A Hybrid Formal Theory of Arguments, Stories and Criminal Evidence

Floris Bex[a], Peter J. van Koppen[b], Henry Prakken[c] and Bart Verheij[d]

Abstract This paper presents a theory of reasoning with evidence in order to determine the facts in a criminal case. The focus is on the process of proof, in which the facts of the case are determined, rather than on related legal issues, such as the admissibility of evidence. In the literature, two approaches to reasoning with evidence can be distinguished, one argument-based and one story-based. In an argument-based approach to reasoning with evidence, the reasons for and against the occurrence of an event, e.g., based on witness testimony, are central. In a story-based approach, evidence is evaluated and interpreted from the perspective of the factual stories as they may have occurred in a case, e.g., as they are defended by the prosecution. In this paper, we argue that both arguments and narratives are relevant and useful in the reasoning with and interpretation of evidence. Therefore a hybrid approach is proposed and formally developed, doing justice to both the argument-based and the narrative-based perspective. By the formalization of the theory and the associated graphical representations, our proposal is the basis for the design of software developed as a tool to make sense of the evidence in complex cases.

Keywords Argumentation, Stories, Legal Evidence

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[a] Argumentation Research Group, School of Computing, School of Computing, University of Dundee, United Kingdom
email: florisbex@computing.dundee.ac.uk
[b] Faculty of Law, Maastricht University, and Faculty of Law, Free University Amsterdam, the Netherlands
email: peter.vankoppen@maastrichtuniversity.nl
[c] Department of Information and Computing Sciences, Utrecht University, The Netherlands
Department of Law and ICT, Faculty of Law, University of Groningen, The Netherlands
email: henry@cs.uu.nl
[d] Department of Artificial Intelligence, University of Groningen, The Netherlands
email: b.verheij@ai.rug.nl

1. Introduction

In this paper, we propose and formalise a general theory for reasoning with evidence in criminal cases. This theory, which is adapted from Bex' thesis (2009), models the *process of proof*, which concerns the facts of the case rather than legal issues such as, for example, the admissibility of evidence. In this process of proof, hypothetical stories or scenarios about "what happened" in a case are constructed and arguments based on evidence or commonsense knowledge are used to support or attack these stories. Thus, the stories can be compared according to the extent they conform to the evidence and our generally accepted commonsense knowledge.

The distinction between the study of evidence law and the study of the process of proof was made in the beginning of the 20th century by Wigmore (1931), who argued for the formulation of rational principles for reasoning with evidence and proof independent of the rules of law. Various theories on reasoning with evidence, both descriptive and normative, have since been proposed in legal theory and legal psychology. Here, two trends can be distinguished: the argument-based approach and the story-based approach. Most of the research from legal theory (Anderson et al. 2005, Schum 1994, Tillers 2005) focuses on the use of Wigmorean argument charts to structure and analyse a mass of evidence and to expose sources of doubt in the reasoning.[5] In contrast, theories from a more psychological perspective (Wagenaar et al. 1993, Pennington and Hastie 1993) stress the use of stories to organize and analyse available evidence. In AI and Law, formal theories influenced by either the argument-based or the story-based approach have been proposed. For example, Bex and colleages (2003) have modelled Wigmorean argument charts in a formal argumentation logic and Bayesian interpretations of Wigmore charts have been studied by, amongst others, Hepler and colleagues (2007). With regards to the story-based approach, Verheij (2000) compares the Anchored Narratives Theory to formal logics for argumentation, Keppens and colleagues (e.g. Keppens and Schäfer 2006) and Josephson (2002) provide logical, model-based approaches to reasoning with crime scenarios and Thagard (2004, 2005) model stories and evidence in connectionist "coherence networks".

A central theme in both the argument-based and the story-based theories is the structuring and analysis of one's reasoning so as to make sense of the case. In a large case it is important that the reasoning, evidence, hypotheses and background knowledge are all made explicit, so that sources of doubt in the reasoning can be identified and reasoned about (Anderson et al. 2005). Furthermore, explicitly identifying and analysing the hypothetical stories lessens the danger of so-called *tunnel vision*, where the most likely story is taken as the

[5] A notable exception here are Pardo and Allen (2007), who advocate using stories to explain the evidence.

leading hypothesis and alternatives are insufficiently considered (Wagenaar et al. 1993, Heuer 1999). A relatively new development in this respect is the emergence of computer-based support tools for investigators and decision makers,[6] which allow for the electronic management of, for example, evidence and timelines. The aim of such tools is to take some of the cognitive load off the users and to provide a basic tool for structuring a case. The interest in sense-making and visualization tools has also grown in AI (and Law) (Reed and Rowe 2004, Verheij 2005, Gordon 2007). Based on ideas from critical thinking and argumentation theory, these tools allow the user to structure and visualize their reasoning, often according to some underlying theory of reasoning. Through this underlying theory, a tool essentially enforces a basic standard of rationality by requiring that the user's reasoning stays within the boundaries set by the theory.

A complex process such as the process of proof ideally has a specialised sense-making tool, in which not only the evidence and stories can be structured in a simple way but in which it is also possible to reason about the evidence and stories using a sound underlying theory. Such a specialised tool for sense-making should not be based on a general theory of reasoning but rather on a specific model of reasoning in the process of proof. This model should be formally specified (in order to facilitate implementation) and at the same time it should be natural so that it can be used by an everyday reasoner such as a crime analyst, who cannot be expected to have in-depth knowledge of mathematical or formal models. In his dissertation, Bex (2009) shows that when dealing with the complex reasoning prevalent in the process of proof, a story-based approach works best for some points of a case, while in other instances an argumentative approach is the most natural. Arguments and stories therefore need to be combined into one *hybrid theory*, where stories are used to causally explain the explananda (facts to be explained) and arguments based on evidence are used to support and attack these stories. Stories can thus be used for constructing intelligible hypotheses about what happened in an intuitive way and arguments can be used to connect the evidence to these stories and to reason about the stories and the evidence in greater detail.

This paper aims to expound mainly the formal logical version of the hybrid theory developed by Bex (2009), previous versions of which were discussed in (Bex et al. 2007a, 2007b). This formal theory, which has served as the basis of the sense-making and visualization tool AVERS,[7] models reasoning with arguments as defeasible argumentation and reasoning with stories as abductive (model-based) inference to the best explanation. The paper is organized as follows. In

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[6] Examples are CaseMap (http://www.casemap.com; accessed on February 5th, 2010) and Analyst's Notebook (http://www.i2group.com/products/analysis-product-line/analysts-notebook; accessed on February 5th, 2010).

[7] AVERS stands for Argument Visualization for Evidential Reasoning based on Stories and was specifically developed for crime analysis by van den Braak and Vreeswijk, see van den Braak et al. (2008), van den Braak (2010) and Bex et al. (2007a).

Section 2, we give a brief overview of the process of proof, that is, the typical aspects and elements of reasoning with evidence. In light of these aspects, Section 3 discusses the advantages and disadvantages of the argument-based and the story-based approaches and argues why a combined approach best captures the process of proof. Section 4 presents the hybrid theory. The paper concludes with a discussion and some ideas for future research.

2. Reasoning with Criminal Evidence

In this section we will give an overview of the typical aspects and elements of the process of proof in a criminal case. We will clarify this overview by means of an example, which will be used throughout the paper. The example is a simplified version of the Rijkbloem case, which was first presented by Wagenaar and colleagues (1993) and later adapted by Bex and colleagues (2007b). The case concerns Danny Rijkbloem, a 23-year old Surinamese man living in the Netherlands. He has a considerable list of sentences (theft, robbery) starting when he was 15 years old. Nicole Lammers is a 20-year old baker's daughter who had a relationship with Rijkbloem and lived together with him. At some point Nicole decided, under pressure of her parents that it is best to break up with Rijkbloem and she leaves him. A few days after the break-up, Nicole and her parents went to Rijkbloem's house to pick up some of Nicole's stuff and got into an argument with Rijkbloem. At some point, a scuffle developed, which ended in the father getting hit by a gunshot to the head. When the police, who had been informed by Rijkbloem, arrived, the father was already dead.

2.1 The Process of Proof

In the process of proof, evidence and general commonsense knowledge of the world around us is used to establish the facts of the case. The process usually starts when some initial observations are made, that is, when some initial evidence is found. These clues or observations then become explananda, facts that need to be explained. In the Rijkbloem case, for example, the main explanandum would be the dead body of the father in Rijkbloem's house. In order to explain the explananda, hypothetical stories about what caused them need to be constructed. In the Rijkbloem case, for example, there were two main stories. The first story has Rijkbloem pulling out a gun and shooting the father during the fight. In the other story Mrs. Lammers pulled a gun out of her purse and threatened to shoot Rijkbloem with it. Rijkbloem pushed the hand holding the gun away and in the struggle the gun accidentally went off, killing father Lammers. Some of the initial hypotheses may perhaps be immediately discarded as implausible (i.e. extraterrestrial aliens killed Mr. Lammers), while others have to be tested by searching for further evidence and then determining which of them are compatible with the new evidence. For example, the police could check physical evidence such as the angle of impact of the bullet and the type of casings discarded by the gun to see whether a small-concealable gun accidentally went off (as would be the case had the mother got out her gun) or a larger gun was deliberately fired (as would be the case had Rijkbloem shot the father). When a particular hypothesis has been chosen as the most likely, this choice should be justified by explicitly showing that it is coherent and conforms to the evidence. Thus a *proof* should be constructed, consisting of a story and a justification of why the particular story was chosen. In this respect, Nijboer and Sennef (1999) speak of *explanatory justification*. According to this purpose of justification, a proper justification should not only meet some standard of rationality but it should also provide a clear explication of one's reasons for the choice of hypothesis which makes sense to not just the reasoner but also to third parties.

2.2 Evidence

The term *evidence* stands for the available body of information indicating whether a belief in some proposition is justified. When people talk about 'the evidence in a case' they usually mean the *evidential data* (Anderson et al. 2005, p 382), that is, the primary sources of evidence. This evidential data, also called *items of evidence*, *pieces of evidence* or *sources of evidence*, is perceived by the reasoner with his own senses (Wigmore 1931 calls this "autoptic proference"). Notwithstanding sensory defects on the part of the reasoner, the existence of the evidential data itself cannot be sensibly denied. In other words, if we hear a testimony of a witness who says that she saw someone who looked like the suspect jump in a red car, the proposition 'there is a testimony by a witness who saw someone who looked like the suspect jumped into a red car' can be accepted as justified.

In addition to evidential data, the term evidence can also point to other propositions which have been accepted as true and which might have been inferred from evidential data themselves. For example, the proposition that 'someone who looked like the suspect jumped into a red car', which has been inferred from the above testimony, is itself evidence for the proposition that 'the suspect jumped into a red car'. It is important that the evidential data and the propositions that are inferred from it are not confused. Anderson, et al. (2005, p. 60) denote this as follows: E^* stands for evidential data about event E; in the above example, E^* is the testimony itself and E is the event that 'someone who looked like the suspect jumped into a red car'. As was already noted, this event E can then be evidence for another event F: 'the suspect jumped into a red car'. The separation between an event and the evidential data from which the event is inferred is important because the existence of the evidential data does not mean that the event actually happened. In the above example, the witness may be lying or he may misremember or the person who looked like the suspect may not be the suspect at all. In sum, the term *evidence* stands for the information that (positively or negatively) influences our belief about a particular proposition. This information can be a piece of evidential data but also a proposition which has itself been inferred from data.

2.3 Generalizations and commonsense knowledge

That a fact at issue in the case follows from the evidence is by no means self-evident and often involves constructing complex chains of inferences using commonsense knowledge. Furthermore, the coherence of the hypothetical scenarios in the process of proof also depends on the degree to which they conform to our commonsense knowledge and expectations. So in addition to knowledge gained from (case-specific) evidence, reasoning with evidence also involves reasoning with commonsense knowledge which is not somehow based on evidential data. This can be general knowledge, which is widely accepted in a certain community (e.g. the date of Christmas is the 25th of December) or personal knowledge gained through firsthand experience (e.g. the University of Groningen is usually closed between Christmas and New Year's Eve).

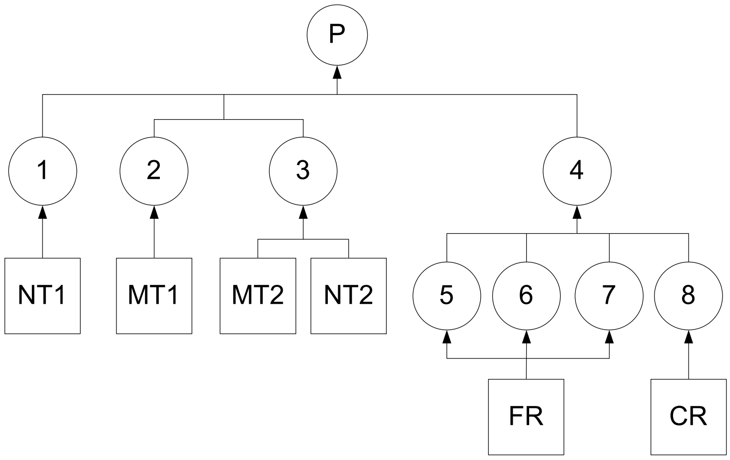
Commonsense knowledge can take the form of simple facts (e.g. Amsterdam is the capital of the Netherlands) or be expressed as *generalizations*. Generalizations are statements about how we think the world around us works, about human actions and intentions, about the environment and about the interaction between humans and their environment (Cohen 1977, pp. 274 – 276). Examples of generalizations are 'being shot in the head can cause a person to die', 'witnesses usually speak the truth', 'mothers usually don't carry guns in their purses' and 'people from Suriname are more prone to becoming involved in crime than native Dutch people'. Generalizations are almost never universally true and there are often exceptions to the generalization. For example, witnesses under oath do not always make true statements, they can lie or misremember. Because they are not universally true, generalizations are often qualified with terms such as *usually*, *often* and *sometimes*. Also, generalizations such as the ones given above can be rewritten as conditional rules of the form 'if…then…'; for example: '*if* there is a forceful impact *then* this can cause a person's skull to break' but also '*if* person *w* is a witness under oath and *w* says that event *e* happened *then* usually *e* will have happened'.

3. Argumentative and Story-based Analysis

In this section we first briefly and informally discuss two dominant approaches to reasoning with legal evidence in AI and Law, namely argumentation (Bex et al. 2003, Verheij 2000, Walton 2002) and inference to the best explanation or abductive-causal reasoning (Josephson 2002, Thagard 2004, 2005, Keppens and Schäfer 2006). After this we will discuss some of the advantages and disadvantages of the two approaches and argue that a combined approach best captures the aspects of reasoning with criminal evidence as discussed in Section 2.

3.1 Evidential Arguments

In logics for argumentation (Prakken and Vreeswijk 2002), the rules of classical logic are augmented with rules for defeasible inference. Associated with a defeasible inference is an underlying evidential generalization. Toulmin (1958/2003) and Verheij (2005) speak of this generalization as a *warrant*, Hage (1996), Prakken and Sartor (1997) and Prakken (2010) call it a *rule*, Pollock (1995) uses the term *rule of inference* and Walton (2002) interprets them as *schemes*. Arguments can be constructed by chaining applications of inferences and such lines of argument can be combined into an argument graph or inference graph (Pollock 1995) with as its premises the pieces of evidence and as its ultimate conclusion one of the explananda. Such a graph is very similar to a Wigmore chart (Wigmore 1931; Anderson et al. 2005). In Figure 1, an example of an argument graph is given. In this figure, some of the evidence for the main hypothesis, that it was Rijkbloem who shot Mr. Lammers (P), is given. The inferences in the argument are all of an *evidential* nature: a piece of evidence *e* and the evidential generalisation '*e* is evidence for *p*' allows us to infer *p*. For example, the inference from NT1 to 1 is justified by the generalization 'a witness testimony that a certain event *e* happened is (usually) evidence for the occurrence of *e*'.



P: It was Rijkbloem who killed Mr. Lammers by shooting at him from close range with a gun
1: Rijkbloem fired at Mr. Lammers from close range
NT1: Nicole's testimony to 1
2: Mrs. Lammers heard a shot when Rijkbloem charged at Mr. Lammers
MT1: Mother's testimony to 2
3: Rijkbloem had a gun
NT2: Nicole's testimony to 3
MT2: Mother's testimony to 3
4: The bullet which killed Lammers was of the same type as the bullets found in Rijkbloem's house
5: Bullet 1 taken out of Mr. Lammers' head
6: Bullet 2, taken from .22 rounds which were found in Rijkbloem's house
7: The chemical composition taken from bullet 1 and bullet 2 is significantly similar
FR: Forensics report
8: Mr. Lammers died because of Bullet 1 in his brain
CR: Coroner's report

Figure 1: An evidential argument graph

Arguments can be *attacked*. They can be *rebutted* with an argument for the opposite conclusion and they can be *undercut* (Pollock 1995) with an argument for why an inference is not allowed (usually because a generalization does not apply in the given circumstances). For example, an argument for 'Rijkbloem did not shoot the Mr. Lammers' rebuts 'Rijkbloem shot Mr. Lammers' and an argument for 'Nicole is lying (for example, because she wants to frame Rijkbloem)' undercuts the inference from NT1 to 1, because the situation where the witness lies is an exception to the general rule that 'a witness testimony that a certain event *e* happened is (usually) evidence for the occurrence of *e*'.

In the argument-based approach, arguments like the one shown in Figure 1 are built, supporting the propositions that have to be proven, and other arguments are also built to attack these arguments. In the example, the prosecution has to prove that Rijkbloem killed the father. In order to do this, arguments like the one in Figure 1 will have to be constructed. The defence will try to attack these arguments by saying, for example, that it was not Rijkbloem but the mother who shot Mr. Lammers, or by arguing that the testimonies of the two women cannot be trusted.

After it has been determined which arguments attack which other arguments, the defeat relations and thus the *dialectical status* of arguments can be assessed (see Prakken and Vreeswijk 2002). In this respect, arguments can be classified into three kinds: the *justified* arguments (those that survive the competition with their counterarguments), the *overruled* arguments (those that lose the competition with their counterarguments) and the *defensible* arguments (those that are involved in a tie). For example, assume that an argument for the conclusion 'Rijkbloem did not shoot Mr. Lammers' (A1) is rebutted by an argument for the conclusion that 'Rijkbloem shot Mr. Lammers' (A2) and vice versa. Furthermore, assume that in A2 the conclusion has been derived from Nicole's testimony and that this argument is undercut by an argument that Nicole is a liar (A3). This situation can be rendered in an abstract argumentation framework (Dung 1995) as follows:

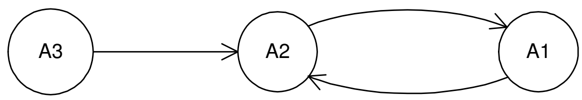


Figure 2: An abstract argumentation framework

In Figure 2, each individual argument is rendered as a single node; the exact internal structure of each argument is for current purposes less important. The arrows do not denote a support relation, as in Figure 1, but rather an attack relation between the arguments. Because A3 is itself not attacked, it is justified and (assuming it is strong enough) defeats A2, which is in turn overruled. A1 is now also justified because its only attacker is overruled. If A3 had not attacked A2, A1 and A2 would both have been defensible.

3.2 Causal stories

In the story-based approach hypothetical stories or scenarios, coherent sequences of states and events, are used to explain the observations, the evidence that has been observed in the case. This explaining is done through abductive reasoning. The basic idea of abductive inference is that if we have a general causal rule *cause* → *effect* and we observe *effect*, we are allowed to infer *cause* as a possible explanation of the effect. This cause which is used to explain the effect can be a single state or event, but it can also be a sequence of events, a story.

Stories are hence modelled (Josephson 2002, Thagard 2004, 2005) as causal networks, where the events in the story are connected by causal (or explanatory) links. These links may denote physical or psychological causation, but sometimes stand for not much more than some kind of temporal precedence between events. These causal relations can be expressed as causal generalizations; for example, ‘Rijkbloem shooting the father causes the father to die’. Figure 3 depicts a small part of the prosecution’s story in the Rijkbloem case.

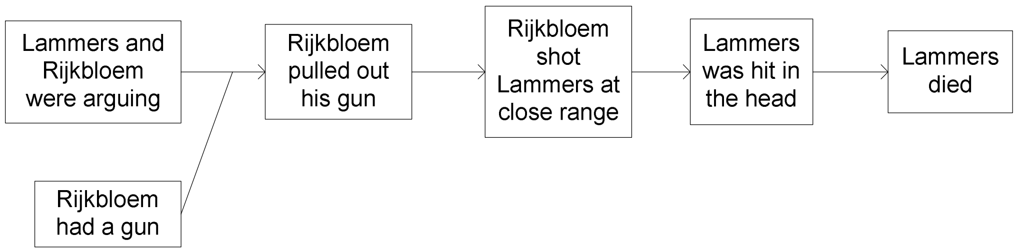


Figure 3: a causal story network

Note the different type of arrow than in Figure 1, which distinguishes the relations in Figure 3 as causal instead of evidential (as in Figure 1). The causal network shown in Figure 3 explains the observations in the case. For example, Mr. Lammers’ dead body is explained by him being shot in the head.

Taken by itself, the abductive scheme is nothing but the fallacy of affirming the consequent (i.e. if $p \rightarrow q$ and q then p). However, in a setting where alternative explanations are generated and compared, it can still be rational to accept one of these explanations. In the story-based approach, the idea is that the *explananda* (which means “facts to be explained”), which are the important observations in the case, are explained by different explanations, the best of which has to be chosen. This type of reasoning is therefore often called *inference to the best explanation* (IBE). IBE is a form of defeasible reasoning, as additional observations might give rise to a new (best) explanation. In the Rijkbloem case, the explanandum would be the dead body of Mr. Lammers. There are two different stories that each explain this: the prosecution’s story that it was Rijkbloem who shot Mr. Lammers and Rijkbloem’s story that it was Mrs. Lammers who (accidentally) shot her husband. This is visualized in Figure 4.

Figure 4: two explanations

An important question in IBE is how it can be determined what the "best" explanation is. Naturally, a good story should explain as much of the observed evidence as possible. The simplest way of determining the best explanation is thus choosing a subset-minimal explanation that explains all the observations in the case. However, this is often not possible in real-world cases, as conflicting evidence leads to conflicting observations. For example, if there are two expert reports, one which says that Mr. Lammers was shot at close range and one which says that he was shot from afar, it is impossible to explain both with the same story, as then the story would be inconsistent. Prakken and Renooij (2001) discuss a more refined method where there are certain observations that must be explained (i.e. the explananda) and other additional observations which are ideally explained; the more additional observations explained, the better. Thagard (2004) has a wholly different way of determining the best explanation. He computes the activation of the individual states and events, where acceptance or rejection of an explanation is represented by the degree of activation of the individual events in the explanation.

Pennington and Hastie (1993) argued that, in addition to explaining the observed evidence, a story should also be coherent. This coherence depends on three sub-criteria. First, a story should be *internally consistent* in that it does not contain internal contradictions; a story which says that Rijkbloem at the same time shot father from up close and from afar is not consistent. Second, a story is *plausible* if it conforms to our general knowledge of the world. Wagenaar et al. (1993) argued that a story is plausible if it is anchored in commonsense knowledge which can be expressed as generalizations. For example, one might argue that the defence's story is less plausible because it appeals to the generalization 'women (often, sometimes) have guns in their handbags'. The prosecution's story, on the other hand, seems much more believable as it is anchored in generalizations such as 'petty criminals often solve problems with violence'. Finally, Pennington and Hastie's coherence also depends on a story's *completeness*. A story is complete if it mentions some *initiating events* that cause the main actor to have *goals*, which give rise to *actions* that have *consequences*. If one of these elements is missing, a story is less coherent. The prosecution's story, for example, mentions the Lammers getting into an argument with Rijkbloem (initiating events), Rijkbloem subsequently pulling out a gun and shooting Mr. Lammers (actions) and Mr. Lammers' death (consequence). The story could be made more complete by explicitly incorporating that it was Rijkbloem's goal to kill Mr. Lammers.

3.3 Advantages and disadvantages of the two approaches

Both the argumentative and the narrative approach can be separately applied to any one case. In real cases argumentative and narrative aspects will often blend into each other in a natural way (as will be shown in Section 4). In Section 3.2, however, we have strived to maximally distinguish the two approaches so that their respective advantages and disadvantages become more clear.

Argumentative reasoning provides us with a transparent, natural and rationally sound way of analysing and assessing reasoning with evidence. The effect of the evidence on a conclusion can be shown in an intelligible way and the evidential generalizations warranting the inferences play an important role in explicating why one thinks the conclusion can be inferred from the particular evidence. Case studies of legal judgements (Bex 2009, Bex et al. 2009, Bex and Verheij 2010) and empirical research (van den Braak 2010) has shown that evidential reasoning is a natural way of reasoning about, for example, witness statements and the conclusions that can be drawn from such statements. The possibility of constructing counterarguments to attack a conclusion or an inference allow one to expose sources of doubt in the reasoning, and the dialectical process of argument and counterargument, if conducted properly, provides a rationally justified conclusion.

The ideas on argumentation presented here are almost all logically and conceptually well-developed in the literature. For example, standard patterns of (evidential) reasoning and their typical sources of doubt have been studied extensively in the work on argumentation schemes (Bex et al. 2003, Walton 2002, Walton et al. 2008). In the field of computational argumentation, formal argumentation-theoretic semantics have been developed which allow for the computation of the acceptability of arguments in light of counterarguments and thus provide a mathematically sound way to determine the status of arguments (i.e. justified, defensible, overruled).

The atomistic nature of arguments makes them very useful for carefully analysing each piece of evidence, the conclusions and the general knowledge used in reasoning from this evidence to the conclusions. However, in a purely argument-based approach the overview of the case tends to be lost. In a real case, the various hypotheses about what (might have) happened are usually not simple propositions but rather hypothetical scenarios, complex sets of propositions, the elements of which are related in various ways. The conclusion of an evidential argument is usually only a single element of such a scenario, an individual state or event, while the scenarios about 'what happened' in the case are cut into pieces. This can be seen in Figure 1, where it is not clarified how the propositions 1 – 4, which are offered as evidence for P, relate to each other or can be combined into a coherent whole. For instance, that Rijkbloem had a gun (3) is clearly a prerequisite for him firing it at Mr. Lammers (1), but this (causal) relation is not made explicit. Furthermore, certain events which have no direct bearing on the conclusion but which might help in understanding the case (e.g. ‘Lammers and Rijkbloem were arguing’) are not included in the argument. In a sense, the individual arguments from evidence only provide us with the pieces of the puzzle; without an idea of what the eventual image should look like, it can be very hard to put together these pieces.

Abductive, story-based reasoning can be used to construct understandable scenarios in a natural way. An important feature of explanatory abduction is that it provides us with new hypotheses. These new hypothetical scenarios may then point to new avenues of investigation by predicting observations that could be made. In this sense, abductive reasoning can be classified as being imaginative, creative or ‘ignorance preserving’ (Gabbay and Woods 2006). This is in contrast to evidential reasoning with arguments, which is more ‘likelihood enhancing’ (each piece of evidence enhances the likelihood that the conclusion is or was the case). Stories also provide an overview of the case and clearly show how the course of events surrounding the crime might have unfolded. They help organize the evidence and help people to fill gaps in a case. For example, the story in the Rijkbloem case (Figure 3) makes it clear what happened and allows us to consider the situation “as a whole”.

An important advantage of the narrative approach is that it is perhaps closest to how investigators and decision-makers actually think about a case. Experiments by Bennett and Feldman (1981) and Pennington and Hastie (1993) suggest that when making a decision, jurors construct and compare stories which explain most evidence and then choose the most coherent and plausible story that explains the most evidence. Studies in story recall and understanding have also shown that our memory is organized through episodes or stories (Schank and Abelson 1977). Other psychological research (Simon 2004) has shown that a holistic coherence approach (which is part of the narrative approach, see also Thagard 2004, 2005) is the natural way of modelling decision making in legal trials.

Furthermore, there seems to be a consensus in the literature on evidence analysis that fact investigators work with causal story structures and timelines (Heuer 1999, de Poot et al. 2004). Finally, Pardo and Allen (2007) have argued that a theory of IBE is a natural way to analyse legal trials; although their focus is on civil trials, they show how a general theory of IBE can be used to, for example, model the shifting of the burden of proof.

The holistic approach of stories, where the elements of the case are not considered separately but rather as a whole, also has some inherent disadvantages and dangers. Often, the evidential data has no clear and separate place in the model of the case (cf. Pennington and Hastie 2003). Purely story-based theories require that the observations are explained by the story, but it is not made clear whether these observations are the actual evidential data itself or the events that follow from the evidence. This an implicit connection to the evidence makes stories dangerous, as a coherent story can be more believable than a story which is incoherent but supported by evidence. In other words, there is a danger of “good stories” pushing out ”true stories” (Bennett and Feldman 1981). Work in AI by Josephson (2002) and Thagard (2004) has elaborated on the narrative approach and given the evidential data a clear place, namely as the causal effects of (events in) the story. This allows for reasoning about the reliability of individual pieces of evidence. However, there are indications that this does not adequately capture reasoning with implicit default knowledge (see Bex 2009, p. 78). By contrast, in an argumentation-based approach, sources of evidence are used to infer the occurrence of events, and the defeasible nature of these inferences gives a natural place to examining the source's reliability, namely, as the search for counter-arguments based on critical questions of argument schemes.

An aspect of the story-based approach which is underdeveloped is exactly how stories should be rationally compared. As Thagard and Shelley (1997) noted, the simplest (in terms of subset minimality) and most complete (in terms of explaining the most observations) explanation is not always the best. For example, a complex explanation that explains only a few important pieces of evidence can be better than a simple explanation that explains many less important pieces of evidence. Furthermore, the link between a story and one piece of evidence may be very strong whereas another piece of evidence may only have a weak connection to the story. Pennington and Hastie’s coherence principles provide some pointers for determining the inherent plausibility of an explanation, but they do not precisely define criteria. Here, a particular disadvantage of a purely story-based approach is that it is impossible to reason *about* the (elements of a) story. For example, one might want to argue that the story in Figure 3 is not plausible as people normally do not shoot other people, even when they are arguing.

Above, the argument- and story-based approach were presented as two different approaches. On a conceptual level, this makes sense: the sequence of events in Figure 3 is clearly not an argument and the argument in Figure 1 has, considered on its own, nothing to do with a story. In practice the distinction is similarly noticeable: for example, a judge considering a single event and the evidential data for and against this event is engaged in atomistic and more argumentative reasoning whilst an investigator trying to determine what course of events led to the current situation is comparing various stories in a more holistic way.

However, it can be argued that the distinction between the two approaches is an artificial one. For example, it is perfectly possible to reason about causality or intentions, goals and actions using just arguments (see e.g. Bex et al. 2009). Alternatively, reasoning about a single witnesses’ credibility can be done in an abductive approach: a testimony will then be caused by the event to which it testifies and attackers of this witness’ credibility are then modeled as alternative explanations (Thagard 2005).[8] The exact way in which the two approaches are modelled further amplifies or downplays their advantages and disadvantages. For example, an argument-based approach which uses only more abstract argument frameworks (Figure 2) can be said to be more holistic, as it provides an overview of how all the evidence in the case interacts while sacrificing the details on how exactly the conclusions follow from the evidence. Similarly, a story-based approach in which all the causal links between the events and the observations are rendered in detail can be said to be more atomistic than holistic.

Because of this overlap between the purely argumentative and narrative approaches, Bex and Verheij (2010) have argued that stories and arguments are "communicating vessels"; in some instances a causal, holistic and more story-based approach works best and in other instances an evidential, atomistic and argumentative approach is the most natural. Here the context and the aims of the analyst can play an important role. For example, when not much evidence is available to the analyst, it makes sense to hypothesize one or more stories to steer the investigation. On the other hand, when the main goal is to organize the reasons for and against a single (important) witness' credibility, arguments may be more suitable.

4. A Hybrid Theory

In the previous section we argued that both the argumentative and the narrative approach have their own advantages. The argumentative approach, which builds on a significant academic tradition of research on informal and formal argumentation, is well suited for a thorough analysis of the individual pieces of evidence, whilst the empirically tested narrative approach is appreciated for its natural account of crime scenarios and causal reasoning. In some cases, a causal, holistic and more story-based approach works best and in other instances an evidential, atomistic and argumentative approach is the most natural.

Hence, arguments and stories need to be combined into one *hybrid theory* which fully combines the two separate approaches. In this hybrid theory, stories in the form of causal networks are used to explain the explananda. Arguments based on evidence are used to support and attack these stories. Thus, stories can be used as an intelligible overview of what might have happened in the case and arguments can be used to support or attack these stories and to reason about the inherent plausibility and coherence of the stories in greater detail. In this combined approach all the features and advantages of the individual argumentative and narrative approaches remain intact; combining the two modes of reasoning only extends the possibilities.

Figure 5, which combines Figures 1 and 3, illustrates these ideas.

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[8] Simon has argued that "…[people] defy the syntactic rules of unidirectional inference…", i.e. that causal and evidential reasoning are both used in conjunction.

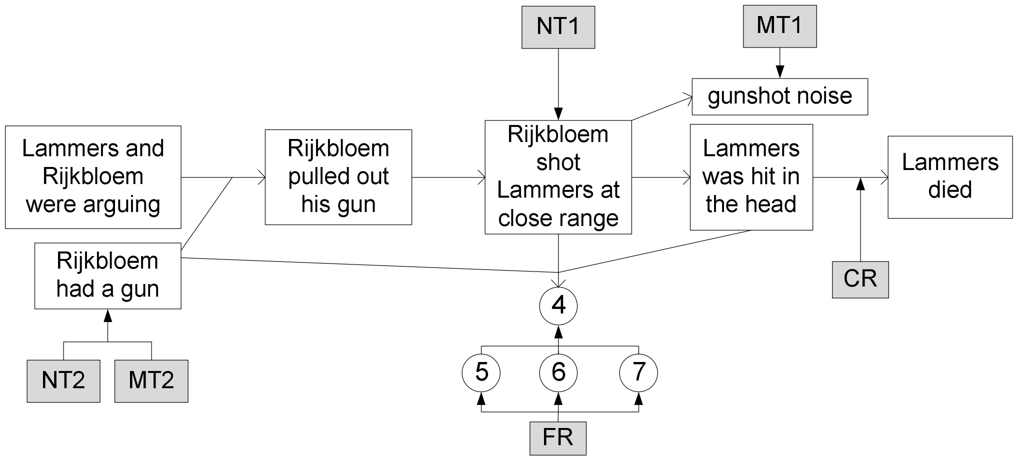

Figure 5: combining arguments and explanations

In the rest of this section, the formal version of the hybrid theory is presented. The basic idea of the formalized hybrid approach is as follows. A logical model of abductive *inference to the best explanation* (IBE) takes as input a causal theory (a set of causal rules or generalizations) and a set of observations that has to be explained, the explananda, and produces as output a set of hypotheses that explain the explananda in terms of the causal theory. The combination of hypotheses and causal theory can be seen as a story about what might have happened. Arguments based on evidence can be used to support and attack stories. These arguments can themselves be attacked and defeated, thus making it possible to reason in detail about the extent to which a story conforms to the evidence. The coherence of a story is also a subject of argumentation: arguments which are not based on evidence but rather on general commonsense knowledge can be given to support or attack a story. In this way, the plausibility of a story (i.e. its conformance with our commonsense world knowledge) can also be discussed in detail. Finally, the stories can be compared according to their coherence and the extent to which they conform to the evidence in a case.

This section is structured as follows. First, the logic underlying the hybrid theory will be briefly presented. Section 4.2 discusses the argumentative part of the hybrid theory and shows how arguments based on evidence can be constructed and attacked. Section 4.3 shows how the basics of the causal (narrative) part of the hybrid theory can be modelled. Section 4.4 discusses the hybrid theory, and in particular the criteria for determining a story's quality given the evidence and arguments.

4.1 A logic for argumentative-narrative reasoning

Logic basically consists of a combination of a formal object language and a notion of valid consequence expressed in a metalanguage. In this paper, the object language, from here on referred to as the logical language $\mathcal{L}$, is largely left unspecified. As in Prakken (2010), the assumption that $\mathcal{L}$ is closed under classical negation is generalized in two ways. Firstly, non-symmetric conflict relations between formulas will be allowed (to capture, for instance, negation as failure). Secondly, in addition to classical negation, other symmetric conflict relations will be allowed, so that, for example, formulas like 'bachelor' and 'married' can, if desired, be declared contradictory.

Definition 1 [Contrariness] Let $\mathcal{L}$, a set, be a logical language and $\bar{\ }$ a contrariness function from $\mathcal{L}$ to $2^{\mathcal{L}}$. If $\varphi \in \overline{\psi}$ then if $\psi \notin \overline{\varphi}$ then φ is called a *contrary* of ψ, otherwise φ and ψ are called *contradictory*. The latter case is denoted by $\varphi = -\psi$ (i.e., $\varphi \in \overline{\psi}$ then if $\psi \in \overline{\varphi}$).

We will not explicitly mention that $\varphi \in \overline{\psi}$ if this is obvious from the text (for example, Rijkbloem shot Mr. Lammers and Rijkbloem did not shoot Mr. Lammers). Now that the notion of negation has been generalised, the same must be done with the notion of consistency.

Definition 2 [Consistent set] Let $\mathcal{P} \subseteq \mathcal{L}$. $\mathcal{P}$ is *consistent* iff there is no $\varphi, \psi \in \mathcal{P}$ such that $\psi \in \overline{\varphi}$, otherwise it is *inconsistent*.

Since reasoning about evidence is defeasible, our logic must be nonmonotonic. Therefore, we augment the inference rules of classical logic with defeasible rules. In the hybrid theory, it should be possible to reason with generalizations: evidential generalizations are used to warrant inferences in an argument and causal generalizations are used to express causal relations in a story. As was discussed in Section 2.3, generalizations can be expressed as conditionals of the form 'if *p* then *q*'. These conditional generalizations can be modelled as object-level conditionals or as (metalinguistic) rules of inference. Bex et al. (2007b) model them as object-level conditionals which are premises for a defeasible modus ponens inference rule. Bex (2009) uses a mixed approach, were oft-used generalizations such as the one for witness testimony (see Section 3.1) are modelled as inference rules and more case-specific ones are modelled as premises at the object level. Following Prakken (2010) and van den Braak (2010) in this paper generalizations are modelled as defeasible rules.

Definition 3 [Defeasible rules] Let $\varphi_1, \ldots, \varphi_n, \psi$ be elements of $\mathcal{L}$.

- An *evidential defeasible rule* is of the form $\varphi_1, \ldots, \varphi_n >>_e \psi$, informally meaning that if $\varphi_1, \ldots, \varphi_n$ hold, then (presumably) this is evidence for ψ.
- A *causal defeasible rule* is of the form $\varphi_1, \ldots, \varphi_n >>_c \psi$, informally meaning that if $\varphi_1, \ldots, \varphi_n$ hold, then this has (presumably) caused ψ.

$\varphi_1, \ldots, \varphi_n$ are called the *antecedents* of the rule and ψ its *consequent*.

As usual in logic, inference rules will often be specified by schemes in which a rule's antecedents and consequent are metavariables ranging over $\mathcal{L}$. Furthermore, it is assumed that applications of inference rules can be expressed in the object language. In this paper we assume that this can be done in terms of a subset $\mathcal{L}_R$ of

$\mathcal{L}$ containing formulas of the form r_i. For convenience we will also use elements of $\mathcal{L}_R$ at the metalevel as names for inference rules, letting the context disambiguate.

4.2 A Theory for Evidential Argumentation

Using the logic as defined in Section 4.1, arguments based on some input information can be built. In accordance with the standard reasoning in the process of proof (Section 2), this input consists of evidential data and commonsense knowledge.

Definition 4 [Evidential theory] An *evidential theory* is a tuple $ET = (\mathcal{R}_e, \mathcal{K})$ where

- $\mathcal{R}_e$ is a set of *evidential defeasible rules*.
- $\mathcal{K} = \mathcal{K}_e \cup \mathcal{K}_a$ is a knowledge base, where:
  - $\mathcal{K}_e$, the *evidence*, is a consistent set of literals from $\mathcal{L}$.
  - $\mathcal{K}_a$ is the set of *commonsense assumptions*.

In an evidential theory, commonsense knowledge is represented in both $\mathcal{R}_e$ and $\mathcal{K}_a$; conditional generalizations are in $\mathcal{R}_e$ and other assumptions are in $\mathcal{K}_a$. Given this commonsense knowledge and the evidence in $\mathcal{K}_e$, arguments can be constructed as in the following definition.

Definition 5 [Argument] An *argument* based on an evidential theory *ET* is a finite sequence $[\varphi_1, \ldots, \varphi_n]$, where $n > 0$, such that for all φ_i $(1 \leq i \leq n)$:

- $\varphi_i \in \mathcal{K}$; or
- There exists a rule in $\mathcal{R}_e$ such that $\psi_1, \ldots, \psi_n >>_e \varphi_i$ and $\psi_1, \ldots, \psi_n \in \{\varphi_1, \ldots, \varphi_{i-1}\}$.

The elements of the sequence are also called *lines of argument*. Alternatively, an argument could be defined as a tree, as in e.g. Prakken 2010. As is well-known, the sequence- and tree-form of an argument are equivalent in that every sequence captures one way to construct a tree.

According to the above definition, a line of argument is a proposition from the input information in *ET* or is derived from preceding lines of argument by the application of some evidential inference rule. In what follows, for a given argument *A*, *Prem*(*A*) denotes the set of all the elements in *A* which are also in $\mathcal{K}$ (i.e. *A*'s premises), *Conc*(*A*) denotes the set of *A*'s conclusions, lines of argument which are not in $\mathcal{K}$ and Rules(*A*) is the set of inference rules from $\mathcal{R}_e$ used in the argument. Furthermore, *Args*(*ET*) denotes the set of all arguments that can be constructed from a theory *ET*.

For an example of an evidential argument, assume that *ET* is as follows:

$\mathcal{K}_e$ = {Nicole testified that 'I remember Rijkbloem shooting my father'}
$\mathcal{R}_e$ = { $r_{witness}$: *w* testifies that '*p*' $>>_e$ *p* is true,

r_{memory}: *w* remembers that *p* happened $>>_e$ *p* happened}

These two inference rules for witness testimony and memory are well-known from the literature (Pollock 1995; Bex et al. 2003; Walton et al. 2008). Now, the following argument A_{shot} for the conclusion that Rijkbloem shot Mr. Lammers can be constructed:

1. Nicole testified that 'I remember Rijkbloem shooting my father' ($\mathcal{K}_e$)
2. Nicole remembers that Rijkbloem shot Mr. Lammers (1, $r_{witness}$)
3. Rijkbloem shot Mr. Lammers (2, r_{memory})

Note that the lines of argument have been numbered and that at the end of each line of argument it is noted how the line was inferred.

Now the notion of attack between arguments must be formally defined. Normally, attacking an argument does not mean that the argument is automatically defeated. For argument *A* to defeat argument *B*, *A* has to *successfully attack* *B* and for this, *A* has to be somehow stronger than *B* or preferred to *B*. However, because currently no notion of strength or preference of arguments is defined, the notions of attack and defeat will simply be equated. Extending the framework to include preferences between arguments (which can themselves be based on, for example, preferences between evidence or inference rules) can be done along the lines of Prakken (2010).

Definition 6 [Defeat] Given two arguments *A* and *B*:

- *A rebuts B* iff $\exists \varphi \in A$ and $\exists \psi \in B$ such that $\varphi \in \bar{\psi}$ and ψ follows from the application of a rule $r_i \in \mathcal{R}_e$.
- *A undercuts B* iff $\exists \varphi \in A$ and $\exists r_i \in \texttt{Rules}(B)$ such that $\varphi \in \bar{r}_i$.
- *A undermines B* iff $\exists \varphi \in A$ and $\exists \psi \in B$ such that $\varphi \in \bar{\psi}$ and $\psi \in \mathcal{K}_a$.

A defeats *B* iff *A* either rebuts, undercuts or undermines *B*.

With the above definition of defeat, the current argumentation theory combines two ways to capture the defeasibility of reasoning, called plausible and defeasible reasoning by Vreeswijk (cf. Prakken and Vreeswijk 2002). In plausible reasoning, arguments can only be attacked on their (defeasible) premises (e.g. Bondarenko et al. 1997). In defeasible reasoning, arguments can only be attacked on the applications of defeasible rules (e.g. Pollock 1995; Vreeswijk 1997). In Verheij (2003), the distinction between plausible and defeasible reasoning is downplayed as the applications of rules are expressed as conditional sentences in the object language. The current approach follows Prakken (2010) and allows arguments to be attacked on the applications of inference rules (rebutting and undercutting) as well as on defeasible premises (undermining).

As an example of a rebuttal, consider the following argument A_{not_shot}.

1. Rijkbloem testified that 'I never shot Mr. Lammers' ($\mathcal{K}_e$)
2. Rijkbloem never shot Mr. Lammers (1, $r_{witness}$)

Line 2 of this argument rebuts line 3 of the argument A_{shot}. Now assume that the following inference rule is added to $\mathcal{R}_e$:

$r_{suspect}$: *w* is a suspect in the case >>$_e$ *w* is not trustworthy

Furthermore, assume that '*w* is not trustworthy' $\in \bar{r}_{witness}$, i.e. if someone is untrustworthy then this contradicts any application of the witness inference rule. The following argument $A_{suspect}$, which undercuts A_{not_shot} can now be constructed:

1. Rijkbloem is a suspect ($\mathcal{K}_e$)
2. Rijkbloem is not trustworthy (2, $r_{suspect}$)

However, this argument possibly is a fallacy: if we were to believe that suspects are always untrustworthy, then they would never be able to defend themselves in court. So what we want to do is give an argument for the fact that $r_{suspect}$ expresses an invalid generalization. First, we add the following rules to $\mathcal{R}_e$:

r_{expert}: *e* is an expert in criminal psychology, *e* says *p* >>$_e$ *p* is true
$r_{invalid\_suspect}$: suspects are no less trustworthy than any other witness >>$_e$
the rule $r_{suspect}$ expresses an invalid generalization

Furthermore, assume that 'the rule r_i expresses an invalid generalization' $\in \bar{r}_i$, i.e. if a particular rule is deemed invalid it is contradicted. Now, the following argument $A_{invalid\_suspect}$ undercuts $A_{suspect}$.

1. Peter is an expert in criminal psychology ($\mathcal{K}_e$)
2. Peter says suspects are no less trustworthy than any other witness ($\mathcal{K}_e$)
3. Suspects are no less trustworthy than any other witness (2, r_{expert})
4. The rule $r_{suspect}$ expresses an invalid generalization (3, $r_{invalid\_suspect}$)

Thus, we can talk about the invalidity of defeasible rules. It is also possible to give an argument for the validity of an inference rule. Assume that the following rules are added to $\mathcal{R}_e$:

$\mathcal{R}_e$ = { r_{gen_knowl}: It is general knowledge that *p* >>$_e$ *p* is true,
$r_{valid\_suspect}$: suspects are not trustworty >>$_e$
the rule $r_{suspect}$ expresses a valid generalization}

The inference rule for general knowledge was first proposed by Bex et al. (2003). The inference rule $r_{valid\_suspect}$ shows that it is possible to talk about the validity of generalizations using arguments. Essentially, this allows one to provide an inference rule with what Toulmin calls a *backing*, a reason for the validity of a rule, viz. argument $A_{valid\_suspect}$:

1. It is general knowledge that 'suspects are not trustworthy' ($\mathcal{K}_a$)
2. Suspects are not trustworthy (1, r_{gen_knowl})
3. The rule $r_{suspect}$ expresses a valid generalization (2, $r_{valid\_suspect}$)

This argument "defends" the argument $A_{suspect}$ that uses r_{memory}, because it defeats any argument that argues that the rule does *not* express a valid generalization: line

3 in $A_{valid\_suspect}$ rebuts line 4 in $A_{invalid\_suspect}$ and vice versa. In this case, however, we assume that $A_{valid\_suspect}$ is *undermined*, which is possible because the premise at line 1 is a commonsense assumption. Undermining $A_{valid\_suspect}$ would involve arguing for the contrary of this assumption (e.g. by giving an argument that says that general knowledge may not be used as a basis for reasoning); assume for the example's sake that we have such an argument $A_{not\_valid\_suspect}$.

The arguments and defeat relations specified above provide a set of arguments, rendered in Figure 6 as an abstract argumentation framework.

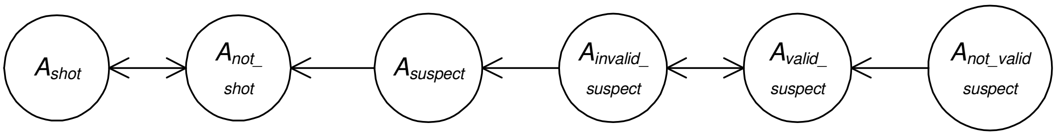

Figure 6: an abstract argumentation framework

Here, A_{shot} rebuts A_{not_shot} and vice versa, $A_{suspect}$ undercuts A_{not_shot}, $A_{invalid\_suspect}$ undercuts $A_{suspect}$, $A_{valid\_suspect}$ and $A_{invalid\_suspect}$ rebut each other and $A_{not\_valid\_suspect}$ undermines $A_{valid\_suspect}$. Based on these defeat relations, constraints on the dialectical status of arguments can be defined.

Definition 7 [Dialectical status assignment] A *dialectical status assignment* is a labelling of arguments with labels either *in*, *out* or *undecided*, such that the following hold:

- An argument is *in* iff all arguments defeating it (if any) are *out*.
- An argument is *out* iff it is defeated by an arguments that is *in*.
- An argument is *undecided* in all other cases.

Using such labelling-based status assignments, any semantics *S* proposed by Dung (1995) can be used to determine the arguments' status (cf. Verheij 1996, Caminada 2006). Here we take it that an argument is *justified* if it is 'in' in all *S* status assignments, it is *overruled* if it is 'out' in all *S* status assignments and it is *defensible* if it is 'in' in some but not all *S* status assignments. For example, $A_{invalid\_suspect}$ and $A_{not\_valid\_suspect}$ are justified and the rest of the arguments are overruled according to grounded semantics. For preferred semantics, these two arguments are also justified but A_{shot} and A_{not_shot} are defensible; the rest are overruled.

4.3 A Theory for Explanatory Stories

As was indicated at the beginning of this section, hypothesized stories should causally explain the explananda, the facts to be explained in the case. As in traditional models of abductive model-based reasoning (Console and Torasso 1991), this *explains* relation between a story and the explananda can be defined through a notion of logical consequence: the explananda should follow from a combination of hypothesized events and causal rules (expressing causal relations between events). A *causal theory* that is to be used as the basis for stories should therefore contain the explananda as well as the events and causal rules from which the explananda follow:

Definition 8 [Causal Theory] A causal theory is a tuple $CT = (\mathcal{R}_c, \mathcal{H}, \mathcal{F})$ *where*

- $\mathcal{R}_c$ is a set of causal rules;
- $\mathcal{H}$, the *hypotheticals* or *hypothetical events,* is a set of ground literals;
- $\mathcal{F}$, the *explananda* which have to be explained, is a consistent set of ground first-order literals.

The causal rules in $\mathcal{R}_c$ denote causal generalizations, which in turn express some kind of (assumed) causal relation in the world and the hypotheticals $\mathcal{H}$ denote assumed events. The *explananda* $\mathcal{F}$ is a set that has to be explained by the combination of hypotheticals and rules (in standard definitions of causal-abductive reasoning these are usually called *observations*). The causal theory *CT* is in a sense analogous to the evidential theory *ET*: an *ET* supplies the input on the basis of which arguments can be constructed and a *CT* supplies the input on the basis of which hypothetical stories can be constructed, namely assumed events (hypotheticals) and causal rules.

Standard accounts of abductive model-based reasoning simulate the abductive inference with classical-logical derivation: some hypothesis *S* explains an observation *o* if *o* is a logical consequence of *S*. In order to define how stories explain explananda in the current logic, first the structure of a story and the way in which propositions can be derived from a story should be defined.

Definition 9 [Story] A story *S* based on a causal theory *CT* is a finite sequence $[\varphi_1,\ldots,\varphi_n]$, where $n > 0$, such that for all φ_i $(1 \leq i \leq n)$*:*

- $\varphi_i \in \mathcal{H}$*;* or
- There exists a rule in $\mathcal{R}_c$ such that $\psi_1, \ldots, \psi_n \gg \varphi_i$ and $\psi_1, \ldots, \psi_n \in \{\varphi_1, \ldots, \varphi_{i-1}\}$.

Here, a story is a set of events put in (chronological) sequence. These events may simply be assumed (i.e. in $\mathcal{H}$) or they can be causally inferred from a previous event in the sequence. The elements of the sequence are called *events*; the function `Events`(*S*) returns all events for a given story *S* and, similar to arguments, `Rules`(*S*) is the set of inference rules from $\mathcal{R}_c$ used in the story and `Stories`(*CT*) denotes all stories which can be constructed from some *CT*. Notice the similarity of a causal story to an evidential argument: both are derivations in the logic as defined in Section 4.1. This structural similarity does, however, not mean that stories and arguments are used in the same way: where arguments are used to evidentially *argue* for a particular conclusion, stories are used to causally *explain* explananda. As an example of a story S_P, take the following sequence:

1. Lammers and Rijkbloem were arguing ($\mathcal{H}$)
2. Rijkbloem had a gun ($\mathcal{H}$)
3. Rijkbloem pulled out his gun (1, 2, *causal inference*)

4. Rijkbloem shot Lammers at close range (3, *causal inference*)
5. Lammers was hit in the head (4, *causal inference*)
6. Lammers died (5, *causal inference*)

Note that we did not first specify the causal theory. The elements which are from $\mathcal{H}$ are indicated in the sequence and it is assumed that $\mathcal{R}_c$ contains the inference rule needed to infer the derived events which are not in $\mathcal{H}$ (indicated by *causal inference*). For example, the inference from 5 to 6 is justified by the causal rule Lammers was hit in the head $>>_c$ Lammers died. This means that the inference rules in the above story are case-specific (i.e. they are not expressed as schemes and do not contain variables) unless explicitly mentioned otherwise.

Some of the causal generalizations in the above explanation stand for not much more than some kind of temporal precedence[9] between events and the actual causal relations between events may be debated. For example, one could argue that a simple argument is not a good motivating cause for Rijkbloem to decide to shoot Mr. Lammers. In the current model, this naïve view on causal reasoning is purposeful, as it allows for the quick and easy construction of stories and thus retains the holistic flavour of narrative reasoning. The ad-hoc interpretation of causality is not a problem, as any objection to doubtful causal links can explicitly be expressed using arguments (see Section 4.4).

Now, a story *explains* some explanandum if the explanandum is an (explicitly) mentioned event in the story. This is slightly different than in traditional models of explanation, where hypotheticals together with rules explain the explananda when the explananda are simply derivable from the hypotheticals and the generalizations (i.e. *hypotheticals* $\cup$ *generalizations* $\vdash$ *explananda*).

Definition 10 [Explanation] Given a causal theory *CT,* a story *S* is an explanation for a set of literals *E* iff

- for all *e*, if $e \in E$ then $e \in \mathit{Events}(S)$; and
- *S* is consistent; and
- *S* contains no two generalizations with the same consequent.

The second condition in the above definition, which is standard in models of abductive causal reasoning, ensures that the explanation does not lead to inconsistencies. Notice that this condition effectively models one of the criteria for the quality of a story, namely the criterion that a story should be internally consistent. The third condition ensures that two different explanations for *F* are really seen as two separate explanations: two stories with the same consequences are considered as alternative stories.

In the Rijkbloem case, the story S_P explains that Mr. Lammers died. Recall that Rijkbloem himself recounted another story about what happened that day,

[9] In the current framework, time is not explicitly represented. Rather, it is implicitly assumed that the further in the sequence an event is, the later it takes place.

namely one in which Mrs. Lammers pulled out a gun and accidentally shot Mr. Lammers. A simplified version of his story S_D is as follows.

1. Lammers and Rijkbloem were arguing ($\mathcal{H}$)
2. Mrs. Lammers had a gun ($\mathcal{H}$)
3. Mrs. Lammers pulled out her gun (1, 2, *causal inference*)
4. Rijkbloem hit Mrs. Lammers hand in which she was holding her gun (3, *causal inference*)
5. The gun Mrs. Lammers was holding went off (4, *causal inference*)
6. Lammers was hit in the head (5, *causal inference*)
7. Lammers died (6, *causal inference*)

This story now also explains the explanandum, Lammers died. The two stories S_P and S_D now have to be compared. Because arguments play a major role in this comparison, first the combination of explanatory stories and arguments based on evidence will have to be defined.

4.4 A Hybrid Theory of Argumentation and Explanation

So far, two separate parts of the hybrid theory have been defined. The argumentative part consists of input data *ET* from which arguments can be constructed. These arguments can defeat each other and they can be assigned a status overruled, defensible or justified accordingly. The causal part *CT* consists of input data *CT* from which hypothetical causal stories that explain the explananda $\mathcal{F}$ can be constructed. The *hybrid theory* is a combination of an evidential theory and a causal theory.

Definition 11 [Hybrid Theory] A *hybrid argumentative-narrative theory* is a tuple $HT = (ET, CT)$, where

- *ET* is an evidential theory
- *CT* is a causal theory such that every $f \in F$ is the conclusion of a justified argument A in $\mathtt{Args}(ET)$ for which there is a $\varphi \in \mathtt{Prem}(A)$ which is in $\mathcal{K}_e$.

In the hybrid theory the argumentative part directly influences the composition of the narrative part: the explananda should follow from evidential data through a justified argument. The reason for this is that we are only interested in states or events which have actually happened, so events which do not follow from evidence (i.e. we are not sure they happened) do not have to be explained.

Given sets of arguments and stories, essentially three criteria for determining the extent to which a story conforms to the evidence can be given. The first is *evidential support*, the extent to which the events or the causal relations in a story are supported by evidence from $\mathcal{K}_e$ through an argument. The second is *evidential contradiction*, the extent to which the events or the causal relations in a story are contradicted by an argument based on evidence from $\mathcal{K}_e$. The third is *evidential* *gaps*, the number of the events in a story about which there is no evidence, that is, the events which are neither supported nor contradicted by evidence.

In order to determine evidential support and contradiction, it first needs to be defined how arguments based on evidence can support or contradict a story.

Definition 12 [Support] Given a story S, φ (justifiably or defensibly) *supports* S iff there is a (justified or defensible) argument $A \in Args$ such that $\varphi \in Prem(A)$ and $\psi \in Conc(A)$, where $\psi \in S$ or ψ is some $r_i \in Rules(S)$.

Definition 13 [Contradiction] Given a story S, φ (justifiably or defensibly) *contradicts* $\psi \in S$ iff φ (justifiably or defensibly) supports $\overline{\psi}$;

So a premise of a non-overruled argument supports its conclusions and contradicts anything that is contradictory to its conclusions. Notice that it is also possible to support or contradict an inference rule and that there are two degrees of support and contradiction (justified and defensible) depending on whether the argument itself is justified or defensible.

Evidential support and contradiction can now be defined as the set of all pieces of evidence that support or contradict some event or causal relation in a story, respectively.

Definition 14 [Evidential support] The *evidential support* of a story S is the set $E^+(S) = \{\varphi \in \mathcal{K}_e \mid \varphi \text{ supports } S\}$.

Definition 15 [Evidential contradiction] The *evidential contradiction* of a story S is the set $E^-(S) = \{\varphi \in \mathcal{K}_e \mid \varphi \text{ contradicts } S\}$.

These two definitions allow us to record the extent to which the evidence supports or contradicts a story. Take, as an example, the story S_P. This story is supported by the evidence Nicole testified that 'I remember Rijkbloem shot my father' because argument A_{shot} has as its conclusion the event in line 4 from the story. In a similar way, an argument A_{cod} from expert opinion can be constructed that supports the causal rule about the cause of Lammers' death r_{cod}: Lammers was hit in the head $>>_c$ Lammers died.

1. Bob is a coroner ($\mathcal{K}_e$)
2. Bob says the cause of Lammers' death was the bullet lodged in his brain ($\mathcal{K}_e$)
3. The cause of Lammers' death was the bullet lodged in his brain (2, r_{expert})
4. The rule r_{cod} is valid (3, *evidential inference*)
5. r_{cod} (4, *evidential inference*)

In this argument, the two inference rules justifying the inferences from 3 to 4 and 4 to 5 have been implicitly assumed. By arguing for the validity of the causal rule, we have thus increased the evidential support of both S_P and S_D.

As an example of evidential contradiction, take argument A_{not_shot}. In addition to defeating argument A_{shot}, this argument also makes that Rijkbloem's testimony (about him not shooting) contradicts the story S_P. Like with support, evidence could also be used to contradict causal rules in the story S_P, further increasing its evidential contradiction.

The third criterion that pertains to a story's conformance to the evidence is that of *evidential gaps*, those events for which there is no evidence from which we may infer either that the event happened or did not happen.

Definition 16 [Evidential gaps] The *evidential gaps* of a story S is the set $E^G(S) = \{\psi \in S \mid \neg\exists\varphi \in \mathcal{K}_e$ such that φ supports or contradicts $\psi\}$.

Evidential gaps are hypothesized events for which there is no direct evidence and which therefore have to be inferred from plausible circumstances, that is, the story as a whole. Thus the circumstances detailed in the story make it plausible that the events in question happened. This is the 'gap-filling' function of stories: gaps in the evidence are filled with events that fit the total picture painted by the story.

Recall from Section 3.2 that a good story not just conforms to the evidence but is also coherent. Here, two criteria for coherence will be given, which are similar to Pennington and Hastie's (1993) criteria but defined in more detail: *internal consistency* and *plausibility*. The criterion of consistency is already incorporated into Definition 10 of an explanation. The criterion of plausibility is less obvious. Pennington and Hastie argue that a story is plausible if it conforms to our general commonsense knowledge of the world. That is, the states, events and causal relations that are not based on evidence should be plausible in that they follow from our stock of knowledge. Such events or relations can be simply assumed: in principle, the causal theory *CT* places no restrictions on the hypothesized events in $\mathcal{H}$ or rules in $\mathcal{R}_c$. However, the plausibility of the story can also be explicitly reasoned about, thus drawing out sources of doubt or arguing why a certain story is inherently plausible. In this reasoning, an event which is explicitly supported by an argument from general knowledge is more plausible than an event which is implicitly assumed. The rationale behind this is that if an explicit argument is given, a consensus about the assumed event is more easily reached because explicit arguments can be tested in the dialectical process.

Thus the *plausibility* of a story can be defined as the events and the generalizations expressing causal relations are supported by *explicit arguments* based on the commonsense assumptions $\mathcal{K}_a$. In a similar way, the *implausibility* of a story is the extent to which the events and the generalizations expressing causal relations are attacked by explicit arguments based on $\mathcal{K}_a$. Whilst, for example, an implicitly assumed rule expressing a causal relation can be implausible, this is not evident unless an argument contradicting the relation has been given.

Definition 17 [Plausibility] The *plausibility* of a story S is the set $P^+(S) = \{\varphi \in \mathcal{K}_g \mid \varphi$ supports $S\}$.

Definition 18 [Implausibility] The *implausibility* of a story S is the set $P^-(S) = \{\varphi \in \mathcal{K}_g \mid \varphi$ contradicts $S\}$.

Note that arguments based on evidence do not directly increase or decrease a story's plausibility, as they are already directly taken into account with evidential support and contradiction. Thus, plausibility is a notion that can be established independently of the evidential data. The reason for this is that when there is evidence for a particular part of a story, its coherence is of secondary importance: if, for example, an event is supported by evidential data, we do not need to reason with our commonsense knowledge in order to make this particular event or generalization more plausible.

As an example of an argument relevant for the plausibility of S_P, consider the following argument for the validity of r_{threat}: Lammers and Rijkbloem were arguing, Rijkbloem had a gun $>>_c$ Rijkbloem pulled out his gun.

1. It is general knowledge that people like Rijkbloem threaten with violence at the slightest provocation ($\mathcal{K}_a$)
2. Rijkbloem can be expected to threaten at the slightest provocation (2, *evidential inference*)
3. The rule r_{threat} is valid (3, *evidential inference*)
4. r_{threat} (4, *evidential inference*)

A similar argument relevant for the implausibility of S_D can be constructed.

1. It is general knowledge that most women do not have guns ($\mathcal{K}_a$)
2. Most women do not have guns (2, *evidential inference*)
3. Mrs. Lammers did not have a gun (3, *evidential inference*)

This argument contradicts an element in S_D, Mrs. Lammers had a gun, with a commonsense assumption, thus adding to the implausibility of the story.

An important question is when one story is better than another story. One way to compare stories is to determine the extent to which the stories conform to the evidence with the criteria of evidential support, contradiction and gaps and the extent to which a story is coherent with the criteria of consistency, plausibility and implausibility and then provide an ordering on stories (for example, *the more evidential data that supports the story, the better the story* or *the less evidential gaps the better the story*). This comparison could be done by simply counting, for example, the total number of evidential data that support story S_1 and S_2; if S_1 is supported by more data it is better than S_2 and vice versa.

Definition 19 [Comparing stories] Given two stories S_i and S_j, a total preordering function $\leq_{ht}$ can be defined as follows:

- If $|E^+(S_i)| < |E^+(S_j)|$ and $|E^-(S_i)| \geq |E^-(S_j)|$ then $S_i <_{ht} S_j$
- If $|E^+(S_i) \leq |E^+(S_j)|$ and $|E^-(S_i)| > |E^-(S_j)|$ then $S_i <_{ht} S_j$
- If $|E^+(S_i)| = |E^+(S_j)|$ and $|E^-(S_i)| = |E^-(S_j)|$ then
  - If $|P^+(S_i)| < |P^+(S_j)|$ and $|P^-(S_i)| \geq |P^-(S_j)|$ then $S_i <_a S_j$
  - If $|P^+(S_i)| \leq |P^+(S_j)|$ and $|P^-(S_i)| > |P^-(S_j)|$ then $S_i <_a S_j$
  - If $|P^+(S_i)| = |P^+(S_j)|$ and $|P^-(S_i)| = |P^-(S_j)|$ then
    - If $|E^G(S_i)| > |E^G(S_j)|$ then $S_i <_a S_j$

- If $|E^G(S_i)| = |E^G(S_j)|$ then $S_i =_a S_j$

Where $|V|$ stands for the cardinality of a set V.

Notice that if the criteria are used to provide an ordering on stories, they should be ranked according to their importance. Here, the extent to which a story conforms to the evidence is ranked as being more important than the coherence of the story. The danger of a "good" story pushing out a "true" story is real. If a more evidentially supported story is, according to the ordering, always better than another story no matter the coherence of both stories, this danger is obviated.

Take the two stories S_P and S_D. Both stories are supported by Bob's expert testimony and both are supported by one witness testimony (through A_{shot} and A_{not_shot}). No arguments based on evidence have been given that contradict either of the stories. In the end, S_P is the better story because it has one explicit argument for its plausibility while S_D has an explicit argument for its implausibility.

Interpreting the various criteria in this discrete, almost mathematical way as discussed here is not without problems. It is, for example, not always the case that if story A is supported by more evidential data than story B, story A is better than story B. If story A is supported by only one piece of evidence that is deemed highly credible and relevant and story B is supported by multiple pieces of evidence whose relevance to the main explananda is slight, we would not say that story B is automatically better because it has a higher evidential support.

A different way of using the criteria is by not interpreting them as providing hard-and-fast rules for the comparison of stories, but rather to regard them as providing guidelines for reaching a rational and well-thought-out decision about the facts of the case. Bex (2009) uses orderings like the one defined above to *guide* the analytic process with evidence stories.

5. Conclusion

The current hybrid theory's contribution lies in particular in its full integration of arguments and stories into one theory for reasoning with criminal evidence. Whilst Modified Wigmorean Analysis (exemplified by the book by Anderson, Schum and Twining 2005) and the Anchored Narratives Theory (Wagenaar, van Koppen and Crombag 1993) both allow the use of stories as well as arguments (or at least some sort of argumentative inference), neither of these theories fully integrates the two. The hybrid theory bridges the gap between the Modified Wigmorean Analysis and the Anchored Narratives Theory. Proponents of the first approach have argued that reasoning with (argument) charts is the best rational way of reasoning with evidence. They argue that stories are mainly useful for organizing and presenting the evidence and that they play a largely psychological (as opposed to a critically rational) role in evidence evaluation. Here we argue that, when combined with arguments and open to criticism, causal stories in inference to the best explanation are not only a natural but also a rational way of reasoning. Proponents of the more story-centred approaches have argued that the only natural way in which people reason with evidence is through stories and that all reasoning in a case takes the form of a story. However, often reasoning from evidential data to some conclusion takes the form of a syllogistic argument, and the hybrid theory shows how stories can be grounded in evidence through such arguments.

The discussion of the separate argument-based and story-based approaches has also shown that stories and arguments are both necessary for a natural and rationally well-founded theory of reasoning with criminal evidence. By retaining the advantages and flexibility of the separate approaches whilst at the same time solving some of their problems by integrating the two approaches, the hybrid theory acknowledges this interaction between evidence, arguments and stories. Holistic stories provide an overview of the various possible scenarios in a case and can be used to make sense of a complex mass of evidence. They can be used in a relatively simple way to construct complex new hypotheses in the discovery phase of the process of proof. Furthermore, when combined with arguments, stories are useful when justifying one's decision in a complex case because they help make sense of the evidence and the events that can be inferred from the evidence. Thus, a decision can be more easily checked by third parties. Arguments provide a natural connection between the evidential data and the facts of the case. Notions such as critical questions and attackers can be used to reason about the relevance and inferential force of an argument and the focused and atomistic way of reasoning with arguments allows for a detailed analysis of the individual pieces of evidence, the hypothetical stories and the commonsense world knowledge that is used in the reasoning. The direct interaction between arguments and stories, that is, the ways in which arguments can directly support and contradict stories and the ways in which the criteria for judging a story's quality are dependent on evidential arguments, are unique to the hybrid theory and allow for a natural and rationally well-founded theory of inference to the best explanation.

In a sense, stories and arguments in the hybrid theory act as communicating vessels. At some point in a case, only one individual state or event will be at issue and in such cases it is most natural to reason with evidential arguments. For example, we might want to know if a suspect was at a particular location at a particular time and consider all the evidence for and against this fact. However, at other points in an investigation, we might use a story to fill an evidential gap and see whether assuming the gap-filling event still allows for a plausible story. For example, if no evidence for the suspects location at a particular important time is available we can assume that the suspect actually was at the location and, given other evidence about the suspect's whereabouts at other points in time, see if the causal and temporal structure of the story is still plausible.

The theory as developed here has been expressly developed to underpin a sense-making tool. Hence, it is one of the few logical theories which has conceptual, cognitive as well as computational aims. In the current project, the logic was developed concurrently with the prototype system AVERS (van den Braak 2010). The logical model of causal stories combined with evidential arguments is directly implemented in the system; the results of the tests performed with the system and the informal contact with various teams of the Dutch police force and Dutch police academy have influenced the theory and strengthened the claim that the hybrid theory is close to how actual reasoning with evidence in an investigation context is performed.

The design of the hybrid theory provides new insights which are interesting for formal defeasible reasoning in general and logical inference to the best explanation in particular. In real domains such as criminal investigation, the logical or mathematical modelling of inference to the best explanation is a hard enterprise. One reason for this is that a logical or mathematical theory which is used to model the explanations in the domain is itself complex. Hence, a model of the domain in a logical theory is too complex to be constructed or understood by (logical or mathematical) laymen. For example, a proper Bayesian Network cannot be constructed or fully appreciated without in depth knowledge of the probabilities and dependencies expressed in the mathematical model underlying the network. In such a case, the user of a model or system based on a logical model does not know if his or her beliefs about the case are correctly expressed.

The hybrid theory is based on a logical model that models explanations as stories, causal networks in which events are connected with simple, case-specific generalizations. The theory is based on research on how we understand the world around us and how the human memory is organized; stories and story schemes are natural tools we use in our everyday reasoning about a complex world. Therefore, no formal mathematical training is needed and models of relatively complex cases (such as the Anjum murder case, which is analyzed using the present theory by Bex 2009) can be constructed and understood by laymen. A formal model of argumentation, based on the intuitive concepts of argument and counterargument, is used to reason about the formal causal model (i.e. a hypothetical story). This combination of stories and critical argumentation makes the hybrid theory ideal for sense-making: the knowledge represented in the system (i.e. the stock of knowledge and the hypothetical stories) can be constructed incrementally and is defeasible in that knowledge which is accepted at one point may be rejected at a later time when new evidence that contradicts this knowledge becomes available. Thus the users of the system can try to reach a cognitive consensus about the model of a case that is compatible with the evidence in a natural and rational way.

When used for factual proof instead of investigation, a limitation of our approach is that it does not tell the trial of fact when the relevant standard of proof has been met. To model reasoning with standards of proof, our model should be extended but we believe that this is rather straightforward. Firstly that a story is the best does not imply that it is sufficiently good to be held true, so the IBE part of our model must be extended with standards of proof for the 'absolute' quality of a story. It should be noted that setting such a standard of proof is a substantial legal issue and not matter of inference, so it lies outside any formal model of reasoning.

Second, in the argumentation part of our model we have not modelled how a choice can be made between rebutting arguments (for example, between arguments based on conflicting evidential sources). Such choices can be expressed if our model is extended with a preference relation on arguments along the lines of e.g. Prakken (2010)[10]. Here too it holds that the decision whether one of two rebutting arguments is preferred over the other and so defeats it is a substantial one and not a matter of inference. However, once such a decision has been expressed, our model captures its impact on other issues.

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[10] See Prakken and Sartor (2009) and Gordon and Walton (2009) for discussions on how burdens and standards of proof can be incorporated in this approach)

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