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A Logical Framework for Grounding-based Dialogue Analysis [1]

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Abstract

A major critique against BDI (Belief, Desire, Intention) approaches to communication is that they require strong hypotheses such as sincerity and cooperation on the mental states of the agents (cf. for example [13,14,5]). The aim of this paper is to remed this defect. Thus we study communication between heterogeneous agents *via* the notion of *grounding*, in the sense of being publicly expressed and established. We show that this notion is different from social commitment, from the standard mental attitudes, and from different versions of common belief. Our notion is founded on speech act theory, and it is directly related to the *expression of the sincerity condition* [9,11,16] when a speech act is performed. We use this notion to characterize speech acts in terms of preconditions and effects. As an example we show how persuasion dialogues *à la Walton & Krabbe* can be analyzed in our framework. In particular we show how speech act preconditions constrain the possible sequences of speech acts.

Keywords: grounding, commitment, dialogue, speech acts, modal logic, common belief, BDI logic

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1 Introduction

Traditionally there are two ways to analyze dialogues: the first one is through their structure, and the second one is through the participants' mental states. The former approaches analyze dialogues independently of the agents' mental states and focus on what a third party would perceive of it. This route is taken by the *conventional* approaches such as Conte and Castelfranchi's [3], Walton and Krabbe's dialogue games [19], Singh [14], and Colombetti et col. [5,18], who study the notion of social commitment.

On the one hand, a major critique concerning the mentalist approaches (cf. e.g. [14,5]) is that they require strong hypotheses on the architecture of the agents' internal state and the principles governing their behavior (such as sincerity, cooperation, competence), while agents communicating in open systems are heterogeneous and might thus work with very different kinds of internal states and principles. Suppose for example a speaker asserts that p. Then he may or may not believe that p, depending on his sincerity. The hearer may or may not believe the speaker believes p, depending his beliefs about the speaker's sincerity. And if the hearer starts to believe the speaker believes p, the hearer may or may not start to believe p himself depending on his beliefs about the speaker's competence.

On the other hand, a common hypothesis in formal frameworks for agent-to-agent communication is to suppose speech acts are public, and that there is no misperception in dialogue: perception of speech acts is sound and complete with respect to reality.

In this paper we propose a *notion of grounding* which captures what is expressed and established during a conversation between different agents (Sect. 2). Using a particular modal operator to capture this notion (Sect. 3), we show that it is at the borderline between mentalist and structure-based approaches (Sect. 4). We then study a particular kind of dialogue (Walton and Krabbe's PPD_0 persuasion dialogues) by characterizing the speech act types that are involved there (Sect. 5). Our characterization induces a protocol governing the conversational moves. Contrarily to what is usually done in Agent Communication Languages (ACL) this protocol is not described in some metalanguage but on the object language level.

2 Grounding

Here we investigate the notion of grounded information, which we view as information that is *publicly expressed and accepted as being true by all the agents participating in a conversation.* A piece of information might be grounded even when some agents privately disagree, as long as they do not manifest their disagreement.

Our notion stems from speech act theory, where Searle's *expression of an Intentional state* [11] is about a psychological state related to the state of the world. Even if an utterance was unsincere an Intentional State has been expressed, and that state corresponds in some way to a particular belief of the speaker.

The concept of groundedness applies to Moore's paradox, according to which one cannot successfully assert "p is true and I do not believe p". The paradox follows from the fact that: on the one hand, the assertion entails expression of the sincerity condition about p (the speaker believes p); on the other hand, the assertion expresses the speaker believes he believes p is false. Via a principle of introspection this expresses that he believes p is false, and the assertion is contradictory.

Vanderveken [16,17] has captured the subtle difference between *expressing* an Intentional state and *really being in* such a state by distinguishing *success conditions* from *non-defectiveness conditions*, thus refining the felicity conditions as defined by Searle [9,10,12]. According to Vanderveken, when we assert p we *express* that we believe p (success condition), while the speaker's being in a state of believing that p is a condition of non-defectiveness.

Whenever an agent asserts p then it is grounded that he believes that p, independently of the agent's individual beliefs. For a group of agents we say that a piece of information is grounded if and only if for every agent it is grounded that he believes it.

Groundedness is an objective notion: it refers to what can be observed, and only to that. While it is related to mental states because it corresponds to the expression of Intentional states, it is not an Intentional state: it is neither a belief nor a goal, nor an intention. As we shall see, it is simple and elegant way of characterizing mutual belief.

We believe that such a notion is interesting because it fits the public character of speech act performance. As far as we are aware the logical investigation of such a notion has neither been undertaken in the social approaches nor in the conventional approaches. A similar notion has been investigated very recently in [7], which formalizes the notions of manifested opinion in the sense of ostensible belief and of ostensible intention.

3 Logical framework

In this section, we present a light version of the logic of belief, choice and intention we developed in [6], augmented by a modal operator expressing "groundedness". In particular, we neither develop here temporal aspects nor relations between action and mental attitudes (the frame problem for belief and choice).

3.1 Semantics

Let $AGT = \{i, j, \ldots\}$ be a set of agents. We suppose AGT is finite. Let $ATM = \{p, q, \ldots\}$ be the set of propositions. Complex formulas are denoted by $A, B, C, \ldots$. A model includes a set of possible worlds W and a mapping $V : W \to (ATM \to \{0, 1\})$ associating a valuation V_w to every $w \in W$. Models moreover contain accessibility relations that will be detailed in the sequel.

Belief.

In order to not only speak about facts, but also the participants' beliefs we introduce a modal operator of belief. $Bel_i A$ reads "agent i believes that A holds", or "agent i believes A". To each agent i and each possible world w we associate a set of possible worlds $\mathcal{B}_i(w)$: the worlds that are consistent with i's beliefs. The function $\mathcal{B}_i$ can be viewed as an accessibility relation. As usual the truth condition for Bel_i stipulates that it holds that A is believed by agent i at w, noted $w \Vdash Bel_i A$, iff A holds in every $w' \in \mathcal{B}_i(w)$. We suppose that:

❶ $\mathcal{B}_i$ is serial, transitive and euclidian.

Grounding.

GA reads "it is grounded (for the considered group of agents) that A is true" (or for short : "A is grounded"). Grounded here means public and agreed by everybody. To each world w we associate the set of possible worlds $\mathcal{G}(w)$ that are consistent with all grounded propositions. $\mathcal{G}(w)$ contains those worlds where all grounded propositions hold. The truth condition for G stipulates that it holds that A is grounded in w, noted $w \Vdash GA$, iff A holds in every $w' \in \mathcal{G}(w)$. Just as the $\mathcal{B}_i$, $\mathcal{G}$ can be viewed as an accessibility relation. We suppose that

❷ $\mathcal{G}$ is serial, transitive and euclidian.

Belief and grounding.

We postulate the following relationship between the accessibility relations for $\mathcal{B}_i$ and G:

❸ if $w' \in \mathcal{B}_i(w)$ then $\mathcal{G}(w) = \mathcal{G}(w')$

❹ if $u\mathcal{G}v$ and $v\mathcal{B}_i w$ then there is w' such that $w\mathcal{G}w'$ and $V(w) = V(w')$

❺ $\mathcal{G} \subseteq \mathcal{G} \circ \bigcup_{i \in AGT} \mathcal{B}_i$

The constraint ❸ stipulates that agents are aware of what is grounded and of what is ungrounded.

The constraint ❹ stipulates that for every grounded proposition it is publicly established that every agent believes it (which does not imply that they actually believe them): whenever w is a world for which all believed propositions of agent i are grounded, then all those propositions are indeed grounded in w.

The constraint ❺ expresses that if a proposition is established for every agent (*i.e.* it is grounded that every agent believes it) then it is grounded: whenever w is a world for which all grounded propositions hold, then it is indeed grounded that it is possible, for every agent, that all these propositions hold in w.

Choice.

Among all the worlds in $\mathcal{B}_i(w)$ that are possible for agent i, there are some that i prefers. Cohen and Levesque [2] say that i *chooses* some subset of $\mathcal{B}_i(w)$. Semantically, these worlds are identified by yet another accessibility relation

$$\mathcal{C}_i : W \to 2^W$$

$Ch_i A$ expresses that agent i chooses that A. We sometimes also say that i *prefers* that A [5]. Without surprise, $w \models Ch_i A$ if A holds in all preferred worlds, i.e. $w \models Ch_i A$ if $w' \models A$ for every $w' \in \mathcal{C}_i(w)$. We suppose that

❻ $\mathcal{C}_i$ is serial, transitive, and euclidian. [6]

Choice and belief, choice and grounding.

As said above, an agent only chooses worlds he considers possible:

❼ $\mathcal{C}_i(w) \subseteq \mathcal{B}_i(w)$.

Hence belief implies choice, and choice is a mental attitude that is weaker than belief. This corresponds to validity of the principle $Bel_i A \to Ch_i A$.

We moreover require that worlds chosen by i are also chosen from i's possible worlds, and *vice versa* (see Figure 1):

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[5] While Cohen and Levesque use a modal operator ‘goal’ (probably in order to have a uniform denomination w.r.t. the different versions of goals they study), it seems more appropriate to us to use the term ‘choice’.

[6] This differs from Cohen and Levesque, who only have supposed seriality, and follows Sadek's approach. The latter [8] has argued that choice is a mental attitude which obeys to principles of introspection that correspond with transitivity and euclideanity.

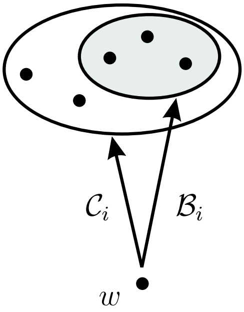

Fig. 1. Belief and choice

❽ if $w\mathcal{B}_i w'$ then $\mathcal{C}_i(w) = \mathcal{C}_i(w')$.

We do not suppose any semantical constraint between choice and grounding beyond those coming with the above $\mathcal{C}_i(w) \subseteq \mathcal{B}_i(w)$.

Action.

Let $ACT = \{\alpha, \beta \ldots\}$ be the set of actions. Speech acts are particular actions; they are 4-uples of the form $\langle i, j, FORCE, A\rangle$ where i is the author of the speech act, j its addressee, $FORCE$ its illocutionary force, and A a formula denoting its propositional content. For example $\langle i, j, \mathsf{Assert}, p\rangle$ expresses that i asserts to j that p is true. We write α_i to denote that i is the author of α.

The formula $After_\alpha A$ expresses that if α happens then A holds after α. The dual $Happens_\alpha A = \neg After_\alpha \neg A$ means that α happens and A is true afterwards. Hence $After_\alpha \bot$ expresses that α does not happen, and $Happens_\alpha \top$ that α happens and we write then $Happens(\alpha)$. For every action $\alpha \in ACT$ there is a relation $R : ACT \to (W \to 2^W)$ associating sets of worlds $R_\alpha(w)$ to w. The truth condition is: $w \Vdash After_\alpha A$ iff $w' \Vdash A$ for every $w' \in R_\alpha(w)$.

The formula $Before_\alpha A$ means that before every execution of α, A holds. The dual $Done_\alpha A = \neg Before_\alpha \neg A$ expresses that the action α has been performed before which A held. Hence $Done_\alpha \top$ means that α just has happened. The accessibility relation for $Before_\alpha$ is the converse of the above relation R_α. The truth condition is: $w \Vdash Before_\alpha A$ iff $w' \Vdash A$ for every $w' \in R_\alpha^{-1}(w)$.

As said above, we do not detail here the relationship between action and mental attitudes and refer the reader to [6].

3.2 Axiomatics

Belief.

The axioms corresponding to the semantical conditions for belief are those of KD45, *i.e.* those of normal modal logics [1], plus the following:

$$Bel_i A \rightarrow \neg Bel_i \neg A \quad (\mathrm{D}_{Bel_i})$$
$$Bel_i A \rightarrow Bel_i Bel_i A \quad (4_{Bel_i})$$
$$\neg Bel_i A \rightarrow Bel_i \neg Bel_i A \quad (5_{Bel_i})$$

Hence an agent's beliefs are consistent (D_{Bel_i}), and he is aware of his beliefs (4_{Bel_i}) and disbeliefs (5_{Bel_i}). The following are theorems of the logic:

$$Bel_i A \leftrightarrow Bel_i Bel_i A \quad (1)$$
$$Bel_i \neg Bel_i A \leftrightarrow \neg Bel_i A \quad (2)$$

Grounding.

The logic of the grounding operator is again a normal modal logic of type KD45:

$$GA \rightarrow \neg G \neg A \quad (\mathrm{D}_G)$$
$$GA \rightarrow GGA \quad (4_G)$$
$$\neg GA \rightarrow G \neg GA \quad (5_G)$$

(D_G) expresses that the set of grounded informations is consistent: it cannot be the case that both A and $\neg A$ are simultaneously grounded.

(4_G) and (5_G) account for the public character of G. From these *collective awareness* results: if A has (resp. has not) been grounded then it is established that A has (resp. has not) been grounded.

The following theorems follow from (D_G), (4_G), and (5_G):

$$GA \leftrightarrow GGA \quad (3)$$
$$G \neg GA \leftrightarrow \neg GA \quad (4)$$

Belief and grounding.

In accordance with the preceding semantic conditions the following are logical axioms:

$$GA \rightarrow Bel_i GA \tag{SR$_+$}$$

$$\neg GA \rightarrow Bel_i \neg GA \tag{SR$_-$}$$

$$G\varphi \rightarrow GBel_i\varphi, \text{ for } \varphi \text{ factual} \tag{WR}$$

$$(\bigwedge_{i \in AGT} GBel_i A) \rightarrow GA \tag{CG}$$

where a factual formula does not contain any modality.

(SR$_+$) and (SR$_-$) together correspond to ❸. (WR) corresponds to ❹, and (CG) to ❺.

The axioms of strong rationality (SR$_+$) and (SR$_-$) express that the agents are aware of the grounded (resp. ungrounded) propositions (cf. (5) and (6) below). This is due to the public character of the grounding operator.

(WR) expresses that if the factual formula φ is grounded then it is necessarily grounded that each agent expressed that he believes φ [7]. Note that this does not imply that every agent actually believe it, *i.e.* (WR) does not entail $G\varphi \rightarrow Bel_i\varphi$.

(WR) concerns only factual formulas. When an agent performs the speech act $\langle i, j, \mathsf{Assert}, p\rangle$, he expresses publicly that he believes p. ($Bel_i p$ is publicly established so $GBel_i p$ holds.) This does not mean that i indeed believes p: i might ignore whether p, or even believe that $\neg p$. It would be hypocritical to impose that it is grounded for another agent j that $Bel_i p$. Therefore $GBel_i p \rightarrow GBel_j Bel_i p$ should not be valid. Moreover, if we applied (WR) to some mental states, we would restrict the agents' autonomy. For example, when agent i performs the speech act: $\langle i, j, \mathsf{Assert}, Bel_j p\rangle$ then afterwards the formula $GBel_i Bel_j p$ holds, and the agent j could not later on express that he believes $\neg p$. Indeed, if he made this speech act, the formulae $GBel_j \neg p$ and, thanks to (WR), $GBel_i Bel_j \neg p$ would hold, which is inconsistent with the above formula $GBel_i Bel_j p$.

(CG) expresses that if a proposition is established for every agent in AGT then it is grounded.

[7] This axiom does not presuppose that an agent i explicitly asserted φ, even if, in our current theory, we do not describe the mechanism of an agent's implicit commitment. Moreover, for Walton & Krabbe [19], agents can not incur implicitly strong commitments. (We will show in Section 5 links between grounding, belief and commitments *à la* Walton & Krabbe.)

The followings are straightforward consequences of (SR_+) and (SR_-):

$$GA \leftrightarrow Bel_i GA \tag{5}$$
$$\neg GA \leftrightarrow Bel_i \neg GA \tag{6}$$

These theorems express that agents are aware of what is grounded.

Choice.

Similar to belief, we have the (D_{Ch_i}), (4_{Ch_i}) and (5_{Ch_i}). (See [6] for more details.)

Choice and belief.

Our semantics validates the equivalences:

$$Ch_i A \leftrightarrow Bel_i Ch_i A \tag{7}$$
$$\neg Ch_i A \leftrightarrow Bel_i \neg Ch_i A \tag{8}$$

This expresses that agents are aware of their choices.

Action.

As the relation $R_\alpha^{-1}(w)$ is the converse of R_α, we have the two conversion axioms:

$$A \to After_\alpha Done_\alpha A \qquad (\mathrm{I}_{After_\alpha,\, Done_\alpha})$$
$$A \to Before_\alpha Happens_\alpha A \qquad (\mathrm{I}_{Before_\alpha,\, Happens_\alpha})$$

3.3 Action laws

Action laws for an action come in two kinds: *executability laws* describe the preconditions of the action, and *effect laws* describe the effects. The preconditions of an action are the conditions that must be fulfilled in order that the action is executable. The effects (or postconditions) are properties that hold after the action because of it. For example, to toss a coin, we need a coin (precondition) and after the toss action the coin is heads or tails (postcondition).

The set of all action laws is noted $LAWS$, and some examples are collected in Table 2. The general form of an executability law is:

$$Ch_i Happens(\alpha_i) \wedge precond(\alpha_i) \leftrightarrow Happens(\alpha_i) \qquad (\mathrm{Int}_{Ch_i,\alpha_i})$$

This expresses a principle of intentional action: an action happens exactly when its preconditions hold and its author chooses it to happen. The general form of an effect law is $A \to After_\alpha postcond(\alpha)$. In order to simplify our exposition we suppose that effect laws are unconditional and therefore the general form of an effect law is here:

$$After_\alpha postcond(\alpha)$$

A way of capturing the conventional aspect of interaction is to suppose that these laws are common to all the agents. Formally they are thus global axioms to which the necessitation rule applies [4].

4 Groundedness compared to other notions

In our formalism, $GBel_iA \to Bel_iA$ is not valid. Thus, when it is grounded that a piece of information A holds for agent i then this does not mean that i indeed believes that A. The other way round, $Bel_iA \to GBel_iA$ is not valid either: an agent might believe A while it is not grounded that A holds for i.

The operator G is objective in nature. It is different from other objective operators such as that of social commitment of [13,14,5,18]. To see this consider speech act semantics: as we have shown (cf. Sect. 2), the formula $GBel_iA$ expresses the idea that it is grounded that A holds for agent i. This has to be linked to the expression of an Intentional state as a necessary condition for the performance of a speech act. This means that when agent i asks agent j to pass him the salt then it has been established either that i wants to know whether j is able to pass him the salt (literal meaning), or that i wants j to pass him the salt (indirect meaning). In a commitment-based approach this typically leads to a conditional commitment (or precommitment) of j to pass the salt, which becomes an unconditional commitment upon a positive reaction. In our approach we do not try to determine whether j *must* do such or such action: we just establish the facts, without any hypothesis on the agents' beliefs, goals, intentions, ... or commitments.

On the other hand, as the next section shows, some obligations that can be found in commitment-based approaches have a counterpart in our formalism: our characterization of speech acts in terms of preconditions and effects constrains the agents' options for the choice of actions, as well as their order (cf. Sect. 5).

In fact, the operator G expresses a sort of common belief. In [15], Tuomela distinguishes *(proper) group beliefs* from *shared we-beliefs*. In the first case a group may typically believe a proposition while none of the agents of the group really believes it. In the second case, the group holds a belief which each individual agent really holds, too.

Our operator G is closer to Tuomela's *(proper) group beliefs* because the formula $GA \rightarrow Bel_i A$ is invalid. Thus, GA means that a group [Agt] "(intentionally) jointly accept A as the view of [Agt] (...) and there is a mutual belief [about this]" [15]. Different from Tuomela we do not distinguish the agents contributing to the grounding of the group belief from those which passively accept it.

5 Walton&Krabbe's persuasion dialogues (PPD_0)

We now apply our formalism to a particular kind of dialogue, viz. persuasion dialogues. We characterize the speech acts of Walton&Krabbe's (W&K for short) game of dialogue PPD_0, also called Permissive Persuasion Dialogue. These works mainly follow from Hamblin's works. In order to simplify our exposition we suppose that there are only two agents (but the account can easily be generalized to n agents).

A persuasion dialogue takes place when there is a conflict between two agents' beleif. The goal of the dialogue is to resolve this situation: an agent can persuade the other party to concede his own thesis (in this case he wins the dialogue game) or concede the point of view of the other party (and thus lose the game).

W&K distinguish two kinds of commitment: those which can be challenged (*assertions*) and those which cannot (*concessions*). We formalize this distinction with the notions of strong commitment (SC) and weak commitment (WC). They are linked by the fact that a strong commitment to a proposition implies a weak commitment to it ([19, p. 133]). We use the logical framework presented above to formalize these two notions, and apply it to PPD_0. In relation with this logical framework, we define: [8]

$$SC_i A \stackrel{def}{=} GBel_i A \qquad (\text{Def}_{SC_i})$$

$$WC_i A \stackrel{def}{=} G\neg Bel_i \neg A \qquad (\text{Def}_{WC_i})$$

Note that we might have chosen to have primitive operators SC_i, and define GA as being an abbreviation of $(\bigwedge_{i \in AGT} SC_i A)$.

In terms of the preceding abbreviations we can prove:

[8] This is an approximation of W&K's *assertion*. Indeed, our $GBel_i A$ is "more logical" than W&K's *a(A)*: W&K allow both $a(A)$ and $a(\neg A)$ to be the case simultaneously, while for us $GBel_i A \wedge GBel_i \neg A$ is inconsistent. In the case of weak commitment, we agree with W&K's works: in our framework, $WC_i A \wedge WC_i \neg A$ is consistant.

$$SC_i\, A \rightarrow \neg SC_i\, \neg A \tag{9}$$
$$SC_i\, A \leftrightarrow SC_i\, SC_i\, A \tag{10}$$
$$\neg SC_i\, A \leftrightarrow SC_i\, \neg SC_i\, A \tag{11}$$

(9) shows the rationality of the agents: they cannot commit both on A and $\neg A$. (10) and (11) account for the public character of commitment. With those three theorems, we can show that SC_i is an operator of a normal modal logic of type KD45, too.[9]

$$G\, A \leftrightarrow SC_i\, G\, A \tag{12}$$
$$\neg G\, A \leftrightarrow SC_i\, \neg G\, A \tag{13}$$
$$SC_i\, A \leftrightarrow SC_j\, SC_i\, A \tag{14}$$
$$\neg SC_i\, A \leftrightarrow SC_j\, \neg SC_i\, A \tag{15}$$

These theorems are some consequences of the public character of the commitment. (12) and (13) entail that it is grounded that the agents are committed to the grounded (resp. ungrounded) propositions. (14) and (15) mean that each agent is committed to the other agents commitments, and non-commitments.

$$SC_i\, A \rightarrow WC_i\, A \tag{16}$$
$$WC_i\, A \rightarrow \neg SC_i\, \neg A \tag{17}$$

(16) says that strong commitment implies weak commitment. (17) expresses that if agent i is weakly committed to A then i is not strongly committed to $\neg A$.

$$WC_i\, A \leftrightarrow SC_j\, WC_i\, A \tag{18}$$
$$\neg WC_i\, A \leftrightarrow SC_j\, \neg WC_i\, A \tag{19}$$

(18) expresses that weak commitment is public. (19) is similar for absence of weak commitment.

[9] We can prove that K is a theorem for SC_i and that the necessitation rule can be applied to it.

Precond(α)	Act α	Postcond(α)
$\neg SC_s\, p$	$\langle s, h, \mathsf{Assert}, p\rangle$	$SC_s\, p$
$SC_s\, p$	$\langle s, h, \mathsf{SRetract}, p\rangle$	$\neg SC_s\, p$
$WC_s\, p$	$\langle s, h, \mathsf{WRetract}, p\rangle$	$\neg\, WC_s\, p$
$SC_s\, p \wedge \neg\, WC_h\, p$	$\langle s, h, \mathsf{Argue}, (q_1, ..., q_n SOp)\rangle$	$\bigwedge_{1\leq i\leq n} SC_s\, q_i \wedge$ $SC_s\, (\bigwedge_{1\leq i\leq n} q_i \rightarrow p)$
$\neg\, WC_s\, p$	$\langle s, h, \mathsf{Concede}, p\rangle$	$WC_s\, p$
$\neg\, WC_s\, p$	$\langle s, h, \mathsf{RefuseConcede}, q\rangle$	$\neg\, WC_s\, p$
$SC_s\, q \wedge \neg\, WC_h\, q \wedge \neg\, WC_h\, p$	$\langle s, h, \mathsf{RequestConcede}, p\rangle$	$\emptyset$
$\neg\, WC_s\, p \wedge SC_h\, p \wedge$ $\neg GDone_{\langle s,h,\mathsf{Challenge},p\rangle} \top$	$\langle s, h, \mathsf{Challenge}, p\rangle$	$\emptyset$
$\neg\, WC_h\, p$	$\langle s, h, \mathsf{Serious}, p\rangle$	$\emptyset$
$WC_h\, p \wedge WC_h\, q \wedge (p \leftrightarrow \neg q)$	$\langle s, h, \mathsf{Resolve}, p\rangle$	$\emptyset$

Table 1
Preconditions and effects of speech acts (with commitments).

5.1 Speech acts and grounding

The dialogues that we want to formalize (W&K-like dialogues) are controlled by some conventions: the rules of the game. The allowed sequences of acts are those of W&K's PPD_0 (cf. [19, p. 150-151]). They are formalized in Figure 2 and will be discussed below. For example, after a speech act $\langle s, h, \mathsf{Assert}, p\rangle$,

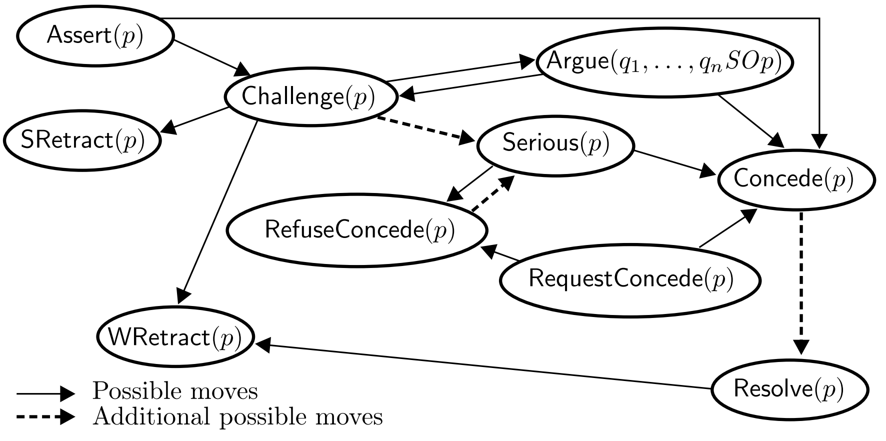

Fig. 2. (Additional) possible moves after each act

the hearer can only challenge p or concede it. We formalize them in our logic by expressing that an act grounds that the hearer's choices are limited only to some acts. Speech acts have two different effects: one is on the commitment store in terms of weak and strong commitments (cf. Table 1) and the other one is the set of acts the hearer can perform in response (cf. Table 2).

We suppose that initially nothing is grounded, *i.e.* the belief base is $\{\neg GA : A \text{ is a formula }\}$.[10]

Acts α	Constraints on the possible actions following α
$\langle s, h, \mathsf{Assert}, p\rangle$	$G(Ch_h Happens(\langle h, s, \mathsf{Challenge}, p\rangle)\vee$ $Ch_h Happens(\langle h, s, \mathsf{Concede}, p\rangle))$
$\langle s, h, \mathsf{SRetract}, p\rangle$	$\emptyset$
$\langle s, h, \mathsf{WRetract}, p\rangle$	$\emptyset$
$\langle s, h, \mathsf{RequestConcede}, p\rangle$	$G(Ch_h Happens(\langle h, s, \mathsf{RefuseConcede}, p\rangle)\vee$ $Ch_h Happens(\langle h, s, \mathsf{Concede}, p\rangle))$
$\langle s, h, \mathsf{Argue}, (q_1, ..., q_n SOp)\rangle$	$\bigwedge_{1\leq i\leq n} G(Ch_h Happens(\langle h, s, \mathsf{Challenge}, q_i\rangle)\vee$ $Ch_h Happens(\langle h, s, \mathsf{Concede}, q_i\rangle))$ $\wedge G(Ch_h Happens(\langle h, s, \mathsf{Challenge}, q_1 \wedge ... \wedge q_n \rightarrow p\rangle)\vee$ $Happens(\langle h, s, \mathsf{Concede}, q_1 \wedge ... \wedge q_n \rightarrow p\rangle))$
$\langle s, h, \mathsf{Challenge}, p\rangle$	$G(Ch_h Happens(\langle h, s, \mathsf{SRetract}, p\rangle)\vee$ $Ch_h Happens(\langle h, s, \mathsf{WRetract}, p\rangle)\vee$ $Ch_h Happens(\langle h, s, \mathsf{Argue}, (q_1, ..., q_n SOp)\rangle)\vee$ $Ch_h Happens(\langle h, s, \mathsf{Serious}, p\rangle))$
$\langle s, h, \mathsf{Concede}, p\rangle$	$\emptyset$
$\langle s, h, \mathsf{RefuseConcede}, p\rangle$	$\emptyset$
$\langle s, h, \mathsf{Serious}, p\rangle$	$G(Ch_h Happens(\langle h, s, \mathsf{RefuseConcede}, p\rangle)\vee$ $Ch_h Happens(\langle h, s, \mathsf{Concede}, p\rangle))$
$\langle s, h, \mathsf{Resolve}, p\rangle$	$G(Ch_h Happens(\langle h, s, \mathsf{WRetract}, p\rangle)\vee$ $Ch_h Happens(\langle h, s, \mathsf{WRetract}, \neg p\rangle))$

Table 2
Additional postconditions of speech acts.

The Assert act on p can only be used by the two parties in some preliminary moves of the dialogue to state the theses of each participant. The effect of the act is that it is grounded that its content p holds for the speaker: he has expressed a kind of strong commitment (an *assertion* for W&K) on p in the sense that he must defend his commitment by an argument if it is challenged.

To Concede p means to admit that p could hold, where p has been asserted by the other party. The effect of this act is that it is grounded that the speaker has taken a kind of commitment on p. But the nature of this commitment is not the same as the former one: this one has not to be defended when it is attacked. W&K call it *concession* and it corresponds to our notion of Weak Commitment.

The Challenge act on p forces the other participant to either put forward an argument for p, or to retract the assertion p. For a given propositional

[10] This is an infinite set. In practice one would resort to default reasoning here.

content this act can only be performed once.

Argue: to defend a challenged assertion p, an argument must have p as conclusion and a set of propositions $q_1...q_n$ as premises. We write it as follows:

$$q_1...q_n SOp \stackrel{def}{=} q_1 \wedge ... \wedge q_n \wedge (q_1 \wedge ... \wedge q_n \rightarrow p) \qquad (\mathrm{Def}_{SO})$$

The effect of this act is that all premises q_1, ..., q_n and the implicit implication $q_1 \wedge ... \wedge q_n \rightarrow p$ are grounded for the speaker. It follows that the challenger must explicitly take position in the next move (challenge or concede) on each premise and on the implicit implication. To challenge one premise means that the argument cannot be applied, while to challenge the implicit implication means that the argument is incorrect. If he does not challenge a proposition, he (implicitly) concedes it. But as soon as he has conceded all the premises and the implication, he must also concede the conclusion. To avoid some digressions, W&K suppose that an unchallenged assertion cannot be defended by an argument. Moreover, we took over their form of the support of arguments, viz. $A \rightarrow B$, although we are aware that more complex forms of reasoning occur in real world argumentation.

At any time, the speaker may request more concessions (with a Request-Concede act) from the hearer, to use them as premises for arguments. The hearer can then accept or refuse to concede.

W&K use the same speech act type to retract a concession and to refuse to concede something (the act $nc(p)$). But it seems to us that it is not the same kind of act, and we decided to create two different acts: $\langle s, h, \mathsf{WRetract}, p\rangle$ to retract one of his own weak commitments, and $\langle s, h, \mathsf{RefuseConcede}, p\rangle$ to decide not to concede anything. A strong commitment can be retracted with a $\langle s, h, \mathsf{SRetract}, p\rangle$. This act removes the strong commitment from the commitment store, but not the weak commitment, whereas the $\langle s, h, \mathsf{WRetract}, p\rangle$ act removes the weak commitment and, if it exists, the strong commitment, too.

In our logic, $WC_i\, A \wedge WC_i\, \neg A$ is satisfiable, but not $SC_i\, A \wedge SC_i\, \neg A$. Thus we are more restrictive than W&K: in the following, a contradiction in an agents' commitment store is only due to contradictory Weak Commitments. [11] When a party detects an contradiction in the other party's commitment store, it can ask him to resolve it (with the act Resolve(p,q) where "p and q are explicit contradictories" [19, p. 151].). The other party must retract one of the inconsistent propositions. W&K do not make any inference in the commitment

[11] W&K allow the agents to have some contradictory concessions (WC) and assertions (SC) in their commitment store (*i.e.* $SC_i\, A$ and $SC_i\, \neg A$ or $WC_i\, A$ and $WC_i\, \neg A$ can hold simultaneously).

store, so Resolve only applies to explicit inconsistency (that is: Resolve(p,$\neg p$)). We will write Resolve(p) instead of Resolve(p,q) where q is $\neg p$. (Resolve(p) and Resolve($\neg p$) are thus equivalent.) To perform the speech act Resolve(p), we can show that it is necessary and sufficient that the propositions p and $\neg p$ are weak commitments of the agent. In our formalism, the act Resolve holds only to weak commitments. Moreover the two contradictory weak commitments cannot be derived from two inconsistent strong commitments (which W&K allow), because such are consistent in our logic.

When an agent chooses to challenge a proposition p or to refuse to concede it, his opponent can query him to reassess his position. Finally the speech act Serious(p) imposes that the agent must concede p or refuse to concede it.

Note that W&K define another commitment store that contains what they call *dark-side commitments*. If p is a dark-side commitment, it must be revealed after a Serious(p) and the agent must concede p and cannot retract it. We do not consider such commitments here because, we focus on what is observable and objective in the dialogue: so if an agent chooses to concede p, we do not know if it was a dark-side commitment or not, consequently the agent may, even if it had a dark-side commitment on p and contrary to W&K's theory, retract it in a subsequent dialogue move dialogue.

The action preconditions are not mutually exclusive. This gives the agents some freedom of choice. We do not describe here the subjective cognitive processes that lead an agent to a particular choice.

5.2 Example

We recast an example of a persuasion dialogue given by W&K [19, p. 153] to illustrate the dialogue game PPD_0 (see Figure 3): initially, agent i asserts p_1 and agent j asserts p_2. Thus, the following preparatory moves have been performed: $\langle i, j, \mathsf{Assert}, p_1\rangle$ and $\langle j, i, \mathsf{Assert}, p_2\rangle$.

After each move, the agents' commitment stores are updated (see Table 3). In his first move, j asks i to concede p_3 and challenges p_1. i responds by conceding p_3, etc. In move (vii), agent j concedes p_1 which is the thesis of his opponent. [12]

As we have said, in order to stay consistent with our logical framework, we have to add an effect to the W&K speech act of concession: when i concedes a proposition p, every strong commitment of i on $\neg p$ is retracted. Agent i is then weakly committed on both p and $\neg p$. We thus weaken the paraconsistent aspects of W&K, viz. that an agent can have assertions or concessions that

[12] He thus loses the game in what concerns the thesis of i but in what concerns his own thesis, the game is not over yet.

(i) $\langle j, i, \mathsf{RequestConcede}, p_3\rangle$,
$\langle j, i, \mathsf{Challenge}, p_1\rangle$

(ii) $\langle i, j, \mathsf{Concede}, p_3\rangle$,
$\langle i, j, \mathsf{Serious}, p_1\rangle$,
$\langle i, j, \mathsf{Argue}, (p_3 SO p_1)\rangle$,
$\langle i, j, \mathsf{Challenge}, p_2\rangle$

(iii) $\langle j, i, \mathsf{RefuseConcede}, p_1\rangle$,
$\langle j, i, \mathsf{Concede}, p_3 \to p_1\rangle$,
$\langle j, i, \mathsf{Argue}, (p_4, p_5 SO p_2)\rangle$,
$\langle j, i, \mathsf{Challenge}, p_3\rangle$

(iv) $\langle i, j, \mathsf{Concede}, p_5\rangle$,
$\langle i, j, \mathsf{Concede}, p_4 \wedge p_5 \to p_2\rangle$,
$\langle i, j, \mathsf{Serious}, p_3\rangle$,
$\langle i, j, \mathsf{Argue}, (\neg p_4, p_5 SO p_3)\rangle$,
$\langle i, j, \mathsf{Challenge}, p_4\rangle$

(v) $\langle j, i, \mathsf{WRetract}, p_3 \to p_1\rangle$,
$\langle j, i, \mathsf{Concede}, p_3\rangle$,
$\langle j, i, \mathsf{Concede}, \neg p_4\rangle$,
$\langle j, i, \mathsf{Concede}, \neg p_4 \wedge p_5 \to p_3\rangle$,
$\langle j, i, \mathsf{Argue}, (p_3 SO p_4)\rangle$,
$\langle j, i, \mathsf{Challenge}, p_3 \to p_1\rangle$

(vi) $\langle i, j, \mathsf{Resolve}, p_4\rangle$,
$\langle i, j, \mathsf{Argue}, (\neg p_4 SO p_3 \to p_1)\rangle$,
$\langle i, j, \mathsf{Challenge}, p_3 \to p_4\rangle$

(vii) $\langle j, i, \mathsf{WRetract}, p_4\rangle$,
$\langle j, i, \mathsf{WRetract}, p_3 \to p_4\rangle$,
$\langle j, i, \mathsf{SRetract}, p_5\rangle$,
$\langle j, i, \mathsf{SRetract}, p_3\rangle$,
$\langle j, i, \mathsf{WRetract}, p_4 \wedge p_5 \to p_2\rangle$,
$\langle j, i, \mathsf{Concede}, \neg p_4 \to (p_3 \to p_1)\rangle$,
$\langle j, i, \mathsf{Concede}, p_3 \to p_1\rangle$,
$\langle j, i, \mathsf{Concede}, p_1\rangle$,
$\langle j, i, \mathsf{Argue}, (p_6 SO p_2)\rangle$,

Fig. 3. Example of dialogue (see [19, p. 153])

are jointly inconsistent, in order to keep in line with standard properties of the modal operator G.

Now we can establish formally that our logic captures W&K's PPD_0-dialogues. For example we have:

Theorem 5.1

$$LAWS \models After_{\langle s,h,\mathsf{Assert},p\rangle}((\neg WC_h\, p \wedge \neg Done_{\langle h,s,\mathsf{Challenge},p\rangle}\top) \to G(Happens(\langle h, s, \mathsf{Challenge}, p\rangle) \vee Happens(\langle h, s, \mathsf{Concede}, p\rangle)))$$

Thus after an assertion of p the only possible reactions of the hearer are to either challenge or concede p, under the condition that he has not doubted that $\neg p$, and that he has not challenged p in the preceding move.

Proof. $LAWS$ contains (see Table 2) the formula

$$After_{\langle s,h,\mathsf{Assert},p\rangle} G(Ch_h Happens(\langle h, s, \mathsf{Challenge}, p\rangle) \vee Ch_h Happens(\langle h, s, \mathsf{Concede}, p\rangle))$$

The precondition for $\langle h, s, \mathsf{Challenge}, p\rangle$ is

$$\neg WC_h\, p \wedge SC_s\, p \wedge \neg Done_{\langle h,s,\mathsf{Challenge},p\rangle}\top$$

Now the postcondition of $\langle s, h, \mathsf{Assert}, p\rangle$ is $SC_s\, p$. Hence we have by the law

Grounded propositions	SC_i	WC_i	SC_j	WC_j
$\emptyset$	p_1		p_2	
$WC_i\, p_3$ $SC_i\, p_3, SC_i\, p_3 \to p_1$	$p_1,$ $p_3, p_3 \to p_1$		p_2	
$WC_j\, p_3 \to p_1, SC_j\, p_4,$ $SC_j\, p_5, SC_j\, p_4 \wedge p_5 \to p_2$			p_2, p_4, p_5 $p_4 \wedge p_5 \to p_2$	$p_3 \to p_1$
$WC_i\, p_5,\ WC_i\, p_4 \wedge p_5 \to p_2$ $SC_i\, \neg p_4, SC_i\, p_5,$ $SC_i\, \neg p_4 \wedge p_5 \to p_3$	$p_1, p_3, p_3 \to p_1$ $\neg p_4, p_5,$ $\neg p_4 \wedge p_5 \to p_3$	p_5 $p_4 \wedge p_5 \to p_2$		
$\neg SC_j\, p_3 \to p_1,\ WC_j\, p_3,$ $WC_j\, \neg p_4 \wedge p_5 \to p_3,$ $SC_j\, p_3, SC_j\, p_3 \to p_4,$ $WC_j\, \neg p_4$			p_2, p_4, p_5, p_3 $p_4 \wedge p_5 \to p_2,$ $p_3 \to p_4$	$\neg p_4$ $\neg p_4 \wedge p_5 \to p_3$
$SC_i\, \neg p_4,$ $SC_i\, \neg p_4(\to p_3 \to p_1)$	$p_1, p_3, p_3 \to p_1$ $\neg p_4, p_5,$ $\neg p_4 \wedge p_5 \to p_3$ $\neg p_4(\to p_3 \to p_1)$	p_5 $p_4 \wedge p_5 \to p_2$		
$\neg SC_j\, p_4, \neg\, WC_j\, p_4$ $\neg\, WC_j\, p_3 \to p_4, \neg SC_j\, p_3$ $\neg SC_j\, p_3 \to p_4, \neg SC_j\, p_5$ $\neg\, WC_j\, p_4 \wedge p_5 \to p_2,$ $\neg SC_j\, p_4 \wedge p_5 \to p_2$ $WC_j\, p_3 \to p_1,\ WC_j\, p_1$ $WC_j\, \neg p_4 \to (p_3 \to p_1)$ $SC_j\, p_6, SC_j\, p_6 \to p_2$			p_2 $p_6, p_6 \to p_2$	$\neg p_4$ $\neg p_4 \wedge p_5 \to p_3$ $p_3, p_5,$ $\neg p_4 \to (p_3 \to p_1)$ $p_3 \to p_1, p_1$

Table 3
Commitment stores in the example dialogue

of intentional action ($\mathrm{Int}_{Ch_i,\alpha_i}$):

$$LAWS \models After_{\langle s,h,\mathsf{Assert},p\rangle}(\neg\, WC_h\, p \wedge \neg Done_{\langle h,s,\mathsf{Challenge},p\rangle}\top \to (Ch_h Happens(\langle h, s, \mathsf{Challenge}, p\rangle) \to Happens(\langle h, s, \mathsf{Challenge}, p\rangle)))$$

Similarly, for concede we have:

$$LAWS \models After_{\langle s,h,\mathsf{Assert},p\rangle}(\neg WC_h\, p \to (Ch_h Happens(\langle h, s, \mathsf{Concede}, p\rangle) \to Happens(\langle h, s, \mathsf{Concede}, p\rangle)))$$

Combining these two with the law of intentional action for Assert we obtain our theorem. □

Similar results for the other speech acts can be stated. They formally express and thus make more precise further properties of W&K's dialogue games. For example, the above theorem illustrates something that remained implicit in W&K's PPD_0 dialogues: the hearer of an assertion that p should not be committed that p himself because, if he were not, the dialogue would no more be a persuasion dialogue and no rule would apply.

Similarly, in a context where h's commitment store contains $SC_h\,(p \vee q)$, $SC_h\,\neg p$, and $SC_h\,\neg q$ (and is thus clearly inconsistent), W&K's dialogue rules do not allow s to execute $\langle s, h, \mathsf{Resolve}, p \vee q, \neg p \wedge \neg q\rangle$. This seems nevertheless a natural move in this context. Our formalization allows for it, the formal reason being that our logic of G is a normal modal logic, and thus validates $(SC_i\, p \wedge SC_i\, q) \to SC_i\,(p \wedge q)$.

6 Conclusion

The main contribution of this paper is the definition of a logic of grounding. We have shown that this notion has its origins in speech act theory [16,17], philosophy of mental states [11], and in philosophy of social action [15]. It is thus a philosophically well-founded notion.

Our formalisation is new as far as we are aware. Just as the structural approaches to dialogue it requires no hypotheses on the internal principles of the agents and accounts for the observation of a dialogue by a third party. Our characterization of speech acts is limited to the establishment of what must be true in order to avoid self-contradictions of the speaker.

We think that our work is very close of the notion of ostensible mental states of [7] and that our works could converge to very interesting results, for example on the definition of the semantics of a speech acts library.

Another feature of our notion is that it bridges the gap between mentalist and structural approaches to dialogue, by accounting for an objective viewpoint on dialogue by means of a logic involving belief.

We did not present a formal account of the dynamics. This requires the integration of a solution to the classical problems in reasoning about actions (frame problem, ramification problem, and belief revision). These technical aspects will be described in future work.

Once we have such a formalism at our disposal it can be used to analyse dialogue corpora in order to formally derive whether some proposition is grounded or not for the participants. This could provide then an explanation for some cases of misunderstanding.

References

[1] Chellas, B. F., "Modal Logic: an introduction," Cambridge University Press, 1980.

[2] Cohen, P. R. and H. J. Levesque, *Intention is choice with commitment*, Artificial Intelligence Journal **42** (1990).

[3] Conte, R. and C. Castelfranchi, "Cognitive and Social Action," UCL Press, London, 1995.

[4] Fitting, M. C., "Proof Methods for Modal and Intuitionistic Logics," D. Reichel Publishing Company, Dordrecht, Netherlands, 1983.

[5] Fornara, N. and M. Colombetti, *Operational Specification of a Commitment-Based Agent Communication Language*, in: C. Castelfranchi and L. W. Johnson, editors, *Proc. First Int. Joint Conf. on Autonomous Agents and MultiAgent Systems (AAMAS-2002)*, ACM Press **2**, 2002, pp. 535–542.

[6] Herzig, A. and D. Longin, *C&L intention revisited*, in: D. Dubois, C. Welty and M.-A. Williams, editors, *Proc. 9th Int. Conf. on Principles on Principles of Knowledge Representation and Reasoning (KR2004) , Whistler, Canada* (2004), pp. 527–535.

[7] Nickles, M., F. Fischer and G. Weiss, *A framework for the representation of opinions and ostensible intentions*, To appear in this Volume.

[8] Sadek, M. D., *A study in the logic of intention*, in: B. Nebel, C. Rich and W. Swartout, editors, *Proc. Third Int. Conf. on Principles of Knowledge Representation and Reasoning (KR'92)* (1992), pp. 462–473.

[9] Searle, J. R., "Speech acts: An essay in the philosophy of language," Cambridge University Press, New York, 1969.

[10] Searle, J. R., "Expression and Meaning. Studies on the Theory of Speech Acts," Cambridge University Press, 1979.

[11] Searle, J. R., "Intentionality: An essay in the philosophy of mind," Cambridge University Press, 1983.

[12] Searle, J. R. and D. Vanderveken, "Foundation of illocutionary logic," Cambridge University Press, 1985.

[13] Singh, M. P., *Agent Communication Languages: Rethinking the Principles*, Computer **31** (1998), pp. 40–47.

[14] Singh, M. P., *A Social Semantics for Agent Communication Languages*, in: F. Dignum and M. Greaves, editors, *Issues in Agent Communication*, number 1916 in LNAI (2000), pp. 31–45.

[15] Tuomela, R., *Group beliefs*, Synthese **91** (1992), pp. 285–318.

[16] Vanderveken, D., "Principles of language use," Meaning and Speech Acts **1**, Cambridge University Press, 1990.

[17] Vanderveken, D., "Formal semantics of success and satisfaction," Meaning and Speech Acts **2**, Cambridge University Press, 1991.

[18] Verdicchio, M. and M. Colombetti, *A Logical Model of Social Commitment for Agent Communication*, in: *Proc. Second Int. Joint Conf. on Autonomous Agents and MultiAgent Systems (AAMAS-2003)* (2003), pp. 528–535.

[19] Walton, D. N. and E. C. Krabbe, "Commitment in Dialogue: Basic Concepts of Interpersonal Reasoning," State University of New-York Press, NY, 1995.