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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 been the focus of extended study in argumentation theory. They have also 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 in multi-agent environments becomes a possibility. The formal, representational and implementational details are presented here, along with results that demonstrate not only advantages of flexibility, scope, and knowledge sharing, but also of computational efficiency.

Keywords: argumentation, knowledge representation, schemes.

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 [29, 30], *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. [22]). In this context, they are treated as a form of rhetoric. Later, they were adopted as a means of identifying bad arguments – 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 [9, 18]. 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 [12, 29] 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 [2, 20, 23, 27]. 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 [21]). But schemes, as construed by argumentation theory, seem to provide a somewhat more fine-grained analysis than is typical within AI. One example lies in the granularity of classification of types: Kienpointner introduces over a dozen, Walton, almost thirty, Grennan, over fifty, [11], over 100 – and none claim exhaustivity. By comparison, AI systems are

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more typically built with a small handful ([19] OSCAR, for example identifies less than 10 – 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 [1, 5, 15] *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 reports on the first completed phase of a work in progress and describes 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 correspond to the structures of arguments used in everyday discourse, as well as in special contexts like legal argumentation or scientific argumentation. They embody 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) identify many of these defeasible types of arguments used to carry evidential weight in a dialogue. Hastings' [10] carries out a systematic analysis of many of the most common of these presumptive schemes. The scheme itself specifies the form of premises and conclusion of the argument. Hastings expresses one special premise in each scheme as a Toulmin warrant [26] linking the other premises to the conclusion. Such a warrant is typically a defeasible generalisation. Along with each scheme, he attaches 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 are described and analyzed by van Eemeren and Grootendorst [6]. Kienpointner [13] develops a comprehensive listing of argumentation schemes that includes deductive and inductive forms in addition to presumptive ones. In Walton [29], 25 argumentation schemes for common types of presumptive reasoning are 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 Position to Know*. It is based on the assumption by one party that another party has information that the first party needs. For example someone lost in a foreign city asks a stranger where the Central Station is. The questioner needs this information, and does not have it. If the respondent gives an answer by citing a location, what reason does the questioner have to think that she can act on this information, or take it as true? The rationale is given by argument from position to know. The version of the argumentation scheme in ([29], pp. 61–63) is given below.

Argument from Position to Know

Major Premise: Source *a* is in a position to know about things in a certain subject domain *S* containing proposition *A*.

Minor Premise: *a* asserts that *A* (in Domain *S*) is true (false).

Conclusion: *A* is true (false).

When a proponent puts forward an argument in a dialogue and it meets the requirements indicated above, then it carries some weight as a presumption. But it is defeasible by questioning. Matching the argument from position to know are three critical questions ([29], p. 62):

CQ1: Is *a* in a position to know whether *A* is true (false)?

CQ2: Is *a* an honest (trustworthy, reliable) source?

CQ3: Did *a* assert that *A* is true (false)?

When the proponent in a dialogue has put forward an argument from position to know, the respondent can ask any one of these three critical questions. Once the question has been asked the presumptive weight the argument had before is withdrawn. But if the proponent gives an acceptable answer to the question, the weight is restored.

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 determining the kinds of argument we are interested in. The problem is wide-ranging, 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 researchers in multi-agent systems, 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 [5]) 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 might 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 [8] 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 [6] 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, [15], offers a 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 concerning the topic layer, either in [15] or in work that takes a very similar approach, such as [1].

If there is a need to stay close to natural language usage (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 the generation and understanding of argument. 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 [20].

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 [11]. 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 of affairs. 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).

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]

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*, which occurs in different guises in most other taxonomies. 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.

The final point 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. One advantage of this general approach is that it can be used with any of the popular systems of schemes, including [6, 9–11, 13, 29] and others.

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.

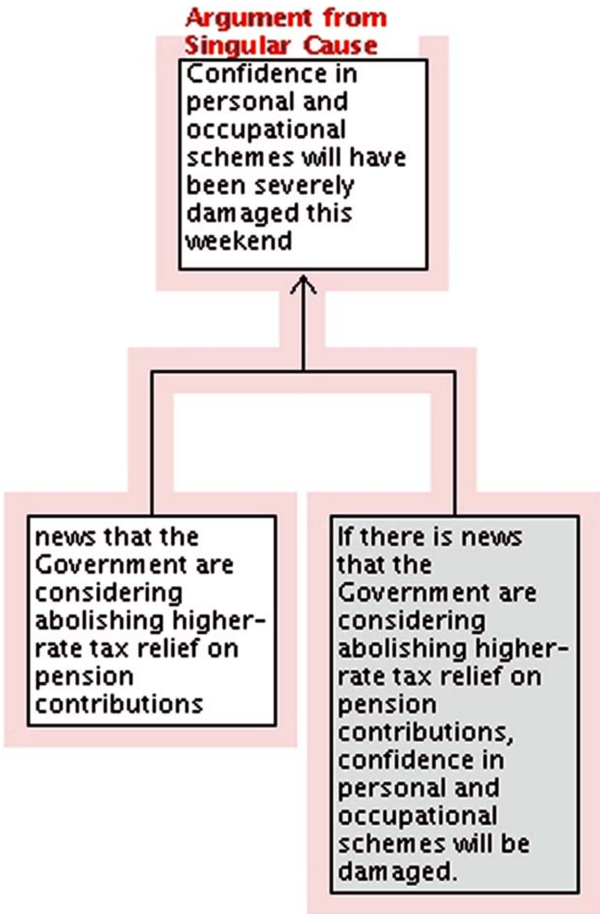

Figure 1. An *Araucaria* analysis of the structure of Ex1. Vertical arrows indicate support; joined arrows indicate linked support [7]; shaded areas around diagram components show schemes, named at their conclusions; and shaded boxes show enthymemes.

4. Elements of a formalisation of argumentation schemes

The starting point is propositional logic, *PL*, from which we take our propositions (*Props*), propositional variables, and all the usual operators. Next, we define a set of attributes, *A*. This set contains any number of arbitrary tokens. Attributes are associated with propositions by the typing relation, τ: $Props \rightarrow \mathrm{P}(A)$. 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 [24, 25], 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, $SConclusion \in \mathrm{P}(A)$, and $SPremises \subset \mathrm{P}(A)$. [3] If $\exists\ \xi \in \Xi$ such that $\xi = <\sigma_0, \sigma_1, \sigma_2>$ then $\neg\exists\ \xi' \in \Xi$ such that $\xi' = <\sigma_0, \sigma_3, \sigma_4>$ or $\xi' = <\sigma_5, \sigma_1, \sigma_2>$, for any σ_3, σ_4, σ_5. In this way, a scheme is uniquely named and is associated with a conclusion type, and a set of premise types.

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 $SName = Name$,

$$\begin{aligned} &Conclusion \in Props \wedge \tau(Conclusion) = t, \qquad \text{and} \\ &\forall p \in Premises, p \in Props \wedge \text{the set}\{\pi \| \pi = \tau(p)\} = SPremises^{4} \end{aligned}$$

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 [29], argumentation schemes offer the potential for a sophisticated model of dialectical argument-based non-monotonic reasoning. Such a model is currently under development (see [20] 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 $\twoheadrightarrow$ that corresponds to implication extended to schemes. That is, in this system, if $\alpha \supset \beta$, then $\alpha \twoheadrightarrow \beta$, but also, if there exists an instantiation of an argument scheme $<N, C, P>$ in which $\beta = C$ and $\alpha \in P$, then $\alpha \twoheadrightarrow \beta$. Dung-style definitions [5] of acceptability and admissibility are then formed using deductive closure on $\twoheadrightarrow$ rather than $\supset$, and everything else remains as before. Thus, the representation of argumentation schemes is brought in to standard models of defeasible argumentation such as [5], [21], [27], etc.

5. Towards implementation

There are two distinct facets to implementation of 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

The diagramming of natural argument is an important topic from the practical, pedagogic point of view [28], and also a driver of theoretical development in informal logic [30]. As a result, Reed and Rowe [24, 25] developed *Araucaria*, a system for aiding human analysts and students in marking up argument. Araucaria adopts the 'standard treatment' [7] 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 diagram).[5] It is thus similar to a range of argument visualisation tools (see [14] for an overview), and familiar from AI techniques such as Pollock inference graphs [19]. 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. The definition for this component is as follows:

```
< !ELEMENT PROP (PROPTEXT, OWNER*, INSCHEME*) >
```

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 have a functional role in more than one argumentation scheme.

The definition of the (empty) INSCHEME tag given 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*) >
```

Thus each scheme has a unique name (e.g., 'Argument from Expert Opinion' in the schemeset corresponding to [29]). The CQ elements allow specification of critical questions, and the FORM element supports specification of a scheme's formal structure:

< !ELEMENT FORM (PREMISE*, CONCLUSION) >

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, currently including examples from [9, 11, 18, 29]. Similarly, it can handle and match other types of argumentation analysis in diverse domains including Wigmore charts in reasoning about legal evidence [20], and representing Pollock-style inference graphs [19]. 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 of natural argumentation.[6]

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 JUDE, primarily because it offers great flexibility in the design and implementation of both mentalistic structures and communication languages and protocols.[7] Here, we describe the first step, namely, the ability for individual agents to handle and reason with schemes.

In order to demonstrate the advantages of the approach, we have selected a relatively simple theory of schemes that yields a relatively small set of proposition types. Pollock [19] proposes an approach to defeasible reasoning that is attractive in its simplicity, and has been shown to be applicable not only in automated reasoning, but also in the analysis of real discourse such as that found in the courtroom [20]. So, for example, a witness's statement that "I saw the accused at the scene", would be analysed as an argument consisting of four parts arranged into a sorites of three argumentation schemes. First, the witness's actual testimony supports the fact that the claim she makes is true – in other words, an inferential leap that has an implicit assumption about honesty (amongst other things). This is the scheme from witness testimony. Next, from the proposition that the witness does in fact recall having seen the accused, we might infer that the witness's recollection is accurate, an inferential leap involving implicit assumptions about the recall ability of the witness. This is the scheme from memory. Finally, from the proposition that the witness did in fact see the accused at the scene, we can infer that the accused was present, via a scheme involving assumptions about the accuracy of perception: the scheme from perception. This analysis is summarised in Figure 2:

In Pollock's system, typing of propositional components is clearly evident (though not explored by him): testimony is of a distinct kind to recollections, which in turn

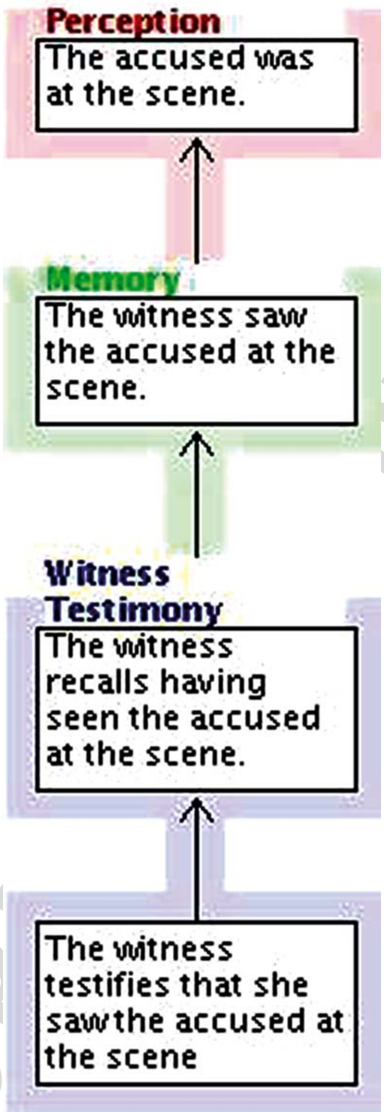

Figure 2. From witness testimony to an objective claim in three steps, *à la* Pollock.

are of a distinct kind from percepts, which in turn are different from other objective propositions. These three schemes and four propositional types, though not exhausting Pollock's typology, are employed here as the basis for investigation. The three schemes can be characterised in the following way (that is directly translatable into both the formal system of Section 4, and the implemented representation language of Section 5.1):

Scheme from Witness Testimony[8]	
Witness A says P	Premise of type Testimony
Witness A saying P is a prima facie reason for believing P	Rule
so, P	Conclusion of any type

Scheme from Memory	
A recalls P	Premise of type Recollection
Recalling P is a prima facie reason for believing P	Rule
so, P	Conclusion of any type

Scheme from Perception	
A has a percept with content P	Premise of type Percept
Having a percept with content P is a prima facie reason to believe P	Rule
so, P	Conclusion of any type

Using the AML format of Section 5.1, these schemes are represented as in Figure 3:

```
<SCHEMESET>
 <SCHEME>
  <NAME>Perception</NAME>
   <FORM>
    <PREMISE type="percept">Having a percept with content P
    </PREMISE>
    <CONCLUSION>P</CONCLUSION>
   </FORM>
   <CQ>Are the circumstances such that having a percept P is
   not a reliable indicator of P?</CQ>
 </SCHEME>
 <SCHEME>
  <NAME>Memory</NAME>
   <FORM>
    <PREMISE type="memory">Recalling P</PREMISE>
    <CONCLUSION>P</CONCLUSION>
   </FORM>
   <CQ>Is P originally based on beliefs of which one is
   false?</CQ>
   <CQ>Is P not originally believed for other reasons?</CQ>
   <CQ>Does the agent who recalls P express doubt about P?</CQ>
 </SCHEME>
 <SCHEME>
  <NAME>Witness Testimony</NAME>
   <FORM>
    <PREMISE type="testimony">Witness W says P</PREMISE>
    <CONCLUSION>P</CONCLUSION>
   </FORM>
   <CQ>Is witness W truthful?</CQ>
 </SCHEME>
</SCHEMESET>
```

Figure 3. AML representation of a simple schemeset.

The belief database of an agent is populated at start up. Beliefs are stored as directed by the model presented in Section 4, with a propositional component and a type component, the latter comprised of a number of attributes (specifically, PROP-TEXT is extended to include typing information). As a fragment of AML, the argument from Figure 2 is represented as in Figure 4 (some detail has been omitted for clarity).

The *inventione* 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.

To assess the impact of typing of beliefs, agents are initialised with an artificially created belief set containing thousands of random "beliefs" of typed, unique tokens. In addition, the beliefs include a small number of inferential compounds that represent instantiations of schemes. Proving a given belief is thus essentially a search problem: stratifying the beliefs on the basis of type partitions the search problem, so it should be expected that search over a stratified set is much more efficient than search over unstratified beliefs. By re-running the implementation with the typing machinery disabled, it is possible to demonstrate that this is indeed the case. With several replicates (to allow for random ordering artifices in the belief sets) at each of a number of belief set sizes between 1000 and 50,000 beliefs, results shown in Figure 5 were recorded.

Thus, as we would expect, partitioning the belief set into the four belief types (*viz. percept*, *recollection*, *testimony* and everything else) has a direct and striking impact on processing time: even though the selected schemes happen to type-constrain only their premises, and despite the small number of types (and therefore, partitions), the data demonstrate a three-to-four-fold reduction in processing time to identify the appropriate instantiations of 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 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. This processing too is simplified by reducing search through

```
<TEXT>The witness testifies that she saw the accused at the scene. The
witness recalls having seen the accused at the scene. The witness saw
the accused at the scene. The accused was at the scene. </TEXT>
<AU>
  <PROP>
   <PROPTEXT>The accused was at the scene. </PROPTEXT>
   <INSCHEME scheme="Perception" schid="2" />
  </PROP>
  <CA>
   <AU>
     <PROP>
      <PROPTEXT type=”percept”>The witness saw the accused at
       the scene.</PROPTEXT>
       <INSCHEME scheme="Memory" schid="1" />
       <INSCHEME scheme="Perception" schid="2" />
     </PROP>
     <CA>
      <AU>
       <PROP>
        <PROPTEXT type=”recollection”>The witness recalls
        having seen the accused at the scene.</PROPTEXT>
        <INSCHEME scheme="Witness Testimony" schid="0" />
        <INSCHEME scheme="Memory" schid="1" />
       </PROP>
       <CA>
        <AU>
         <PROP>
          <PROPTEXT type=”testimony”>The witness testifies that
           she saw the accused at the scene</PROPTEXT>
          <INSCHEME scheme="Witness Testimony" schid="0" />
         </PROP>
        </AU>
       </CA>
      </AU>
     </CA>
   </AU>
  </CA>
</AU>
```

Figure 4. AML representation of a sample argument.

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 are 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.

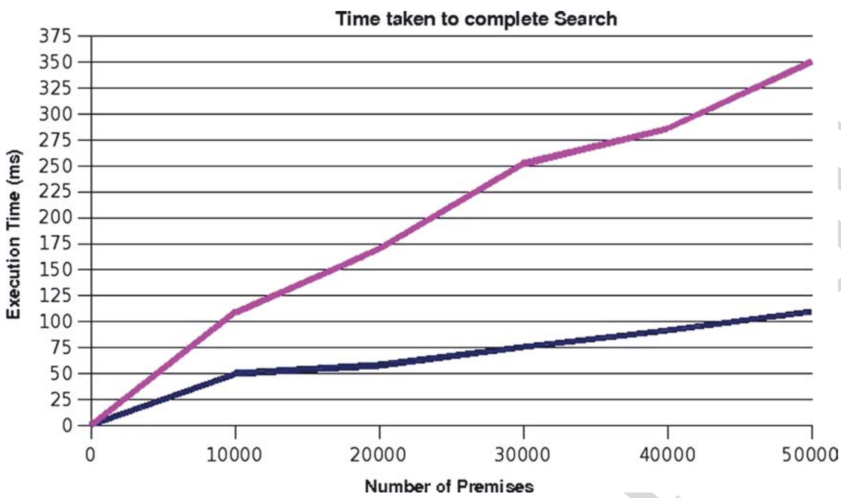

Figure 5. The effect of belief typing on search time; the lower line records performance with typing enabled.

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 [14], and scheme-based communication represents a further step in that direction.

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: [11, 12, 29] represent three divergent theoretical views, and [16] 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 [1, 15], *inter alia*, but integrates work on argumentation schemes, both the more mature research in argumentation theory, and the nascent results with a more computational bent [2, 3, 16, 27]. This paper has aimed to lay out some groundwork for such an integration in three ways: at a conceptual level, arguing for the importance of naturalistic models; at the formal level, sketching a coherent formal framework; and at the implementation level, showing how implemented components are slotted together to provide clear and concrete results.

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Notes

1 This apparently simple starting point has various ramifications, some of which are convenient (such as the fact that 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).

2. A corpus of analysed natural argumentation available at http://araucaria.computing.dundee.ac.uk/

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 constitute a premise type. In this way, *SPremises* remains a set and yet multiple instances of a given premise type are permitted.

4. Set equivalence here is taken to mean identical membership

5. Though recent work has extended Araucaria to support conventional Toulmin diagrams [26], and the interchange between Toulmin diagrams and the standard treatment.

6. Clearly the use of a markup language and the presentation here are 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: http://araucaria.computing.dundee.ac.uk.

7. See http://www.calicojack.co.uk/

8. Witness Testimony is not presented as a class of prima facie reasons in Pollock's account. Here it is presented as if it were for simplicity and clarity (for Pollock, the prima facie reason, *If a witness says P then one may infer P* is nothing special). A more detailed analysis is offered in [4].

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