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A Paraconsistent Approach to Speech Acts*

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Abstract. This paper discusses an implementation of speech acts in a paraconsistent framework. We analyze four speech acts: *assert*, *concede*, *request* and *challenge* as building blocks of agents' interactions. A natural four-valued model of interaction yields multiple new cognitive situations. They are analyzed in the context of communicative relations, which partially replace the concept of trust. These assumptions naturally lead to six types of situations: perceiving inconsistent information, perceiving previously inconsistent information, perceiving previously unknown information, perceiving unknown information, perceiving compatible information and perceiving contradictory information. These new situations often require performing conflict resolution and belief revision.
The particular choice of a rule-based, DATALOG$^{\neg\neg}$-like query language 4QL as a four-valued implementation framework ensures that, in contrast to the standard two-valued approaches, tractability of the model is maintained.
The work concludes with a discussion of an example.

1 Modeling Assumptions

The development of contemporary multiagent systems (MAS) demands an adequate and precise logical modeling of the environment. Recently, there is a wide choice of knowledge representation methods. Each time, these methods should be selected carefully on an application-specific basis. When confining to logic-based approaches and formalisms, traditionally two-valued logics prevail. They fail, however, to express richer modeling possibilities when some values or properties are simply not known, or when the available information is inconsistent. A natural remedy for such situations is introducing four logical values [3, 23, 27]. This work aligns with a whole line of research concerning logical modeling, reasoning and communicating about the surrounding reality, under the assumption that we deal with four types of situations, encoded in the four logical values:

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– fact a holds,
– fact a does not hold,
– it is not known whether a holds,
– information about a is inconsistent.

This reflects the current informational stance of an agent, which is dynamic in nature, exhibiting the dynamism of its environment. Whenever a change occurs, a belief revision is performed to account for the alteration in question.

This paper opens our research programme on paraconsistent modeling of communication in the four-valued framework. We start from a paraconsistent model of speech acts, aiming ultimately at achieving a four-valued formalization of dialogues and argumentation. If argumentation-based dialogues are considered as communicative games between two or more agents, speech acts can be viewed as their building blocks. They are used to compose complex dialogues, such as persuasion, deliberation, information seeking, negotiation or inquiry and can be seen as the underlying reactive layer of communication (see [35] for the definitions of various dialogue types, and [1,4,10,14,16,17,29,30,32] for investigations in multi-agent argumentation-based dialogue).

In the process of exchanging messages, we naturally treat the sender and the receiver as two independent information sources, which try to expand, update, and revise their beliefs through communication. Usually, the level of trust between agents influences this process. We intend to disregard the heavily computational theory of trust [6, 7] in favor of three model situations, which take place in traditional communication. Instead of introducing the levels of trust between the sender and receiver, we consider three communicative relations between the two agents involved:

– communication with authority,
– peer to peer communication,
– communication with subordinate.

When deciding on what four-valued formalism to adopt, we directed out attention to 4QL [26, 27], a rule-based, paraconsistent language, due to its low complexity and unique features distinguishing it from other similar formalisms. Keeping in mind our goal: adequate modeling of human-computer interactions in time-critical systems, we are prepared to pay the price of some expressiveness limitations concerning dialogues in order to maintain those important properties of 4QL. This four-valued approach to speech acts, based on 4QL, is most likely new in the literature.

The aim of this paper is to give foundations for communication in multiagent systems based on 4QL. We analyze perceiving speech acts and propose a specific conflict resolution method. A natural four-valued model of interaction yields multiple new cognitive situations. Therefore we distinguish six types of them: perceiving inconsistent information, perceiving previously inconsistent information, perceiving previously unknown information, perceiving unknown information, perceiving compatible information and perceiving contradictory information. We analyze them one by one, providing a sort of semantics of four selected speech acts: *assert*, *concede*, *request* and *challenge*. It is given in terms of triples consisting of *preconditions*, *speech acts* and *complex post actions*. Along with defining rules for perceiving speech acts, we indicate their detailed impact on the receiver's informational stance.

The paper is structured as follows. First, in Section 2, we introduce speech acts theory. Section 3 is devoted to a four-valued logic which is used throughout the paper and to basic information on 4QL, a rule language suitable as an efficient implementation tool. Section 4 discusses the main technical contribution of the paper. Section 5 illustrates our ideas by an example. Finally, Section 6 concludes the paper.

2 Drawing upon Speech Acts Theory

Since the early 20th century linguists and philosophers of language have been studying speech acts. Their theory originates from J.L. Austin's book [2], where he stated an observation that some utterances cannot be verified as true or false. This led to the division of speech acts into *constatives*, which can be assigned a logical truth value, and the remaining group of *performatives*. Austin's successor, Searle, created perhaps the most popular taxonomy, identifying: *assertives*, *directives*, *commissives*, *expressives* and *declaratives* [33].

The aim of an assertive act is to make a commitment to the truth of the expressed proposition. A way in which an assertive can be assessed is with respect to the truth or falsity of the asserted proposition. Some examples of assertives include: suggesting, hypothesizing, stating. Directives are aimed at getting the hearer to do something, for example: inviting, begging, pleading and challenging. A special case of directives are questions. The purpose of commissives is to commit the speaker to some future action, for example, promising or swearing. The goal of uttering an expressive act is to express a psychological state (thanking, apologizing, congratulating). The essence of a declarative is reflected in the expression "saying makes it so". For example, by uttering "I pronounce you husband and wife", a couple is declared to be married. Other examples of such speech acts are christening or declaring war.

This theory views communication as complex actions changing the mental states of dialogue participants. Various speech acts, viewed as *typical actions* can be represented in dynamic logic, by characterizing their pre- and post-conditions. Austin defined the effects of illocutionary acts as *perlocutionary acts*: the effects on the attitudes and actions of the hearer. We define them in terms of the changes in agents' beliefs and actions (see also [10, 14, 16, 17]).

Speech acts have been extensively used in modeling communication in MAS to express intentions of the sender [22]. There have been many approaches to defining their semantics [1,24,29,30], some based on Belnap's four-valued logic [25]. Still, some researchers view them as primitive notions [31]. Within the most popular *mentalistic* approach, reflected in languages such as KQML and FIPA ACL [22], speech acts are defined through their impact on agents' mental attitudes. The current paper clearly falls in that approach (see especially Subsection 4.6).

3 Four-valued Framework

3.1 The Underlying Logic

To model phenomena such as lack and inconsistency of information, a commonly used logic is the four-valued logic proposed in [3]. However, as discussed, e.g., in [12, 34], the approach of [3] is problematic. Namely, in areas we focus on it often provides results deviating from intuitions. Our approach is strongly influenced by ideas underlying the 4QL query language [26, 27] which does not share such problems.

In what follows all sets are finite except for sets of formulas. We deal with the classical first-order language over a given vocabulary without function symbols. We assume that *Const* is a fixed set of constants, Var is a fixed set of variables and Rel is a fixed set of relation symbols. A *literal* is an expression of the form $R(\bar{\tau})$ or $\neg R(\bar{\tau})$, with $\bar{\tau} \in (Const \cup Var)^k$, where k is the arity of R. *Ground literals over Const*, denoted by $\mathcal{G}(Const)$, are literals without variables, with all constants in *Const*. If $\ell = \neg R(\bar{\tau})$ then $\neg\ell \stackrel{\text{def}}{=} R(\bar{\tau})$.

Though we use the classical first-order syntax, the presented semantics substantially differs from the classical one. Namely,

– truth values $\mathfrak{t}, \mathfrak{i}, \mathfrak{u}, \mathfrak{f}$ (true, inconsistent, unknown, false) are explicitly present;[5]
– the semantics is based on sets of ground literals rather than on relational structures.

This allows one to deal with the lack of information as well as inconsistencies (indicated respectively by truth values $\mathfrak{u}$ and $\mathfrak{i}$). The semantics of propositional connectives is summarized in Table 1. Observe that definitions of $\wedge$ and $\vee$ reflect minimum and maximum w.r.t. the ordering

$$\mathfrak{f} < \mathfrak{u} < \mathfrak{i} < \mathfrak{t}, \tag{1}$$

as advocated, e.g., in [9, 26, 27, 34]. This natural truth ordering indicates how "true" a given proposition is. The value $\mathfrak{f}$ indicates that the proposition is definitely not true, $\mathfrak{u}$ admits a possibility that the proposition is true, $\mathfrak{i}$ shows that there is at least one witness/evidence indicating the truth of the proposition, and finally, $\mathfrak{t}$ expresses that the proposition is definitely true. Note that (1) linearizes the truth ordering of [3], where $\mathfrak{u}$ and $\mathfrak{i}$ are incomparable. We order them using the knowledge ordering of [3], in which $\mathfrak{u} < \mathfrak{i}$. The implication $\rightarrow$, a four-valued extension of the classical implication, is discussed in [26, 27].

Let $v : Var \longrightarrow Const$ be a *valuation of variables*. For a literal ℓ, by $\ell(v)$ we understand the ground literal obtained from ℓ by substituting each variable x occurring in ℓ by constant $v(x)$.

Definition 3.1. The *truth value* of a literal ℓ w.r.t. a set of ground literals L and valuation v, denoted by $\ell(L, v)$, is defined as follows:

$$\ell(L,v) \stackrel{\text{def}}{=} \begin{cases} \mathfrak{t} \text{ if } \ell(v) \in L \text{ and } (\neg\ell(v)) \notin L; \\ \mathfrak{i} \text{ if } \ell(v) \in L \text{ and } (\neg\ell(v)) \in L; \\ \mathfrak{u} \text{ if } \ell(v) \notin L \text{ and } (\neg\ell(v)) \notin L; \\ \mathfrak{f} \text{ if } \ell(v) \notin L \text{ and } (\neg\ell(v)) \in L. \end{cases}$$ ◁

[5] For simplicity we use the same symbols to denote truth constants and corresponding truth values.

Table 1. Truth tables for ∧, ∨, → and ¬ (see [26, 27, 34]).

∧	f	u	i	t
f	f	f	f	f
u	f	u	u	u
i	f	u	i	i
t	f	u	i	t

∨	f	u	i	t
f	f	u	i	t
u	u	u	i	t
i	i	i	i	t
t	t	t	t	t

→	f	u	i	t
f	t	t	t	t
u	t	t	t	t
i	f	f	t	f
t	f	f	t	t

	¬
f	t
u	u
i	i
t	f

For a formula $\alpha(x)$ with a free variable x and $c \in \mathit{Const}$, by $\alpha(x)^x_c$ we understand the formula obtained from α by substituting all occurrences of x by c. Definition 3.1 is extended to all formulas in Table 2, where α denotes a first-order formula, v is a valuation of variables, L is a set of ground literals, and the semantics of propositional connectives appearing at righthand sides of equivalences is given in Table 1.

Table 2. Semantics of first-order formulas.

- if α is a literal then $\alpha(L, v)$ is defined in Definition 3.1;
- $(\neg\alpha)(L, v) \stackrel{\text{def}}{=} \neg(\alpha(L, v))$;
- $(\alpha \circ \beta)(L, v) \stackrel{\text{def}}{=} \alpha(L, v) \circ \beta(L, v)$, where $\circ \in \{\vee, \wedge, \rightarrow\}$;
- $(\forall x\alpha(x))(L, v) = \min_{a \in \mathit{Const}} (\alpha^x_a)(L, v)$, where min is the minimum w.r.t. ordering (1);
- $(\exists x\alpha(x))(L, v) = \max_{a \in \mathit{Const}} (\alpha^x_a)(L, v)$, where max is the maximum w.r.t. ordering (1).

3.2 Implementation Tool: 4QL

There are several languages designed for programming BDI agents (for a survey see, e.g., [28]). However, none of them directly addresses belief formation, in particular nonmonotonic or defeasible reasoning techniques. Our choice is 4QL, a DATALOG$^{\neg\neg}$-like query language. It enjoys tractable query computation and captures all tractable queries. Moreover, it provides simple, yet powerful constructs for expressing nonmonotonic rules reflecting, among others, default reasoning, autoepistemic reasoning, defeasible reasoning, the local closed world assumption, etc. [26]. It supports a modular and layered architecture, and provides a tractable framework for many forms of rule-based reasoning, both monotonic and nonmonotonic. As the underpinning principle, openness of the world is assumed, which may lead to lack of knowledge. Negation in rule heads may lead to inconsistencies. 4QL provides means for:

- the application-specific disambiguation of inconsistent information;
- the use of Local Closed World Assumption (Closed World Assumption, if needed);
- the implementation of various forms of nonmonotonic and defeasible reasoning.

Therefore, 4QL is a natural implementation tool for a diversity of applications.

Definition 3.2. By a *rule* we mean any expression of the form:

$$\ell :\!-\, b_{11}, \ldots, b_{1i_1} \mid \ldots \mid b_{m1}, \ldots, b_{mi_m}. \tag{2}$$

where $\ell, b_{11}, \ldots, b_{1i_1}, \ldots, b_{m1}, \ldots, b_{mi_m}$ are (negative or positive) literals and ',' and '|' abbreviate conjunction and disjunction, respectively.

Literal ℓ is called the *head* of the rule and the expression at the righthand side of :– in (2) is called the *body* of the rule.

By a *fact* we mean a rule with an empty body. Facts 'ℓ :– .' are abbreviated to 'ℓ.'. A finite set of rules is called a *program*. ◁

Definition 3.3. Let a set of constants, $Const$, be given. A set of ground literals L with constants in $Const$ is a *model of a set of rules* S iff for each rule (2) and any valuation v mapping variables into constants in $Const$, we have that:

$$\big(((b_{11} \land \ldots \land b_{1i_1}) \lor \ldots \lor (b_{m1} \land \ldots \land b_{mi_m})) \rightarrow \ell\big)(L, v) = \mathbf{t},$$

where it is assumed that the empty body takes the value $\mathbf{t}$ in any interpretation. ◁

The semantics of 4QL is defined by well-supported models generalizing the idea of [21]. Intuitively, a model is *well-supported* if all derived literals are supported by a reasoning that is grounded in facts. It appears that for any set of rules there is a unique well-supported model and this can be computed in polynomial time. Here we only indicate 4QL as a suitable implementation tool based on the logic discussed in Subsection 3.1. It is then fully compatible with solutions we propose in the current paper. For further details concerning 4QL consult [26, 27].

4 Solution Details

4.1 Modeling Speech Acts in the Four-Valued Framework

In a four-valued world, maintaining truth or falsity of a proposition, in the presence of multiple information sources, is challenging. Two additional logical values allow to model interactions between agents in a more intuitive and realistic way. This, however, introduces several new situations as compared to the two-valued case.

In what follows we introduce a basis for defining communication in general-purpose paraconsistent multi-agent systems.

When contradictory information comes into play we differentiate between two situations. In the first case, we interpret such contradiction as uncertainty or doubt, which may be of great importance in some systems. Clearly, in legal systems the contradictory statements bring doubts interpreted in favor of the defendant when deciding about guilt. This is commonly referred to as "the benefit of doubt". In other kinds of situations, contradiction is interpreted as a threat to the stability of the system. This means in practice, that protecting the knowledge that a system possesses and minimizing the impact of inconsistent information is of great importance. A classical example is a power plant service. Contradictory and thus not entirely dependable information about the functioning of the system may imply hazards and should trigger a thorough analysis of the situation, before undertaking any action.

We can approach both situations differently. Recently in MAS, many conflict resolution methods have become available, like those originating form social choice theory [8, 13, 20]. 4QL enables implementing them by introducing the notion of modules. Conflicts emerging between multiple information sources (agents), represented as particular modules can be resolved on the higher (meta-) level by a mediator module, which has in its repertoire various strategies implemented as rules (cf. [11]). In this work, we intend to construct the building blocks for defining complex dialogues, therefore we remain on the level of speech acts, which already can be used as a basic conflict resolution method. Thus, in the sequel, we do not refer to the previously mentioned general methods of conflict resolution, even though they are available for us. Instead, we focus on one speech act named `challenge`, which stands for questioning whether something is true by demanding a proof. Depending on the situation we deal with, `challenge` should be realized differently. It is described in more details in Subsection 4.6.

We begin this section by introducing epistemic profiles and communicative relations, which define the way agents react to perceiving speech acts. Next, we explain how belief revision is done in our framework and how conflict resolution is approached. Then we shed some light on the process of building a shared belief base via communication.[6] Finally, we present our characteristics of speech acts in 4QL.

4.2 Epistemic Profiles and Communicative Relations

An essential question is how to realize heterogeneity of agents in multiagent systems. Clearly, being different, when seeing the same thing the agents may draw different conclusions. In MAS there are many ways of differentiating agents' characteristics, for example, by equipping them with different intentional and/or commitment strategies. As we focus on agents' reasoning capabilities we look for a way to express diverse *epistemic profiles* of agents. The goal of introducing epistemic profiles explicitly is twofold. First of all, they define the way an agent reasons (e.g., by the use of rules). Secondly, they permit expressing the granularity of reasoning (e.g., by varying the level of certain attributes or accuracy of rules expressing the modeled phenomena). Third, they also characterize the manner of dealing with conflicting or lacking information by combining various forms of reasoning, including belief fusion, disambiguation of conflicting beliefs or completion of lacking information. The following definitions are adapted from [15], where also more intuition and examples can be found.

If S is a set then by $\textsc{Fin}(S)$ we understand the set of all finite subsets of S.

Definition 4.1. Let $\mathbb{C} \stackrel{\text{def}}{=} \textsc{Fin}(\mathcal{G}(\mathit{Const}))$ be the set of all finite sets of ground literals over the set of constants *Const*. Then:

- by a *constituent* we understand any set $C \in \mathbb{C}$;
- by an *epistemic profile* we understand any function $\mathcal{E} : \textsc{Fin}(\mathbb{C}) \longrightarrow \mathbb{C}$;
- by a *belief structure over an epistemic profile* $\mathcal{E}$ we mean $\mathcal{B}^{\mathcal{E}} = \langle \mathcal{C}, F \rangle$, where:
  - $\mathcal{C} \subseteq \mathbb{C}$ is a nonempty set of constituents;
  - $F \stackrel{\text{def}}{=} \mathcal{E}(\mathcal{C})$ is the *consequent* of $\mathcal{B}^{\mathcal{E}}$. ◁

[6] We use the notion of belief base as an analogue to knowledge base.

In the sequel we often use the notions of the set of consequents and the well-supported models interchangeably.

Definition 4.2. Let $\mathcal{E}$ be an epistemic profile. The *truth value of formula* α w.r.t. belief structure $\mathcal{B}^{\mathcal{E}} = \langle \mathcal{C}, F \rangle$ and valuation v, denoted by $\alpha(\mathcal{B}^{\mathcal{E}}, v)$, is defined by:[7]

$$\alpha(\mathcal{B}^{\mathcal{E}}, v) \stackrel{\text{def}}{=} \alpha(\bigcup_{C \in \mathcal{C}} C, v). \qquad \triangleleft$$

Depending on the epistemic profiles, agents may react variously to the perceived information. We distinguish three types of *communicative relations*, considered from the receiver's perspective:

1. *communication with authority*: an agent (receiver) communicating with an authority (sender) is prone to adopt the interlocutor's theses. However, when in strong disagreement, instead of abandoning his beliefs totally, he would rather investigate the reasons of the conflict. Nevertheless, in case of a mere discrepancy of opinions he would give up on his own prior beliefs,
2. *peer to peer communication*: both parties are viewed as equally credible and important information sources, therefore nobody's opinion prevails a priori. This shows up when dealing with inconsistent information, which taints everything: whenever one party believes a proposition is inconsistent, the other party's prior beliefs do not matter. The peer, upon receiving information that introduces inconsistency to its beliefs, is obliged to comply with it. Therefore every discrepancy of opinions boils down to inconsistency,
3. *communication with subordinate*: when dealing with a less reliable source of information, the receiver with authority would not be willing to abandon his beliefs in favor of the interlocutor's. He would value his observations higher and protect true and false propositions from being infected by inconsistency. However, in case of strong disagreements, he engages in conflict resolution.

4.3 Belief Revision

Perceiving new information, whether it is some previously unknown fact or a new valuation of a proposition, may lead to belief revision. Its frequency varies: authorities need to revise their beliefs more seldom than peers. Also, some application-specific matters come into play as explained above. Apparently, the communicative relation functions as a filter, which determines in what cases a new percept triggers belief revision.

The great advantage of 4QL is the ease of performing belief revision. Importantly, such a revision can be performed in polynomial time which is guaranteed due to the use of 4QL [27].

Belief revision strategies, as expressed in 4QL, may vary from conservative to more drastic ones. In such cases belief revision amounts to computing a new well-supported model on the basis of a refreshed set of facts and rules. More precisely, consider a situation where an agent revises its beliefs so that it accepts that (positive or negative)

[7] Since $\bigcup_{C \in \mathcal{C}} C$ is a set of ground literals, $\alpha(\mathcal{S}, v)$ is well-defined by Table 2.

ground literal ℓ becomes true. The *conservative* approach depends on making ℓ true and temporarily blocking rules contradicting ℓ. There are two cases involved (for simplicity assume that there are only ground rules with unique heads):

– when the value of ℓ in the well-supported model is $\mathtt{t}$ then no updates are required;
– when the value of ℓ in the well-supported model is in $\{\mathtt{u}, \mathtt{f}, \mathtt{i}\}$ then:
  1. add ℓ to the set of facts;
  2. remove $\neg\ell$ from the set of facts (if any);
  3. block the rule with the head $\neg\ell$ (if such a rule exists);
  4. recompute the well-supported model.

The *drastic* strategy depends on removing the rule with the head $\neg\ell$ rather than blocking it. Note that removing the rule with $\neg\ell$ as its head is harmless for possible further belief revisions making $\neg\ell$ true. In such cases one adds $\neg\ell$ to the set of facts (step 1. above), so the rule with the head $\neg\ell$ becomes redundant. Of course, the original knowledge expressed by rules is partly lost.

Thanks to the flexibility of 4QL, one can combine conservative and drastic strategies. For example, in particular circumstances one can disallow removing certain rules, for example those representing "hard" beliefs, and allow for removing other ones having a weaker status, for example because they have been machine learned and temporarily assumed to be valid.

4.4 Conflict Resolution

Introducing inconsistency as a first-class citizen entails a need of frequent conflict resolution. We distinguish two types of conflicts: *strong disagreements* and *mere discrepancies*. The first situation occurs when agents have contradictory opinions, that is whenever one believes φ is true and the other believes $\neg\varphi$ is true. We deal with discrepancies, when one agents believes φ is inconsistent, and the other believes it is true or false. Depending on the application in question, these conflicts can be solved differently.

For instance, in the critical systems domain, true and false propositions are naturally protected as to avoid the growth of uncertainty. Therefore, cases of strong disagreements must be solved by means of the `challenge` speech act, regardless of the communicative relation between the interlocutors. This ensures that true or false beliefs are abandoned for good reasons solely. However, in domains where the communicative relation is of greater significance, we imagine different solutions.

In case of discrepancies, we believe to have attained an application-independent solution, where only agents' communicative relation matters, as explained in Subsection 4.6.

4.5 Shared Beliefs

Whenever two agents first engage in communication, we assume that they form a virtual group. For such a group we can define epistemic profiles as well, which is however outside of the scope of this paper, but is characterized in [15]. In the current work we concentrate on information acquired via speech acts. Such information is then stored in the set of constituents of the group level, which are naturally transformed into consequents according to the epistemic profile. They represent the beliefs shared by the agents via communication, including the perceived knowledge about each other.

Notice, that in our framework we refrain from explicitly stating what do agents learn about one another via speech acts. However, the way of acquiring this information reciprocally is of a great significance to functioning of a multiagent system. By introducing the concept of shared beliefs here, we aim at giving some intuitions and sketching the path for future research. See also Subsection 5.1.

4.6 A Four-valued Characterization of Speech Acts

Let us now outline the universal rules for perceiving speech acts by individual agents. This section describes realization of four different speech acts in the four-valued framework. We will also provide solutions for dialogical conflict resolution and adjusting discrepancies of opinions. Next, we provide the semantics of four selected speech acts, which serve as building blocks of communication.

We define speech acts by specifying their *preconditions* and *complex post actions*. By the expression:

$$\{\textit{precondition}\}\langle \textit{speech act}\rangle[\textit{complex post action}] \tag{3}$$

we mean that performing a *speech act* in the presence of the *precondition* triggers the *complex post action*. In what follows we detail the semantics of speech acts in the form of tables, in which, depending on the type of communicative relation, we determine the preconditions, the shape of the speech act and the resulting complex post action. For simplicity, we number the respective communicative relation types, where:

- 1 signifies communication with an authority,
- 2 signifies peer to peer communication,
- 3 refers to communication with subordinate.

The precondition is in this case the receiver's valuation of the proposition in question. For clarity, throughout this section we employ the following notation:

$$v_R(\alpha) \stackrel{\text{def}}{=} \alpha(\mathcal{B}^{\mathcal{E}}, v), \text{ where } \mathcal{E} \text{ is agent } R\text{'s epistemic profile;}$$
$$v'_R(\alpha) \stackrel{\text{def}}{=} \alpha(\mathcal{B}^{\mathcal{E}'}, v), \text{ where } \mathcal{E}' \text{ is agent } R\text{'s epistemic profile after performing belief revision on } \mathcal{E}.$$

Assertions $\texttt{assert}_{S,R}(\alpha, x)$ stands for agent S (sender) telling agent R (receiver) that its valuation of α is x. After such perception, agent R can behave variously. Let us focus on different configurations, taking into account distinct communicative relations between the agents and their different valuations of α:

1. *Perceiving inconsistent information*, where agents engaged in peer-to-peer communication or communication with authority relations, adopt the interlocutors' theses about inconsistent information. Authorities, however, adopt such a thesis only if it was already inconsistent or unknown. In both cases a `concede` is sent as an acknowledge, but only in the latter case, belief revision takes place.

Table 3. Perceiving inconsistent information.

Type	Precondition	Speech Act	Complex Post Action[8]
1, 2	$v_R(\alpha) = \mathfrak{f}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{i})$	$v'_R(\alpha) = \mathfrak{i}; \texttt{concede}_{R,S}(\alpha, \mathfrak{i})$
3	$v_R(\alpha) = \mathfrak{f}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{i})$	-
1, 2, 3	$v_R(\alpha) = \mathfrak{u}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{i})$	$v'_R(\alpha) = \mathfrak{i}; \texttt{concede}_{R,S}(\alpha, \mathfrak{i})$
1, 2, 3	$v_R(\alpha) = \mathfrak{i}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{i})$	$\texttt{concede}_{R,S}(\alpha, \mathfrak{i})$
1, 2	$v_R(\alpha) = \mathfrak{t}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{i})$	$v'_R(\alpha) = \mathfrak{i}; \texttt{concede}_{R,S}(\alpha, \mathfrak{i})$
3	$v_R(\alpha) = \mathfrak{t}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{i})$	-

2. *Perceiving previously unknown information*, which leads to adopting it by the receiver regardless the communicative relation. In all but one special case (when the new information is also unknown, see below), belief revision takes place and a `concede` is sent.

Table 4. Perceiving previously unknown information.

Type	Precondition	Speech Act	Complex Post Action
1, 2, 3	$v_R(\alpha) = \mathfrak{u}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{f})$	$v'_R(\alpha) = \mathfrak{f}; \texttt{concede}_{R,S}(\alpha, \mathfrak{f})$
1, 2, 3	$v_R(\alpha) = \mathfrak{u}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{u})$	-
1, 2, 3	$v_R(\alpha) = \mathfrak{u}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{i})$	$v'_R(\alpha) = \mathfrak{i}; \texttt{concede}_{R,S}(\alpha, \mathfrak{i})$
1, 2, 3	$v_R(\alpha) = \mathfrak{u}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{t})$	$v'_R(\alpha) = \mathfrak{t}; \texttt{concede}_{R,S}(\alpha, \mathfrak{t})$

3. *Perceiving information that is unknown*, which is ignored regardless the communicative relation, because by default all information is unknown. Therefore, taking action under such circumstances would be redundant.

Table 5. Perceiving information that is unknown.

Type	Precondition	Speech Act	Complex Post Action
1, 2, 3	$v_R(\alpha) = \mathfrak{f}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{u})$	-
1, 2, 3	$v_R(\alpha) = \mathfrak{u}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{u})$	-
1, 2, 3	$v_R(\alpha) = \mathfrak{i}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{u})$	-
1, 2, 3	$v_R(\alpha) = \mathfrak{t}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{u})$	-

4. *Perceiving previously inconsistent information*, which depends on the communicative relation. In case of communication with authority, the sender's belief (unless unknown) overrides the receiver's. A belief revision takes place if necessary, that is, unless their beliefs are equal, and a `concede` is sent. In the two remaining cases the message is ignored, unless it is also inconsistent. If so, a `concede` is sent.

Table 6. Perceiving previously inconsistent information.

Type	Precondition	Speech Act	Complex Post Action
1	$v_R(\alpha) = \mathfrak{i}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{f})$	$v'_R(\alpha) = \mathfrak{f}$; $\texttt{concede}_{R,S}(\alpha, \mathfrak{f})$
2, 3	$v_R(\alpha) = \mathfrak{i}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{f})$	–
1, 2, 3	$v_R(\alpha) = \mathfrak{i}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{u})$	-
1, 2, 3	$v_R(\alpha) = \mathfrak{i}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{i})$	$\texttt{concede}_{R,S}(\alpha, \mathfrak{i})$
1	$v_R(\alpha) = \mathfrak{i}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{t})$	$v'_R(\alpha) = \mathfrak{t}$; $\texttt{concede}_{R,S}(\alpha, \mathfrak{t})$
2, 3	$v_R(\alpha) = \mathfrak{i}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{t})$	–

5. *Perceiving compatible information*, where by "compatible" we mean that both agents have exactly the same valuation of the proposition. This yields no belief revision, but in all cases but one, the assertion is acknowledged by sending a `concede`. In the one case of unknown information such a perception is ignored.

Table 7. Perceiving compatible information.

Type	Precondition	Speech Act	Complex Post Action
1, 2, 3	$v_R(\alpha) = \mathfrak{f}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{f})$	$\texttt{concede}_{R,S}(\alpha, \mathfrak{f})$
1, 2, 3	$v_R(\alpha) = \mathfrak{u}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{u})$	-
1, 2, 3	$v_R(\alpha) = \mathfrak{i}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{i})$	$\texttt{concede}_{R,S}(\alpha, \mathfrak{i})$
1, 2, 3	$v_R(\alpha) = \mathfrak{t}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{t})$	$\texttt{concede}_{R,S}(\alpha, \mathfrak{t})$

6. *Perceiving contradictory information* where, regardless communicative relation, whenever one agent believes a proposition is true and the other believes the contrary, they must come to an agreement by means of a `challenge` speech act. This may succeed, leading to adopting the sender's thesis, or fail, with no direct effect on the interlocutors. This choice is application-specific, for details see Subsection 4.6. Notice, that upon receiving the contradictory information $\texttt{assert}_{S,R}(\alpha, x)$, the speech act $\texttt{challenge}_{R,S}(\alpha, x)$ stands for agent R asking agent S: "why does your valuation of α equal x?". See Subsection Challenges of this Section for more details on the semantics of challenges.

Table 8. Perceiving contradictory information.

Type	Precondition	Speech Act	Complex Post Action
1, 2, 3	$v_R(\alpha) = \mathfrak{t}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{f})$	$\texttt{challenge}_{R,S}(\alpha, \mathfrak{f})$
1, 2, 3	$v_R(\alpha) = \mathfrak{f}$	$\texttt{assert}_{S,R}(\alpha, \mathfrak{t})$	$\texttt{challenge}_{R,S}(\alpha, \mathfrak{t})$

In Table 9, all complex post actions of assertions discussed in cases 1-6 above are summarized.

Table 9. Perceiving assertions in different communicative relations: summary. Here, $\lightning$ means that a `challenge` speech act must be sent as a reply, · indicates that the receiver maintains his beliefs and no action is needed. In the remaining cases a `concede` speech act is sent after a possible belief revision. ◯ means an application-specific solution.

Receiver (subordinate)		Sender $\mathfrak{f}$	$\mathfrak{u}$	$\mathfrak{i}$	$\mathfrak{t}$
	$\mathfrak{f}$	$\mathfrak{f}$	·	$\mathfrak{i}$	(↯)
	$\mathfrak{u}$	$\mathfrak{f}$	·	$\mathfrak{i}$	$\mathfrak{t}$
	$\mathfrak{i}$	$\mathfrak{f}$	·	$\mathfrak{i}$	$\mathfrak{t}$
	$\mathfrak{t}$	(↯)	·	$\mathfrak{i}$	$\mathfrak{t}$

Receiver (peer)		Sender $\mathfrak{f}$	$\mathfrak{u}$	$\mathfrak{i}$	$\mathfrak{t}$
	$\mathfrak{f}$	$\mathfrak{f}$	·	$\mathfrak{i}$	(↯)
	$\mathfrak{u}$	$\mathfrak{f}$	·	$\mathfrak{i}$	$\mathfrak{t}$
	$\mathfrak{i}$	·	·	$\mathfrak{i}$	·
	$\mathfrak{t}$	(↯)	·	$\mathfrak{i}$	$\mathfrak{t}$

Receiver (authority)		Sender $\mathfrak{f}$	$\mathfrak{u}$	$\mathfrak{i}$	$\mathfrak{t}$
	$\mathfrak{f}$	$\mathfrak{f}$	·	·	(↯)
	$\mathfrak{u}$	$\mathfrak{f}$	·	$\mathfrak{i}$	$\mathfrak{t}$
	$\mathfrak{i}$	·	·	$\mathfrak{i}$	·
	$\mathfrak{t}$	(↯)	·	·	$\mathfrak{t}$

Requests $\texttt{request}_{S,R}(\alpha)$ stands for agent S requesting agent R to provide information about α. After such a request, the sender must wait for a reply. The receiver R should reply with what he knows about α:

$$\{v_R(\alpha) = x\} \ \langle \texttt{request}_{S,R}(\alpha) \rangle \ [\texttt{assert}_{R,S}(\alpha, x)]$$

For the receiver of a request, no belief revision takes place. The sender, after receiving the response, behaves according to the rules for assertions.

Table 10. Perceiving requests.

Type	Precondition	Speech Act	Complex Post Action
1, 2, 3	$v_R(\alpha) = \mathfrak{f}$	$\texttt{request}_{S,R}(\alpha)$	$\texttt{assert}_{R,S}(\alpha, \mathfrak{f})$
1, 2, 3	$v_R(\alpha) = \mathfrak{u}$	$\texttt{request}_{S,R}(\alpha)$	$\texttt{assert}_{R,S}(\alpha, \mathfrak{u})$
1, 2, 3	$v_R(\alpha) = \mathfrak{i}$	$\texttt{request}_{S,R}(\alpha)$	$\texttt{assert}_{R,S}(\alpha, \mathfrak{i})$
1, 2, 3	$v_R(\alpha) = \mathfrak{t}$	$\texttt{request}_{S,R}(\alpha)$	$\texttt{assert}_{R,S}(\alpha, \mathfrak{t})$

Concessions $\texttt{concede}_{S,R}(\alpha, x)$ stands for agent S's communicating its agreement about the valuation of φ. Importantly, only concessions about compatible valuations are considered, other are ignored, as indicated in Table 11. Concession is more of an acknowledgement, as no belief revision on the individual level takes place here. Instead, α with a valuation x is added to the agents' virtual group's set of constituents (see Subsection 4.2) and (possibly) a belief revision on the virtual group's level occurs.

Challenges $\texttt{challenge}_{S,R}(\alpha, x)$ stands for S's communicating its contradictory stance with respect to R's opinions regarding α (x is either $\mathfrak{t}$ or $\mathfrak{f}$ here). Inspired by the two-valued case of challenges treated in [35], a challenge is in fact a request to provide a proof of the receiver's stance towards α together with an implicit assertion of the contradictory stance towards α. However, in our approach we do not make this assertion explicit, in order not to emit redundant information.

$$\texttt{challenge}_{S,R}(\alpha, \mathfrak{t}) \equiv \texttt{request}_{S,R}(\texttt{assert}_{R,S}(PROOF(\alpha, \mathfrak{t})))$$
$$\texttt{challenge}_{S,R}(\alpha, \mathfrak{f}) \equiv \texttt{request}_{S,R}(\texttt{assert}_{R,S}(PROOF(\alpha, \mathfrak{f})))$$

Table 11. Perceiving concessions. Cases not included in the table are ignored.

Type	Precondition	Speech Act	Complex Post Action
1, 2, 3	$v_R(\alpha) = \mathfrak{f}$	$\texttt{concede}_{S,R}(\alpha, \mathfrak{f})$	add α to group[a] constituents[b]
1, 2, 3	$v_R(\alpha) = \mathfrak{u}$	$\texttt{concede}_{S,R}(\alpha, \mathfrak{u})$	add α to group constituents
1, 2, 3	$v_R(\alpha) = \mathfrak{i}$	$\texttt{concede}_{S,R}(\alpha, \mathfrak{i})$	add α to group constituents
1, 2, 3	$v_R(\alpha) = \mathfrak{t}$	$\texttt{concede}_{S,R}(\alpha, \mathfrak{t})$	add α to group constituents

[a] The virtual group consisting of R and S.
[b] Adding facts to the set of constituents may trigger belief revision on the virtual group level.

The proof in question depends on the structure of α and might represent just the last rule used to derive α (or a choice of rules if there were several ways to achieve α). If, for an atomic α, its negation $\neg\alpha$ is a fact, there is no way to prove that α is true, and the challenged agent who received $\texttt{challenge}_{S,R}(\alpha, \mathfrak{t})$ should reply with a special symbol $\texttt{assert}_{R,S}(\alpha, \bot)$ for "I give up" (cf. [35]). This counts as agent's R failure to prove α. An agent who receives a `challenge` should react according to the rules for requests. Challenges per se do not yield belief revision, the true impact on agents' beliefs is achieved by the assertions initiated by them. However, when a (possibly deeply nested) challenge folds, if it was successful, an acknowledgement must be sent. Therefore whenever an agent sends $\texttt{challenge}_{S,R}(\alpha, x)$, if at some point α becomes x it triggers sending a `concede` by S. This is a sign of a challenge ending successfully for R. Otherwise a challenge fails. It is important to notice that even a failed challenge might have caused some belief revision if some of the assertions have been acknowledged.

Table 12. Perceiving challenges. Cases not included in the table are ignored.

Type	Precondition	Speech Act	Complex Post Action
1, 2, 3	$v_R(\alpha) = \mathfrak{f}$	$\texttt{challenge}_{S,R}(\alpha, \mathfrak{t})$	$\texttt{assert}_{R,S}(PROOF(\alpha, \mathfrak{t}))$
1, 2, 3	$v_R(\alpha) = \mathfrak{t}$	$\texttt{challenge}_{S,R}(\alpha, \mathfrak{f})$	$\texttt{assert}_{R,S}(PROOF(\alpha, \mathfrak{f}))$

5 An Example

This example is intended to demonstrate perceiving speech acts in the four-valued framework. We use the 4QL interpreter for modeling and for computing well-supported models.[9] In what follows, we detail how an agent reacts to perceiving an assertion, a concession or a challenge. For simplicity, we focus on the case when the sender S is an authority and the receiver R a subordinate.

Assume that the receiver, a rescue-agent, is capable of putting out fire and detoxicating an area. Suppose at the given moment he is aware of the fire but cannot sense the heat, because of faulty sensors. A very simplified program in 4QL referring to this situation is presented in Figure 1.

[9] The interpreter is available from http://www.4ql.org/ .q

```
module r:
  relations:
    a(literal).
  rules:
    a(risky) :- a(poison) | a(heat).
    -a(risky) :- -a(poison), -a(heat).
    a(heat) :- a(fire).
    -a(poison) :- a(safe).
    a(busy) :- a(detox) | a(extinguish).
    -a(detox) :- a(heat).
    -a(heat) :- a(lowtemp).
    -a(fire) :- a(lowtemp).
  facts:
    a(fire).
    -a(heat).
    a(extinguish).
end.
```

Fig. 1. Exemplary 4QL program.

Then, the following unique well-supported model B_{R_1} represents agent R's belief base:[10]

$$B_{R_1} = \{heat, \neg heat, detox, \neg detox, fire, busy, extinguish\}. \quad (4)$$

On the basis of B_{R_1} we know that agent R is inconsistent about $heat$ and $detox$. Literals $fire$, $busy$ and $extinguish$ are true. Recall that literals absent in the model are unknown.

First, we show the simple case covering belief revision and responding with an acknowledgement only (see Figure 2). Next, we present an example of an assertion that leads to conflict resolution performed by means of `challenge` (see Figure 3).

The story starts when agent S, an authority, asserts to R that $heat$ is true (see (a) in Figure 2). In R's belief base B_{R_1}, $heat$ is inconsistent. Therefore, after perceiving such an assertion, according to the rules (see Table 9), agent R adopts S's belief. In the course of belief revision, the program shown in Figure 1 is changed so that $\neg heat$ is no longer a fact. Instead, we put $heat$ as a new fact and compute the new well-supported model B_{R_2}:

$$B_{R_2} = \{heat, \neg detox, fire, busy, extinguish, risky\}. \quad (5)$$

Finally, agent R answers with a concession (see (b) in Figure 2), acknowledging that it shares a belief about $heat$ being true.

Let us now consider a case of conflict resolution by means of a challenge. We continue with the scenario, therefore agent's R belief base is B_{R_2} as shown in (5). Now the

[10] To compute the well-supported model one can use the 4QL interpreter or use the algorithm from [26, 27].

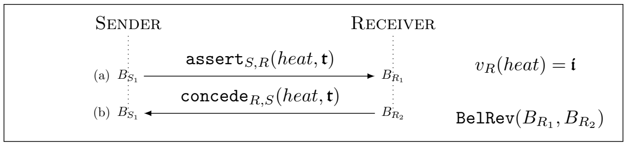

Fig. 2. Perceiving compatible information.

sender makes an assertion that $risky$ is false (see (a) in Figure 3), which is contradictory with the receiver's beliefs. In our scenario, regardless the communicative relation, R must challenge (5), as it should abandon $risky$ only if entirely convinced. Therefore, R sends a challenge (see (b) in Figure 3), to which S must answer with a proof. As indicated in the description of the `challenge` speech act, we focus on the request part. The additional assertion is omitted to keep the picture clear. Assume that the relevant rules from agent S's epistemic profile are:

```
-risky :- -poison, -heat.
-heat :- lowtemp, -fire.
```
(6)

As explained in Subsection 4.6 in the part about challenges, agent S must provide a proof for the assertion about $\neg risky$ he has made before. In our example, the last rule in the derivation of $\neg risky$ determines the proof (see (6)). In order for $\neg risky$ to hold, $poison$ and $heat$ must both be false. Therefore, S answers with a sequence of assertions (see (c) and (e) in Figure 3), one about $poison$ and one about $heat$. Now we analyze what impact these assertions have on agent R. The first assertion causes R to adopt $\neg poison$, since $poison$ was not present (therefore unknown) in R's belief base B_{R_2}. This leads to another belief revision, after which B_{R_3} is R's new belief base:

$$B_{R_3} = \{heat, \neg detox, fire, \neg poison, busy, extinguish, risky\} \tag{7}$$

To acknowledge this situation, R replies with a concession (see (d) in Figure 3). The subsequent assertion about $heat$ being false, made by agent S, causes another challenge (see (f) in Figure 3), because $heat$ was true in B_{R_3}. Luckily, again S knows how to prove this (see (6)) and answers with another sequence of assertions (see (g) and (i) in Figure 3): one about $lowtemp$ and one about $\neg fire$.

Similarly, the first assertion causes R to revise its beliefs and acknowledge (see (h) in Figure 3), which results in its subsequent belief base B_{R_4}:

$$\begin{aligned} B_{R_4} = \{&heat, \neg heat, detox, \neg detox, fire, \neg fire, \neg poison, busy, extinguish, \\ &lowtemp, risky, \neg risky\}. \end{aligned} \tag{8}$$

The second assertion also causes belief revision (S is an authority and $fire$ is inconsistent in B_{R_4}), resulting in the new belief base B_{R_5}:

$$B_{R_5} = \{\neg heat, \neg fire, \neg poison, busy, extinguish, lowtemp, \neg risky\}. \tag{9}$$

Agent R concedes that $fire$ is false (see (j) in Figure 3) and sends the acknowledgement about falsity of $heat$ (see (k) in Figure 3) at which point the second challenge folds.

Since agent R has been convinced that $risky$ is false (9), it replies with a concession (see (l) in Figure 3). That causes the first challenge to fold and we may conclude that agent S has successfully convinced R that $risky$ no longer holds.

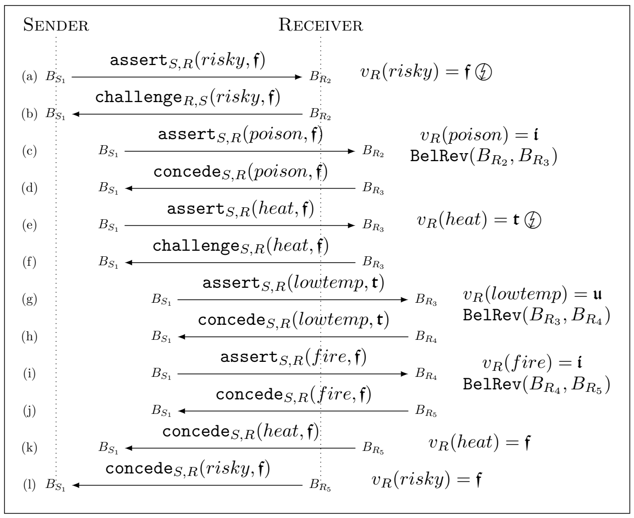

Fig. 3. Perceiving contradictory information.

Notice, that although the above scenario partially resembles a persuasion dialogue, it should not be considered as an example of such. As mentioned before, in this work we provide a basis for building more complex dialogues by analyzing what happens when agents perceive speech acts, the reactional layer of communication. In true persuasion dialogues, various interesting aspects come into play, among others the motivation of agents and their pro-activeness when choosing to utter a speech act, which clearly is outside of the scope of this paper (but see [35] and [16, Chapter 8]).

5.1 Building a Shared Belief Base

In the course of the dialogue above, the agents exchange their beliefs and acknowledge the common ones. Whenever a concession is sent, it means an agreement has been made, therefore the conceded literals add to the agents' shared knowledge base. Adding new facts may, similarly as in the case of individual agents, lead to belief revision. In our example this happened, e.g., after the first assertion (see (a) in Figure 2), agent R conceded that $heat$ was true. Then, in the course of the challenge, S managed to convince him that *heat* was not the case anymore (see (k) in Figure 3). Therefore, at first $heat$ was in the shared belief base but ultimately $\neg heat$ took its place.

In summary, after the process of exchanging information, the belief base of the virtual group consisting of S and R includes the following facts:

$$\{\neg poison,\ lowtemp, \neg fire, \neg heat, \neg risky\}. \tag{10}$$

6 Conclusions

Agents need to act in an uncertain and dynamic environments, where they receive information from multiple sources. Therefore it is vital that knowledge representation methods for modeling multi-agent systems respect this fact and allow agents to act in the presence of lack of information and inconsistent information. A new four-valued paraconsistent logic [26, 27] appears to be cut out for this situation, as it allows for much more precise modeling of reality than was possible in the classical two-valued case. Nonmonotonic logic, in turn, allows for drawing conclusions that typically hold, but not necessarily always. Their combination, implemented in 4QL, has already been shown to model agent's individual and group beliefs. As to the agents' internal reasoning, their reasoning schemas are formalized in terms of rules in the chosen four-valued knowledge-based framework, in terms of belief structures and epistemic profiles [15]. A great bonus of the 4QL approach is that queries can be computed in polynomial time. This tractability stands in stark contrast to the usual two-valued approaches to group interactions, where EXPTIME completeness of satisfiability problems is a common hindrance [18, 19].

This paper is a first step in a research program that combines dialogue theory and argumentation theory with the new four-valued approach to modeling multi-agent interactions. Before turning to full-fledged argumentation-based dialogues in future work, this paper characterizes four types of speech acts, namely assertions, requests, concessions and challenges, that play an important role in, for example, persuasion and deliberation dialogues [4, 5, 10, 14, 16, 17, 35].

We consider three types of communication: from an authority, from a peer, and from a subordinate. In each type of communication, the speech acts are considered from the mentalistic perspective, as expressed in the triple: precondition, speech act, complex post action. Based on a pre-condition, namely the stance towards the proposition of the receiving agent, and on the three types of relation between sender and receiver, each speech act will result in different follow-up actions, both in terms of belief revision and new speech acts to be performed.

Thus, along with defining rules for perceiving speech acts, we indicated how communication influences agents' beliefs, that is, when belief revision is done and how a shared belief base is built between a sender and receiver. There is no universal schema describing realization of a speech act, but they can be summarized as follows:

- assertions may lead to belief revision on the individual level and are replied to with `concede` or `challenge` or ignored,
- requests do not cause belief revision and are replied to with `assert` or ignored,
- concessions cause belief revision on the group level and are never replied to,
- challenges do not cause belief revision, and are replied to with multiple `asserts` or ignored.

Our example of a simple dialogue between a rescue-agent and its boss shows how speech acts and agents' reasoning rules naturally combine in the framework of 4QL, leading to intuitive conclusions while maintaining tractability. Thus, a foundation has been laid for extending the four-valued approach to modeling more complex dialogues and argumentations between agents reasoning in uncertain and dynamic environments.

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