Modelling Users, Intentions, and Structure in Spoken Dialog

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September 17, 1998

Abstract

We outline how utterances in dialogs can be interpreted using a partial first order logic. We exploit the capability of this logic to talk about the truth status of formulae to define a notion of coherence between utterances and explain how this coherence relation can serve for the construction of AND/OR trees that represent the segmentation of the dialog. In a BDI model we formalize basic assumptions about dialog and cooperative behaviour of participants. These assumptions provide a basis for inferring speech acts from coherence relations between utterances and attitudes of dialog participants. Speech acts prove to be useful for determining dialog segments defined on the notion of completing expectations of dialog participants. Finally, we sketch how explicit segmentation signalled by cue phrases and performatives is covered by our dialog model.

1 Introduction

During the last years, a large number of spoken language dialog systems have been developed whose functionality normally is restricted to a certain application domain. [SadMor97] give an quite extensive overview of existing implementations.

Only few systems for generating dialog managers exist or are under development currently. These tools identify task and discourse structure and describe it by means of finite state automata. Using these tools one can easily and quickly implement spoken language human-machine communication for simple tasks. Nevertheless, this approach lacks theoretical sufficiency for a large number of phenomena occurring frequently in natural language dialogs. [SadMor97] state that “these limitations rule out these approaches as a basis for computational models of intelligent interaction”.

Recently, there has been some research on extracting dialog structure out of annotated corpora ([Moe97]); algorithms for learning probability distributions of speech acts are used in this case. The estimated distributions serve as a basis for generating stochastic models for sequences of speech acts. But in this case, exploring common elements of dialogs in different domains is substituted by an abstract optimization process, although knowledge of these elements could be useful for improving parameter estimation.

On the other hand, many approaches to dialog processing consider different structural elements important to gain a deeper understanding of the effects that utterances have on the dialog itself and its participants. But these approaches do not take spoken language and the problems related to speech recognition into account.

Following the opinion of [Poe94] we consider the separation of describing and described situation to be a crucial point for dialog processing. This reflection is backed up by philological and linguistic research on discourse ([Die87], [Mar92], [BriGoe82], [Bun97]).

On this basis we present fundamental elements of dialog structure to handle even spoken language. The main aim of this paper is to build a bridge between research on spoken language processing and study of discourse structure and cognitive approaches to communication between individuals in order to conceptualize dialog systems that integrate experience from all areas of research just mentioned.
2 Different Previous Approaches

As there exists a vast amount of literature on discourse and user models, we first give an account of some of the important directions of research performed up to now. The main interest of all this work is to make precise the notion of “context” which is said to be of great importance for natural language understanding. Inspired by the work of Grosz and Sidner ([GroSid86]) on the interrelations of task and discourse structure, a diversification to structural, semantical and plan-oriented studies has taken place.

2.1 Discourse Structure

The fundamental consideration for work on the structure of discourse is that there is a correspondence between the ordering of utterances in a discourse and how they are related among each other on the semantic level ([Gar94], [Gar97]). Tree structures are used to describe the semantic coherence of discourse. By using these structures, one can define constraints on possible places for attaching a new utterance to an existing discourse ([Web91]) and on accessibility relations for potential referents for deictic expressions ([Pol95]). In approaches based on Discourse Representation Theory ([KamRey93]) this correspondence is captured by construction rules (which can be defined in terms of an extended λ-calculus—see [Kus96]) building up Discourse Representation Structures that describe the coherence relation of all the included contributions¹.

2.2 Speech Act based Theories

Many semantic theories work only locally, i.e. they describe the meaning of one single utterance, ignoring its context and the discourse situation in general. Insofar, they are unable to account for the functionality (i.e. intention) of a perceived utterance.

Basing on earlier work by Austin, [Sea69] proposed a theory of speech acts that has been fundamental for research on this area. Speech acts are implemented in dialog managers to derive hypotheses of how the current utterance contributes to the dialog so far. But considering the last utterance only is insufficient for a cooperative dialog participant as this local view does not pay attention to expectations of other parties involved in the dialog (e.g. when somebody asks a question, she expects the following utterance to be an answer to it). Consequently, to describe coherence in dialog steps, the effects of previous utterances have to be recorded somehow. So, the structural approach of conversational games mentioned briefly above provides an explanation for the speaker uttering something in the course of dialog. Another point of view to the coherence problem is taken by [TraAll94]: they propose that the speech acts associated to each utterance impose social and conventional obligations on the hearer and therefore constrain the set of possible legal responses. Equivalently, one can state that after uttering something the speaker has certain expectations that she wants to be fulfilled by any response that will be given in the next dialog step.

2.3 Intentions, Plans, and Coherence of Utterances

By now, we are able to describe how linearly (by time of being uttered) ordered contributions to a dialog can be integrated into a (partially ordered) discourse structure, but it is still impossible to explain the motivations of the speaker to use a certain speech act, especially in the case when the expectations introduced by the previous are violated. To answer this question, one has to study the mental attitudes of dialog participants.

Motivations for engaging in a dialog can be taken into account by studying planning of utterances. Discourse planning is discussed extensively e.g. by Lambert and Lochbaum ([Lam93] and

¹DRT has been extended by many researchers in different ways—e.g. by Asher for capturing discourse segments ([Ash93]) or in the VERBMOBIL project for handling complex phenomena of spontaneous speech for machine translation ([vm135], [vm83]). But all these theories initially describe monologs and therefore do not consider multi-party communication which is characteristic for dialogs.
Both authors concentrate on the integration of domain dependent planning steps into
the interpretation of utterances. Approaches such as those by [MooYou94] or [CarCar94]
devise a model for collaborative plans for response generation.

Another line of research focuses on the BDI model which is a more domain independent
approach. This accentuates an agent-based view of dialog as the participants in dialog and their
personal attitudes are considered to be of main interest. Beliefs, desires, and intentions are
assumed to drive utterances and speech acts ([AshLas97], [AshSin93]). So the key problem for the
interpretation by the dialog manager is the reconstruction of the speaker’s attitudes from what
she uttered. Coherence of utterances is obtained by fundamental assumptions on cooperative
behaviour ([Grice]) and by analyzing how the content of utterances coheres on the basis of the
(mutually believed) domain knowledge ([AshLas91], [AshLas94], [AshLasObe92]). Along this di-
rection of research there is also some work on coherence relations between utterances ([Kno96],
for an overview see [BatRon94]). These relations characterize the logical connection between ut-
terances and thereby serve as a basic instrument for an analysis of the argumentative structure
described by a given dialog.

2.4 Spoken Language Phenomena

In spoken language hesitations, repairs, etc. are very common, because in oral communication
concentration on the topic of the dialog limits mental resources available for speech production.
These phenomena cannot be captured by semantic formalisms as sketched above. To overcome this
problem, multi-level processing of spoken language utterances has been proposed in the literature
(e.g. see [TraHin91]).

3 Interpretation of Utterances

This section explains our approach how utterances can be interpreted using First Order Partial
Information Ionic Logic (FIL, [Abd95]) as a language for describing the semantics of utterances.

A central issue of dialog management is that dialogs are motivated by the speaker’s desire
to add information to the knowledge of the dialog participants. On the other hand, it occurs
frequently that the shared knowledge of the participants does not contain enough information
to meet the expectations that are “pending” between speaker and hearer. For that reason, our
semantic language must be able to handle situations of partial knowledge. FIL provides formulae
(so called ionic formulae) like

\[ *\left( \{\phi_1, ..., \phi_k\}, \xi \right)\]

meaning intuitively that \( \xi \) is true when it is plausible that \( \Phi = \{\phi_1, ..., \phi_k\} \) (called justification set
or justification context) is true, too (see [Abd95], Sect. 5). \( \Phi \) is the set of missing information to
infer \( \xi \). FIL can be used to compute such justification contexts.

We incorporate FIL for the description of conditions in a DRT-based framework to represent
dialog structure. An example of such a discourse representation structure (DRS) would be:

\[ \text{Does a plane depart from Athens to Rome?} \]

has the semantic representation

\[
\begin{array}{c}
\text{t.Rome Athens} \\
\text{PLANE(t)} \\
\text{DEPART(t)} \\
\text{AIRPORT(Athens)} \\
\text{AIRPORT(Rome)} \\
\text{FROM(t, Athens)} \\
\text{TO(t, Rome)} \\
\end{array}
\]

In DRT, there exists a number of construction rules for incremental composition of several
individual utterances. One can even infer whether DRS \( K_N \) is a consequence of the DRS \( K_1, ..., K_{N-1} \). But whilst in standard DRT conditions are described by classical first order formulae, in
our approach FIL is used for that purpose. As FIL is a partial logic, we can compute whether $K_N$ is undefined given $K_1, \ldots, K_{N-1}$. This is true, as FIL allows to talk about the truth value of a formula:

$$\text{undefined}(\phi) \iff \neg \phi \land \neg \phi$$

So, we are able to assign one of the following three consequence states to $K_N$:

- $\models K_N$: $K_N$ follows from the discourse so far.
- $\not\models K_N \iff \neg K_N$: $\neg K_N$ follows from previous utterances.
- $\models \neg K_N \land \neg K_N$: $K_N$ is still undefined.

Using the deduction theorem $(\Delta \cup \{ \phi_1, \ldots, \phi_K \} \models \psi \iff \Delta \models \phi_1 \land \ldots \land \phi_K \rightarrow \psi)$ we have established a coherence relation between utterances via implication in FIL. When $\phi_1 \land \ldots \land \phi_K \rightarrow \psi$ is true, $\ast(\{\phi_1, \ldots, \phi_K\}, \psi)$ is true, too.

Interpreting an utterance requires a knowledge base $\Delta$ for the representation of the domain relevant knowledge. As described in [LudGoNie98], we use description logics to define the notions to be understood by the dialog manager for a given application. More precisely, description logics serve for constructing a terminology of the domain, thereby representing domain dependent, but situation independent knowledge. In order to interpret a specific utterance in a given situation, the given terminology is instantiated by concrete facts that are entailed by the semantic representation of the current utterance. To give a simple example of this idea, we could state in the knowledge base of a flight information system that a flight from a departure location to an arrival location is a flight characterized by the existence of an airport at the departure and the arrival location, respectively. In description logics, we could say:

$$\text{FlightFromTo} = \exists \text{From.airport} \cap \exists \text{To.airport} \cap \text{Flight}$$

So, this definition characterizes knowledge that holds in every situation in the given application domain. On the other hand, the DRS above describes a concrete situation.

We conclude that the consequence states mentioned above have to be understood as consequence on the basis of a situation independent knowledge base that characterizes the application domain. To interpret utterances in a given situation, the dialog manager tries to infer the consequence state of the current utterance relying on his domain knowledge. In general, this state depends on a certain justification context as outlined above. As will be shown below, we can verify the truth value of all elements in a justification context $\Phi$ if we interpret each $\phi_i$ as a question to the hearer and view the subsequent response as an answer to this question. This means that the dialog manager’s planning steps are strongly affected by the results of inference in its knowledge base. From that view and the semantics of $\ast(\{\phi_1, \ldots, \phi_K\}, \psi)$ we can derive an $n$-ary AND/OR tree that reflects the discourse structure of the discussed dialog segment.

In the tradition of [GroSto84] and [GabRey92] we consider (free) discourse referents of interrogative pronouns as $\lambda$-bound variables. If the problem solver finds a solution for the posed query, then it binds these variables to discourse referents that have been introduced earlier (or during the process of problem solving). Of course, there can be more than one possible substitution of the $\lambda$-variables. For given variables $x_1, \ldots, x_M$, we denote a substitution of all variables by discourse referents $t_1, \ldots, t_M$ as $\Sigma = \{[x_1/t_1], \ldots, [x_M/t_M]\}$. $\{\Sigma_1, \ldots, \Sigma_K\}$ is a set of $K$ pairwise distinct substitutions.

In the general case where the result of the inference process consists of a set $\{\Sigma_1, \ldots, \Sigma_K\}$ of answer substitutions and a set $\{\phi_1, \ldots, \phi_{N-1}\}$ of justification substitutions, each $\Sigma_i$ induces an edge in a OR-subtree of the overall discourse structure.

This tree structure is part of the describing situation for the current dialog. Below we will introduce operations on the dialog tree that characterize how the structure is expanded in the course of dialog. In this sense, such a tree constitutes the “syntax” of the current dialog. But there is a strong connection to what could be called “dialog semantics”. It is grounded basically on the meaning of the edges in the tree: they express the fact that parent and child nodes are coherent in the sense of FIL consequence explained above. Furthermore, by the notion of satisfiability of FIL
ionic formulae we exploit the tree structure to reformulate Grosz’ and Sidner’s relations $dominance$ and $satisfaction$ precedence: because justification context $\Phi = \{\phi_1, \ldots, \phi_k\}$, when $\models (\Phi, \psi)$ is given, is true if and only if all $\phi_i$ are true on the justification level, we have $\psi \uparrow \phi_i$ for all $1 \leq i \leq k$. And as $\not\models \phi_i$ for one $i \in \{1, \ldots, k\}$ implies $\not\models (\Phi, \psi)$, we obtain $\phi_i < \phi_j$ for $1 \leq i < j \leq k$.

4 Basic Elements of Dialogs

4.1 Empirical Evidence for the Need of User Models

Dialog managers for real world applications have to be robust in the sense that they always terminate an (user-)initiated dialog in a controlled way. So, the study of how to build robust generic dialog managers implies to reason about what structures exist in a dialog and how they get modified by utterances. On the other hand, it is also important to understand how dialogs affect the participants and their future utterances.

A first approach to this problem is to see the function of utterances as that of updating the shared knowledge—a data structure maintained and used by all dialog participants. From this point of view, each dialog participant infers the same consequences from every new utterance.

But as pointed out in the AI literature, actually people hold personal assumptions about the meaning of an utterance. These assumptions can differ among dialog participants. We illustrate this by an example taken from the TRAINS corpus (see [TrainsCorpus]):

1.1 M: okay
1.2: we have to get .. a
1.3: tanker car of orange juice to uh Avon
1.4: and a
1.5: boxcar of bananas to Corning
1.6: and we have to do that by 3 PM today
2.1 S: okay
3.1 M: okay
3.2: so let’s see umm
3.3: ... we probably have to take the tanker car
3.4: from Corning to Elmira
3.5: to get uh
3.6: orange juice in it
3.7: um
[2sec]
3.8: [click] and uh
3.9: how far is it from Corning to Elmira
3.10: how long would it take
4.1 S: 2 hours
5.1 M: m hm
5.2: okay so
[2sec]
5.3: why don’t we uh

In (1.1) to (1.6) M describes the goal of this dialog and some constraints. Doing that he makes some of his mental attitudes public, thereby assuming that S will be able to interpret them appropriately. So (1.1) to (1.6) do not transport content about the domain, but about M exclusively. The impact of the observation that utterances can contain domain relevant knowledge as well as knowledge about other dialog participants is enormous: In (6.1) and (6.2) S tries to

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2 $\alpha$ dominates $\beta$ ($\alpha \uparrow \beta$) if and only if $\beta$ is part of $\alpha$, while $\alpha$ satisfaction-precedes $\beta$ ($\alpha < \beta$) if and only if $\alpha$ is necessary for $\beta$.

3 i.e. (stated in model-theoretic semantics) there exists an interpretation that expands any interpretation that makes $\psi$ true in such a way that it assigns true to all $\phi_i$, too.
explain why \( M \) will not be able to reach his goals by explaining why \( M \)'s information about the domain and the current domain scenario is incomplete or false. This is possible only because \( S \) can differentiate between his own domain knowledge and that transported by the previous utterances. As a consequence, \( S \)'s cooperative behaviour is made possible by his ability to reason about the domain and about his assumptions of \( M \)'s view of the domain.

This example shows that cooperative dialog managers must maintain some sort of user model. Our approach will be discussed in the remainder of this section.

### 4.2 Rational Behaviour of Dialog Participants

Discussing dialog management, one normally assumes that people initiate communication with others in order to get help for achieving a certain goal. From these observations, we can derive that questions are asked to get an answer that completes the speaker’s knowledge in some way.

For an answer to be helpful, it has to meet certain constraints (expressed by [Grice] in his maxims of cooperation): first, it has to be coherent with the question so that it can deliver valuable information. And, of course, it should be true. These requirements pose constraints on the behaviour of the person that is giving the response, too. This person has to be cooperative, i.e. she should adopt the speaker’s goals, as far as she can realize them. Honesty is another crucial point. For a person not feeling obliged to telling the truth is not a reliable source of information.

Our discussion is restricted to dialogs that fulfill the requirements above. I.e., we assume some amount of rational behaviour for all dialog participants.

To reason about goals and intentions, one has to study the cognitive structures that underly rational behaviour. For dialogs, these structures are described at length in [TR663].

One major challenge for designing robust dialog systems seems to be how to reconstruct the contents of the mental states of the user out of the utterances—the only observable facts. So the study of how language can transfer attitudes and reflect planning steps of dialog participants becomes very important. [Eng88] notes that in German basically one can communicate three different types of utterances:

- **constative**: state facts. Our requirement of honesty admits the conclusion that nothing wrong is intentionally stated to be true.
- **interrogative**: ask something.
- **imperative**: request something.

### 4.3 Discourse Domain and Application Domain

To formalize the intuitions described up to now, we need a framework that enables us to talk about utterances or the corresponding DRS, respectively.

We can achieve this by introducing a *discourse domain*\(^4\) that is the domain of describing situations. Atomic elements are DRS whereas in the application domain (consequently to be defined as the domain of described situations) atomic elements are objects of the application. This reflects the ability of natural language to “climb up” to a meta-level, e.g. simply by saying “What you have told me up to now, has been clear to me. But I can’t understand what I should do now.” If one thinks about a situation when a teacher instructs a pupil how to achieve some goal, then it becomes obvious that responses as above refer only to the instructions, but not to what is instructed currently. We use this framework to reason about the relation of utterances and speaker’s attitudes. Following the notation in [AshLas97], we express the connection between formulating attitudes and the attitudes themselves in the following way\(^5\):

\[
\text{constative}(K) \rightarrow W_I(B_R(K))
\]  

\(^4\)The discourse domain is *not* the domain of discourse as we try to make clear in the remainder of this section. We call the domain of discourse the *application domain* to express the fact that discourse structure and application structure (sometimes called task structure) are different and not isomorphic.

\(^5\)We denote the speaker \( I \) (initiator) and the hearer \( R \) (responder). \( B \) expresses beliefs, \( W \) desires, \( I \) intentions, and \( K \) knowledge.
To describe defeasible rules, we exploit FIL ionic formulae: defaults eventually to be defeated by
overriding exceptions are expressed as ionic formulae. By that the consequence of an implication
is assumed to be valid as long as there is no evidence to the contrary. If we have \( \phi \rightarrow \ast(\psi, \psi) \) and
\( \phi \), then \( \psi \) is considered true, unless there is evidence for \( \psi \) to be false. So we can formulate

- a principle of sincerity:
  \[
  I_I(B_R(K)) \rightarrow \ast(B_I(K), B_I(K))
  \]

- principles of cooperation:
  \[
  \begin{align*}
  W_I(K) \land B_I(\sim K) & \rightarrow \ast(W_R(K) \land B_R(\sim K), W_R(K) \land B_R(\sim K)) \\
  W_I(\text{do}_I(K)) & \rightarrow \ast(W_R(K_I(K)), W_R(K_I(K)))
  \end{align*}
  \]

After having defined how linguistically motivated types of utterances and mental states are
interrelated among each other and how fundamental principles of collaboration in dialogs are
expressed formally, we show (by means of two examples) how mental states and speech acts are
connected via defeasible rules in FIL:

\[
\begin{align*}
I_I(K_I(K)) & \rightarrow \ast(\text{query}_I(K), \text{query}_I(K)) \\
B_R(\sim(\sim(\xi \rightarrow K) \land \sim(\xi \rightarrow K))) \land \\
W_R(K_I(K)) \land W_R(B_I(\xi)) & \rightarrow \ast(\text{inform}_R(\xi), \text{inform}_R(\xi))
\end{align*}
\]

Informally, the first rule states that anything one wants to know is normally asked for, while the
second rule claims that if one wants another dialog participant to know something and believes it
could be a consequence of something else and wants the other to know that, too, then one informs
about that new fact.

We can draw the following conclusion: After the speaker \( I \) has asked \( K \) and gets \( \xi \) as response,
she can infer defeasibly \( \text{inform}_R(\xi) \) assuming that \( \xi \) is constative and relying on cooperation if there
is no evidence for \( R \) (the hearer of \( I \)'s utterance, but now speaker of \( \xi \)) against the belief \( \xi \rightarrow K \).
Furthermore, by sincerity \( I \) can also infer that \( R \) intends \( I \) to believe \( \xi \rightarrow K \).

This example outlines our approach of to how reconstruct speech acts from observable utterance
types via reasoning about the speaker’s intentions. Recognizing speech acts is important for a
cooperative dialog manager as it helps to explore what state the dialog currently is in (e.g. a
question has been asked and an appropriate answer is now expected). It seems to be just this
notion of dialog state that captures the interactive nature of dialogs in contrast to monological
discourse like a newspaper article. Describing how the transition of the dialog state looks like in
the course of utterances therefore extends the notion of coherence in discourse sketched above.
But, as can be seen easily from the \( \text{inform} \) rule (8) above, coherence is the link between mental
states and speech acts: no speech act can be recognized without reasoning about coherence of
utterances. In the rule above, \( \text{inform}_R(\xi) \) can be inferred only if \( \models \xi \rightarrow K \) or \( \notmodels \xi \rightarrow K \). The case
when \( \xi \rightarrow K \) is undefined, will be discussed later.

### 4.4 Dialog States and Dialog Structure

First we turn to the discussion of dialog states and their transition relation: As noted in the
literature (see e.g. [TraAll94, CriWeb97]), utterances in dialogs induce expectations of what a
plausible response should look like. Stated differently, by her speech act, the speaker poses some
obligation on the hearer that constrains the preferred responses. Nevertheless, a model of dialog
that does not restrict the range of “valid” utterances too much, should give an account for a
cooperative reaction even if expectations have been violated in a response.
Meeting an expectation and thereby completing the conversational game opened by the initiator, the responder implicitly performs a segmentation of the discourse. In what follows, we describe the syntax of discourse segments using a context free grammar whose rules are attributed by operations on the dialog structure depending on the coherence between the current utterance and the knowledge shared between the dialog participants. In that way, we define the semantics of discourse segmentation in terms of coherence of utterances using the notion of the AND/OR tree introduced above.

4.4.1 Simple Segments

In a simple segment the speaker poses no obligations on the hearer. When no obligations are pending, an inform act would create a simple segment according to the following rule:

\[
\text{SEG} \to \text{inform}_I(K) \\
\text{SEG} = \text{newAND}(\text{SEG}, K)
\]  

This rule states \( K \) can be added as a new fact to the shared knowledge, and therefore be inserted as an AND branch into the currently centered segment. In the absence of pending expectations, the root segment (i.e. the root of the dialog tree) is centered by default\(^6\).

4.4.2 Complex Segments

Dialog segments are called complex when the speaker assigns expectations to her utterance. For example, when asking a question she expects an answer to be given by the hearer that helps perform her intentions. But it is obvious that the hearer could have reason not to fulfill the expectations (at least temporarily): she could need additional information first in order to answer the question and therefore respond with a new one. After this question will have been answered the hearer will respond according to the still pending expectation. We capture this situation with the following rules:

\[
\text{SEG} \to \text{query}_I(K) \text{QUERYEXP} \\
\text{SEG}_1 = \text{newAND}(\text{SEG}_1, \text{newSubTree}(K, \text{QUERYEXP}))
\]

\[
\text{SEG} \to \text{SEG SEG} \\
\text{SEG}_1 = \text{newAND}(\text{SEG}_2, \text{SEG}_3)
\]

Here, the first rule says that a segment can be initiated by a query imposing an obligation to answer it. On the other hand, as it is expressed in the second rule, a segment can consist of two subsegments forming an AND subtree. QUERYEXP follows the rule:

\[
\text{QUERYEXP} \to \text{ANSWER} \\
\text{QUERYEXP} = \text{ANSWER}
\]  

\[
\text{QUERYEXP} \to \text{ANSWER QUERYEXP} \\
\text{QUERYEXP}_1 = \text{newOR}(\text{ANSWER}_2, \text{QUERYEXP}_3)
\]

ANSWER is defined as follows:

\[
\text{ANSWER} \to \text{inform}_I(K) \\
\text{ANSWER} = \text{newNode}(K)
\]  

\[
\text{ANSWER} \to \text{SEG inform}_I(K) \\
\text{ANSWER} = \text{changeRoot}(\text{SEG}, K)
\]

\( ^6\)Below, after having introduced the operations on the dialog tree, we will give an example illustrating the application of the segmentation rules.
4.5 Example

In this section, we give an example of how our dialog model behaves at work. For the purpose of illustration we use the following short flight information dialog:

\[ \alpha \text{ User: I want a flight from Athens.} \]
\[ \beta_1 \text{ System: Where do you want to go to?} \]
\[ \gamma_1 \text{ User: To Rome.} \]
\[ \beta_2 \text{ System: On which day?} \]
\[ \gamma_2 \text{ User: On Monday.} \]
\[ \beta_3 \text{ System: When do you want to depart?} \]
\[ \gamma_3 \text{ User: At 12 o’clock.} \]
\[ \rho \text{ System: There are several connections: AZ717 at 06:55, OA233 at 09:05, AZ725 at 09:20, OA235 at 12:55, AZ721 at 16:00, OA239 at 17:10, AZ723 at 20:20.} \]

As will be discussed in Sect. 7.2, I want expresses a desire explicitly and is therefore represented as \( W_I(\alpha) \). From that we conclude \( *(query_I(\alpha), query_I(\alpha)) \). Besides of that, we have the implications \( W_R(K_I(\alpha)) \) by cooperation and \( ¬inform_I(\alpha) \). On the other hand, grammatically \( \alpha \) is constative. Therefore constative(\( \alpha \)) \( \rightarrow W_I(K_R(\alpha)) \) and, consequently, \( *(inform_I(\alpha), inform_I(\alpha)) \). But justification context \( inform_I(\alpha) \) is in conflict with \( ¬inform_I(\alpha) \). Therefore, the only derivable hypothesis for \( \alpha \)’s speech act is \( query_I(\alpha) \). According to the rules for discourse segmentation above, this induces a QUERYEXP for \( R \) (i.e. the dialog manager). This obligation is expressed in the user model by \( W_R(K_I(\alpha)) \).

In order to fulfill this desire, the dialog manager tries to evaluate the consequence status of \( \alpha \) (see Sect. 3). This evaluation is performed on the basis of the domain model (for a more elaborate example see [LudGönNie98]). Its result is that the status of \( \alpha \) depends on the justification context \( \{At, To, On\} \). i.e. departure day and time as well as the destination are still unknown.

So, mental attitudes of the dialog manager change: a new desire \( W_R(K_R(\gamma_1)) \) is added that implies \( *(query_R(\beta_1), query_R(\beta_1)) \). i.e. a new discourse obligation is being introduced leaving the old one pending.

For the user’s response constative(\( \gamma_1 \)) holds, implying \( W_I(K_R(\gamma_1)) \). From \( \gamma_1 \) the dialog manager infers \( \gamma_1 \rightarrow \beta_1 \). Consequently, it assumes \( B_I(\gamma_1 \rightarrow \beta_1) \) and \( *(inform_I(\gamma_1), inform_I(\gamma_1)) \). As there is no evidence against \( inform_I(\gamma_1) \) and no other hypothesis for a possible speech act, \( inform_I(\gamma_1) \) is assumed. This completes \( query_R(\beta_1) \). With this completion, the dialog manager obtains information about the destination.

Processing of \( \beta_2, \gamma_2 \) and \( \beta_3, \gamma_3 \) is performed analogously. After that, the justification context inferred during the interpretation \( \alpha \) has been answered completely. Having got all this information the dialog manager can compute a solution for \( \alpha \) that is uttered in \( \rho \).

Fig. 1 shows the dialog segmentation for this example, while Fig. 2 sketches the coherence structure of all utterances, represented in a DRS in Fig. 3. A point worth mentioning is that the structure of the justification context as an AND tree is embedded in the coherence structure of the dialog.

5 Incoherence and its Effects on Dialog Structure

This section explains in more detail how our dialog manager handles situations when two utterances are incoherent in the sense mentioned earlier although they otherwise would not violate any expectations. Consider the dialog is Fig. 4 for a motivation of the problem:

This dialog is quite regular according to the rules on dialog state described in the previous section until \( U \) utters \( \theta \). Shared domain knowledge \( \Delta \) and the facts collected during the dialog do not allow to conclude that \( \theta \) and \( \eta \) are coherent. One can derive that \( \Delta \cup \{ \theta \} \models ¬\eta \land ¬\eta \). So the question arises which speech act to assign to \( \theta \). To answer that question we have to go back some steps in the dialog: in occasion of uttering \( \gamma \), \( S \) made \( U \) assume \( W_S(K_S(\gamma)) \) implying
$W_U(K_S(\gamma))$. From this observation and from $\Delta \cup \{\zeta\} \models \gamma$, $S$ can infer that $U$ wants to give an answer to $\gamma$—thereby ignoring $S$’s expectation that $\epsilon$ will be answered by $U$.

How can such a situation be described in our model of dialog states? Following [Tra94], we assume that several speech acts can be assigned to one utterance allowing the speaker to express multiple intentions at one time. Except of the inform act derived by inferring coherence between $\theta$ and $\gamma$, we assign a cancel act to $U$’s last utterance. cancel has the meaning that a pending dialog obligation is violated intentionally as it is the case when $U$ referred to $\gamma$ when responding to $\eta$.

cancel is defined by

$$\neg K \wedge \neg K \wedge \text{inform}_R(K) \rightarrow \text{cancel}_R(K)$$ (16)

To integrate cancel into speech act processing, we add a new rule for ANSWER:

$$\text{ANSWER} \rightarrow \text{cancel}_I(K)$$ (17)
$$\text{ANSWER} = \emptyset$$ (18)
6 Configuration of Dialog Managers

Our approach to dialog understanding as it has been characterized up to now is dominated by the idea to separate domain independent algorithms and data structures from domain dependent data for specific applications and to separate the discourse domain proper from the application domain. By the isolation of domain independent dialog elements we try to explore the minimal amount of dialog structures to be configured for a specific application. In particular, we have distinguished

\begin{align*}
\alpha = & \beta_1 \beta_2 \beta_3 \gamma_1 \gamma_2 \gamma_3 \rho \\
\alpha = & \bar{u} \\
\bar{\alpha} = & \begin{bmatrix}
        \text{I Athens} \\
        \text{FLIGHT}(f) \\
        \text{FROM}(f, \text{Athens})
    \end{bmatrix} \\
\text{want}(u, \bar{\alpha}) = & \begin{bmatrix}
        \text{u} \\
        \bar{\alpha}
    \end{bmatrix} \\
\beta_1 = & \lambda l. \begin{bmatrix}
        \text{GO}(u) \\
        \text{LOCATION}(l)
    \end{bmatrix} \\
\gamma_1 = & \beta_1(\text{Rome}) \\
\beta_2 = & \lambda d. \begin{bmatrix}
        \text{GO}(u) \\
        \text{DAY}(d)
    \end{bmatrix} \\
\gamma_2 = & \beta_2(\text{Monday}) \\
\beta_3 = & \lambda t. \begin{bmatrix}
        \text{GO}(u) \\
        \text{TIME}(t)
    \end{bmatrix} \\
\gamma_3 = & \beta_3(12 \text{ o’clock}) \\
\rho = & \begin{bmatrix}
        \text{c} \\
        \text{AZ717} \\
        \text{OA233} \\
        \text{AZ725} \\
        \text{OA235} \\
        \text{AZ721} \\
        \text{OA239} \\
        \text{AZ723}
    \end{bmatrix}
\end{align*}

\begin{align*}
\text{SEVERAL(c)} \\
\text{CONNECTION(c)} \\
\text{FLIGHT(AZ717) AT(AZ717, 06 : 55)} \\
\text{FLIGHT(OA233) AT(OA233, 09 : 05)} \\
\text{FLIGHT(AZ725) AT(AZ725, 09 : 20)} \\
\text{FLIGHT(OA235) AT(OA235, 12 : 55)} \\
\text{FLIGHT(AZ721) AT(AZ721, 16 : 00)} \\
\text{FLIGHT(OA239) AT(OA239, 17 : 10)} \\
\text{FLIGHT(AZ723) AT(AZ723, 20 : 20)}
\end{align*}

Figure 3: Discourse Representation Structure for the Example Dialog

Figure 4: Example Dialog

?α U: Is there a flight to Rome on Saturday?
β S: Yes, LH745 at 10:38, AZ304 at 15:03, or 2G261 at 16:25.
γ U: Which airline do you prefer?
δ S: The Alitalia flight would be quite convenient.
ε U: Do they offer business class?
ζ S: Yes, they do.
η S: Have you got a MilleMiglia card?
θ U: [Hmm, actually] I rather prefer Lufthansa due to their superb service.
three models contributing to the setup of a dialog system for a given application:

- Domain model
  It defines the notions that exist in the application domain and how these notions are being interpreted. Additionally, it describes how the vocabulary of the domain is connected with notions defined in the domain model (see Sect. 3).

- Dialog model
  The conversational games valid for the application (see Sect. 4.3) and the rules how moves of different games can be interleaved among each other are defined in the dialog model. Rules for the games specify how the dialog structure (represented by the dialog manager as an AND/OR tree) is affected by a certain game. In addition, it is possible to restrict dialog participants to different sets of conversational games that they are allowed to begin. E.g. in a dialog model without mixed initiative the user would not be permitted to begin a query game, but only be allowed to react with inform. It is an open question whether a restriction of the kind just described could serve as a sufficient characterization of the complexity of dialogs.

- Model of dialog participants (user model)
  In order to reason about motivations for conversational games one has to connect game moves (i.e. speech acts) with mental attitudes of dialog participants. For this purpose, the user model defines necessary conditions of mental attitudes for each speech act. On the other hand, it also contains the general principles of rational behaviour that hold between the attitudes of dialog participants (see 4.2).

During the configuration for a specific application the models sketched above have to be defined. We argue that at least for the dialog model and the user model there exists a large application independent subset of definitions that holds for any application and has only to be completed for a concrete domain.

In many cases, such a subset would reduce configuration to the definition of an appropriate domain model. From this point of view, it would be worth analyzing which classes of dialogs could be covered by proposals for domain independent sets of speech acts (such as the one described by the Discourse Resource Initiative—see [DRI97]).

7 Explicit Modification and Segmentation of Dialog Structures

Any model for describing discourse as the one sketched in this paper should give an account not only for an implicit construction of dialog structures, but also for its explicit modification by the dialog participants (see e.g. [Coh90]). Such an account would reflect the capability of dialog to talk about what [Bun97] has called “dialog control”, or about attitudes and mental states of dialog participants. Switching to the “meta-level” is normally signalled by cue phrases or performatives.

In the remainder of this section we will discuss how these special types of utterances that have a well-defined meaning only in the describing situation of the dialog affect our dialog model.

7.1 Cue Phrases

In our opinion, many natural language expressions are like polymorphous operators in object-oriented programming languages: they take arguments of different type and have different semantics each time. This view is shared by other researchers, too—e.g. [Ben88]. E.g. in the utterance “Do you want to depart from Munich or from Frankfurt?” or expresses a choice between two locations—i.e. two objects of the described situation. On the other hand, in “Will you go there by
bus or rather take the car?” or again states two possible alternatives, but, in this case, they are utterances—i.e. objects of the describing situation.

To incorporate interpretation of cue phrases of into the dialog model we rely on Knott’s work ([Kno96]) on coherence relations. Knott discusses extensively how cue phrases contribute to the understanding of discourse coherence: He assumes that any cue phrase has the function of an operator between previous utterances $\alpha_1, \ldots, \alpha_N$ and an utterance $\beta$ following the cue phrase. These utterances are connected by a defeasible rule $P_1 \land \ldots \land P_N \rightarrow C$ which we can express in FIL as $(P_1 \land \ldots \land P_N \rightarrow C, P_1 \land \ldots \land P_N \rightarrow C)$. Each cue phrase has an associated set of features like polarity of the consequent etc. that define its semantics and how the utterances in the scope of the cue phrase are linked to $P_i$ and $C$. E.g. for but, we have $P_i := \neg \alpha_i$ and $C := \beta$. Consequently for “$\alpha$, but $\beta$” coherence between $\alpha$ and $\beta$ is expressed by $\neg \alpha \rightarrow \beta$.

For the general case, coherence between utterances in the scope of the cue phrase can be established if $\{P_1, \ldots, P_N\} \models C$ or $\{P_1, \ldots, P_N\} \not\models C$. This result can be exploited to update the dialog structure appropriately.

For a deeper investigation of this topic let’s have a look at the following dialog:

- **U**: Is there a flight to Rome on Saturday?
- **S**: Yes. AZ631 at 15:03
- **U**: How much is it?
- **S**: DM 528 plus tax.
- **U**: or on Monday, what about that?
- **S**: On Monday you can fly with Debonair.
- **U**: How much is a ticket?
- **S**: DM 199 plus tax.

How is “or on Monday?” processed and integrated into the dialog structure? Firstly, it has to be noticed that ellipsis resolution on the PP “on Monday” yields as syntactic referent “Is there a flight to Rome?”.

Secondly, the DRS for the describing situation after $\delta$ has been processed, is as shown in Fig. 5.

Combining the remark on the ellipsis “on Monday” and the DRS for the dialog so far, we find that the right-hand argument of the operator or is $\alpha([Saturday/Monday])$. So, we can denote a DRS (see Fig. 6) that describes the semantics of $\epsilon$.

Obviously, as can be seen from the DRS for $\epsilon$, the problem of finding an appropriate discourse referent for $X$ can be solved by anaphora resolution in the describing situation. The only antecedent in the describing situation compatible with $\alpha([Saturday/Monday])$ is $\alpha$. So, $\alpha$ has been centered by $\epsilon$.

\footnote{i.e. in $\alpha$ all appearences of Saturday are substituted by Monday}
The impact of \( \epsilon \) on the dialog structure is determined essentially by how or modifies the dialog segmentation: the segment of \( \alpha \) is substituted by an OR subtree representing the two arguments of or (see Fig. 7). For the utterances to follow, \( \epsilon \) is the center, and dialog processing works as usual.

### 7.2 Performatives and Modal Verbs

Performatives and modal verbs state assertions not about the described, but the describing situation; more precisely, they express assertions about mental states and speech acts as in “I must leave you now”, “On what day do you want to depart?”, “I suggest not to pay at all for this bad film.”

As such utterances do not talk about the described situation, they cannot be processed as if they did. Consequently, speech act recognition does not apply as normally in this case. For that reason, all rules above for inferring speech acts are defeasible. Therefore we can devise “special” rules for performatives and modal verbs that “override” defeasible inferences based solely on syntactic and prosodic criteria if an inspection of the content of the utterance provides evidence against these “default conclusions”. To do this, we classify performatives and modal verbs according to what mental state they operate on or what speech act they express.

In the utterance “I want to fly to Rome on Saturday.”, \textit{want} expresses implicitly the query “Is there a flight to Rome on Saturday.”. It is clear immediately that the utterance is actually not an inform act that poses no obligations to respond cooperatively on the hearer. So desires and queries are defeasibly connected by:

\[
W_f(\text{do}_f(K)) \rightarrow *(\text{query}_f(K), \text{query}_f(K)) \quad (19)
\]

\( W_f(\text{do}_f(K)) \) overrides inform in the following way:

\[
W_f(\text{do}_f(K)) \rightarrow \neg \text{inform}_f(K) \quad (20)
\]

When the dialog manager starts processing the utterance above, it infers the following:
inform\(_I(K)\) with justification context inform\(_I(K)\)

query\(_I(K)\) with justification context query\(_I(K)\)

As the semantics of “I want to” belongs to the class \(W_I(\text{do}_I(K))\), we can use this fact (that has been derived from the semantic representation of the utterance) to infer \(\neg\text{inform}_I(K)\) by (20). As a result, the only valid inference is query\(_I(K)\). By cooperation, we can infer \(W_R(K_1(K))\). After that, we are in exactly the same situation as if the speaker had asked directly for a flight to Rome.

8 Conclusions

We have reported about work in progress on developing a theoretical approach on dialog structure in order to build domain independent, cooperative, and robust dialog managers. The theoretical framework outlined in this paper has already been implemented partially and was tested for a small domain. In an evaluation, the implementation has proven to perform well. On the other hand, we have analyzed a large corpus of train-inquiry dialogs collected with our EVAR ([EckNie94]) system. An important result is that the quality of speech recognition determines how cooperative the EVAR system\(^8\) really is. To improve this situation we work towards improving dialog theory as presented in this paper by integrating BDI-oriented, structural, and plan based approaches to dialog understanding. Experience from analyzing dialogs that have not been terminated successfully has shown that our approach is capable to overcome the failures that caused the unacceptable terminations.

9 Future Research

Using the results presented in this paper as a basis, we will continue our work on dialog structure by describing precisely how a processing level for handling typically difficult phenomena of spoken language like repairs etc. can be integrated into our model. We intend to achieve this by incorporating Traum’s model of grounding (see [Tra94]) into our framework. This mechanism will have to be expanded to work properly on word hypothesis graphs that are the basic data structure of the common ground. This allows for a full exploitation of the results produced by the speech recognizer. Furthermore, we want to integrate our implementation of a chunk parser as a robust algorithmic approach to a theory of incremental discourse processing as described e.g. in [Poe94].

References

[Abd95] N. Abdallah, The Logic of Partial Information, Springer, New York 1995
[Ash93] N. Asher, Reference to Abstract Objects in Discourse, Kluwer, Dordrecht 1993
[AshLas91] N. Asher, A. Lascarides, Discourse Relations and Defeasible Knowledge, in: Proceedings of the 29nd Annual Meeting of the Association of Computational Linguistics (ACL 91), pp. 55–63, Berkeley 1994
[AshLas94] N. Asher, A. Lascarides, Intentions and Information in Discourse, in: Proceedings of the 32nd Annual Meeting of the Association of Computational Linguistics (ACL 94), pp. 35–41, Las Cruces 1994
[AshLas97] N. Asher, A. Lascarides, Questions in Dialogue, to appear in Linguistics and Philosophy
[AshLasObe92] N. Asher, A. Lascarides, J. Oberlander, Inferring Discourse Relations in Context, in: Proceedings of the 30th Annual Meeting of the Association of Computational Linguistics (ACL 92), pp. 1–8, Delaware 1992
[AshSin93] N. Asher, M. Singh, A Logic of Intentions and Beliefs, in: Journal of Philosophical Logic, (22):5, pp. 513–544
[BatRon94] J. Bateman, K. Ronhuis, Coherence relations: Analysis and specification, Technical Report R 1.1.2: a, b, The DANDELION Consortium, Darmstadt 1994
[Ben88] J. van Benthem, A manual of intensional logic, CSLI lecture notes, 1988
[vm135] J. Bos et al., Compositional Semantics in Verbmobil, Verbmobil-Report 135, 1996
[BriGoe82] A. Brietzmann, G. Görz, Pragmatics in Speech Understanding Revisited, in: Proceedings of COLING 82, pp. 49–54, Prag 1982

\(^8\)EVAR is not based on the dialog model sketched in this paper.
[Tra94] **D. Traum**, *A Computational Theory of Grounding in Natural Language Conversation*, Ph.D. Thesis, Computer Science Dept., University of Rochester 1994  
[TraAl94] **D. Traum, J. Allen**, *Discourse Obligations in Dialogue Processing*, in: *Proceedings of the 32nd Annual Meeting of the Association of Computational Linguistics (ACL 94)*, pp. 1−8, Las Cruces 1994  
[TR663] **D. Traum et al.**, *Knowledge Representation in the TRAINS-93 Conversation System*, Technical Report 663, University of Rochester, 1996