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On the Generation of Coherent Dialogue: A Computational Approach

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'Now on the water surface pensively she rests,
desire she has no more'

Translation from: *De Waterlelie*
Frederik van Eeden

Abstract

In this paper a dialogue game is presented that enables us to generate coherent elementary conversational sequences at the speech act level. Central to this approach is the fact that the cognitive states of players change as a result of the interpretation of speech acts and that these changes provoke the production of a subsequent speech act. The rules of the game are roughly based on the Gricean maxims of co-operation – i.e. agents are forbidden to put forward information they do not believe and are forbidden to ask anything they already believe; the Gricean maxim of relevance is determined by a so-called imbalance in the players' belief and desire state. As in realistic conversational situations, it is assumed that the information needed to answer a question can be present in a distributed manner. Consequently, the structure of the dialogues may become rather complex, and may result in the generation of counter-questions and sub-dialogues. It will be shown that the structure and the coherence of conversational units do not necessarily have to be the product of a complex planning process or a speech act grammar, but can be based on elementary generation rules that take only into account the local context. As a result, the conversational game does not suffer from the same computational complexity as existing planning models for speech act generation. Although simple in its basic form, the framework enables us to produce abstract conversations with some properties that agree strikingly with dialogue properties found in Conversation Analysis.

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1. Introduction

In his wonderful book on Pragmatics, Levinson argues that in contrast with more fundamentally oriented approaches towards conversation, the proper way to study conversational organisation is through empirical techniques (Levinson, 1983: Chapter 6). Indeed, the empirical approach has made important contributions in the area of a systematic description of conversational phenomena and is indispensable in the study of human communicative behaviour. In order to understand conversation, however, we *also* need to carefully model the basic concepts and the underlying theoretical principles that drive a conversation, and, to some extent, we must be able to build computational models that predict which type of communicative act will be generated given the circumstances of the conversation.

The central goal of this paper is to present some of these theoretical principles and a computational framework that enables us to generate coherent elementary conversational sequences at the speech act level. For that, we will embrace the notion of a *dialogue game* in which two players produce speech acts or 'moves' to transfer relevant information with respect to their goals. Central to the approach is that the cognitive states of the players change as a result of the interpretation of the speech acts (see e.g. Gazdar, 1981, Bunt, 1989 & 1994) and that these changes provoke the production of a subsequent move. The game works roughly like this: A speech act is generated on the basis of preconditions formed the cognitive state of the sender, but changes the cognitive states of both sender and addressee after it has been manifested. In the next turn the addressee adopts the sender role and, subsequently, the changed mental constructs of his or her state function as the new preconditions for the next speech act. Conversational relevance of subsequent speech acts is established by the initial cognitive state of the participants and the rules for cognitive update that change a particular cognitive state and the rules for cooperative behaviour that dictate the performance of a particular speech act. As in realistic conversational situations, it is assumed that the relevant information can be distributed among the participants. Consequently, the structure of the dialogues may become rather complex, and may result in sub-dialogues and the generation of counter-questions. Although simple in its basic form, the framework enables us to produce abstract conversations with some properties that agree strikingly with dialogue properties found in, for instance, Conversation Analysis.

The idea of a game should not be taken too seriously. Even though central concepts in game theory are, for instance, choice, decision, strategy, pay-off and success, these notions will not be included in the systematic descriptions presented here. I believe that, to some extent, the concepts can be included on the basis of the presented framework and will even contribute to a better understanding of dialogue – it may explain, for instance, why in a particular argumentative discourse a player chooses a question rather than a statement – but whether a specific strategy in real dialogues is an optimal one, is probably impossible to decide due to the complexity of most situations. Here the idea of a game brings into prominence that language use is *goal-oriented* and *context dependent* (see also Carlson, 1985).

Furthermore, since neither text-grammars, nor sentence-grammars support our intuitions about the acceptability or well formedness of coherent conversations (see e.g. Dascal & Margalit, 1974), I will distance myself from the idea that conversation can be modelled by a concatenation of speech acts regulated by a set of sequencing rules or a grammar (see also Levinson (1983) and Good (1989)). In this paper, we assume that modelling the properties of conversation demands a notion of context in terms of cognitive states of the participants (e.g. beliefs and intentions) and a set of rules that update the context and regulate the communicative behaviour of the participants based on this context. It will be shown that coherence of the speech acts merely is a result of the conversational rules that operate on these contexts (see also Searle, 1992; Dascal, 1992).

Before we will discuss the game and its underlying communication model, the notion of a coherent dialogue will first be considered in the next section. In Section 3, we then turn to the basic concepts and the underlying theoretical principles on which the game and its rules are founded. In the actual game, which is defined in Section 4, some important simplifications are made with respect to the basic communication model. An example of a particular instantiation of the game is given in Section 5; the example accurately exposes how the cognitive states of the participants change as a result of the speech acts and how these changes provoke the generation of another speech act. In section 6, some extensions are suggested and their consequences are discussed.

2. Coherence in Dialogue

In its basic form, a dialogue can be conceived as a linear alternating sequence of symbolic elements – or utterances – between two participants (see e.g. Hamblin, 1971). The various contributions in the dialogue have a meaning and a purpose – i.e. there is a relation between the symbolic elements and particular mental constructs that result from the interpretation process of the separate dialogue contributions, and they are intended to accomplish a particular effect by the sender with respect to the cognitive state of the addressee. In general, the utterances do not form independent segments of speech, but show a coherent structure of conversational units like words in a single sentence. Hence, there not only is a relation between the revealed symbols and the mental constructs, but also between the various constructs themselves – so-called *coherence relations.* Sometimes the words in a sentence explicitly refer to this type of relations (e.g. anaphoric reference, temporal and rhetorical phrases), but often, explicit verbalisation of these structural units is left out from the surface structure of the sentence (see also Givón (1995), Sanders & Noordman (2000)).

Coherence relations can be described on a syntactic and a semantic level. Syntactically, most models of conversation include both a *linear* and a *hierarchical* conception of coherence relations. Linearity is established by a notion of pairing – two utterances that for some reason seem to be related to each other at the same level. In Conversation Analysis, for instance, the fundamental pairs of conversational organisation are sequences called 'adjacency pairs' or – less restrictive with respect to the immediate follow up – 'conditional relevant units' (Schegloff, 1972): a question is followed by an answer, an assertion by an acceptance or a rejection, etcetera. From speech act theory we know the notion of 'uptake' (Austin, 1962), being the dependency of a successful performance of an illocutionary act on the reaction of the addressee. Also, particular illocutionary forces explicitly refer to speech acts that are already part of the context, such as 'deny', 'accept' and 'illustrate' (Holdcroft, 1992). Hierarchy, on the other hand, is established by embedded structures that may appear between paired units. In conversation this can be created by so-called 'insertion sequences' or 'sub-conversations' – i.e. deviations from the main point that are usually expressed by the first part of an adjacency pair. Insertion sequences, which in turn may consist of a sequence of adjacency pairs, are often produced to satisfy the preconditions of the second part of the initial adjacency pair. Through the embedding structures of adjacency pairs, the *recursive* organisation of conversation becomes apparent. Similar structures can be found in, for instance, Power (1979), Grosz & Sidner (1986), Polanyi (1988) and Longacre (1996).

In line with, for instance, Redeker (1990) and Bateman & Rondhuis (1997), it is assumed that the semantic nature of the coherence relations is twofold: a. *informational*, where the relation between the units corresponds to an existing relation in the world that is described by the discourse (co-reference, spatio-temporal relations, causation, and the like) and b. *intentional*, where the relation is not between the state of affairs described in the units, but between the mental constructs of the dialogue participants in terms of attitudes, such as beliefs and intentions (the illocutionary and perlocutionary relations, such as question-answer, offer-rejection and threat-defence). The informational view often refers to discourse produced by single speakers, while the intentional view is often used in connection with dialogue situations. Clearly, coherence in a dialogue could not be established without the continuity or recurrence of informational elements. Since this paper is about dialogue, we will concentrate on the latter type of relation.

In the intentional view, the participants of the dialogue are usually assumed to generate and execute a particular plan, and the utterances are considered actions that achieve some sort of communicative effect. Plans can be viewed as sequences of mental activities based on some type of reasoning mechanism designed to accomplish some goal state, and are therefore considered as a prerequisite to action. The idea is that the participants understand language, not only when they understand the informational part, but especially when they successfully infer each other's plans and goals. In Allen & Perrault (1980), for instance, agents generate meaningful responses on the basis of a recognised plan of the other – in their model, they particularly focus on responses to implicit requests and indirect speech acts. The structure of the plan reflects the coherence between the mental constructs, which are expressed in terms of goals, shared intentions and nested beliefs.

Although the planning model has had an enormous impact on artificial intelligence approaches to natural language processing and communication, there seem to be valid reasons why it can be rejected in a first approach to the generation of conversational units (c.f. Suchmann, 1987). A problem with most of the planning work is that the belief and intentional models are overly complex and unattractive from a computational point of view. For instance, the closure of the belief and intention axioms generates an infinite set of belief and intention constructs,[1] which among other formulae contains the preconditions for the next turn. It is unclear, however, how the next speaker selects the relevant mental constructs from a possibly infinite set of potential preconditions. Humans have only finite information resources and limited reasoning capabilities, and it is highly unlikely that they take into account the almost infinite amount of pre- and postconditions that have to be calculated prior to almost any action. Moreover, humans live in an extremely dynamic and complex world that has to be monitored constantly to avoid unexpected occurrences. Consequently, even if all the necessary calculations are made to perform a particular action, communication models must incorporate sensitivity to local circumstances and resources for the redundancy and correction of unexpected outcomes.

Another problem is the choice of the proper type of mental constructs. Whether we have to include such constructs as shared intentionality (Searle, 1992) or mutual beliefs (e.g. Clark & Marshall, 1981) probably depends on the type of dialogue phenomenon one wants to describe. It has been shown, for instance, in Taylor, Carletta & Mellish (1996) that particular mental constructs such as nested beliefs of the third level – 'A believes that B believes that A believes' – and beyond are simply unnecessary to model the properties of a co-operative dialogue.

In this paper, I will try to show that the coherence of the speech acts is tied to local interactions contingent to the agent's particular situation and that the coherence relations can be described in a strictly situated sense, entirely driven by the history of the speech acts and the dynamics of the mental constructs of the participants. In other words, coherence is not considered as an intrinsic property of a text or a dialogue, but mainly as a mental phenomenon (c.f. Gernsbacher and Givón, 1995).[2] In what follows, a dialogue game and its underlying communication model will be described that enable us to generate linear and hierarchical speech act sequences. A particular instance of the model will be chosen in which participants have no access to the outside world and only receive information based on the exchange of conversational units. Describing the properties and the dynamics of the mental constructs in relation to the various dialogue contributions is an essential part of this work. In order to develop such a framework and to avoid the problems of infinity in the planning approach, the following questions will be addressed:

1. What type of mental constructs should be included to model a dialogue's basic structural properties?
2. How do the various dialogue contributions change the existing mental constructs?
3. How do these changes influence the generation of new contributions?

3. The Basic Model

The dialogue game presented in this paper is based on a simple model employed in human-computer interaction (Hutchins, 1989; Ahn et al. 1995). Underlying this model is the recognition that humans interact naturally with their environment in two ways: symbolically and physically. On the one hand, if there is an intermediary interpreter, humans can interact symbolically and use language to give commands, ask for or provide information, etcetera. On the other hand, physically, one manipulates objects, for instance, by moving or fastening them, or observes them by seeing, feeling, hearing, tasting or smelling. The essential difference between the two types of interaction is that actions of the first type (e.g. illocutionary acts and their semantic content; Austin, 1962; Searle, 1969) need an interpreter who can bridge the gap between the symbols and their actual meaning and purpose, while actions of the second type are related in a more direct manner to human perception and action.

In parallel with the distinction symbolical vs. physical, humans engaged in dialogues can perform two types of *external* actions: a. *communicative actions* intended to cause some cognitive effect in the recipient, and b. *non-*

communicative actions to observe or change particular properties of the domain. Obviously, the two types of action can be considerably interrelated (c.f. Grosz & Sidner, 1986; Airenti, Bara & Colombetti, 1993). In addition, we will include an action type that is neither communicative nor external, namely *inference* – i.e. the process of adjusting the cognitive states of participants solely based on their previous states.[3] In short, the basic model includes perception, action, communication and thinking in an extremely rudimentary form.

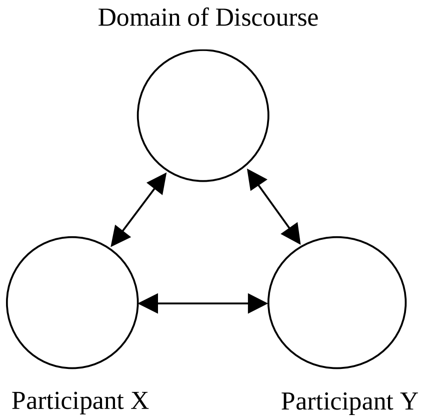

Figure 1. The triangle metaphor.

The distinctive interaction channels are represented in the so-called triangle metaphor (Fig. 1), where the corners represent the domain of discourse (or the external world) and the two participants, and the arrows the flow of information between the participants themselves and between the participants and the domain. The external actions can be expressed in terms of the flow of information between the corners of the triangle. A communicative act performed by participant *x* towards participant *y* is a flow of information from *x* to *y*; observation of the domain is a flow of information from the domain towards the observer and an action carried out in the domain is a flow of information from the actor to the domain. Below, the term *communication* will be used exclusively in reference to an information flow between the participants; *interaction* will be conceived in a broader sense and includes flows of information between the participants and the domain.

In practice, the communication channel between the two participants may cause messages to be delayed (as in letters) or disturbed by, for instance, noise. Also, the channel can be duplex, where both participants can speak at a time, or half-duplex, where only one participant can speak at the time. Here, we will consider the channel between the participants and between the participants and the domain of discourse as an ideal half-duplex channel, which means that no information is delayed or lost during transfer and that information can flow only in one direction at a time. Time is unimportant, but the order of communicative and non-communicative acts is important, since the acts change the cognitive states of the dialogue agents.

An important question to be answered is *why* information flows in the first place. In other words, what is an agent's basic motivation to perform a communicative action? Although the answer touches upon the heart of psychology, we will abstract from concepts such as fear, hunger and sexuality, and borrow some concepts from Perceptual Control Theory (PCT; Powers, 1973). Main issue in PCT is that all behaviour is the control of perception. In PCT discrepancies in two input signals, the reference signal and the perceptual signal, lead to an output signal. As long as the incoming perception does not match the required reference level, the error is transformed into an output appropriate to bring the perception closer to the reference signal.

In this paper, the reference signal corresponds with the *desire* state of the agent, the perceptual signal with the *belief* state, and the output signal with the agent's actions – internal or external. The basic assumption that all behaviour is control of perception can be interpreted as the process of balancing the belief and the desire states, i.e. an agent believes everything that is desired by the agent.

It should be noted that '*x* desires p' means that the agent *x* wants p to be true in the domain of discourse, *not* that the agent wants to know that p is true.[4] The point is, however, that the agent has only access to the world by observation, which causes a *representation* of the world. In other words, the desire can only be compared with a representation of facts about the world, not the world itself; this representation is what we will call 'the agent's belief'. Although the agent intends to acquire knowledge – i.e. a perfect correspondence between the represented information and a part of the world – I have abandoned the term knowledge as much as possible to emphasize the subjective nature of the agent's information state.[5] One problem with knowledge is, for instance, that if the world changes autonomously without intervening observations of the agent, the knowledge may easily become false. As in realistic situations, the agents in this paper have only partial information about the world and the information may even be inconsistent with the facts in the world. On the other hand, there should be a strong relation between the world and the agent's belief state about the world. Therefore, the agent's beliefs are subject to strict update rules. For instance, if p is false in the world, an agent should not come to believe by observation that p is true. Here, the meaning of the belief state will be fully determined by its use, as described below.

We will make the simplification that an agent's belief or desire about a particular fact in the world can be positive, negative or void. In the latter case, the agent has no belief or desire with respect to that particular fact. Consequently, we can distinguish nine situations (see Table 1).

Belief / Desire	p	¬p	void
p	1	***2***	***3***
¬p	***4***	5	***6***
void	7	8	9

Table 1: Various combinations of belief and desire constitute nine basic states of the agent.

No action is required in cases 1 and 5, since the agent's cognitive state is balanced with respect to p. Also in cases 7, 8 and 9, no action is required, since the agent has no desire. In four other cases indicated in bold italics (2, 3, 4 and 6), the situation is out of balance: in 2 and 4 the belief state is in conflict with the desire state; in 3 and 6 the agent is ignorant with respect to p. Below, the imbalance between the two states will be represented in a temporary help state, that we will call the *intention* state; as long as the imbalance exists, the intention state is not empty and motivates the agent to perform some type of action.

While beliefs and desires are relatively unlinked – the only relation between them is that in a balanced situation the agents' desire state is a subset of their belief state – we assume that beliefs and intentions have a strong relation. If agents intend to achieve a situation in which they believe p is true, they do not believe that p is already true. Moreover, intentions are supposed to be consistent with an agent's belief; consequently, if agents believe that p is true and believe that from p follows q, they do not intend to achieve a situation in which they believe q is false (c.f. Bratman, 1990 and Beun, 1994). This is expressed in the following rules (where $B_x p$ and $IK_x p$ mean '*x* believes that p' and '*x* has the intention to know that p is true', respectively):

BI1. $IK_x p \rightarrow \neg B_x p$

BI2. $IK_x p \;\&\; B_x(p \rightarrow q) \rightarrow \neg IK_x \neg q$

In order to empty the intention state and thus achieve a balanced situation, agents may either modify their belief state or modify their desire state. It is assumed that belief can be modified in three ways: a. by a flow of information from the domain, b. by an appropriate information flow from the dialogue partner, and c. by reasoning. A flow of information from the domain can be established by observation of particular aspects of the domain; a flow of information from the dialogue partner can be provoked by means of the performance of a question; the reasoning mechanism enables the agent to make implicit beliefs explicit.

Belief	*Desire*	*Balance*	*External Action*
p	p	yes	–
p	void	yes	–
p	¬p	no	Observation, Manipulation, Command
void	p	no	Observation, Question

Table 2: Possible initial external actions performed as a result of the imbalance between the belief and the desire state of an agent.

An initial desire state can be adjusted in two ways:[6] a. if the agent receives particular information with respect to the desire state of his partner, or b. if the agent concludes that he is unable to change the belief state in such a way that the situation can be balanced (c.f. Cohen & Levesque, 1990). In the first case, agents may 'take over' the desire of the dialogue partner and behave as a co-operative participant as long as the desire does not conflict their own desire state; in the second case, the desire will be cancelled.

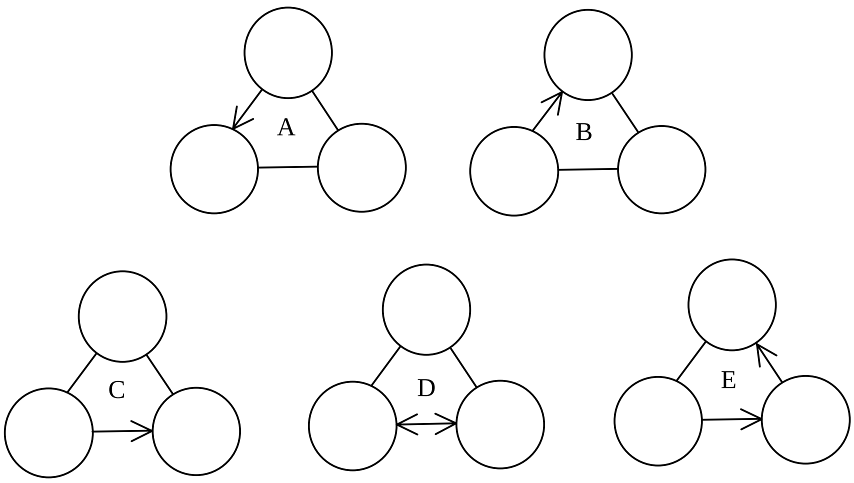

Figure 2: The basic action types and information flow in a communicative situation. The top of each triangle represents the domain of discourse, with the two participants below. A: observation, B: manipulation, C: stating, D: question-answer and E: command-execution.

Thus, if agents detect that the desire state and the belief state do not agree, they will perform an action. Precisely which action depends on the situation and the rules of the game. In Table 2 an overview is given of an agent's first possible external actions – or, what we will later call the initial moves of the game – depending on the type of imbalance and the communicative situation. For instance, in the case of ignorance (Table 2 bottom), agents may start to observe a particular part of the domain, but if the domain is inaccessible, they may ask a question to their dialogue partner. Subsequently, the partner may give the answer or, if he or she cannot provide an answer, indicate that he or she is unable to give the answer. In the latter case, the first agent may decide to adjust the desire state and drop the first desire.

The basic action types and their flow of information are depicted in Figure 2. Note that the communicative action types – C, D and E – correspond to the basic sentence types in natural language: declarative, imperative and interrogative.

4. A Co-operative Dialogue Game

To avoid unnecessary complexity, we will make three important simplifications in the dialogue game presented in this paper. First, the participants have no access to the domain of discourse, i.e. they are unable to observe or manipulate particular aspects of the domain. In other words, information only flows between the two dialogue partners like, for instance, in a telephone dialogue. Consequently, they only have communicative intentions. New explicit beliefs can thus only be modified in two ways: by communication with the partner and via a reasoning mechanism for the belief states of the agents. A second simplification is that the participants only hold positive information about the domain of discourse, i.e. negation is excluded. This implies that the two participants will never hold conflicting beliefs or desires, and, since alleged inconsistencies will never arise, the agents will never argue about a specific statement. The content of a statement about the domain of discourse is simply added to the belief state of the partner. This information may be incorrect with respect to a particular instance of the domain of discourse, but the incorrectness will never be discovered, since the agents have no access to the domain. The third simplification concerns the imbalance of the desire and belief states. It is assumed that only one of the participants has an imbalanced state (the so-called 'initiator'). The initiator starts the dialogue, while the other (the 'follower') has no initial desires and reacts to the initiator's wishes in a co-operative manner.[7] Both the initiator and the follower act according to the same dialogue rules, but have discrepancies in the content of their cognitive states.

The dialogue game is divided into two parts (for a similar approach, see Piwek (1998) or Amgoud, Maudet & Parsons (2000)): a. the *game-board* that contains information about a particular state of the game, and b. the *dialogue rules* that control the behaviour of the participants (generation rules) and that prescribe how the game-board changes (update rules). The game-board represents the participants' cognitive state and typically changes because of the participants' communicative actions. In line with the basic model, the participants' cognitive state roughly contains two types of information: a. information about the participants' beliefs, and b. information about desires or intentions. The second type of information is related to the agents' commitments to perform a specific action and gives relevance to the individual moves of the participants. In this respect, it should be noted that the concept of relevance in these games is totally determined by the process of balancing the belief and the desire state. In the initial state, the imbalance between the desire and the belief of the initiator motivates the performance of the first speech act. In the second and subsequent states, the imbalance is caused by the adjustments of the desire state as a result of subsequent speech acts and the cooperative attitude of the participants (desires of the other are adopted as long as no conflicts arise).

'Moves' or information flows between the two participants are composed of two elements (c.f. Searle (1969) and Bunt (1989)): a. plain information about the domain of discourse (the semantic content), and b. information about the way the different mental constructs should be updated (the communicative function).[8] Every move is completely determined by the cognitive state of the participant who has the turn to act and by the rules for co-operative behaviour that will be presented below. Since the cognitive states are updated after every move, the next move is not only determined by the previous one, as would be the case in a dialogue grammar, but also by the context of the move. In line with Carlson (1985), explicit turn-taking conventions will not be included into the dialogue rules; each play is a sequence – not necessarily finite – of linearly or hierarchically alternating moves.

The agents' communicative strategy is determined by the rules of the dialogue game, which is roughly played in line with the Gricean maxims of co-operation (Grice, 1975). Agents are forbidden to put forward any domain information they do not believe and are forbidden to ask anything they already believe or they believe that their partner does not believe. Questions should be answered if the information is available and, if not available, this should be indicated accordingly. This may take more than one turn, because the information to answer the question may be distributed among the participants. Beliefs or desires that are explicitly stated in the dialogue are called *manifested*.

The agents' cognitive state
Two types of domain information will be distinguished: simple propositions ('p', 'q', 'r',…) and compound propositions ('p→q',…), which connect a simple proposition (the antecedent) with a simple proposition (the consequence). We will not allow tautologies ('p→p', …), since they carry no information.

The agents' cognitive state consists of the following mental constructs:

- Private information of an agent about the domain of discourse ($B_x p$; '*x* believes that p').
- Information of which the other is ignorant ($B_x \neg B_y p$; '*x* believes that *y* does not believe that p').
- Desire about a particular state of the domain of discourse ($D_x p$; '*x* desires that p').
- A list of manifested intentions of the other ($B_x IK_y \langle \ldots, p \rangle$; '*x* believes that *y* intends to know that p').

Here $IK_y \langle \ldots, p \rangle$ means that the agent *y* has an intention to know the truth value of several propositions, of which p is the last (in this case). The list may be empty, indicated by $IK_y \langle \varnothing \rangle$, which means that *y* has no intentions. In the above, the addition of agent *x*'s belief indicates that *y*'s intention is manifest.

We assume that the agents can reason about their beliefs by Modus Ponens (I1).

I1. $B_x p \;\&\; B_x(p \rightarrow q) \rightarrow B_x q$

The private belief states are monotonic, i.e. everything that can be inferred from previous states, can also be inferred from new belief states. Information about the desire and the intention state can be retracted after particular communicative acts. For example, if a question 'whether p' has been answered, the intention to answer this question is dropped. We are not concerned with the full details of the update mechanism, but assume that the cognitive states are updated in line with the principle I1 and the update rules presented below.

Below, we will use the function *link* that gives us the set of all antecedents that are connected to a particular consequence in a belief state. More precisely, *link* is defined in the following way:

- $link(x, q) \equiv \{p \mid B_x(p \rightarrow q)\}$

For instance, if *x* believes that 'p→q' and believes that 'r→q', then $link(x,q)=\{p,r\}$. If there is no compound proposition with q as its consequence in belief state *x*, the set is empty.

Communicative acts
Agents manifest their beliefs and intentions by means of communicative acts or moves, such as statements and questions. The content of a move consists of a simple proposition; the communicative function is tagged by one of the following markers ('–','+','∗','♦'):

- Questions: $[x,p]^{-}$
- Statements: $[x,p]^{+}$
- Ignorance: $[x,p]^{*}$
- Closure of the dialogue: $x^{\blacklozenge}$.

In line with Ahn (2000), the '–' and '+' refer to the polarity of information; '–' indicates an information gap that has to be filled, '+' indicates a particular fact that extends the belief state of the partner.

Rules of the dialogue
Moves are fully determined by the cognitive state of the participant who performs the move and the rules that are applicable to this state. A double arrow '⇒' links the preconditions of the move to the move itself. The left side of the arrow is of type proposition and represents the preconditions in terms of the cognitive state of an agent; the right side is of type action and represents the generated move.

Since the agents have no access to the domain of discourse, the initial move can only be a question (see Table 2):

G0. $D_x q \ \& \ \neg B_x q \ \& \ B_x IK_y <\emptyset> \Rightarrow [x,q]^-$

The first two preconditions indicate that the agent's state is out of balance; the third precondition was included to avoid the agent from repeating the question every turn.[9] Note that generation rule G0 is applicable to the initiator only; the rules presented below are applicable to both participants. Hence, below *x* and *y* range over both the initiator and follower.

After the initiator has asked the initial question, her intention becomes manifest. Now, there are three possibilities for the next move:

a. The follower knows the answer and thus gives the answer.
b. The follower does not know the answer directly, but concludes that there may be a way to find the answer.
c. The follower is ignorant and does not know a solution.

Generation rule G1 expresses that if *x* believes that q is the last item on the manifested intention list (i.e. q has been asked for) of participant *y* and q is believed by *x*, then *x* will answer q:

G1. $B_x IK_y <\ldots,q> \ \& \ B_x q \Rightarrow [x,q]^+$

If *x* does not know the answer, *x* may ask a counter-question. The counter-question can only be asked if the agent finds the antecedent of a linked proposition, and if he or she does not believe that the other is ignorant with respect to the linked proposition (G2):

G2. $B_x IK_y <\ldots,q> \ \& \ \neg B_x q \ \& \ p \in link(x,q) \ \& \ \neg B_x \neg B_y p \Rightarrow [x,p]^-$

Note that if the set *link*(*x*,q) contains more than one element, *x* has to make a choice for one of the linked propositions. In the examples below, we simply take the first one.

If *x* does not know the answer and cannot ask a counter-question, *x* will manifest his or her ignorance (G3).

G3. $B_x IK_y <\ldots,q> \ \& \ \neg B_x q \ \& \ \neg(p \in link(x,q) \ \& \ \neg B_x \neg B_y p) \Rightarrow [x,q]^*$

Finally, in G4 a closing act is generated if the intention list is empty and if the situation is balanced:

G4. $B_x IK_y <\emptyset> \ \& \ \neg(D_x q \ \& \ \neg B_x q) \Rightarrow x^\blacklozenge$

Closing the dialogue means that the turn is given to the next speaker. To avoid an infinite sequence of closing acts, a meta-rule has to be defined to close the dialogue:

Closing (CL)

Both dialogue partners stop generating communicative acts iff two successive closing acts are performed (i.e. the sequence $x^{\blacklozenge}$ & $y^{\blacklozenge}$).

The update of cognitive states

The update function yields a new cognitive state depending on the old state and the move just performed. To represent the consequences (or postconditions) of a particular move, we introduce '>'. The left side is of type action and represents the performed move; the right side represents the postconditions and denotes how the cognitive states should be updated. If information has to be removed, the relevant attitudes are preceded by *Del*. So, for instance, $Del(B_x IK_y\langle q\rangle)$ means that q should be deleted from the intention list.

In update rule U1, it is expressed that if *x* utters a statement with content q, the following states are updated: a. *y* now believes that q, b. the content q will be removed from the intention list and, if relevant, c. *x* no longer believes that *y* is ignorant with respect to q:

U1. $[x,q]^{+} > B_y q \;\&\; Del(B_x IK_y\langle q\rangle) \;\&\; Del(B_x \neg B_y q)$

Rule U2 expresses that if *x* utters a question with content q, *y* subsequently believes that q is a communicative intention of *x* and, therefore, q will be added to the end of the list:

U2. $[x,q]^{-} > B_y IK_x\langle q\rangle$

Rule U3 expresses that if *x* indicates that he or she has no information about q, q will be added to *y*'s belief about *x*'s ignorance and q will be removed from the intention list and, if present, from the desire state:

U3. $[x,q]^{*} > B_y \neg B_x q \;\&\; Del(B_x IK_y\langle q\rangle) \;\&\; Del(D_y q)$

Note that the desire state only changes if the partner indicates that the question cannot be answered (retraction). Intentions, on the other hand, display much more dynamic behaviour: they may be added as a result of a manifested intention of the other, or removed if the question has been answered or if the question cannot be answered.

The last rule, U4, expresses that cognitive states do not change after a closing act:

U4. $x^{\blacklozenge} > \otimes$

5. An Example Dialogue

We shall now turn to an example where John and Mary play the co-operative dialogue game based on the previously introduced mental constructs, and the generation and update rules. First, we present an abstract version of the example, and next, we convert the example into a natural language dialogue.

In Table 3, we have depicted the game-board, i.e. the cognitive states of John and Mary, the communicative acts (MOVES) that occur as a result of the dialogue rules, and, in addition, a reference to the applied update and generation rules. The information that represents the preconditions for the next move is indicated in bold italics; empty states are indicated by '∅'. In the example, we left out John's and Mary's desire state, since in this particular situation the desire states do not change during the course of the dialogue.

In the initial situation, John believes that $p \rightarrow q$ and believes that $r \rightarrow q$, John has no desires; Mary believes that $s \rightarrow p$ and believes that r, Mary has the desire that q. Therefore, Mary is the initiator and starts with the initial question whether q. John is unable to answer the question directly, but may find an answer if he has information about p or r. Hence, according to rule G2, John will generate the question whether p or the question whether r; in

Table 3, John starts with the first solution (move 2). Now, the same rule is applicable to Mary's situation, therefore she asks for s,

Nr.	John			MOVES	Mary		
	B_J	$B_J I_M$	$B_J \neg B_M$		B_M	$B_M I_J$	$B_M \neg B_J$
Initial state G0	p→q r→q	∅	∅		s→p r	∅	∅
1				$[M,q]^-$			
U2 G2	***p→q*** r→q	<***q***>	∅		s→p r	∅	∅
2				$[J,p]^-$			
U2 G2	p→q r→q	<q>	∅		***s→p*** r	<***p***>	∅
3				$[M,s]^-$			
U2 G3	p→q r→q	<q,***s***>	∅		s→p r	<p>	∅
4				$[J,s]^*$			
U3 G3	p→q r→q	<q>	∅		***s→p*** r	<***p***>	***s***
5				$[M,p]^*$			
U3 G2	***p→q*** ***r→q***	<***q***>	***p***		s→p r	∅	s
6				$[J,r]^-$			
U2 G1	p→q r→q	<q>	p		s→p ***r***	<***r***>	s
7				$[M,r]^+$			
U1 G1	p→q, r r→q, ***q***	<***q***>	p		s→p r	∅	s
8				$[J,q]^+$			
U1 G4	p→q, r r→q, q	∅	p		s→p r,q	∅	s
9				M♦			
U4 G4	p→q, r r→q, q	∅	p		s→p r,q	∅	s
10				J♦			
U4 CL	p→q, r r→q, q	∅	p		s→p r,q	∅	s

Table 3: John and Mary try to solve the problem whether q is true. Initially, the information about q is distributed; in the final state, both John and Mary believe that q is true.

but subsequently, John has to inform Mary that he has no information about s (move 4). Dead end, the intention s will be retracted by rule U3. There is a way out, however: q is still on the intention list and p cannot be asked for again, since John now believes that Mary is ignorant about p. John will question r and, since Mary has direct information about r, the question can be answered by Mary (move 7). In turn, John can answer Mary's initial question and finally, since all manifested intentions are removed, the dialogue will be closed (move 9 and move 10). Note that in the final situation both John's and Mary's belief and desire states are balanced.

To make the example a little more concrete, suppose a domain where the following propositions hold:

p: *'Olga smokes cigars'*
q: *'Olga is happy'*
r: *'Olga works at IPO'*
s: *'Olga is a manager'*

In correspondence with Table 2, John and Mary initially believe the following information:

B_{John}: *'If Olga smokes cigars, then she is happy'*
'If Olga works at IPO, then she is happy'

B_{Mary}: *'If Olga is a manager, then she smokes cigars'*
'Olga works at IPO'

Mary wants Olga to be happy, but she has no direct information about Olga's state. Below, the example is presented in 'natural' language.

Dialogue I
1. Mary: Is Olga happy?
2. John: Does Olga smoke cigars?
3. Mary: Is Olga a manager?
4. John: I do not know whether Olga is a manager.
5. Mary: I do not know whether Olga smokes cigars.
6. John: Does Olga work at IPO?
7. Mary: Olga works at IPO.
8. John: Olga is happy.
9. Mary: Thank you.
10. John: Thank you.

6. Discussion

At first, Dialogue I looks quite unnatural and lacks many of the ingredients that we usually observe when we study the properties of natural language dialogue. If we take a more profound look, however, we notice the elementary structural phenomena discussed at the beginning of this paper. First of all, in Table 3 we can observe the linear management organisation of adjacency pairs, such as question-response (moves 3-4, and moves 6-7) and the closing of the dialogue (moves 9-10). Second, we observe the hierarchical organisation of insertion sequences, such as moves 3 and 4 between the question in 2 and its reply in 5, and moves 2-7 between 1 and 8. Depending on the initial states, the dialogue rules generate an arbitrary number of levels of sub-sequences and the final reply may be originated many turns away from the initial question. Since especially deeply nested structures require an intense memory process, empirical research should disclose how human participants organise these structures in natural discourse.

Furthermore, Table 3 exposes *why* particular sequences of conversational units are interpreted as linear and others as hierarchical: as long as the content of a question is not removed from the intention list, all conversational units subsequent to the question are interpreted on a lower level with the exception of the unit that causes the elimination of the intentional content. So, for instance, moves 2-7 are interpreted on a lower level than move 1, because they do not remove the content q from John's intention list; move 8 is categorised on the same level as move 1, because it removes q. Syntactically, the structure of Dialogue I can be schematised as follows (Q = Question; R = Response):[10]

$$(QA_1((QB_2(QC_3- RC_4)RB_5)(QD_6- RD_7))RA_8)$$

Table 3 also accurately depicts which set of constructs of the speaker's cognitive state induces the performance of a particular speech act and how the cognitive states of both participants change as a consequence of the dialogue contributions. It can be observed, for instance, *how* John and Mary were able to answer the question in a co-operative manner, although the information was not directly available in one of the private belief states of the agents. In this case, the generation and update rules guarantee that, if the information is distributed, adequate questions will be asked and relevant replies will be provided.

The unnaturalness of Dialogue I has many reasons. One is that the generation rules do not take into account the generation of extra management utterances and coherence markers; another reason is that the domain language is far too simple and that only simple propositions can be communicated. Let us take a more detailed look at these aspects.

To obtain a more realistic dialogue, a 'decorated' version of Dialogue I was constructed. In the decorated dialogue, we included, for instance, pronominalisation and expressions that are not generated by the rules G0-G4, such as the opening of the dialogue, indirect questioning, thanking and particles on the process level ('Aha', 'Well', 'Uh'). The basic structure of both dialogues, however, is isomorphic to the structure presented in Table 3.

Dialogue II (decorated version of Dialogue I)
1. Mary: Hello John, I have a question. Can you tell me whether Olga is happy?
2. John: I don't know, does she smoke cigars?
3. Mary: Uh… that depends, is she a manager?
4. John: Sorry, I don't know.
5. Mary: Then I don't know whether she smokes cigars.
6. John: Aha, wait… does she work at IPO?
7. Mary: Yes, she does.
8. John: Well, in that case, don't worry, she is happy.
9. Mary: Great, thanks a lot, bye.
10. John: Okay, bye.

An extension along the line of Levinson's preference organisation (Levinson, 1983), in which linguistic markers are added in the dialogue if non-preferred sequences of moves are generated, looks promising. Although in a premature stage of development, another interesting candidate is Bego's context-change approach (Bego, 1995), where specific types of feedback are considered as side-effects of updates on the cognitive states. It should be stressed, however, that the author considers these types of management moves to be a second order effect, which are based on more fundamental principles such as the ones presented in this paper.

It can also be observed in Table 3 that the behaviour of the participants is strictly contingent to the situation in terms of a very limited set of mental constructs and that, although a simple form of reasoning has been included, a planning component is not required to generate adequate conversational units. The basic principle of answering questions and asking counter-questions is depicted in Table 4, where a simplified version of the game-board is shown (only the private belief states and the moves are shown). In Table 5 we have opted for another strategy that allows for moves with linked propositions, which may result in the indirect answer 'if p then q'. Note that the number of moves to transfer the information is smaller in Table 5 and, therefore, more efficient with respect to the channel capacity. On the other hand, an advantage of the strategy in Table 4 is that both *x* and *y* have the information in the final state that p and that q; in other words, *x* knows that the question has been answered. In order to achieve the same effect in Table 5, an extra dialogue rule would be required that states that the *questioner* has to manifest the answer. The latter option sounds reasonable, but has important implications for the cognitive states and the dialogue rules. Here, the reader is invited to modify the dialogue game and play the game with the initial situation of Table 3.

X	MOVE	Y
$p \rightarrow q$		p
	$[Y,q]^-$	
$p \rightarrow q$		p
	$[X,p]^-$	
$p \rightarrow q$		p
	$[Y,p]^+$	
$p \rightarrow q$, p,q		p
	$[X,q]^+$	
$p \rightarrow q$, p,q		p,q

Table 4: The basic principle of asking questions and counter-questions.

X	MOVE	Y
$p \rightarrow q$		p
	$[Y,q]^-$	
$p \rightarrow q$		p
	$[X,p \rightarrow q]^+$	
$p \rightarrow q$		$p \rightarrow q$, p,q

Table 5: The question whether ‘q’ is answered by the indirect answer ‘if p then q’.

One of the problems in Table 5 is that, as long as only simple propositions or simple indirections (i.e. compound propositions consisting of only two simple propositions) are communicated, it cannot easily be guaranteed that information becomes available if it is distributed among the participants. Therefore, in Tables 6 and 7 a variant of the game – with the initial situation of Table 3 – is shown in the simplified version of the game-board. In this variant, disjunctions (‘$\vee$’) and conjunctions (‘&’) are included. In addition to inference rule I1, we assume that the following inference rules hold:

I2. $B_x p$ & $B_x q \leftrightarrow B_x(p\&q)$
I3. $B_x(p\rightarrow q)$ & $B_x(r\rightarrow q) \leftrightarrow B_x(p\vee r\rightarrow q)$

where p, q and r are simple propositions. In other words, if the agent *x* believes that ‘p’ and believes that ‘q’, *x* also believes that ‘p and q’ (I2); if the agent *x* believes that ‘$p\rightarrow q$’ and believes that ‘$r\rightarrow q$’, *x* also believes that ‘$p\vee r\rightarrow q$’ (I3). If we now allow communication of multiple propositions in one dialogue turn, not only can we guarantee that distributed information becomes available to the questioner, but also that the dialogue looks more natural. In Table 6, for example, the follower provides an indirect answer that includes a disjunction of all the linked propositions in the antecedence; in Table 7, the follower asks for the value of a disjunction of all the linked propositions. Note that in Table 6 the answer is provided by the initiator (move 3). A precise definition of the adapted dialogue rules is omitted here, however. The resulting decorated natural language dialogues are presented in Dialogue III and Dialogue IV, respectively.

Dialogue III.

1. Mary: Hello John, I have a question. Can you tell me whether Olga is happy?
2. John: Hm… I know that Olga is happy if she smokes cigars or if she works at IPO.
3. Mary: Well, she works at IPO, so she must be happy. Thanks a lot.
4. John: You're welcome, bye.
5. Mary: Bye.

Dialogue IV

1. Mary: Hello John, I have a question. Can you tell me whether Olga is happy?
2. John: Do you know if she smokes cigars or if she works at IPO?
3. Mary: Well, I know that she works at IPO.
4. John: In that case, she must be happy.
5. Mary: Thanks a lot, bye.
6. John: Bye.

John (J)	MOVE	Mary (M)
$p \rightarrow q$ $r \rightarrow q$		$s \rightarrow p$ r
	$[M,q]^-$	
$p \rightarrow q$ $r \rightarrow q$		$s \rightarrow p$ r
	$[J,p \vee r \rightarrow q]^+$	
$p \rightarrow q$ $r \rightarrow q$		$s \rightarrow p$ $p \rightarrow q$ $r \rightarrow q$ $r \& q$
	$[M,r\&q]^+$	
$p \rightarrow q$ $r \rightarrow q$ $r \& q$		$s \rightarrow p$ $p \rightarrow q$ $r \rightarrow q$ $r \& q$

Table 6: The question whether 'q' is answered by an indirect answer and a disjunction in the antecedent.

John (J)	MOVE	Mary (M)
$p \rightarrow q$ $r \rightarrow q$		$s \rightarrow p$ r
	$[M,q]^-$	
$p \rightarrow q$ $r \rightarrow q$		$s \rightarrow p$ r
	$[J,p \vee r]^-$	
$p \rightarrow q$ $r \rightarrow q$		$s \rightarrow p$ r
	$[M,r]^+$	
$p \rightarrow q$ $r \rightarrow q$ $r \& q$		$s \rightarrow p$ r
	$[J,q]^+$	
$p \rightarrow q$ $r \rightarrow q$ $r \& q$		$s \rightarrow p$ $r \& q$

Table 7: A disjunctive counter-question is asked to answer the question whether 'q'.

Although simple in its basic form, the game also has important technical complications. In Table 8 and 9, for instance, a situation is represented where John and Mary have distributed circular information in the initial private belief states, but have no distributed information to answer the initial question. As a result of the dialogue rules, John and Mary infinitely pose questions in Table 8. This drawback can be repaired by adding, for instance, an extra – but not really elegant – constraint that prohibits the performance of a question for a second time by the same speaker.

In Table 9, the dialogue ends because the circular information is distributed in a different way. Also, in this case, the same question is put forward twice, but this time by different agents (move 1 and 4). This can be avoided by changing the update rule U2, for instance: if a question is asked, not only should the hearer come to believe that the speaker has some manifested intention, but also that the speaker does not know the answer. Note that the same change will not solve the problem in Table 8.

Nr.	John			MOVES	Mary		
	B_J	$B_J I_M$	$B_J \neg B_M$		B_M	$B_M I_J$	$B_M \neg B_J$
Initial state G0	p→q	∅	∅		q→p	∅	∅
1				[M,q]⁻			
U2 G2	***p→q***	<***q***>	∅		q→p	∅	∅
2				[J,p]⁻			
U2 G2	p→q	<q>	∅		***q→p***	<***p***>	∅
3				[M,q]⁻			
U2 G2	***p→q***	<q,***q***>	∅		q→p	<p>	∅
4				[J,p]⁻			
U2 G2	p→q	<q,q>	∅		***q→p***	<p,***p***>	∅
5				Etc.			

Table 8: An eternal dialogue. Mary repeatedly asks John for the value of q; and conversely, John repeatedly asks for the value of p.

Evidently, the dialogue game presented in this paper is still rudimentary and extensions can be developed along many different lines. An interesting candidate would be the introduction of 'beliefs about mutual belief' – i.e. a set of background assumptions shared by both participants (see e.g. Clark & Marshall, 1981). The introduction of belief about mutual belief enables the participants to store declarative information that has been manifested in the dialogue and, since manifesting mutually believed information would be a violation of the Gricean quantity maxim, to leave out particular information in the message. For instance, if objects and their relations and properties could be discussed, entities present in the background assumptions can be presupposed and therefore do not have to be introduced explicitly; also, in the case of argumentation, parts of a proof that are believed to be mutually believed can be left out.[11]

It should be noted, however, that some extensions may have far-reaching consequences for different aspects of the game. For instance, including negation in the domain language seems another inevitable step towards a generalisation of the framework, since it introduces the possibility of modelling conflicting beliefs and the generation of argumentative dialogues (see e.g. Springorum, 1982). Nevertheless, a negated proposition cannot simply be added to a belief state of one of the participants, since it may result in unwanted inconsistencies. A solution is the introduction of a temporary state that represents the beliefs of an agent about the beliefs of his or her partner – 'A believes that B believes' – so that the different types of information can be carefully separated and inconsistencies can be avoided. It is unclear, however, how these conflicts will ever be resolved in the present game without other extensions, since both participants are considered 'equal' and there is no reason why they would prefer one proposition over the other. In other words, an agent can never accept a conflicting proposition stated by the other if the model does not contain a notion of 'expertise' or 'power'.

Nr.	John			MOVES	Mary		
	B_M	$B_J I_M$	$B_J \neg B_M$		B_M	$B_M I_J$	$B_M \neg B_J$
Initial state G0	o→q q→p	∅	∅		p→o	∅	∅
1				[M,q]$^-$			
U2 G2	***o→q*** q→p	<***q***>	∅		p→o	∅	∅
2				[J,o]$^-$			
U2 G2	o→q q→p	<q>	∅		***p→o***	<***o***>	∅
3				[M,p]$^-$			
U2 G2	o→q ***q→p***	<q,***p***>	∅		p→o	<o>	∅
4				[J,q]$^-$			
U2 G3	o→q q→p	<q,p>	∅		***p→o***	<o,***q***>	∅
5				[M,q]*			
U3 G3	***o→q*** ***q→p***	<q,***p***>	***q***		p→o	<o>	∅
6				[J,p]*			
U3 G3	o→q q→p	<q>	q		***p→o***	<***o***>	***p***
7				[M,o]*			
U3 G3	***o→q*** q→p	<***q***>	***q***,o		p→o	∅	p
8				[J,q]*			
U3 G4	o→q q→p	∅	q,o		p→o	∅	p,q
9				M♦			
U4 G4	o→q q→p	∅	q,o		p→o	∅	p,q
10				J♦			
U4 CL	o→q q→p	∅	q,o		p→o	∅	p,q

Table 9: John and Mary have distributed circular information, but the dialogue finishes, nevertheless. The rules do not prevent the same question from being asked by Mary (move 1) and by John (move 4).

7. Conclusions

In spoken dialogue, decisions about the function, content and form of the conversational units are taken within tenths of a second, therefore any computational theory of human dialogue must be subject to simple decision rules. The computational and generative aspect of the game presented in this paper forces us to be very explicit about these rules. The game provides a formal set of generation and update rules for the conduct of a dialogue and accurately shows how, during a dialogue, the cognitive states of participants change as a result of the exchange of information. It can be shown that neither a planning approach, nor a speech act grammar approach is needed (or wanted) to build coherent structures of conversation, and that coherence relations can be described in a situated sense, based on the context of the dialogue in terms of the agents' cognitive state and the immediately preceding conversational unit. Since only a limited number of attitudes was included, the framework does not suffer from the same computational complexity as in most planning approaches where agents are not only able to reason about the discourse domain, but also about their own and their partner's beliefs and intentions. Although admittedly still incomplete, the framework provides an explanation of some important dialogue phenomena – for instance, adjacency pairs, insertion sequences and the context-dependency of conversational sequences – without an explicit theory of intentions and beliefs.

Some important simplifications were made in the game with respect to the underlying communication model. The dialogue participants could never be interrupted and never obtain information in addition to their private beliefs and manifested beliefs and goals. Furthermore, utterances were always accepted and did not have to be checked for inconsistencies or other counter-evidence. Players could never be mis-informed and players did not have weak evidence for a specific fact. In natural situations, however, where people have multimodal access to various aspects of the world, information channels may be disturbed and an agent's attention may be attracted by a variety of sources, including pointing acts of the dialogue partner. The triangle model described in Section 3 includes some of the necessary basic ingredients to describe these phenomena, but there are a number of important questions left. For instance, when do agents decide to observe the domain rather than infer the information from their own belief state or ask a question to their partner? How does an agent's cognitive representation depend on whether information is observed or communicated and how do these representations influence the course of the dialogue? Partly, the answers depend on fundamental psychological issues, such as perceptual abilities, memory capacity and attention capabilities. In this paper, however, we abstracted from these matters, since including them dramatically increases the complexity of the model without supplying a substantial contribution to the explanation of the dialogue structure.

Hence, stripping a dialogue down to some of its basic components shows us which phenomena can be explained with fairly simple constructs and which aspects explicitly have to be included in the model. Nevertheless, there still is considerable work to be done of which the following is probably of primary importance:

1. Extension of the domain language: players should be able to negate sentences and to discuss objects, their relations and properties.
2. Addition of relevant mental constructs, such as beliefs about the other's belief and about mutual beliefs.
3. Possibility to play different agent roles, such as expert/novice or teacher/student.
4. Investigation of different communicative situations, in particular cases where the communication channel is disturbed or subjects have various multimodal ways of access to a domain of discourse.

Finally, it is the author's impression that we should strive for a more integrative theory of language use, based on a profound analysis of what people actually do in conversation combined with results from philosophically and computationally oriented approaches. Traditionally, speech act theory, as a representative of more theoretical oriented approaches, has focused on single conversational units; in contrast, conversation analysis has been oriented towards empirical aspects of language use and rules for turn taking. Speech acts are part of conversation and therefore should be one of the structuring elements of conversation – but by no means all of them. Viewing conversation as a Wittgensteinian game, where speech acts are considered to be context-changing operations on mental contexts, could be a promising start for a more systematic formalisation in the area of language use, but only if it is integrated in a more general framework of human behaviour.

Notes

1. An example is the ‘positive introspection’ axiom: if agents believe p, they also believe that they believe that p.

2. Probably the early roots of coherence can be traced in developmental psychology (Piaget, 1954). At a certain stage a child understands the continuity or ‘permanence’ of objects across time and recognises that objects do not cease to exist when they are out of reach or view. In order to establish ‘permanence’ in dialogue, listeners connect incoming utterances to information in previous utterances or to global mental structures of a more permanent nature.

3. It can be argued that inference has a communicative function as well (see e.g. Lorenz (1981) or Barth and Krabbe (1982)); this is beyond the scope of this paper, however.

4. Below, we will see that an agent’s intention to know a particular fact can be derived from the agent’s desire.

5. See, for instance, Thijsse (1992) for an extensive discussion on knowledge and belief.

6. The author is aware of the immense simplifications in the model; for instance, in reality a desire is a continuously changing attitude: people get hungry, eat, are satisfied and, after a while, get hungry again. However, this paper is about the basic coherence relations in a dialogue, and not an attempt to explain human behaviour in general (see e.g. Engler, 1995).

7. The initiator of the goal will receive feminine pronominalisation, and the partner will be masculine.

8. In Searle (1969) these are called the *propositional content* and *illocutionary force*, respectively.

9. Another solution is that agents are aware of their own manifested intentions, but this construct was not included to keep the framework as simple as possible.

10. Note that the R-utterances always cause a deletion of the intentional content of a question in Table 3.

11. It is important to see that ‘mutual belief’ as such cannot be included, since it contains the beliefs of both participants (A believes & B believes & A believes B believes & B believes A believes & etc.). Agents have no direct access to the cognitive state of the other; therefore, mutual belief always has to be preceded by belief of one of the agents. This would also allow us to model dialogue phenomena that follow from discrepancies in the mutual beliefs of both participants.

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