Linked and Convergent Structures in Discourse-Based Reasoning

Andrew Potter

Sentar, Inc.
4900 University Square Suite 8
Huntsville, Alabama 35816 USA
apotter@sentar.com
http://www.sentar.com/

Abstract. Explanation and argumentation are fundamental to reasoning. They are therefore of some importance to artificial intelligence. Discourse-based reasoning (DBR) is a knowledge representation technology that uses natural patterns of discourse as a basis for a structural ontology of explanatory and argumentative reasoning. By this means, we may ontologize the reasoning process itself, thus rendering it accessible as an explanatory mechanism. Towards this objective, this paper introduces three general categories of rhetorical relations, including inferential, synthetic, and multinuclear. Inferential relations are argumentative, causal, or conditional; synthetic relations are purely explanatory; and multinuclear relations are used to express rhetorically bound pluralities of concept instantiations. These categories are used to explore design-time and runtime dimensions for representing linked and convergent structures. Using discourse-based reasoning, human and artificial agents will engage in collaborative reasoning, discover knowledge, resolve conflict, and render explanations using rhetorically explicit representations.

1 Introduction

It is ironic that, in the field of artificial intelligence, so little attention is now given to explanation. Certainly no software application is going to pass the Turing test if it cannot engage in explanatory discourse. And certainly, any collaborative activity between computers and humans would benefit if the participants could explain themselves to one another. Discourse-based reasoning (DBR) is a knowledge representation theory that uses natural patterns of discourse as the basis for an ontological model of explanatory reasoning. Given an ability to engage in discourse-based reasoning, computers would use DBR to engage with humans in collaborative activities that would address a variety of problems that would otherwise remain inaccessible. For humans and computers to collaborate, they must reason together, and in order to reason together, they must engage in common discourse.

This paper builds on our previous work [1, 2] by providing an ontological mechanism for distinguishing between inferential, synthetic, and multinuclear structures. These structures are used as the basis for representing linked and convergent discourse. Linkages and convergences occur commonly in discourse, each involving multiple premises which either combine to support a claim (linked) or work independently to support a common thesis (convergent). Because they occur frequently in discourse, it is important that DBR provide a means for their expression. First, we will review the foundations of DBR. This will be followed by an explication of the DBR ontology. This prepares us for a discussion of linked and convergent structures, and how they may be represented in discourse-based reasoning. The paper then concludes with a summary of the findings and a few suggestions for future research.

2 Theoretical Background

Discourse-based reasoning (DBR) draws on Toulmin's [3] model of argumentation, Mann and Thompson's [4] Rhetorical Structure Theory (RST), and Perelman and Olbrechts-Tyteca's [5] strategic forms of argumentative processes. The Toulmin model provides a framework for argumentation. RST provides schemas, constraints, and rhetorical relations used in generating coherent discourse structures. The concept of strategic argumentative processes leads to a formal definition of argumentative interactions. The contributions of these theories to DBR have been discussed previously [1]. For this paper, we limit the discussion to RST, as is central to the concepts of linked and convergent structures.

RST defines the coherence of a text in terms of the way its parts, or *text-spans*, relate to one another. It postulates a small number of schemas for defining the possible structural relationships among spans and defines an extensible set of rhetorical relations that may be used when applying a schema to a set of text spans. An RST analysis of a coherent document defines a hierarchical structure representing the rhetorical interrelationships of the text spans comprising the document. A text span may be either an individual *segment* or it may be a structure consisting of several segments interrelated by one or more *relations*. Most relations are binary, consisting of two text spans, with one designated as the *nucleus* and the other as the *satellite*. The nucleus is the more salient of the two. The example shown in Fig.1 uses the EVIDENCE relation, where the satellite provides information that makes the nucleus more believable [1].

Like rule-based knowledge representations, both the Toulmin model and RST are concerned with defining plausible relationships among units of information. A Toulmin warrant provides a linkage between a ground and a claim, where the ground corresponds to the rule's condition, and the claim corresponds to the rule's consequent [6]. In an RST structure, the satellite typically gives evidence or explanation for the nucleus. However, RST differ from rules in important ways. In stating that one situation is contingent on another, a rule says nothing

[1] This and other RST analyses in this paper are based on an editorial by Paul Krugman that appeared in *The New York Times* on March 21, 2008, http://www.nytimes.com/2008/03/21/opinion/21krugman.html

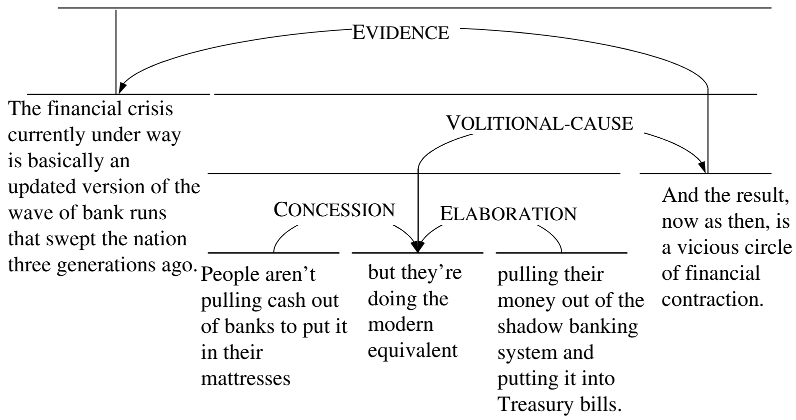

Fig. 1. An RST Example

about why this is so. It is essentially an RST structure in which only one relation is permittted, namely the CONDITION relation. As such it offers little in the way of explanation. RST provides a model for representing complex structures of hierarchically nested rhetorical relationships. Both Toulmin and RST provide expressive information models that are inaccessible using using rules-based approaches.

3 An Ontology for Discourse-Based Reasoning

An ontology, as famously defined by Gruber [8], is a "specification of a conceptualization." Thus an ontology delimits what may be thought and said within a universe of discourse, and it specifies the manner in which these thoughts may be expressed and interrelated. The DBR ontology is a *structural* ontology. Unlike domain ontologies which are specific to a subject matter, the DBR structural ontology specifies a conceptualization of a reasoning process, irrespective of any particular domain.

The DBR ontology discussed here makes several improvements to our earlier version [1]. Some of these changes are made purely for clarity, but there are substantive changes as well. The main change is that the concept of *Relation* is treated with greater specificity. This was undertaken to facilitate treatment of linked, inferential, and synthetic structures. This permits clearer distinction between argumentative and explanatory knowledge and it enables representation of important knowledge structures which could not be expressed in the previous ontology.

As shown in Fig.2, an *explanation* is a *warrant* and a set of *interactions*. The warrant and its associated concepts are *design-time* resources; they may be used by a knowledge engineer to create a knowledge base. The warrant identifies the *satellite* (ground) and the *nucleus* (claim) of an explanation (or argument). This,

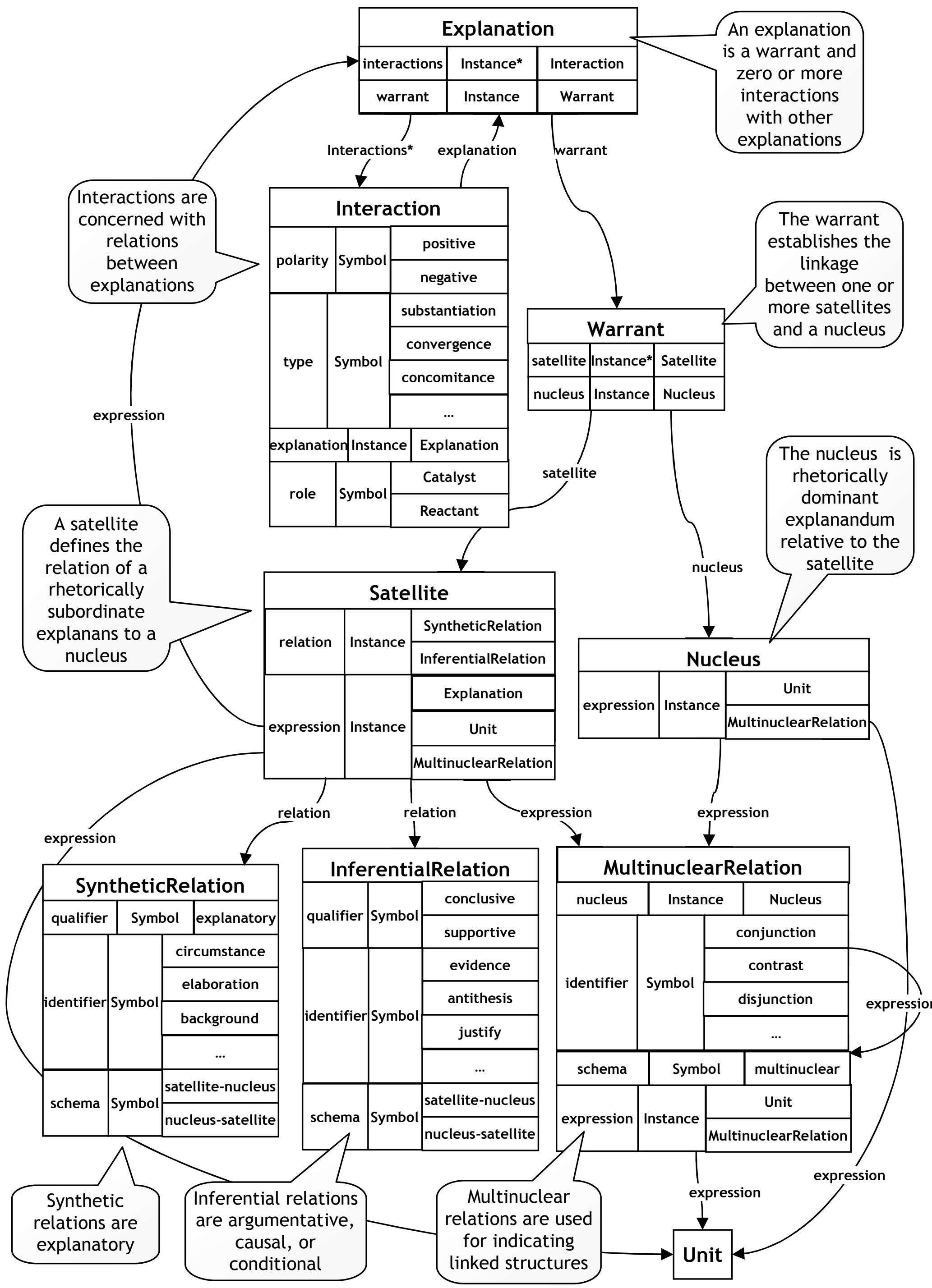

Fig. 2. The DBR Ontology

in Hempel and Oppenheim's terminology [9], the nucleus is the *explanandum*, or expression that is to be explained, and the satellite is the *explanans*, or the expression that does the explaining. Interactions define the possible interrelationships an explanation may have with other explanations.

A *satellite* is defined in terms of an expression and a relation. The expression may be a *unit*, a *multinuclear relation*, or an *explanation*. A *unit* is an instantiation of an ontologically normalized sentential expression, usually of a domain specific nature.[2] The domain ontology used to articulate the expression is not part of the DBR ontology.

There are three types of relations: *inferential*, *synthetic*, and *multinuclear*. *Inferential* relations include argumentative, causal, and conditional relations. They involve some notion of truth functionality in the relationship between the satellite and the nucleus, such that the truth value of one has some influence on the truth value of the other. For example, in Fig. 3, the nucleus is contingent upon the satellite through use of the CONDITION relation.

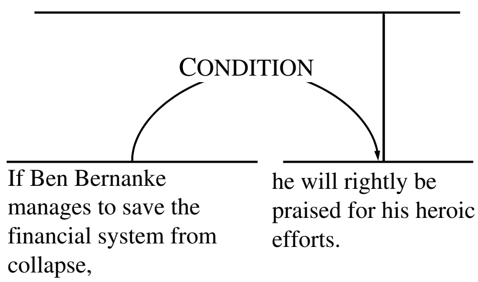

Fig. 3. Condition as Inferential Relation

Not all inferential relations are as simple as this, however. Given the means to construct hierarchies of distinct and sometimes complementary relations, complex structures may be used to render subtle design-time lines of reasoning [10]. In Fig. 4, the CONCESSION and ANTITHESIS relations are used to indicate a rhetorical tension between the units comprising the argument. The CONCESSION relation, as defined in RST, is used to indicate that the writer does not dispute the satellite, but rather contends that despite any apparent incompatibility between the satellite and the nucleus, the nucleus holds nevertheless. In the ANTITHESIS relation, the writer indicates that there is an incompatibility between the satellite and the nucleus, and that the incompatibility is such that the nucleus holds and the satellite does not. From a purely truth-functional perspective, CONCESSION states that the satellite does not preclude the nucleus. ANTITHESIS says that the satellite and nucleus preclude one another, and it is the nucleus which prevails.

[2] For ease of readability, in this paper none of the examples use normalized units.

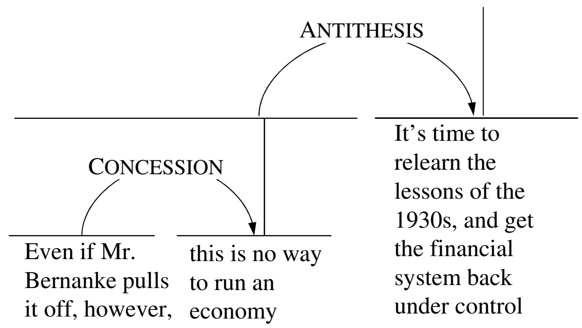

Fig. 4. Inferential Relations

A *synthetic* relation defines an explanatory RST relation between a satellite and a nucleus. The Elaboration relation is the most commonly used synthetic relation (Indeed, it is the most commonly used relation of any sort). In Fig. 5, Elaboration is used several times. In the Elaboration relation the satellite provides additional information about the situation presented in nucleus.

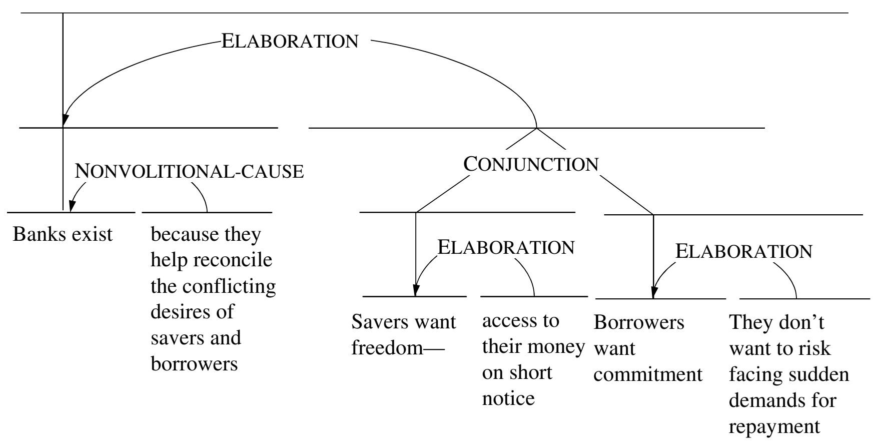

Fig. 5. Elaboration as Synthetic Relation

A multinuclear relation specifies two or more nuclei expressions, a relation identifier, a qualifier, and a schema. Fig. 5 includes an example of a multinuclear relation. In the Conjunction relation, multiple items are aggregated to form a unit in which each item plays a comparable role [7]. Table 1 provides a listing of inferential, synthetic, and multinuclear relations. The qualifier of an inferential relation will be either supportive or conclusive; the qualifier of a synthetic relation will be explanatory. The qualifier of a multinuclear relation is assumed to be explanatory.

Table 1. Relation Modalities

Inferential Relations		Synthetic	Multinuclear
Antithesis	Nonvolitional-Cause	Background	Conjunction
Concession	Volitional-Result	Circumstance	Contrast
Evidence	Nonvolitional-Result	Elaboration	Disjunction
Enablement	Otherwise	Evaluation	Joint
Justification	Purpose	Interpretation	List
Means	Solutionhood	Preparation	Sequence
Motivation	Unconditional	Restatement	
Volitional-Cause	Unless	Summary	

The final piece of the ontology to be discussed is the Interaction concept. Whereas warrants are defined by the knowledge engineer at design-time, interactions are discovered at runtime and define the possible relations instantiated explanations may have with one another. For example, suppose we have a knowledge-base containing two inferential explanations, as shown in Fig. 6. At runtime, these explanations may be instantiated, such that X now refers to the US economy of 2008, for example.

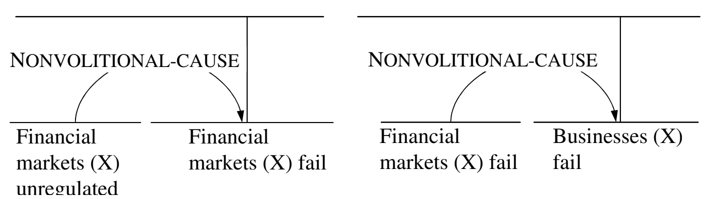

Fig. 6. A Small Financial Knowledge Base

However, we now have more than just the two separate explanations, because the satellite of one reoccurs as the nucleus of the other. That is, the first explanation substantiates the second. This interaction leads to the discovery of a more elaborate structure, shown in Fig. 7. In our earlier work [1] we identified a set of eight possible interactions that may occur among explanations. The interaction used in this example is *substantiation*: when the nucleus of one argument or explanation unifies with the satellite of another, the substantiation interaction applies. Interactions like this support the runtime construction of a rhetorical network, in which discourse elements are linked together to form explanatory structures representing the system's understanding of the universe of discourse.

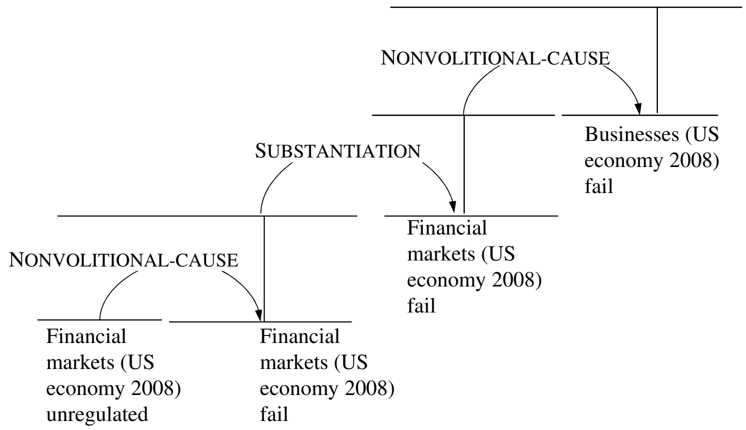

Fig. 7. Interacting Explanations

4 Linked and Convergent Structures

A perennial issue in informal logic is the distinction between linked and convergent arguments. As defined by Walton [11], a linked argument is one with multiple premises, where the premises combine to support the conclusion. In a convergent argument, multiple premises support a conclusion, but they do so independently. It is important that both linked and convergent arguments be expressible, and to the extent possible, the structures should reflect the distinction between the two types of argument. Yanal [12] uses this example of a linked argument:

She's either in the study or the kitchen
She's not in the study
She's in the kitchen

Neither premise taken alone is sufficient to establish the conclusion. Knowing that a person is in one room or another does not tell us what room she is in. And knowing what room she is not in is insufficient to establish what room she is in, unless there are only two possible locations. So the argument is linked.

A convergent argument is actually two arguments which share the same conclusion. Yanal [12] uses these two arguments:

She typically goes to the kitchen around this time to make a cup of tea
She's in the kitchen

I saw her walking in the general direction of the kitchen
She's in the kitchen

Here, the two separate premises converge on the conclusion that *she's in the kitchen.* It is easy to imagine situations in which either of the two arguments could be advanced without any mention of the other. From that perspective, it is easy to see the arguments as convergent rather than linked. However, there is some question as to whether the arguments are *necessarily* convergent, not linked. As Yanal [12] points out, having both arguments could add to our certainty of the conclusion. In Yanal's analysis, any uncertainty associated with the first premise may be reduced by the second premise. In support of this, Walton [11] cites what he calls *evidence-accumulating* arguments as a non-deductive linked type of argument, for example:

Bob is sneezing a lot
Bob has a snore throat
Therefore, Bob has a cold

While this could be interpreted as a set of convergent arguments, it seems clear that the combination of premises lends greater plausibility to the conclusion than either premise would when offered alone. As Walton [11] notes, determining whether an argument is convergent or linked is not always possible without the full context in which the argument occurs. Much depends on the intent of the person advancing the argument.

5 Linked and Convergent Structures in DBR

In DBR, the person advancing the argument is the knowledge engineer. To this extent, some of the difficulties encountered in distinguishing between linked and convergent structures may be avoided. The knowledge engineer can indicate that a structure is linked by making this information explicit at design-time.

This can be accomplished using the three kinds of relations: multinuclear, synthetic, and inferential. As introduced earlier, multinuclear relations consist of collections of nuclei and a single relation. Synthetic and inferential relations are structurally identical, consisting of a single nucleus and a satellite. These may be referred to as *single-nucleus structures*. Note that single-nucleus structures can have multiple satellites, each with its own relation, as shown in Fig. 8.

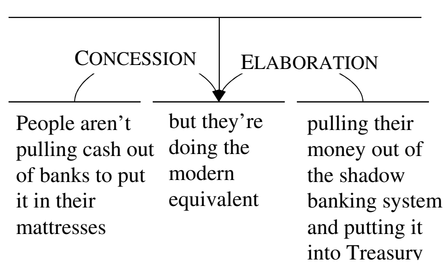

Fig. 8. Multi-Satellite Strategy for Linked Structures

Thus, there are two strategies available for designing linked structures in DBR. Using multinuclear relations, we can aggregate units in an explicitly defined relationship and then use a single nucleus relation to relate the aggregation to some nucleus. An example of this multinuclear linking strategy appeared earlier in this paper (Fig. 5). The second strategy is to specify the linkage using a multiple satellites and a single nucleus. This strategy is appropriate when the satellites each hold a unique relation to the nucleus. Fig.8 shows an example of this multiple satellite strategy.

Under these strategies, the commitment to a linked structure is made at design time. However, linked structures may also be discovered at runtime. These inferred structures are derived from separate arguments or explanations that were created separately, possibly at different times and by different authors. Fig. 9 shows two structures derived from two separate articles by two separate writers on two separate occasions. The two structures interact, because their nuclei are identical.

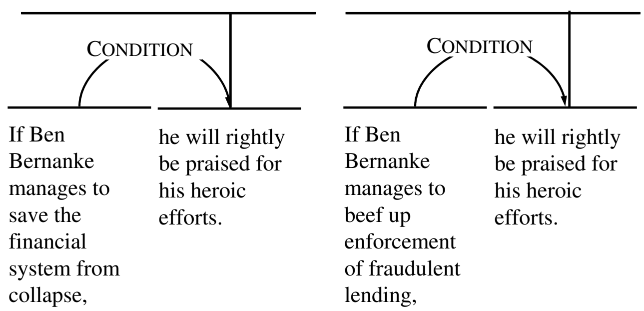

Fig. 9. Convergent Structures

In some respects, these appear to be convergent arguments. Each argument works well on its own. However, if we are to decide whether history will praise Ben Bernanke for his heroic efforts, we may wish to take both arguments into account. If one argument fails, we still have the other one to make our case. And if both arguments succeed (and at this moment that remains to be seen), we may regard the arguments as evidence-accumulating arguments of the sort discussed by Walton [11]. The accumulation of arguments would then become grounds for heaping praise on Bernanke.

Whereas design-time linkages are easy to identify, because the author of the argument has explicitly committed to a linked argument strategy, inferred linkages are more difficult, because the discovery is not simply a matter of matching structural patterns. This can be made clear by considering a third possible argument, one in which Bernanke's praiseworthiness would be contingent upon him desisting altogether in meddling with the financial markets. This argument would have the same structure as the other two, but would proceed from a premise that is incompatible with the other two. Similarly, in Prakken's [13] jogging example, one argument warrants rain as a reason not to go jogging and the other uses heat as the excuse. The arguments converge upon a single claim. But rather than strengthening the claim for avoiding jogging, the effect of the convergence may be weakening: the combination of rain and heat may be satisfactory conditions for jogging.

In examples such as these, we can see that what is needed is additional information. The difficulty is not just that the arguments are enthymemes, because we need not raise questions of inference in order to encounter the problem. The problem is ontological; recognizing the strengthening and weakening effects of different combinations of arguments requires understanding the constraints and relationships among the concepts comprising the subject matter. In the absence of such knowledge, we cannot reach a judgment.

While this might seem a shortcoming in the proposed approach, it is simply a matter of recognition of the boundary between the DBR and domain ontologies. As a structural ontology, DBR provides a mechanism for reasoning about explanatory structures; it makes no attempt to finesse the subtleties of specific knowledge domains. Thus, DBR supports design-time construction of linked structures and runtime discovery of convergent structures, but runtime discovery of linked structures appears to be a domain specific activity.

6 Conclusion

Discourse-based reasoning is a knowledge representation theory that uses natural patterns of discourse as the basis for an ontological model of explanatory reasoning. The DBR ontology is based on patterns natural discourse. The resulting knowledge structures and processes possess salient characteristics of intelligent explanatory reasoning. Using the DBR ontology, knowledge may be encoded in a manner similar to that used in rule-based expert systems. And at runtime, explanations and arguments would be instantiated, in a manner similar to the way rules fire in an expert system. An important difference is that the resulting instantiations would then be mapped into a rhetorical network by unifying their interactions. This results in a structured explanation of what is known to the system, which may be queried, updated, or merged with other networks. By providing ontological elements necessary for linked and convergent structures, we have provided DBR with a more complete basis for representing explanatory knowledge. Future work will include additional research in argument interaction, particularly with respect to accrual, analogical reasoning, and summarization.

Acknowledgments. I wish to thank Douglas Walton for suggesting that I take a look at the linking and convergence as they relate to discourse-based reasoning.

References

1. Potter, A.: A discourse approach to explanation aware knowledge representation. In: Roth-Berghofer, T., Schulz, S., Leake, D.B., Bahls, D. (eds.): Explanation-aware

computing: Papers from the 2007 AAAI Workshop. AAAI Press, Menlo Park, CA (2007) 56-63
2. Potter, A.: Generating discourse-based explanations. Künstliche Intelligenz 22(2) (2008) 28-31
3. Toulmin, S.E.: The uses of argument. Cambridge University Press, Cambridge, UK (1958)
4. Mann, W.C., Thompson, S.A.: Rhetorical structure theory: Towards a functional theory of text organization. Text 8 (1988) 243-281
5. Perelman, C., Olbrechts-Tyteca, L.: The new rhetoric: A treatise on argumentation. University of Notre Dame, Notre Dame, IA (1969 [1958])
6. Sartor, G.: A simple computational model for nonmonotonic and adversarial legal reasoning. ICAIL '93: Proceedings of the 4th International Conference on Artificial Intelligence and Law. ACM Press, New York (1993) 192-201
7. Mann, W.C., Taboada, M.T.: Relation definitions. (2007) http://www.sfu.ca/rst/01intro/definitions.html
8. Gruber, T.R.: Toward principles for the design of ontologies used for knowledge sharing. International Journal of Human-Computer Studies 43 (1995) 907-928
9. Hempel, C.G., Oppenheim, P.: Studies in the Logic of Explanation. Philosophy of Science 15(2) (1948) 135-175
10. Thompson, S.A., Mann, W.C.: Antithesis: A study in clause combining and discourse structure. In: Steele, R., Threadgold, T. (eds.): Language Topics: Essays in Honour of Michael Halliday, Volume II. John Benjamins, Amsterdam (1987) 359-381
11. Walton, D.N.: Argument structure: A pragmatic theory. University of Toronto Press, Toronto, Canada (1996)
12. Yanal, R.J.: Linked and convergent reasons - Again. In: Blair, J.A., Johnson, R.H., Hansen, H.V., Tindale, C.W. (eds.): Informal logic at 25: Proceedings of the Windsor Conference, Windsor, ON (2003)
13. Prakken, H.: A Study of Accrual of Arguments, with Applications to evidential reasoning. The Tenth International Conference on Artificial Intelligence and Law, Proceedings of the Conference, June 6-11, 2005. ACM, New York (2005) 85-94