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Visualizing the dynamics around the rule–evidence interface in legal reasoning

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This paper presents a visual framework for modelling complex legal reasoning—reasoning that integrates legal rules and policies with expert and non-expert evidence. The framework is based on a many-valued, predicate, default logic. The paper first visualizes the two sides of the rule–evidence interface: rule-based deductions and evidence evaluation. It then explores ways to visualize several dynamics around that interface, including dynamics concerning evidentiary relevance, findings of fact, process decision making about motions, policy-based reasoning about rules and relevant-factor reasoning. The paper then concludes with visualizing dynamics across multiple cases and briefly discusses one pathway by which new legal rules might emerge from the factfinding process. The paper therefore presents a visual working environment for people who litigate or decide actual cases, who study judicial or administrative reasoning or who teach law.

Keywords: default logic; many-valued logic; predicate logic; legal reasoning; visualization; graphical representation; rule-based reasoning; factfinding; evidence evaluation; policy-based reasoning; relevant-factor reasoning.

1. Introduction

In modern legal systems, the litigated issues are numerous, the reasoning is complex and the decision-making processes are highly regulated. Moreover, the decision making integrates legal rules and policies with expert and non-expert evidence. What is needed is a means of representing, studying and partially automating such complex legal reasoning. The goal of this paper is to visualize elements of one solution to this problem—a default-logic framework based on a many-valued, predicate, default logic. Details of the logic of this framework have been published elsewhere.[1] The purpose here is to visualize the logical landscape, not to provide a detailed map of that terrain.

The paper first visualizes the two sides of the 'rule–evidence interface' and then discusses the basic dynamics that occur around that interface. Part 2 presents visualizations for legal rules and the deductions based on them, as well as for evidence and the reasoning that evaluates it. Part 3 then

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1 VERN R. WALKER, A Default-Logic Paradigm for Legal Fact-Finding, **47** *Jurimetrics Journal* 193–243 (2007). For other discussions of default reasoning within the research on artificial intelligence and law, see, e.g. HENRY PRAKKEN & GIOVANNI SARTOR, The Three Faces of Defeasibility in the Law, **17** *Ratio Juris* 118–39 (2004); BART VERHEIJ, *Virtual Arguments: On the Design of Argument Assistants for Lawyers and Other Arguers* 97–122 (The Hague: T.M.C. Asser Press, 2005).

visualizes five aspects of the dynamics around that interface that occur within a single case: evidentiary relevance, findings based on the evidence, process decision making about motions, policy-based reasoning about rules and relevant-factor reasoning generally. Part 4 introduces the topic of visualizing dynamics across multiple cases and briefly discusses one pathway by which new legal rules might emerge from the factfinding process.

2. Visualizing the two sides of the interface

This part of the paper introduces the logic model for the two sides of the rule–evidence interface. It first visualizes the 'rules side' of the interface and models the reasoning that consists of deductions based on legal rules. The second section visualizes the 'evidence side' of the interface and models the reasoning involved in evaluating evidence. The extended examples throughout this part are drawn from the federal compensation system established by the National Childhood Vaccine Injury Act (the 'Vaccine Act').[2]

2.1 *Visualizing rule-based deductions*

It is common to model legal rules as conditional propositions[3] and to visualize a set of related legal rules as having a tree-like structure.[4] The 'implication tree' shown in Fig. 1 is a drawing of some of the high-level rules that govern compensation awards under the Vaccine Act. The ultimate issue to be determined (the proposition at the top of the tree) is whether compensation should be awarded under the National Vaccine Injury Compensation Program. The conjunction below this conclusion shows that compensation should be awarded if several conditions are met: first, that 'the person who suffered the injury or who died received a vaccine set forth in the Vaccine Injury Table' of the Vaccine Act; second, that 'there is a causal relationship between the vaccination and the injury' and, finally, that other conditions are met—e.g. concerning where the vaccination occurred or the extent of the injury. (In this drawing, as in the other drawings in this paper, the implication tree shown is only a partial tree. A tree incorporating all applicable rules would be quite extensive.) The model also shows that the second condition (causation) can be established in turn by a disjunction: if either 'there is a statutorily prescribed presumption of causation' or 'there was "causation in fact" between the vaccination and the injury'. Finally, this entire line of reasoning can be defeated by proof that 'the

[2] 42 U.S.C. §§300aa-10 *et seq.*

[3] See, e.g. SCOTT BREWER, Exemplary Reasoning: Semantics, Pragmatics, and the Rational Force of Legal Argument by Analogy, **109** *Harv. L. Rev.* 923, 972 (1996) (defining 'rule' in a 'logically spare manner' as 'a prescriptive proposition that has a logical structure the most abstract form of which is reflected in the standard conditional proposition, either propositional ("if P then Q") or predicate ("for all x, if x is an F then x is a G")').

[4] See, e.g. TERENCE ANDERSON & WILLIAM TWINING, *Analysis of Evidence: How to Do Things with Facts Based on Wigmore's Science of Judicial Proof* 108–55 (Evanston, Illinois: Northwestern University Press, 1991) (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 (New York: John Wiley & Sons, Inc., 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 upwards to the root node); DAVID A. SCHUM, *Evidential Foundations of Probabilistic Reasoning* 156–94 (New York: John Wiley & Sons, Inc., 1994) (interpreting Wigmorean evidence charts as 'directed acyclic graphs whose nodes indicate propositions and whose arcs represent fuzzy probabilistic linkages among these nodes'); DOUGLAS WALTON, *Legal Argumentation and Evidence* 338–48 (University Park, Pennsylvania: The Pennsylvania State University Press, 2002) (discussing argument diagramming).

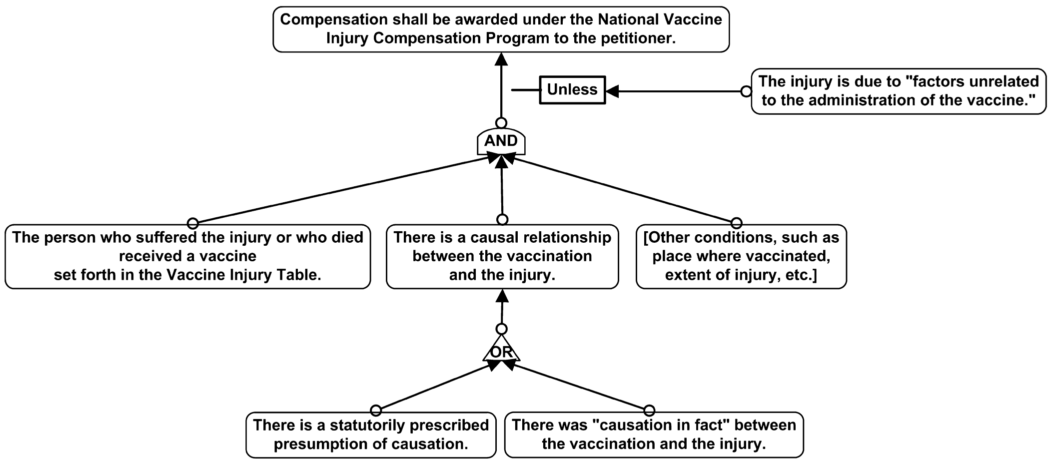

FIG. 1. Partial implication tree for the Vaccine Act.

injury is due to "factors unrelated to the administration of the vaccine"'. This defeating proposition attaches to the appropriate branch of the tree by the connective 'UNLESS', inserted in this example just below the ultimate issue at the top.

In general, therefore, an implication tree is an inverted tree with the root node at the top (representing the ultimate issue of fact to be proved) and branches extending downwards (representing all of the legally recognized lines of proof that can support a finding of that ultimate issue). The set of all 'terminal propositions' at the ends of the branches of the implication tree contains all of the issues of fact relevant to proving the ultimate issue. Logical connectives link the levels within such trees—connectives such as conjunction, disjunction and defeater (shown in Fig. 1 as 'AND', 'OR' and 'UNLESS', respectively).[5] When two levels of the tree are connected by 'AND', then the conclusion (the upper level) is true if all of the premises (the propositions on the lower level) are true. For the connective 'OR', the conclusion is true if one or more of the premises is true. When the connective is 'UNLESS', then the conclusion is false if the defeater premise is true.

When courts decide cases and interpret the statutory wording of the Vaccine Act, they add new legal rules and therefore modify the branches of the implication tree. For example, one issue of fact identified by the implication tree in Fig. 1 is whether there was 'causation in fact' between the vaccination and the injury. The case of *Althen* v. *Secretary of Health and Human Services*[6] interpreted this issue as involving a conjunction of the three premises shown in Fig. 2. Causation in fact is proved by establishing three propositions: 'an acceptable "medical theory" causally connects the vaccination and the injury'; 'a "logical sequence of cause and effect" shows that the vaccination was "the reason for" the injury' and 'there is a "proximate temporal relationship" between the vaccination and the injury'. When courts extend the statutory tree, they add new terminal propositions to the set of issues of fact—presumably, new issues that provide needed guidance to courts and factfinders

[5] For a discussion of the logical properties of these truth-functional connectives, see Walker, *supra* n. 1, at 198–202.
[6] 418 F.3d 1274, 1278 (Fed. Cir. 2005).

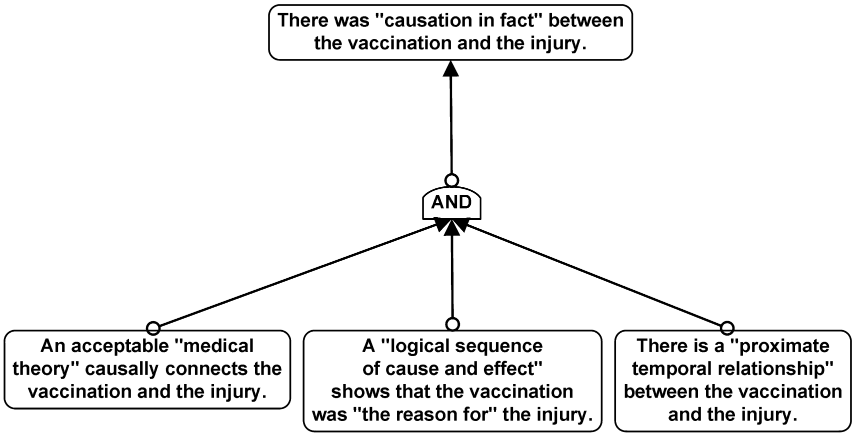

FIG. 2. The causation rule of *Althen*.

in future cases. It is the combination of legislative and judicial authority, therefore, that creates the legal rules modelled by an implication tree.

Whereas traditional logic operates with two truth values (True/False), it is more natural to model legal rules as having one of three truth values (True/Undecided/False).[7] When a legal case begins, all of the propositions in the implication tree are undecided. As the case proceeds, the parties might stipulate certain issues to be either true or false, the judge may determine truth or falsehood as a matter of law or the parties might introduce evidence and try to convince the trier of fact to evaluate particular issues as being true or false. These three truth values could be visualized in many ways, such as by colouring the outlines or fills of the proposition shapes.

In addition, it is sometimes useful to introduce predicate-logic functionalities into the implication tree.[8] For example, some logical subjects within legal rules are 'context variables': they take different values or referents in different cases, but have the same value or referent throughout any particular case. For example, in the legal rules governing the vaccine cases, such context variables include 'the petitioner' who is filing the claim, 'the vaccination' involved and 'the injury' alleged. Figure 3 shows the high-level implication tree for the legal rules of the vaccine cases (combined from Figs 1 and 2), with these three context variables embedded in some of the proposition shapes to which they apply. In any particular case, these variables take values that refer to specific people, events or conditions. For example, in the case of *Schrum* v. *Secretary of Health and Human Services*,[9] these context variables had the following values: 'the petitioner' = Patricia Schrum; 'the vaccination' = a series of hepatitis B vaccinations in 2001 and 'the injury' = polyarteritis nodosa (PAN). In modelling that case, these specific values would be substituted for the context variables in the rules, so that the issues of fact in the case would incorporate the specifics of Patricia

[7] See Walker, *supra* n. 1, at 199.

[8] For other research applying predicate logic to legal reasoning, see JAAP HAGE, *Studies in Legal Logic* 69–99 (Dordrecht, The Netherlands: Springer, 2005).

[9] 2006 WL 1073012 (Fed. Cl. 2006).

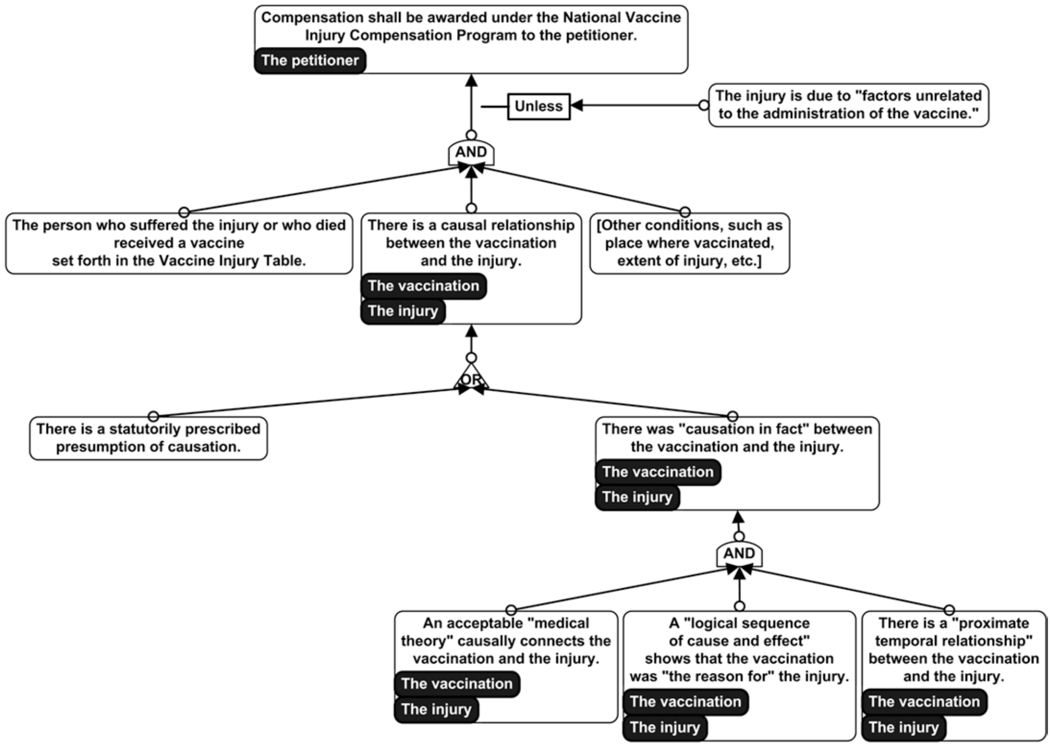

FIG. 3. Partial implication tree for the Vaccine Act with embedded context variables.

Schrum's case. The visualization in Fig. 3 helps to identify those critical referents needed to apply the legal rules to a particular case and helps to clarify what it means to 'apply a rule to a case'.

2.2 *Visualizing evidence evaluation*

If the legal rules applicable across many cases form one side of the rule–evidence interface, then the other side consists of the evidence introduced in any particular case. Just as propositions can capture the informational content of the rules, propositions can also capture the informational content of the evidence that is used in legal proof. The easiest example of such evidence is the assertion of a witness, taken directly from the witness's testimony. Other propositions, however, are those formulated by the factfinder—such as a description of an exhibit or a description of the demeanor of a witness. From a logical standpoint, the evidence consists of propositions called 'evidentiary assertions', a name that helps distinguish them from the propositions involved in legal rules.

While the propositions of legal rules and evidentiary assertions are both propositions, the propositions of legal rules have one of three truth values (as discussed above), while evidentiary assertions can have various degrees of plausibility. For example, a factfinder might assign to one evidentiary assertion a plausibility value on a five-valued scale (such as 'Very Plausible/Plausible/Undecided/ Implausible/Very Implausible') and to another evidentiary assertion a plausibility value from a seven-valued scale (such as ‘Highly Plausible/Very Plausible/Slightly Plausible/Undecided/Slightly Implausible/Very Implausible/Highly Implausible’).[10] While it is an important question why the law formulates legal rules on a three-valued scale, but allows factfinders to use a variety of plausibility scales to evaluate the evidence, that question goes well beyond the scope of this paper.[11] So does the question of how a reasonable factfinder would select the best plausibility scale to use to evaluate any particular evidentiary assertion. The topic here, however, is visualizing the factfinder’s task of evaluating the evidence, not explaining the logical structure of that evidence.

Evaluating the evidence in a particular case involves more than assigning plausibility values to the evidentiary assertions in the case. It also requires organizing those evidentiary assertions into logical patterns of proof. ‘Plausibility schemas’ are patterns of default reasoning that presumptively support a conclusion based upon the plausibility of the premises.[12] The reasoning is merely presumptive because there is a potential for error in assigning plausibility values to particular assertions and also in organizing the reasoning that incorporates those assertions. Like implication trees, plausibility schemas can be visualized as an inverted tree, with the conclusion at the top and the premises in levels below. The levels are connected by ‘plausibility connectives’—logical connectives that determine the plausibility value of the conclusion as a function of the plausibility values of the premises.[13]

[10] For a discussion of plausibility scales, see Walker, *supra* n. 1, at 209–12. Occasionally there may be such a well-understood causal system that factfinders can evaluate evidentiary assertions using a mathematical probability scale (the real numbers between 0 and 1), although such occasions are probably rare in legal cases. For a critique of using probability systems within legal factfinding, see VERN R. WALKER, Language, Meaning, and Warrant: An Essay on the Use of Bayesian Probability Systems in Legal Factfinding, **39** *Jurimetrics* 391–430 (1999).

[11] See the discussion in Walker, *supra* n. 1, at 199, 209–12 (arguing that a system of legal rules based on more than three values would be very complicated and probably largely unprincipled; moreover, that a three-valued system suits the pragmatic needs of legal decision making, promotes consistency among findings and allows maximum discretion to factfinders in selecting the plausibility scales to use in particular cases).

[12] For a discussion of the logical properties of plausibility schemas, see Walker, *supra* n. 1, at 212–32.

[13] These logical properties distinguish plausibility schemas from ‘argumentation schemes’. See Walker, *supra* n. 1, at 212 & n. 70, 72. A logical schema is 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, 147–8 (New York: Harper & Row, 1970); JOHN M. ANDERSON & HENRY W. JOHNSTONE, JR, *Natural Deduction: The Logical Basis of Axiom Systems* 20–1 (Belmont, California: Wadsworth Publishing Co., Inc., 1962). In semantics, schemas are used to specify conditions for assigning a truth value to a sentence, see, e.g. JOHN I. SAEED, *Semantics* 89, 305–9 (2nd edn. Oxford, UK: Blackwell Publishing, 2003), or more generally, to organize cognitive domains such as language, see ibid. at 353–7.

The function of an argumentation scheme, however, 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’. DOUGLAS N. WALTON, *Argumentation Schemes for Presumptive Reasoning* 13–14, 46 (Mahwah, New Jersey: Lawrence Erlbaum Associates, 1996). Argumentation schemes are ‘presumptive and plausibilistic in nature’, supporting a conclusion that is ‘a reasonable presumption’. Ibid. 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’. Ibid. at 13–14. Thus, argumentation schemes are dialectical in nature, and they provide one approach to modelling default reasoning from the perspective of rhetoric or informal logic.

Researchers in artificial intelligence and law have also studied argumentation schemes. See, e.g. Prakken & Sartor, *supra* n. 1, at 124–6, 129–30 (discussing ‘a model of legal reasoning as the dialectical interaction of competing inferences’); HENRY PRAKKEN, CHRIS REED & DOUGLAS WALTON, Argumentation Schemes and Generalisations in Reasoning about Evidence, 9 *International Conference on Artificial Intelligence and Law Proceedings* 32 (The ACM Digital Library: Association for Computing Machinery (ACM), 2003) (using argumentation schemes to model legal reasoning about evidence); BART VERHEIJ, Dialectical Argumentation with Argumentation Schemes: An Approach to Legal Logic, **11** *Artificial Intelligence and Law* 167–95 (2003).

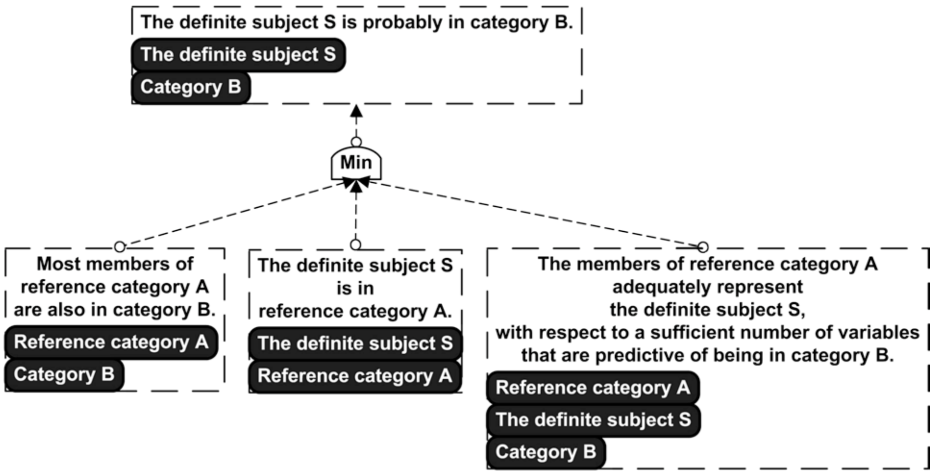

FIG. 4. The statistical-syllogism plausibility schema.

An example of a plausibility schema is the statistical-syllogism schema, shown in Fig. 4. The lines around the evidentiary assertion shapes are dashed instead of solid, to show that the proposition is evaluated for its plausibility value, not its truth value. Similarly, the lines of the arrows between assertions are also dashed instead of solid, to indicate that the inference is merely plausible (operates on plausibility values instead of truth values). What logicians call a 'statistical syllogism' or a 'direct inference' draws a plausible conclusion that places a specific individual in a particular class or category, based upon that individual's membership in another, 'reference' category.[14] While the logic behind the statistical-syllogism schema is discussed elsewhere,[15] the schema can be visualized as shown in Fig. 4. When values are substituted for the subject variables shown in Fig. 4, the result is a plausible pattern of default reasoning that supports or warrants drawing the conclusion at the top of the schema.

Plausibility schemas employ plausibility connectives to model the logical relationship from premises to conclusion. For example, in the statistical-syllogism schema in Fig. 4, the connective employed is 'MIN', an abbreviation for 'minimum'. The 'minimum' connective assigns to the conclusion a plausibility value identical to that of the *least plausible* premise. The conclusion can only be as plausible as its weakest premise. This is functionally equivalent to conjunction, only

[14] The inference is called a 'statistical syllogism' because a statistical premise (such as 'Most As are Bs' or 'X percent of As are B') is used instead of a universal generalization (All As are B). See, e.g. WESLEY C. SALMON, *Logic* 88–91 (2nd edn. Englewood Cliffs, New Jersey: Prentice–Hall, Inc., 1973); JOHN L. POLLOCK, *Nomic Probability and the Foundations of Induction* 75–7 (New York, Oxford: Oxford University Press, 1990). For discussions of the inference as 'direct inference', see, e.g. 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*, Chapter 4. Toulmin has referred to direct inferences as 'quasi-syllogisms'. See STEPHEN TOULMIN, *The Uses of Argument* 108–11, 131–4, 139–40 (Cambridge, UK: Cambridge University Press, 1958).

For research on this inference pattern in artificial intelligence and law, see HENRY PRAKKEN, Analysing Reasoning about Evidence with Formal Models of Argumentation, **3** *Law, Probability & Risk* 33–50 (2004) (formalizing the statistical syllogism); Prakken *et al.*, *supra* n. 13, at 39 (stating that if certain argumentation schemes are regarded as 'empirical generalizations', then 'applying the schemes boils down to applying the (qualitative) statistical syllogism').

[15] See Walker, *supra* n. 1, at 221–32.

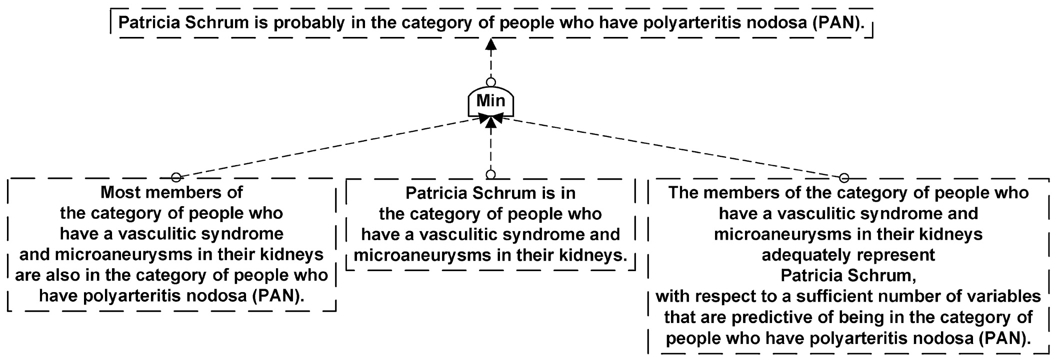

FIG. 5. The instantiated statistical-syllogism schema in the *Schrum* case.

generalized from a three-valued scale to a many-valued scale. Other plausibility connectives that are useful in constructing schemas are generalized disjunction (MAX), strong defeater (REBUT) and weak defeater (UNDERCUT).[16] A plausible strong defeater makes the conclusion implausible, while a plausible weak defeater merely undercuts the support that the line of reasoning would otherwise have provided and leaves the plausibility of the conclusion what it otherwise would have been.

The *Schrum* case discussed above also illustrates the use of the statistical-syllogism schema in factfinding.[17] The Special Master in that case used the reasoning pattern modelled by the schema to arrive at the conclusion that Patricia Schrum probably had the condition called polyarteritis nodosa (PAN). The values in the *Schrum* case for the context variables of the statistical-syllogism schema were the following: 'the definite subject S' = Patricia Schrum, the petitioner; 'reference category A' = the category of people who have a vasculitic syndrome and microaneurysms in their kidneys and 'category B' = the category of people who have polyarteritis nodosa. The diagram in Fig. 5 shows the instantiated schema using these context values in the *Schrum* case. The support for this conclusion was that Patricia Schrum had both a vasculitic syndrome and microaneurysms in her kidneys (a premise supported in turn by evidence about Patricia's medical condition). Also, the Special Master concluded (based on the general medical evidence in the case) that most people who have this combination of medical conditions also have polyarteritis nodosa. Moreover, the Special Master obviously believed that the people studied to reach this medical generalization were sufficiently representative of Patricia, at least with respect to predicting whether Patricia had polyarteritis nodosa. This combination of plausible premises warranted making this diagnosis in her case. Of course, such a conclusion is only presumptive and defeasible, but it was sufficient to shift to the government the burden of proving otherwise —by rebutting, e.g. one of the three premises of the schema.

Plausibility schemas are generic patterns of plausible reasoning. They are not case specific, like evidentiary assertions are. Nor are most schemas even domain specific, like legal rules are—although there can be patterns of presumptive reasoning used in particular areas of the law because they are based on policies or principles operative in that area. Schemas might be drawn from logic (such as

[16] For discussion of the four plausibility connectives discussed here, see Walker, *supra* n. 1, at 213–15.

[17] For another extended illustration of the statistical-syllogism schema applied to a vaccine case, see Walker, *supra* n. 1, at 226–32 (modelling *Huber* v. *Secretary of the Department of Health and Human Services*, No. 89-72V, 1990 WL 293881 (Cl. Ct. 1990), *remanded* 22 Ct. Cl. 255 (1991), *on remand* 1991 WL 62124 (Cl. Ct. 1991)).

the statistical-syllogism schema), science (schemas that capture the reasoning patterns of scientists), statistical theory (schemas that model statistical reasoning) or particular areas of decision making (such as regulatory risk assessment[18]), as well as from presumptions created by legislatures or courts. The function of a plausibility schema is to provide a template for organizing the available evidence in a case, in such a way that the instantiated schema provides the warrant for drawing a presumptive or tentative conclusion—a conclusion which is nevertheless defeasible due to adding new evidence or reorganizing the existing evidence.

The major principle in designing any plausibility schema is the theory of uncertainty underlying the type of inference.[19] A theory of uncertainty identifies the possible sources of error in the type of inference, and therefore helps a factfinder to identify the sources, types and degrees of uncertainty associated with drawing the conclusion. The theory explains how the available evidence could be plausible but the conclusion could still be false (or in the case of a defeater, how the conclusion could still be true). When a theory of uncertainty is reflected in the inference structure of a plausibility schema, the schema can alert the factfinder to the kinds of evidence needed to warrant the inference as presumptively plausible. The factfinder can then decide whether the available evidence is adequate under the circumstances or whether additional evidence is needed. Moreover, if one line of reasoning (instantiated plausibility schema) appears to be too weak, given the available evidence, then there may be another line of reasoning (another instantiated schema) that is stronger and which utilizes the same evidence. Thus, a theory of uncertainty explains why the associated plausibility schema can warrant the conclusion as presumptively plausible.

3. Visualizing dynamics around the rule–evidence interface within a single case

Part 2 above discussed the visualization of the two sides of the rule–evidence interface. While the logic models of both rules and evidence exhibit inverted tree structures, rules are constructed from truth-functional connectives that operate on the three possible truth values of the conditions, while plausibility schemas are constructed from plausibility connectives that operate on the many possible plausibility values of the premises. Thus, the two sides of the rule–evidence interface have logical similarities and dissimilarities. This second part of the paper discusses the visualization of various dynamics across the interface, or between the two sides of that interface—the interaction of rules and evidence in legal reasoning. This part will briefly discuss five topics: the visualization of ‘relevance’ (attaching schematized evidence to an implication tree of rules); the visualization of ‘propagation’ (making findings of fact by converting the plausibility values of evidentiary assertions into the truth values of rule propositions); the visualization of ‘process decision making’ (integrating motions practice into substantive decision making); the visualization of ‘policy-based reasoning’ about rules (reasoning about the adoption, maintenance or rescission of legal rules) and the visualization of how ‘relevant factors’ are used in factfinding and legal reasoning.

[18] See, e.g. VERN R. WALKER, Keeping the WTO from Becoming the “World Trans-Science Organization”: Scientific Uncertainty, Science Policy, and Factfinding in the Growth Hormones Dispute, **31** *Cornell International Law Journal* 251, 256–67 (1998) (discussing default reasoning in the form of ‘science policies’ as a means of addressing scientific uncertainty within regulatory risk assessment).

[19] For a discussion of theories of uncertainty, see VERN R. WALKER, Theories of Uncertainty: Explaining the Possible Sources of Error in Inferences, **22** *Cardozo Law Review* 1523 (2001). For a discussion of applying theories of uncertainty to the design of plausibility schemas, see Walker, *supra* n. 1, at 215–16, 222–6.

3.1 *Visualizing 'relevance'*

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'.[20] Relevance is therefore a logical relationship between one or more evidentiary assertions in a case and a terminal proposition of an implication tree. One task of a factfinder is to determine which evidentiary assertions are relevant to which terminal propositions or 'issues of fact'. A related task is to create a chain of reasoning that organizes the relevant evidence and 'attaches' it to the appropriate terminal propositions. The tools used to accomplish this are plausibility schemas. Plausibility schemas model the patterns of default reasoning that show how the evidence is relevant to any particular issue of fact. An evidentiary assertion is relevant to an issue of fact if it can help instantiate a plausibility schema, or chain of schemas, that can make that issue of fact more or less likely to be true.

For example, in the *Schrum* case discussed above, the petitioner and the government produced the standard types of evidence in the case: fact testimony by witnesses based on their personal knowledge, expert opinions, medical records, copies of published scientific articles and excerpts from medical textbooks. One task of the Special Master was to sift through the evidence and identify those evidentiary assertions that were relevant to the particular issues of fact that were in contention. A major issue was whether Patricia Schrum had in fact developed PAN following her hepatitis B vaccinations or whether she had developed Wegener's granulomatosis prior to the vaccinations.[21] In order to determine relevance, the Special Master had to identify a chain of plausible reasoning that connected the available evidentiary assertions to the contested issue of fact.

At this point it is necessary to distinguish whatever the actual reasoning of the Special Master might have been at the time, from a model of the reasoning that was reported in the opinion written in the case. The modeller uses the written opinion to reconstruct a possible line of reasoning and to determine its plausibility. In the *Schrum* case, the Special Master seemed to be particularly impressed that Patricia Schrum had not only a vasculitic syndrome but also microaneurysms in her kidneys.[22] Moreover, the Special Master concluded, based on the testimony and medical literature, that this combination was normally sufficient to diagnose polyarteritis nodosa.[23] One can surmise, further, that the Special Master found no peculiar factor in Patricia's condition or history that suggested that a diagnosis of polyarteritis nodosa should not be made in Patricia's case. In the language of the third premise in the statistical-syllogism schema, it was plausible that people with a vasculitic syndrome and microaneurysms in their kidneys adequately represented Patricia Schrum, at least with respect to predicting whether she had polyarteritis nodosa. This is not conclusive proof, but rather a plausible line of presumptive reasoning. If the evidence were to show some peculiar feature of Patricia Schrum's case that would cast doubt on this presumptive reasoning, then the third premise would no longer be plausible. But absent such a peculiar feature, a reasonable factfinder could make the diagnosis of polyarteritis nodosa—just as any competent and knowledgeable physician might.

[20] A proposition is 'probably true' to the extent that 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).

[21] See *Schrum*, 2006 WL 1073012 at *1, *15–*16.

[22] Ibid. at *17–*21.

[23] Ibid. at *9, *21.

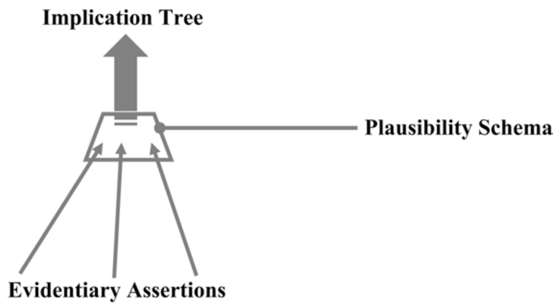

FIG. 6. Plausibility schemas guiding the attachment of evidence to implication trees.

From the perspective of visualization, the determination of relevance involves a number of aspects. First, for any particular issue to be proved, the factfinder identifies those evidentiary assertions that seem to be of relevance. This selection process could be guided by the intuitive patterns of reasoning that plausibility schemas are designed to capture. Moreover, in the *Schrum* case the parties had narrowed the legally significant medical possibilities to two: either polyarteritis nodosa or Wegener's granulomatosis. Therefore, additional factors were needed that could differentiate the two possibilities—factors that would be predictive of one medical condition but not the other. In terms of the statistical syllogism, such a set of factors would form the reference category to use in the reasoning.

In general, therefore, the question of relevance is resolved by finding a plausibility schema (or chain of such schemas) that, if instantiated by the available evidentiary assertions, would make an issue of fact more or less probable. The instantiated schema is then 'attached' to the terminal proposition to which it is relevant, thus extending the tree structure by adding evidence. Figure 6 suggests how plausibility schemas can help the factfinder to select and organize evidence for attaching to an implication tree. The model of the complete reasoning in a particular case can be visualized as an 'inference tree', consisting of the implication tree of legal rules in the top region and extended branches of instantiated plausibility schemas in the lower region.[24]

3.2 *Visualizing 'propagation'*

Once the factfinder determines the relevance of evidence in a particular case, the rule-based deductions of the implication tree (at the top) rest upon its terminal propositions, which rest in turn upon the schematized evidentiary assertions attached to those terminal propositions. The second major dynamic can then occur across the rule–evidence interface: the plausibility values that the factfinder assigns to the evidentiary assertions can then propagate upwards through the plausibility schemas, determine the truth values of the terminal propositions and therefore determine the truth value of the ultimate issue of fact. Visualizing this process of propagation raises the question of how to convert the plausibility values of schematized evidentiary assertions into the truth values of propositions within rules.

[24] See Walker, *supra* n. 1, at 208, 219.

This is the modelling counterpart to what the law refers to as the standard of proof.[25] The preponderance of evidence standard of proof provides the most intuitive resolution of the propagation problem. Any degree of plausibility in the evidentiary assertion attached directly to the terminal proposition converts to a value of 'true' for that proposition and any degree of implausibility converts to a value of 'false'. The appropriate conversion rules for the standards 'clear and convincing' evidence and proof 'beyond a reasonable doubt' raise more controversial questions of modelling—which are beyond the scope of this paper. What is important here is understanding the legal concept of standard of proof as part of the modelling problem of 'propagation'.

3.3 *Visualizing 'process decision making'*

The first two dynamics around the rule–evidence interface (determining relevance and propagating values across the interface) involve the fundamental aspects of factfinding about the substantive issues in a legal case. In a typical judicial case in the United States, the judge determines the content of the legal rules that are potentially applicable in the case, while the jury determines the relevance of the evidence, evaluates its plausibility and uses that evidence to determine the issues of fact. But in addition to these substantive determinations, judges decide motions that affect the outcome of the case in a variety of ways. Some motions are about the legal rules applicable to the case, while other motions are about the evidence in the case or about the reasoning from the evidence to the terminal propositions of the rules. The modelling task is to visualize the reasoning involved in deciding such motions and to visualize how to integrate decisions about motions into the main inference tree for the case. 'Process decision making' refers to the reasoning and decision making involved in granting or denying such motions.[26]

Examples of such motions include motions to dismiss, motions for summary judgement, motions to exclude evidence and motions for judgement as a matter of law.[27] The issues raised in such motions might be purely procedural (e.g. whether discovery should be allowed or whether a party was afforded fair notice); might be about the content of the rules that are applicable to the case (e.g. a motion to dismiss for failure to state a claim upon which relief can be granted or an objection to a requested jury instruction) or might be about the admissibility or sufficiency of the evidence or about the standard of proof to be used. Such motions have as their subject matter some element of the main inference tree in the case—they are either about the rules portion of the tree (the implication tree), about the evidence portion of the tree (the schematized plausibility schemas) or about some relationship between the rules and evidence.

Within the default-logic framework, modelling the reasoning involved in deciding motions requires no new logical objects or structures. Implication trees can model the legal rules that govern the decision making for a particular type of motion. Evidentiary assertions can apply those legal rules in the context of the particular case. The reasoning involved in deciding the motion can be modelled, therefore, as an inference tree. The primary difference between such process inference trees and the

[25] See, e.g. FLEMING JAMES, JR, GEOFFREY C. HAZARD, JR & JOHN LEUBSDORF, *Civil Procedure* Sections 7.5, 7.14, Boston: Little, Brown and Company, 1992 (discussing 'the three generally recognized standards of proof . . . : preponderance, clear and convincing, and beyond a reasonable doubt'); 2 *McCormick on Evidence* Section 339, at 438 (John W. Strong ed., 4th edn., St. Paul, Minnesota: West Publishing Co., 1992); Walker, *supra* n. 20, at 1075–8, 1097–1120 (discussing possible interpretations of the preponderance standard of proof, in light of the policies behind the rule).

[26] For further discussion of how to model process decision making, see Walker, *supra* n. 1, at 232–41.

[27] See, e.g. Federal Rules of Civil Procedure 12 (motions to dismiss), 50 (motions for judgement as a matter of law), 56 (motions for summary judgement); Federal Rule of Evidence 103 (rulings on evidence).

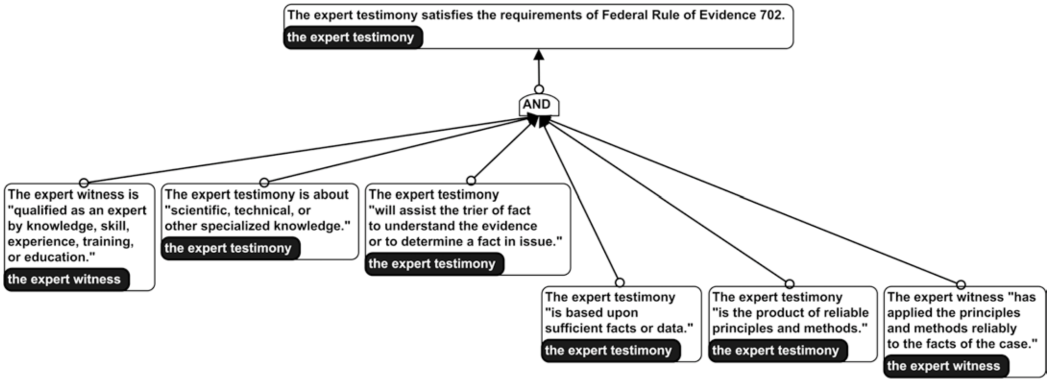

FIG. 7. Partial implication tree for the admissibility of testimony under FRE 702.

main substantive inference tree is that one or more context variables in the process implication tree refer to propositions, assertions or other items in the substantive inference tree. The process reasoning is ancillary to the substantive reasoning in the sense that the process reasoning is *about* or *refers to* the substantive reasoning, and is therefore, in logical terminology, 'second-order reasoning'.

Several illustrations will help to visualize this point. Figure 7 shows part of the implication tree for a motion to exclude from evidence a proffered expert opinion under Federal Rule of Evidence 702. The two context variables in this model are 'the expert witness' and 'the expert testimony'. The former takes as possible values the names of individual expert witnesses. The latter takes its values from the evidentiary assertions proffered by those witnesses as evidence in the case. If the motion to exclude this evidence is denied, then the proffered evidentiary assertion becomes available to the factfinder, to use in instantiating plausibility schemas. If the motion is granted, however, then the evidentiary assertion is not legally available to the factfinder.

Figure 8 shows a partial implication tree for a motion for judgement as a matter of law.[28] Such a motion can challenge the legal sufficiency of the totality of evidence relevant to a particular issue of fact in a case. If the judge grants a motion for judgement as a matter of law on a particular issue of fact, then the motion decides the truth value of that terminal proposition, and the factfinder's evaluation of the evidence does not. In the implication tree of rules for this motion, two of the three context variables refer to elements in the main substantive tree. 'The issue of fact' refers to the terminal proposition to which the evidence is relevant or would attach. 'The totality of relevant evidence' refers to the set of all the admissible evidentiary assertions that might be used to prove that terminal proposition. In the terminology of the default-logic framework, the issue that the motion raises is whether there is any plausibility schema (or chain of such schemas) that could organize that evidence into an acceptable proof of that terminal proposition. Such a motion, therefore, is also about the existence and structure of legally acceptable plausibility schemas.

As a final example of a motion, Fig. 9 displays a partial implication tree for a motion to dismiss a claim in a pleading for failure to state a claim upon which relief can be granted.[29] This implication tree includes a context variable that refers to 'the rule relied upon' in the pleading and argues that

[28] See Federal Rule of Civil Procedure 50(a)(1).
[29] See Federal Rule of Civil Procedure 12(b)(6).

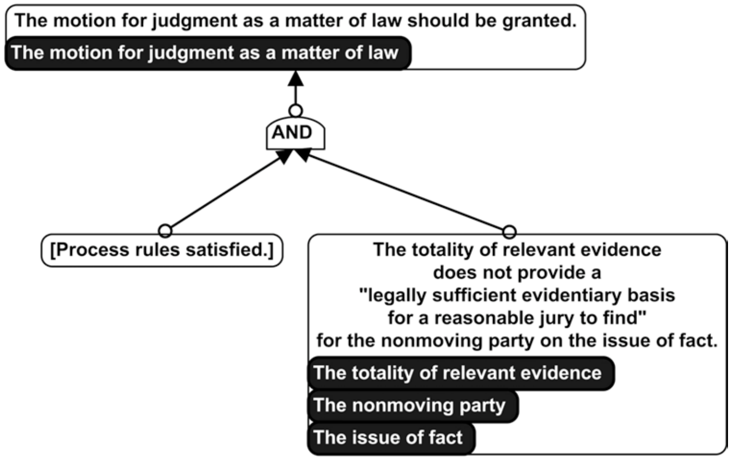

FIG. 8. Partial implication tree for judgement as a matter of law.

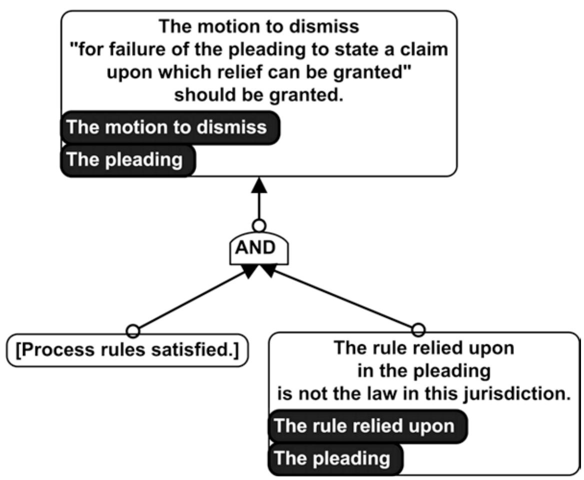

FIG. 9. Partial implication tree for a motion to dismiss for failure to state a claim.

the proffered rule is not a valid legal rule of the jurisdiction. Such motions lead to decisions about the structure of the substantive implication tree in the case.

As these examples illustrate, motions provide a means for reasoned decision making about the elements, structure or truth values of substantive inference trees. In an important sense, they provide second-order decision making about the law itself. As discussed below, process decision making provides the law with a structure within which the law can evolve new legal rules and refine existing ones. Within the default-logic framework, however, process decision making provides few new modelling challenges.

3.4 *Visualizing policy-based reasoning about rules*

Some motions are about adopting, maintaining or rescinding legal rules, and many courts decide such issues by reasoning about the policy rationales or fundamental legal principles 'behind' those rules. Examples of such policies include protection of public health, corrective justice, deterrence of criminal behaviour, procedural fairness and judicial efficiency. Many policies depend in turn upon evidence of consequences for their warrant (e.g. policies of deterrence and efficiency). Modelling and visualizing such reasoning can be a difficult matter, and it is currently at the frontier of logical research.[30] Two promising approaches, however, are to model such policy balancing along the lines of plausibility schemas (discussed above) or relevant-factor reasoning (discussed below). Just as factfinders may organize evidence into lines of default reasoning, judges might apply default patterns of reasoning to the mix of policies appropriate to a particular statute or area of law. Moreover, as is the case with weighing relevant factors, judges might balance competing policies in reaching a decision, perhaps incorporating some default priority between policies that weigh in opposite directions. Visualization of such reasoning will develop hand in hand with the understanding of the logical structure involved.

3.5 *Visualizing reasoning about relevant factors*

An important feature of legal reasoning is the role played by relevant factors. Statutes and lead cases sometimes adopt legal rules about which factors are relevant or irrelevant with respect to determining a particular issue of fact.[31] What is distinctive about relevant-factor rules is that while they specify which types of evidence are relevant, they do not impose a structure on how that evidence should be integrated into the warrant for a finding of fact. Normal rules of law do impose such structure, using truth-functional connectives, and are not merely relevant-factor rules. Relevant-factor rules impose some minimal relevancy constraints on the factfinder, but do not impose a normal rule structure.

[30] For example, the research within artificial intelligence and law on analogical reasoning is one type of policy-based reasoning. See, e.g. KEVIN D. ASHLEY & EDWINA L. RISSLAND, Law, Learning and Representation, **150** *Artificial Intelligence* 17–58, at 55 (2003) (stating that 'more study is needed to determine how legal experts evaluate analogical arguments in light of principles and policies' and that 'it is not yet clear how to represent principles and policies at the top of the argumentation pyramid, nor how to develop algorithms for integrating them into realistic arguments'); ibid. at 18 (discussing two ways in which rules can change: by changing the rule's structure, e.g. by adding conditions or exceptions, and by changing the meaning of the rule's constituent concepts).

For discussions of 'case-based reasoning' in artificial intelligence and law, which attempts to model legal reasoning that is based on case precedents, see Ashley & Rissland, *supra*, at 33–54 (surveying 'the HYPO family of case-based reasoning (CBR) models', including HYPO, CABARET and CATO); L. KARL BRANTING, *Reasoning with Rules and Precedents: A Computational Model of Legal Analysis* 1–25 (Dordrecht: Kluwer Academic Publishers, 2000) (discussing the research goal of using rule-based reasoning and case-based reasoning 'as complementary processes for classification and explanation in legal analysis'); EDWINA L. RISSLAND, Artificial Intelligence and Law: Stepping Stones to a Model of Legal Reasoning, **99** *Yale L. J.* 1957, 1968–78 (1990) (surveying early developments in artificial intelligence and law that used case-based reasoning).

For leading legal research on rule justification by analogy to precedents, see, e.g. EDWARD H. LEVI, *An Introduction to Legal Reasoning* (Chicago & London: The University of Chicago Press, 1949); CASS R. SUNSTEIN, On Analogical Reasoning, **106** *Harv. L. Rev.* 741 (1993); SCOTT BREWER, Exemplary Reasoning: Semantics, Pragmatics, and the Rational Force of Legal Argument by Analogy, **109** *Harv. L. Rev.* 923 (1996).

[31] See, e.g. the Federal Food, Drug, and Cosmetic Act, 21 U.S.C. §348(c)(5) (stating that the Secretary of Health and Human Services, in determining whether a proposed use of a food additive is safe, shall consider, among other relevant factors, the probable consumption of the additive, the cumulative effect of such additive in the diet and appropriate safety factors); *Whitman* v. *American Trucking Associations, Inc.*, 531 U.S. 457, 464–71 (2001) (holding that Section 109 of the Clean Air Act 'unambiguously bars cost considerations' from the process of setting national ambient air quality standards).

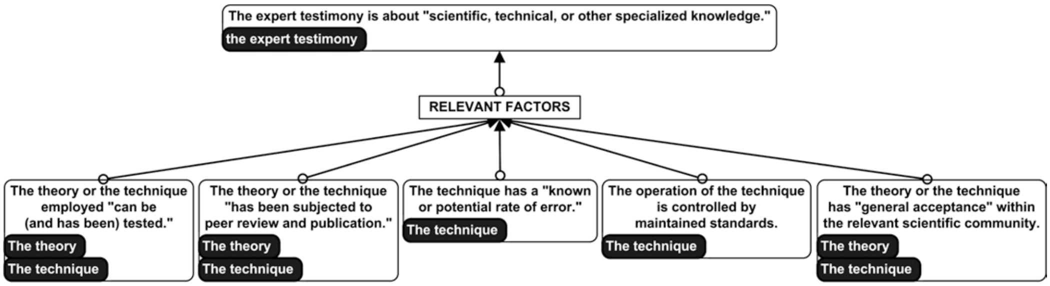

FIG. 10. A visualization of the relevant factors from the *Daubert* case.

The modelling and visualization of relevant-factor rules therefore present the following problem. On the one hand, a relevant-factor rule is an authoritative rule and not merely an option available to the factfinder in conducting evidence evaluation. On the other hand, it is not a logically structured legal rule, nor is it even as structured as a plausibility schema, which organizes relevant evidence into a default pattern of reasoning. The modelling challenge is to integrate certain rule-like qualities with certain evidence-evaluation qualities, in such a way that the resulting structure can represent the relevant-factor reasoning in a particular case.

One initial attempt at visualization is shown in Fig. 10. The partial tree shown in this figure extends one branch of the implication tree for Federal Rule of Evidence 702, shown in Fig. 7. The model in Fig. 10 represents five factors relevant to proving that the expert testimony is about 'scientific, technical, or other specialized knowledge', as those factors were enunciated in the lead Supreme Court case of *Daubert* v. *Merrell Dow Pharmaceuticals, Inc*.[32] This model represents each relevant factor as a complete proposition, capable of having a truth value. Moreover, the proposition is stated in such a way that if it is true, then the conclusion at the top is more likely to be true. The model therefore moves beyond the typical approach found in legal sources of merely identifying a factor as a category of evidence. Instead, the model requires that the factor be expressed as a proposition, and it shows the direction in which the factor weighs.

What is missing from the model in Fig. 10 is any of the truth-functional connectives normally found in legal rules. This initial attempt at a model merely connects the two levels of the tree with a function named 'relevant factors'. How this connective might operate is the topic of ongoing research. One possibility is that the relevant-factor propositions on the lower level would have plausibility values, as evidentiary assertions do, and that the evaluator is free to assign both plausibility values and relative weights for combining the plausibility values of those propositions. The connective would then compute a weighted plausibility for the conclusion at the top. But such an approach might not validly model how the reasoning occurs in real cases, and other approaches may be needed. What is of interest in this paper is that the attempt at visualization raises important questions about how the logic works and may suggest some possible solutions.

[32] 509 U.S. 579, 592–95 (1993). While the *Daubert* decision addressed the admissibility of testimony based on scientific knowledge, the Court later recognized that the same factors could also be relevant to the admissibility of testimony based on technical knowledge. See *Kumho Tire Co., Ltd*. v. *Carmichael*, 526 U.S. 137 (1999).

4. Visualizing dynamics over multiple cases: the emergence and evolution of new legal rules

Visualizing the reasoning in a particular legal case is possible using the logical tools discussed in Parts 2 and 3—namely, implication trees for legal rules, attached and instantiated plausibility schemas, process inference trees to represent reasoning about motions and relevant-factor reasoning in both main inference trees and in motions. Once this default-logic framework is used to model the reasoning in particular cases, however, the next step is to represent changes in such reasoning over time, comparing numerous cases. There could be various approaches to visualizing such changes—e.g. using a computer-generated video to show how an implication tree of legal rules in a particular area of law evolved over a succession of statutory amendments or within the case law.

Although such changes are difficult to visualize in the two dimensions of a printed page, this section of the paper briefly suggests one pathway for evolving new legal rules. When a judge or factfinder makes decisions on the basis of evaluating and weighing relevant factors and those decisions occur in a procedural context where the reasoning is explicitly documented and deferentially reviewed, then 'soft rules' can emerge. 'Soft rules' in this context are patterns of reasoning that are 'safe havens' of reasoning for judges or factfinders. Once one decision maker evaluates evidence in a certain way and makes the required finding of fact and the finding is upheld on review as reasonable, then that pattern of reasoning shows later decision makers one acceptable way to organize the evidence on that type of issue.

Over a line of cases, such soft rules might create *de facto* priorities among relevant factors, as decision makers enunciate informal presumptions or defaults when weighing the factors. Moreover, when it comes to evaluating evidence, as in the Vaccine Act cases, new plausibility schemas might emerge that later factfinders also use in evaluating evidence. Although no legal authority has 'hardened' such patterns of reasoning into rules of law, those schemas might guide factfinders who are aware of the line of cases. The emergence of *de facto* priorities and plausibility schemas can also set the stage for the adoption of new rules of law in the normal sense—rules about the relevance or irrelevance of certain factors, rules about the necessity of certain factors in order to have legally sufficient evidence or rules laying down new conditions for drawing the conclusion.

Such a hypothesis about a possible pathway for evolving new rules should be an empirical hypothesis. What is needed is empirical research into the changes in reasoning patterns over multiple cases, such as factfinding in the Vaccine Act cases or federal district court decisions applying the *Daubert* factors. Such research would be valuable for understanding the interaction of rule adoption with factfinding, for increasing the library of generally accepted plausibility schemas and even for improving the design of factfinding institutions.

5. Conclusion

A default-logic model is one tool for visualizing the actual reasoning in a legal case. Implication trees can represent legal rules, and supplying values for context variables can apply those rules to the particular case. Evidentiary assertions can represent the evidence, plausibility schemas can organize the reasoning about that evidence and the organized evidence can be attached to the factual conditions of the rules. Plausibility values assigned to the evidentiary assertions can propagate up the inference tree and help generate truth values for the findings of fact and for the ultimate issue of fact. These same logical elements can represent the reasoning used to decide motions in the case.

In addition, ongoing research is investigating the logic and visualization of policy-based reasoning about rules, relevant-factor reasoning and changes in reasoning patterns over multiple cases.

This method of representing legal reasoning illustrates how visualization can clarify inherent logical problems, as well as suggest solutions. Visualization can abstract the important logical elements in such reasoning and highlight the logical relationships among those elements. It can also show how it might be possible to automate parts of that reasoning. Such visualization of the underlying logic can be useful in litigating or deciding actual cases and in researching and teaching judicial or administrative reasoning.

What is needed is empirical research into the reasoning patterns found in actual cases. There is good reason to think that the default reasoning found in legal cases has distinctive features that only close observation is likely to discover. Once discovered, those patterns of default reasoning can be critiqued, improved and taught more effectively. The visual tools of the default-logic framework can be very useful in conducting that research and in bringing its fruits to the law office, the courtroom, the agency and the classroom.

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