An Empirically Based Computationally Tractable Dialogue Model

Proceedings of the Annual Meeting of the Cognitive Science Society, 14(0)

Dahlback, Nils
Jonsson, Arne

1992

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Abstract

We describe an empirically based approach to the computational management of dialogues. It is based on an explicit theoretically motivated position regarding the status of computational models, where it is claimed that computational models of discourse can *only* be about computers' processing of language. The dialogue model is based on an extensive analysis of collected dialogues from various application domains. Issues concerning computational tractability has also been decisive for its development. It is concluded that a simple dialogue grammar based model is sufficient for the management of dialogues with natural language interfaces. We also describe the grammar used by the dialogue manager for a Natural Language interface for a database system.

Introduction

Most, if not all, work on dialogues in present- day computational linguistics do not make explicit to which extent the models and theories developed should be seen as theories about the processing of dialogue by computers or people or both. Though never explicitly stated, the underlying assumption seem to be that the theories are to be general theories of discourse for all kinds of agents and situations. There are, however, a number of reasons for assuming that the cognitive architecture of present day computers and people are sufficiently different to make it necessary to clarify to which extent a computational theory of discourse (or any other cognitive phenomenon, for that matter) is primarily to be seen as a psychological account or an account of computer's processing of discourse. This is not only true for those that are critical to the computational theory of mind, but also for the defenders of that view (cf. Pylyshyn, 1984). It is thus, in a sense, an uncontroversial position. But what is perhaps less so, is the consequences that we claim of necessity follows from it.

As far as the internal, or representational, aspect is concerned, we want to claim that procedural computational accounts of the process of discourse using concepts from present day computer technology cannot be seen as a psychological account. "Two programs can be thought of as strongly equivalent or as different realizations of the same algorithm or the same cognitive process if they can be represented by the same program in some theoretically specified virtual machine" Pylyshyn (1984, p 91). A consequence of this is that "*any* notion of equivalence stronger than weak equivalence[1] must presuppose an underlying functional architecture, or at least some aspects of such an architecture." (ibid , p 92) "Typical, commercial computers, however, are likely to have a far different functional architecture from that of the brain; hence, we would expect that, in constructing a computational model, the mental architecture must first be emulated (that is, itself modelled) before the mental algorithm can be implemented" (ibid., p 96).

There are some obvious consequences that follows from this. The most important is that most, if not all, present day theories in computational linguistics are about computer's processing of language, and nothing else. Why then, is this important? Because we know that language use is situation dependent. Content and form differs depending on the situation in which occurs (e.g. Levinson, 1981, 1983), but also depending on the perceived qualities of the interlocutors; language directed to children is different from language directed to grownups (Phillips, 1973, Snow, 1972), as is the case with talking to foreigners, brain-injured people, and people that do not know who John Lennon was. The ability to modify the language to the perceived needs of the speaker seem to be present already at the age of four (Shatz & Gelman, 1973).

One simple but important consequence of the position outlined above is therefore that goals of research on dialogue in computational linguistics such as "Getting computers to talk like you and me" (Reichman, 1985), or developing interfaces that will "allow the user to forget that he is questioning a machine" (Gal, 1988), are not only difficult to reach. They are misconceived. We always adapt to the qualities of our dialogue partner, and there is every reason to believe that NLI-users will adapt to the fact that they are interacting with a computer.

Another important consequence is that the lan-

This research was financed by the Swedish National Board for Technical Development (STU) and the Swedish Council for Research in the Humanities and Social Sciences (HSFR). The authors names are in alphabetical order.

[1] I.e. realizing the same input-output function (N.D. & A.J.)

guage samples used for providing the empirical ground of the computational theories should come from relevant application domains for such software technology. We are therefore advocating a sub-language approach (Grishman & Kittredge, 1986) to studies of dialogue in computational linguistics, where language samples used to develop, motivate or illustrate computational theories are taken from the relevant application domains.

Finally, since the functional architecture of man and machine are different, psychological realism on the representational level is of no interest here. We therefore argue for a position of 'representational agnosticism' (Dahlbäck, 1991b).

Previous Empirical Studies

An increasing number of researchers have acted on positions similar to the one outlined above (though not necessarily with similar explicit theoretical commitments), and there is accumulating evidence in support of the theoretical assumptions presented here. One important source of information has been the use of so-called Wizard-of-Oz investigations. (For reviews, see Dahlbäck 1991b, Jönsson & Dahlbäck, 1988, and Gilbert & Fraser, 1991). A number of linguistic differences between the language used when communicating with a computer and characterizations of human dialogues have been observed: The syntactic variation is limited (Reilly, 1987). The use of pronouns is rare (Guindon, 1988 and Dahlbäck & Jönsson, 1989, Kennedy et al. 1988) and the antecedent of a pronoun is mostly found in the immediate linguistic context (Dahlbäck & Jönsson, 1989). So-called 'ill-formed input' is very frequent (Grosz, 1977, Guindon et al., 1986). A limited vocabulary seem to be sufficient for communication in restricted domains (Malhotra, 1975). In our own work we have found that indirect speech acts are rare, lack of cue phrases, abrupt dropping of topics (which creates problems for plane-based models), frequent use of domain-specific conceptual relations and, most important for our present purposes, a dialogue structure which differs from the one often found in human dialogues.

Dialogue Management for Natural Language Interfaces

Managing the dialogue in an NLI can be performed in various ways. There are today two competing approaches to dialogue management. One is the plan based approach, i.e. to reason about the user's goals and intentions using plans describing the actions which may possibly be carried out in different situations (c.f Cohen & Perrault, 1979; Allen & Perrault 1980, Litman, 1985, Carberry, 1990). The other approach is to model speech act information in a dialogue grammar.

The plan based approach is mostly used in search for a general computational model of discourse. This is a more comprehensive goal than dialogue management for natural language interfaces. (For a survey of plan based approaches see Carberry, 1990.)

Central to the plan based approach is the recognition by the listeners of the speakers goals, where goals are modelled using plans. There exists, however, today no efficient plan recognition algorithm for general "STRIPS"-like planners. Attempts have been made by adding restrictions to plans to get them more tractable. Chapman (1987) was the first to present a plan generator that could be theoretically analysed. He presented a planning algorithm that subsumed most previous planners, for instance STRIPS. Chapman showed that, under certain conditions, planning is undecidable. Bäckström & Klein (1991) showed that it is not possible to construct a polynomial-time planning algorithm for a more restricted class of problems, the SAS-PU[2] class. Furthermore, the SAS-PU class is probably too restricted for practical use in natural language processing. However, it should be noted that recent results, (Bylander, 1991) regarding the problems to be solved by polynomial planners might be a bit more optimistic. Moreover, both Bylander and Bäckström & Klein state that a careful examination of the problem might provide a polynomial planner for some problem classes, but there seems to be no single domain-independent planning algorithm.

Vilain (1990) presents a parser that can recognize plans in polynomial time using Earley's algorithm (Earley, 1970). The plan formalism used by Vilain is developed by Kautz (Kautz, 1991). Kautz developed a plan recognition formalism for recognizing plans whose types appear in an event hierarchy. Thus, he uses more restricted plans than those proposed by Allen, Cohen & Perrault, where new plans can be recognized by chaining together the preconditions and effects of other plans. Kautz maintains this restriction because otherwise ".. it would lead to massive increase in the size of the search space, since an infinite number of plans could be constructed by chaining on preconditions and effects." (Kautz, 1991, p. 72). It seems therefore that plan recognition for natural language dialogue is exponential if it is based on the STRIPS-formalism.

Another reason for our doubt concerning the use of plan recognition for dialogue management in certain natural language interface applications is that in many situations it is overkill: the interaction between a human and a computer using written language through a terminal does not include all the many difficult phenomena that arrive in human-human interaction, c.f. the previous section. Furthermore, it is difficult to correctly describe the different goals and intentions that can be carried out

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[2] SAS is a simplified version of the action structures (Sandewall & Rönnquist, 1986) where the simplification reduces the parallelism that is modelled in the action structures and is thus similar in expressiveness to that of regular planners like STRIPS. P stands for post-unique which means that one action achieves only one effect in the world; U means that it is Unary, i.e. every operator has only one effect in the world.

in a dialogue situation (Guindon 1988).

The other approach when building a dialogue manager that can efficiently handle a limited set of dialogue features is to identify adjacency-pairs (Schegloff & Sacks, 1973) and to use a dialogue grammar (e.g. Reichman, 1985 , Polanyi & Scha, 1984, Frohlich & Luff, 1990, and Bilange, 1991). This approach has been criticised for not adequately describing a naturally occurring discourse (see for instance Levinson, 1983). However, for a restricted sublanguage, such as natural language communication with computers, we believe that this can be a very efficient way of managing the dialogue (cf. Levinson, 1981, p 114).

Our work differs, however, from previous proposed dialogue grammars. Reichman and Polanyi & Scha try to manage discourse in general. Thus, they need rules to cover a wide variety of phenomena that seldom occur in interface interactions. Frohlich & Luff also present a rich grammar, basing their menu-based natural language interface grammar on studies of human-human conversations. Problems with this approach is pointed out in Dahlbäck & Jönsson (1989).

Bilange designed his system for oral communication which suggests a number of interesting differences compared to typed dialogue; for instance, his need for elaboration as the third part of an adjacency-pair, i.e. he demonstrates that the structure negotiation-reaction-elaboration is very common in oral dialogue. Stubbs' (1983) model for human dialogues also includes a third confirmatory move. This pattern seems not to occur in written human-computer communication (Dahlbäck, 1991a, b).

As for dialogue grammars, one might ask whether they are also complex, requiring exponential algorithms for parsing? The reply is that if a dialogue grammar can be written using a context-free grammar, then there are well-known polynomial-time algorithms. The question then arises as to whether it is possible to write a context-free grammar for the dialogues that we are interested in?

The Empirical Study

The dialogue model is based on the analysis of a number of dialogues collected by the means of Wizard of Oz NLI-simulations[3]. We have used five different background systems, varying not only the content domain, but also the 'intelligence' of the systems, and the number and types of tasks possible to perform by the user. The most detailed analysis has been conducted on a corpus of 21 dialogues.

We have used two database systems. PUB is a library DB in use at our department. C-line is a simulated DB containing information about the computer science curriculum at Linköping University. In the HiFi-system the user can order HiFi-equipment after having queried a (simulated) DB containing information about the available equipment. The Travel system simulates an automated travel agency offering charter holidays to Greek islands. These systems differs from the two above in two respects; the system is more 'cognitively' advanced, and there are more actions that can be performed by the user, i.e. not only asking for information but also order something. The Wine system is a simulated advisory system, capable of suggesting suitable wines for different dishes, if necessary within a specific price range. (The experimental settings are described in more detail in Jönsson & Dahlbäck, 1988, Dahlbäck & Jönsson 1989, and Dahlbäck, 1991a, b)

The total number of dialogues is 21; PUB: 4, HiFi: 5, C-line: 5, Wine: 4, Travel: 3. The total number of utterances is 1055, where we count each turn by user or system as one utterance. This gives us an average of 50 utterances/dialogue. The longest are in the travel domain, where the average dialogue is 92 utterances long, and the shortest are the PUB dialogues with an average of 25 utterances. Apart from the dialogues analysed here, we have collected more than 60 others, using four other real or simulated background systems. Dahlbäck (1991b) describes some of these in more detail. A current project has collected another set of 60 dialogues, some of which are described below.

Analysis and Results

The dialogue structure is analysed using only two basic types of moves, initiatives (I) and responses (R). The definition of the categories is only based on local information. If the move is seen as introducing a goal it is scored as an initiative, if it is a goal-satisfying move, it is scored as a response. One important reason for this is that the categories are domain independent. We can therefore compare dialogues from different domains. Another advantage is that the categories are (fairly) simple to define and identify, making it possible to code the dialogues with sufficient inter-rater reliability (97%).

Discourse management moves such as *Welcome to WingHolidays. What can we do for you?, Can I help you with anything more?* and *Bye* etc. are all scored as initiatives. We subcategorize them as DO (discourse opening), DC (discourse continuation), and DE (discourse ending), to make it possible to exclude them from some of the analysis presented below. (Responses to these kind of initiatives are optional in the model).

Since we only used local information when ascribing a category to a move, we can get a measure of the structural complexity of the dialogues by analysing them using a simple dialogue tree model called LINDA.

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[3] The model is implemented as a module for the Swedish NLI developed in the LINLIN-project. Ahrenberg, Jönsson and Dahlbäck (1990) gives an overview of the project. Dahlbäck (1989, 1991a, 1991b), Dahlbäck and Jönsson (1989), Jönsson (1990), and Jönsson and Dahlbäck (1988) presents other aspects of the empirical issues. Further aspects of the implemented system can be found in Jönsson (1991a and 1991b)

(For LINköping DiAlogue, see Dahlbäck, 1991a, b for a detailed description) The model only accepts units consisting of an initiative followed by a response or embeddings of such units in higher IR-units, e.g. (I R), or successive and recursive embeddings such as (I (I R) R), (I (I R) (I R) R), or (I (I (I R) R) R) etc. All moves must belong to some discourse segment, and no segments with the structure (I I R) or (I R R) are allowed.

We find that 92% or more of the dialogues fit this structure, see Figure 1. Furthermore, the use of recursive embeddings is limited, as seen in the high number of adjacency pairs in the dialogues.

	LINDA model fit	Adjacency pairs
PUB	100%	75%
C-line	98%	96%
HiFi	99%	98%
Travel	99%	88%
Wines	92%	78%

Figure 1: LINDA model fit.

This does not mean that the dialogues consist of a sequence of isolated questions and answers, as there is frequent use of anaphoric expressions. In fact 49% of the *initiatives* contain some kind of anaphoric expression (Dahlbäck & Jönsson, 1989). What the figures show is rather that in spite of being clear cases of connected discourse, these dialogues have a much simpler structural complexity than most other genres. It thus seems as if most man-machine dialogues in natural language, even when no restrictions on the users' way of expressing themselves, lack most of the complexity found in other types of discourse. Our corpus is admittedly of a limited size, but it covers some of the most typical possible applications for NLI technology, and, apart from the advisory type of system, is not tied to one particular topic domain. Taken together, this gives us confidence in believing that the results have some generalizability

We have also found (Dahlbäck, 1991b) that the LINDA-structure can be used to direct the search of antecedents to anaphors. It is thus not only possible to describe the dialogues using the IR tree structure, but this structure can then be used to guide further processing of the dialogue.

The LINLIN Dialogue Manager

We have developed a dialogue manager based on the LINDA-model and in this section the dialogue grammar will be presented. However, there are some notions from the LINLIN-system that needs to be presented before we can present the dialogue grammar.

We refer to the constituents of a dialogue by the name of ***dialogue objects***. The communication is hierarchically structured using three different categories of dialogue objects. There are various proposals as to the number of levels needed and they differ mainly on the modelling of complex units that consist of sequences of discourse segments, but do not comprise the whole dialogue. For instance the system developed by Polanyi & Scha (1984) uses five different levels to hierarchically structure a dialogue and LOKI (Wachtel, 1986) and SUNDIAL Bilange (1991) uses four.

The feature characterizing the intermediate level is that of having a common topic, i.e. an object whose properties are discussed over a sequence of exchanges. When analysing our dialogues we found no certain criteria concerning how to divide a dialogue into a set of exchanges. In fact, a sequence of segments may hang together in a number of different ways; e.g. by being about one object for which different properties are at issue. But it may also be the other way around, so that the same property is topical, while different objects are talked about. (This is discussed and illustrated in more detail in Ahrenberg, Jönsson and Dahlbäck (1990))

In our model the instances of dialogue objects form a dialogue tree which represent the dialogue as it develops in the interaction. The root category is called Dialogue (D), the intermediate category Initiative-Response (IR), and the smallest unit, the move.

An utterance can consist of more than one move and is thus regarded as a sequence of moves. A move object contains information about a move. They are categorized according to type of illocutionary act and topic. Some typical move types are: Question (Q), Assertion and declaration of intent (AS), Answer (A) and Directive (DI). Topic describes which knowledge source to consult — the background system, i.e. solving a task (T), the ongoing discourse (D) or the organisation of the background system (S). For brevity when we refer to a move with its associated topic, the move type is subscribed with topic, e.g. Q_T.

Following the LINDA-model, the only intermediate level consists of recursively embedded IR-units. The initiative can come from the system or the user. A typical IR-unit in a question-answer data base application is a task related question followed by a successful answer Q_T/A_T. Other typical IR-units are: Q_S/A_S for information about the system, Q_T/AS_S when the requested information is not in the data base, Q_D/A_D for questions about the ongoing dialogue, e.g. requests for clarification.

A Dialogue Grammar for the Cars Database

The dialogue manager is implemented for yet another dialogue domain; an existing INGRES-database containing information on used cars. To customize the dialogue manager to the new application, we ran a new set of Wizard of Oz-experiments. The number of dialogues is five and the average number of utterances per dialogue is 32.

The structural analysis has been carried out according to the principles described above. On the level of a move we have only identified two different illocutionary types: Question (Q) and Answer (A). The module responsible for translating the syntactic form of an utterance to these categories is called the instantiator (Ahrenberg, 1988). The instantiator will identify the illocutionary type of an utterance. So, for instance, the instantiator will interpret the utterance ***Show data for Mercedes*** as a request for information and it will thus categorize it as a question, although it's syntactic form is directive. The instantiator will not be considered further in this paper, a similar module for syntactic and semantic analysis is used by for instance Litman (1985, p 15) and Carberry (1990, p 75).

The resulting grammar is context free. It is very simple and consists merely of sequences of task-related questions followed by answers Q_T/A_T or in some cases an embedded reparation sequence Q_D/A_D, initiated by the system, see Figure 2.

$$D ::= IR^{+}$$
$$IR ::= Q_T/A_T \mid Q_x/A_S$$
$$Q_T/A_T ::= Q_T\,(Q_D/A_D)^{*}\,(A_T)$$
$$Q_D/A_D ::= Q_D\,(A_D)$$
$$Q_x/A_S ::= Q_T\,A_S \mid Q_S\,A_S \mid Q_D\,A_S$$

Figure 2. A dialogue grammar for the Cars application[4]

The grammar is not to be regarded as providing an accurate description of every database information retrieval application, but it will accurately describe the dialogue used by five different experimental subjects interacting with such a system in the domain of used cars.

The grammar presented here only shows two of the attributes of our dialogue objects. In fact, we use a number of descriptors with attributes describing for instance focused objects (Ahrenberg, Jönsson & Dahlbäck, 1990, and Jönsson, 1991a), but this does not affect the type of grammar. Furthermore, it is a simplified version of the grammar that is to be used in the Cars application. Acknowledgement phrases like *Wait...Searching* occur in all our dialogues, but they only serve to indicate that the user utterance is received. Thus they are omitted as they pose no interesting problems.

Summary

We have described a computational model of dialogue management for human-computer dialogues in natural language. The development is based on a sublanguage approach, on the belief that it is necessarily to distinguish between computational models for efficient processing of natural language and simulations of human processing of natural language, on the concern with computational tractability and empirical validity. The essential characteristics of the model is the use of a simple context-free dialogue grammar generating a dialogue structure of sequential and recursively embedded initiative-response (IR) units. It is not to be seen as a psychologically realistic cognitive model, but as a model that will successfully emulate human linguistic behaviour in the situations for which it is intended to be used, i.e. natural language interfaces.

Acknowledgements

This work on dialogue management in the LINLIN project is much inspired by the work that we have done in collaboration with Lars Ahrenberg, Åke Thurée and Mats Wirén.

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[4] The * is the closure operator meaning zero or more instances and the $^{+}$ is the positive closure denoting one or more instances. Parenthesis denote optionality and vertical bars denote disjunction.

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