Towards a Formal and Implemented Model of Argumentation Schemes in Agent Communication

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Abstract. Argumentation schemes are patterns of non-deductive reasoning that have long been studied in argumentation theory, and have more recently been identified in computational domains including multi-agent systems as holding the potential for significant improvements in reasoning and communication abilities. By focusing on models of natural language argumentation schemes, and then building formal systems from them, direct implementation becomes possible that not only has advantages in flexibility and scope, but also computational efficiency.

1 Introduction

Argumentation schemes capture stereotypical patterns of reasoning. Their study constitutes an ancient part of argumentation theory that has recently been attracting increasing attention (Walton, 1996), *inter alia*. Very early expositions laid out schemes as types of proofs -- a handy guide to the ways and means of persuading an audience (see, e.g. (Quintilian, 1920)). In this context, they are treated as a form of rhetoric. Later, they were adopted as a means of identifying bad argument -- this is very much the Aristotelian approach, in which schemes form a foundation stone for fallacy theory. Both of these traditions, the fallacy-theoretic and rhetorical, have had much more recent exponents, such as Grennan (1997) and Perelman and Olbrechts-Tyteca (1967). But a new approach has also emerged from informal logic, whereby a more analytical, more objective approach has been taken to the characterisation of these reasoning patterns. Good examples include Kienpointner (1986) and Walton (1996) who both attempt to sketch means for the classification of schemes.

Schemes have also been attracting the attentions of those who are interested in exploiting the rich interdisciplinary area between argumentation and AI (Reed & Norman, 2003; Verheij, 2003). Of course, AI has long been interested in non-deductive forms of reasoning (for a good review of a large proportion of the area, see (Prakken & Vreeswijk, 2002)). But schemes, as construed by argumentation theory, seem to provide a somewhat more fine-grained analysis that is typical within AI. One example

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lies in the granularity of classification of types: Kienpointner introduces over a dozen, Walton, almost thirty, Grennan, over fifty, Katzav and Reed (2004), over one hundred -- and none claim exhaustivity. By comparison, AI systems are more typically built with a small handful (Pollock's (1995) OSCAR, for example identifies less than ten -- with an uneven amount of work spread between them). This profligacy in philosophical classification might be argued to be as much a problem as an advantage - this is explored further below - but it serves to demonstrate that more detail is in some way being adduced. In particular, the propositional logic upon which a great deal of multi-agent argumentation is based is being further analysed to yield more refined structures of reasoning. It is the contention of this paper that those refined structures of reasoning yield well to a computational interpretation, and can be implemented to useful effect.

The aim of this paper is to employ conventional techniques (demonstrated in (Dung, 1995; McBurney and Parsons, 2002; Amgoud and Cayrol, 2002; *inter alia*) to handle the structure of argumentation schemes in such a way that (a) individual agents can reason about and develop arguments that employ schemes, and (b) that communication structures can be built up around those schemes. A formal account is an important objective servicing this aim, but equally important is a concrete implementation that demonstrates that both (a) and (b) can be achieved in practice. Although the implementation necessarily makes specific choices with regard to development, the formal component guarantees the broader applicability of the approach.

This paper represents a work in progress and sketches the framework, both theoretical and applied, around which development continues.

2 Argumentation Schemes in Natural Discourse

Argumentation schemes are forms of argument (structures of inference) representing common types of argumentation. They represent structures of arguments used in everyday discourse, as well as in special contexts like legal argumentation or scientific argumentation. They represent the deductive and inductive forms of argument that we are so highly familiar with in logic. But they can also represent forms of argument that are neither deductive nor inductive, but that fall into a third category, sometimes called abductive or presumptive. This third type of argument is defeasible, and carries weight on a balance of considerations in a dialogue. Perelman and Olbrechts-Tyteca, in *The New Rhetoric* (1969) identified many of these defeasible types of arguments used to carry evidential weight in a dialogue. Arthur Hastings' Ph.D. thesis (1963) carried out a systematic analysis of many of the most common of these presumptive schemes. The scheme itself specified the form of premises and conclusion of the argument. Hastings expressed one special premise in each scheme as a Toulmin warrant linking the other premises to the conclusion. Such a warrant is typically a defeasible generalization. Along with each scheme, he attached a corresponding set of critical questions. These features set the basic pattern for argumentation schemes in the literature that followed.

Many of these argumentation schemes were described and analyzed by van Eemeren and Grootendorst (1992). Kienpointner (1992) developed a comprehensive listing of argumentation schemes that includes deductive and inductive forms in addition to presumptive ones. In (Walton, 1996), twenty-five argumentation schemes for common types of presumptive reasoning were identified. Following Hastings' format, a set of critical questions is attached to each scheme. If an argument put forward by a proponent meets the requirements of a scheme, and the premises are acceptable to the respondent, then the respondent is obliged to accept the conclusion. But this acceptance, or commitment as it is often called, is provisional in the dialogue. If the respondent asks one of the critical questions matching the scheme, the argument defaults and the burden shifts back to the proponent. The weight of the argument is only restored when the proponent gives a successful answer to the question.

An argumentation scheme that can be used as an example is that for argument from sign. An example would be a case in which Helen and Bob are hiking along a trail in Banff, and Bob points out some tracks along the path, saying, "These look like bear tracks, so a bear must have passed along this trail." In the argumentation scheme below, one premise is seen to function as a Toulmin warrant.

Argument from Sign (Walton, 1996, p. 49).

Minor Premise: Given data represented as statement *A* is true in this situation.

Major (Toulmin Warrant) Premise: Statement *B* is generally indicated as true when its sign, *A*, is true, in this kind of situation.

Conclusion: Therefore, *B* is true in this situation.

The major premise is a presumptive conditional stating that if *A* is true, then generally, but subject to exceptions, *B* is also true. In the case cited, the tracks could have been "planted" on the trail by tricksters. But in the absence of evidence of such trickery, it is reasonable to provisionally draw the conclusion that a bear passed along the trail. Argument from sign is closely related to abductive inference, or inference to the best explanation. The best explanation of the existence of the observed tracks is the hypothesis that a bear walked along the trail producing the tracks. Of course, there could be other explanations. But in the absence of additional evidence, the bear hypothesis could be plausible as a basis for proceeding carefully.

3 A Theory of Argumentation Schemes

Unfortunately, though the argumentation literature includes a wide variety of approaches to definition, classification, collection, analysis and specification of schemes, there is none that represents either a definitive or a consensual view. Any current computational work on schemes must therefore position itself somewhere in the space of theoretical work.

If argumentation schemes capture types of argument, perhaps the first theoretical issue is to resolve the scope of our study by answering the question, 'What is argument?' The question is interesting, and has direct impact on models in multi-agent systems. Does, for example, the bid-counter-bid protocol of many auctions count as argument? For most MAS people, this is too trivial to count, though for some argumentation theorists who take an inclusive view (such as Walton) it certainly could. Alternatively, would the exchange of sets of acceptable theorems (in the sense of Dung (1995)) count as argument? For most MAS people using argumentation, the answer is that it is, self-evidently, argument. Yet argumentation theorists of a communication theoretic or pragma-dialectic stripe would beg to differ. If we want a theory of argumentation in multi-agent systems, we need to delimit what that theory should account for.

There are, as might be expected, almost as many definitions of argument as there are argumentation theorists. At one end, the all encompassing taxonomy of Gilbert (1997) covers a panoply of situated action that can count as argument, from artistic creation, through non-linguistic communication, to physical activity. At the other end, van Eemeren and Grootendorst's (1992) pragma-dialectics associates argument with the notion of critical discussion, a closely bounded, tightly specified linguistic activity whose definition rests upon speech act theory.

In multi-agent systems, the majority of recent work exploring notions of argumentation has a propositional foundation. Thus one of the foremost examples, (McBurney and Parsons, 2002), offers brief description of the "topic layer": "Topics are matters under discussion by the participating agents, and we assume that they can be represented in a suitable logic *L*. Topics are denoted by the lower case Roman letters *p*, *q*, *r*, etc. ... Topics may refer to either real-world objects or to states of affairs". They go on to explain that *L* may also include modalities, but even though the concept of "real-world objects" is a little ambiguous, it is clear that the intention here is to use something rather close to a (possibly modal) propositional logic as the language for expressing the content of locutions. There is little more said in (McBurney and Parsons, 2002) – or in work that takes a very similar approach (of which a good example is (Amgoud & Cayrol, 2002)) – on the topic layer.

If there is a need to stay close to natural language use (in order, for example, to exploit theories of communication that have been developed for natural languages), then such a propositional basis starts to falter – or at least, starts to be inadequate on its own.

The aims of a formalisation should therefore be (a) to remain sufficiently close to linguistic practice that the richness and flexibility of natural argumentation can be exploited, whilst aiming (b) to render a model that is straightforwardly implementable, both in generation and understanding. The focus here is upon the definition, representation and manipulation of scheme-based structures. There are many and rich interplays between argumentation schemes and the progress and conduct of dialogue. Some of these are explored in (Prakken *et al.*, 2003).

With these aims, and this focus in mind, and building on the multi-agent systems tradition of the propositional underpinning, the theoretical basis here borrows heavily from (Katzav and Reed, 2004). Arguments themselves are construed as (non-atomic) propositions[1]. These propositions refer to facts that "wholly convey" other facts through a variety of relations of conveyance. That is, the communicative structures refer to relationships that exist in the world between fully specified states. Examples of these relationships include causal relations, class-membership relations, constitutive relations and others (and these relation types can form the basis of a system of classification).

[1] This apparently simple starting point has various ramifications, some of which are convenient (such as the fact that it any argument *R* can be referred to with an appropriate 'that' clause – the argument that *R*: this is a property of propositions) and some of which are less so (such as the requirement to exclude interrogatives and imperatives from the concept of argument for now). Further discussions can be found in (Katzav and Reed, 2004).

An example will serve to clarify. The following extract, Ex1, is taken from the *The United Kingdom Commons Hansard Debate Text* for 21 October 2002: Vol. No. 391, Part No. 192, Column 2:

> (Ex1) *Confidence in personal and occupational schemes will have been severely damaged this week by news that the Government are abolishing higher-rate tax relief on pension contributions.*

The analysis in Figure 1 is taken from the AraucariaDB online corpus[2]:

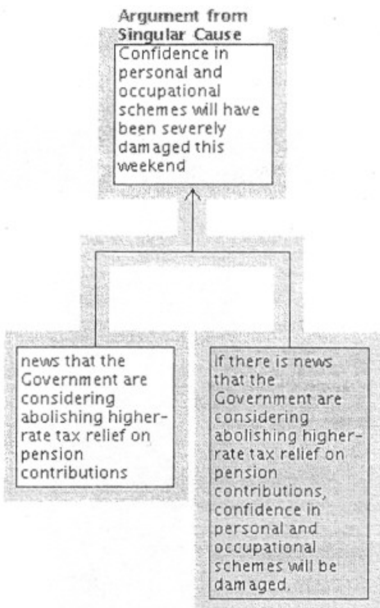

Fig. 1. An *Araucaria* analysis of the structure of the *Pensions* argument. Vertical arrows indicate support; joined arrows indicate linked support (Freeman, 1991); shaded areas around diagram components show schemes, named at their conclusions; and shaded boxes show enthymemes

This is one of the simpler examples in the corpus. Figure 1 shows an instantiation of a scheme in the Katzav-Reed taxonomy called *Argument from Singular Cause*. The implicit conditional is presumed in this analysis to express a causal relationship between premise as cause and conclusion as effect. Thus the fact that there is news from the Government (...) conveys via a causal relation of conveyance the fact that confidence (...) will have been damaged. This ('compound') fact is the one identified by the proposition that is the argument in Ex1 and Figure 1.

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[2] Available at http://www.computing.dundee.ac.uk/staff/creed/araucaria

The final component is to notice that there is a relationship between the type of argumentation scheme and the type of atomic propositions that instantiate it. Thus, in the example above, of the three atomic components, one expresses a causal relation (the major premise), and the other two express the sort of facts that can stand as cause and effect, respectively. (Note that the task here is not to develop an all encompassing ontology. Nor is it to claim that some propositions can be uniquely labelled as 'causes' or 'effects' – such a position would be absurd. But nevertheless, it is self evident that some types of propositions can stand in such places, and that others cannot, and it is merely this distinction that is being drawn here). Individual propositions may have numerous attributes that characterise their type.

In this way, a conventional propositional database of intentional attitudes such as beliefs, is stratified by typing the propositions that it contains. This typing then supports autonomous reasoning mechanisms by which agents can identify and communicate arguments constructed from schemes instantiated by propositions of the appropriate type.

This approach to the theoretical basis has the benefit of not only providing a means for exploiting theories of argumentation from empirical sources, but also makes possible reuse of analysed data within implemented multi-agent communities.

4 Elements of a Formalisation of Argumentation Schemes

The starting point is propositional logic, *PL*, from which we take our propositions (*Props*) and propositional variables, and all the usual operators. Next, we define a set of attributes, *T*. This set contains any number of arbitrary tokens. Attributes are associated with propositions by the typing relation, τ, thus: τ: *Props* $\rightarrow \mathrm{P}(T)$. That is, the typing relation associates with every proposition a set of attributes, or "type".

The next step is to define scheme structures formally. The approach presented here is based on the implementation of the Argument Markup Language DTD (Reed and Rowe, 2001), and is designed to facilitate practical and reusable implementation.

The set, Ξ, of schemes in a particular system is comprised of a set of tuples of the following form: <*SName*, *SConclusion*, *SPremises*>, where *SName* is some arbitrary token, *SConclusion* $\in \mathrm{P}(T)$, and *SPremises* $\subset \mathrm{P}(T)$[3]. If $\exists\xi \in \Xi$ such that $\xi = <\sigma_0, \sigma_1, \sigma_2>$ then $\neg\exists\xi' \in \Xi / \{\xi\}$ such that $\xi' = <\sigma_0, \sigma_3, \sigma_4>$ or $\xi' = <\sigma_5, \sigma_1, \sigma_2>$, for any $\sigma_3, \sigma_4, \sigma_5$. In this way, a scheme is uniquely named and is associated with a conclusion type, and a set of premise types.

[3] In fact, the picture for *SPremises* is rather more complicated. Clearly, an argument scheme can include more than one premise of the same type. Thus *SPremises* can have multiple identical elements. Hence *SPremises* is not a set, but a bag. In order to keep the presentation simple, and to focus on the broad structural aspect of the formalism, it is here simplified and restricted such that there can only be one premise of each type. In detail, extra machinery can be added quite simply such that each element of *SPremises* is a tuple in which the first element is a unique natural number, and the second element the set of attributes that consitute a premise type. In this way, *SPremises* remains a set and yet multiple instances of a given premise type are permitted

Finally, an instantiation is an argument based upon one of the schemes. An instantiation is thus a tuple, *<Name, Conclusion, Premises>* such that for some *<SName, t, SPremises>* $\in \Xi$, where *SName* = *Name*,

$$\begin{array}{lll} Conclusion \in Props & \wedge\ \tau(Conclusion) = t, & \text{and} \\ \forall p \in Premises,\ p \in Props & \wedge\ \text{the set } \{\pi \mid \pi = \tau(p)\} = SPremises & \end{array}$$ [4]

In this way, an instantiation of a scheme named *SName* must have a conclusion of the right type, and all the premises, each of which is also of the right type. (Note that this latter requirement is actually a little too strong for most natural models of scheme usage, as schemes often involve some premises being left implicit, to form enthymematic arguments. The simplification is useful at this stage of development, and does not preclude more sophisticated handling later).

This model supports a straightforward mechanism for representation of schemes. It does not, as it stands, give an agent a mechanism for reasoning with schemes and for building (that is to say, chaining) arguments using schemes. Through structures such as critical questions (Walton, 1996), argumentation schemes offer the potential for a sophisticated model of dialectical argument-based nonmonotonic reasoning. Such a model is currently under development (see (Prakken *et al.*, 2003) for some preliminary steps in this direction). In the meantime, a simple solution suffices to support development of both theory and implementation.

To sketch how this works, we define a new operator, $\Rrightarrow$, that corresponds to implication extended to schemes. That is, in this system, if $\alpha \supset \beta$, then $\alpha \Rrightarrow \beta$, but also, if there exists an instantiation of an argument scheme *<N, C, P>* in which $\beta = C$ and $\alpha \in P$, then $\alpha \Rrightarrow \beta$. Dung-style definitions of acceptability, admissibility are then formed using deductive closure on $\Rrightarrow$ rather than $\supset$, and everything else remains as before. Thus, the representation of argumentation schemes is brought in to standard models of defeasible argumentation of Dung, Prakken, Vreeswijk, Verheij, etc.

5 Towards Implementation

There are two distinct facets to implementation that can handle schemes. The first is the ability to represent and manipulate scheme based structures in the one-agent setting in a flexible and scalable way. The second is to utilise that representation in the multi-agent case, and exploit representational structure in communication design.

5.1 Representation

Following work examining the diagramming of natural argument – an important topic from the practical, pedagogic point of view (van Gelder & Rizzo, 2001), but also a driver of theoretical development in informal logic (Walton & Reed, 2004) – Reed and Rowe (2001) developed *Araucaria*, a system for aiding human analysts and students in marking up argument. Araucaria adopts the 'standard treatment' (Freeman, 1991) for argument analysis, based on identification of propositions (as vertices in a diagram) and the relationships of support and attack holding between them (edges in a

4 Set equivalence here is taken to mean identical membership.

diagram). It is thus similar to a range of argument visualisation tools (see (Kirschner *et al.*, 2003) for an overview), and familiar from AI techniques such as Pollock's (1995) inference graphs. As well as having a number of features that make it particularly well suited to teaching and research in argumentation, it is also unique in having explicit support for argumentation schemes.

Araucaria's underlying representation language is an XML language, the Argument Markup Language. AML is defined using a DTD, a simple and straightforward language-design mechanism. One of the basic components of arguments from Araucaria's point of view is a proposition or PROP - loosely, a text-box in Figure 1, above. The definition for this component is as follows:

```
<!ELEMENT PROP (PROPTEXT, OWNER*, INSCHEME*)>
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The PROPTEXT component details the text or, roughly, the propositional content of a given PROP. The OWNERs of a PROP allow analysts to distinguish between viewpoints in an argument (and lay a foundation for marking up argumentative dialogue, which is currently work in progress). Finally, the INSCHEME component allows the analyst to indicate that a PROP belongs to a given scheme. Notice that the Kleene star in the definition allows multiple INSCHEME tags for a given PROP - that is, a given proposition can be in more than one argumentation scheme.

The definition of the (empty) INSCHEME tag, below, includes two references, one to a unique scheme name, the *scheme* attribute, and one to a unique identifier, *schid*. It is important to include both so that any given PROP can be marked as belonging not only to a scheme of a particular type, but also a particular instance of that scheme within the current text (so that multiple instances of a given scheme can be identified uniquely).

```
<!ATTLIST INSCHEME scheme   CDATA #REQUIRED
                   schid    CDATA #REQUIRED>
```

Finally, the *scheme* attribute in the definition above corresponds (in processing, not in AML definition) to an element in the SCHEMESET tag of the AML file. For ease of exchange and independence, each AML analysis includes the complete set of scheme definitions that are used in the analysed text. The SCHEMESET (which can also be saved separately, and thereby adopted in different analyses) is composed of a series of SCHEME elements.

```
<!ELEMENT SCHEME (NAME, FORM, CQ*)>
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Thus each scheme has a unique name (e.g., 'Argument from Expert Opinion' in the schemeset corresponding to (Walton, 1996)). The CQ elements allow specification of critical questions, and the FORM element supports specification of the formal structure of a scheme thus:

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<!ELEMENT FORM (PREMISE*, CONCLUSION)>
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where both PREMISEs and CONCLUSIONs are ultimately just propositions expressed in text.

In this way, AML supports the specification of argumentation schemes in a machine readable format. It is flexible enough to capture various types of argumentation schemes, including examples from (Kienpointner, 1986), (Walton, 1996), (Grennan,

1997) and (Katzav and Reed, 2004). Similarly, it is flexible enough to handle and match other types of argumentation analysis in diverse domains including Wigmore charts in reasoning about legal evidence (Prakken *et al.*, 2003), and representing Pollock-style inference graphs (Pollock, 1995). At the same time, the language is simple enough to support manipulation by a number of systems, tools and utilities, including, of course, Araucaria. But AML is also used by several other utilities, and its schemes are being employed in the construction of a large online corpus[5] of natural argumentation, available online at http://www.computing.dundee.ac.uk/staff/creed/araucaria.

5.2 Agent Communication

Implementing scheme-based communication situated in a multi-agent system is currently a work in progress. We have adopted a flexible, lightweight and easily deployed agent platform called Jackdaw[6], primarily because it offers great flexibility in the design and implementation of both mentalistic structures and communication languages and protocols.

The belief database is populated at start up. Beliefs are stored as directed by the model of section 4, with a propositional component and a type component, the latter comprised of a number of attributes. The "invention" of the argument is beyond the scope of the current work – in implementation, the agent simply has the user select a proposition to argue for. The agent then selects a supporting argument at random. That is, by chaining through the belief database, it identifies instantiations of schemes, replete with appropriately typed propositions, and selects one of them. The argument is then rendered as a fragment of AML, and communicated to an opponent.

Following in the spirit of Parsons and Jennings' (1996) style interaction, agents determine responses on the basis of acceptability classes. Specifically, if the hearer has an argument (that is, an instantiation of a scheme) that attacks a component of the speaker's argument, they can return such an argument as a counter[7]. If the hearer has no such argument, it simply updates it belief database with both premises and conclusions of the speakers argument. Such a dialogic protocol is extremely simple: the focus here is not upon how argumentation schemes interact with protocols (which is being pursued in companion work), nor on how argumentation-based dialogue games can structure inter-agent communication (which is the topic of much current research) – but rather, on the contents of the moves as schemes.

6 The Role of Schemes in Agent Communication

There are several key advantages that are delivered by using argumentation schemes in inter-agent argument. The first is that the belief database is stratified. As agents become larger, and have larger belief databases, and as agent systems are deployed in more real world situations, deduction and search through that database – even by the

[5] Clearly the use of a markup language and the presentation here is suggestive of other work in corpus linguistics. There is not space here to explore the relationships between AML and corpus research; the interested reader is directed to the website for further details.

[6] See http://www.calicojack.co.uk/

[7] We abstract here from the distinction between undercutting and rebutting arguments.

very fastest theorem provers – becomes extremely computationally expensive. Tackling this problem is going to require a battery of techniques. One of those techniques could be to partition or stratify the database to guide the search process. That particular schemes (i.e. particular ways of reaching conclusions) can only take certain types of proposition cuts the processing required to generate arguments by substantially reducing the branching factor. A second, analogous advantage reduces load for the hearer – processing an incoming argument to assess its acceptability (or some other standard for validity, reasonableness, or sufficiency) is similarly computationally intensive. It too is simplified by reducing search through scheme-based stratification. A third advantage also becomes manifest at this step in the process of inter-agent argumentation. For not only is the computational load of judging incoming arguments reduced, but further, the mechanisms by which that judging can be carried out and much broader. Individual argument schemes might have their own standards of validity by which they might be judged (in a similar way to the distinction between deductive validity and inductive strength). The way in which particular schemes are judged is then a feature of the community or society in which that agent resides (demonstrating a close analogy to human communities).

There are also broader, practical advantages of equipping agents, both autonomous and those working directly on behalf of users, with the ability to formulate and handle argumentation schemes as fragments of AML. The first is that it offers the opportunity to re-use increasingly rich resources of existing argumentation, such as AraucariaDB, that could provide a way of overcoming some of the limitations of the "knowledge bottleneck", that limits many real world deployments of interesting AI and MAS models. The second advantage is that with wide heterogeneity in the types of arguments used in domains such as law, pedagogy and e-government, it is important to have communication and reasoning models that are as theory-neutral as possible.

Finally, it becomes possible to envisage heterogeneous environments in which completely autonomous agents can interact with humans, or agents representing humans, through the medium of natural language restricted through structural constraints and ontological limits – but not requiring natural language understanding and generation. Though an ambitious aim, such systems are being hinted at by increasingly sophisticated models of CSCW and CSCA in particular (Kirschner *et al.*, 2003), and scheme-based communication represents a further step in that direction.

7 Concluding Remarks

There are several tasks that require immediate attention in implementation. Empirical evaluation is then planned for the implementation to show the advantages discussed in section 6 in situ, and to provide quantitative justification for the currently qualitative, theoretical claims.

In conjunction with parallel work, an important next step is to tie the internal representation and thence communication structures with larger scale characterisations of dialogue and the dynamics of dialogue. So, for example, critical questions have a key role to play in capturing the shifting burden of proof and dialectical obligations in discourse. Investigation of these topics will be aided by having a simple, sound foundation for representation and exchange of the schemes and their instantiations.

One further exciting opportunity is to have agents configure their reasoning capabilities on the basis of schemeset definitions. There are many alternative ways of defining schemes (Walton, 1996), (Kienpointner, 1986) and (Katzav and Reed, 2004) represent three divergent theoretical views, and (Norman *et al.*, 2003) indicate that it is likely that more will be developed in the computational domain. It was for these reasons that Araucaria was designed to support the definition, manipulation and exploitation of "schemesets" that use the same AML language to characterise different sets of schemes. These schemesets essentially represent a more or less complete way of performing reasoning, and so could be used to reconfigure agent reasoning capabilities on the fly.

But despite the work that remains to be done, it is already clear that there is a need for a model of scheme-based communication that builds on the successes of (McBurney and Parsons (2003), Amgoud and Cayrol (2002), *et al.*, but integrates work on argumentation schemes, both the more mature research in argumentation theory, and the nascent results with a more computational bent (Norman *et al.*, 2003; Verheij, 2002). This paper has aimed to lay out some groundwork for such an integration at a conceptual level, arguing for the importance of including naturalistic models; at the formal level, sketching the formal framework; and at the implementation level, showing how implemented components are being slotted together to provide testable systems. In this way, our objective is to develop models and systems of inter-agent behaviour for a wide class of agents and a wide class of reasoning structures.

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