Towards an Analysis of Dialogue Acts and Indirect Speech Acts in a BDI Framework

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Abstract

We study the dynamics of belief in cooperative task-oriented man-machine dialogues. We introduce a modal logic of action, belief and intention, where intention has a non-normal modal logic. We focus on two aspects of speech acts: we define a semantics to take into account a feedback from the adressee of a speech act; we characterize indirect speech acts.

1. Introduction

Task-oriented man-machine dialogue is one of the most important challenges for AI. Participants in such dialogues have one major common goal, viz. to achieve the task under concern. Each of the participants has some information contributing to the achievement of the goal, but none of them can achieve it alone.

Cooperativity is a fundamental and useful hypothesis. Informally, an agent is cooperative w.r.t. another one if the former helps the latter to achieve his goals (cf. Grice's cooperation principles, as well as his conversation maxims (Grice, 1989)).

Cooperativity does not always entail *sincerity* because *unsincerity* may serve cooperativity (Longin, 1999). We suppose here that each participant is *sincere*. This means that his utterances faithfully mirror his beliefs: if a participant says "the sky is blue" then he indeed believes that the sky is blue. Such a hypothesis entails that contradictions between the presuppositions of an utterance and the hearer's beliefs about the speaker cannot be explained in terms of lies.

We finally suppose that utterances are *public*: all the agents perceive the performance of an utterance (but might misinterpret them).

The background of our work is an effective generic real-time cooperative dialogue system which has been specified and developped by the France Telecom R&D Center, as an instantiation of a rational agent technology called ARTIMIS (Sadek et al., 1997, 1996). This approach consists in first describing the agent's behaviour within a logical *theory of rational interaction* (Sadek, 1991a, 1991b, 1992, 1994), and second implementing this theory by an *inference engine* (Sadek et al., 1997; Bretier, 1995). The latter is the kernel of ARTIMIS. For a fixed set of domains, this system is able to accept nearly unconstrained spontaneous language as input, and react in a cooperative way. The activities of the dialogue system are twofold: to take into account the speaker's utterances, and to generate appropriate reactions. The reactive part is completely defined in the current state of both the theory and the implementation. On the other hand, the consommation of an utterance is handled only partially, in particular its belief change part.

In the next sections we introduce the ingredients of our BDI framework, summarizing (Herzig and Longin, 1999a). First we define our multimodal language (Sect. 2.). Then we give a simple theory of topics: we associate a set of topics to every formula (its subject), every agent (his competence), and action (its scope) (Sect. 3.). Then we define a topic-based possible worlds semantics of dialogue acts, with an appropriate semantics of intention and of the update of the agents' mental states after an action. It also integrates (possibly non-linguistic) actions of feedback (Sect. 4.). Finally we sketch how indirect speech acts can be inferred in that framework (Sect. 5.).

2. The multimodal language

As most of the authors, we work in a multi-modal framework, with modal operators for belief, mutual belief, intention and action. Our language is that of first-order multimodal logic without equality and without function symbols.

Let AGT be the set of agents. For every $i, j \in AGT$, there are *modal operators* Bel_i, $Intend_i$ and $Bel_{i,j}$. $Bel_i A$ is read "agent i believes that A", and $Intend_i A$ is read "agent i intends that A". $BelIf_i A$ abbreviates $Bel_i A \vee Bel_i \neg A$. $Bel_{i,j} A$ is read "i and j mutual believe that A". For example in a ticket selling scenario, $Bel_u Dest(\text{Göteborg})$ expresses that the agent u believes that the destination is Göteborg.[1]

Speech acts (Austin, 1962; Searle, 1969) are represented by tuples of the form $\langle \mathsf{FORCE}_{i,j}\ A \rangle$ where

- $\mathsf{FORCE} \in \{\mathsf{Assert}, \mathsf{Inform}, \mathsf{Request}, \mathsf{QueryYN}, \mathsf{QueryWh}\}$ is the illocutionary force of the act,
- $i, j \in AGT$, and
- A is a formula (the propositional content of the act).

[1] In our ticket selling scenario, u is the user of a man-machine dialogue system s.

For example, $\langle \mathsf{Inform}_{u,s}\ Dest(\text{Göteborg})\rangle$ represents a declarative utterance of the user u informing the system s that his destination is Göteborg; $\langle \mathsf{QueryYN}_{u,s}\ Bel_s Price(150\,€)\rangle$ means ¡¡ the user asks the system if he believes the price is 150 € ¿¿.

Actions are either speech acts, or physical actions such as $\langle \mathsf{Give}_{i,j}\ \text{salt}\rangle$ (the agent i gives the salt to the agent j). Let ACT be the set of all actions, containing in particular all speech acts. With every $\alpha \in ACT$ we associate *modal operators* $Done_\alpha$ and $Feasible_\alpha$. $Done_\alpha A$ is read "α has just been performed, before which A was true". $Done_\alpha \top$ is read "α has just been performed". $Feasible_\alpha A$ is nothing but the $\langle\alpha\rangle A$ of dynamic logic (Harel, 1984), while $Done_\alpha A$ is $\langle\alpha^{-1}\rangle A$.

$Bel_s Dest(\text{Göteborg})$ is an example of a formula. Another one is $Bel_s(Dest(\text{Göteborg}) \wedge Class(\text{1st}) \rightarrow Price(150\,€))$. The latter is also a nonlogical axiom (alias domain law), allowing the system to deduce the price from information about destination and class. Another meaningful example is the formula $Done_{\langle \mathsf{Inform}_{u,s}\ p\rangle} Bel_u p$ expressing the sincerity of u (which is also a domain law) : the agent u has just informed the agent s that p, before that u believed that p.

Atomic formulas are noted $p, q, \ldots$ or $P(t_1, \ldots, t_n)$. Atm is the set of all atomic formulas. Formulas are noted $A, B, \ldots$.

3. Adding topics

The competence of agents and the influence of speech acts. Which mental attitudes of an agent can 'survive' the performance of a speech act α? In our approach, we proceed in two steps: the hearer always accepts the indirect and intentional effects, but not all of their consequences. We consider that if there exists a relation of influence of α towards an attitude, then the latter cannot be preserved in the new mental state.

A topic-based approach. All this presupposes that we are able to determine the competence of an agent and the influence of a speech act. In our approach, we base both notions on the concept *topics*. This is a natural and intuitively appealing concept, and it allows us to fine-tune the consommation of speech acts.

Topics are well studied in linguistics and philosophy (Ginzburg, 1995; van Kuppevelt, 1995; Lewis, 1972). Epstein (Epstein, 1990) associates to a formula its *subject matter*, and defines two formulas as being related if they have some subject matter in common. Generalizing his idea, we associate a set of topics to every agent i, speech act α, and formula A. Then we consider that i is competent at a topic if and only if that topic is associated to i. And a speech act α influences a topic if that topic is associated to α.

We have developped a metalinguistic theory of topics in (Herzig and Longin, 1999a). We give a brief overview in the rest of the section.

Themes and topics. Topics are themes in context. We suppose that there is a nonempty set of *themes*, such as destinations, classes, and prices in a ticket selling scenario. Our notion of theme is very closed to the Epstein's *subject-matter*. But we need here a more subtil notion and we introduce now the notion of context.

For $i \in AGT$, ma_i is called an *atomic context*. ma_i stands for "the mental attitude of agent i". A *context* is a possibly empty sequence of atomic contexts, noted $ma_{i_1}{:}ma_{i_2}{:}\ldots ma_{i_n}$. A theme t together with a context c makes up a *topic of information*, noted $c{:}t$. For example, $ma_u{:}price$ is a topic consisting in the user's mental attitude at prices, and $ma_s{:}ma_u{:}price$ is a topic consisting in the system's mental attitude at the user's mental attitude at prices.

The empty context is noted λ. By convention

$$\lambda{:}c = c{:}\lambda = c, \tag{1}$$

$$\lambda{:}t = t. \tag{2}$$

Moreover, we require $ma_i{:}ma_i = ma_i$. This identity is justified by principles of introspection that are valid in standard modal logics of belief.

Given a set of themes and a set of agents we note $\mathbb{T}$ the associated set of topics.

The subject of a formula. The *subject of a formula* is the set of topics the formula is about: $\mathfrak{subject}(A) \subseteq \mathbb{T}$. For example, $\mathfrak{subject}(Bel_s Class(\text{1st})) = \{ma_s{:}class\}$, and expresses that $Bel_s Class(\text{1st})$ is about the system's attitude at classes.

By (1) and (2), every theme is a topic and then, e.g. $\mathfrak{subject}(Dest(\text{Göteborg})) = \{\lambda{:}dest\} = \{dest\}$.

The competence of an agent. We suppose that we can associate to each agent a set of topics, the topics he is *competent* at: $\mathfrak{competence}(i) \subseteq \mathbb{T}$. For example, in our ticket selling scenario, the user is competent at destinations and classes, but not at prices.

The scope of an act. The *scope* of an act α tells us which mental attitudes of an agent are influenced by this act: $\mathfrak{scope}(\alpha) \subseteq \mathbb{T}$. An act always influences the hearer's beliefs about the speaker's attitude towards the propositional content. Consider e.g. the speech act where the user informs the system about the ticket price. This speech act influences the system's beliefs about the user's attitude towards prices. Hence $ma_s{:}ma_u{:}price \in \mathfrak{scope}(\langle \mathsf{Inform}_{u,s}\ Price(150\,€)\rangle)$. Formally, if $t \in \mathfrak{subject}(A)$ then

$$ma_j{:}ma_i{:}t \in \mathfrak{scope}(\langle \mathsf{FORCE}_{i,j}\ A\rangle) \tag{3}$$

for every illocutionary force FORCE. In the case of request, these mental attitudes are typically the only ones that are influenced.

Interactions. Is there a relationship between these functions? We propose the following axiom for acts of the informative type.

$$\text{If } \alpha = \langle \mathsf{Inform}_{i,j}\ A\rangle \text{ and } t \in \mathfrak{themes}(A) \cap \mathfrak{competence}(i) \text{ then } t \in \mathfrak{scope}(\alpha) \text{ and } ma_j{:}t \in \mathfrak{scope}(\alpha). \tag{4}$$

Suppose e.g. the user informs the system about his destination. As the user is competent at destinations, this influences the system's factual beliefs about the destination. And also about prices: a new destination means a new price. Hence $\mathfrak{scope}(\langle \mathsf{Inform}_{u,s}\ Dest(\text{Göteborg})\rangle)$ contains $dest$, $price$, $ma_s{:}dest$ and $ma_s{:}price$. Postulates for other illucutionary forces are in (Longin, 1999).

4. Towards a semantics of dialogue acts

We aim at a semantics having both a complete axiomatization and an associated automated deduction procedure. This has motivated several choices, in particular a Sahlqvist-type possible worlds semantics (Sahlqvist, 1975), for which general completeness results exist, and a notion of intention that is primitive (contrarily to the complex constructions in the literature). Intentions have a non-normal modal logic, reflecting that they are not closed under conjunction and implication. They can nevertheless be reduced to the Sahlqvist framework (Fariñas del Cerro and Herzig, 1995).

Semantics is in terms of *possible worlds models* $\langle W, \mathcal{S}, D, V\rangle$, where

- W is a set of worlds;
- D is the domain of objects;
- V is a valuation mapping variable and constant symbols to elements of D, and associating to each possible world $w \in W$ an interpretation V_w of predicate symbols;
- $\mathcal{S}$ is a collection of structures on W, consisting of
  - partial functions
    $$\mathcal{D}_\alpha : W \longrightarrow W \text{ for every } \alpha \in ACT, \quad (5)$$
  - mappings
    $$\mathcal{B}_i : W \longrightarrow 2^W \text{ for every } i \in AGT \quad (6)$$
  - and mappings
    $$\mathcal{I}_i : W \longrightarrow 2^{2^W} \text{ for every } i \in AGT. \quad (7)$$

The $\mathcal{B}_i$ are accessibility relations as usual. The set of possible worlds $\mathcal{B}_i(w)$ is called the *belief state* of i. The partial functions $\mathcal{D}_\alpha$ correspond to deterministic accessibility relations. $\mathcal{D}_\alpha(w)$ represents the possible result of α. The $\mathcal{I}_i$ are *neighbourhood functions* (Chellas, 1980, Chap. 7). Every set of worlds $U \in \mathcal{I}_i(w)$ stands for an intention of i.

The satisfaction relation $\Vdash$ is defined as usual. A useful abbreviation is $[\![A]\!] = \{w \in W : w \Vdash A\}$, called the *extension* of the formula A. Then

$$w \Vdash P(t_1, \ldots, t_n) \text{ if } \langle V_w(t_1), \ldots, V_w(t_n)\rangle \in V_w(P); \quad (8)$$

the standard truth conditions for the connectives of classical logic are still true; (9)

$$w \Vdash Feasible_\alpha A \text{ if } \mathcal{D}_\alpha(w) \text{ is defined and } \mathcal{D}_\alpha(w) \in [\![A]\!]; \quad (10)$$

$$w \Vdash Done_\alpha A \text{ if } \mathcal{D}_\alpha^{-1}(w) \text{ is defined and } \mathcal{D}_\alpha^{-1}(w) \in [\![A]\!]; \quad (11)$$

$$w \Vdash Bel_i A \text{ if } \mathcal{B}_i(w) \subseteq [\![A]\!]; \quad (12)$$

$$w \Vdash Intend_i A \text{ if } [\![A]\!] \in \mathcal{I}_i(w). \quad (13)$$

Contrarily to previous work of ours in (Herzig and Longin, 1999a), our notion of intention is not necessarily closed under logical truth, logical consequence, conjunction, and material implication.[2] This is in accordance with Bratman's (1987), Cohen&Levesque's (1990a; 1990b) and Sadek's (1992) analyses of intention. Contrarily to these approaches, intention is primitive here, as in (Rao and Georgeff, 1991) and (Konolige and Pollack, 1993). We thus generalize the semantics in (Konolige and Pollack, 1993), where only closure under logical consequence had been given up. The only principle that is valid is

$$\frac{A \equiv B}{Intend_i A \equiv Intend_i B} \quad (14)$$

We have chosen this solution for three reasons. First, building intention from other primitive notions such as goals or desires leads to various sophisticated notions of intention, with subtle differences between them. We have kept here only those properties common to all of them, viz. extensionality. Second, the definitions in the literature are rather complex, and it is difficult to find complete automated theorem proving methods for them, while our analysis enables more or less standard completeness techniques and proof methods. Third and most importantly, we think that our simplified notion of intention is sufficient in most applications.

Indeed, we think that rather than the interaction of intentions with goals or desires, it is their interaction with belief which is crucial. For example, an agent i should abandon his intention that A when he starts to believe that A. This is guaranteed by the semantical constraint

$$U \cap \mathcal{B}_i(w) = \emptyset \text{ for every } U \in \mathcal{I}_i(w). \quad (15)$$

Syntactically, this corresponds to validity of the axiom schema

$$Intend_i A \rightarrow Bel_i \neg A \quad (16)$$

[2] Hence our semantics does **not** validate

$$\frac{A}{Intend_i A}$$
$$\frac{A \rightarrow B}{Intend_i A \rightarrow Intend_i B}$$
$$Intend_i A \wedge Intend_i B \rightarrow Intend_i (A \wedge B)$$
$$Intend_i A \wedge Intend_i (A \rightarrow B) \rightarrow Intend_i B$$

which are all valid in any normal modal logic.

This axiom together with the standard axiom for belief

$$Bel_i \neg A \to \neg Bel_i A \tag{17}$$

entails

$$Bel_i A \to \neg Intend_i A \tag{18}$$

as expected.

Models must satisfy several other *constraints*. In particular, if an atom is independent of α then its truth value should be preserved. Hence we would like to validate

$$A \to \neg Done_\alpha \neg A \text{ if } \mathfrak{scope}(\alpha) \cap \mathfrak{subject}(A) = \emptyset \tag{19}$$

This is guaranteed by the semantical constraint

$$\begin{array}{c}\text{If } \mathcal{D}_\alpha(w) \text{ is defined and } \mathfrak{subject}(p) \cap \mathfrak{scope}(\alpha) = \emptyset \\ \text{then } \{p \in Atm \mid w \Vdash p\} = \{p \in Atm \mid \mathcal{D}_\alpha(w) \Vdash p\}\end{array} \tag{20}$$

We have defined other constraints warranting preservation of beliefs and intentions that are independent of a given act. We have also defined a topic-based belief adoption constraint stipulating that belief should amount to knowledge in the case of competence; formally we thus validate the axiom schema

$$Bel_i A \to A \text{ if } \mathfrak{subject}(A) \subseteq \mathfrak{competence}(i) \tag{21}$$

The semantical constraint associated to the above axiom is as following :

$$\begin{array}{c}\text{For every } w \in W \text{ and every agent } i \\ \text{there is some } v \in \mathcal{B}_i(w) \text{ such that} \\ Atm_W(w, \mathfrak{competence}(i)) = \\ \qquad Atm_W(v, \mathfrak{competence}(i)).\end{array} \tag{22}$$

This means that in the belief state of i there is a "witness world" mirroring the part of the actual world i is competent at.

Following Sadek (1991b), we associate with each speech act its preconditions and effects. Consider e.g. the informative act $\langle \mathsf{Inform}_{i,j}\ A \rangle$. It has the sincerity precondition $Bel_i A$ and the precondition of relevance to the context $\neg Bel_i BelIf_j A$. $\langle \mathsf{Inform}_{i,j}\ A \rangle$ has an intentional effect (in the Gricean sense, viz. $Intend_i Bel_j Intend_i Bel_j A$), an indirect effect (viz. the persistence of preconditions after the performance of the speech act), and a perlocutionary effect (expected effect).

Our agents being autonomous, the expected effect of an act does not obtain systematically. This means that the perlocutionary effect is not always consumed, in the sense that the propositional content is not necessarily added to the hearer's belief state. In the case where the new mental state (obtained by the admission of a speech act and the consommation of his indirect and intentional effects) entails the perlocutionary effect, then we say that the latter has been consumed.

The indirect effect of precondition preservation is problematic in the case of the relevance precondition: it means that the speaker believes that the expected effect of his speech act has not been consumed by the hearer. Our idea is to integrate a *feedback* from the hearer into the speech act. Thus, the latter is considered to be completely performed when the feedback has been consumed by the speaker.

In this perspective, we propose that the relevance precondition should not be preserved, but should be (transiently) replaced by a particular effect. This effect must express that transitionally, the speaker doesn't know anything about the hearer's attitude towards the propositional content of his act. For example, after the informative speech act $\langle \mathsf{Inform}_{i,j} A \rangle$, the speaker i ignores whether the adressee j believes A, i.e. neither $Bel_i \neg BelIf_j A$ nor $BelIf_i Bel_j A$ should hold. This means that $\langle \mathsf{Inform}_{i,j} A \rangle$ should influence the speaker's mental attitudes towards those of the hearer about the subject of A. Formally, if $t \in \mathfrak{themes}(A)$ then

$$ma_i{:}ma_j{:}t \in \mathfrak{scope}(\langle \mathsf{Inform}_{i,j}\ A \rangle) \tag{23}$$

Feedback actions are not necessarily speech acts. Being about some proposition A, they take the form

$$\langle \mathsf{Feedback}_{h,s}\ A \rangle.$$

Semantically, such actions are very similar to informative speech acts. In particular they have the same scope:

$$\mathfrak{scope}(\langle \mathsf{Feedback}_{i,j}\ A \rangle) = \mathfrak{scope}(\langle \mathsf{Inform}_{i,j}\ A \rangle). \tag{24}$$

They are related to dynamic logic test actions. Indeed, we may consider that $\langle \mathsf{Feedback}_{h,s} A \rangle$ amounts to testing truth of the formula $Bel_h A$.

5. Towards a formalisation of indirections

In this section we propose an analysis of indirect speech acts in our framework. We illustrate our purpose by the case of directive speech acts. Consider the following utterances:

1. *Give me the salt!*
2. *I ask you to give me the salt!*
3. *You give me the salt.*
4. *You can give me the salt.*
5. *Can you give me the salt?*
6. *I want you to give me the salt.*
7. *You must give me the salt.*

The *main speech act* is the act intended by its author. It can be performed directly or indirectly. In the above utterances, the main speech act is an order from the speaker s to the hearer h to give him the salt. This main speech act is direct in the cases of (1.) and (2.), and indirect in the cases of utterances from (3.) to (7.). With respect to Searle's point of view of indirection notion, if the mean of the utterance and the mean of the speaker match, the speech act performed is purely direct, and indirect(ly performed) else (Searle, 1979).

Let $\alpha_1 = \langle \mathsf{Request}_{s,h}\ p \rangle$ be the speech act corresponding to the utterance (1.). Suppose $\beta = \langle \mathsf{Give}_{h,s}\ \text{salt} \rangle$ is the action requested in α_1. (Hence the propositional content p of α_1 is $Done_\beta \top$.) From Searle's point of view, Σ_{α_1}, the *preparatory precondition* of α_1, is $Feasible_\beta\top$ (viz. the hearer can perform β). And its *sincerity precondition* Ψ_{α_1} is $Intend_s Done_\beta\top$ (s wants h to perform β).

Roughly speaking, α_2 (representing (2.)) can be identified with α_1. More precisely, the latter is an *implicit direct speech act*, while the former is an *explicit direct speech act*. The main speech act of (1.) and (2.) being direct, their main speech act is identified with α_1 (and α_2).

Suppose now the main speech act is obtained indirectly. How can we infer it from the associated litteral act? According to Virbel (Virbel, 1999), a small set of rules is enough to characterize a large set of indirect speech acts[3]. For example, to obtain the main speech act of (1.) (viz. α_1), we can:

- assert its propositional content p (as in (3.))
- assert its preparatory condition (as in (4.))
- query about its preparatory condition (as in (5.))
- assert its sincerity condition (as in (6.))
- assert on the obligation to perform β (as in (7.))

We thus have a set of simple and elegant properties of indirect speech acts. Utterances from (3.) to (7.) can be respectively represented by the following speech acts:

- $\alpha_3 = \langle \mathsf{Assert}_{s,h}\ p\rangle$,
- $\alpha_4 = \langle \mathsf{Assert}_{s,h}\ \Sigma_{\alpha_1}\rangle$,
- $\alpha_5 = \langle \mathsf{QueryYN}_{s,h}\ \Sigma_{\alpha_1}\rangle$,
- $\alpha_6 = \langle \mathsf{Assert}_{s,h}\ \Psi_{\alpha_1}\rangle$,
- $\alpha_7 = \langle \mathsf{Assert}_{s,h}\ MustPerform(h, \beta)\rangle$.

When can we infer an indirect act α' from a direct α? For example, consider $\alpha_5 = \langle \mathsf{QueryYN}_{s,h}\ \Sigma_{\alpha_1}\rangle$, querying the preparatory precondition $\Sigma_{\alpha_1} = Feasible_\beta\top$. The precondition of context relevance of α_5 is $\neg BelIf_s Feasible_\beta\top$. If h presupposes that s has satisfied the preconditions of α_5, then $Bel_h Done_{\alpha_5}\neg BelIf_s Feasible_\beta\top$ holds. Suppose now that we are in a situation where $Bel_h Done_{\alpha_5} Bel_h Bel_s Feasible_\beta\top$ holds in the memory of the hearer. Then this type of indirection is characterized by the inconsistency of the preservation of (a part of) the memory with the preservation of the presuppositions. This makes it possible to infer (at the meta-level) $Done_{\alpha_1}\top$ from $Done_{\alpha_5}\top$.

We can generalize this approach to the other indirections, and we hope also to other classes of speech acts (such as indirect assertive speech acts).

[3] A large set of (meta-)rules describing indirections can be found in (Bretier, 1995). Although the Bretier's approach and the Virbel's approach have been both developped separately the one from the other, there are several similarities between them. We adopt here the Virbel's approach because it seams to us more general

Our analysis is compatible with our approach to belief dynamics: all we have to do in the belief preservation and adoption process is to take into account the set of preconditions and effects. Thus, as the feedback is viewed as a particular action, the hearer can admit it in the same way as the other actions.

6. Conclusions

We have defined a multimodal logic of actions, beliefs, and intentions, integrating both speech acts and physical actions. We have provided a simple non-normal semantics for intentions, and thus removed some problems concerning closure of intentions under logical consequence and conjunction.

We have also refined the analysis of speech acts towards a two-step process, taking into account feedback actions.

Finally, we have sketched how to characterize indirect speech acts within that framework.

7. Thanks

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