule, if the factfinder evaluates the relevant evidence as having any plausibility-value other than "undecided," then the factfinder must assign the corresponding truth-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.[82] 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

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[80] *See* JAMES ET AL., *supra* note 30, §§ 7.5, 7.14 (discussing "the three generally recognized standards of proof … : preponderance, clear and convincing, and beyond a reasonable doubt").

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

[82] Walker, *supra* note 45, 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).

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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. Examples of Plausibility Schemas

This section illustrates the use of default logic to evaluate evidence, by briefly considering three plausibility schemas: the direct-inference schema, the statistical-generalization schema, and the personal-observation schema. These three schemas can model one type of warrant 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,"[83] "the defendant was driving under the influence of marijuana,"[84] and "the claimant contracted pneumoconiosis."[85] 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"[86]; "the person [driving a motor vehicle] was under the influence of a controlled substance"[87]; and "the claimant suffers from pneumoconiosis."[88] The logical problem is modeling the kind of reasoning that can warrant the plausibility of such findings of fact.[89]

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[83] *E.g.*, Kumho Tire Co., Ltd. v. Carmichael, 526 U.S. 137, 142-45 (1999) (judicial civil case).

[84] *E.g.*, State v. Klawitter, 518 N.W.2d 577, 578 (Minn. 1994) (judicial criminal case).

[85] Greenwich Collieries v. Director, Office of Workers' Compensation Programs, 990 F.2d 730, 731 (3rd Cir. 1993), *aff'd*, 512 U.S. 269 (1994) (administrative case involving judicial review of a decision of the Benefits Review Board).

[86] *See* RESTATEMENT OF TORTS, THIRD: PRODUCTS LIABILITY § 1; 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., Ltd. v. Carmichael, 526 U.S. 137 (1999) (applying the products liability law of Alabama).

[87] *See* MINN. STATUTES §§ 152.02, 169A.20 (controlled substances; driving while impaired).

[88] *See* 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).

[89] 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. D.L. Sackett, W.M. Rosenberg, J.A.M. Gray, R.B. Haynes & W.S. Richardson, *Evidence based medicine: what it is and what it isn't*, 312 BRITISH MEDICAL JOURNAL 71-72 (1996) (defining EBM as "the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual

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There may be several possible patterns of reasoning that could provide the needed warrant,[90] but logicians have called the particular pattern discussed here "direct inference."[91] The direct-inference syllogism has the following form:[92]

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.

A direct-inference schema consists of two premises leading to a conclusion. The first or major premise is a generalization that asserts that some portion of things in category A are in fact also in category B.[93] The second or minor premise is an assertion that a specific individual or definite subject (S) is in category A.[94] A logic diagram of this direct-inference syllogism is as follows:

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patients"); DAN MAYER, ESSENTIAL EVIDENCE-BASED MEDICINE 9-15 (2004) (discussing six steps in the process of EBM).

[90] 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 25, 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").

[91] Isaac Levi, *Direct Inference*, 74 THE JOURNAL OF PHILOSOPHY 5 (1977); Isaac Levi, *Direct Inference and Confirmational Conditionalization*, 48 PHILOSOPHY OF SCIENCE 532 (1981); Henry E. Kyburg, Jr., *The Reference Class*, 50 PHILOSOPHY OF SCIENCE 374 (1983); POLLOCK, *supra* note 7, Chapter 4. Toulmin has referred to direct inferences as "quasi-syllogisms." *See* TOULMIN, *supra* note 72, at 108-11, 131-34, 139-40.

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 41, at 5, 7, 17. However, some authors explicitly exclude direct inference from the definition of abduction. *See id.* at 23-24.

[92] *See* Walker, *supra* note 51, at 386-89 (discussing direct inference in warranting conclusions about specific causation in tort cases).

[93] 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," and the direct-inference pattern a "statistical syllogism." *See, e.g.*, Josephson & Tanner, *supra* note 41, at 23; POLLOCK & CRUZ, *supra* note 10, at 229-30; WESLEY C. SALMON, LOGIC 87-91 (2d ed. 1973). The

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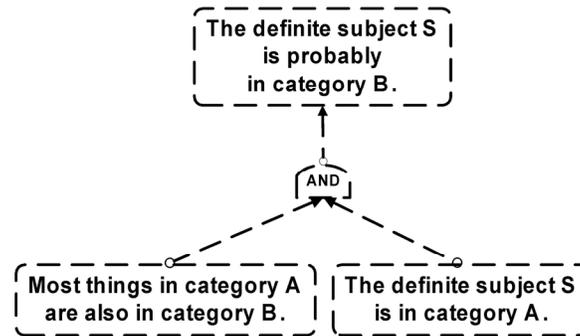
Because a direct inference uses a generalization about a reference group to warrant inferences about specific individuals in that group,[95] this pattern of reasoning is particularly useful when the individual's membership in category B is not directly observed.

While direct-inference reasoning has intuitive appeal, the uncertainties inherent in such reasoning become clearer by examining each of the two premises. The first or major premise is a generalization asserting that some portion of the members of reference class A are also in category B.[96] The plausibility of this premise rests in turn upon a plausibility schema for warranting generalizations. One possible type of evidence is statistical data, and a theory of uncertainty would explain the potential for error in generalizing from such data. One plausibility schema for warranting statistical generalizations incorporates two types or sources of uncertainty: measurement uncertainty and sampling uncertainty. Each type of uncertainty can increase or decrease the

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inference is called a "statistical syllogism" because a statistical premise (such as "X percent of As are B") is used instead of a universal generalization ("All As are B"). SALMON, *supra*, at 88-91; POLLOCK, *supra* note 7, at 75-77. For early recognition of the difficulty such inferences pose for legal theory, see George F. James, *Relevancy, Probability, and the Law*, 29 CALIFORNIA LAW REVIEW 689 (1941).

[94] 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.

[95] 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 51, at 452-60.

[96] For a general discussion of reasoning involving the backing for generalizations, see TOULMIN ET AL., *supra* note 7, at 219-29.
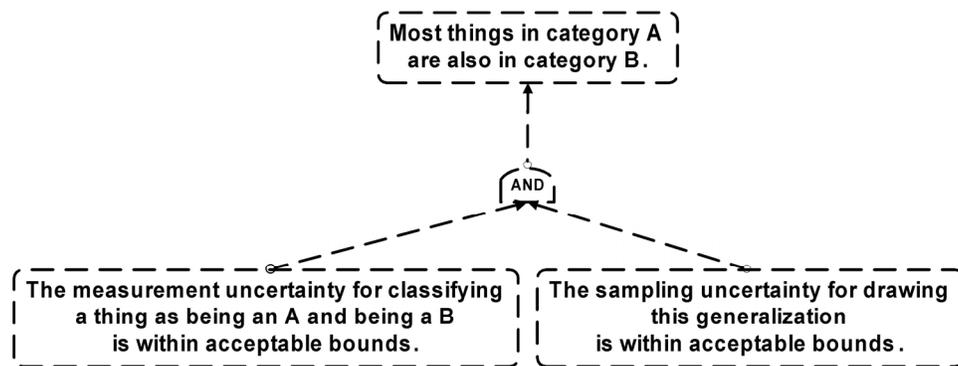
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plausibility of the generalization, and therefore each type of uncertainty is modeled as a separate conjunctive branch in the plausibility schema.[97]

Within the first branch, the plausibility of the statistical generalization depends upon how much measurement uncertainty there is in classifying things as being A and being B.[98] The asserted proportion of As that are Bs can be warranted as accurate only if the classifications of individuals into groups A and B have acceptable accuracy.[99] If individuals are misclassified as being A or being B, then the asserted proportion of As that are Bs will be inaccurate to some extent. Of course, more plausibility schemas may come into play in warranting that the measurement uncertainties for A and B are acceptable.[100] Unless the data classifying individuals as A and B have acceptable measurement accuracy, the generalization about As being Bs is itself unwarranted.

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[97] This plausibility schema for warranting a statistical generalization can be diagrammed as:

Most things in category A are also in category B.

AND

The measurement uncertainty for classifying a thing as being an A and being a B is within acceptable bounds.

The sampling uncertainty for drawing this generalization is within acceptable bounds.

[98] For discussion and references on measurement or classification uncertainty, see Walker, *supra* note 51, at 389-95.

[99] The degree of precision asserted in the generalization can also affect its plausibility. A generalization asserting that a precise percentage of As are Bs may require stronger support than a generalization asserting merely that "most" As are Bs.

[100] Measurement uncertainty rests in turn on reliability and validity, each of which can reduce the plausibility of the generalization. *See supra* note 53. 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. *See* Walker, *supra* note 51, at 394-95. Moreover, as discussed above in the context of classifying evidentiary assertions, *supra* text accompanying notes 51-56, 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 51, at 395. Acceptable

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Within the second branch, the plausibility of the statistical generalization depends upon whether the sampling uncertainty is acceptable.[101] 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. 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.[102]

The minor premise of the direct-inference syllogism 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 conclusion is the report of an eyewitness based upon her own perceptual observation.[103] A complete plausibility schema for observational reports based upon personal perception (a "personal-observation schema") is likely to be very complicated, but some theorists have explored the reasoning that forms the upper levels of that schema.[104] According to a theory of uncertainty based

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reliability and validity in the measurements of A and B are therefore necessary conditions for finding a statistical generalization to be plausible.

[101] For discussion and references on sampling uncertainty, see Walker, *supra* note 51, at 396-405.

[102] The reasoning behind sampling uncertainty has two sub-branches, depending upon whether the possible lack of representativeness can cause biased or random error in the assertion about the ratio of B/A in the population. Walker, *supra* note 51, at 396-405.

[103] An alternative line of reasoning to the same kind of conclusion is another direct inference, because the conclusions of the direct-inference schema and of the personal-observation schema have the same logical form (classifying a single definite subject into a category). 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.

[104] See SCHUM, *supra* note 25, at 100-09; KADANE & SCHUM, *supra* note 25, at 53-60; Walker, *supra* note 67, at 1559-68. For a general analysis of Schum's system, see Walker, *supra* note 25, 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.

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on the analysis by Schum, 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.[105] Taken together, these three branches constitute the credibility of the witness herself in asserting that she observed the subject S as being an A.[106] Additional conditions for the plausibility of the witness's assertion that S is an A are whether this assertion is consistent with the meaning of "being an A" (e.g., S must possess the properties entailed by being an A), and whether the assertion is plausible in light of what else is known about S (and about things like S).[107] A plausibility schema for an eyewitness report about a definite subject, therefore, would have a tree-like structure possessing these conditions in some combination, and each branch could lead to further analysis.

The plausibility of the major and minor premises considered individually, however, does not exhaust the potential for error in a direct inference. The generalization (the major premise) could be plausible, as well as the categorization of S as an A (the minor premise), but the fit between these premises and the conclusion can still cause uncertainty about the inference. One possible fallacy is relying on the proportion B/A to make an inference about a specific individual S when there no warrant for doing so. For example, 52% of U.S. citizens might be female, and a certain person S might be a U.S. citizen, but finding on this basis alone a 0.52 probability that S is female would be unwarranted without more information about S. The finding could be warranted by the additional information that S has been randomly selected from the set of U.S. citizens. This reasoning is familiar from predictions about lottery drawings. In a lottery drawing, the probability of drawing a particular type of object (such as a numbered ball) is equal to the proportion of such objects in the lottery pool, provided each object in the pool has an equal chance of being selected on the next draw.[108] Similarly in a direct inference, if there is warrant that the definite subject S is a randomly drawn member of A with respect to being B, then the probability that S is a B will equal the ratio

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[105] SCHUM, *supra* note 25, 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).

[106] *Id.*; KADANE & SCHUM, *supra* note 25, at 55-58.

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

[108] *See* Walker, *supra* note 51, 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).

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B/A.[109] In a case with suitable evidence, therefore, a factfinder may have the warrant to plausibly conclude by direct inference that "the probability = B/A that definite subject S is (also) in category B."

The plausibility of the direct inference is also a function of the fit between the degree of quantification in the generalization and the probability asserted within the conclusion.[110] The size of the ratio B/A asserted in the generalization (major premise) certainly limits the range of probabilities that can plausibly be asserted in a conclusion.[111] For example, if only "a few" As are Bs, then this evidence alone cannot warrant a conclusion stating that "probably" S is a B. On the other hand, if "most" As are Bs, then this evidence would warrant a conclusion that "probably" S is a B, provided S is a random member of A with respect to B. Other things being equal, if the definite subject S is a random member of A with respect to B, then as the proportion B/A increases, the probability within a plausible conclusion can also increase; and as the proportion B/A decreases, the plausible probability within the conclusion decreases.

The revised plausibility schema for direct inference therefore includes the major and minor premise of the direct-inference syllogism, together with the two conditions just discussed:

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[109] In many legal cases, however, there is instead good evidence that the definite subject is *not* a random member of A with respect to B, or there is documented ignorance of the nature of this relationship. *See, e.g.*, Walker, *supra* note 51, at 468-73. In such a case, a reasonable factfinder may still be warranted in using the ratio B/A as a measure of the plausibility that the definite subject S is a B if the reference group A is sufficiently representative of the definite subject S with respect to being B, so that random selection is not required. For example, the reference group A may consist only of persons who are like S on all causally relevant factors for being B. *Id.* at 439-73.

When the direct inference is not only a description or prediction of a property possessed by S, but also an explanation that S's being in category A *caused* S's being in category B, then the plausibility schema must contain as a condition of plausibility that the reference group A represents the definite subject S on a sufficient number of the important variables that are causally relevant to being in category B. *Id.* at 439-48.

[110] This probability may be implicit, or it may be asserted explicitly. When it is asserted explicitly, it often has the connotation of a modal hedge, see *supra* text accompanying notes 78-79. Not all modal hedges express probability, however; some modal hedges, for example, limit the claim being made to particular places or times. *Id.*

[111] The use of mathematical probabilities within legal reasoning incorporates into that reasoning the implication tree for the inference rules of the probability calculus. Assigning a particular probability value to a particular type of event is plausible only if the value is calculated according to the mathematical rules for calculating probabilities. For references on the probability calculus, see *supra* note 50. *Cf.* Walker, *supra* note 25, at 413-30 (discussing problems and dangers inherent in the use of formalized languages, such as the probability calculus, to help provide the warrant for legal factfinding).

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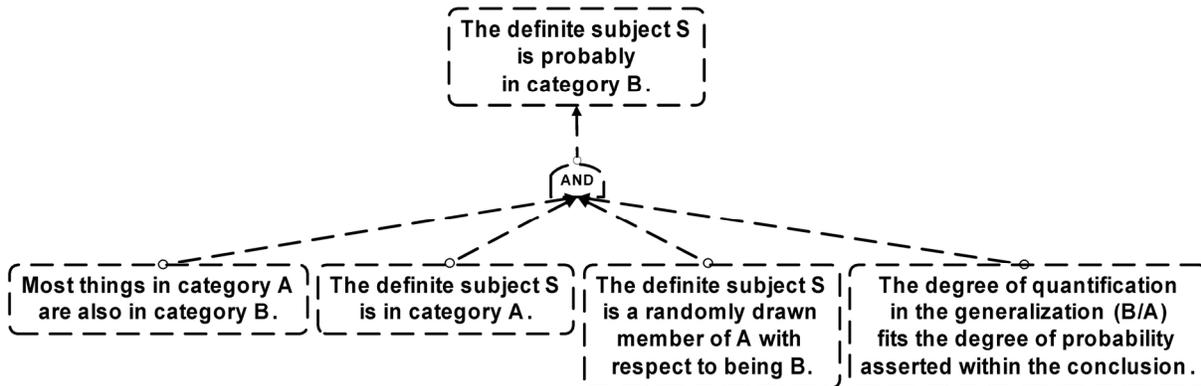
The text above has discussed each branch in turn, in enough detail to suggest additional schemas that could prove plausibility for each branch. The plausibility connective "AND" conjoining the branches makes the plausibility-value of the conclusion, insofar as it is warranted by a direct inference, equal to the plausibility-value of the least plausible of these four conjuncts.

The direct-inference schema also illustrates how plausibility schemas can integrate scientific or other expert evidence with lay, non-expert 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 S was selected from category A may seriously undermine the probative value of the generalization in the particular case.[112]

This brief discussion of direct inference 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 attaches. The evidence, however, might be eyewitness testimony, or a direct inference based on a scientific generalization, or some other type of plausible

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[112] Schum uses the notion of "ancillary evidence" to test whether a generalization applies in a particular instance. SCHUM, *supra* note 25, at 109-20, 187-92; KADANE & SCHUM, *supra* note 25, at 52-53.

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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.[113]

Second, the branches within a plausibility schema can themselves generate a chain of plausibility schemas, with lower schemas providing the plausibility-values for evidentiary propositions 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.

Third, the goal of developing an adequate default logic for legal factfinding (and eventually for policy balancing[114]) requires research into the variety of plausibility schemas that are acceptable. Such research is partly empirical (to identify how legal factfinders actually reason) and partly logical (to critique actual reasoning from the epistemic perspective). Moreover, such research is needed into those schemas that combine quantitative and qualitative scales of plausibility, and expert evidence with non-expert evidence. Finally, 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 by providing criteria for success.

III.   LEGAL PROCESS RULES AND COMPLETE INFERENCE TREES

Modeling legal process rules, which govern the dynamics of default reasoning,[115] requires no new logical structures. Implication trees can model legal process rules in the same way that they can model substantive legal rules. Concept-based entailments can establish necessary or sufficient conditions for legal predicates or indefinite subjects. A balance of legal policies can justify adopting legal process rules, just as they can justify adopting substantive rules. Process rules apply in a

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[113] 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. *E.g.*, Director, Office of Workers' Compensation Programs, Department of Labor 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.

[114] *See supra* Part I.B.

[115] *Cf.* Walker, *supra* note 36, at 135 (concluding that a "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").

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particular case when the decision-maker attaches 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. In order to model default reasoning about legal process, therefore, no new logical structures are needed – only new content for the structures developed in Parts I and II of this article.

The default-logic paradigm integrates substantive and process reasoning by connecting a process implication tree to a substantive implication tree, usually as a conjunctive branch. Most governmental actions are legitimate only if all applicable substantive and process rules are satisfied. Sometimes a process tree connects to the substantive tree at a very high level, and states process requirements for the entire action or decision. An example of such a high-level process condition is whether a court or administrative agency has jurisdiction to act at all. Part III.A 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 a statutory rule that certain types of evidence are irrelevant to a particular terminal proposition, or judicial rules about the admissibility of evidence. Such rules govern decisions about attaching evidence to terminal propositions of a substantive tree. Part III.B will discuss these examples. The complete implication tree for legitimating a governmental action, therefore, consists of main substantive branches to which process branches connect at various levels.

This part of the article discusses several major types of process rules. Because the same process implication tree can connect to many substantive trees (e.g., process trees for deciding jurisdiction), or can connect to many branches in the same implication tree (e.g., process trees for deciding the admissibility of evidence), it is practical to study those process rules separately from the substantive trees to which they connect. For the same reason, software modules to automate process decisions could "launch" from any number of levels in a main substantive tree. 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. 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.

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 jurisdiction,[116] general federal question jurisdiction,[117]

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[116] 28 U.S.C. § 1332. On jurisdiction generally, see JAMES ET AL., *supra* note 30, at §§ 2.24-2.31.

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admiralty jurisdiction,[118] and actions in which the United States is a party.[119] Such provisions, as well as numerous statutes dealing with specific types of jurisdiction,[120] provide the legal process rules governing decisions about jurisdiction. For example, under federal diversity jurisdiction, the rule "complete diversity" is that "all plaintiffs properly joined must have state citizenship different from that of all the defendants."[121] 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.[122] Implication trees can model these rules and make them conjunctive branches in any case brought in federal district court under diversity jurisdiction.

As with any implication tree, the appropriate findings on the issues stated in the terminal propositions depend on evaluating the relevant and available 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.[123] Other issues might be contested and raise triable issues of fact. For example, under Article III of the United States Constitution, as interpreted by caselaw, a plaintiff must have standing to bring the lawsuit for the court to have jurisdiction.[124] While a particular plaintiff's

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[117] 28 U.S.C. § 1331 (authorizing actions "arising under the Constitution, laws, or treaties of the United States").

[118] 28 U.S.C. § 1333.

[119] *E.g.*, 28 U.S.C. § 1345 (authorizing the United States to bring civil actions in federal courts).

[120] *E.g.*, 21 U.S.C. § 371(f) (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).

[121] JAMES ET AL., *supra* note 30, § 2.24, at 98.

[122] 28 U.S.C. § 1332(c).

[123] On the rules of judicial notice, see, e.g., FEDERAL RULE OF EVIDENCE 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").

[124] *E.g.*, Vermont Agency of Natural Resources 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").

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standing might be decidable on summary judgment, it is also possible that in an appropriate case a trial of the issue of standing might be required.[125] As with any issue stated in a terminal proposition of an implication tree, in a particular case the evidence might require the issue to be decided by the factfinder, or it might allow the issue to be decided by the court as a matter of law.[126]

Procedural rules govern the dynamics and timing of default reasoning by authorizing interlocutory or final decisions whose conditions can be satisfied only over time. In a civil proceeding in federal court, for example, a defendant may move to dismiss for lack of jurisdiction on the basis of the pleadings,[127] whereas a party seeking summary judgment often bases the motion on depositions and other products of discovery, together with affidavits,[128] and motions for directed verdict or for judgment as a matter of law are decided upon the evidence produced at trial.[129] Types of motion vary by where they branch from the main implication tree, the nature of the issue raised by the motion, and the nature of the evidence relevant to deciding that issue. From a logical perspective, the timing of procedural motions is controlled by the content of the conditions specified for granting the motions. The rules governing the granting of motions are themselves modeled by implication trees, whose terminal propositions might be true only at certain times or stages of the proceeding. The dynamics and timing of the public process of legal reasoning, therefore, are controlled solely by content, with no new logical structures needed.

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[125] *Id.* 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).

[126] For the rule when the factfinder is a jury, see FEDERAL RULE OF CIVIL PROCEDURE 50(a)(1) (providing that if "[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").

[127] FEDERAL RULE OF CIVIL PROCEDURE 12(b).

[128] *See* FEDERAL RULE OF CIVIL PROCEDURE 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").

[129] *See* FEDERAL RULE OF CIVIL PROCEDURE 50(a); JAMES ET AL., *supra* note 30, §§ 7.19, 7.21.

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B.   Evidentiary Process Rules

Within the default-logic paradigm, evidentiary process rules include much more than the traditional law of evidence. Evidentiary process rules structure the decision-making process involved in evaluating evidence and making findings or rulings on terminal propositions. This includes rules about relevancy (attaching evidentiary assertions to terminal propositions)[130]; rules about admissibility (either excluding some proffered evidence from the case altogether, or prohibiting the attachment of particular items of admitted evidence to certain terminal propositions)[131]; rules about sufficiency of evidence (deciding whether the totality of evidence attached to a terminal proposition can reasonably warrant a finding that the proposition is true)[132]; standards of proof (establishing the threshold degree of plausibility required to assign a truth-value to a terminal proposition)[133]; and rules allocating the burden of persuasion (determining what finding to make when the totality of attached evidence evaluates precisely on the threshold degree of plausibility established by the standard of proof).[134] All of these rules constrain the factfinder's discretion in evaluating the evidence and making findings, by allowing the presiding legal authority to oversee the factfinding process. From a logical perspective, evidentiary process rules supply implication trees for deciding issues raised by various kinds of motions.[135]

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[130] For example, rules about relevant and irrelevant factors, as discussed *infra* text accompanying notes 136-37.

[131] *E.g.*, FEDERAL RULE OF EVIDENCE 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").

[132] *See* JAMES ET AL., *supra* note 30, § 7.19.

[133] *See* JAMES ET AL., *supra* note 30, §§ 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, at 438 (John W. Strong ed., 4th ed. 1992); Walker, *supra* note 45, at 1075-78, 1097-1120 (discussing possible interpretations of the preponderance standard of proof, in light of the policies behind the rule).

[134] *See* JAMES ET AL., *supra* note 30, § 7.13 (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").

[135] From the standpoint of designing software modules to automate decisions on motions, an implication tree for deciding a substantive motion could "launch" from the appropriate proposition in the main substantive tree. The appropriate proposition is the one whose truth-value will be determined by a ruling on the motion.

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As with any implication tree, the appropriate findings to be made on the terminal propositions of an evidentiary implication tree depend on evaluating the relevant and available evidence. One type of evidentiary process rule prescribes what factors are relevant or irrelevant in factfinding. The Supreme Court, for example, has held that the text of § 109(b) of the Clean Air Act, which governs the promulgation of national ambient air quality standards (NAAQS), "unambiguously bars cost considerations from the NAAQS-setting process."[136] What counts as a "cost consideration" and whether an agency has taken costs into account are issues to be decided in the particular case. According to the Court, if it could be proved that the agency "is secretly considering costs of attainment without telling anyone," then this "would be grounds for vacating the NAAQS" adopted.[137] In this example, the fact that an administrative agency is the factfinder governed by the evidentiary process rule, and that the agency evaluates the evidence while setting a particular NAAQS, does not change the underlying default logic. The example illustrates the general applicability of the default-logic paradigm, regardless of the nature of the factfinder.

A second example of an evidentiary process rule, in which the trial court itself evaluates the evidence and rules on the terminal propositions of an evidentiary implication tree, is decision-making about the admissibility of expert testimony. In order to admit an expert opinion under Federal Rule of Evidence 702, federal district courts must find that the subject of the opinion is "scientific, technical, or other specialized knowledge" and that it "will assist the trier of fact."[138] 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."[139] Evidence relevant to deciding these issues is produced pursuant to Federal Rule of Evidence 104(a), either in written form or at an evidentiary hearing.[140] The trial court evaluates the relevant evidence and determines by a

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[136] Whitman v. American Trucking Assoc., Inc., 531 U.S. 457, 462, 471 (2001).

[137] *Id.* at 471, note 4. Such relevant-factor rules may play a significant role in judicial review of agency action. *See, e.g.*, Motor Vehicle Mfr. Ass'n v. State Farm Mutual Automobile Ins. Co., 463 U.S. 29, 42 (1983) (stating that an agency's rule is arbitrary and capricious "if the agency has relied on factors which Congress has not intended it to consider, [or] entirely failed to consider an important aspect of the problem"); Citizens to Preserve Overton Park, Inc. v. Volpe, 401 U.S. 402, 416 (1971) (holding that in judicial review of an agency's action for arbitrariness, an important issue is whether the agency's decision "was based on a consideration of the relevant factors").

[138] FEDERAL RULE OF EVIDENCE 702.

[139] *Id.*

[140] FEDERAL RULE OF EVIDENCE 104(a); Kumho Tire Company, Ltd. v. Carmichael, 526 U.S. at 152 (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

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preponderance of the evidence whether these conditions are satisfied.[141] On appellate review, the standard of review for the district court's evidentiary rulings is the deferential "abuse-of-discretion" standard.[142] A motion to exclude proffered expert testimony therefore triggers a decision-making process governed by procedural and evidentiary process rules,[143] which the default-logic paradigm models using implication trees, concept-based entailments, plausibility schemas, and theories of uncertainty.[144]

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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").

[141] *See* Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579, 592-93, note 10; Kumho Tire Company, Ltd. v. Carmichael, 526 U.S. at 152.

[142] General Electric Company v. Joiner, 522 U.S. 136, 141-43 (1997).

[143] 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 non-epistemic policy objectives. See Kumho Tire Company, Ltd. v. Carmichael, 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") (brackets in original).

[144] 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 Daubert v. Merrell Dow Pharmaceuticals, Inc., 43 F.3d 1311 (1995) (judgment after remand from the Supreme Court) (case involving the evaluation of epidemiologic, statistical, and other types of evidence allegedly relevant to proving causation of limb reduction birth defects); General Electric Company v. Joiner, 522 U.S. 136 (1997) (case involving the evaluation of epidemiologic and animal-study evidence allegedly relevant to proving causation of small cell lung cancer); Kumho Tire Company, Ltd. v. Carmichael, 526 U.S. 137 (1999) (case involving the evaluation of physical evidence allegedly relevant to proving causation of a tire blow-out).

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C.   Process Rules and Inference Trees

Procedural and evidentiary process rules control the dynamics of legal reasoning by their content, and there is no difference in logical structure between process rules and substantive rules. A complete inference tree for the legal reasoning in a particular case will include an implication tree modeling the substantive and process rules that are applicable, with schematized evidentiary assertions attached to the terminal propositions of both substantive and process branches. Because, however, the same process implication tree connects to many substantive trees (e.g., process trees for deciding jurisdiction), or connects to many branches in the same implication tree (e.g., process trees for deciding the admissibility of evidence), it is practical to model those process rules separately from the substantive trees to which they connect.[145] In addition, distinctive non-epistemic policies behind process rules make it efficient to justify process rules separately. Such separate modeling and justification, however, should not obscure the identity of logical structure between rules of substance and rules of process, or the fact that the main implication tree for a decision includes branches for both kinds of rules.

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. When the personal knowledge of the lawyers for the parties and of the judge can determine the truth or falsehood of the terminal propositions of strategic process rules, then the court can dispose of entire claims without the need for witnesses. For example, a ruling that the court lacks jurisdiction warrants dismissal of the entire complaint.[146] It is not always possible, however, to decide even a high-level process rule early in the case. For example, factfinding might be needed to decide whether the statute of limitations has been satisfied.[147] 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

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[145] For the same reason, software modules automating process decisions can be written as self-contained programs, and would "launch" from any number of levels in a main substantive tree.

[146] *See supra* text accompanying notes 116-22.

[147] *E.g.*, Cipollone v. Liggett Group, Inc., 893 F.2d 541, 579 (3rd Cir. 1990), *aff'd in part and rev'd in part on other grounds*, 499 U.S. 935 (1991) (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).

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inexorable growth in complexity.[148] Careful empirical research is required to determine whether, when actual cases begin to apply those process rules, there is an actual increase in efficiency.[149]

CONCLUSION

The inference trees of the default-logic paradigm are designed to model the legal reasoning, including the factfinding, that warrants the conclusions, decisions, and actions of any governmental institution.[150] The upper portion of any inference tree consists of an implication tree that models all of the substantive and process legal rules that could affect the ultimate conclusion. Such implication trees may be supplemented by more local, concept-based entailments, which warrant deductions between branches of the same tree or of different trees. Policy-based reasoning aims at justifying the legal rules (that is, the form of the implication trees) by using objectives and principles that are outside the trees themselves. The legal rules modeled by implication trees and entailments should be the same for all cases in the jurisdiction at any point in time, although the rules (trees and entailments) can also change over time.

The lower portion of an inference tree for a particular case consists of evidentiary assertions attached to the terminal propositions of the implication tree. The plausibility schemas that organize those evidentiary assertions extend the inference tree downward and outward. This overall tree structure shows the continuity and parallelism between rule adoption and evidence attachment, between policy balancing and evidence evaluation, and between making legal rulings and finding facts. Plausibility schemas also integrate into single patterns of reasoning both expert and non-expert evidence. As the factfinder evaluates the plausibility of individual evidentiary assertions, the

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[148] 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 supra* text accompanying notes 138-44.

[149] An advantage of the default-logic model of process rules is that it makes this complexity transparent and an easier subject of empirical study. In the default-logic paradigm, additional process rules always add complexity to the implication tree, and therefore increase the number of terminal propositions that are in play. The research question is whether the content of those process rules actually increases or decreases efficiency in actual cases (including factfinding).

[150] 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 model 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 model for analysis therefore creates the possibility of extensive comparative research.

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plausibility schemas warrant assigning truth-values to the terminal propositions of the implication tree, which in turn determine the truth-values of propositions further up the implication tree. Plausibility schemas, through the theories of uncertainty that they represent, make the evidentiary warrant for default reasoning more transparent and formal.

These same logical structures can model legal process rules, which balance the epistemic objective with such non-epistemic objectives as fairness and administrative efficiency. The implication trees for procedural rules are conjunctive branches of main implication trees. The implication trees for evidentiary rules supply the rules of decision for certain procedural trees – for example, the admissibility rules used to decide motions to exclude proffered evidence. The default-logic paradigm shows how substantive and process rules together structure the legal reasoning 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 legal reasoning.[151] Implication trees for legal rules and plausibility schemas for factfinding 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, or 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 factfinding also allows comparative analyses of different factfinding 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 accounts of the law. Such empirical research should also lead to testable theories about patterns of legal reasoning and factfinding.[152]

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[151] 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 factfinding 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.

[152] For example, legal researchers can test hypotheses about how new legal rules evolve out of established factfinding patterns or about how new plausibility schemas evolve within institutions that conduct reasoned and transparent factfinding. 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 138-44).

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The default-logic paradigm also makes the results of such research available for immediate use. Artificial intelligence software can incorporate the inference trees of particular cases into a coordinated system of "smart" legal "objects."[153] 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" would make far better use of the vast legal databases that are now available. Intelligent software would also allow 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. For the default-logic paradigm, especially when incorporated into intelligent software, is above all a framework to help legal systems improve the legal reasoning and factfinding in the next legal case.

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[153] 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.*, Michael Wooldridge, *Intelligent Agents*, in MULTIAGENT SYSTEMS, *supra* note 6, at 28-36 (comparing computing objects and agents); RUSSELL & NORVIG, *supra* note 6, at 322-28 (discussing categories and objects within computing environments). Implication trees, plausibility schemas, and inference trees are themselves suitable for programming as objects.