Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

Meaning and Dialogue Coherence: A Proof-theoretic Investigation

Paul Piwek
Centre for Research in Computing, The Open University, UK

Abstract. This paper presents a novel proof-theoretic account of dialogue coherence. It focuses on an abstract class of cooperative information-oriented dialogues and describes how their structure can be accounted for in terms of a multi-agent hybrid inference system that combines natural deduction with information transfer and observation. We show how certain dialogue structures arise out of the interplay between the inferential roles of logical connectives (i.e., sentence semantics), a rule for transferring information between agents, and a rule for information flow between agents and their environment. The order of explanation is opposite in direction to that adopted in game-theoretic semantics, where sentence semantics (or a notion of valid inference) is derived from winning dialogue strategies. That approach and the current one may, however, be reconcilable, since we focus on cooperative dialogue, whereas the game-theoretic tradition concentrates on adversarial dialogue.

Keywords: Coherence, Dialogue Modelling, Natural Deduction, Multi-agent Inference, Proof-Theoretic Semantics

1. Introduction

Models of coherence come in many different shapes, from proposals based on scripts, grammars, and social rule following to models of topic continuity. A now slightly dated collection that provides an overview of the multitude of approaches to *dialogue coherence* is Craig and Tracy (1983). More recently, Mann (2002) surveys a number of extant analyses of dialogue coherence.

The aim of this paper is to work out in detail a logic-based notion of coherence for a particular abstract class of cooperative dialogues, rather than to criticize or dismiss other approaches. In our view, coherence is a complex phenomenon that is likely to require analyses from more than one single perspective.

We provide an explication of dialogue coherence for the current class of dialogues in terms of the meaning of the expressions that are used in such dialogues against the background of the participants' discursive dispositions. Thus, coherence is modelled as a property of dialogues whose meaning-bearing parts fit together in a certain way in context.

To construct an explication of dialogue coherence along these lines, we adopt the following strategy. Firstly, we describe a theory of meaning that provides the foundation for the current endeavour. This theory

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

complies with the Wittgensteinian slogan that "meaning is use".[1, 2] This pragmatist slogan is fleshed out by identifying the meaning of an expression with its role in reasoning. This role is given by the circumstances of appropriate *application* of the expression and the appropriate *consequences* of such an application. The meaning of logical vocabulary will be assigned a privileged status in this undertaking and receive a formalization in terms of a variant of Gentzen's (1934) calculus of Natural Deduction. Secondly, this standard Natural Deduction calculus for solitary reasoners is extended to a calculus for *multiple situated* reasoners. Thirdly, this extended Natural Deduction calculus is used to model dialogue coherence. Whereas Gentzen's calculus allows us to characterize valid inferences, the extended calculus demarcates a certain type of coherent dialogue. We provide examples of dialogues that are generated by the calculus and use these to bolster the initial plausibility of the claim that coherence according to the extended calculus mirrors certain features of coherence in natural language dialogue. This is achieved by drawing attention to a number of structural properties

[1] In particular, it conforms with the later Wittgenstein's view that grasping the meaning of a term involves mastering the language game in which that term is used, analogous to mastering a calculus – e.g., being able to multiply: "Aber dieses Verständnis, die Kenntniss der Sprache ist nicht ein Bewußtseinszustand, der die Sätze der Sprache begleitet. [...] Vielmehr ist es von der gleichen Art wie das Verstehen, Beherschen eines Kalküls also wie: multiplizieren *können*. [...] Was der macht, der ein Zeichen in dem und dem Sinne deutet, versteht, is ein Schritt eines Kalküls (quasi einer Rechnung)." (Wittgenstein, 1984:47–51). Wittgenstein contrasts his concept of meaning with the Augustinian approach where meaning is equated with objects in the world, and also with the view that meaning can be characterized in terms of the images that come to the mind of the language user.

[2] The current paper (*cf.* section 2) presents a formal model of a certain aspect of language use and might therefore not be considered truly Wittgensteinian in spirit. The later Wittgenstein seems to have indeed been sceptical about the possibility of a complete and rigorous theory of human language use. However, between the extreme positions taken up by the early and the later Wittgenstein, there also appears to have been a period – between 1929 and 1936 – where Wittgenstein occupied a position that underpins the approach of the current paper. In that period, Wittgenstein cooperated closely with Friedrich Waismann on a book, eventually published as Waismann (1965), that would present a systematic account of his ideas. There, we find a favourable account of Boltzman's (1905) conception of a rigorous model as "[not] making any claim that it conformed to something in the real world. It is simply described and then whatever similarities exist between it and reality will reveal themselves. This is no defect in the model. [...] What Boltzman accomplished by this means was to keep his explanation undefiled. There is no temptation to counterfeit reality, for the model is, so to speak, given once and for all, and it can be seen how far it agrees with reality. And even if it does not, it still retains its value." (Waismann, 1965:77). For further discussion of the relation between language use and rules in Wittgenstein's thought see also Stenius (1967).

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1
(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

of naturally occurring dialogues that are also found in dialogues that are generated with the extended calculus.

2. Cooperative information-oriented dialogue

Walton and Krabbe (1995) point out that dialogue comes in many varieties. Each variety has its own distinctive purpose and participant aims and, as a result, concomitant notion of coherence. This makes it impossible to study dialogue coherence regardless of dialogue type. Consequently, in the current study, we restrict our attention to a specific class of dialogues which we call *cooperative information-oriented dialogues*. The *main purpose* of this type of dialogue is the exchange of information. Moreover, the *participants' aim* (whether out of personal interest or through external pressure) is to cooperate with each others' requests for information. In such dialogues, participants are not interested in persuading each other of a certain point of view or negotiating a particular course of action. The principal aim is simply the exchange of information.

A relatively pure form of this type of dialogue is the information desk dialogue, which has been a central topic of study in computational linguistics and natural language processing, witness the large number of projects on dialogue systems for providing travel information. Usually, in travel information dialogues, there is an enquirer who knows the place of departure, destination, and approximate time of travel. Given this information, the person at the information desk provides the precise travel details. Most dialogues are, however, of a more hybrid nature. Consider, for example, the following dialogue fragment from Merritt (1976:333):

(1) 1. *A*: May I have a bottle of Mich?
2. *B*: Are you twenty one?
3. *A*: No
4. *B*: No

The turns in this dialogue all appear to contribute to information being transferred between the interlocutors: the turns 1 and 2 introduce two questions whereas 3 and 4 contain the answers. Turn 1 does, however, also play another role: it signals to *B* that *A* would like *B* to sell *A* a bottle of Mich. In other words, turn 1 also has an *action-oriented* dimension: an (indirect) request is made. This dimension is beyond the

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

scope of the current study; here the focus is strictly on the information-oriented dimension.[3]

The dialogue in 1 neatly illustrates a number of phenomena which are at the heart of coherent dialogue. Firstly, its utterances can be viewed as being organized in pairs: question 1 and answer 4, and question 2 and answer 3. Conversation analysts (Sudnow, 1972) have observed that most dialogues are organized in this way: there is a *first part* of a pair that sets up the expectation for a particular kind of *second part* that is immediately relevant to the first part. The term *conditional relevance* (Schegloff, 1972) has been introduced to describe the relation between first and second parts. Such pairs often consist of adjacent parts – in which case we speak of an *adjacency pair* (Schegloff and Sacks, 1973). The following extract from a legal examination (from the London–Lund Corpus 11.1:677–91; quoted from Stenström 1994) shows a sequence of four such pairs:

(2)
1. A: Well Captain and Mrs Kay live in a flat on their own?
2. B: Yes
3. A: And they didn't come down until after tea, did they?
4. B: No
5. A: Some time between tea and church?
6. B: Yes
7. A: So, there's only Elsie and your wife?
8. B: Yes

In dialogue 2, all pairs are adjacency pairs. We have already seen that the parts of a pair do not need to be adjacent: this is illustrated by the embedded configuration consisting of 2 and 3 in dialogue fragment 1. Such configurations are quite common and known as *insertion sequences* (Schegloff, 1972).

Descriptive work on dialogue has uncovered a wealth of information regarding the structures that are exhibited by coherent dialogue. Let us now turn to the question how to account for such structures. Levinson (1983) argues at length that "Conversation is not a structural product in the same way that a sentence is – it is rather the outcome of the interaction of two or more independent, goal-directed individuals, with often divergent interests." (Levinson, 1983:294) The aim of the current paper is to offer a model that accounts for certain structural properties precisely in terms of the interaction between independent, goal-directed

[3] Viewing dialogue acts as occupying multiple dimensions has been advocated by several researchers on dialogue act annotation; see, e.g., Bunt & Girard (2005) and Petukhova & Bunt (2007).

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

agents, with a focus on agents as logical reasoners. The orientation of the current paper is primarily formal rather than descriptive. In the words of one of the pioneers of formal models of dialogue, C.L. Hamblin: "A formal approach, on the other hand, [as opposed to a descriptive one] consists in the setting up of simple systems of precise but not necessarily realistic rules, and the plotting of the properties of the dialogues that might be played out in accordance with them." (Hamblin, 1970:256) Thus, the system we propose is described in its own right, and the extent to which it agrees with reality is illustrated by investigating similarities and differences between the dialogues that it produces and the structural properties of naturally occurring dialogues as described by conversation analysts (see also footnote 2).

The motivating idea behind the current paper is an exercise in *philosophical logic*: to explore the relation between cooperative dialogue and logical inference. For this reason, a logical inference system sits at the core of our formal systems and we try to keep extension of this core to a minimum; in particular, we refrain from recourse to nested beliefs, intentions, and any other complex propositional attitudes that have been invoked for modelling dialogue.[4]

Since we aim to present formal systems for modelling coherent cooperative information-oriented dialogue, it is inevitable that we need to make a number of idealizing assumptions. Before we proceed, let us declare these assumptions:

- The systems that we will study are based on propositional logic without negation. Thus, we forego issues concerning natural language interpretation and maintenance of consistency.
- The scope of the systems is restricted to successful communicative acts:
    - We assume that there is a perfect communication channel (no misperception).
    - The language is fully shared.
    - The language is free of ambiguous expressions.

[4] In this respect, we follow Taylor et al (1996) who argue that for reactive cooperative dialogue (i.e., where no interpretation/plan recognition is involved), as in our current work, nested beliefs are superfluous. They also show that even if plan recognition is added, as long as the dialogue is cooperative, nested beliefs beyond level 2 are unnecessary. However, for modeling intentional deception in dialogue, nested beliefs beyond level 2 do play a role. See Cohen et al. (1990) for a collection of papers where nested beliefs and intentions are dealth with. In section 8, we compare our approach with other work on dialogue modelling.

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

- All communication is literal; speakers express what they mean by saying it, rather than by Gricean implicature (Grice, 1975).

3. Meaning as Inferential Role

The theory of meaning that we employ broadly follows the meaning-theoretic deliberations of Brandom (1994). The formalization is along the lines described in Sundholm (1986),[5] though there are also important differences (see section 8). Meaning is characterized in terms of inferential role, rather than truth-conditions.[6] This does, however, not exclude the possibility of a reconstruction of truth in terms of the framework described in this paper (*cf.* Brandom 1994).

We start with a system involving a single agent, henceforth α. This system captures the practical ability of the agent to reason with expressions of a language $\mathcal{L}$. This language consists exclusively of atomic formulae $At \subset \mathcal{L}$, *and* formulae that are constructed from members of $\mathcal{L}$ using the connectives for implication '$\rightarrow$' and conjunction '&': if $A, B \in \mathcal{L}$, then $(A \rightarrow B) \in \mathcal{L}$ and $(A\&B) \in \mathcal{L}$.[7]

Inferences are formalized in terms of *judgements* of the form $[\alpha]\ H \vdash A$. These should be read as agent α (henceforth, references to agents are omitted when it is clear from the context which agent the judgement belongs to) affirms/derives A, given the local assumptions H (i.e., assumptions that are only accessible for the duration of an inference). In addition to the collection of local assumptions (H), an agent, such as α, also relies on a set of global assumptions (Γ_α). In our system, Γ_α functions like a global variable in a programming language whose value is accessible at any time during an inference. The value of Γ_α can be updated through declarations. For instance, the following declaration adds the assumption denoted by the proposition letter a to Γ_α's current value: $\Gamma_\alpha := \Gamma_\alpha \cup \{a\}$. Note that we use capitals (e.g., A and B) as meta-variables over proposition letters and lower case (e.g., a and b) for the actual proposition letters.

An assumption $A \in (H \cup \Gamma_\alpha)$ is thought of in terms of the disposition of α to affirm A. This disposition is made explicit by the following deduction rule:

(3) (member) $$\frac{A \in \Gamma \cup H}{H \vdash A}$$

[5] Sundholm bases much of his formalization on proposals by the philosophers/logicians Michael Dummett and Dag Prawitz.

[6] Peter Schroeder-Heister introduced the term "Proof-Theoretic Semantics" for this approach to meaning.

[7] Henceforth, brackets will be omitted when there is no danger of ambiguity.

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

This rule says that formula A can be inferred/derived/deduced from H and the implicit global assumptions Γ, *if* A is a member of the union of Γ and H. The characterization $\Gamma \cup H$ in terms of its inferential role replaces classical explications in terms of representation/truth-conditions.

The inferential role of logical vocabulary is given a special place in the current scheme: a logical connective allows an agent to express explicitly a pattern of inference that it already follows. For instance, an agent who is disposed to deriving 'The tiles get wet' from 'it rains', can make this practical activity explicit by affirming 'If it rains, the tiles get wet'.

The meaning of a logical connective is given by the circumstances of appropriate application of that connective and the appropriate consequences of such an application. For the conditional '$\rightarrow$' the appropriate circumstances of application are given by the following introduction rule for conditionals:

(4) (arrow intro) $$\frac{H \cup \{A\} \vdash B}{H \vdash A \rightarrow B}$$

Thus, we can derive the conditional $A \rightarrow B$, if we can derive B from the local assumptions extended with the new assumption A. The appropriate consequences of using '$\rightarrow$' are given by the following rule for eliminating the arrow:

(5) (arrow elim) $$\frac{H \vdash A \rightarrow B \quad H \vdash A}{H \vdash B}$$

This rule is chosen so that the arrow intro and elim rules together introduce only inferences regarding the logical connective '$\rightarrow$'. In Dummett's terms, the rules are in harmony with antecedent inferential practices. This requirement is essential, because of the explicative role of logical vocabulary: it should serve to make explicit existing inferential practices; it should not license novel inferences involving the pre-existing vocabulary, since that would destroy its explicative role. In the words of Schroeder-Heister (2006:533): "nothing is gained by an application of an elimination rule if its major premiss has been derived *according to its meaning* (i.e., by means of an introduction rule).".

The rules for conjunction introduction and elimination are the following:

(6) (conj. intro) $$\frac{H \vdash A \quad H \vdash B}{H \vdash A \& B}$$

(7) (conj. elim) $$\frac{H \vdash A \& B}{H \vdash A} \qquad \frac{H \vdash A \& B}{H \vdash B}$$

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

Given these explications of the logical constants '→' and '&', derivations can be constructed. For example, given a set of global assumptions $\Gamma = \{a \to b, b \to c\}$, we can derive the judgement $\emptyset \vdash a \to c$ (henceforth, the *goal* of the derivation):

(8)

$$\dfrac{\dfrac{\dfrac{\dfrac{a \in \Gamma \cup \{a\}}{\{a\} \vdash a}\,(v) \quad \dfrac{(a \to b) \in \Gamma \cup \{a\}}{\{a\} \vdash a \to b}\,(vi)}{\{a\} \vdash b}\,(iv) \quad \dfrac{(b \to c) \in \Gamma \cup \{a\}}{\{a\} \vdash b \to c}\,(iii)}{\{a\} \vdash c}\,(ii)}{\emptyset \vdash a \to c}\,(i)$$

The individual inference steps in derivation 8 have been labelled with roman numerals. The goal of the derivation is located at the root of the derivation tree. This goal has no local assumptions. Working backwards (i.e., upwards from the root), the arrow introduction rule can be applied (i). This leads to a judgement with one local assumption (a): the goal is to derive c against the background of this local assumption. Moving up one step further via (ii) – the arrow elimination rule – we arrive at two goals. The second of these is $\{a\} \vdash b \to c$. This goal can be derived via the member rule (step iii), and consequently the second branch of the derivation tree is closed. The member rule applies, because we assumed at the outset that $(b \to c)$ is a member of the set of global assumptions Γ. The other branch requires a derivation of the judgement $\{a\} \vdash b$. We arrive at this judgement via step (iv), which is another application of the arrow elimination rule. Steps (v) and (vi) both involve the member rule. Firstly, $a \in \Gamma \cup \{a\}$ succeeds because a is member of the local assumptions, and secondly, $(a \to b) \in \Gamma \cup \{a\}$ succeeds in virtue of $(a \to b)$ being a member of the global assumptions Γ.

Generally, in a derivation tree the goal resides at the root of the tree, and application of the member rule takes places at the leaves of the tree.

4. System $\mathcal{S}_1$: Situated Inferential Practice and Dialogue

The system presented so far is limited to solitary reasoners that are isolated both from other reasoners and from the world around them. In this section, we present a first extension which removes the former limitation. We will refer to the system described in the current section as $\mathcal{S}_1$.

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

4.1. The Transfer Rule

We introduce a set of agents $\mathcal{A}$, with α, β, γ, ... as meta-variables over members of $\mathcal{A}$ (further on we will also use α, β, γ, ... as names for specific agents). We now add a rule for *transferring* proof goals between agents:

(9) (tr) $\dfrac{[\beta]\ H \vdash A}{[\alpha]\ H \vdash A}$ $\quad \Gamma_\alpha := \Gamma_\alpha \cup \{\bigwedge H \rightarrow A\}$ and $\langle \alpha, \beta \rangle \in \mathcal{C}$

This transfer rule (tr) tells us that if agent β can derive A under the local assumptions H, then agent α can also derive A under the local assumptions H, provided that the two conditions on the right-hand side are satisfied.

The first condition says that the context Γ_α of global assumptions entertained by α, should be extended with $\bigwedge H \rightarrow A$. Here, $\bigwedge H$ stands for the conjunction $A_1 \& A_2 \& \ldots$ of the formulae $A_1, A_2, \ldots$ that are members of H. If H is empty, $\bigwedge H \rightarrow A = A$. This condition ensures that as a result of a transfer step the information that is transferred, say N, becomes part of the global assumptions of the recipient of the information. In other words, as a result of the transfer step, the recipient of the information can now derive N without invoking the transfer step; the information has become a part of the global assumptions and can also be accessed directly via the member rule.

The second condition ($\langle \alpha, \beta \rangle \in \mathcal{C}$) says that there should be a communication channel between α and β (where $\mathcal{C} \subseteq \mathcal{A} \times \mathcal{A}$). The side condition in combination with $\mathcal{C}$ allows us to model situations in which not every agent can exchange information with every other agent in $\mathcal{A}$. However, unless stated otherwise, we will henceforth assume that $\mathcal{C} = \mathcal{A} \times \mathcal{A}$, i.e., information can be transferred between any pair of agents.

4.2. Example of a Proof Tree

Take a situation involving the agents α, β and γ in which $\Gamma_\alpha = \emptyset$, $\Gamma_\beta = \{a\}$, and $\Gamma_\gamma = \{b\}$. Let us assume that α wants to build a proof for $a\&b$. Since neither a nor b is part of Γ_α, α will need to access information held by β and γ. This situation is represented pictorially in Figure 1 where each dot represents an agent, boxes represent the global assumptions of the agents and the arrows represent the communication channels between the agents. The following proof tree illustrates what a derivation of $a\&b$ looks like in this multi-agent setting:

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

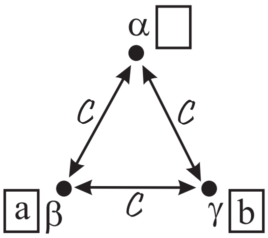

Figure 1. Multi-agent situation

(10)

$$\dfrac{\dfrac{\dfrac{[\beta]\ a \in \Gamma_\beta \cup \emptyset}{[\beta]\ \emptyset \vdash a}\ (mem.)}{[\alpha]\ \emptyset \vdash a}\ (1)(tr) \qquad \dfrac{\dfrac{[\gamma]\ b \in \Gamma_\gamma \cup \emptyset}{[\gamma]\ \emptyset \vdash b}\ (mem.)}{[\alpha]\ \emptyset \vdash b}\ (2)(tr)}{[\alpha]\ \emptyset \vdash a\&b}\ (conj.intro)$$

Side conditions:
(1) $\Gamma_\alpha := \Gamma_\alpha \cup \{a\}$;
(2) $\Gamma_\alpha := \Gamma_\alpha \cup \{b\}$.

Note that we omitted the side condition regarding the communication channel. We conveniently assumed that all agents can exchange information with all other agents.

Execution of the side conditions (1) and (2) results in $\Gamma_\alpha = \{a, b\}$. As a result of the construction of this proof, we have arrived at a Γ_α in which a proof for $a\&b$ can be constructed directly, without recourse to the transfer. In other words, $a\&b$ has become part of α's information.

4.3. From Proof Trees to Dialogue Structure

The final steps for going from logic to dialogue consist of a transformation of the proof tree to a dialogue (structure). Here we describe an algorithm that has been implemented.[8] We proceed in two steps. Firstly, we map the hierarchical tree to a linear structure. For the tree in 10, we obtain the linear representation 11. Each tree node is represented by an item in the linear structure (for example, the items 4 and 9 below each represent a single node; the nodes in question are the terminal nodes of tree 10), and possibly a second item indicating that the part of the tree dominated by the node has been closed (e.g., the pairs $\langle 1, 12\rangle$ and $\langle 2, 6\rangle$ represent single tree nodes; the former corresponds to the root node of tree 10).

[8] See `mcs.open.ac.uk/pp2464/resources`

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

(11) 1. α : goal-derive($a\&b$)
2. α : (transfer) goal-derive(a)
3. β : goal-derive(a)
4. β : in-assumptions(a)
5. β : confirmed(a)
6. α : confirmed(a)
7. α : (transfer) goal-derive(b)
8. γ : goal-derive(b)
9. γ : in-assumptions(b)
10 γ : confirmed(b)
11. α : confirmed(b)
12. α : confirmed($a\&b$)

For brevity's sake, we have omitted reference to the empty set of local hypotheses. Strictly speaking, we should, for instance, have written goal-derive($a\&b$,given-that,$\emptyset$) instead of goal-derive($a\&b$).

The sequence in 11 is not yet a straightforward dialogue. It contains various locutions which can be thought of as internal monologues of the interlocutors with themselves. For the mapping from an extensive dialogue representation, such as 11, to a more compact and readable dialogue structure we use the following rules (which are applied in their order of appearance):

(12)
1. α_i : goal-derive(A) $\mapsto$ α_i : I am wondering whether A can be derived.
2. α_i : (transfer) goal-derive(A), α_j : I am wondering whether A can be derived. $\mapsto$ α_i : Tell me α_j, is A derivable?
3. α_i : confirmed(A), α_j : confirmed(A) $\mapsto$ α_i : confirmed(A).
4. α_i : in-assumptions(A), α_i : confirmed(A) $\mapsto$ α_i : Yes, A.
5. α_i : I am wondering whether A can be derived. $(\alpha_i : X)^*$ α_i : confirmed(A) $\mapsto$ ϵ
6. α_i : confirmed(A) $\mapsto$ α_i : That confirms A.

Let us briefly motivate each of these rules. Rule 12.1 serves readability by paraphrasing a dialogue move in English. Rule 12.2 implements the assumption that the dialogue is cooperative, by expressing the transfer of a derivation goal as a request and making the take up by the addressee implicit. Rule 12.3 removes redundant repetition of information: if α_i performs a confirmation regarding some bit of information, followed by α_j's confirmation, then α_j's agreement does not need to be made explicit. Rule 12.4 maps the completion of a derivation branch ('in-assumptions(A)') to a 'yes'-answer. Rule 12.5 makes sure

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

that proof searches that involve only a single agent are omitted from the conversation (these would otherwise show up as internal monologues of the agent in question). Finally, rule 12.6 again merely serves readability of the resulting dialogue. For the purpose of this paper these rules fulfil their function: they allow us to show how a proof tree can be related to a dialogue. How much of the proof tree is made explicit in the dialogue depends, however, on factors (e.g., personality characteristics of the agent) that are beyond the scope of this paper and deserve further study. When the current mapping rules are applied to 11, we obtain:

(13)
1. α : I am wondering whether $a\&b$ can be derived.
2. α : Tell me β, is a derivable?
3. β : Yes, a.
4. α : Tell me γ, is b derivable?
5. γ : Yes, b.
6. α : That confirms $a\&b$.

This dialogue exhibits three of the conversation analytical configurations we discussed in section 2: there are two adjacency pairs (2,3), (4,5), one non-adjacent pair (1,6), and an insertion sequence consisting of the pairs (2,3) and (4,5).

5. Generative Systems as Abstract Models of Dialogue

Before we proceed with presenting a number of extensions to system $\mathcal{S}_1$, let us take a step back and make explicit what such systems have in common. Each generative system $\mathcal{S}$ functions as an abstract model of cooperative information-oriented dialogue, and has the following components:

1. A hybrid inference system $\mathcal{I}$ consisting of:

   a) A language $\mathcal{L}$ (e.g., the language of propositional logic or a fragment thereof);

   b) A set of agents $\alpha_i \in \mathcal{A}$, each with a set of assumptions Γ_{α_i};

   c) A communication channel $\mathcal{C}$ that specifies which agents can communicate with each other (i.e., $\mathcal{C} \subseteq \mathcal{A} \times \mathcal{A}$);

   d) A set of hybrid inference rules $\mathcal{R}$ for the language and the agents. The rules are hybrid because they can encompass natural deduction, observation and communication. The rules enable us to build proof trees (or proof search trees, as we will see in a moment).

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

2. A specification of the set of potential dialogues $\mathcal{D}_P$ between the agents, given the language $\mathcal{L}$.

3. A mapping m from proof trees, generated with $\mathcal{I}$, to coherent dialogues $\mathcal{D}$.

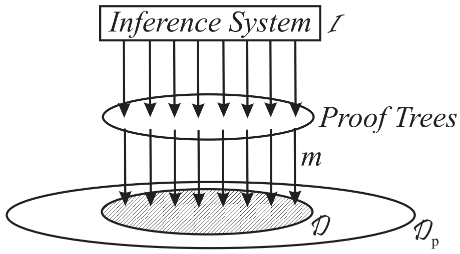

Figure 2. Diagram of a Generative System for Dialogue Generation

In short, a generative system $\mathcal{S}$ is a triple $\langle \mathcal{I}, \mathcal{D}_P, m \rangle$. The purpose of such a system is the characterization of coherent dialogues (members of $\mathcal{D}$). This is achieved by using $\mathcal{I} = \langle \mathcal{L}, \mathcal{A}, \mathcal{C}, \mathcal{R} \rangle$ to generate proof trees, that is trees representing valid inferences (or, as we shall see in a moment, searches for valid inferences). These proof trees are then mapped by m to members of $\mathcal{D}_P$ (the set of potential dialogues, which we will characterize using a grammar in BNF notation).

A member of $\mathcal{D}_P$ that can be generated from a proof tree using m is a member of the set of proper, i.e., coherent, dialogues $\mathcal{D}$ (with $\mathcal{D} \subset \mathcal{D}_P$); see Figure 2. The mapping m turns a proof tree into a linear dialogue representation (omitting proof steps that do not involve communication between agents).

We will investigate a series of more and more complex systems for the generation of abstract coherent dialogues. As we progress through the series, an increasing number of phenomena that occur in real dialogue will be covered.

6. System $\mathcal{S}_2$: From Proof Trees to Proof Search Trees

System $\mathcal{S}_1$ has one major drawback: it only allows for dialogues generated from complete proof trees. What is lost is the *search* for a proof which many cooperative information-oriented dialogues revolve around. People in conversation will often explore unfruitful paths, and have to use locutions such as: ‘I cannot derive A’ (or in more colloquial language: ‘I don’t know’). A first step toward remedying this situation is

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

the addition of such locutions to $\mathcal{D}_P$. The new set of potential dialogues $\mathcal{D}_P$ is given using BNF notation:

(14)
$$\begin{array}{lll}
\langle D_P \rangle & \texttt{:==} & \langle Loc\rangle\texttt{,}\langle D_P\rangle \mid \epsilon \\
\langle Loc \rangle & \texttt{:==} & \langle Agent\rangle\texttt{: I am wondering whether} \\
 & & \langle Prop\rangle\ \texttt{can be derived.} \mid \\
 & & \langle Agent\rangle\texttt{: Tell me } \langle Agent\rangle\texttt{, can you} \\
 & & \texttt{derive } \langle Prop\rangle\texttt{?} \mid \\
 & & \langle Agent\rangle\texttt{: No, I can't derive } \langle Prop\rangle\texttt{.} \mid \\
 & & \langle Agent\rangle\texttt{: Yes, } \langle Prop\rangle\texttt{.} \mid \\
 & & \langle Agent\rangle\texttt{: That confirms } \langle Prop\rangle\texttt{.} \\
\langle Agent \rangle & \texttt{:==} & \alpha \mid \beta \mid \ldots \\
\langle Prop \rangle & \texttt{:==} & a \mid b \mid \ldots \mid \langle Prop\rangle \,\&\, \langle Prop\rangle \mid \langle Prop\rangle \rightarrow \langle Prop\rangle
\end{array}$$

With respect to this set of potential dialogues, our inference system is incomplete: there are members of $\mathcal{D}_P$ which are intuitively coherent dialogues (involving the locution '$\langle Agent\rangle$: No, I can't derive $\langle Prop\rangle$'), which cannot be generated in $\mathcal{S}_1$. To address this problem, we move from proof trees to proof *search* trees and then define the mapping m for proof search trees.

Let us examine an example of a proof search tree. We have omitted rule labels and conditions to fit the tree on this page.

(15)
$$\dfrac{\dfrac{\dfrac{}{(\star_1)\ [\beta]\ \emptyset \vdash a} \quad \dfrac{[\gamma]\ a \in \Gamma_\gamma \cup \emptyset}{(\star_2)\ [\gamma]\ \emptyset \vdash a}}{[\alpha]\ \emptyset \vdash a} \qquad \dfrac{\dfrac{[\gamma]\ b \in \Gamma_\gamma \cup \emptyset}{[\gamma]\ \emptyset \vdash b}}{[\alpha]\ \emptyset \vdash b}}{[\alpha]\ \emptyset \vdash a\&b}$$

The difference between a proof search tree, such as 15, and a proof tree, such as 10, is that a proof search tree can contain alternative search branches. These are indicated by the use of $\star$. The proof search tree 15 has an unsuccessful branch $\star_1$ and a successful one, i.e., $\star_2$ (henceforth we assume that successful search branches are always to the right of unsuccessful ones). This tree would, for example, fit a situation where we set out with $\Gamma_\alpha = \Gamma_\beta = \emptyset$ and $\Gamma_\gamma = \{a, b\}$.

As before, we map the tree to a dialogue in two steps. The result of applying the first mapping is:

(16)
1. α : goal-derive($a\&b$)
2. α : (transfer) goal-derive(a)
3. β : goal-derive(a)
4. β : not-derived(a)
5. α : not-derived(a)
6. α : (transfer) goal-derive(a)

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

7. γ : goal-derive(a)
8. γ : in-assumptions(a)
9. γ : confirmed(a)
10. α : confirmed(a)
11. α : (transfer) goal-derive(b)
12. γ : goal-derive(b)
13. γ : in-assumptions(b)
14. γ : confirmed(b)
15. α : confirmed(b)
16. α : confirmed($a\&b$)

The second half of the mapping requires the mapping rules of $\mathcal{S}_1$ and two additional rules:

- α_i : not-derived(A), α_j : not-derived(A) $\mapsto$ α_i : not-derived(A)
- α_i : not-derived(A) $\mapsto$ α_i : No, I can't derive A.

Application of the extended set of mapping rules to 16 results in:

(17)
1. α : I am wondering whether $a\&b$ can be derived.
2. α : Tell me β, can you derive a?
3. β : No, I can't derive a.
4. α : Tell me γ, can you derive a?
5. γ : Yes, a.
6. α : Tell me γ, can you derive b?
7. γ : Yes, b.
8. α : That confirms $a\&b$.

7. System $\mathcal{S}_3$: Adding Observation

In $\mathcal{S}_1$ and $\mathcal{S}_2$, we went beyond common inference systems by moving from the model of a solitary reasoner to a community of reasoners who exchange information with each other. Communication is, however, not the only way reasoners acquire new information. In particular, observation of the environment is a further means of information acquisition that the traditional model of logical inference does not deal with. In this respect, $\mathcal{S}_1$ and $\mathcal{S}_2$ are incomplete.

It is beyond the scope of this paper to address all the intricacies of interspersing reasoning with observation. Rather, we explore a minimal extension of $\mathcal{S}_2$ with a rule that introduces observation:

(18) (obs.) $$\frac{A \in \mathcal{O}_\alpha \quad obs(\alpha, A)}{[\alpha]H \ \vdash \ A} \qquad \Gamma_\alpha := \Gamma_\alpha \cup \{A\}$$

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

This rule states that if the proposition A is an observable proposition for agent α (written as $A \in \mathcal{O}_\alpha$) and α actually observes that A – i.e., $obs(\alpha, A)$ – then α can derive A. The rule has one side condition which requires that Γ_α is extended with A; written: $\Gamma_\alpha := \Gamma_\alpha \cup \{A\}$.

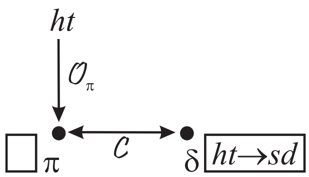

Figure 3. Multi-agent situation with observation

To illustrate how this extended calculus can be applied, we model a conversation between π and δ. π has the flu and rings δ (information desk of π's surgery) to find out whether she needs to see a doctor (sd). For that purpose, she needs to find out whether she has a temperature (ht). We have $\Gamma_\pi = \emptyset$ and $\Gamma_\delta = \{ht \rightarrow sd\}$ (see Figure 3). π's goal is to find out whether sd; so π tries to derive sd relative to her assumptions. Given Γ_π, π won't succeed unless she decides to communicate. The following is a derivation of sd for π that involves both communication and observation. It highlights how information possessed by δ and observations that only π is able to perform are combined to obtain a proof for sd:

(19)

$$\dfrac{\dfrac{\dfrac{\dfrac{ht \in \mathcal{O}_\pi \quad obs(\pi, ht)}{[\pi]\ \emptyset \vdash ht}\ (3)\ (obs.)}{[\delta]\ \emptyset \vdash ht}\ (2)\ (tr) \qquad \dfrac{[\delta]\ ht \rightarrow sd \in \Gamma_\delta}{[\delta]\ \emptyset \vdash ht \rightarrow sd}}{[\delta]\ \emptyset \vdash sd}}{[\pi]\ \emptyset \vdash sd}\ (1)\ (tr)$$

SIDE CONDITIONS: (1) $\Gamma_\pi := \Gamma_\pi \cup \{sd\}$, (2) $\Gamma_\delta := \Gamma_\delta \cup \{ht\}$, (3) $\Gamma_\pi := \Gamma_\pi \cup \{ht\}$.

As a result of the proof construction, $\Gamma_\pi = \{ht, sd\}$ and $\Gamma_\delta = \{ht \rightarrow sd, ht\}$. Note that although $sd \notin \Gamma_\delta$, δ can now infer sd without recourse to observation or communication. From the proof tree, we can extract the moves paraphrased in dialogue 20 (see the appendix at the end of this paper for details of the mapping). The dialogue contains a well-known conversation analytical structure, i.e., the insertion sequence (the subdialogue consisting of 3 and 4):

(20) 1. π: Do I need to see a doctor?
2. δ: Do you have a temperature?

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

3. π: Wait a minute [π checks her temperature], yes, I do.
4. δ: Then you do need to see a doctor.

At the end of this dialogue, π and δ both possess the information ht and sd. This comes about as a side effect of the derivation of sd, in particular, the application twice of the transfer rule.

Note that no explicit reasoning about cooperative behaviour is involved (e.g., a rule saying that if π wants to achieve a goal, then δ helps π achieve it). Rather, multi-agent inference is modelled as a joint activity which an agent can engage in. In doing so, the agent becomes part of an ensemble of agents who reason as a group rather than as individuals. Thus the decision whether to be cooperative is shifted from individual dialogue moves to joint activities. It is beyond the scope of this paper to model that decision-making process; here, we simply assume that the agents are positively disposed to cooperative activities.

8. Related Work

In this section we contrast the approach described in this paper with other approaches. Firstly, we would like to identify a number of ways in which the extended Natural Deduction calculus diverges from the standard calculus that is employed by, for instance, Sundholm (for specifying inferential roles). In particular, we introduced a distinction between local and global assumptions and used the member rule to access both types of assumptions. Global assumptions were introduced to collect premises from sources other than inference (i.e., communication and observation). Another crucial extension was the explicit relativization of judgements and assumptions to agents.

Secondly, the proof-theoretic transfer rule for information exchange between agents should not be confused with rules for transferring information between modalities in Modal Logic (ML). In ML, one can paraphrase the transfer rule with the axiom scheme $\vdash \Box_\alpha A \rightarrow \Box_\beta A$ which allows information to be transferred between the modalities $\Box_\alpha$ and $\Box_\beta$ (for arbitrary α and β). However, according to the model-theoretic interpretation of ML, such an axiom destroys the distinction between $\Box_\alpha$ and $\Box_\beta$: the axiom scheme is true if for a model M and world w: $\langle M, w\rangle \models \Box_\alpha A$ then $\langle M, w\rangle \models \Box_\beta A$ and vice versa. If meaning is conceived of in strictly model-theoretical terms, inference steps play no role, and consequently no distinction is made between *explicit* information that is directly available to an agent (information that is part of the global assumptions of the agent), and *implicit* information

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

that is only accessible through inference, communication and/or observation. In the systems proposed in this paper, if agents α and β can transfer information between each other, they implicitly have access to exactly the same information. They differ, however, with regards to the ease with which this information can be accessed: if some piece of information is part of α's global assumptions, but not β's, then α has direct access, whereas access by β requires transfer of information with α. In terms of proof trees/derivations, α's proof tree for the same information requires less steps than β's proof tree.

Thirdly, our approach differs in a number of respects from extant models of dialogue. Here we compare our approach with two representative classes of alternatives. Firstly, there is a body of work based on the idea that dialogues can be characterized in terms of update and generation rules for information states. For example, (Beun, 2001) introduces special purpose generation rules to achieve the same effect as our intro and elim rules for '$\rightarrow$', Power (1979) makes use of conversational procedures, Ginzburg (1996) proposes up- and downdating rules for the partially ordered questions under discussion, and Traum & Larsson (2003) describe a generic framework for information state-based dialogue. A comparison of some of these approaches is provided by Pulman (1999). Our approach distinguishes itself from these proposals by explaining dialogue coherence in terms of the independently motivated inferential roles of the logical constants. Secondly, there is a dialogue game approach going back to the work of Lorenzen – see Lorenzen & Lorenz (1978) – where the logical constants are defined in terms of their role in rational debates. There the order of explanation is from (a) formal winning strategies for *adversarial* dialogues (debate) to (b) valid patterns of reasoning involving the logical constants.[9] In contrast, we proceed from (b) valid patterns of reasoning involving the logical constants to (c) coherent *cooperative* dialogue. The undertakings are complementary and raise the rather surprising prospect of an account of cooperative dialogue based on adversarial dialogue (debate); that is, an account from (a) to (c) via (b).

[9] The relations between this dialogue method and other formal logics (axiomatic, natural deduction, etc.) is examined in detail in Barth & Krabbe (1982). Hamblin (1971) also explores derivations in this direction: *from* a specification of legal dialogue – though his dialogues are information-oriented, rather than adversarial – *to* semantic properties of locutions. Furthermore, the game-theoretical semantics that has been developed by Hintikka and collaborators (Saarinen, 1979) has some central features in common Lorenzen's dialogue games.

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

9. Limitations and Further Research

The aim of this paper is to provide the foundations for a generative logic-based model of dialogue coherence. The generic framework is described in section 5, whereas specific systems are developed in sections 4, 6 and 7. The purpose of these systems was to demonstrate that the type of analysis advocated here can account for certain dialogue structures. We discussed a number of idealizing assumptions underlying the current systems in section 2. In this section, we provide some suggestions on how to address these in further research.

The current systems only deal with information-oriented dialogues. In future, we would like to investigate application of the current framework to action-oriented dialogues that involve imperatives and actions. This will require the introduction of new types of judgements alongside the current one of a proposition A being derivable by agent α. In particular, for action-oriented dialogue a notion of A being *realizable* by agent α is needed.

Even within the scope of information-oriented dialogues, the current work is limited to the language of proposition logic without negation. This is a serious limitation, since it restricts our treatment of polar questions. Currently, we only deal with questions of the form *Can A be derived?*, whose answers correspond to the outcome of a proof search for A. We do not deal with the more straightforward question A?, since this requires negation to model the possible answer $\neg A$. Our first priority for further work is to develop further systems that incorporate more expressive logics with negation, up to the full predicate calculus. For this purpose, we will build on an implementation of a system for natural deduction for predicate and higher order logics (Piwek, 2006), and the work on consistency maintenance in type theory-based natural deduction systems by Borghuis and Nederpelt (2000). A type-theoretic framework will also allow us to address certain aspects of the process of language interpretation. In particular, it allows us to cast presupposition and anaphora resolution in proof-theoretic terms as shown by, among others, (Piwek and Krahmer, 2000).

Non-standard inferences, which are needed to deal with implicatures (Grice, 1975) can be accommodated by the systems proposed here. For that purpose, we need to model such patterns of inference in terms of *abduction*. Abduction does not require novel deduction rules, but rather involves introducing a new type of proof goal, i.e., the goal to find a set of assumptions Δ such that with respect to $\Gamma \cup \Delta$ some proposition can be derived. There is an extensive literature on the constraints that members of Δ should satisfy, such as minimality (Cox and Pietrzykowski, 1986) and corroboration (Evans and Kakas, 1992).

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

Moreover, default reasoning can be dealt with in terms of abduction (see, e.g., Kakas et al. 1998).

Currently, our model of dialogue coherence only distinguishes between coherent and incoherent dialogue. Within the group of coherent dialogues, one might, however, also wish to distinguish between different degrees of coherence. For example, Beun (2001) points out that his system needs to be extended with rules to prevent generation of dialogues with loops (e.g., by not allowing an agent to ask the same question twice). We propose to introduce an ordering from more to less coherent, rather than to mark such dialogue as incoherent. Soft global constraints/preferences (assigning satisfaction levels to proof search trees, e.g., based on the number of repetitions of particular derivation steps) promise to be a suitable means for ordering proof trees with respect to each other, and indirectly the dialogues that are generated from them.

Finally, our framework is set up so that proof (search) trees are produced first and then mapped to dialogue (structures). This provides us with a theoretically clean and transparent framework for relating inference systems to dialogue structure. The work also has practical potential, for example, as a framework for generating information presentations in dialogue form; see the discussion of dialogue as discourse in Piwek & Van Deemter (2002). Nevertheless, there is also scope for investigating how the mapping rules can be integrated with proof search, thus making it possible to use the resulting system in human-computer dialogue.

10. Conclusion

The current paper is foundational in nature. We show how to model dialogue coherence in terms of generative systems that rely on an extended calculus of Natural Deduction. At the core of this account is the standard Natural Deduction calculus which has been motivated independently. The paper presents extensions of the calculus with rules for communication and observation, and describes a mapping from proof (search) trees to dialogue structures that exhibit some of the properties that are also found in naturally occurring dialogues.

We hope that this paper will stimulate further research into the relation between logic/sentence semantics and dialogue coherence, and provide a starting pointing for understanding logical reasoning as an activity that is inseparable from other information processing activities such as observation and communication – something which is often

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

neglected when logical reasoning is taught as a disembodied, solitary activity.[10]

Acknowledgements

I would like to thank the audience at the ESSLLI 2006 Workshop on "Coherence in Dialogue and Generation" and the three anonymous reviewers of the workshop for their extremely helpful comments and suggestions [...]

Appendix

(21) EXTENSIVE DIALOGUE (for proof tree 19)

1.	π :	goal-derive(sd)
2.	π :	(transfer) goal-derive(sd)
3.	δ :	goal-derive(sd)
4.	δ :	goal-derive(ht)
5.	δ :	(transfer) goal-derive(ht)
6.	π :	goal-derive(ht)
7.	π :	observe(ht)
8.	π :	confirmed(ht)
9.	δ :	confirmed(ht)
10	δ :	goal($ht \rightarrow sd$)
11.	δ :	in-assumptions($ht \rightarrow sd$)
12.	δ :	confirmed($ht \rightarrow sd$)
13.	δ :	confirmed(sd)
14.	π :	confirmed(sd)

For the mapping from this extensive to a compact dialogue we need one new locution ('Yes, I observed that A') and an additional mapping rule:

$$\alpha_i : \text{observe}(A),\ \alpha_i : \text{confirmed}(A) \mapsto \alpha_i : \text{Yes, I observed that } A.$$

Application of the mapping rules to the extensive dialogue 21 results in the following compact dialogue:

(22) COMPACT DIALOGUE

[10] A commendable exception is Barwise & Etchemendy (1994) which does deal with the role of observation, though not communication, in logical reasoning.

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

1.	π :	I am wondering whether *sd* can be
2.		derived. Tell me δ, is *sd* derivable?
3.	δ :	Tell me π, is *ht* derivable?
4.	π :	Yes, I observed *ht*.
5.	δ :	That confirms *sd*.

References

Barth, E. and E. Krabbe: 1982, *From Axiom to Dialogue: A philosophical study of logics and argumentation*. Berlin: Walter de Gruyter.

Barwise, J. and J. Etchemendy: 1994, *Hyperproof*, CSLI Lecture Notes. New York: Cambridge University Press.

Beun, R.: 2001, 'On the Generation of Coherent Dialogue: A Computational Approach'. *Pragmatics & Cognition* **9**(1).

Boltzmann, L.: 1905, *Über die Methoden der theoretischen Physik*. Leipzig: Barth.

Borghuis, T. and R. Nederpelt: 2000, 'Belief Revision with Explicit Justifications: An Exploration in Type Theory'. CS-Report 00-17, Eindhoven University of Technology.

Brandom, R.: 1994, *Making It Explicit: reasoning, representing, and discursive commitment*. Cambridge, Mass.: Harvard University Press.

Bunt, H. and Y. Girard: 2005, 'Designing an Open, Multidimensional Dialogue Taxonomy'. In: C. Gardent and B. Gaiffe (eds.): *Proceedings of the Ninth Workshop on the Semantics and Pragmatics of Dialogue (DIALOR'05)*. Nancy, France.

Cohen, P., J. Morgan, and M. Pollack: 1990, 'Intentions in Communication'. Cambridge, MA: MIT Press.

Cox, P. and T. Pietrzykowski: 1986, 'Causes for events: their computation and applications'. In: *Proc. 8th International Conference on Automated Deduction (CADE'86)*. Oxford, pp. 608–621.

Craig, R. and K. Tracy (eds.): 1983, *Conversational Coherence: Form, Structure and Strategy*. Beverly Hills: Sage Publications.

Evans, C. and A. Kakas: 1992, 'Hypothetico-deductive reasoning'. In: *Proc. International Conference on Fifth Generation Computer Systems*. Tokyo, pp. 546–554.

Gentzen, G.: 1934, 'Untersuchungen über das logische Schliessen'. *Mathematische Zeitschrift* **39**, 176–210, 405–431.

Ginzburg, J.: 1996, 'Dynamics and the Semantics of Dialogue'. In: *Language, Logic and Computation*, Vol. 1. Stanford: CSLI.

Grice, H.: 1975, 'Logic and Conversation'. In: P. Cole and J. Morgan (eds.): *Syntax and Semantics 3: Speech Acts*. New York: Academic Press, pp. 64–75.

Hamblin, C.: 1970, *Fallacies*. Methuen & Co Ltd. [Quote from reprint by Vale Press, Newport New, Virginia, 1993].

Hamblin, C.: 1971, 'Mathematical Models of Dialogue'. *Theoria* **37**, 130–155.

Kakas, A., R. Kowalski, and F. Toni: 1998, 'The Role of Abduction'. In: D. Gabbay, C. Hogger, and J. Robinson (eds.): *Logic Programming*, Vol. 5 of *Handbook of Logic in Artificial Intelligence and Logic Programming*. Oxford: Clarendon Press, pp. 235–324.

Levinson, S.: 1983, *Pragmatics*. Cambridge: Cambridge University Press.

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)

Lorenzen, P. and K. Lorenz: 1978, *Dialogische Logik*. Darmstadt: Wissenschaftliche Buchgesellschaft.

Mann, B.: 2002, 'What is dialogue coherence?'. Memo available at http://www-rcf.usc.edu/ billmann/WMlinguistic/dcoherence.htm.

Merritt, M.: 1976, 'On questions following questions (in service encounters)'. *Language in Society* **5**(3), 315–357.

Petukhova, V. and H. Bunt: 2007, 'A Multidimensional Approach to Multimodal Dialogue Act Annotation'. In: J. Geertzen, E. Thijsse, H. Bunt, and A. Schiffrin (eds.): *Proceedings of the Seventh International Workshop on Computational Semantics IWCS-7*. Tilburg, pp. 142–153.

Piwek, P.: 2006, 'The ALLIGATOR Theorem Prover for Dependent Type Systems: Description and Proof Sample'. In: *Proceedings of the Inference in Computational Semantics Workshop (ICoS-5)*. Buxton, UK.

Piwek, P. and E. Krahmer: 2000, 'Presuppositions in Context: Constructing Bridges'. In: P. Bonzon, M. Cavalcanti, and R. Nossum (eds.): *Formal Aspects of Context*, Vol. 20 of *Applied Logic Series*. Dordrecht: Kluwer Academic Publishers, pp. 85–106.

Piwek, P. and K. van Deemter: 2002, 'Towards Automated Generation of Scripted Dialogue: Some Time-Honoured Strategies'. In: *EDILOG 2002: Proceedings of the sixth workshop on the semantics and pragmatics of dialogue*. pp. 141–148.

Power, R.: 1979, 'The organisation of purposeful dialogues'. *Linguistics* **17**, 107–152.

Pulman, S.: 1999, 'Relating Dialogue Games to Information States'. In: *Proceedings of the European Speech Communication Association workshop on Dialogue and Prosody*. De Koningshof, The Netherlands, pp. 17–24.

Saarinen, E. (ed.): 1979, *Game-theoretical Semantics*. Dordrecht: D. Reidel.

Schegloff, E.: 1972, 'Sequencing in conversational openings'. In: *Directions in Sociolinguistics*. New York: Holt, Rinehart & Winston, pp. 346–380.

Schegloff, E. and H. Sacks: 1973, 'Opening up closings'. *Semiotica* **7**(4), 289–327.

Schroeder-Heister, P.: 2006, 'Validity Concepts in Proof-Theoretics Semantics'. *Synthese* **148**, 525–571.

Stenius, E.: 1967, 'Mood and Language-Game'. *Synthese* **17**, 254–274.

Stenström, A.-B.: 1994, *An Introduction to Spoken Interaction*. London and New York: Longman.

Sudnow, D. (ed.): 1972, *Studies in Social Interaction*. New York: The Free Press.

Sundholm, G.: 1986, 'Proof Theory and Meaning'. In: *Handbook of Philosophical Logic*, Vol. III. D. Reidel, pp. 471–506.

Taylor, J. A., J. Carletta, and C. Mellish: 1996, 'Requirements for belief models in cooperative dialogue'. *User Modeling and User-Adapted Interaction* **6**(1), 23–68.

Traum, D. and S. Larsson: 2003, 'The Information State Approach to Dialogue Management'. In: *Current and New Directions in Discourse and Dialogue*. Kluwer Academic Publishers, pp. 325–353.

Waismann, F.: 1965, *The Principles of Linguistic Philosophy*. Macmillan.

Walton, D. and E. Krabbe: 1995, *Commitment in Dialogue: Basic Concepts of Interpersonal Reasoning*. New York: SUNY Press.

Wittgenstein, L.: 1984, *Philosophische Grammatik*. Frankfurt a.M.: Suhrkamp.

Published online August 2007 in Journal of Logic, Language and Information. DOI: 10.1007/s10849-007-9046-1

(See also springerlink: http://www.springerlink.com/content/u8537r552377414j/)