Abductive argumentation with stories

Floris Bex
Humanities Computing Department
University of Groningen
Groningen, The Netherlands
florisbex@gmail.com

ABSTRACT

The process of proof is one of inference to the best explanation, in which alternative stories are supported and attacked by arguments. This combination of stories and arguments was previously presented as a formal hybrid theory. In this paper, the aim is to further integrate stories and arguments by treating stories as abductive arguments and by showing how arguments can be explanations, just like stories. Thus, stories and arguments can be incorporated in the same dialectical framework.

Keywords

Argumentation, stories, evidence, abductive reasoning.

1. INTRODUCTION

The process of proof involves can be viewed as *inference to the best explanation* (IBE): there are alternative hypothetical stories about "what happened?" in a case, these stories are tested using the evidence and ultimately the best story is chosen. In IBE, hypotheses that explain initial observations are inferred using *abductive reasoning*: if we observe some effect (e.g. a body with gunshot wounds), we are allowed to hypothesise its possible causes (e.g. the person was shot). This cause can be a single event, but it can also be a sequence of events, a story.

Most of the examples of IBE in the AI literature (see e.g. [8] for an overview) do not incorporate a way to effectively reason about the alternative hypothetical stories using the evidence. This has been remedied in Bex' recent work on the *hybrid theory* [1], which combines classic theories of model-based causal reasoning (stories) with the ASPIC+ framework [11] (arguments). Thus, evidential arguments based on, for example, testimonies or forensic reports can be used to support and attack the alternative stories in a case.

One shortcoming of the hybrid theory is that the combination of the two reasoning frameworks leads to two different ways of determining the "status" of stories and arguments, that is, whether we are justified in accepting them as true. For arguments, this status is relative to the available counterarguments and the status of these counterarguments. For stories, this status is determined with a more absolute measure: the more observations a story explains, the better. What is still missing from the hybrid theory is a way to properly compare alternative stories relative to each other and the available arguments.

The present paper aims to further integrate arguments and stories by considering alternative stories as *counterarguments*, thus combining abductive and evidential argumentation in one framework. Thus, the status of both stories as well as arguments can be determined using well-known argumentation-theoretic semantics [6].

The rest of this paper is structured as follows. Section 2 discusses the existing hybrid theory as proposed in [2]. Section 3 then discusses how stories and arguments can be used interchangeably in reasoning with evidence. Section 4 presents an integrated theory of stories and arguments which expands the hybrid theory. Section 5 concludes the paper.

2. A HYBRID THEORY OF STORIES AND ARGUMENTS

It is possible to distinguish at least two[1] separate methods for the analysis of evidence and legal cases. The first method [1] has its roots in Wigmore's evidence charts and focuses on *arguments* from evidence to an ultimate claim that is to be proven. The second analytical method [9][18] is inspired by experiments on how people structure the evidence in a case [11], and hence uses *stories* to structure and analyse the available evidence.

In the argument-based approach, arguments based on evidence are offered for a conclusion, which is usually a main claim in the case. The arguments evidential rules of the form "*e* is evidence for *p*", and this argumentative reasoning is therefore characterized as *evidential reasoning*. Reasoning with arguments is dialectical, in that not only arguments for a conclusion but also arguments against the conclusion and other kinds of counterarguments are considered.

The story-based or narrative approach involves constructing stories about what (might have) happened in a case that explain the evidence. The relations between the events and the evidence are expressed as causal rules of the form "*c* is a cause for *e*", and this reasoning is therefore characterized as *causal reasoning*. The narrative approach also has a clear dialectical component, as in a case multiple incompatible accounts of the events are considered and compared.

Both the argumentative and the narrative approach can be separately applied to any one case, and they each have their own advantages. Arguments provide 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 allows one to ask critical questions and thus expose sources of doubt in the reasoning [19]. The mathematical properties of argument and counterargument are well-developed in the literature on computational argumentation [6].

In a purely argument-based approach the overview of the case tends to be lost. Stories can help here as they are understandable scenarios that explain the evidence in a natural way [11]. However, one aspect that is relatively underdeveloped in AI is exactly how the quality of the different stories should be determined. In model-based diagnosis [8] often the simplest (in terms of subset minimality) and most complete (in terms of

[1] An influential third method is the Bayesian approach [13]. See recent work by [17] on the connection between Bayesian reasoning, stories and arguments.

explaining the most evidence) scenario is chosen, but this need not necessarily be the best scenario [15].

The combination of evidential arguments and causal stories then seems to be an intuitive and analytically useful perspective for looking at cases and evidence, as the weaknesses of one approach are alleviated by the strengths of the other and vice versa. Hence, [2] proposes a hybrid theory for reasoning with arguments and stories. The hybrid theory is a theory of *Inference to the Best Explanation* (IBE), where causal stories are hypothesised to explain the evidence, after which these stories can be supported and attacked using evidential arguments. For example, arguments can be used to further support a story with evidence or to reason about the plausibility of a causal link in a story.

2.1 A formal hybrid theory

The formal hybrid theory is a combination of a formal model of causal-abductive reasoning *CT*, which is based on model-based approaches to causal-abductive inference [8] and an evidential argumentation theory *ET*, which takes its inspiration from standard accounts of structured and abstract argumentation [6][12]). The logic *L* of this theory is a combination of the inference rules of classical logic and a modus ponens inference rule for the connective $\Rightarrow$ (defeasible implication). Object-level rules in *CT* and *ET* are formalised using this connective: r_i: $p_1 \wedge ... \wedge p_n \Rightarrow q$. Here r_i is the name of the rule, $p_1,\ldots,p_n$ and q are literals. The type of rule is indicated with a subscript: $\Rightarrow_E$ denotes an evidential rule used in arguments and $\Rightarrow_C$ denotes a causal rule used in stories. As usual, a rule with variables is a scheme standing for all its ground instances.

2.1.1 Causal reasoning with stories

A criminal case usually starts when some initial evidence is found that points to the possibility that a crime has been committed. On the basis of this preliminary evidence, we can formulate one or more explananda, facts that can be explained by constructing *stories* – coherent sequences of states and events – about what might have happened. A coherent story is causally connected in that the individual events are connected by (sometimes implicit) causal links. These causal links allow us to perform abductive reasoning: if we have a general rule $s_1 \Rightarrow_C s_2$ and we observe s_2, we are allowed to infer s_1 as a possible hypothetical explanation of s_2. The cause s_1 can be a single state or event, but it can also be a causally connected chain of events, a story.

The causal theory *CT* consists of a set of causal rules R_C, a set of hypothetical events *H* (ground literals) and *a* set of explananda *E* (ground literals). A story is then defined as follows.

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

- $\varphi_i \in H \cup R_C$; or
- φ_i follows from $\psi_1, \ldots, \psi_n \in \{\varphi_1, \ldots,\varphi_{i-1}\}$ by application of defeasible modus ponens.

The ordering of the events in the sequence suggests their chronological succession. *Stories*(*CT*) denotes the set of all stories that can be constructed from a theory *CT*.

As an example of a story, take the following story S1, which says that rain makes the grass wet, which causes one's shoes to get wet.

- rain
- r_{c1}: rain $\Rightarrow_c$ grass_wet,
- grass_wet,
- r_{c2}: grass_wet $\Rightarrow_c$ shoes_wet,
- shoes_wet

A story serves as an explanation for the explananda in *F* if these explananda causally follow from the story. That is, a story *S explains* an explanandum *f* iff $S \vdash_C f$, where $\vdash_C$ stands for logical consequence according to the set of common deductive inference rules extended with modus ponens for $\Rightarrow_C$. For example, the above story explains why my shoes are wet.

2.1.2 Evidential reasoning with arguments

Given a piece of evidence, we can treat it as an explanandum and try to find a causal story that explains it. However, we can also infer conclusions from the evidence using evidential rules, thus creating arguments, which can then be used to support or attack stories.

The evidential theory *ET* consists of a set of evidential rules R_E and a consistent set of evidence *K* (ground literals). Arguments are then defined as follows.

Definition [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 ($1 \le i \le n$):

- $\varphi_i \in K \cup R_C$; or
- φ_i follows from $\psi_1, \ldots, \psi_n \in \{\varphi_1, \ldots,\varphi_{i-1}\}$ by application of defeasible modus ponens.

We say that *Args*(*ET*) denotes the set of all arguments that can be constructed from a theory *ET*.

As an example of an argument, take A1, where my observation that my shoes look wet is used as evidence for that fact that my shoes are wet:

- shoes_look_wet,
- r_{e1}: shoes_look_wet $\Rightarrow$ shoes_wet,
- shoes_wet

Arguments are a tool to deal with the contradictory evidence that is often available in a case. Conflict between arguments based on evidence leads to one argument attacking the other. An argument A_1 can attack another argument A_2 in two ways. A_1 and A_2 *rebut* each other if they have an opposite (intermediate) conclusion; for example, an argument with the conclusion that my shoes are dry (based on, for example, me feeling whether my shoes are wet) will rebut the above argument. A_1 *undercuts* A_2 if there is a conclusion $\neg r_i$ in A_1 and an application of defeasible modus ponens to r_i in A_2 (where r_i is the name of a rule in R_E). Here, $\neg r_i$ generalises the two cases where a rule is invalid (inapplicable in all cases) and where there is an exception to the rule (inapplicable in some cases). As an example, consider the knowledge that my shoes always gleam in the light, making them look wet. In this case, the rule r_{e1} will be undercut.

An advantage of formal models of argumentation is that they can be used to evaluate a particular argument given a set of other evidential arguments. In other words, given a collection of arguments and their attack relations, the *dialectical status* of the arguments can be determined. Following [12], we assume that our theory for arguments instantiates one of [6]'s semantics. For present purposes, the exact type of semantics is not important and we simply assume that arguments can be *justified*, which means

that they are not defeated by other justified arguments, *overruled*, which means that they are defeated by other justified arguments, or *defensible*, which means that they are neither justified nor overruled.

2.1.3 Combining stories and arguments in a hybrid theory of IBE

An important part of the hybrid theory is the consideration of alternative stories. In most cases there are alternative stories, for each of which there is some support (but not conclusively justifying) and for each of which there is some attack (but not conclusively defeating). Moreover, a search and consideration of alternative stories is a good method to lessen the danger of so-called confirmation bias. Take our example where our shoes are wet. One alternative explanation S2, is that the sprinkler was on:

- sprinkler_on
- r_{c1}: sprinkler_on $\Rightarrow_c$ grass_wet,
- grass_wet,
- r_{c2}: grass_wet $\Rightarrow_c$ shoes_wet,
- shoes_wet

In addition to the search for alternatives, the stories themselves also have to be thoroughly analysed and compared. There are various criteria with which stories can be compared. The most important of these criteria are about to what extent a story conforms to the evidence in a case. In [2], there are two criteria that pertain to the relations between a story and the evidence in a case. The first is *evidential support*, the number of pieces of evidence that support a story, and the second is *evidential contradiction*, the number of pieces of evidence that contradict a story. Note that these numbers are not objective measures for the quality of stories, but rather aids in the comparison of stories. Furthermore, by contrasting the evidential support or contradiction to the total number of pieces of evidence in a case we get an indication of the relevance and coverage of a story [11].

The above criteria can be defined in the hybrid theory as follows. For a piece of evidence to support a story there should be a non-overruled argument $A \in Args(ET)$ such that $e \in K$ is a premise of A and some $s \in S$ is a conclusion of A. Evidence $e \in K$ contradicts a story S if there is a non-overruled argument $A \in Args(ET)$ such that e is a premise of A and $\neg s$ is a conclusion of A, where $s \in S$. Note that only arguments which are not overruled support or contradict an explanation: if an argument based on evidence is itself defeated, the evidence does not support the explanation.

The criteria of evidential support and contradiction can be used for a direct comparison of stories. For example, all other things being equal, a story S can be considered better than a story S' if the number of sources of evidence that support S is higher than S' and the number of sources of evidence that contradict S are equal or lower to S'.

3. STORIES AND ARGUMENTS AS COMMUNICATING VESSELS

The two separate approaches to reasoning with evidence, arguments and stories are abstract accounts of two dominant trends in research about evidence and proof, which have been very clearly distinguished here to make a point. In real cases, argumentative and narrative aspects will often blend into each other. Furthermore, the literature mentioned for each of these approaches does usually not completely disregard the "competing" approach. For example, the Anchored Narratives Theory [18] has clear argumentative aspects (cf. [16]) and the "New Wigmoreans" also discuss the use of stories and scenario's in evidential reasoning [1].

To distinguish arguments and stories, in the hybrid theory fairly "narrow" definitions of argument and story are used: an argument is a tree-like structure in which one or more premises support a single conclusion through one or more consecutive inference steps, whilst a story is a coherent sequence of events in chronological order. However, if more broad definitions are adhered to, this distinction fades. For example, in [3] we show that a story as a whole can be used as a premise to a legal argument, and it is argued in [7] that stories play an important role in arguments from analogy. As argued in [5], it is not the structure of the reasoning (i.e. evidential, causal) but rather the intention of the speaker that determines whether something is an explanation or an argument. Thus, it is possible to use stories to explain, to entertain and to argue.

The overlap between story-based and argument-based reasoning is also in the relationship between causal and evidential reasoning, which are closely related: if we have a causal rule '*c* causes *e*' then we will usually also accept that '*e* is evidence for *c*'. For example, fire can cause visible smoke so the observation of smoke can be seen as evidence for the fact that there is a fire. On this subject, Note that both forms of reasoning are defeasible: fire does not necessarily cause (visible) smoke as some types of fire (e.g. a gas flame) do not cause smoke; similarly, observing smoke does not necessarily imply that there is a fire as there are other causes of smoke (e.g. a smoke machine).

The close relation between causal and evidential reasoning is also evident in the *explains* relation between a story and the explananda in the hybrid theory. [14] argues that some proposition *c* explains some other proposition *e* if the states of affairs described by *c* are part of the "causal process" that produces the states of affairs described by *e*. For example, by accepting a testimony *E** as evidence for an event *E* we implicitly make a causal judgment that the witness tells us *E** because that witness really believes *E* happened.

This interweaving of causal and evidential reasoning is also evident in formal models. For example, [4] show that the information in causal models can equally well be represented by evidential rules; instead of abductive reasoning we then perform argumentation to infer hypothetical scenarios for our explananda. Alternative explanations then become counterarguments. As an example, take Figure 1 where the same piece of evidential data is used in two different ways. On the left side, the fact that my shoes look wet is used to evidentially infer that my shoes are wet (closed arrowhead). This argument is undercut by an argument that I have special gleaming shoes which always look wet (dotted arrowhead). On the right side, the fact that my shoes are wet is used to explain the fact that my shoes look wet (open arrowhead). The counterargument is here modelled as an alternative explanation: that I have gleaming shoes also explains why they look wet.

The situation in Figure 1 shows that, in a purely argumentative approach, alternative interpretations of the evidence lead to counterarguments and in a purely narrative approach, such alternative interpretation lead to different explanatory stories. So it would seem that in the hybrid approach, an alternative story can also be expressed as a counterargument

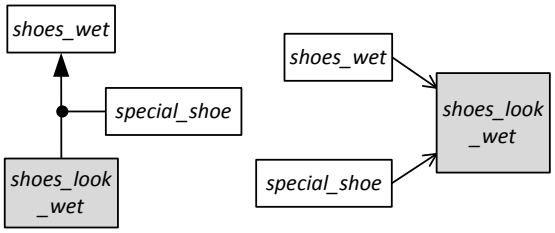

Figure 1: Stories and arguments as communicating vessels

The exact choice whether to use causal or evidential rules in one's reasoning seems somewhat arbitrary and it has also been argued that both causal and evidential reasoning is needed in complex situations [10].

Since it is possible to emphasize either evidential, argument-oriented elements or causal, story-oriented elements in a case analysis, one could say that arguments and stories behave as "communicating vessels": a change in an argument-oriented version of a case analysis requires a matching change in a story-oriented analysis. As a consequence of this communicating vessels property it is possible to choose what works best when performing an analysis: some cases or aspects of a case will more conveniently be modelled in terms of evidential arguments, others in terms of causal stories. For example, if the decision whether the suspect is guilty or not hinges on a single fact (e.g. whether the suspect was at a particular location at a particular time), alternative stories are less important and the main analytical technique is to carefully consider all the arguments for and against this fact. In other cases, certain facts might not necessarily be justified because they are supported by strong evidence but rather because they are part of the most coherent story. Take, for instance, a case with multiple contradicting claims based on different testimonies. Simply considering these claims as counter-arguments to each other does not tell us which one, if any, is true. Rather, we should look which claim is part of the most coherent story that is supported by the most additional evidence, that is, which claim is compatible with the totality of the evidence.

4. EXPANDING THE HYBRID THEORY

The fact that arguments and stories to a certain extent behave as communicating vessels indicates that there is room for a deeper understanding of the relation between arguments and stories in reasoning about evidence, in such a way that they are treated in a genuinely integrated way, further building on the hybrid theory.

The first step towards an integrated theory of arguments and stories is to determine the dialectical component of story-based reasoning, that is, exactly how different stories interact in a dialectical way with each other and with the arguments in a case. The current method for this is to consider alternative stories as counterarguments, thus combining causal and evidential argumentation in one framework.

One way to integrate causal and evidential reasoning into one framework is to consider stories as *causal arguments*. This would allow us to integrate stories into the ASPIC+ argumentation frameworks [12], which allows us to determine their status according to well-known argumentation-theoretic semantics [6].

When comparing the formal definitions of stories and arguments given above, it is clear that they are similar in structure: both are derivations in the defeasible logic *L*, the difference being that stories use causal rules and arguments use evidential rules. Furthermore, as was already argued earlier, it is the intention of the speaker that determines whether a story should be considered as an explanation or an argument. So is it not possible to simply have two types of argument: causal arguments and evidential arguments?

When considering causal argumentation, it is instructive to look at the argumentation schemes for causal reasoning. [19] consider two schemes which are important for current purposes: a scheme from cause to effect and a scheme from effect to cause. The scheme from cause to effect is as follows ([19], p. 168).

Generally, if A occurs then B will (might) occur.
In this case, A occurs (might occur).
Therefore, in this case B will (might) occur.

This scheme can be captured by the causal rules in *CT*. Note, however, that this type of causal reasoning is essentially *prediction*, where one makes an observation and tries to predict what will be the case as a consequence of this observation.

In contrast, in the hybrid theory we used the causal rules for *explanatory (abductive) reasoning*, where one makes an observation and tries to explain how this observation could have followed from some hypothesized states of affairs. Hence, in the hybrid theory we mainly use stories and the causal rules contained in them to reason from effect to cause, viz. ([19], p. 170).

Generally, if A occurs then B will (might) occur.
In this case, B did in fact occur.
Therefore, in this case, A also presumably occurred.

Such abductive reasoning can be valid if multiple alternative causes are considered. This requirement is contained in the scheme's critical questions (adapted from [19]).

CQ1: Are there alternative explanations of B?
CQ2: How much better an explanation is A when compared to the alternatives?

Note that explanatory (abductive) reasoning and predictive reasoning with causal rules are close intertwined: a hypothesis *explains* some observations if the hypothesis correctly *predicts* these observations. This means that abductive reasoning is similar to a special subspecies of predictive cause-to-effect reasoning, where the premise "A occurs" is a hypothesis instead of an observation. This clearly distinguishes this causal reasoning from evidential reasoning, where the arguments are based on direct evidence.

So in our integrated framework there must be a way of distinguishing arguments based on evidence and arguments based on hypotheses. This is made possible by the different types of elements of the knowledge base in ASPIC+. We will return to this distinction in section 4.1.

In addition, it is also necessary to revisit the attack relations between arguments. Two evidential arguments attack each other if they have an opposite conclusion. Abductive causal arguments, however, also attack each other if they are alternative explanations of the same "conclusion" (cf. CQ1 of the "cause to effect" scheme above). This will be discussed in sections 4.1.1 and 4.1.2.

4.1 An integrated formal framework

In this section I propose an integrated formal framework for causal and evidential reasoning, based on the ASPIC+ framework. The logic and object-level language of this integrated theory are the same as for the hybrid theory: there are connectives $\Rightarrow_E$ and $\Rightarrow_C$ for evidential and causal rules, and a modus ponens inference

rule for these connectives. Like in the hybrid theory, there are sets of causal and evidential rules.

Definition [Rules] The set of rules is $R = R_E \cup R_C$, where

- R_E is the set of *evidential rules*.
- R_C is the set of *causal rules.*

Following the ASPIC+ framework, in the integrated theory there is one knowledge base (with appropriate subsets).

Definition [Knowledge base] A knowledge base is a set $K = K_E \cup K_H$, where

- K_n is the set of necessary axioms, which cannot be attacked. This set contains the *evidence*, of which the existence cannot be sensibly denied.
- K_p is a set of normal premises, which can be attacked as explained in section 4.1.2.

Using this knowledge base and the rulesets, we can build evidential and causal rules.

Definition [Arguments] A *causal/evidential argument* based on is a finite sequence $[\varphi_1, \ldots, \varphi_n]$, where $n > 0$, such that for all φ_i ($1 \leq i \leq n$):

- $\varphi_i \in K_p \cup R_C$ (causal argument), $\varphi_i \in K_n \cup R_E$ (evidential argument); or
- φ_i follows from $\psi_1, \ldots, \psi_n \in \{\varphi_1, \ldots, \varphi_{i-1}\}$ by application of defeasible modus ponens.

Basically, this definition is the same as the definitions of arguments and stories in section 2.1. Note that causal arguments are based on normal premises that can be attacked; after all, causal arguments are hypotheses that explain their conclusion and we should be able to attack these hypotheses. We also define some auxiliary notions related to arguments, which are needed for later definitions.

Definition [Elements of arguments] For any argument A and A'

1. The set of premises of A is Prem(A) = $\{\varphi \in A \mid \varphi \in K\}$;
2. The conclusion of A is Conc(A) = $\{\varphi \in A \mid \varphi$ is the last element in the sequence$\}$;
3. The set of evidence in A is Evidence(A) = $\{e_i \in A \mid e_i \in K_n\}$;
4. An argument A' is a (proper) subargument of A iff A' is a (proper) subsequence of A.

4.1.1 Alternatives

Before we determine when causal and evidential arguments attack each other, it has to be determined when two explanations are alternatives. The reason for this is that in explanatory, abductive reasoning this is where the dialectical component lies: two explanations (whether stories or arguments) are in competition of they are alternative causes for the same consequence. For example, the two example stories S_1 and S_2 are not compatible, nor are the two explanations in Figure 1.

For causal arguments, alternatives can be defined as follows.

Definition [Alternative Causal Arguments] A causal argument C1 is an alternative to a causal argument C2 if Conc(C1) = Conc(C2) and Conc(C1') ≠ Conc(C2'), where C1' and C2' are (proper) subarguments of C1 and C2, respectively.

Two causal arguments are alternatives if their conclusion (the last element in the sequence) is the same but they have a subargument of which the conclusion is not the same. In our example, S1 and S2 are thus alternatives: they both have the conclusion shoes_wet, but S1 has a subargument with conclusion rain and S2 has a subargument with conclusion *sprinkler_on* (Figure 2).

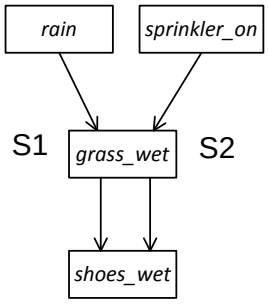

Figure 2: alternative causal arguments

Note that evidential arguments can also be alternatives. An evidential rule is essentially nothing more than an explicit expression of an abductive reasoning step applied to a causal rule. For example, in Figure 1 it was shown that the evidential A1 can be represented as a causal argument. Similarly, we can rewrite the causal arguments S1 and S2 as evidential arguments A2: [shoes_wet, shoes_wet $\Rightarrow_e$ grass_wet, grass_wet, grass_wet $\Rightarrow_e$ rain, rain] and A3: [shoes_wet, shoes_wet $\Rightarrow_e$ grass_wet, grass_wet, grass_wet $\Rightarrow_e$ sprinkler_on, sprinkler_on] respectively. Here, A2 and A3 are alternatives: A2 says that the fact that the grass is wet is evidence for rain, whilst A3 argues that grass_wet is evidence for the fact that the sprinkler was on.

Definition [Alternative Evidential Arguments] An evidential argument E1 is an alternative to an evidential argument E2 if Conc(E1) ≠ Conc(E2) and Conc(E1') = Conc(E2'), where E1' and E2' are (proper) subarguments of E1 and E2, respectively.

A2 and A3 have different conclusions, *rain* and *sprinkler_on*, which have been derived from the same proposition, *grass_wet* (Figure 3).

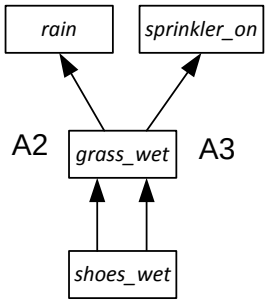

Figure 3 alternative evidential arguments

Note that it is even possible for an evidential argument and a causal argument to represent alternatives. For example,

Definition [Alternative Evidential/Causal Arguments] An evidential argument E is an alternative to a causal argument C if Conc(C') = Conc(E') and Conc(C'') ≠ Conc(E''), where C' and E' are subarguments of C and E, C'' is a subargument of C' and E' is a subargument of E''.

So, for example, arguments S1 and A3 are alternatives. Consider the different subarguments from the definition:

S1: [rain, rain $\Rightarrow_c$ grass_wet, grass_wet, grass_wet $\Rightarrow_c$ shoes_wet, shoes_wet]

A3:[shoes_wet, shoes_wet $\Rightarrow_e$ grass_wet, grass_wet, grass_wet $\Rightarrow_e$ sprinkler_on, sprinkler_on]

S1': [rain, rain $\Rightarrow_c$ grass_wet, grass_wet]

A3': [shoes_wet, shoes_wet $\Rightarrow_e$ grass_wet, grass_wet]

S1'': [rain]

A3'': [shoes_wet, shoes_wet $\Rightarrow$ grass_wet, grass_wet, grass_wet $\Rightarrow$ sprinkler_on, sprinkler_on]

So Conc(S1') = Conc(A3') and Conc(S1'') $\neq$ Conc(A3''), where where S1' and A3' are subarguments of S1 and A3, S1'' is a subargument of S1' and A3' is a subargument of A3''. In Figure 4, the situation where evidential (closed arrowhead) and causal (open arrowhead) arguments are combined is shown.

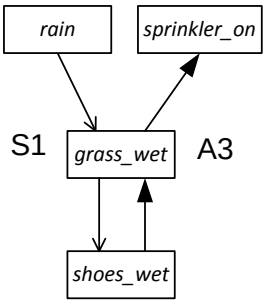

Figure 4: alternative causal and evidential arguments

4.1.2 Attack and defeat

In ASPIC+, arguments attack each other if they, or their subarguments, have opposing conclusions. Furthermore, an argument further attacks another if it undercuts it, that is, if it denies an inference. In the hybrid theory these types of attacks are allowed between evidential arguments. In the integrated theory, causal arguments (stories) can also attack each other.

Definition [Attack] An argument A1 attacks an argument A2 iff

- There are two subarguments A1' and A2' that have an opposite conclusion, and the conclusion of A2' is not in K_n (*rebut*); or
- There is a subargument A1' which has conclusion $\neg r_i$ in and there is an application of defeasible modus ponens to r_i in A2 (where r_i is the name of a rule in *R*) (*undercut*); or
- A1 and A2 are alternatives (*alternative attack*).

Note that attack relations can be between two causal arguments, two evidential arguments or a causal and an evidential argument. Also note that it is not possible to attack a piece of evidence.

As an example of these new attack relations between arguments and stories, consider Figure 5. The different labels S1, S2, S3 for stories indicate the maximal causal sequence (open arrowhead) starting at that particular proposition, and the argument labels indicate the maximal evidential sequence (closed arrowhead) starting at the labelled proposition. There are three stories: one (S1) that the grass is wet because it rained, one (S2) that the grass is wet because the sprinkler was on and one (S3) that the grass is not wet. The stories are supported and attacked (indicated by the arrow with the dot for its head) by arguments. One of these arguments (A1) is undercut.

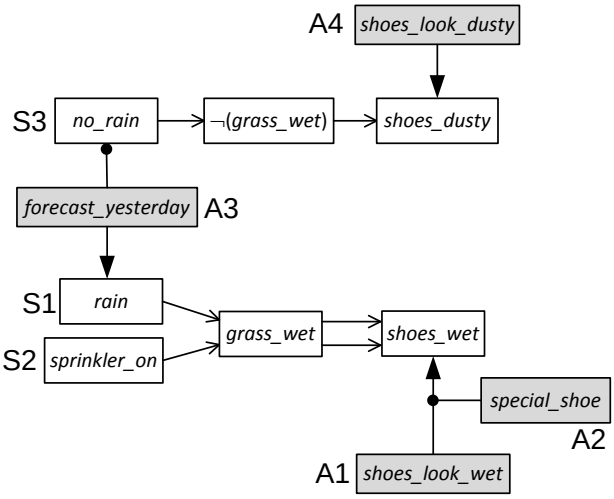

Figure 5: stories and arguments

Not all the attacks between the different stories and arguments are indicated in Figure 5. Figure 6 shows the different arguments and stories as an argumentation framework in the style of [6]. The arrows here stand for "attack" relations.

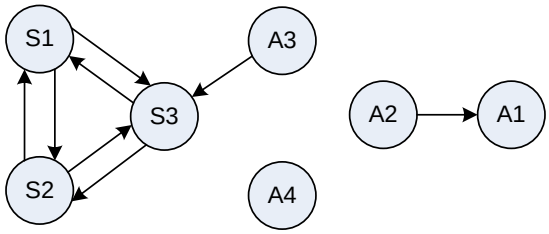

Figure 6: Attack relations between arguments and stories

Stories S1 and S2 attack each other because they are alternatives. Story S3, however, attacks S1 and S2 because it has a contradictory subconclusion, ¬(*grass_wet*). Thus, it is possible to indicate incompatible stories even if they are not alternatives, something which was not possible in the standard hybrid theory. This is an important improvement, as now alibi stories can be correctly represented. An alibi story usually does not explain any of the evidence that the main prosecution's story does because it does not have to. If the suspect shows he was somewhere else, he does not have to explain why, for example, the victim died.

4.2 Positions

While it is interesting to see the different attack relations between the stories, it is even more informative to consider positions, particular combinations of stories and arguments in a case.

Definition [Position] A position *P* in a case is a conflict-free set of arguments such that for each evidential argument E in *P*, there is a subargument E' which has as its conclusion an element in causal argument C, where C is part of *P*.

What this means is that a position in a case contains stories and the arguments supporting them. Thus, a position is essentially a consistent view on the case at hand, given the evidence, arguments and stories. In Figure 7, three positions that correspond to the different stories from our example are shown. Notice the attacks between the elements of the positions.

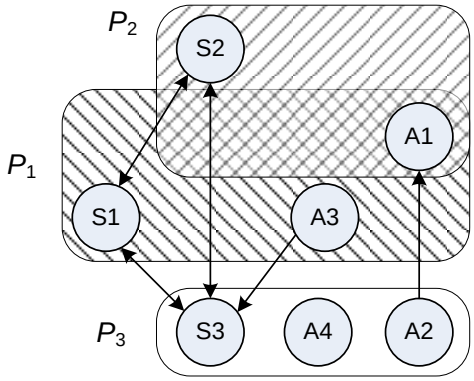

Figure 7: Three cases

Because a position is a set in an argumentation framework, we can check whether, for example, a position corresponds to an extension of the argumentation framework. Furthermore, it now becomes possible for a position to defend itself by reinstating the story when it is attacked by an argument from another position. Thus, the dialectical characteristics of stories have been further detailed compared to the original hybrid theory.

5. CONCLUSION

The hybrid theory [2] provides a way to reason with stories, arguments and evidence. The ideas presented in this paper further integrate the reasoning with stories and arguments. By treating stories as causal-abductive arguments, they can be integrated into the dialectical framework of [6]. This allows for the "calculus of opposition" to be applied to the different viewpoints in a case.

Note that the original criteria like evidential support and evidential contradiction (section 2.1.3) are still valid. The integrated theory simply adds new ways of comparing stories. Most importantly, stories that provide, for example, an alibi can now be incorporated into the dialectical process. In the hybrid theory these stories were ignored as they do not explain the main explananda, but in the integrated theory they attack other stories because they claim that, for example, the suspect could not have committed the crime because he was somewhere else.

The integrated theory allows us to correctly reason with stories and arguments as communicating vessels. As was argued above, a change in an argument-oriented version of a case analysis requires a matching change in a story-oriented analysis. Furthermore, if stories and arguments are truly communicating vessels then changing a case from story-oriented to argument-oriented should not change its outcome. The hybrid theory has aspects where how a case is modelled influences the conclusions one can draw. For example, two contradictory stories do not attack each other whilst two contradictory arguments do. On the other hand, two alternative stories are in competition, whilst two arguments that present alternatives are not. By embedding stories in the dialectical framework and allowing evidential arguments to attack each other as "alternatives", the integrated theory allows stories and arguments to be treated as equals in the dialectical process.

6. REFERENCES

[1] Anderson, T.J., Schum, D. A., and Twining, W. L. (2005) *Analysis of Evidence*, 2nd edition, CUP, Cambridge.

[2] Bex, F.J. (2011) *Arguments, Stories and Criminal Evidence: A Formal Hybrid Theory*, Springer, Dordrecht.

[3] Bex, F.J. & Verheij, B. (2012) Legal Stories and the Process of Proof. *Artificial Intelligence and Law*. Online first, doi: 10.1007/s10506-012-9137-4.

[4] Bex, F.J. & Verheij, B. (2011) Solving a Murder Case by Asking Critical Questions: An Approach to Fact-Finding in Terms of Argumentation and Story Schemes. *Argumentation*, 26:3, 325-353.

[5] Bex, F. & Walton, D. (2013) Combining Explanation and Argumentation in Dialogue. *Proceedings of CMNA12, Lecture Notes in Artificial Intelligence*, Springer, to appear.

[6] Dung, P.M. (1995) On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n–person games. *Artificial Intelligence* 77:2, 321 – 357.

[7] Govier, T. & Ayers, L. (2012) Logic, Parables and Argument *Informal Logic* 32:2.

[8] Lucas, P. (1997) Symbolic diagnosis and its formalisation. The Knowledge Engineering Review 12: 109 – 146.

[9] Pardo, M.S. and Allen, R.J. (2007) Juridical Proof and the Best Explanation, *Law and Philosophy* 27: 223 – 268.

[10] Pearl, J. (1988a) Embracing causality in default reasoning. *Artificial Intelligence* 35, 259 – 271.

[11] Pennington, N., and Hastie, R. (1993) Reasoning in explanation–based decision making. *Cognition* 49:1–2, 123 – 163.

[12] Prakken, H. (2010) An abstract framework for argumentation with structured arguments. *Argument and Computation*, 1:93–124.

[13] Taroni, F., Aitken, C., Garbolino, P. and Biedermann, A. (2006). *Bayesian Networks and Probabilistic Inference in Forensic Science*. Wiley, Chichester.

[14] Thagard, P. (2004) Causal Inference in Legal Decision Making: Explanatory Coherence vs. Bayesian Networks. *Applied Artificial Intelligence* 18:3, 231 – 249.

[15] Thagard, P., and Shelley, C.P. (1997) Abductive reasoning: Logic, visual thinking, and coherence. In Dalla Chiara, M. L. (eds.), *Logic and Scientific methods*, Kluwer, Dordrecht.

[16] Verheij, B. (2000) Anchored narratives and dialectical argumentation. In Van Koppen, P. J. and Roos, N. (eds.), *Rationality, Information and Progress in Law and Psychology*, 203 – 226, Metajuridica, Maastricht.

[17] Vlek, C., Prakken, H., Renooij, S. & Verheij, B. (2013) Modeling Crime Scenarios in a Bayesian Network. *Proceedings of ICAIL 2013*, ACM Press, to appear.

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

[19] Walton, D., Reed, C. and Macagno, F. (2008) *Argumentation Schemes*, Cambridge University Press.