A dialogical model for collaborative decision making based on compromises

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Abstract. In this paper, we deal with group decision making and propose a model of dialogue among agents that have different knowledge and preferences, but are willing to compromise in order to collaboratively reach a common decision. Agents participating in the dialogue use internal reasoning to resolve conflicts emerging in their knowledge during communication and to reach a decision that requires the least compromises. Our approach has significant potential, as it may allow targeted knowledge exchange, partial disclosure of information and efficient or informed decision-making depending on the topic of the agents' discussion.

Keywords: Group Decision Making, Multi-Agent Systems, Conflicts, Conflict Resolution, Preferential Reasoning, Dialogues

1 Introduction

The effectiveness of any community of autonomous agents is highly contingent on the interaction schemes of its members. Even when decision making within the community is collaborative, conflicts frequently arise for a multitude of reasons, e.g., because the agents may be heterogeneous (i.e., they perceive the world in different ways), self-interested (i.e., they pursue atomic objectives), etc. Negotiation is inevitable and takes the form of an exchange of offers and positions attempting to find the best mutually beneficial deal in the space of possible deals or of bargaining based on the exchange of richer information (such as arguments), attempting to persuade the other parties to modify their positions.

The relevant literature is rich with approaches that propose elegant protocols for many different cases, especially when finding the optimal solution is a well-defined, as well as highly desirable goal. Nevertheless, many real-world multi-agent systems resemble in complexity the social interactions of humans; as such, adopting typical human negotiation attitudes in certain types of automated dialogues can prove to be more appropriate. Imagine the following example:

Example 1. Mary and Anne, each with her own knowledge and preferences, want to decide whether to go to a party (go_party or $\neg$ go_party). Mary is positive, as she knows that the whole class will be invited. She would also like to go if there is a live band, even though she has no such information. Unlike Mary, Anne prefers going to the theatre than going to the party. If the party is far away, she does not want to go, even though knowing that transport to the party is available could make her reconsider. She also knows that the party will have a live band. The individual Knowledge Bases (KBs) are presented below:

Mary	**Anne**
r_1: live_band $\Rightarrow$ go_party	r_7: long_distance $\Rightarrow$ $\neg$ go_party
r_2: class_invited $\Rightarrow$ go_party	r_8: $\neg$ go_party $\Rightarrow$ theatre
r_3: go_party $\Rightarrow$ meet_new_people	r_9: transport $\Rightarrow$ go_party
r_4: live_band $>$ long_distance	r_{10}: theatre $>$ go_party
r_5: $\Rightarrow$ transport	r_{11}: $\Rightarrow$ live_band
r_6: $\Rightarrow$ class_invited	r_{12}: $\Rightarrow$ long_distance

To decide, the girls engage in the following dialogue:

M: *The whole class will be invited so we should go to the party.*

A: *Yes, but the party is a long distance from here so we shouldn't go.*

M: *Do you know whether the party will have a live band?*

A: *Yes, it will.*

M: *We should go to the party, since there will be a live band.*

A: *Do you know whether there will be transportation to the party?*

M: *Yes there will be.*

A: *Ok, I agree going to the party, as there is transportation.* □

Even in this simple example, there are complex features that constitute traditional negotiation schemes less preferable in approaching how to reach agreement. Notice, for instance, that both parties typically desire to come to a common decision without having to disclose all their local information (e.g., r_3), which is often impractical. More importantly, decision making is not a take-it-or-leave-it kind of information exchange, but typically involves some degree of *compromise* by each involved party, decided in the course of the discussion. These compromises are driven by the desire to accommodate each other's preferences until an agreement is acceptable to all (i.e., the best for the group), even if this agreement is not optimal for any individual agent. In this sense, negotiations of this type can be seen as a combination of what Walton describes as *persuasion* and *information-seeking* dialogues [14]: information exchange is equally important to being convincing, in order to resolve conflicts.

In this paper, we present an initial attempt towards a formal framework that enables complex negotiations among collaborative agents that are willing to compromise by putting forward partial, yet justifiable positions of their mindset. The compromise per decision is quantified, facilitating the evaluation of individual and group compromise under various alternative methods. To support message exchange, we propose a dialectical model. Our work will enable modelling agents' willingness to compromise, the definition of strategies allowing targeted message exchange, and the support of efficient (quick) decisions.

The paper proceeds with an introduction to the basic notions of our model. Then, Section 3 explains different types of internal reasoning related to decision-making, while Section 4 defines the protocol of the dialogue. We conclude with a discussion on related work and a description of the currently pursued extensions.

2 Preliminaries

Agents use a common *language* ($\mathcal{L}$), generated by a set of *positive literals* $\mathcal{L}_0 = \{\alpha_1, \alpha_2, \dots\}$, and defined as $\mathcal{L} = \{\alpha, \neg\,\alpha \mid \alpha \in \mathcal{L}_0\}$. We also consider a set of *rules* $\mathcal{R} = \{r_1, r_2, \dots,\}$, which represents all the rules that can be used by the agents. Rules may be either *inference* or *preference* rules. *Inference rules* are of the form $\ell_1, \dots, \ell_n \rightsquigarrow \ell_0$, where $\rightsquigarrow \in \{\rightarrow, \Rightarrow\}$, $n \geq 0$, $\ell_1, \dots, \ell_n, \ell_0 \in \mathcal{L}$. An inference rule is called *strict* iff $\rightsquigarrow = \rightarrow$, *defeasible* iff $\rightsquigarrow = \Rightarrow$; it is called a *fact* iff $n = 0$. For an inference rule r, we set $body(r) = \{\ell_1, \dots, \ell_n\}$, $head(r) = \ell$. *Preference rules* are of the form $\ell_1 > \ell_2$, where $\ell_1, \ell_2 \in \mathcal{L}$. We denote by $\mathcal{R}^F, \mathcal{R}^\rightarrow, \mathcal{R}^\Rightarrow, \mathcal{R}^>$ the set of facts, strict rules, defeasible rules and preference rules in $\mathcal{R}$ respectively.

A literal ℓ is *inferred from* $T \subseteq \mathcal{L}$ given a set of rules $R \subseteq \mathcal{R}$, iff $\ell \in T$ or there is some $r \in R \cap (\mathcal{R}^\rightarrow \cup \mathcal{R}^\Rightarrow)$ such that $head(r) = \ell$ and ℓ_i is inferred from T given R for all $\ell_i \in body(r)$. We denote by $Cn^R(T)$ the set of literals inferred from T given R (or simply Cn^R when $T = \emptyset$). A set of rules $R \subseteq \mathcal{R}$ will be called *inconsistent* iff there is some $\alpha \in \mathcal{L}_0$ such that $\alpha, \neg\,\alpha \in Cn^R$; *consistent* otherwise. We require that $\mathcal{R}^\rightarrow$ is consistent, but $\mathcal{R}$ may be inconsistent.

3 Decision-Making Using Compromises

3.1 Setting and Basic Concepts

Our framework assumes two agents, say ag_1, ag_2 who are faced with a binary decision (e.g., "go to the party"/"not go to the party"), which they have to take collaboratively. Thus, a decision-making process is about the truth value of a positive literal α and the two related *choices* are α and $\neg\,\alpha$. Both agents use the same, arbitrary but fixed, language and set of rules $(\mathcal{L}, \mathcal{R})$. Agent ag_i has a KB $K_i \subseteq \mathcal{R}$ $(i = 1, 2)$, containing all the rules that he *is aware of*. The agents are aware of all the strict rules, i.e., $K_i \supseteq \mathcal{R}^\rightarrow$.

An agent's KB contains all the knowledge (rules) that the agent has acquired, including *both* his own (original) rules (e.g., strict rules, or rules acquired from personal observation, K^*), *and* the knowledge acquired by other agents via message exchange (communicating a rule makes the recipient aware of it). The KB is finite, which implies that the set of facts in $\mathcal{R}^\rightarrow$ is also finite. As the agents' KBs may contain contradicting knowledge, this exchange of rules may result to inconsistencies. Agents tolerate inconsistency in their KBs, but reasoning and decision-making should be based on a consistent subset of the KB. The following subsection, describes the way an agent handles inconsistencies and results to a decision.

3.2 Conflict Resolution and Compromises

The main idea behind conflict resolution, is that when an agent's KB is inconsistent, the agent "ignores" some rules so as to achieve consistency. Note that "ignoring" does not mean dropping the rules from the KB, just considering the subset which makes the KB consistent for the purposes of decision-making. The end result should be conflict-free and "compatible" with the preferences encoded in preference rules. Compatibility in this respect means that the agent cannot ignore rules in such a way that his final knowledge implies a less preferred literal but does not imply a more preferred one. Formally:

Definition 1 (Inferable). A literal ℓ is called *inferable* by a set of rules R iff there is a consistent subset of R, say R', such that $\ell \in Cn^{R'}$.

Definition 2 (Conflict Resolution). Given a KB K, a set of rules $\widehat{K}$ is called a *conflict resolution (CR)* for K iff:

- $\mathcal{R}^{\rightarrow} \subseteq \widehat{K} \subseteq K$.
- $\widehat{K}$ is consistent.
- If $\ell_1 > \ell_2 \in \widehat{K}$, $\ell_2 \in Cn^{\widehat{K}}$ and ℓ_1 is inferable, then $\ell_1 \in Cn^{\widehat{K}}$.

Each KB is amenable to several, but not equally desirable, CRs, as each ignored rule corresponds to a compromise on behalf of the agent. In particular, each CR is associated with a *level of compromise* determined by the amount and type of rules the agent ignores. Formally, this is determined by an arbitrary asymmetric (i.e., irreflexive and antisymmetric) ordering ($\rhd$) between sets of rules, that we will call *conflict resolution policy (CRP)*. Intuitively, $\widehat{K}_1 \rhd \widehat{K}_2$ means that $\widehat{K}_1$ is "more preferred" than $\widehat{K}_2$, so $\widehat{K}_1$ requires a lower compromise.

Definition 3 (Compromises). Let *ag* be an agent and K his KB. *ag accepts* $\widehat{K}_1$ *with 0-compromise* iff $\widehat{K}_1$ is a CR of K, and there is no CR of K, say $\widehat{K}_2$, such that $\widehat{K}_2 \rhd \widehat{K}_1$. *ag accepts* $\widehat{K}_1$ *with i-compromise* ($i > 0$) iff $\widehat{K}_2 \rhd \widehat{K}_1$, where $\widehat{K}_2$ is a CR of K, implies that $\widehat{K}_2$ is accepted with j-compromise and $j < i$.

3.3 Defining a Conflict Resolution Policy

Our model is agnostic as to the actual CRP used, and we don't require any specific properties for it (e.g., transitivity). However, some of the proposed extensions of this work (namely strategies) require a fixed CRP, so in this subsection we propose a specific ordering, which is based on the idea that the agents should ignore as few rules as possible; to resolve ties, we differentiate the significance of each rule type, so we aim to ignore as little of the "important" information as possible. To formalize these ideas we need the following definitions:

Definition 4 (Contribution). Given a set of rules R and some $r \in R$, the *contribution* of r in R, denoted $Ctr^R(r)$, is defined as $Ctr^R(r) = Cn^R \setminus Cn^{R \setminus \{r\}}$.

Intuitively, the contribution of r determines the inferred literals that would be "missed" if r was removed from R, i.e., it is an indicator of the amount of new knowledge that r helps infer. The following relations, that we call *CRP heuristics*, can be used to rank two CRs, $\widehat{K}_1, \widehat{K}_2$ based on different dimensions:

h_1. **Total rules:** $\widehat{K}_1 \succ_1 \widehat{K}_2$ iff $|\widehat{K}_1| > |\widehat{K}_2|$

h_2. **Own preferences:** $\widehat{K}_1 \succ_2 \widehat{K}_2$ iff $|\widehat{K}_1 \cap \mathcal{R}^{>} \cap K^*| > |\widehat{K}_2 \cap \mathcal{R}^{>} \cap K^*|$
h_3. **Contribution:** $\widehat{K}_1 \succ_3 \widehat{K}_2$ iff $\sum_{r \in CR_1} |Ctr^K(r)| > \sum_{r \in CR_1} |Ctr^K(r)|$
h_4. **Defeasible facts:** $\widehat{K}_1 \succ_4 \widehat{K}_2$ iff $|\widehat{K}_1 \cap \mathcal{R}^{\Rightarrow} \cap \mathcal{R}^F| > |\widehat{K}_2 \cap \mathcal{R}^{\Rightarrow} \cap \mathcal{R}^F|$
h_5. **Defeasible rules:** $\widehat{K}_1 \succ_5 \widehat{K}_2$ iff $|(\widehat{K}_1 \cap \mathcal{R}^{\Rightarrow}) \setminus \mathcal{R}^F| > |(\widehat{K}_2 \cap \mathcal{R}^{\Rightarrow}) \setminus \mathcal{R}^F|$
h_6. **Others' preferences:** $\widehat{K}_1 \succ_6 \widehat{K}_2$ iff $|(\widehat{K}_1 \cap \mathcal{R}^{>}) \setminus K^*| > |(\widehat{K}_2 \cap \mathcal{R}^{>}) \setminus K^*|$

Definition 5 (Proposed CRP). Given two conflict resolutions, $\widehat{K}_1, \widehat{K}_2$, and the relations $\succ_i, i = 1, \ldots, 6$ as defined above, we set $\widehat{K}_1 \rhd \widehat{K}_2$ iff $\widehat{K}_1 \succ_i \widehat{K}_2$ for some $i \in \{1, \ldots, 6\}$ and there is no $j \in \{1, \ldots, 6\}$, $j < i$, such that $\widehat{K}_2 \succ_j \widehat{K}_1$.

Intuitively, these definitions imply that the optimal CR will be the one that ignores the least number of others' preferences (h_6) and nothing else; followed by those that ignore defeasible rules, facts or rules with a small contribution (h_5, h_4, h_3); and so on.

3.4 Single-Agent Decision Making Using Compromises

Decision making is a cognitive skill that initially happens internally to each agent (to select the optimal decision) before extending to a group of participants. The process of conflict resolution is just the first step in this process. Obviously, each agent would prefer the choice that requires the least compromise. Formally:

Definition 6 (Beliefs). An agent believes a literal ℓ with i-compromise ($i \geq 0$) iff there is a CR $\widehat{K}$ that the agent accepts with i-compromise such that $\ell \in Cn^{\widehat{K}}$ and for all CRs $\widehat{K}'$ that the agent accepts with j-compromise ($0 \leq j < i$), $\ell \notin Cn^{\widehat{K}'}$. If there is no CR $\widehat{K}$ such that $\ell \in Cn^{\widehat{K}}$, then we say that the agent *does not believe* ℓ, or that he believes it with ∞-compromise.

Definition 7 (Optimal Choice). Given a pair of choices $\alpha, \neg\alpha$, the choice that is *optimal* for an agent is the one that is believed with the least compromise; if both are believed with the same compromise, we say that the agent is *indifferent* between the two choices.

Example 2. In example 1, assume that Anne has become aware of $\{r_2, r_6\}$ (sent by Mary). Then her KB (say K_A^1) will be conflicting; a partial list of conflict resolutions, compromises and choices believed per CR are shown below.

CR_{ID}	Conflict Resolution	Compromise	Choice believed (for the given CR)
$\widehat{K}_1$	$K_A^1 \setminus \{r_2\}$	0-compromise	$\neg$ go_party
$\widehat{K}_2$	$K_A^1 \setminus \{r_6\}$	1-compromise	$\neg$ go_party

4 Dialectical Model and Protocol

Our previous analysis described the internal reasoning performed by agents to perform conflict resolution, compromise computation and optimal choice selection. Here, we describe the dialectical model that the agents use to communicate their choices and justifications, in order to reach a consensus. In particular, we consider two interlocutor agents, ag_1, ag_2; for an agent ag, we will use $\overline{ag}$ to denote the other agent. The discussion consists of *locutions*, each of which allows an agent to communicate some rule(s). These rules are internalized in the other agent's KB, allowing him to reconsider his ignored rules in future conflict resolution if adequate support for a rejected rule appears. This fact differentiates a cooperative dialogue from classic argumentative, where agents support their own position and counter-argue [13].

Locution	**Description**
Ask(ℓ)	Used by an agent to ask for justification about a literal ℓ.
Believe(ℓ, JUST)	Used in response to an "Ask" locution, to state an agent's belief in literal ℓ (of the form α or $\neg\alpha$), along with a justification (JUST), which is a set of rules such that $\ell \in Cn^{\text{JUST}}$. In case that the agent's KB contains no justification for either α or $\neg\alpha$, then Believe($\sim\alpha, \emptyset$) should be returned. Finally, if the agent's KB contains justification for both α and $\neg\alpha$, then Believe($\pm\alpha$,JUST) should be returned, such that $\alpha, \neg\alpha \in Cn^{\text{JUST}}$.
Propose(ℓ, JUST)	Used to exchange rules (JUST) in favour of a choice ($\ell \in Cn^{\text{JUST}}$) that the agent proposes. The justification may optionally contain preference rules that affected his conflict resolution process.
Agree(ℓ)	Used to express agreement with the last proposed literal.
Pass	Used when the agent has nothing to add to the discussion.

Table 1. Locution summary

The different locution types and their intuition are shown in the Table 1. The type of a locution LOC is denoted by *type*(LOC). A *dialectical move* is a pair (ag, LOC), which states that agent ag made the locution LOC. A *dialogue* D is a sequence of dialogical moves; the i^{th} dialectical move will be denoted by D_i. We will denote by K^i_{ag} the KB of agent ag after D_i. The dialogue is governed by a *protocol*, inspired by [13], which indicates conditions regarding dialogue initialization, message exchange and dialogue termination:

Initialization. The dialogue starts by agent ag_1, with a Propose or an Ask move. Thus, $D_1 = (ag_1, \text{LOC})$, where $type(\text{LOC}) \in$ {Ask, Propose}.

Message exchange. The conditions below determine the allowable moves:

- *Turn-taking:* the agents should alternate in providing locutions, i.e, if $D_i = (ag, \text{LOC})$, $D_{i+1} = (ag', \text{LOC}')$, then $ag' = \overline{ag}$.
- *Move succession:* each move type can be followed by specific move types, in particular, if $D_i = (ag, \text{LOC})$, $D_{i+1} = (ag', \text{LOC}')$, then:
  - If $type(\text{LOC})$ =Ask, then $type(\text{LOC}')$ =Believe
  - If $type(\text{LOC})$ =Believe, then $type(\text{LOC}') \in$ {Ask, Propose, Pass, Agree}
  - If $type(\text{LOC})$ =Propose, then $type(\text{LOC}') \in$ {Ask, Propose, Agree}
  - If $type(\text{LOC})$ =Pass, then $type(\text{LOC}') \in$ {Ask, Propose}
- *Agreement:* an agreement cannot be reached unless there was a specific proposal. Formally, if $D_i = (ag, \text{LOC})$ and $type(\text{LOC})$ =Agree, then there is some $1 \le j < i$ such that $D_j = (ag^*, \text{LOC}^*)$, $ag^* = \overline{ag}$ and $type(\text{LOC}^*)$ =Propose.

– *Effects:* locutions containing a justification cause these rules to be incorporated in the KB of the recipient agent. Formally, if $D_i = (ag, \textsc{loc})$ then:
  - If $\textsc{loc}$ =Propose(ℓ,$\textsc{just}$) then $K^{i+1}_{\overline{ag}} = K^{i}_{\overline{ag}} \cup \textsc{just}$
  - If $\textsc{loc}$ =Believe(ℓ,$\textsc{just}$) then $K^{i+1}_{\overline{ag}} = K^{i}_{\overline{ag}} \cup \textsc{just}$

– *Move uniqueness:* an agent cannot make the same move twice, i.e., if $i \neq j$ then $D_i \neq D_j$.

– *Honesty:* agents communicate rules they are aware of, i.e., if $D_i = (ag, \textsc{loc})$ and $\textsc{loc}$ =Believe(ℓ,$\textsc{just}$) or $\textsc{loc}$ =Propose(ℓ,$\textsc{just}$) then $\textsc{just} \subseteq K^{i-1}_{ag}$.

Termination. The dialogue terminates when an Agree locution has been made, or when both agents use a Pass in succession. Formally, we say that the dialogue *terminates in step i* in the following two cases:

– *Consensus:* $D_i = (ag, \textsc{loc})$ and $type(\textsc{loc})$ =Agree. In this case, we say that the dialogue *terminates with a consensus*, and the *decision* of the dialogue is determined by the last Propose locution. Specifically, if j is the maximum integer for which $D_j = (ag^*, \textsc{loc}^*)$, $ag^* = \overline{ag}$ and $type(\textsc{loc}^*)$ =Propose, then the decision is the literal ℓ in the first parameter of $\textsc{loc}^*$.

– *No consensus:* $D_i = (ag, \textsc{loc}), D_{i-1} = (ag', \textsc{loc}')$ and $type(\textsc{loc}) = type(\textsc{loc}')$ = Pass. In this case, we say that the dialogue *terminates with no consensus.*

The termination of the dialogue is guaranteed by the conditions of move uniqueness and honesty, as well as by the fact that the agents' KBs are assumed finite.

5 Related Work

Dialogues for reaching agreement have been studied in other frameworks, too. Prakken [13] formally models dialogue games for argumentation. The framework is flexible enough to capture different protocols. A approach similar to ours, is described in [1], where agents engage in a collaborative dialogue to achieve consensus, conformed to a predefined protocol allowing the dialogue to end up with no agreement.

The system described in [3] represents a cooperative dialectical model for practical reasoning equipped with a formalization about opponent's preferences and a strategic selection mechanism. None of the previous models have features of information seeking that enhance the notion of collaboration. A dialectical protocol targeting in agreement that supports this feature is presented in [10], where the agents negotiate to agree in a common ontology. However, in our model we additionally focus on the process of single-agent decision making through the notion of compromise.

Fan et al. [8] rely on the assumption-based framework to model decision making as a setting of two communicating agents, each one equipped with a decision making framework that respectively resolves conflicts according to the trustworthiness between agents, but ignoring preferences. In [11] a dialogue protocol between cooperative agents is presented, although it is based on three-valued non-monotonic modal logic in order to reason with incomplete knowledge. Co-operative agents aiming for a common goal, are also presented in [12]. The main differentiations lie in the outcome of the dialogue which, in their approach is a common plan, whilst in our model is a final decision, as well as in the protocol of the dialogue.

6 Discussion and Possible Extensions

The current study sets the foundations for enabling agents to engage in complex negotiations. This is just the first step towards a more ambitious aim; in essence, our framework will be the substrate on top of which different extensions are going to be investigated. First, we plan to expand the expressiveness of the underlying language with more complex features, such as contextual preferences of the form $a \Rightarrow (b > c)$ or even $(a > b) \Rightarrow (c > d)$, similar in style to [4].

A topic we are currently working on is to enhance the reasoning capacity of the agents with *strategies* that would make them "smarter" in selecting their next moves. Note that the protocol defined in Section 4 gives the allowable moves, but does not provide any algorithm for selecting the next move. Such an algorithm would include targeted information seeking, in order to satisfy preferences and lighten the compromise, or "smart" rule exchange to decrease the total number of messages exchanged before terminating the dialogue. In this respect, the work in [2] is relevant, which uses argumentation and relies on preferences on arguments to perform decision making, even though the setting is not distributed, as in our case. Our strategies will be inspired by the persuasion field [9, 5], exploiting knowledge about other agents' KBs, or applying the notion of *relevant* literals or rules, which should be communicated first.

Additionally, we plan to accommodate more complex dialogues with more than two agents that negotiate over more involved decisions (e.g., choosing among a set of diverse choices), use more complex locutions (e.g., stating reasons for ignoring rules), and have different and more complex CRPs (e.g., using trust considerations, or ideas from utility theory and heuristics like utilitarian, egalitarian, elitist, etc. [6]). Multi-party dialogues demand more complex models regulating turn-taking, termination, different roles or ways of cooperation and other issues highlighted in [7]. In such models it will be challenging how the interplay of different strategies and CRPs will affect the course of the dialogue and possibly also the notion of *group compromise*.

Another possible extension would be to incorporate the notion of *willingness to compromise*, which would make agents more (or less) receptive to accepting a decision that requires more compromise than the optimal one, or even forcing them to reject optimal decisions that are above a certain level of compromise. This would prevent from prematurely taking decisions with large compromises when it comes to important topics. It could also be coupled with a mechanism for successively lowering the threshold; the latter would prohibit quick decisions on important matters, and would force the agents to engage in longer dialogues.

Finally, our future work includes studying formal properties of dialogues, such as the rate of reaching consensus with different strategies, or how decisions reached by agents are related to the optimal (and informed) decision obtained by an omniscient agent. A prolog-based implementation is under way, so as to couple the theoretical properties with experimental evaluations, which would consider, apart from performance, also issues of dialogue quality, such as the length of the dialogue or the quality of the decision taken under different strategies or settings.

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References

1. Amgoud, L., Belabbes, S., Prade, H.: Towards a formal framework for the search of a consensus between autonomous agents. In: Argumentation in Multi-Agent Systems, Lecture Notes in Computer Science, vol. 4049, pp. 264–278 (2006)
2. Amgoud, L., Prade, H.: Using arguments for making and explaining decisions. Artif. Intell. 173(3-4), 413–436 (2009)
3. Black, E., Atkinson, K.: Choosing persuasive arguments for action (2011)
4. Brewka, G.: Logic programming with ordered disjunction. In: Eighteenth national conference on Artificial intelligence. pp. 100–105 (2002)
5. Budzynska, K., Kacprzak, M.: Formal models for persuasive aspects of argumentation. Studies in Logic, Grammar and Rhetoric 16(29), 159–187 (2009)
6. Chevaleyre, Y., Dunne, P.E., Endriss, U., Lang, J., Lemaitre, M., Maudet, N., Padget, J., Phelps, S., Rodriguez-aguilar, J.A., Sousa, P.: Issues in multiagent resource allocation. INFORMATICA 30 (2006)
7. Dignum, F.P., Vreeswijk, G.A.: Towards a testbed for multi-party dialogues. In: Advances in Agent Communication, pp. 212–230. Springer (2004)
8. Fan, X., Toni, F., Mocanu, A., Williams, M.: Dialogical two-agent decision making with assumption-based argumentation. pp. 533–540. AAMAS '14 (2014)
9. Hunter, A.: Making argumentation more believable. In: AAAI-04 (2004)
10. Morge, M., Routier, J.C., Secq, Y., Dujardin, T.: A formal framework for inter-agents dialogue to reach an agreement about a representation. In: Proceedings of the Workshop on Formal Ontologies for Communicating Agents (FOCA'2006)
11. Moubaiddin, A., Obeid, N.: Partial information basis for agent-based collaborative dialogue. Applied Intelligence 30(2), 142–167 (2009)
12. Pardo, P., Pajares, S., Onaindia, E., Godo, L., Dellunde, P.: Multiagent argumentation for cooperative planning in DeLP-POP. In: The 10th International Conference on Autonomous Agents and Multiagent Systems - Volume 3. AAMAS '11
13. Prakken, H.: Coherence and flexibility in dialogue games for argumentation. Journal of Logic and Computation 15(6) (2005)
14. Walton, D., Krabbe, E.C.W.: Commitment in Dialogue: Basic Concepts of Interpersonal Reasoning. State University of New York Press (1995)