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Dialogue Frames in Agent Communication

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Abstract

Sophisticated models of inter-agent communication are making increasing use of intuitive notions of persuasion and negotiation. In this paper, a formal characterisation is provided which not only clearly distinguishes persuasion from negotiation, but also introduces three other dialogue types, and sets all five in a coherent framework. The notion of a dialogue frame is introduced, and is used to explore the dialogue typology and one of its important features, the concept of functional embedding. The approach offers a number of substantial benefits, including (i) the provision of definitions for classes of communicative encounters, (ii) improvements in expressive capability, (iii) facilitating comparison between diverse multi-agent research, and in some cases, (iv) reducing computational cost.

1. Introduction

There is an increasing use in agent communication research of terms such as 'negotiation', 'argument' and 'persuasion' (e.g. (Parsons and Jennings, 1996), (Reed *et al.*, 1997), (Sierra *et al.*, 1997a), (Sycara, 1990), etc.). Furthermore, rich multi-agent communication protocols are also employing what have classically been termed as 'fallacies' (Woods and Walton, 1989) – both Sycara, (1989) and Sierra *et al.* (1997b), for example, model *appeal to authority*, and *threats* (known traditionally as the *argumentum ad baculum*) inter alia. In building systems which make use of such techniques, there is usually a preliminary, implicit appeal to intuitions as to what these terms mean, and what effects they have on the dialogue process and the states of the interlocutors. There is, however, a long tradition in argumentation theory and informal logic of precisely characterising these notions and detailing how they should be integrated into a model of argumentative dialogue. There exist formal and semi-formal models of the dynamics of persuasion and negotiation (and of other types of argumentation not currently addressed explicitly in the DAI research community), and the aim of this paper is to examine some of these contributions and recast them formally in an abstract model of inter-agent communication.

The basis of this work is the account of argument structuring offered in (Walton and Krabbe, 1995) which provides a number of important contributions. In the first place, they describe a first cut at a broad typology of (argument) dialogue types. It is interesting to note that this typology includes not only persuasion and negotiation (as quite separate techniques), but also information-seeking (with clear parallels to existing MAS work) and inquiry and deliberation (not currently recognised explicitly in the MAS literature). Although the typology is based exclusively on dialogue encounters between human interlocutors, and although it is not exhaustive, it is both formal and robust enough to withstand application to a MAS domain. Section 2 provides an overview of the typology and its rationale. The second contribution of Walton and Krabbe developed here is in the provision of a limited 'informal-logic' account of the structure of persuasive dialogue, detailing the restrictions on participants' turns and thus on the way in which an argument can unfold. It is this work which motivates the formal model presented in section 3, and developed through sections 4 and 5, and which opens up a number of promising avenues for future work discussed in section 6.

2. Dialogue Typology

The typology in (Walton and Krabbe, 1995), p66 distinguishes six classes of dialogue, of which five will be examined here - the sixth, 'Eristic', is unlikely to play a significant role in current MAS research, since its aim is to "serve primarily as a substitute for [physical] fighting". The remaining five – persuasion, negotiation, inquiry, deliberation, and information seeking are characterised on the basis of three factors: (i) the initial situation (and, chiefly, the presence or absence of conflict, a notion elaborated upon below), (ii) the private aims of the participating agents, and (iii) the joint aims to which all participating agents implicitly subscribe – i.e. the overarching motivation for the dialogue taking place.

A persuasion dialogue is initiated from a position of recognised conflict. Typically, this conflict will be epistemic: one agent may believe p, the other ~p (and both agents are mutually aware of this situation)[1]. The private aim of each agent is then simply to offer arguments in support of their own thesis. Importantly, however, if two agents agree to enter into a persuasion dialogue, they implicitly agree to the joint aim of resolving the conflict. As a direct result, each agent must be prepared to alter their beliefs with respect to the thesis – otherwise, any persuasion dialogue would be futile. An agent entering into a persuasion dialogue can therefore assume that the other agent is at least prepared to alter their beliefs.

A negotiation dialogue arises from a situation of "conflict of interests": the canonical example (both in informal logic and MAS) is conflict over scarce resources – and optimising a number of issues such as price, quality and timeliness can clearly fall into this category (e.g. (Sierra *et al.*, 1997a)). Selfish agents adopt goals of maximising their own share of any resource, but again, there is the overarching aim of reaching a deal. In many multi-agent scenarios, of course, this aim is not of key importance as any single agent may be able to negotiate a better deal with a third party (a buyer may find a cheaper seller, etc.). However, there are a number of projects (such as the ADEPT work, (Jennings *et al.*, 1996)) where the options are extremely limited – there may only be a single seller, or a very small set of trusted buyers, etc. In such scenarios, the fact that both agents want and need to make a deal becomes an important factor in the negotiation process (especially when taken in conjunction with, for example, temporal information – a buyer may become more 'anxious' as time runs out, (Chavez *et al.*, 1997)). This point is re-examined in more detail below. Apart from the contextual differences, negotiation differs procedurally from persuasion in an important respect, in that coherence between beliefs is not demanded, and the relevant beliefs of the participants may very well remain at odds after negotiation. For example, if *a* believes there are 10 resource units available, and negotiates with *b* who believes there are 14, *b* may agree to offer *a* 6 units - both parties thinking they are getting the better deal, with no need for consensus on the issue of available resource units.

The inquiry dialogue differs from the previous two in that it starts not from conflict, but from a perceived lack of knowledge – participants are trying to establish truth or falsity rather than challenge any extant knowledge. The overall aim of an inquiry is to establish a 'proof' (and Walton and Krabbe offer as an example the Warren Commission Report); the individual aims of the participants accord very closely with this joint aim – both aim to contribute to the proof building process. It has been suggested that this accord between private and joint aims in dialogue could form part of a definition of agent 'collaboration' – as distinct from Cupertino (Reed and Long, 1997).

Deliberation represents the process of forming a plan of action. As the joint aim is to reach an agreement, and the individual aims of the participants are to influence the agreement to their benefit, it bears some similarities to negotiation (and certainly to the conventional MAS use of the term). However, it is important to make a clear distinction: deliberation starts not from a point of conflict but simply from a need for action, and as a result, it is usually oriented around means-ends discussion rather than displaying the proposal-counterproposal bidding characteristic of negotiation.

Information-seeking dialogues are initiated when there is a recognised asymmetry between one agent with more information than another in regard to some particular data. As with inquiry, there is a close accord between the joint aim (to transfer information from one agent to the other), and the individual aims of the agents (either to give or receive that information). Information-seeking dialogues differ from the others in that they are the only class which is always asymmetric.

3. Modelling dialogue types

Clearly the various types of dialogue are not concerned with identical substrate: persuasion, inquiry and information-seeking are epistemic, negotiation is concerned with what might generically be called 'contracts', and deliberation with 'plans'. The model presented below does not aim to restrict either the agent architecture or the underlying communication protocol to any one particular formalism. Thus when mentioning epistemic issues, the referent could equally well be modelled by a BDI architecture (Rao and Georgeff, 1992) or a propositional logic, thus encompassing not only factual beliefs, but values (such as those employed to evaluate issues during negotiation), rules, intentions, etc. (this list is explored in detail in (Reed *et al.*, 1997). Similarly, the notion of 'contract' is intended to abstract from the precise structure used to arrive at a deal – most deals take place across a range of issues ascribed particular values. Finally, 'plan' refers neither to the limited construct in a BDI architecture nor to the rich output of a modern planner such as UCPOP (Penberthy and Weld, 1992) – though it is compatible with both – rather, it refers to the abstract notion of a set of partially ordered, partially specified contracts (thus assuming some sort of '?' operator suggested in (Sierra *et al.*, 1997b)).

Thus the foundation of the model is a set of agents, *A*, each of whom have a set of beliefs, *B*, contracts, *C*, and

[1] In common with much research on communication protocols, it is assumed for the sake of clarity that communication is occurring between exactly two agents: extending to multilateral argumentation presents no fundamental problems for the approach.

plans, P. Following (Sierra *et al.*, 1997a) – both because the approach is particularly clear, and because it is generic and can be interpreted as an abstract negotiation structure – contracts are composed of (possibly underspecified) $\langle issue, value \rangle$ pairs. In addition, it is also necessary to make explicit the assumption that there is some basic result of a fulfilled contract. This result can be expressed as a conjunction of beliefs (e.g. a contract might specify that for a to receive information from b, the issue-value pairs are $(Price = £10) \wedge (Quality = High) \wedge (Penalty = ?)$: the result of the contract might be represented as $has(a, information) \wedge has(a, £10\text{-}less) \wedge has(b, £10\text{-}more)$). This information can be adjoined to the basic contract structure, resulting in a contract specified by $\langle r, \{v_0, \ldots v_n\}\rangle$, where r is a conjunction of beliefs specifying the resultant situation of the agreed contract, and $\{v_0, \ldots v_n\}$ are issue-value pairs.

Plans can then be constructed from contracts: a complete plan is a fully ordered set of contracts each of which is fully specified with respect to its result, r, its list of issue-value pairs, v_n, and the settings of both issue and value in each v_i. During the course of deliberation – i.e. determining a plan – a plan will clearly be heavily underspecified in each of the three respects: the component contracts may not have clearly defined (or agreed upon) results, they may not have a full complement of issue-value pairs, and the settings may not be fixed. In addition, the plan may also not include all necessary contracts (it is clear from this brief summary that such a definition easily admits classical planning techniques to the deliberation process).

On the basis of the sets defined above, it is possible to define the set of dialogue types, where each type is a name-substrate pair,

$$D = \{ \langle persuade, B\rangle, \langle negotiate, C\rangle, \langle inquire, B\rangle, \langle deliberate, P\rangle, \langle infoseek, B\rangle \}$$

From this matrix, a **dialogue frame** is defined as a tuple with four elements:

$$F = \langle \langle t, \Delta\rangle \in D, \tau \in \Delta, \{u^0_{x_0 \to y_0}, \ldots u^n_{x_n \to y_n}\} \rangle$$

where t is the type of this dialogue frame, τ is the **topic** of the dialogue frame, x_0, $y_0 \in A$ are the interlocutors ($x_0 \neq y_0$), and $u^i_{x_i \to y_i}$ refers to the ith utterance occurring in a dialogue between agents x_i and y_i, in which x_i is the originator of the utterance. Through the series, $u^0_{x_0 \to y_0}, \ldots u^n_{x_n \to y_n}$, turns alternate between exactly two participants, following (Sierra *et al.*, 1997b):

$$x_i = y_{i+1} \quad \text{and} \quad y_i = x_{i+1}$$

An utterance $u^i_{x_i \to y_i}$ is a pair $\langle s, \{\sigma_0, \ldots, \sigma_n\}\rangle$, in which s is a statement (i.e. a wff in the communication language), and the $\sigma_i \in B$ represent the supports for that statement, if any (following, for example, the LDS (Gabbay, 1992) approach of (Parsons and Jennings, 1996) discussed below).

A dialogue frame is thus of a particular type, t, and focused on a particular topic, τ, – a persuasion dialogue will be focused on a particular belief, a negotiation on a contract, a deliberation on a plan, and so on. A dialogical frame is initiated by a *propose-accept* sequence, and terminates with a characteristic utterance indicating acceptance or concession to the topic on the part of one of the agents. Such utterances have no supports (i.e. the set of $\sigma_i = \emptyset$).

Negotiation traditionally forms the most common type of non-trivial inter-agent communication; the following examples show how the proposed framework captures and extends the traditional notion of negotiation, and distinguishes between persuasion and deliberation, which have not previously been recognised as distinct forms of agent dialogue. In all the examples which follow, no assumptions have been made about the formal definitions of the underlying communication language: the locution acts *propose*, *accept*, etc. are abstractions of the types of locutions available in common protocols such as KQML, etc. The framework does not depend upon the exact nature of the protocol, as it captures structure and relationships holding at a higher level of abstraction.

$u^0_{a \to b}$: $\langle \langle propose\ (negotiate, \langle has(a, information), \{\langle Price, £10\rangle, \langle Quality, High\rangle\} \rangle)\rangle, \{\emptyset\}\rangle$

$u^1_{b \to a}$: $\langle \langle accept\ (negotiate, \langle has(a, information), \{\langle Price, £10\rangle, \langle Quality, High\rangle\} \rangle)\rangle, \{\emptyset\}\rangle$

$u^2_{a \to b}$: $\langle \langle propose\ (\langle has(a, information) \wedge has(a, £10\text{-}less) \wedge has(b, £10\text{-}more),$
$\{\langle Price, £10\rangle, \langle Quality, High\rangle\} \rangle)\rangle, \{\emptyset\} \rangle$

$u^3_{b \to a}$: $\langle \langle propose\ (\langle has(a, information) \wedge has(a, £20\text{-}less) \wedge has(b, £20\text{-}more),$
$\{\langle Price, £20\rangle, \langle Quality, High\rangle\} \rangle)\rangle, \{\emptyset\} \rangle$

$u^4_{a \to b}$: $\langle \langle propose\ (\langle has(a, information) \wedge has(a, £15\text{-}less) \wedge has(b, £15\text{-}more),$
$\{\langle Price, £15\rangle, \langle Quality, High\rangle\} \rangle)\rangle, \{\emptyset\} \rangle$

$u^5_{b \to a}$: $\langle \langle accept\ (\langle has(a, information) \wedge has(a, £15\text{-}less) \wedge has(b, £15\text{-}more),$
$\{\langle Price, £15\rangle, \langle Quality, High\rangle\} \rangle)\rangle, \{\emptyset\} \rangle$

Example 1

$u^0_{b\rightarrow a}$: ⟨ ⟨ *propose* (*persuade*, *has*(*c*, *information*)) ⟩,{∅}⟩
$u^1_{a\rightarrow b}$: ⟨ ⟨ *accept* (*persuade*, *has*(*c*, *information*)) ⟩,{∅}⟩
$u^2_{b\rightarrow a}$: ⟨ ⟨ *tell* (*has*(*c*, *information*))⟩, {*told_by*(*has*(*c*, *information*), *d*)} ⟩
$u^3_{a\rightarrow b}$: ⟨ ⟨ *tell* (*unreliable*(*d*)) ⟩,{∅}⟩
$u^4_{b\rightarrow a}$: ⟨ ⟨ *concede* (*unknown*(*has*(*c*, *information*))) ⟩, {∅} ⟩

Example 2

In the first example, agent *a* requests a negotiation dialogue in $u^0_{a\rightarrow b}$, which *b* then accepts in $u^1_{b\rightarrow a}$. The dialogue frame is thus initiated, and in its first utterance, $u^2_{a\rightarrow b}$, *a* proposes a contract in which he pays *b* £10 for high quality information. At $u^3_{b\rightarrow a}$, *b* offers a counterproposal, in which *a* pays £20, at $u^4_{a\rightarrow b}$, *a* retorts with an offer of £15, which *b* accepts at $u^5_{b\rightarrow a}$. The *accept*(*contract*) utterance is the characteristic closing of a negotiation dialogue frame, so the dialogue terminates.

In the simple persuasion dialogue of example two, *b* initiates a dialogue to persuade *a* that some third party, *c*, has information (*b* is thus acting as a 'broker', (Decker, 1997)). *b* supports his claim by citing *d* as his source. *a* undercuts the argument by pointing out the unreliability of *d*, and with no further supports available, *b* retracts his assertion with a *concede* which terminates the dialogue frame.

Before examining the more complex dialogue type of deliberation, it is necessary to introduce the notion of 'support'. All but the most trivial plans employ such support, because the concept of support corresponds closely to the classical planning notion of precondition.

4. Argument supports

Parsons and Jennings (1996) propose a model of inter-agent communication by which agents reach agreement through communicating sets of supports for their beliefs. Thus, in his example, on the basis of (1) having an intention to hang a picture, (2) having the picture, (3) having a hammer, (4) knowing Agent 2 has a nail, and (5) knowing that having hammer, picture and nail enables picture hanging, Agent 1 might propose hanging the picture using Agent 2's nail (Parsons' example then continues further, but the remainder is omitted for clarity). Although Parsons classes the work as negotiation, in the framework proposed above, it might better be termed deliberation – a means-ends analysis of, in the example, how to successfully hang a picture. Although his examples are entirely propositional, the framework put forward in the previous section shows how it might be possible to price the 'selling' of Agent 2's nail to Agent 1, and to include temporal information such as Agent 1 needing the nail tonight. This would be achieved by extending the 'contracts' which Parsons' agents are proposing from their current form ⟨*r*, {∅}⟩ to ⟨*r*, {v_0, … v_n}⟩, where the {v_0, … v_n} are the temporal or pricing issue-value pairs (an example of this extension is given below).

As shown in example three, Parsons' example can easily be translated into the current formalism to provide an example of deliberation. For the sake of clarity, the premises in the above paraphrase are referred to by the labels *f1*, *f2*, *f3*, *f4* and *r5*, respectively.

After initiating the deliberation on how to produce the effect *can*(*a*, *hang_picture*), *a* proposes a single contract solution which has as its result, *r*, a conjunction of two components: the desired *can*(*a*, *hang_picture*), and the crucial *have*(*a, nail*). The contract is justified by the set of supports { *f1*, *f2*, *f3*, *f4*, *r5*}. In the final step, *b* accepts the contract, terminating the dialogue frame. In Parsons' original example, *b* does not immediately accept and *a* is forced to generate an alternative contract which is agreed: the example above could be straightforwardly continued in this vein – and, as mentioned, could also be extended for *b* to suggest a price for the nail (a continuation not possible in Parsons' original formalism).

The approach proposed in (Parsons and Jennings, 1996), whereby simplified contracts (simplified in the sense that the set of v_i is ∅) are supported by beliefs (in the general sense introduced above, which admits propositions, rules, etc.) can be generalised, so that any utterance can be supported by beliefs. This holds not only for plan determination in deliberation and belief establishment in persuasion, but also for the other

$u^0_{a\rightarrow b}$: ⟨ ⟨ *propose* (*deliberate*, {⟨*can*(*a*, *hang_picture*), {∅}⟩} ⟩,{∅}⟩
$u^1_{b\rightarrow a}$: ⟨ ⟨ *accept* (*deliberate*, {⟨*can*(*a*, *hang_picture*), {∅}⟩} ⟩,{∅}⟩
$u^2_{a\rightarrow b}$: ⟨ ⟨ *propose* (⟨*have*(*a*, *nail*) ∧ *can*(*a*, *hang_picture*), {∅}⟩ ⟩,{ *f1*, *f2*, *f3*, *f4*, *r5*}⟩
$u^3_{b\rightarrow a}$: ⟨ ⟨ *accept* (⟨*have*(*a*, *nail*) ∧ *can*(*a*, *hang_picture*), {∅}⟩ ⟩,{ *f1*, *f2*, *f3*, *f4*, *r5*}⟩

Example 3

$u^0_{a\rightarrow b}$: $\langle\langle$ $has(a, information) \wedge has(a, £10\text{-}less) \wedge has(b, £10\text{-}more)$,
$\{\langle Price, £10\rangle, \langle Quality, High\rangle, \langle Delivery, Tomorrow\rangle\}\ \rangle$
$\{\emptyset\}\ \rangle$

$u^1_{b\rightarrow a}$: $\langle\langle$ $has(a, information) \wedge has(a, £10\text{-}less) \wedge has(b, £10\text{-}more)$,
$\{\langle Price, £10\rangle, \langle Quality, High\rangle, \langle Delivery, Friday\rangle\}\ \rangle$
$\{\emptyset\}\ \rangle$

$u^2_{a\rightarrow b}$: $\langle\langle$ $has(a, information) \wedge has(a, £15\text{-}less) \wedge has(b, £15\text{-}more)$,
$\{\langle Price, £15\rangle, \langle Quality, High\rangle, \langle Delivery, Tomorrow\rangle\}\ \rangle$
$\{deadline\_for\_information(Tomorrow)\}\ \rangle$

Example 4

dialogue types, of which the most interesting example is contract negotiation (inquiry and information-seeking follow the persuasion model, since for all three $\tau \in B$). Using argument supports in negotiation enriches the standard model, since it follows from the definitions in the previous section that an utterance of the form $\langle\langle r, \{v_0, \dots v_n\}\rangle, \{\sigma_0,\dots, \sigma_m\}\rangle$ is valid, i.e. supports can be given for a particular contract proposal. Example four illustrates the point, detailing an exchange between agents *a* and *b*, where *a* is trying to negotiate terms for the purchase of information.

At $u^0_{a\rightarrow b}$, agent *a* proposes a contract (the first line is *r*, the second $\{v_0, \dots, v_n\}$ and the third $\{\sigma_0, \dots, \sigma_m\}$) paying £10 for high quality information to be delivered tomorrow. At $u^1_{b\rightarrow a}$, agent *b* counterproposes that the information be provided on Tuesday. At $u^2_{a\rightarrow b}$, agent *a* rejects the proposal, offering more money rather than changing the delivery date. In addition, *a* offers support for that offer, explaining that the delivery date cannot slip because of an external deadline. This additional information can now be employed by *b* in directing further negotiations – there is no point in *b* offering any counterproposals involving a delivery date other than tomorrow. By permitting such additional supporting information, the negotiation process can thus be pruned and made more efficient.

Another feature of the use of argument supports is that it enables exploitation of the additional knowledge made available to agents by their explicit adoption of a particular dialogue frame. As mentioned in section 2, in addition to the private aims of agents in a dialogue, there is also a set of aims which motivate the dialogue itself: these latter aims are adopted by both agents and this adoption is a consequence of accepting a particular dialogue frame. Thus two agents entering a negotiation dialogue both know that both are disposed to reach an agreement. This knowledge can have a direct influence on the negotiation process, when the argument supports are considered:

In example five, today is Saturday, and in $u^0_{a\rightarrow b}$, agent *a* requests high quality information by tomorrow, at a cost of £10. At $u^1_{b\rightarrow a}$, agent *b* quadruples the price because (i) he knows he is the only agent working weekends, and therefore has no competition for supplying information by tomorrow and (ii) he knows that agent *a* wants to make the deal (and can therefore ask whatever he wants). Furthermore, if agent *a* proceeds to alter the *Quality* value, (requesting, say, only poor quality information), agent *b* is still in a position to charge his inflated prices for the same reasons as before. Clearly, there are still conventional negotiation issues of *b* avoiding putting the price so high that *a* allows the delivery date to shift, but in making his decision, *b* appeals to the joint aims of the dialogue frame which he knows *a* subscribes to (namely, that *a* wants to make a deal, and is therefore unlikely to reject an offer altogether if there are no alternatives).

$u^0_{a\rightarrow b}$: $\langle\langle$ $has(a, information) \wedge has(a, £10\text{-}less) \wedge has(b, £10\text{-}more)$,
$\{\langle Price, £10\rangle, \langle Quality, High\rangle, \langle Delivery, Tomorrow\rangle\}\ \rangle$
$\{\emptyset\}\ \rangle$

$u^1_{b\rightarrow a}$: $\langle\langle$ $has(a, information) \wedge has(a, £40\text{-}less) \wedge has(b, £40\text{-}more)$,
$\{\langle Price, £40\rangle, \langle Quality, High\rangle, \langle Delivery, Tomorrow\rangle\}\ \rangle$
$\{only\_supplier\_agent\_working\_at\_weekend(b)\}\ \rangle$

Example 5

Finally, there is an intuitive relationship between the dialogue types which becomes manifest as a canonical ordering between successive frames of different types. Parsons' work assumes that a propositionally adequate argument (i.e. one which falls into the higher acceptability classes), will be accepted. Similarly, Sierra *et al.* assume that a contract exists upon which agents can negotiate. The intuition is that the sort of communication discussed in (Jennings and Parsons, 1996) should precede the sort of communication focused upon in (Sierra *et al.*, 1997b). And indeed this makes sense from an informal point of view: first it is necessary to deliberate how a set of goals should be achieved, only then is it appropriate to negotiate terms. Such canonical orderings, however, account for only a small proportion of relationships between dialogue frames of different types. More common – and much more powerful – is the way in which one dialogue frame may be used within another.

5. Functional Embedding

One of the key features of Walton and Krabbe's approach is that dialogue types may be nested inside one another. If, for example, a persuasion dialogue (or any of the other types) reaches a stage at which it becomes apparent that the proponent knows considerably more about a topic than her opponent, it is likely that the exchange will temporarily shift into an information-seeking dialogue. When both parties have the appropriate information, the information-seeking concludes and the persuasion dialogue resumes. Similarly, if during an inquiry, one participant forms an intermediate conclusion ahead of the other, it may be appropriate for that participant to shift into a persuasion dialogue to convince her opponent of the veracity of her conclusion. Importantly, these subdialogues are initiated to fulfil a precise purpose in the parent dialogue; when that purpose is fulfilled (one way or the other), the parent dialogue can be resumed at precisely the point it was interrupted, but with the information provided by the subdialogue adduced appropriately. Dialogue frames can thus be functionally embedded, and this can easily be incorporated into the model.

An utterance, as mentioned above, can be a request to initiate a dialogue frame, and clearly, such an utterance can be made within an existing dialogue frame. Let us assume one dialogue frame, ϕ, is currently active, and agent *a* makes a request at turn *i* in that frame for a new dialogue frame, ψ, to be embedded. At turn *i*+1, agent *b* may either accept or reject that proposal. Rejection would lead to normal resumption of ϕ, whilst acceptance would mean that at the next turn, ψ is open, ϕ is temporarily suspended, and *a* can utter $\psi_{u^0 a\rightarrow b}$. It is thus generally the case that $\phi_{x_i} = \psi_{x_0}$ and $\phi_{y_i} = \psi_{y_0}$.

As Walton and Krabbe mention, at the termination of an embedded discourse, the way in which the original dialogue is resumed depends on the outcome of the embedded dialogue (in fact, they only describe in detail the embedding of one type of persuasion in another, but the point can be generalised). With a persuasion dialogue, for example, a dialogue frame will usually end with consensus – i.e. one agent concedes their opponent's original thesis. If the initiator of the embedded dialogue frame concedes, then it is the opponent who resumes the original frame, and vice versa. Thus with *n* utterances in ψ,

$$\phi_{x_i} = \psi_{x_n} \rightarrow \phi_{x_{i+2}} = \phi_{y_i} \quad \text{and} \quad \phi_{y_i} = \psi_{x_n} \rightarrow \phi_{x_{i+2}} = \phi_{x_i}$$

By way of example, consider agents *a* and *b* in a dialogue frame ϕ, and *a* wishes to initiate a persuasion dialogue, ψ, concerning a thesis *p*.

$\phi_{u^i a\rightarrow b}$: *propose* (*persuade*, *p*)
$\phi_{u^{i+1} b\rightarrow a}$: *accept* (*persuade*, *p*)
$\psi_{u^0 a\rightarrow b}$: *tell* (*p*, {*x*})
$\psi_{u^1 b\rightarrow a}$: *tell* (~*x*, {*y*})
$\psi_{u^2 a\rightarrow b}$: *tell* (~*y*, {*z*, *w*})
$\psi_{u^3 b\rightarrow a}$: *concede* (*p*, {})
$\phi_{u^{i+2} a\rightarrow b}$: …

Because it is *b* who concedes in $\psi_{u^3 b\rightarrow a}$, it is *a* who resumes at $\phi_{u^{i+2} a\rightarrow b}$.

To illustrate the use of functional embedding, Parsons' picture hanging example is continued from above in example six, where *b* sets a price for the nail, upon which *a* then requests a negotiation.

At $\phi_{u^3 b\rightarrow a}$, *b* proposes to charge *a* £5 for the nail; *a* requests negotiation on the matter and the result of their bargaining is an accepted price of £2. At the last step, *b* might accept the proposal or go on to introduce another issue – in either case, the price of the nail is inherited by the dialogue frame ϕ, and remains constant unless another negotiation is initiated with additional issues to consider (which may then affect the price).

$\phi_{u}{}^{3}{}_{b\rightarrow a}$: $\langle\langle$ *propose* ($\langle$*have*(*a, nail*) $\wedge$ *can*(*a, hang_picture*), $\{\langle$*Price,£5*$\rangle\}\rangle$ $\rangle$,{ *f1, f2, f3, f4, r5*}$\rangle$

$\phi_{u}{}^{4}{}_{a\rightarrow b}$: $\langle\langle$ *propose* (*negotiate* ($\langle$*have*(*a, nail*) $\wedge$ *can*(*a, hang_picture*), $\{\langle$*Price,£5*$\rangle\}\rangle$ $\rangle$,{$\varnothing$}$\rangle$

$\phi_{u}{}^{5}{}_{b\rightarrow a}$: $\langle\langle$ *accept* (*negotiate* ($\langle$*have*(*a, nail*) $\wedge$ *can*(*a, hang_picture*), $\{\langle$*Price,£5*$\rangle\}\rangle$ $\rangle$,{$\varnothing$}$\rangle$

$\psi_{u}{}^{0}{}_{a\rightarrow b}$: $\langle\langle$ *propose* ($\langle$*have*(*a, nail*) $\wedge$ *can*(*a, hang_picture*), $\{\langle$*Price,£1*$\rangle\}\rangle$ $\rangle$,{ *f1, f2, f3, f4, r5*}$\rangle$

$\psi_{u}{}^{1}{}_{b\rightarrow a}$: $\langle\langle$ *propose* ($\langle$*have*(*a, nail*) $\wedge$ *can*(*a, hang_picture*), $\{\langle$*Price,£2*$\rangle\}\rangle$ $\rangle$,{ *f1, f2, f3, f4, r5*}$\rangle$

$\psi_{u}{}^{2}{}_{a\rightarrow b}$: $\langle\langle$ *accept* ($\langle$*have*(*a, nail*) $\wedge$ *can*(*a, hang_picture*), $\{\langle$*Price,£2*$\rangle\}\rangle$ $\rangle$,{ *f1, f2, f3, f4, r5*}$\rangle$

$\phi_{u}{}^{6}{}_{b\rightarrow a}$: …

Example 6

6. Conclusions and future work

There are a number of reasons why recognising and differentiating between dialogue types plays a key role in designing communication protocols for complex multi-agent societies in which agents have rich representation structures. In the first place, defining dialogue types on the basis of agent goals – both individual and joint – enables a formal definition of the terms which are used to characterise encounters. This formal definition can support a common framework, by which a particular scenario can be unequivocally assessed as ‘persuasive’ (for example), and thus be amenable to particular dialogic techniques and call for characteristic forms of representation, exchange and evaluation. Relatedly, the provision of a common framework also enables comparison, and possibly integration, of otherwise disparate research concentrating on single types of dialogue – comparing, for example, the work presented in (Parsons and Jennings, 1996) with that of (Sierra *et al.*, 1997b) – the latter focusing on negotiation, the former on deliberation (despite the ‘negotiation’ in its title). The current work encompasses both of these approaches in a single coherent framework. As a side-effect of this unification, the advantages discussed in (Parsons and Jennings, 1996) and (Reed *et al.*, 1997) of using argumentation in particular types of inter-agent communication can be extended to cover all the dialogue classes in the Walton and Krabbe typology, with a number of associated benefits in expressiveness and computational efficiency. In addition, the common framework offers a means of inter-relating the abstracted notions of belief, contract, and plan, which form the substrate for agent communication. In particular, it highlights the use of types of belief in contracts and the way in which partially specified, partially ordered contracts can combine to form a notion of ‘plan’ which is consistent with that in the traditional planning literature. Finally, this approach makes explicit the ‘process knowledge’ which agents are assumed to have: by agreeing to enter into a particular dialogue frame, both agents can infer capabilities, beliefs and desires held by the other (e.g. in accepting negotiation, an agent can assume the other wants the contract executed, is prepared to modify their offer, is able to fulfil their part of the contract, etc.). Importantly, this knowledge is different between dialogue types – in an inquiry, for example, one agent can safely assume that the other will not hold information back; in a persuasion or negotiation dialogue, such an assumption could be detrimental to an agent’s strategy.

With such a substantial catalogue of work in informal logic (see (Eemeren *et al.*, 1996) for a comprehensive overview, and Hamblin’s (Hamblin, 1970) seminal work on commitment, to which (Walton and Krabbe, 1995) represents a extension) there is a huge potential for formalising exchange structures of “interpersonal reasoning” for direct application to agent communication protocols. This paper has followed the spirit of the work of Walton and Krabbe in presenting an overarching framework. As in Walton and Krabbe, there is great scope for formalising each of the dialogue types in turn, and then each of the legitimate embeddings, and the interactions between frame and sub-frame. Walton and Krabbe also mention that particular combinations of embeddings can lead to fallacies – embedding a negotiation in a persuasion, inquiry, or in some cases, information-seeking dialogue, often becomes manifest as the *fallacy of bargaining* (Walton and Krabbe 1995)p104[2]. As fallacies violate important principles of communication, (Grice, 1975), it is important to recognise situations in which they might occur, and then probably try and avoid or prevent those situations. The use of fallacies in the work of Sierra *et al.*, and Sycara, mentioned in section 1, needs to be carefully appraised in this light, and the framework proposed above facilitates such work, though clearly more research is required to fully understand both the mechanics of fallacies in multi-agent dialogue and their impact on the success of communication.

In addition, Walton and Krabbe distinguish between two forms of persuasive dialogue: *permissive persuasive dialogue* (PPD) and *rigorous persuasive dialogue* (RPD).

[2] Walton and Krabbe do not exhaustively enumerate the validity of each of the combinatorially possible embeddings – a preliminary attempt is offered in (Reed and Long, 1997).

This analysis was motivated by two main considerations: to incorporate into a single unified theory formerly disparate forms of dialogue game (notably those of Hamblin (1970) characterised by PPD and Lorenzen, characterised by RPD); and to formalise the technique – found in natural argument – of slipping from a conventional, free style of argument into a more restricted style where the proponent forces concessions from the opponent. This further distinction within the class of persuasive dialogue is both amenable to MAS utilisation and potentially of great significance, offering agents finely cast strategies for particular situations (RPD, for example, is useful for terminological and definitional discussion).

Finally, commitment-based dialogue logics (such as (Walton and Krabbe, 1995) and (Hamblin, 1970)) also provide an attractive approach to dealing with the thorny problem of agent rationality, as they constrain the possible dialogical moves an agent is permitted to make at any point on the basis of the previous utterances of the two agents. An investigation of how such dialogue logic can be employed to constrain the ways in which an agent can contribute to a dialogue of a given type appears to be a fruitful avenue for future research.

This paper presents initial work aimed at introducing the rich models developed in informal logic into multi-agent settings, and has demonstrated that the typology designed on the basis of empirical research into natural argumentation can be successfully formalised and applied in a multi-agent domain. The approach offers a wide range of consequent benefits, which include improvements in both computational efficiency and expressive power, in addition to the identification of abstractions which enable classification and inter-relation of a range of current MAS research. The model includes both a formal description of the five major dialogue types, and an account of the way in which functional embedding can be effected. Employment of the distinction between the dialogue types and the use of embedding is likely to become an important issue, not only to compare research in the increasingly prolific field of MAS, but also to support the growing demands of sophisticated agent communication in complex domains.

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