Enthymeme Construction in Dialogues using Shared Knowledge

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Abstract. Enthymemes, arguments with incomplete structure, are a ubiquitous feature of human communication and argumentation. This paper proposes a way of representing enthymemes and arguments within the ASPIC+ framework, and how enthymemes are constructed based on estimates of shared knowledge. It then proposes a framework in which agents are capable of constructing a model of other agent's knowledge.

Keywords. Enthymeme, Shared Knowledge, Dialogue, Argumentation

1. Introduction

Computational models of arguments [6,9] characterise non-monotonic reasoning through the use of principles familiar in human reasoning and debate, and thus have the potential to underpin and integrate human and computational reasoning and dialogue [11]. In order to realise this potential, a formal treatment of human modes of argumentation is required; in particular a formalisation of enthymemes: arguments with some missing logical structure and/or internal components [16].

This paper develops a formal, general account of enthymeme representation and construction. Such an account is needed to enable computational agents to interact with humans and process their arguments, as well as enabling computational agents to communicate with a level of economy that mirrors humans' utilisation of arguments.

Although enthymemes have long been studied informally (e.g. [17,8,12,13]), with the notion being first introduced by Aristotle (see Rhetoric, I, 2, 1355a, and [16]), there has been very little work on formal aspects of enthymemes. A notable exception is [2] which proposes a framework for construction and reconstruction of enthymemes. There are however a number of issues that are not addressed in [2]. Firstly, the logic for argument construction in [2] is deductive, and so does not accommodate features of other logical formalisms for argumentation, such as defeasible inference rules, negation as failure, etc. Secondly, arguments and enthymemes are not defined so as to include an explicit representation of the argument's proof structure, which may be relevant in the process of enthymeme construction and reconstruction, especially in dialogues. Furthermore, although in [2] agents make use of the knowledge that they share with other agents to remove elements from their arguments, the approach they use to calculate shared knowledge is left unspecified.

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In this paper we propose a model for constructing enthymemes. Section 2 proposes a unified model for arguments and enthymemes based on ASPIC+ [9,10] as well as a procedure for constructing enthymemes from arguments based on what agents consider as shared knowledge. Our choice of ASPIC+ is motivated by the fact that the framework allows for a broad range of instantiations and provides an explicit representation of arguments' proof structure, thus addressing the first limitation of [2]'s framework. Section 3 then proposes a mechanism whereby agents can construct and maintain a model of another agent's knowledge, enabling them to use this method in order to determine the knowledge that is shared between themselves for the purpose of enthymeme construction. The mechanism exploits the idea of agent communities as a way of distinguishing agents and classifying them based on their knowledge. Finally, Section 4 concludes with a discussion of related and future work.

2. Arguments and Enthymemes

We formalise arguments and enthymemes in ASPIC+ because ASPIC+ provides a structural account of argumentation while being general enough to accommodate a broad range of instantiations (including deductive argumentation [1], ABA [3], and argument schemes [19]). Furthermore, ASPIC+ identifies conditions under which [4]'s rationality postulates are satisfied. However, we motivate and introduce an alternative structural representation of arguments to that defined by ASPIC+, which is necessary for defining enthymemes, while ensuring that it is still fully compatible with the remaining aspects of the ASPIC+ framework.

In ASPIC+, arguments are defined based on an *argumentation theory* $\langle \mathcal{AS}, \mathcal{K} \rangle$. $\mathcal{AS}$ is an *argumentation system* consisting of a logical language $\mathcal{L}$, strict ($\mathcal{R}^s$) and defeasible ($\mathcal{R}^d$) inference rules where the latter are assigned names (wff in $\mathcal{L}$) by a naming function n, and a contrary function $^-$ which generalises the notion of negation. $\mathcal{K}$ is a *knowledge-base* consisting of axiom ($\mathcal{K}^n$) and ordinary ($\mathcal{K}^p$) premises from which arguments may be built together with the inference rules. Arguments are trees with nodes representing formulae from $\mathcal{L}$, and edges from a node ψ to its children $\phi_1, \ldots, \phi_n$ implicitly representing an inference rule with conclusion ψ and antecedents $\phi_1, \ldots, \phi_n$.

The absence of an explicit representation of inference rules means that if a sub-argument needed to prove a rule's antecedent, or indeed the conclusion of a rule is removed when constructing an enthymeme A' from an argument A, the receiver of A' would not be able to access the inference rule in A. We therefore modify the structure of ASPIC+ arguments so as to render explicit the representation of inference rules as well as premises and (intermediate and final) conclusions.

Example 1 Figure 1(a) shows an ASPIC+ argument with explicit representation of inference rules. If several components of the argument are removed, e.g. an instance of premise p, every instance of r, s and n, and inference rules $v, u, m \to w$ and $p \Rightarrow t$, the resulting structure will be a set of sub-trees. This is shown in Figure 1(b).

Upon receiving the structure depicted in Figure 1(b) – essentially an unordered set of trees – the receiving agent cannot determine the relative location of the trees within the original argument. To overcome this problem, the trees are reconnected to each other based on their ancestor-descendant relationship in the original argument. In Example 1, the sub-trees shown in Figure 1(b) are reconnected in Figure 1(c).

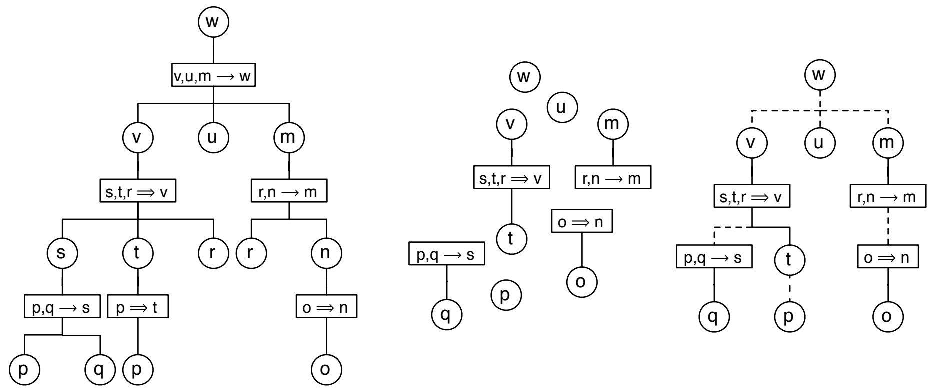

Figure 1. An argument with its rules explicitly represented (a), some of its components removed (b), and an enthymeme constructed from it (c) in which solid/dotted lines represent legitimate/illegitimate edges.

Definition 1 An *Argument-Tree*, based on a knowledge-base $\mathcal{K}$ and an argumentation system $\mathcal{AS} = \langle \mathcal{L}, \mathcal{R}, -, n \rangle$, is a tree, in which a node is either:

- a formula from $\mathcal{L}$, called an *f-node* or
- a rule from $\mathcal{R}$, called an *r-node*.

An edge from A to its child B is said to be *legitimate* (otherwise *illegitimate*) iff:

- A is the formula ϕ and B is a rule with conclusion ϕ, or
- A is a rule with ϕ in its antecedent and B is the formula ϕ.

In both cases B is said to *correspond* to ϕ in A. For any formula ϕ in a parent node, there is only one child node that corresponds to it.

For any argument-tree A, $nodes(A)$ and $edges(A)$ respectively return A's nodes and edges, while $legit(A)/illegit(A)$ returns A's legitimate/illegitimate edges.

Definition 2 Let A be an argument-tree. Then A is an *argument* iff:

- $edges(A) = legit(A)$,
- for every ϕ in the antecedent of any rule r in A, r has a child corresponding to it,
- any f-node which is not in $\mathcal{K}$ has a child.

Otherwise A is an *enthymeme*.

Example 2 Figures 1(a) and 1(c) respectively depict an argument and an enthymeme.

The above definitions capture the notions of an argument and an enthymeme, both being based on the auxiliary notion of an argument-tree. The definition of arguments corresponds to that of ASPIC+, with the only difference being the explicit representation of inference rules. Hence, every element of the ASPIC+ argumentation machinery (e.g. attacks, defeats, preferences) can be applied to this structure.

There are different motivations for removing elements from an argument in order to construct enthymemes for submission in dialogues. One such motivation is to avoid sending that which is known to the receivers of an argument, with the obvious benefit of increasing the economy of communication. This requires an agent i to have a model of what it believes another agent j knows when it intends to send an enthymeme to j. This

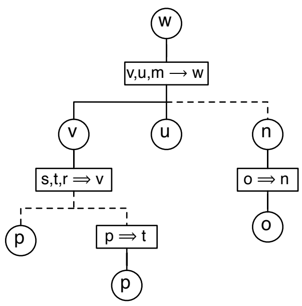

Figure 2. Enthymeme Instance corresponding to example 3

is formalised by agent i assigning for every agent j, a value to every α it knows[2] using a function γ_{ij}.

This number represents the degree to which i believes j knows α. Different methods can be developed to specify how γ might be specified. In the next section we propose one such method that makes use of the dialogical history of agents (in a manner different to that addressed in [7,14])

We now describe a simple method for constructing enthymemes from arguments. After an agent i constructs an argument to be sent to a receiver, it examines every constituent element (node) of the argument, and removes those for which $\gamma_{ij} \geq \tau$, j being the receiver of the enthymeme, and $0 \leq \tau \leq 1$ being a threshold.[3] Every remaining node is then reconnected to its closest ancestor in the remaining set of nodes, thus introducing illegitimate edges. In what follows, an edge is represented by the pair of nodes it joins and $path_t(n_1, n_2)$ returns true if there is a path from n_1 to n_2 in the tree t, and false otherwise.

Definition 3 Let A be an argument constructed by i, for sending to j, and $0 \leq \tau \leq 1$ a threshold. Then the Enthymeme Instance $EI(A, i, j, \tau)$ is an enthymeme B such that:

- $n \in nodes(B)$ iff $n \in nodes(A), \gamma_{ij}(n) < \tau$
- $(n_1, n_2) \in edges(B)$ iff $n_1 \in nodes(B), n_2 \in nodes(B), path_A(n_1, n_2)$ is true and $\neg \exists n_3 \in nodes(B)$ such that $path_A(n_1, n_3) \wedge path_A(n_3, n_2)$ is true.

Example 3 Consider the argument depicted in Figure 1(a), with the following list of elements and their γ_{ij} values. Assuming $\tau = 0.7$, the enthymeme instance constructed from this argument will yield the enthymeme depicted in Figure 2.

Node n:	p	q	s	t	r	v	u	o	n	m	w
$\gamma_{ij}(n) =$	0.15	0.2	0.8	0.9	0.8	0.4	0	0.2	0.3	1	0.2
Node n:	$p, q \Rightarrow s$	$p \Rightarrow t$	$s, t, r \Rightarrow v$	$o \Rightarrow n$	$r, n \rightarrow m$	$v, u, m \Rightarrow w$					
$\gamma_{ij}(n) =$	0.7	0.6	0.1	0	1	0.5					

[2] An agent i knowing α means that either α is a formula in i's knowledge-base $\mathcal{K}_i$, a rule in $\mathcal{R}_i$, or it is the conclusion (a wff of $\mathcal{L}_i$) of *any*, and not just the justified, argument that i can construct from its theory.

[3] Clearly, the lower the value of τ, the greater the level of economy in communication, along with a higher probability of misjudgements by agent i in assuming that some α is known by j.

3. Modelling the Knowledge of Others

We now propose a method whereby agents can create and maintain a model of other agents' knowledge (i.e. a method for specifying the function γ). To preserve generality, we focus on the method's underlying principles, but also offer an instantiation for each different concept as an example of how they may be designed.

In our framework, we are concerned with an agent i who aims to determine the content of another agent j's knowledge-base (a wff from $\mathcal{L}$), argumentation system (a rule in $\mathcal{R}$), and the conclusion (a wff of $\mathcal{L}$) of *any* (and not just the justified) argument that j can construct from its theory; we use α to refer to any of the above. We assume that agents harness their experience of participating in dialogues, in order to estimate other agents' knowledge of some α, using two functions.

The first function $\omega_{ij} : \{\mathcal{L} \cup \mathcal{R}\} \mapsto [0,1]$ assigns a value between 0 and 1 to every α, representing the degree to which agent i believes agent j knows α based on dialogical interactions in which i is directly or indirectly informed of j's knowledge of α. The value of the function is 0 for all agents j when i has no evidence about j knowing α and 1 when i is *directly* informed that j knows α. The latter case may arise when j commits to α in a dialogue in which agent i is also participating.[4] However, any other method by which i is informed that j knows α is also valid, such as when an agent k informs i that j knows α. The values between 0 to 1 then account for a factor or a combination of factors that influence this *indirect* means of i acquiring beliefs about j's knowledge. An example of such a factor is trust [15], in which case, the less i trusts k, the lower the value of $\omega_{ij}(\alpha)$. Since each interaction in a dialogue affects how agents perceive other agent's knowledge, the value of ω_{ij} is recalculated by i every time agent j makes a move in the dialogue.

Often, the reason for removing information from an argument when constructing an enthymeme, is not because of any direct or indirect dialogue-based evidence about the receiver knowing that information. Rather, one assumes that the receiver knows something because it is known by most agents similar to the receiver. In fact, this is the idea behind scripts or common knowledge which has long been an issue in AI [16]. With ω_{ij}, an agent i determines the knowledge of other agents j based on dialogical interactions. Now this knowledge should be propagated to all other agents k for whom $\omega_{ik} = 0$, in accordance with how similar agents k are to agents j. We turn to this issue by introducing a second function.

The function $\sigma_{ik} : \{\mathcal{L} \cup \mathcal{R}\} \mapsto [0,1]$ represents agent i's estimate of another agent k knowing α based on the similarity of agent k and agents j for whom $\omega_{ij}(\alpha) > 0$. For all agents k, the value of $\sigma_{ik}(\alpha)$ is initially 0, but as $\omega_{ij}(\alpha)$ is updated for some j, so is $\sigma_{ik}(\alpha)$. In other words, each time in a dialogue, i updates $\omega_{ij}(\alpha)$ for an agent j it also updates $\sigma_{ik}(\alpha)$ for all agents k ($k \neq i, j$) based on the similarity of k to j. This estimated value then gets more accurate over time, as the number of dialogues that i has with different agents increase. This property represents an intuitive yet important social phenomenon: the more one engages with a society through dialogues, the more accurate one's perception is regarding the relative knowledge of its members.

Here, we introduce two factors that influence the amount by which agent i increases $\sigma_{ik}(\alpha)$'s value:

[4] In such circumstances not only $\omega_{ij}(\alpha) = 1$, but also $\omega_{ik}(\alpha) = 1$ for every other agent k in the dialogue.

- The overall number of agents who know α
- The similarity of those who know α with agent k

Example 4 Suppose in an early morning email dialogue with a university colleague, he informs you that the research assessment exercise figures have been released. On arriving at the university, your PhD student tells you the same news. You then run into your colleague from the same department who also tells you the same thing and that he heard it from his friend in the Physics department of another university. Subsequent to these interactions, you assume when having lunch with your research group, there is a high probability that all those present are already aware of this news.

The first factor that influences an agent i's estimate of the likelihood of another agent knowing α, is the overall number of agents that i knows are aware of α. In other words, the higher the number of agents j with $\omega_{ij}(\alpha) > 0$, the higher the probability that another agent k also knows α. Referring to the above example, upon seeing only one individual committing to a piece of knowledge, one does not necessarily assume that it is known by a large number of people; it could well be a specialised piece of knowledge known by a very few, that individual being one of them. But as one realises that the number of people who know about something increases, the probability that one assigns to a new person knowing it increases too. For this, we define (AG represents the set of all agents):

$$n_i = \left(\frac{\left|\{x \mid x \in AG, \omega_{ij}(\alpha) > 0\}\right|}{\left|\{x \mid x \in AG\}\right|} \right)^p \tag{1}$$

n is defined as the ratio of the agents who know α over all agents. This ratio on its own suggests a linear growth. However, it may be argued that the growth is exponential: the more agents commit to α, the more i should increase its estimate of others knowing α. Thus, the power p is introduced in order to enable parameterising the growth rate.

The other factor that influences i's estimate of k knowing α is the similarity of k to those who know α. In Example 4, since all those who committed to knowing the news are in a *community of researchers*, then the estimate for others in the same community knowing the news is more than those who are not.

A community of agents is simply a set of agents who all have a certain property. Since this paper focuses on the knowledge and reasoning capabilities of agents, as modelled in ASPIC+, we are concerned with defining communities with reference to the type/content of their members' knowledge-base/argumentation-system. One might, for example, define a community based on whether they share a specific set of premises and/or inference rules. We believe this to be compatible with the characterisation of communities with reference to other attributes of their constituent agents, such as organisational roles and responsibilities [5], since the fact that a set of agents share an organisational role or responsibility implies that they share knowledge. Note of course that communities may intersect: an agent may belong to more than one community based on what it knows.

Using this notion of communities we can define the similarity factor as follows: for any two agents, the more communities in common they belong to, the more similar they are assumed to be in terms of their knowledge. Any agent i can then determine its degree of similarity to any other agent j, denoted s_{ij}, using the Equation 2 below (here $c(ag)$ returns the set of communities that agent ag is a member of):

$$s_{ij} = \frac{|c(i) \cap c(j)|}{|c(j)|} \quad (2)$$

Note that s is not symmetric: $s_{ij} \neq s_{ji}$. For example, if i is in all communities that j belongs to and more, then $s_{ij} = 1$ but $s_{ji} < 1$.

With the above two factors specified, we can now define how σ is updated. Each time the value of ω_{ij} is updated for an agent j, the value of σ_{ik} is updated for all agents $k \neq i, j$ using the following equation (here, σ'_{ik} represents the updated value of σ_{ik}).

$$\sigma_{ik}(\alpha)' = \min((n_i \times s_{kj} + \sigma_{ik}(\alpha)), 1) \quad (3)$$

The above equation can be interpreted as follows: as i realises more agents know α (i.e. n_i increases), the probability i assigns to an agent k knowing α increases too. s_{kj} then adjusts the effect of increase based on how similar agent k is to agent j who just committed to α: the less similar k is to j, the less the amount of increase for agent k.

The two functions ω and σ can now be combined to define the function γ, a numerical estimate representing the degree to which an agent believes another agent knows some α (as described in the previous section). There are different ways to define γ, such as taking the maximum/minimum of ω and σ in order to respectively adopt a credulous/sceptical approach, as well as having the option of introducing a coefficient for ω, in order to express a higher value for dialogical evidence over community-based estimates. Nevertheless, for obvious reasons, γ must satisfy monotonicity with respect to ω and σ: as the values of ω and/or σ increase, the value of γ must not decrease.

In this section we have proposed an approach whereby agents can determine the knowledge shared between themselves, something that was left unspecified in the framework of Black and Hunter [2]. The method is designed based on dialogical interactions, and intuitive principles such as the effect of the overall number of agents who know some α, on one's estimate about another agent knowing α, and the similarity of those who know α, with the agent whose knowledge is being estimated. Note, we do not claim that our approach accounts for every aspect of agents' cognitive and social complexities, but we do believe it represents an intuitive and useful starting point for modelling the acquisition of shared knowledge.

4. Conclusions

Enthymemes are a ubiquitous feature of everyday reasoning and debate. This paper has proposed a coherent and integrated model for arguments and enthymemes based on ASPIC+, and formalised how enthymemes can be constructed from arguments using shared knowledge. We also presented an approach that agents can use to construct a model of another agent's knowledge, making use of the notion of communities of agents. As discussed in Section 1, the aforementioned contributions address issues not addressed in [2], the only other logic-based formal account of enthymemes that we are aware of.

Currently more sophisticated methods for determining shared knowledge, enthymeme construction and community definition are being investigated as a precursor to formalising techniques for how receivers reconstruct arguments from enthymemes they receive in dialogues.

Although, so far the focus in studies of enthymemes (e.g. [17,12,18]) has been on reconstruction, we consider this task to be related to how enthymemes are constructed, since clearly, if the mechanisms used in enthymeme construction are shared amongst agents, then this will influence how the original arguments are reconstructed from the enthymemes received. We also intend to investigate other techniques used in enthymeme construction/reconstruction, including the use of argument schemes and critical questions [19,18], and dialogue-specific information such as commitment stores [20].

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