

Towards a Formal Account of Reasoning about Evidence: Argumentation Schemes and Generalisations

Floris Bex, Henry Prakken
Institute of Information and
Computing Sciences
Utrecht University
PO Box 80089
3508 TB Utrecht, The Netherlands
{fjbex,henry}@cs.uu.nl

Chris Reed
Division of Applied Computing
University of Dundee
Dundee DD1 4HN
Scotland
chris@computing.dundee.ac.uk

Douglas Walton
Department of Philosophy
University of Winnipeg
Winnipeg, Manitoba
R3B 3E9 Canada
d.walton@uwinnipeg.ca

ABSTRACT

This paper studies the modelling of legal reasoning about evidence within general theories of defeasible reasoning and argumentation. In particular, Wigmore's method for charting evidence and its use by modern legal evidence scholars is studied in order to give a formal underpinning in terms of logics for defeasible argumentation. Two notions turn out to be crucial, viz. argumentation schemes and empirical generalisations.

1. INTRODUCTION

This paper addresses the formal modelling of legal reasoning about evidence within general theories of defeasible reasoning and argumentation. In AI & Law evidential reasoning is a little studied topic. Of the few studies that have been made, some zoom in on specific aspects, such as Lutomski (1989) on reasoning with statistical evidence, and Bromby & Hall (2002) on the credibility of eyewitness testimonies. Other research takes its starting point in mathematical or computational models, such as probability theory (e.g. Jøsang & Bondi, 2000) or model-based reasoning for automated diagnosis (e.g. Keppens & Zeleznikow, 2003). We instead follow a more cognitively inspired approach, aiming to stay close to the evidential reasoning forms used in practice. Thus we hope that our approach might better lead to practically useful software applications, such as knowledge-based systems, and sense-making systems.

Knowledge-based systems, which are the prime focus of AI & Law research, contain knowledge about a certain problem domain and reason with this knowledge in order to solve a certain concrete problem, or at least to suggest alternative solutions to it. Both Bromby & Hall (2002) and Keppens & Zeleznikow (2003) attempt to build a knowledge-based system for evidential reasoning. Sense-making systems (see e.g. Kirschner et al., 2003) do not themselves reason to solve a problem. Instead, the goal of such software is to support humans in making sense of a problem. To this end, [Peter Till]they provide tools for structuring (usually visualising) the problem and the user's reasoning in solving it. Often they also provide tools for manipulating these structures, e.g. by converting one visualisation into another, by combining pieces of information, or by performing logical or probabilistic computations on the user's input. In addition, some sense-making systems also support the communication between different people working on the same problem. An early example of sense-making software for evidential reasoning is Tiller and Schum's MarshalPlan project (Schum & Tillers, 1991), an early, pre-world-wide-web Hypertext application that supports preliminary fact investigations. Two general sense-making systems within AI & Law are Loui et al.'s (1997) Room 5 system and Verheij's (1999) ArguMed system. A domain independent sense-making system that supports the use of argumentation schemes is Reed & Rowe's (2001) Araucaria system. All systems mentioned thus far are still experimental; a commercial sense-making system for evidential reasoning currently being developed is *Legal Apprentice*, jointly developed by Vern Walker and Legal Apprentice, Inc.¹

The main difference between knowledge-based and sense-making systems is that the latter have no knowledge base, i.e., no collection of permanently stored general knowledge about a certain

¹ Demos can be found at http://people.hofstra.edu/faculty/vern_r_walker/LegalReasoning.html

domain. This means that for building sense-making systems, unlike for knowledge-based systems, no laborious and difficult knowledge-acquisition phase is necessary. This is very significant for applications to evidential reasoning, for which knowledge acquisition seems particularly hard.

Since both knowledge-based and sense-making software are supposed to support humans in realistic professional or educational contexts, such software arguably has a better chance of acceptance if it is based on the reasoning forms used in practice. In the context of legal reasoning about evidence, the use and naturalness of statistical methods has been heavily debated (e.g. Tribe, 1971, Lempert, 1986, Wagenaar et al., 1993, Schum, 1994). Although such methods certainly have their use (see e.g. Kadane & Schum, 1996 for an insightful probabilistic analysis of the famous Sacco & Vanzetti case), there are several reasons for taking a different approach. Firstly, statistical methods require numbers as input, and in the majority of legal cases reliable numbers are very hard to obtain, either because there are no reliable statistics, or because legal experts are unable or reluctant to provide numerical estimates. Secondly, probabilistic networks have additional limitations which are especially problematic for sense-making systems. Essentially, probabilistic networks compile all available knowledge into a probability distribution over certain variables of interest, and thus conceal some important distinctions of ordinary evidential reasoning. One such distinction concerns relationships between evidence, and the rhetorical, dialectical structure of discourse: legal disputes often consist of an exchange of explicit arguments and counterarguments, stated by opposing sides of the dispute. Moreover, probabilistic networks blur the distinction between directly relevant and ancillary evidence. (Ancillary evidence is evidence that has a bearing on the probative force of directly relevant evidence. A typical example is information on the credibility of a witness.) Schum (2001, p. 1948) remarks that the need for ancillary evidence especially arises when the conditional probabilities cannot be established by statistical relative frequencies. Moreover, even when such statistics are available, one may still need ancillary evidence, since lawyers often try to undermine the use of statistics by their adversary. For all these reasons it is important to study alternative accounts of evidential reasoning, which can deal with the predominantly qualitative and adversarial nature of legal reasoning about evidence.

We take as our starting point a specific technique developed in legal theory, studying a method for structuring evidential reasoning that goes back to John Henry Wigmore (1931). Wigmore developed a graphical method for charting legal evidence, a tool for making sense of a large body of evidence. Stripped to the bones, his charts depict the arguments that can be constructed from a given body of evidence, as well as possible sources of doubt with respect to these arguments. At the time, Wigmore's charting method went largely unnoticed but it was recently rediscovered by Anglo-American "new evidence scholars", for example, Anderson & Twining (1991), Schum & Tillers (1991) and Schum (1994). Today his method looks surprisingly modern, anticipating recent AI models of defeasible reasoning as well as recent sense-making software for argument visualisation. Our present aim is to explore both of these directions, capturing some of the 'logic' underlying Wigmore's charts in an outline of a formal account of evidential reasoning in terms the work of John Pollock (1987,1995,1998) on defeasible argumentation, and illustrating this account with a case study using argument visualisation techniques. We have chosen Pollock's approach since its emphasis on epistemology makes it suitable for modelling evidential reasoning. A crucial element in our account is the notion of argumentation schemes. When looking at evidential reasoning (or indeed at reasoning in general), one sees that many arguments, as well as attacks on them, are instances of recurring patterns, such as inferences from witness or expert testimonies, causal arguments, or temporal projections. The idea of systematising reasoning in terms of such argumentation schemes rather than just in terms of abstract principles of inference is the subject of much current study in argumentation theory. In fact, a great deal of AI (& Law) work can also be regarded as studying argumentation schemes (although it is usually not presented as such). For instance, we think that John Pollock's work on prima facie reasons is of this kind, as is much AI & Law research on modelling legal argument. However, to our knowledge, the only AI & Law work that addresses argumentation schemes for evidential reasoning directly is Lutomski (1989), who studies ways of

using and attacking statistical evidence.

In light of this, the aim of this paper is twofold:

- Showing how recent developments in legal evidence theory can be analysed with formal models of defeasible reasoning.
- Arguing for the relevance of the idea of argumentation schemes to models of evidential reasoning, and indicating a possible formalisation of reasoning with such schemes.

The rest of this paper is organised as follows. In Section 2 Wigmore's charting method is discussed by way of a simple example chart from his original work, and in Section 3 the notion of argumentation schemes is introduced. Then Section 4 outlines a formal account of Wigmore-style evidential reasoning with argumentation schemes within the formal framework of Pollock and applies it to the same example chart. In section 5 a more detailed case study is carried of a modern use of Wigmore's charting method by Kadane & Schum (1996) in their probabilistic analysis of the Sacco & Vanzetti case and some conclusions are drawn from it in Section 6. We end in Section 7 with a comparison with related work and some issues for future research.

This paper is an extended and revised version of Prakken, et al. (2003) and it also reuses some material from Prakken (2004). The discussion in Prakken et al. (2003) of argument visualisation has here been mostly omitted to allow space for the addition of a detailed second case study (Section 5, adapted from Bex, 2003), and an exploration of the issues of accrual of reasons and witness testimonies (Section 6).

2. WIGMORE'S CHARTING METHOD

A Wigmore chart looks very much (in broad outline) like the kind of argument diagram often used in logic textbooks to visualise the inferential structure of a given specimen of natural language argumentation. In an argument diagram the various premises and conclusions are represented as statements (propositions). The diagram is a set of points joined by lines. Each point represents a statement. Each statement is only represented once on the diagram. Each line represents an inference from one or more statements to another statement. Because it represents an inference, each line is normally drawn as an arrow, indicating a direction of the inference from premises to conclusion. Such a diagram is fairly simple. It looks like a directed graph of the kind so familiar in AI. A Wigmore chart looks like this too, but has all kinds of special features and notation that make it highly distinctive. The purpose of the Wigmore chart is to represent the proof of facts in the evidence presented on either side in a trial. Thus there are all kinds of special notations for distinguishing features like circumstantial evidence as opposed to testimonial evidence. It is best to begin with an example, to explain how the Wigmore evidence chart works.

2.1 An Example: the Umilian Case

The best source on charting is the second edition of Wigmore's Principles (1931). In this book, Wigmore (1931, pp. 62-66) used the case of *Commonwealth v. Umilian* (1901, Supreme Judicial Court of Massachusetts, 177 Mass. 582) to illustrate how method of evidence charts can be used in an actual case. A combination of two small charts for one aspect of the case that Wigmore himself used (1931, pp. 56,59) is displayed below in Figure 1.

Each arrow represents an inference. Wigmore describes it as "provisional force given to an inference by affirmatory evidence, testimonial or circumstantial". What the arrows join together (the circles, squares, and so forth) are "kinds of evidence" representing "human assertions" offered as "testimonial facts" or "circumstantial facts" (p. 52). These could be called "facts" for short. Circumstantial evidence is represented by a square, while testimonial evidence is represented by a circle. A triangle represents corroborative evidence that strengthens or supports an inference. For example (p. 53), "No third person was near the parties when the knife was found" or "Witness stood close by, was not excited, (and) was (a) disinterested spectator". An angle represents "explanatory

evidence” that explains away the effect of some other evidence (p. 53). A double bar at the top line of the angle tells us that this explanatory evidence was offered by the defendant. A dot within any of these symbols means “we now believe it to be a fact”. The infinity symbol below a fact means that the fact was “observed by a tribunal, or judicially admitted or noticed” (p. 53). For example, a witness’s assertion made in court on the witness stand would fit this category, or a coat shown in court (p. 52).

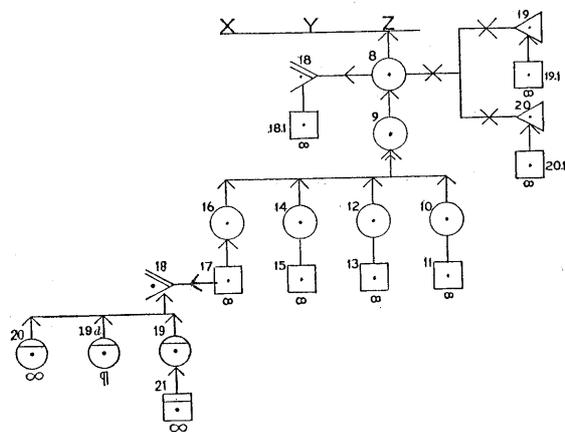


Figure 1: A Wigmore chart for the Umilian case

There are some bits of Wigmore’s notation that are less clearly explained. Notice that some lines have arrows while other do not, and some lines have an X on them. The X on the line signifies that the inference represented by the line is “a strong one” (Wigmore, 1931, p. 55). Also, the positioning of the facts, that is whether the lines are vertical or horizontal, seems to be significant. Wigmore tells us “A supposed fact tending to prove or disprove the existence of another fact is placed below it”, whereas an explanatory fact “tending to lessen or strengthen the force” of a fact, is place to the right or left of it.

The case of Commonwealth v. Umilian was a murder trial in which Umilian was accused of murdering Jedrusik. Wigmore presented many details of the evidence in the case. It would take too long to try to present all of this evidence. Instead we present a summary, consisting mainly of those facts of the case that are represented on the small chart in Figure 1.

2.2 Some Facts of the Case

U (Umilian) and J (Jedrusik) worked together as farm labourers until one day in December 1899 when J disappeared. In April, his headless body was found in the well 500 feet from the barn. In November, U had gone to a priest to have the marriage ceremony performed between him and a woman who had been working as a maid at the farm. He found that the priest had received a letter charging him with having a wife and children in the old country. The priest to refuse to marry him, and sent someone to investigate the letter. It turned out that J had written the letter and that its contents were not true. U was then married by the priest, but showed that he was very angry with J, and made threats of vengeance against him. There was much other circumstantial and testimonial evidence listed by Wigmore, but the gist of it, in relation to the small chart, is that U and J were isolated in the area of the barn for the period around the murder, so if anyone other than U had committed the murder, it is highly likely that he or she would have been detected.

With every chart Wigmore presented a “key list” numbering all the facts. Below are set out the various facts from Wigmore’s key list (pp. 64-66) that appear on the small chart. Z, he tells us (p. 56) is “one of the ultimate probanda under the pleadings, viz. that the accused killed the deceased”. (A probandum is something that has to be proven.) Note that, since we combine two separate charts,

the numbers 18, 19 and 20 are each used for two different nodes. The nodes referred to in the key list as 18(2), 19(2) and 20(2) can be found in the chart's bottom left corner.

KEY LIST

- Z: The charge that U killed J.
- 8: Revengeful murderous emotion toward J.
- 9: J's falsely charging U with bigamy, trying to prevent the marriage.
- 10: Letter received by priest stating that U already had a family in the old country.
- 11: Anonymous witnesses to 10.
- 12: J was author of letter (although it was in a fictitious name).
- 13: Anonymous witnesses to 12.
- 14: Letter communicated by priest to U.
- 15: Anonymous witnesses to 14.
- 16: Letter's statements were untrue.
- 17: Anonymous witnesses to 16.
- 18: U's marriage being finally performed, U would not have had a strong feeling of revenge.
- 18.1: Wigmore does not tell us what this represents. Maybe it is witness testimony.
- 18(2): The witness is biased.
- 19: U and J remaining in daily contact, wound must have rankled.
- 19.1: Witness to daily contact.
- 19(2): The witness is a discharged employee of U.
- 21: Anonymous witness to 19(2).
- 19d: Discharged employees are apt to have an emotion of hostility.
- 20: Wife remaining there, jealousy between U and J probably continued.
- 20.1: Witness to wife remaining.
- 20(2): The witnesses's strong demeanor of bias while on the stand.

Putting all these components together, it is possible to get an overview of the evidence represented on the small chart, and see how all the various items of evidence fit together in an inferential structure leading to the ultimate probandum Z.

We now proceed to summarizing Wigmore's explanation of argumentation represented in the small chart (pp. 56-57,9). Circle 8 is the revengeful murderous emotion. The arrow from 8 to Z "signifies provisional force" that 8 gives to Z. 9 is J's attempt to prevent U from marrying. It gives provisional force to 8. The dot in 8 indicates that it is believed by the drawer of the chart that the revengeful emotion was excited. Angle 18, just to the left of 8, is the fact that U actually married the woman, which tends to explain away the revengeful emotion. Square 18.1 is the testimony to the fact of marriage. The infinity symbol beneath it means that the evidence was heard in court. Triangle 19 means that U and J remained in daily contact after the marriage, thus keeping the emotion alive. Triangle 20 means that the wife remained there, and thus the emotion was intensified. That covers the top half of the chart. Looking now at the bottom half, 9 represents J's attempts to prevent the marriage. Each of 10, 12, 14 and 16 are bits of circumstantial evidence that go towards supporting 9. The line across these four arrows meeting the arrow that goes to 9 represents a "composite fact" joining all four elements 10, 12, 16 and 14. Each of these is individually backed by a bit of testimonial evidence – 11, 13, 15 and 17 respectively. The composite fact line is reminiscent of what is called a linked argument in modern argument diagramming. Finally, the bottom left part of the chart (which Wigmore actually depicted as a separate chat on p. 59) represents an attack on the truthfulness of one of the witnesses. Angle 18(2), placed just left of square 17, stands for the attack that one of the witness testifying to 16 was biased, while the structure below angle 18(2) represents support for the claim of bias.

There are good reasons to study the Wigmore chart. The diagram, when it is stripped to its essentials, and when some newly discovered features of argument structure have been incorporated, can reveal the logical structure of evidential reasoning in a powerful way, and this structure can be extremely useful for automating legal argumentation of the kind especially prominent in evidence law. Thus the theoretical implications for logic, law and AI are quite deep.

One very important aspect of Wigmore's method, as emphasized also by the new evidence scholars, is that he sees charting not primarily as an attempt to express reasons for belief but to

express reasons for doubt. Wigmore's basic purpose is more critical than constructive. It is to lay bare the possibilities of doubt by making the weak points in a chain of argumentation explicit. It shares this purpose with recent developments in argumentation theory. Argumentation schemes represent typical presumptive forms of reasoning that need to be analysed and evaluated in specific cases by using matching sets of critical questions. The critical questions function as a device to help make doubts explicit.

3. ARGUMENTATION SCHEMES

Argumentation schemes are forms of argument that represent stereotypical patterns of human reasoning. Among other things, they have been applied to model structures of human reasoning that are troublesome to view deductively, and that have even been classified as fallacious in the past. Although such arguments can sometimes be fallacious, in other instances they can be reasonable. For example, appealing to expert opinion could be reasonable if the field of the expert is appropriate, and other conditions are met. But, of course, as the logic texts have so often pointed out, such arguments can sometimes be fallacious appeal to authority. One might try to "deductivize" the reasonable instances, by viewing the major premise as a conditional that is true if the authority is knowledgeable. For example, a deductivist might view the major premise as the material implication: if X says A then A is true. But this deductivist strategy fails, unless the authority is omniscient, meaning that epistemic closure of the knowledge base can be assumed. But it is rare, if it ever occurs, that an expert knows everything, and thus that her knowledge in a domain is beyond challenge. Thus for many, or perhaps even all cases of appeal to expert opinion, the deductivist approach does not work. Thus the motivation for much recent research into argumentation schemes has been this tension between forms of argument that are clearly reasonable in some instances, but that cannot be analysed as deductively valid (Kienpointner, 1992; Walton, 1996a; Reed & Walton, 2001).

Perelman and Olbrechts-Tyteca (1969) cited numerous distinctive kinds of arguments that shift a weight of evidence on a balance of considerations. Hastings (1963) worked out the first modern taxonomy of argumentation schemes. A comprehensive list of argumentation schemes has been offered by Kienpointner (1992). Some schemes classified as presumptive in (Walton, 1996a) are: argument from sign, argument from example, argument from commitment, argument from position to know, argument from expert opinion, argument from analogy, argument from precedent, argument from gradualism, and the slippery slope argument.

3.1 Argument from Expert Opinion

Argument from expert opinion is not only a very common form of argumentation, it is also highly controversial. It is represented by the following argumentation scheme in the analysis given in (Walton, 1996a, p. 65).

Source E is an expert in domain D .

E asserts that proposition A is known to be true (false).

A is within D

Therefore, A may plausibly be taken to be true (false).

As shown by experiments in social psychology, there is a tendency to defer to experts, sometimes without questioning, resulting in fallacious appeals to authority. When confronted with such an appeal, the best reaction is to have some critical questions ready. The following six basic critical questions matching the appeal to expert opinion have been recommended in (Walton, 1997, p. 223).

1. *Expertise Question*: How credible is E as an expert source?
2. *Field Question*: Is E an expert in D ?
3. *Opinion Question*: What did E assert that implies A ?

4. *Trustworthiness Question*: Is *E* personally reliable as a source?
5. *Consistency Question*: Is *A* consistent with what other experts assert?
6. *Backup Evidence Question*: Is *A*'s assertion based on evidence?

Expert testimony has become an increasingly important type of evidence, and is the subject of much recent investigation (e.g. Morsek, 2001; Malsch & Nijboer, 1999). For this reason the exact formulation of critical questions is worth further study. Suffice it to say that, in many cases, asking one of the basic critical questions above will lead to critical subquestions at a deeper level of examination.

3.2 Appeal to Witness Testimony

The following argumentation scheme (taken from Walton, 1996a, p. 61) represents the form of appeal to witness opinion as an argument. The variable *W* refers to a witness. A witness is an agent that has incoming information about things it can perceive as facts or data, and that can relay that information to another agent. The variable *A* stands for a statement (or proposition, taken to be an equivalent term).

Witness *W* is in a position to know whether *A* is true or not.

Witness *W* asserts that *A* is true (false).

Therefore, *A* may plausibly be taken to be true (false).

When evaluating an appeal to witness testimony, the evaluator has no direct access to the evidence that the witness presumably possesses. This form of direct verification, by observation of the facts, is not possible. Hence the best the evaluator can do is to test the consistency of the account given by the witness, to see if the account hangs together, and is consistent with other evidence that is known about the case independently of the testimony. Probing into the consistency of the witness's account is achieved by asking critical questions. Critical questions relating to consistency concern the internal consistency of what the witness said, consistency with known external facts, and consistency with what other witnesses said. Wagenaar et al. (1993, p. 38) have studied such questions in evaluating the plausibility of witness testimony in accounts offered by witnesses in trials. Other critical questions important to cite in this connection concern the bias of the witness and the plausibility of the account offered. There are many indicators of bias. One of the most important ones is the finding that witness has something to gain by testifying in a certain way. Another indicator is the language used by the witness. For example, the language may have strong emotive connotations that are accusatory. Another indicator of bias is the selectivity of the witness's account. The account may stress details on one side, but overlook details that should be on the other side. If a witness is biased, it doesn't necessarily follow that the witness is lying. The bias could be unintentional. This plausibility factor can react on the evaluation of the appeal to witness testimony in various ways. If the statement made by the witness is highly implausible, it can backfire on the credibility of the witness. However, in some cases, the implausibility of the statement made can actually be a basis for conjecturing that what the witness claimed is really true. For example, if two independent witnesses have made the same implausible claim, it could suggest that their observations are careful and accurate.

The role of such critical questions has been discussed extensively in the legal literature on witness testimony and examination. Schum (1994, p. 325) has identified three requirements of the credibility of the testimony of a witness that can be questioned: (1) veracity, or whether the witness believes what she said, (2) objectivity, or whether what was reported corresponds to the event believed, and (3) observational sensitivity, or observations of linkages between events. Bromby and Hall (2002) devised a system to advise on the credibility of witness testimony by citing factors of (1) competency, (2) compellability, including the connection between the witness and the accused and any immunity the witness may have, and (3) reliability, which includes position to know factors.

do not discuss suppositional arguments, and we ignore issues of strength of arguments; instead, we focus only on the representation of evidential knowledge and on the construction of evidential arguments and counterarguments with such information. Moreover, since we aim to give a general picture of how evidential reasoning fits into the formal framework, we will suppress many technical details of Pollock's framework and we will largely abstract from underlying issues of knowledge representation.

4.1 Outline of Pollock's Framework

Essentially, Pollock augments the inference rules of classical logic (which he calls "strict reasons") with a set of defeasible inference rules (which he calls "prima facie reasons"), and he defines how defeasible inferences can be attacked. Prima facie reasons are not meant to express domain-specific generalisation; Pollock intends them to be general epistemic principles for obtaining beliefs from other beliefs and perceptual inputs, such as memory, statistical reasoning and induction. Arguments can be constructed by chaining reasons, starting from given input information. As usual in logic, arguments can be represented in two alternative but equivalent ways. To express the order in which the inferences are made, Pollock sometimes displays them as deductions, i.e., as sequences of formulas that are either given as input information or are derived by applying a reason to one or more earlier members in the sequence. This is also the form in which we will display arguments below. To represent instead the inferential dependencies between the propositions in an argument, Pollock sometimes represents arguments as AND trees, where the links represent applications of reasons. Finally, Pollock combines sets of such trees into an AND/OR graph and adds defeat links between nodes, resulting in an "inference graph". Clearly, such a graph is very similar to a Wigmore chart.

Pollock defines two ways in which a (defeasible) argument can be defeated. Such an argument can be *rebut* with an argument for the opposite conclusion, and it can be *undercut* with an argument why a prima facie reason does not apply in the given circumstances. Consider, for instance, an argument "The suspect was at the murder scene at the time of the murder since witness John says so" (applying a prima facie reason "if a witness says ϕ , one may infer ϕ "). This argument is rebut by another application of the same reason: "The suspect was not at the murder scene since witness Bob says he was with him in the pub at the time of the murder, and one cannot be in two places at the same time". And the argument is undercut by "It was too dark, so John could not have made a reliable identification" (applying another reason "if a witness says ϕ but the circumstances make reliable observation of ϕ impossible, one may not infer ϕ "). Intuitively, undercutting attacks do not argue that the attacked conclusion is false, but only that the conclusion is not sufficiently supported by its premises.

Finally, the dialectical status of an argument must be defined, to identify the defeasibly valid inferences. Since Pollock's system results in a collection of arguments and their binary defeat relations, Dung's (1995) general framework for argumentation is applicable. Pollock's definition is equivalent to Dung's preferred semantics, but nothing prevents the use of another appropriate semantics, such as Dung's grounded semantics (used by e.g. Prakken & Sartor, 1996).

What makes Pollock's approach especially interesting for us is his work on the various kinds of prima facie reasons, resulting in a general theory of epistemic defeasible reasoning. For present purposes, five reasons are especially relevant. We now paraphrase them and some of their undercutters as defined by Pollock (1987,1995,1998). Mostly, Pollock states them with numerical probabilities, but since, as noted above, in legal contexts reliable numbers are often not available, we give qualitative versions. We also leave Pollock's so-called "projectibility" conditions and some technical detail implicit. As for notation, if principle R says that P is a prima facie reason for Q , then " S is an undercutting defeater of R " is shorthand for " S is a prima facie reason for " P is not a prima facie reason for Q " (this presupposes that reasons can somehow be expressed in the object language).

The full picture can be summarised as follows. First *perception* is applied to sense data,

yielding specific beliefs, and *memory* is used to record and retrieve these data. Then *induction* infers general rules from them, after which the *statistical syllogism* derives new specific beliefs from these rules. Finally, beliefs thus derived *persist* over time.

R1: Perception: *Having a percept with content ϕ is a prima facie reason to believe ϕ*

In legal contexts perception applies to witness testimonies, but also to tangible evidence as presented at trial. Pollock (1987) formulates a general undercutter for perception, which we paraphrase as follows:

“The present circumstances are such that having a percept with content ϕ is not a reliable indicator of ϕ ” undercuts R1.

Clearly, this undercutter is just the tip of the iceberg of theories on the reliability of perception.

R2: Memory: *Recalling ϕ is a prima facie reason to believe ϕ .*

Two undercutters defined by (Pollock, 1987) are:

“ ϕ was originally based on beliefs of which one is false” undercuts R2.

“ ϕ was not originally believed for reasons other than R2” undercuts R2.

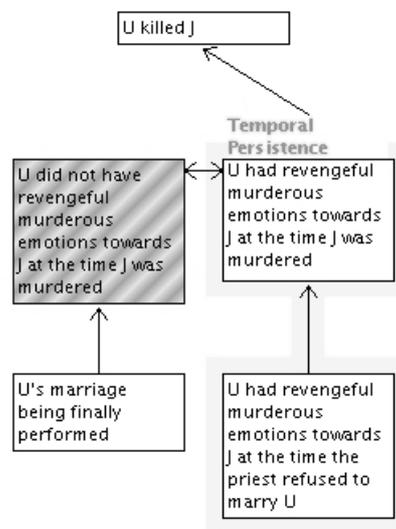


Figure 3: Temporal Persistence in the Umilian case

R3: Statistical syllogism: *‘c is an F’ and ‘F’s are usually G’s’ is a prima facie reason for ‘c is a G’*

This principle drives default reasoning with empirical generalisations. The main undercutter is subproperty defeat, which we give both in a weak and a strong qualitative form:

‘c is an F&H’ and ‘it is not the case that F&H’s are usually G’s’ is an undercutter of R3.

‘c is an F&H’ and ‘F&H’s are usually not G’s’ is an undercutter of R3.

R4: Induction: ‘most observed F ’s were G ’s’ is a *prima facie* reason for ‘ F ’s are usually G ’s’

Pollock formulates various undercutters to induction based on *bias of samples*.

R5: Temporal persistence: *Believing that ϕ is true at T_1 is a prima facie reason for believing ϕ at a later time T_2 .*

The general scheme for undercutters of temporal persistence arguments is

“Having reason to believe $\neg\phi$ at T_2 between T_1 and T_3 is an undercutter of R5”.

(Actually, Pollock restricts this to percepts of $\neg\phi$). Temporal persistence is an important aspect of evidential reasoning. For instance, in civil cases the usual way to prove that one has a legal right (e.g. ownership) is to prove that the right was created (e.g. by sale plus delivery). The other party must then usually prove later events that terminated the right. Our two case studies will illustrate that temporal-persistence arguments are also common in criminal cases.

However, the temporal persistence scheme does not apply to all kinds of facts. Clearly, many propositions, such as a position of a moving object, do not typically persist in time, so they are not “temporally projectible”. Pollock’s projectibility condition (which we have left implicit) is meant to capture which kinds of facts tend to persist in time. A technical example of propositions that are not temporally projectible is disjunctive weakenings of a proposition. Suppose that P is observed to be true at T_1 . Then it follows deductively that $P \vee Q$ is true at T_1 , for any Q . If next $\neg P$ is observed at T_2 , then P does not persist after T_2 . However, if $P \vee Q$ is allowed to persist from T_1 , its persistence is not affected by the observation of $\neg P$ at T_2 , so $P \vee Q$ persists until T_3 . But then it deductively follows that Q is true at T_3 . This is, of course, undesirable, so Pollock declares disjunctive weakenings of propositions as not temporally projectible.

This completes our very brief overview of Pollock’s theory of epistemic defeasible reasoning. We will now discuss how evidential reasoning as captured in Wigmore’s charts can be reconstructed within this theory. Two notions are especially important: generalisations and argumentation schemes.

4.2 Generalisations

One point stressed by current evidence theorists (e.g. Twining 1999, Wagenaar et al., 1993) is the key role of empirical generalisations in evidential reasoning. According to Schum (1994), such generalisations, which are usually left implicit, are the “glue” which holds evidential arguments together. For example, in Wigmore’s chart of the Umilian case, the inference of node 8 from node 9 seems to presuppose the generalisation “If x tries to prevent y ’s marriage with false claims, a revengeful murderous emotion from y towards x tends to be created”. Clearly, the probative force of the inference depends to a large extent on the strength of this generalisation. It might be argued in this case that the tendency expressed by this generalisation is too weak or does not exist; the point of making it explicit is to reveal this source of doubt. (Interestingly, Wigmore’s chart also contains an explicit generalisation, viz. 19d).

4.2.1 Obtaining and Applying Generalisations

In Pollock’s framework, generalisations are applied with the statistical syllogism, and part of their critical testing can be modelled as the search for counterarguments. One subtlety not captured by our current qualitative version of the syllogism is that generalisations often come with different modalities, such as “almost always, probably, usually, sometimes”. This is an issue that we leave for future research.

Something also seems to be missing from Pollock’s original account. Pollock simply assumes that all generalisations are based on the reason from *induction*, and that attacks on generalisations can

be expressed as undercutters of this reason. However, the generalisations used in evidential reasoning are often not based on careful empirical testing. In fact, according to Twining (1999) they are often based on folk beliefs, infected with value judgements, prejudice or ideology, and so on. Therefore, the induction scheme must be supplemented with other sources of generalisations, and suitable undercutters for these sources must be formulated. We now briefly sketch how this could be done.

Anderson (1999) distinguishes five kinds of generalisations according to their sources: scientific, expert-based, general knowledge, experience-based and belief-based generalisations. The first source is captured by the induction scheme and the second source will be captured by the expert testimony scheme (see below). Experience-based and perhaps also belief-based generalisations seem to be based on a commonsense counterpart of scientific induction (briefly discussed by Pollock 1995, pp. 82-3). Furthermore, the general-knowledge source could be formulated as a new *prima facie* reason:

R6: general knowledge: *'It is general knowledge that φ ' is a prima facie reason for φ*

Possible undercutters are that a piece of general knowledge is infected by prejudice or value judgements, etcetera.

A typical argument is then analysed as follows (ending each line with the reason with and the preceding lines from which the line is inferred, and suppressing classical reasoning steps):

- 1 It is general knowledge that "If x tries to prevent y 's marriage with false claims, then usually a revengeful murderous emotion from y towards x is created". (Input)
- 2 So (presumably) If x tries to prevent y 's marriage with false claims, then usually a revengeful murderous emotion from y towards x is created (1, R6)
- 3 J tried to prevent U 's marriage with false claims (Input)
- 4 So (presumably) a revengeful murderous emotion from U towards J was created" (2,3, Stat. Syll.)

4.2.2 *Attacking Generalisations*

Critically testing generalisations is just as important as obtaining and applying them. In our account, four ways to attack a generalisation can be modelled.

1 *Attacking the validity of the source of the generalisation*, e.g. "it is not general knowledge that If x tries to prevent y 's marriage with false claims, then usually a revengeful murderous emotion from y towards x is created". This attack can be modelled as a rebutting attack on a subargument for the intermediate conclusion that something is general knowledge.

2 *Attacking the defeasible derivation from the source*, for instance: "it is indeed general knowledge that if x tries to prevent y 's marriage with false claims, then usually a revengeful murderous emotion from y towards x is created, but this particular piece of general knowledge is infected by folk belief". This attack can be modelled as an undercutter of R6.

3 *Attacking application of the generalisation in the given circumstances*. This can be modelled as the application of applying more specific generalisations (e.g. "If x tries to prevent y 's marriage with false claims but y is known to be not violent and aggressive, then usually not a revengeful murderous emotion from y towards x is created", or the weak form with "not usually") Then the subproperty defeater of the statistical syllogism undercuts the use of the general default.

4 *Attacking the generalisation itself*. Such an attack takes the form of an argument for the negation of the attacked generalisation (provided that this can be expressed in the object language). An example of such an attack is the combination of the above more specific generalisation with the claim that the additional condition is not unusual, or perhaps even that it is usual, as in "People are usually not aggressive and violent".

The main difference between attacks of the third and the fourth kind is that the third kind of attack accepts the generalisation as a general rule, but denies its application in the case at hand, while the fourth kind of attack denies the generalisation as a general rule (“it is not the case that usually ...”). For a more detailed discussion of this difference see Prakken (2004).

4.3 Argumentation schemes

We now turn to the formulation of argumentation schemes in Pollock’s framework, focusing on the schemes from expert and witness testimony. The main question is whether these schemes must be regarded as additional prima facie reasons or as empirical generalisations: in the latter case applying the schemes boils down to applying the (qualitative) statistical syllogism. Technically, the main difference is that the body of reasons is fixed while generalisations can be inferred from, and attacked on the basis of, other knowledge. The argumentation-theoretic literature is ambiguous about whether argumentation schemes can best be analysed as inference rules or as generalised content (see Hitchcock, 2003 for a similar discussion about Toulmin's notion of warrants). In this paper we have chosen to regard them as defeasible inference rules, so (within Pollock's framework) as prima facie reasons. This is mainly since thus the representation of arguments is more concise. However, formulating them instead as generalisations is straightforward. For instance, R6 can be formulated as the generalisation

If it is general knowledge that φ then usually φ

Then in the above argument an extra line 1’ between 1 and 2 must be added containing this generalisation and 2 is then derived from 1 and 1’ by the statistical syllogism. Undercutters of R6 should now be represented as conflicting conditionals with a more specific antecedent. For example:

If it is general knowledge that φ but φ is infected with prejudice then it is not the case that usually φ

In cases where φ is indeed infected with prejudice, this gives rise to an instance of the subproperty defeater of the statistical syllogism.

We first discuss the scheme from expert testimony. Its precise formulation depends on what may be presumed. Suppose that the trustworthiness of the expert and the availability of backup evidence may be presumed. This yields:

R7: Expert testimonies: *‘E says φ and φ is within domain S and E is expert in domain S’ is a prima facie reason to believe φ .*

Of the critical questions listed above in Section 3.1, we believe that the first is a matter of adding strength of reasons to our account, the fifth searches for rebutting applications of the same scheme, while the second and third question seem to be challenges of the premises of R7. This leaves the trustworthiness and backup evidence question as possible pointers to undercutters. Alternatively, if the expert’s trustworthiness and the availability of backup evidence cannot be presumed, these statements must be added as conditions of R7.

Next we discuss the scheme from witness testimony. Several formulations of this scheme are possible. Our version follows the terminology of Schum (1994). Recall from Section 3.2 that Schum decomposes the quality of a witness testimony into three issues: the witness' veracity, objectivity and observational sensitivity. Objectivity and observational sensitivity are summarised in the first premise of the scheme as presented in Section 3.2 while veracity corresponds to the main critical question of the scheme as proposed by Walton (1996a). As with the expert testimony scheme, the precise formulation of the witness testimony scheme also depends on what may be presumed. On our account, the witness' veracity, objectivity and observational sensitivity are presumed (alternatively,

they can be regarded as additional premises of the relevant schemes).

R8: Witness testimonies: *'Witness W says ϕ ' is a prima facie reason for believing ϕ .*

We define the following undercutter for this scheme: "*Witness W is not truthful*" is an undercutter of R8.

Must we also formulate lack of a witness' objectivity and observational sensitivity as undercutters of this scheme? We think that this is not necessary, since a witness will usually talk about his or her past observations, so usually it will be possible to interpret ϕ as "I recall that I observed ψ ". On this account, arguments using witness testimonies apply a chain of three prima facie reasons: first the witness scheme is used to infer "I recall I observed ψ ", then the memory scheme provides "I observed ψ " and finally the perception scheme yields ψ . Thus lack of objectivity can be handled by undercutters of both memory and perception, and defects in observational sensitivity by undercutters of perception. Summarising, on our account the first premise of the scheme as presented in Section 3.2 is decomposed into undercutters of the perception and memory reasons R1 and R2, while the second premise is captured as the sole premise of R8.

However, a refinement of this analysis is necessary. If we have a closer look at Pollock's perception and memory reasons, we see that they provide reasons for a single agent to form beliefs on the basis of the agent's own memory or observations. By contrast, memories and observations of witnesses are used by other agents to form beliefs, such as triers of fact. Accordingly, the memory and perception reasons must be generalised. Perception becomes:

R1': Perception: *Agent A_i having a percept with content ϕ is a prima facie reason for agent A_j to believe ϕ*

(where A_i and A_j may or may not be identical). Likewise for the memory reason.

4.4 Outline of a Formal Analysis of the Umilian Case

We now briefly outline a formal analysis of the Umilian case (for a more detailed analysis see Prakken, 2004). Obviously, the Umilian case contains several uses of the witness testimony scheme. Wigmore discusses one attack on such a use, viz. an attack on the inference of 16 from 17 on the ground that the witness was a discharged employee of the suspect (angle 18(2) and its supporting child nodes). This is an undercutter, concluding to "the witness is not truthful". The case also seems to contain two applications of the temporal persistence scheme (although Wigmore's chart leaves them implicit. Firstly, the revengeful emotion created when the priest refuses to marry U is assumed to persist till the time of the murder (shown in Figure 3 as a possible extension of Figure 2). This persistence argument is undercut by the argument that the emotion disappeared when the priest still agreed to marry U . This conclusion in turn persists till the time of the murder. Arguably, this application of temporal persistence is undercut by the argument that the emotion was recreated since U and J remained in daily contact and U 's wife also remained there. The other inferences in the chart all seem to be based on implicit generalisations, which all seem to be of the general-knowledge, experience-based or belief-based type.

Determining the dialectical status of node 8 in our Pollock-style analysis, two sources of doubt prevent it from being a defeasible consequence of the theory. The first is the rebutting argument for node 18. This attack should be neutralised either by looking at the relative strength of the conflicting arguments, or by somehow undercutting the appeals to witness testimony on which node 18 is based. The second source of doubt is that one of the supporting child nodes, node 16, is undercut. This attack can be neutralised by providing alternative evidence of 16, or by attacking the argument that witness 17 is biased. An obvious target for such an attack seems the generalisation 19d.

5. A SECOND CASE STUDY: SACCO & VANZETTI

We now turn to an analysis of a modern use of Wigmore's charting method, as used by Kadane & Schum (1996) in their probabilistic analysis of the Sacco & Vanzetti case. Unlike our brief informal account of the Umilian case, we will now give our Pollock-style reconstruction in full detail, in order to fully illustrate our approach and to learn more about it.

5.1 The Sacco & Vanzetti Case

We start with a brief description of the case (following Kadane & Schum's (1996) own description). Nicola Sacco and Bartolomeo Vanzetti were convicted and executed for shooting and killing a payroll guard, Alessandro Berardelli, during a robbery that took place in South Braintree, Massachusetts on April 15, 1920. Berardelli and another payroll guard, Frederick Parmenter, were supposed to take a total of over \$15 000 in two iron boxes from one factory of the Slater and Morrill shoe factory to the second Slater and Morrill factory in South Braintree. During their route, they passed two men leaning against a piperail fence and, as they passed, were attacked from behind by these two men. Berardelli was shot four times and Parmenter two times. After this, the two men picked up the iron boxes containing the money and fled, along with three other men, in a black touring car which had approached the scene of the crime. Berardelli died about an hour later, Parmenter succumbed to his wounds the following morning.

Sacco and Vanzetti were known members of an anarchist movement in the US. The investigators knew that members of an anarchist group were involved in the robbery, and following a series of events, Sacco and Vanzetti were arrested on May 5. After a long trial with many witnesses, they were found guilty of the shooting of Berardelli while performing a criminal act, the robbery. An appeals process was launched and the Governor of Massachusetts launched his own investigation of the case. The committee entitled with this investigation also found Sacco and Vanzetti guilty as charged. Final appeals to the Supreme Court did not have any effect, and on August 23, 1927, Sacco and Vanzetti were executed.

Numerous books and articles have been written on this case by experts from fields including law, history and social sciences, since many felt that the case was probably one of the worst miscarriages of justice in American legal history. Recent studies of, for example, Young and Kaiser (1985) have introduced new evidence and evidence never introduced at the trial. Kadane & Schum carried a thorough probabilistic analysis of the case based on their modernised, more user-friendly version of Wigmore's charting method. Their analysis consisted of two parts. First they represented all the available evidence in 28 connected Wigmore charts, and then they used several of these charts to carry out probabilistic sensitivity analyses. Such an analysis intends to investigate the sensitivity of a probabilistic variable of interest (for instance, whether it was Sacco who shot Berardelli) to variations in the probability of other variables (for instance, whether Sacco was one of the men leaning against the piperail fence just before the murder). To carry out this analysis, Kadane & Schum reinterpreted their Wigmore charts of the case as Bayesian probabilistic networks, added various estimates of probability distributions on the networks and investigated their consequences with standard software tools for Bayesian networks.

5.2 The Wigmore chart

Our case study concerns one of Kadane & Schum's Wigmore charts, viz. Chart 4 (p.290) which displays evidence concerning the identification of Sacco as present at the scene of the crime while it was being committed. This chart was chosen since it is of realistic yet manageable size and since it illustrates the use of most of the prima facie reasons discussed above. We have copied the chart in Figure 4. Our analysis concerns only part of the chart. We take the proposition labelled '18' in the chart, that Sacco was at the scene of the robbery when it occurred, as the main probandum and therefore ignore the part of the chart above node 18. Also, we ignore the post-trial Young & Kaiser evidence (labelled YK in the chart).

The directly relevant evidence given by the prosecution's witnesses and its interim probanda are represented as circles, and the ancillary evidence given by the prosecution's witnesses and its interim probanda are represented as squares. The prosecution had two witnesses. Lewis Pelser testified (26) that he saw Sacco at the scene of the robbery and the shootings from the window of the Rice and Hutchins factory. The prosecution inferred from this that Sacco was at the scene of the crime (18). Lewis Wade testified (25) that he saw someone who looked like Sacco at the scene of the crime (18a), which, according to the prosecution, implied that Sacco was at the scene of the crime. The directly relevant evidence given by the defense witnesses and its interim probanda are represented as diamonds, and the ancillary evidence given by the defense witnesses and its interim probanda are represented as triangles. A defense witness called Albert Frantello testified (324) that Sacco was not one of the men leaning against the fence when he passed it five minutes before the robbery occurred (323). The defense argued from this that Sacco could thus not have been at the scene of the crime when the robbery took place. The reasoning from Frantello's testimony was strengthened by the fact that, according to Frantello (326), the man on the fence spoke "American" (325) while, as observable during trial (328) Sacco spoke broken English (327). The prosecution argued that Frantello's powers of observation were weak (329) since at cross-examination (330) he incorrectly identified characteristics of jurors he had been asked to view, and thus his testimony carried less weight towards 323. Further defense witnesses were brought forth to cast doubt upon whether Pelser could have actually seen the robbery. McCullum testified (318c) that Pelser could not have seen the shooting for reasons not further specified (318b). Constantino testified (317) that Pelser was under a bench when the shootings took place (316), and thus Pelser could not have seen the shooting, weakening the link between 26 and 18. On cross-examination (318a), however, Constantino had doubts about his observation (318), weakening his own argument that Pelser was under the bench. Pelser nevertheless admitted (319) that he was under the bench on cross-examination, strengthening 316. Brenner testified (321) that Pelser was not near the window (320) so that he could not have seen the robbery. At his cross-examination, Brenner also expressed (322a) doubts about where Pelser was (322), weakening the defense's argument from 321 to 320.

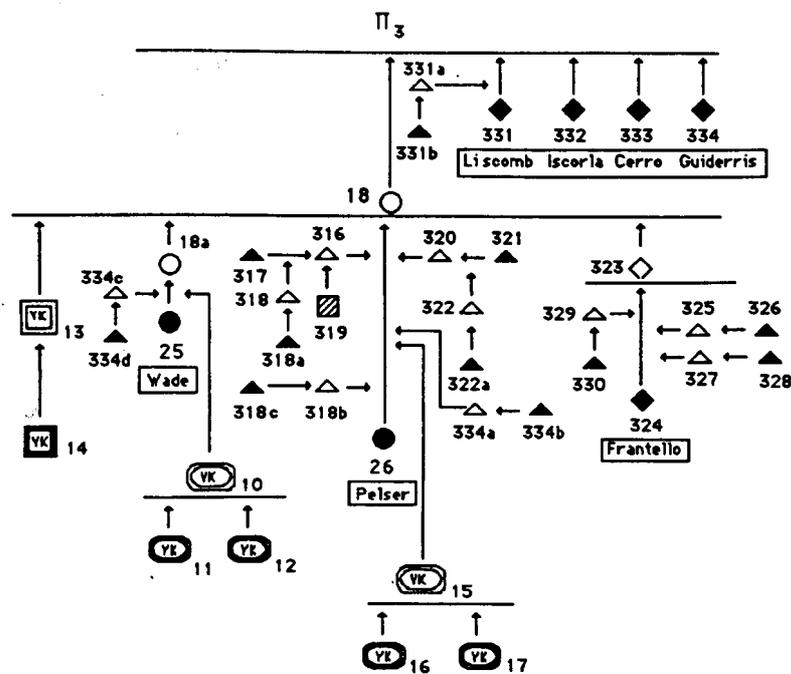


Figure 4: Chart 4 of Kadane & Schum (1996)

5.3 A formal reconstruction

We now transform our selection from Kadane & Schum's Chart 4 into a formalisation in Pollock's system as explained in Section 4. This formalisation is a shorter and revised version of the one given in Bex (2003). We have tried to be faithful to the original chart except in one or two places where a slightly different interpretation is necessary. Moreover, we have added generalisations wherever they are left implicit in the original chart. Of course our choices can be debated but, as remarked above in Section 4.2, the point of making generalisations explicit is precisely to make them the subject of debate.

The chart contains two main witnesses for the prosecution, Wade and Pelser. We start with Wade's testimony that he saw someone who looked like Sacco at the scene of the crime when the robbery and shooting occurred. From this an argument can be built for the claim that Sacco was at the crime scene.

Argument P₁ (Kadane and Schum: 25 \Rightarrow 18a)

1. Wade says: "I recall I saw someone who looked like Sacco at the crime scene when the crime occurred" (Input)
2. Wade recalls having seen someone who looked like Sacco at the crime scene when the crime occurred (1, Witness Testimony)
3. Wade saw someone who looks like Sacco at the crime scene when the crime occurred (2, Memory)
4. If a person X saw someone who looks like person Y , then usually X saw Y (Input)
5. Wade saw Sacco at the crime scene when the crime occurred (3,4, Stat. Syll.)
6. Sacco was at the crime scene when the crime occurred (5, Perception)

Wade's argument was weakened by the fact that he would not admit that it was Sacco who shot Berrardelli. Wade never denied that the man he saw "looked like Sacco", but he did express his doubts about the fact that the man he saw actually was Sacco. This gives rise to the following undercutting argument, which begins in the same way as the first argument.

Argument D₁ (Kadane and Schum: 334d \Rightarrow 334c)

1. Wade says: "I recall I saw someone who looked like Sacco at the scene of the crime when it occurred" (Input)
2. Wade recalls having seen someone who looked like Sacco at the scene of the crime when it occurred (1, Witness Testimony)
3. Wade saw someone who looks like Sacco at the scene of the crime when it occurred (2, Memory)
4. Wade would not say "Sacco is the man I saw shooting Berrardelli at the crime" (Input)
5. If a person X saw someone who looked like person Y , but X will not testify he saw Y , then usually X has doubts about Y 's look-alike being Y (Input)
6. Wade had doubts about the fact that the man who looked like Sacco actually was Sacco (3,4,5, Stat. Syll.)
7. If a person X saw someone who looks like person Y , but X has doubts about Y 's look-alike being Y , then it is not usually the case that if a person X saw someone who looks like Person Y , then person X saw person Y (Input)
8. Wade saw someone who looks like Sacco at the scene of the crime when it occurred & Wade had doubts about the fact that the man who looked like Sacco actually was Sacco & If a person X saw someone who looks like person Y , but X has doubts about Y 's look-alike being Y , then it is not usually the case that if a person X saw someone who looks like Person Y , then person X saw person Y (3,6,7, strict reason)

This argument undercuts argument P_1 at line 5. It is an instance of the subproperty defeater of the statistical syllogism: the antecedent of the generalisation 7 in D_1 is more specific than the antecedent of the generalisation 4 in P_1 and it has a contradictory consequent.

The second main prosecution witness, Pelsler, testified that he saw Sacco from the window of the Rice and Hutchins factory. This gives rise to a second argument for the claim that Sacco was at the crime. (To make the observational-sensitivity undercutters apply to Pelsler's testimony, we interpret it as an example of self-observation.)

Argument P_2 (Kadane and Schum: 26 \Rightarrow 18)

1. Pelsler says "I recall that I experienced I was at the window and that I saw Sacco at the scene of the crime when it occurred" (Input)
2. Pelsler recalls that he experienced he was at the window and that saw Sacco at the scene of the crime when it occurred (1, Witness Testimony)
3. Pelsler experienced he was at the window and Pelsler saw Sacco at the scene of the crime when it occurred (2, Memory)
4. Pelsler saw Sacco at the scene of the crime when it occurred (3, strict reason)
5. Sacco was at the scene of the crime when it occurred (4, Perception)

The defense witnesses McCullum, Constantino, Brenner and Frantello all cast doubt on Pelsler's testimony. McCullum gave an equivocal testimony from which the defense argued that Pelsler could not have seen Sacco (318c \Rightarrow 318b), but McCullum was not clear on why Pelsler could not have seen Sacco, so his testimony is ambiguous between an undercutter of the Witness, Memory or Perception reason. We formalise it as an undercutter of the Perception reason.

Argument D_2 (Kadane and Schum: 318c \Rightarrow 318b)

1. McCullum says: "I recall that Pelsler could not have seen Sacco" (Input)
2. McCullum recalls that Pelsler could not have seen Sacco (1, Witness Testimony)
3. Pelsler could not have seen Sacco (2, Memory)
4. X could not have seen $P \rightarrow X$'s perception of P is not a reliable indicator of P (Input)
5. Pelsler's perception of Sacco at the scene of the crime when it occurred is not a reliable indicator of this fact (3,4, strict reason)

Argument D_2 undercuts the application of the Perception reason at line 5 of argument P_2 .

The second defense witness, Constantino, testified that Pelsler was not at the window so that he could not have seen Sacco (from the window). Like McCullum's testimony, Constantino's testimony is also ambiguous in how exactly it attacks Pelsler's testimony. For purposes of illustration we formalise it as an undercutter of the Witness Testimony reason.

Argument D_3 (Kadane and Schum: 317 \Rightarrow 316)

1. Constantino says "I recall I have seen Pelsler under a bench" (Input)
2. Constantino recalls having seen Pelsler under a bench (1, Witness Testimony)
3. Constantino saw Pelsler under a bench (2, Memory)
4. Pelsler was under a bench (3, Perception)
5. Pelsler was under a bench \rightarrow Pelsler was not at the window (Input)
6. Pelsler was not at the window (4,5, strict reason)
7. It is not the case that Pelsler was at the window and that he saw Sacco at the scene of the crime when it occurred (6, strict reason)
8. If X says he recalls he was in circumstances Y but X was not in circumstances Y, then usually X is not truthful. (Input)

9. Pelser says “I recall that I was at the window and that I saw Sacco at the scene of the crime when it occurred” (Input)
10. Pelser is not truthful (7,8,9, Stat. Syll.)

Argument **D₃** undercuts the application of the Witness testimony reason at line 2 of argument **P₂**.

Constantino admitted during cross-examination that he had doubts about where Pelser was. It is not exactly clear from Kadane & Schum (1996) why Constantino had these doubts. This is a third example of a testimony that is ambiguous in its nature. We interpret Constantino’s doubts as about his memory of Pelser's whereabouts:

Argument P₃ (Kadane and Schum: 318a \Rightarrow 318)

1. Constantino says “I have doubts about my memory of Pelser's whereabouts” (Input)
2. Constantino has doubts about his memory of Pelser's whereabouts (1, Witness testimony)
3. If a witness has doubts about his memory of P, then usually P was originally based on false beliefs (Input)
4. Constantino’s recollection of having seen Pelser under a bench was originally based on false beliefs (2,3, Stat. Syll.)

Argument **P₃** undercuts the application of the memory reason at line 3 of argument **D₃**, using the first undercutter of this scheme.

Witness Brenner did not say where Pelser was, but he did testify that Pelser was not near the window. This gives rise to an attack on **P₂** similar to **D₃**.

Argument D₄ (Kadane and Schum: 321 \Rightarrow 320)

1. Brenner says: “I recall I saw that Pelser was not near the window” (Input)
2. Brenners recalls having seen that Pelser was not near the window (1, Witness Testimony)
3. Brenner saw that Pelser was not near the window (2, Memory)
4. Pelser was not near the window (3, Perception)
5. Pelser was not near the window \rightarrow Pelser was not at the window (Input)
6. Pelser was not at the window (4,5, strict reason)

And further as argument **D₃**.

On cross-examination, Brenner also expressed doubts about his memory.

Argument P₄ (Kadane and Schum: 322a \Rightarrow 322)

1. Brenner says “I have doubts about my memory of Pelser’s whereabouts” (Input)
2. Brenner has doubts about his memory of Pelser’s whereabouts (1, Witness testimony)
3. If a witness has doubts about his memory of P, then usually P was originally based on false beliefs (Input)
4. Brenner’s recollection of having seen that Pelser was not near the window was originally based on false beliefs (2,3, Stat. Syll.)

Argument **P₄** undercuts the application of the memory reason at line 3 of argument **D₄**, using the first undercutter of this reason.

The final defense witness, Frantello, testified that Sacco was not at the scene of the crime 5 minutes before it happened. Frantello also testified that he heard the man leaning on the pipe-rail fence who might resemble Sacco speak American. This contradicts the fact observable in court that Sacco speaks broken English. Kadane & Schum regard the latter two facts as two pieces of ancillary evidence strengthening Frantello’s that Sacco was not at the scene of the crime 5 minutes before it happened. We think that it is more natural to formalise Frantelli’s statements as two independent

testimonies and the observable fact as a component in one of them. See further Section 5.4 below.

Argument D₅ (Kadane and Schum: 324 \Rightarrow 323)

1. Frantello says “I recall I saw that Sacco was not one of the men leaning on the pipe-rail fence 5 minutes before the crime” (Input)
2. Frantello recalls that he saw that Sacco was not one of the men leaning on the pipe-rail fence 5 minutes before the crime (1, Witness testimony)
3. Frantello saw that Sacco was not one of the men leaning on the pipe-rail fence 5 minutes before the crime (2, Memory)
4. Sacco was not one of the men leaning on the pipe-rail fence 5 minutes before the crime (3, Perception)
5. If Sacco was not one of the men leaning on the pipe-rail fence 5 minutes before the crime then presumably Sacco was not at scene of the crime 5 minutes before it occurred (Input)
6. Sacco was not at scene of the crime 5 minutes before it occurred (5, Stat. Syll.)
7. Sacco was not at the scene of the crime when it occurred (6, Temporal persistence)

Argument **D₅** rebuts and is rebut by line 6 of **P₁** and line 5 of **P₂**. Note, by the way, that line (5) is a case-specific generalisation; this is why we have expressed it with “presumably” instead of with “usually”.

Argument D₆ (Kadane and Schum: 326 \Rightarrow 325 and 328 \Rightarrow 327)

1. Frantello: “I recall I heard the man leaning on the fence 5 minutes before the crime speak American” (Input)
2. Frantello recalls having heard the man leaning on the fence 5 minutes before the crime speak American (1, Witness testimony)
3. Frantello heard the man leaning on the fence 5 minutes before the crime speak American (2, Memory)
4. The man leaning on the fence 5 minutes before the crime spoke American (3, Perception)
5. Sacco speaks broken English (Input)
6. If the man leaning on the fence 5 minutes before the crime spoke American & Sacco speaks broken English then presumably Sacco was not the man leaning on the fence 5 minutes before the crime (Input)
7. Sacco was not one of the men leaning on the pipe-rail fence 5 minutes before the crime (4,5,6, Stat. Syll.)
8. If Sacco was not one of the men leaning on the pipe-rail fence 5 minutes before the crime then presumably Sacco was not at scene of the crime 5 minutes before it occurred (Input)
9. Sacco was not at scene of the crime 5 minutes before it occurred (7,8, Stat. Syll.)
10. Sacco was not at the scene of the crime when it occurred (9, Temporal persistence)

Argument **D₆** also rebuts and is rebut by line 6 of **P₁** and line 5 of **P₂**. (Note that line 6 of **D₆** contains another case-specific generalisation.)

Frantello's cross-examination in the courtroom gives rise to a counterargument against **D₅** and **D₆**, since Frantello performed poorly in recalling characteristics of some of the jurors he had been asked to view.

Argument P₅ (Kadane and Schum: 330 \Rightarrow 329)

1. Frantello incorrectly identified characteristic of jurors he had been asked to view (Input)
2. If person *X* cannot identify characteristics of people he has been asked to view, then usually *X*'s observational powers are weak (Input)
3. Frantello's observational powers are weak (1, 2, Stat. Syll.)

4. If a person's observational powers are weak, then that person having a percept of P usually is not a reliable indicator of P (Input)
5. Frantello having seen that the man on the fence was not Sacco is not a reliable indicator for the fact that the man on the fence was not Sacco (3, 4, Stat. Syll.)

Argument \mathbf{P}_5 undercuts the application of the Perception reason at line 4 of arguments \mathbf{D}_5 and \mathbf{D}_6 .

Although thus all four defense witnesses who cast doubt on Pelser's testimony can be attacked, Pelser himself admitted during cross-examination that was under a bench. Like Constantino's testimony, Pelser's is also ambiguous in the precise way it undermines his original testimony. We interpret it in the same way as Constantino's testimony.

Argument \mathbf{D}_7 (Kadane and Schum: 319 \Rightarrow 316)

- 1 Pelser says "I recall I experienced I was under a bench" (Input)
- 2 Pelser recalls he experienced he was under a bench (1, Witness testimony)
- 3 Pelser experienced he was under a bench (2, Memory)
- 4 Pelser was under a bench (3, Perception)

And further as argument \mathbf{D}_3 .

Argument \mathbf{D}_7 undercuts the application of the Witness Testimony reason at line 2 of argument \mathbf{P}_2 .

What remains is to determine the dialectical status of all arguments. Figure 5 shows all

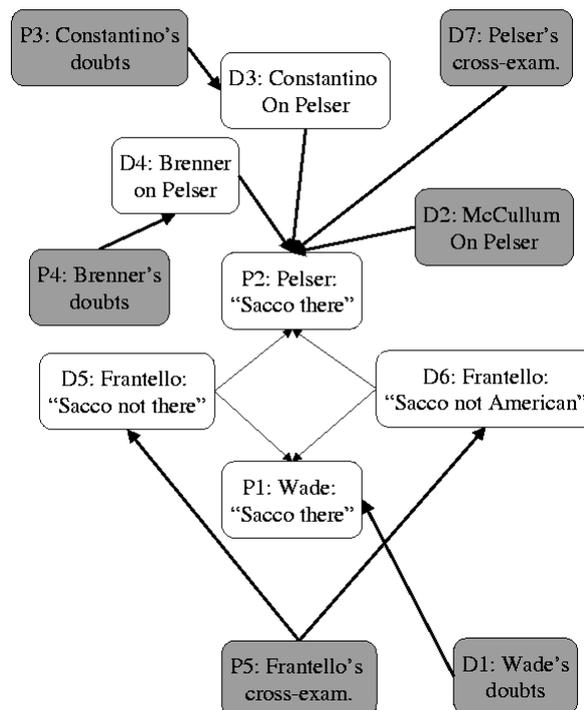


Figure 5: The argument graph

arguments, their defeat relations and their status: the grey arguments are justified and the blank arguments are overruled (in this case grounded and preferred semantics yield the same result). Because of space limitations this figure does not represent the structure of the arguments or the exact ways in which arguments defeat each other. Thin lines stand for rebutting defeat relations and thick lines for undercutting defeat relations. Since we have not specified strengths of arguments, all mutually rebutting arguments defeat each other, while all undercutting arguments strictly defeat their

target. A decision maker or analyst could use such information to determine the consequences of his or her relative assessments of conflicting arguments. If one argument of a rebutting pair is regarded as significantly stronger than another, than their mutual defeat relation will turn into a one-sided relation. If an undercutting argument is regarded as stronger than or equally strong as its target, the strict defeat relation remains unchanged. However, if it is regarded as weaker, the result depends on whether Pollock's treatment of weak undercutters is followed or not. According to Pollock (1995) an undercutter that is weaker than its target does not defeat it. This has the somewhat strange consequence that an undercutting argument and its target can both be dialectically justified. An alternative solution is to let undercutting result in defeat whatever the strength is of the undercutter. We adopt the latter solution, resulting in the dialectical assessment of the arguments as shown in Figure 5. It turns out that both of the prosecution's arguments that Sacco was at the scene of the crime when it occurred are overruled. To turn, say, P1 into a justified argument, the trier of fact should find a convincing counterattack on both of Frantello's testimonies (D5 and D6) and on Wade's doubts at cross-examination (D1).

6. DISCUSSION

We now draw some conclusions from the case study and discuss some issues that arise from it.

6.1 Revealing sources of doubt

Both Wigmore and Kadane & Schum stress that one benefit of the charting method is that it reveals sources of doubt in evidential arguments. One way in which our analysis achieves this is that it forces us to make implicit generalisations explicit. In many cases these generalisations will become the subject of debate and testing (see e.g. Twining, 1999 and Wagenaar et al., 1993 for instructive examples). Another way in which our analysis reveals sources of doubt is by indicating the precise argumentation schemes used in an argument. Thus we are, for instance, able to represent the fact that Wade's testimony is (*ceteris paribus*) inherently weaker than Pelsler's: in our analysis Wade's testimony has an additional attacking point, viz. the generalisation "If a person *X* saw someone who looks like person *Y*, then usually *X* saw *Y*". This generalisation was the target of the counterargument **D₁**. A similar counterargument cannot be launched against Pelsler's testimony as used in argument **P₂**.

6.2 Different levels of abstraction

A few times a counterargument was stated at a higher level of abstraction than its target. For instance, while Pelsler's testimony was decomposed into applications of the Memory, Witness Testimony and Perception schemes, the testimonies of the counterwitnesses McCullum, Constantino and Brenner did not specifically attack any of these three inferences but instead seem to be an attack on the more abstract version of the witness testimony scheme that witnesses usually speak the truth. We think that this is not a weakness of our approach or the underlying formalism; any analysis of a reasoning problem will have to choose an appropriate level of abstraction. However, this problem may offer a justification for representing argumentation schemes as generalisations (i.e., as propositions) instead of as reasons (i.e., as inference rules): if depending on the dialogical context argumentation schemes can be expressed at different levels of abstraction, then it may not be wise to fix their formulation in a set of inference rules. Finally, in dialogical models of evidential reasoning it may be interesting to investigate principles that enforce dialogues to be coherent in their level of abstraction, or to investigate moves in a dialogue that are suitable for changing the dialogue's level of abstraction. For instance, Loui & Norman (1995) model moves for 'unpacking' an opponent's argument "P therefore Q" into "P therefore R, therefore Q" and then attacking the new argument on its intermediate conclusion R.

6.3 Ancillary evidence.

Ancillary evidence is evidence that has a bearing on the probative force of other evidence. In their charts, Kadane & Schum depict ancillary evidence as links from a node to an evidence link. In our formal reconstruction ancillary evidence can be represented in various ways, depending on its exact nature. Ancillary evidence weakening the probative force of a piece of evidence is easily modelled as a counterargument, usually an undercutter. See for instance, argument P_5 on Frantello's weak observational powers, attacking the arguments D_5 and D_6 based on his testimony. However, the modelling of ancillary supporting evidence is less obvious. Kadane & Schum depict Frantello's testimony as ancillary evidence, drawing links from his testimony 326 and the observable fact 328 to the link between 324 and 323. However, it seems hard to see how the testimony 326 supports the link between Frantello's other testimony and the claim 323. It seems more natural to regard these testimonies as two separate reasons for the same claim, which may be stronger when combined than when considered in isolation. We formalised this interpretation in arguments D_5 and D_6 . This brings us to the issue of accrual of reasons. First, however, we note that genuine supporting ancillary evidence will often be stated in the form of counterattacks on undercutting arguments. For instance, an attack on a witness's truthfulness may be countered with reasons why he is truthful.

6.4 Accrual of reasons.

Something which has not been modelled in the arguments above is the *accrual* of reasons for a conclusion. For example, both Wade's and Pelser's testimonies are used to conclude that Sacco was at the scene of the crime when it occurred, and Constantino's and Brenner's testimonies can be combined with Pelser's testimony at cross-examination to conclude that Pelser was not truthful. Most, if not all, triers of fact operate under the assumption that, other things being equal, a higher number of witnesses testifying to the same proposition increases the evidential support of that proposition. How can this assumption be modelled in our account? It has been suggested that an argument based on accrual of reasons is neither an argument with disjunctive premises nor one with conjunctive premises but a special type of argument (e.g. Walton, 1996b). Verheij (1996) argues that an argument-based logic should somehow let the force of these two arguments accrue to reflect the fact that having two arguments for a conclusion is stronger than having one argument. Against this, Pollock (1995, pp. 101/2) argues that accrual of arguments (or reasons) is not a matter of logic. Discussing the example of witness testimonies (which he expresses as a generalisation "Witnesses usually speak the truth" and applies with the statistical syllogism), he argues that whether witness testimonies accrue, depends on the linguistic community which the speakers are part of. We could have, for example, one community in which speakers make assertions completely independently of each other, and then the strength of the combined reason would be greater than the strength of either of the separate reasons. But we could also be dealing with a community where the second speaker tends to assert every proposition of which the first speaker said it was false. Then the strength of the combined reason would be less than the strength of the first separate reason. Thus, Pollock argues, the degree of justification for a proposition in such cases depends on a separate instance of the statistical syllogism, applied to a separate generalisation "If two witnesses say that P , then usually P ".

Let us see how this account can be formalised in our present use of Pollock's framework. One way is to apply the Witness Testimony and Memory Reasons to the individual testimonies and to combine the resulting observation statements in a many-agent version of the Perception reason. In fact, a new version of this reason is needed for each natural number n . These reasons are combined in the following template:

R1ⁿ: Multiple-agent observations: *'Agent A_1 observed φ and ... and agent A_n observed φ ' is a prima facie reason for agent A to believe φ .*

(where A may or may not be among A_i, \dots, A_n). The undercutters of the original Perception reason

also apply to each multiple-agent version of perception. Note that attacks on the witness's veracity and objectivity can still be modelled as undercutters of the reasons applied to the individual testimonies. Does $R1^n$ also have new undercutters? An often-used way to discredit appeals to multiple witnesses is to argue that the witnesses conferred before their testimonies and knowingly or unknowingly influenced each other's testimonies. We think that this can still be represented as attacks on the individual testimonies. For instance, if witnesses conferred to fabricate a story, then the following generalisation gives rise to an instance of the truthfulness undercutter:

If Witness W_i conferred with agent A_j before his testimony to fabricate a story then usually W_i is not truthful.

The situation that witnesses are truthful but are influenced in unconscious ways so that they are not objective, can be expressed as an additional undercutter of the Memory reason:

'Agent A_i recalls φ but was influenced concerning φ before recalling it' is an undercutter of $R2$ '.

Note that this undercutter also covers cases where a witness was influenced by, for instance, news reports.

Let us illustrate our proposal with the testimonies of Constantino, Brenner and Pelsler-at-cross-examination that Pelsler was not at the window of the Rice and Hutchins factory when the crime occurred. An instance of $R1^n$ must be used with $n = 3$. (We leave implicit the parts of the argument that conclude to 1,4 and 7. Note that premises 2,5 and 8 capture that, although the witnesses made different statements, these statements all imply the same thing.)

Argument D_8

- 1 Constantino saw Pelsler was under a bench (line 3 of D_3)
- 2 Constantino saw that Pelsler was under a bench \rightarrow Constantino saw that Pelsler was not at the window (Input)
- 3 Constantino saw that Pelsler was not at the window (1,2, strict reason)
- 4 Brenner saw that Pelsler was not near the window" (line 3 of D_4)
- 5 Brenner saw that Pelsler was not near the window \rightarrow Brenner saw that Pelsler was not at the window (Input)
- 6 Brenner saw that Pelsler was not at the window (5,6, strict reason)
- 7 Pelsler experienced he was under a bench" (line 3 of D_7)
- 8 Pelsler experienced he was under a bench \rightarrow Pelsler experienced he was not at the window (Input)
- 9 Pelsler experienced he was not at the window (3,4, strict reason)
- 10 Pelsler was not at the window (3,6,9, $R1^3$).

Note that P_3 undercuts D_3 and thereby D_8 while P_4 undercuts D_4 and thereby D_8 . Interestingly, the testimonies might be combined again to save D_8 , viz. in a generalisation

If a witness has doubts about his memory of P but other witnesses also recall P , then it is not usually the case that P was originally based on false beliefs

This generalisation gives rise to a subproperty defeater of P_3 and P_4 at their lines 4 so that D_8 is reinstated. However, suppose that for whatever reason the defeater of P_4 is in turn defeated. Then this attempt to reinstate D_8 does not work. If the trier-of-fact still wants to conclude that Pelsler was not at the window on the basis of Constantino's and Pelsler's testimonies, then s/he has to formulate a weaker version of D_8 with an instance of $R1^n$ with $n = 2$.

One consequence of this analysis is that the set of relevant arguments in our case study is larger than as depicted in Figure 5: since we now have $R1^n$ as a reason, we must add four new arguments in Figure 5: Wade + Pelser, Constantino + Brenner, Constantino + Pelser, Brenner + Pelser and Constantino + Pelser + Brenner. By contrast, in formalisms that somehow aggregate multiple reasons, such as Bayesian Networks, Reason-based logic (Hage, 1996) or Krause et al.'s (1995) LA system it suffices to represent a link from each individual observation statement to the supported claim; the aggregation mechanism ensures that only the applicable statements exert their influence on the claim (note, however, that in such formalism the strength of the combined reasons is still independent of the strengths of the individual reasons; this agrees with Pollock's analysis of accrual). It remains to be seen whether this difference is an advantage or a disadvantage of the present approach. For instance, our approach induces the following kind of dialogue, which seems quite natural:

D: Constantino, Brenner and Pelser observed that Pelser was not at the window, so, Pelser was not at the window.

P: But Brenner was not sure about his memory where Pelser was.

D: OK, but still Constantino's and Pelser's observations together suffice to prove that Pelser was not at the window.

The problem of accrual of reasons is not confined to witness testimonies. Firstly, sometimes generalisations have to be combined. For instance, the arguments D_5 and D_6 based on Frantello's testimonies both use a generalisation with the consequent '*Sacco was not the man leaning on the fence 5 minutes before the crime*', viz. at line 5 of D_5 and line 6 of D_6 . To combine Frantello's two testimonies, a third generalisation must be formulated with the same consequent but conjoining the antecedents of these two generalisations. Applying the statistical syllogism to the new generalisation results in a fifth addition to the argument graph of Figure 5.

The most complicated case of accrual is when reasons of a different nature have to be combined. For instance, the prosecution presented another piece of evidence against Sacco, viz. a cap that was found at the crime scene that allegedly belonged to Sacco. This gives rise to another argument for the conclusion that Sacco was at the scene of the crime when it occurred, based on a generalisation, say '*If a cap found at the scene of the crime belongs to Sacco, then presumably Sacco was at the scene of the crime*', to which the statistical syllogism can be applied. To combine this argument with Wade's and Pelser's testimonies, reason $R1^n$ cannot be used. Instead the generalisation used in the new argument must be combined with Wade's and Pelser's testimonies into a new generalisation:

If witnesses W1 and W2 observed that Sacco was at the scene of the crime when it occurred and a cap found at the scene of the crime belongs to Sacco, then presumably Sacco was at the scene of the crime.

In fact, the need for this generalisation yields a second reason why it might be better to formulate the argumentation schemes introduced in this paper as generalisations (the first reason we identified was that witness testimonies are often expressed at different levels of abstraction).

7. CONCLUSION

In this paper we have studied how some common reasoning forms used in evidential legal reasoning can be analysed within general theories of defeasible reasoning and argumentation. We have seen that within Pollock's logic for defeasible argumentation a natural account can be given of two key concepts of evidential reasoning, viz. argumentation schemes and generalisations, in a way that captures the spirit of both Wigmore's charts and recent research of evidence theory scholars. Our

account made it possible to formally distinguish four ways in which generalisations can be attacked. We have also discussed a method for combining different pieces of evidence supporting the same conclusion, especially witness statements. Our discussion suggests that combining evidence in an argument-based framework leads to less compact representations of a problem than in, for instance, Bayesian networks or reason-based logic, but that an argument-based approach may induce more natural dialogues.

As for related research, we know of only one earlier formal proposal to model evidential legal reasoning as defeasible argumentation, viz. Verheij (2000). He develops his proposal as an alternative to Wagenaar et al.'s (1993) anchored-narratives theory. According to this theory legal proof should have the form of persuasive stories about what happened. The stories should not only be persuasive but also be anchored in the available evidence with empirical generalisations. An important aspect of the anchored-narratives theory is that these anchors should be progressively refined in a critical testing procedure until they are sufficiently plausible to be accepted. Verheij argues like us that anchors can be modelled as default rules, which can be used to build arguments and, being defeasible, give rise to counterarguments. (Twining, 1999 also claims that arguments are a good alternative to stories, stressing some dangers of using stories in legal proof, such as that they can deceptively appeal to the emotions of the triers of fact.) Verheij also stresses the need for a formal theory of the dynamics of fact-finding investigations, to account for the testing of generalisations as proposed in the anchored narratives theory. Finally, Verheij (2002) suggests like us that argumentation schemes can be regarded as defeasible inference rules and negative answers to some critical questions as undercutters. Probably the main contributions of the present paper to Verheij's work are our detailed formal analysis of some of the main argumentation schemes operative in evidential reasoning, our systematic account of various ways to attack generalisations and our detailed discussion of accrual of evidential arguments.

As for future research, our Pollock-style approach should be further developed by adding qualitative means to express strength of evidential arguments and by investigating more evidential argumentation schemes, such as schemes for causal reasoning. Also, our suggested approach to accrual of reasons should be compared in more detail to approaches using other formalisms, As for sense-making systems, it remains to be tested how our argument-based account can be used to provide the formal foundations of implemented sense-making systems and whether the possibility of expressing argumentation schemes (as in Araucaria) is indeed a useful feature of such systems. Another research issue concerns the treatment of different levels of abstraction in evidential reasoning. It has been stressed by e.g. Wagenaar et al. (1993) and Verheij (2000) that evidential reasoning does not only consist of the construction of arguments and counterarguments, but also in the progressive refinement of these arguments and the statements from which they are composed. This was clearly illustrated by our second case study. This issue should be addressed in models of the dynamics of fact-finding investigation.

Finally, in this paper we have employed a high level of abstraction, focussing mainly on the place of evidential reasoning forms in a general theory of reasoning. When applying our account in a knowledge-based system, it must be supplemented with detailed knowledge-engineering research on the relevant knowledge and argumentation schemes used in evidential arguments. Nevertheless, our account provides a framework in which such detailed research can be put to use.

8. REFERENCES

- Anderson, T.J. (1999), On generalisations I: a preliminary Exploration. *South Texas Law Review*, Summer 1999, 455-481.
- Anderson, T.J. & Twining, W. (1991), *Analysis of Evidence. How to Do Things with Facts Based on Wigmore's Science of Judicial Proof*. Boston: Little, Brown and Company.
- Bex, F.J. (2003), Formalising evidential reasoning. Student paper Cognitive Artificial Intelligence, Utrecht University.
- Bromby, M.C. & Hall, M.J.J (2002), The development and rapid evaluation of the knowledge model of

- ADVOKATE: an advisory system to assess the credibility of eyewitness testimony, in T. J. M. Bench-Capon, A. Daskalopulu and R. G. F. Winkels (eds), *Legal Knowledge and Information Systems, JURIX 2002: The Fifteenth Annual Conference*, Amsterdam, IOS Press, 2002, 143-152.
- Dung, P.M. (1995), On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming, and *n*-person games. *Artificial Intelligence* 77:321-357.
- Hage, J.C. (1996), A theory of legal reasoning and a logic to match. *Artificial Intelligence and Law* 4:199-273.
- Hastings, A.C. (1963), *A Reformulation of the Modes of Reasoning in Argumentation*, Evanston, Illinois, Ph.D. Dissertation.
- Hitchcock, D. (2003), Toulmin's Warrants. In F. H. van Eemeren et al. (eds.), *Proceedings of the Fifth Conference of the International Society for the Study of Argumentation*, Amsterdam SicSat, 485-490.
- Jøsang, A. & Bondi, V.A. (2000), Legal reasoning with subjective logic. *Artificial Intelligence and Law* 8: 289-315.
- Kadane, J.B. & Schum, D.A. (1996), *A Probabilistic Analysis of the Sacco and Vanzetti Evidence*. New York: John Wiley & Sons.
- Keppens, J. & Zelezniak, J. (2003), A model based reasoning approach for generating plausible crime scenarios from evidence. *Proceedings of the Ninth International Conference of Artificial Intelligence and Law*. New York: ACM Press, pp. 51-59.
- Kienpointner, M. (1992), *Alltagslogik: Struktur und Funktion von Argumentationsmustern*, Stuttgart: Fromman-Holzboog.
- Kirschner, P.A., Buckingham Shum, S.J. & Carr, C.S. (2003) (eds.): *Visualizing Argumentation. Software Tools for Collaborative and Educational Sense-Making*, London: Springer Verlag, pp. 75-96.
- Krause, P., Ambler, S. Elvang-Gøransson, M., and Fox, J. (1995), A logic of argumentation for reasoning under uncertainty. *Computational Intelligence* 11: 113-131.
- Lempert, R. (1986), The new evidence scholarship: analyzing the process of proof. *Boston University Law Review* 66: 439-477.
- Loui, R.P. & Norman, J. (1995), Rationales and argument moves. *Artificial Intelligence and Law* 3:159-189.
- Loui, R.P., Norman, J., Alpeter, J., Pinkard, D., Craven, D., Lindsay, J., & Foltz, M., Progress on Room 5: a testbed for public interactive semi-formal legal argumentation. *Proceedings of the Sixth International Conference of Artificial Intelligence and Law*. New York: ACM Press, 1997, pp. 207-214.
- Lutomski, L.S. (1989), The design of an attorney's statistical consultant. *Proceedings of the Second International Conference of Artificial Intelligence and Law*. New York: ACM Press, 1989, pp. 224-233.
- Malsch, M. & Nijboer, J.F. (eds.) (1999), *Complex Cases. Perspectives on the Netherlands Criminal Justice System*, Amsterdam: Thela Thesis.
- Morsek, L. (2001), 'Get on Board for the Ride of Your Life! The Ups, the Downs, the Twists, and the Turns of the Applicability of the "Gatekeeper" Function to Scientific and Non-Scientific Expert Evidence', *Akron Law Review*, 34, 2001, 689-739.
- Perelman, Ch. & Olbrechts-Tyteca, L. (1969), *The New Rhetoric (La Nouvelle Rhetorique)*, Notre Dame: University of Notre Dame Press.
- Pollock, J.L. (1987), Defeasible reasoning. *Cognitive Science* 11:481-518.
- Pollock, J.L. (1995), *Cognitive Carpentry. A Blueprint for How to Build a Person*. Cambridge, MA: MIT Press.
- Pollock, J.L. (1998), Perceiving and reasoning about a changing world. *Computational Intelligence* 14:498-562.
- Prakken, H. (2004), Analysing reasoning about evidence with formal models of argumentation. *Law, Probability & Risk* 3:33-50.
- Prakken, H. & Reed, C. & Walton, D.N. (2003), Argumentation schemes and generalisations in reasoning about evidence. *Proceedings of the Ninth International Conference of Artificial Intelligence and Law*. New York: ACM Press, pp. 32-41.
- Prakken, H. & Sartor, G. (1996), A dialectical model of assessing conflicting arguments in legal reasoning. *Artificial Intelligence and Law* 4:331-368.
- Reed, C.A. & Walton, D.N. (2001), Applications of Argumentation Schemes. *Proceedings of the 4th OSSA Conference*, Ontario.
- Reed, C.A. & Rowe, G.W.A (2001), Araucaria: Software for Puzzles in Argument Diagramming and XML. Department of Applied Computing, University of Dundee Technical Report. [The Araucaria software can be

downloaded from www.computing.dundee.ac.uk/staff/creed/araucaria/]

Schum, D.A. (1994), *The Evidential Foundations of Probabilistic Reasoning*. New York: John Wiley & Sons.

Schum, D.A. (2001), Alternative views of argument construction from a mass of evidence. *Cardozo Law Review* 22:1461-1502.

Schum, D.A. & Tillers, P. (1991), Marshalling evidence for adversary litigation. *Cardozo Law Review* 13:657-704.

Tribe, L. (1971), Trial by mathematics: precision and ritual in the legal process. *Harvard Law Review* 84: 1329-1393.

Twining, W. (1999), Necessary but dangerous? Generalisations and narrative in argumentation about “facts” in criminal process. In Malsch & Nijboer (1999), pp. 69-98.

Verheij, B. (1996), *Rules, Reasons, Arguments. Formal Studies of Argumentation and Defeat*. Doctoral Dissertation University of Maastricht.

Verheij, B. (1999), Automated argument assistance for lawyers. *Proceedings of the Seventh International Conference of Artificial Intelligence and Law*. New York: ACM Press, 1999, pp. 43-52.

Verheij, B. (2000), Dialectical argumentation as a heuristic for courtroom decision-making. In P.J. van Koppen & N.H.M. Roos (eds.): *Rationality, Information and Progress in Law and Psychology. Liber Amoricum Hans F. Crombag*. Maastricht: Metajuridica Publications, pp. 203-226.

Verheij, B. (2002), Dialectical argumentation with argumentation schemes: towards a methodology for the investigation of argumentation schemes. *Fifth International Conference on Argumentation (ISSA-2002)*, Amsterdam.

Wagenaar, W.A., Koppen, P.J. van & Crombag, H. (1993), *Anchored Narratives. The Psychology of Criminal Evidence*. New York: St. Martin's Press.

Walton, D.N. (1996a), *Argumentation Schemes for Presumptive Reasoning*. Mahwah, N. J.: Erlbaum.

Walton, D.N. (1996b), *Argument Structure: A Pragmatic Theory*. Toronto: University of Toronto Press.

Walton, D.N. (1997), *Appeal to Expert Opinion*, University Park: Penn State Press.

Wigmore, J.H. (1931), *The Principles of Judicial Proof*, 2nd ed., Boston: Little, Brown and Company

Young, W. & Kaiser, D. (1985), *Postmortem: New Evidence in the Case of Sacco and Vanzetti*. University of Massachusetts Press, Amherst.