Abstract

This paper presents an augmented context free grammar which describes important features of the surface structure and the semantics of discourse in a formal way, integrating new as well as previously existing insights into a unified framework. The structures covered include lists, narratives, subordinating and coordinating rhetorical relations, topic chains and interruptions. The paper discusses the problem of parsing discourse, and compares different grammatical formalisms which could be used for describing discourse structure.

1. Introduction

Though a wealth of insights on the structure and meaning of discourse has been gathered by researchers in linguistics, psychology, ethnomethodology and artificial intelligence, these insights have not been integrated into formal grammars which display the breadth, depth and precision of formal treatments of sentential syntax and semantics. In the present paper we make a step towards a formal, integrated description of the surface structure and semantic interpretation of discourse. We introduce a formalism which uses augmented context free rules for specifying discourse grammars, and demonstrate its viability by developing a set of syntactic/semantic rules which covers a number of important discourse phenomena. We discuss the issue of parsing discourse in a semi-deterministic left-to-right fashion, and relate the grammar presented here to the strategies outlined in [24] [25] for building up a structural description of an unfolding discourse. Finally, we compare the formalism used here to some possible alternatives.

2. Discourse Structure and Discourse Semantics

The semantic interpretation of the utterances in a discourse has been shown to depend on the structural relations obtaining among the segments of discourse. In developing a grammar for the discourse, these variables are bound to values picked up from the context into which the sentence is inserted. The next section describes this in more detail.

3. An Augmented Context Free Grammar for Discourse

Discourses have a hierarchical structure. They are built up recursively out of units of various kinds which can occur as constituents of each other. To account for this, a discourse grammar must be able to assign a tree structure to a discourse. We call this tree structure the discourse parse tree. To describe in formal way how a discourse parse tree is constructed out of constituent sentences, we use a context free grammar whose non-terminal symbols are augmented with attribute/value pairs. (Distinct non-terminal categories have distinct sets of attributes.) Context free rules describe how the constituent segments of a discourse (which we call discourse constituent units or dcu) are built up out of their subconstituents. The values of the attributes on a non-terminal represent the relevant structural and semantic properties of the dcu generated by that non-terminal. Every attribute has a fixed set of possible value-expressions. The value-expressions may be of different kinds: they may be atomic, they may themselves be sets of attribute/value pairs, or they may be logical expressions.

The context-free rules enforce agreement and upwards-inheritance of the relevant properties of different constituents through the fact that different occurrences of the same variable take on identical values. To put this in more precise terms, we define the meaning of an augmented context free rule as follows. If A, B, C, Y, Z stand for complex category symbols, then <B,C> and <Y,Z> are legitimate complex category symbols (including attribute/value-expression pairs) and G(A) is a legitimate complex category which is a pair consisting of (1) the linguistic expression of accessible dcu’s.

The Rhetorical Structure of Discourse

The insight of work focused on the rhetorical structure of discourse is that a speaker engaged in a discourse may perform speech acts whose illocutionary force has scope over complex propositions which are built up out of individual sentence meanings and the rhetorical relations between them. (See, for example, [13], [19], and [20]). These rhetorical relations may be overtly expressed, or they may have to be abduced on the basis of the sentence meanings. Paradigmatic examples of such complex propositions are “A caused B”, “A was caused by B”, “A provides evidence for B”, etc. – where A and B may stand for propositions expressed by individual sentences, or may themselves be complex propositions expressed by discourse segments. Because of the latter case, a correct constituent analysis of the discourse is necessary to establish the arguments of the rhetorical relations. On the other hand, the rhetorical relations themselves constitute an important structuring component of discourse.

In the approach to discourse semantics outlined in this paper, every sentence is initially interpreted in a local, context-independent fashion. This results in a meaning representation which will usually contain free variables, standing for the discourse-dependent elements in the utterance meaning. When a sentence is integrated into the ongoing discourse, these variables are bound to values picked up from the context into which the sentence is inserted. The next section describes this in more detail.

3.1. Attribute Values and Semantic Interpretation

The propagation of attribute values between dcu’s plays an important part in establishing the semantic interpretation of the utterances in a discourse. We now list some of these attributes, and discuss their role in semantic interpretation and discourse processing.

The Semantics attribute records the most general unfolding of the terms <B,C> and <Y,Z>, and c(A) is a legitimate complex category symbol, not containing empty attribute-value expressions.

The Referents Set records the entities introduced in the discourse unit that it is associated with. These, plus the entities in the Referent Sets of the embedding units (dominating nodes in the tree) are the entities which are available for anaphoric reference in an utterance which extends or expands that discourse unit. Every Discourse Referent is a pair consisting of (1) the linguistic expression that introduced it, and (2) the semantic representation that the system attached to that expression. Discourse Referent Sets are accessed in different ways by a number of algorithms, which resolve the meanings of
different types of context-dependent expressions such as definite descriptions, anaphoric pronouns, demonstrative pronouns, the words "for" and "one", and implicit arguments of function nouns, comparatives, etc.

The Reference-Time records the time-interval which is to serve as the temporal index for extensions and expansions of the discourse unit under consideration. The Reference-Time can be reset by the occurrence of explicit temporal adverbs. Narratives constitute a specific type of discourse units in which time plays a special role; they are marked by the occurrence of sentences with non-durative aspect (event-sentences). In a narrative, the reference-time is reset whenever an event occurs. [15][12]

The Spatial Index and the Modal Index play a role in the semantic interpretation of the utterances which is similar to the role of the Reference-Time: they specify a value for components of the index of evaluation of the semantic formula. In English, they can be indicated by the occurrence of spatial and modal adverbials or other similarly explicit information.

In the next section we describe the rules of a discourse grammar. They use some other attributes besides the ones just mentioned. These can be most easily explained as we introduce the rules that use them.

3.2. Grammar Rules

The grammar we present here, though necessarily limited and schematic in many ways, covers a wide range of phenomena that are usually discussed separately. An adequate account of discourse structure, however, depends on their integration into a consistent mechanism. The semantic phenomena that we pay attention to include anaphor resolution, scope of modal indices, movement of reference time, and rhetorical relations. The grammar consists of rules which describe how to build up various kinds of structurally different discourse constituent units. We distinguish the following kinds of dcu's:

- **Subordinations.** These are binary structures in which the first element remains accessible; we view them as units in which all or most of the structurally relevant features are inherited from the left constituent. (In discourse, unlike in the sentence, the subordinating element is always to the left of the subordinated one.) In semantic subordinations there is a semantic relation between the two constituents; this is the case in rhetorical subordinations and in topic-dominant chains. Interruptions, on the other hand, though structurally analogous, are semantically very different: in this case, there is no semantic connection whatsoever between the two constituents.

- **Binary Coordinations.** These are binary structures in which the second element has equal status to the first, thus making the first one inaccessible. Under this category we include rhetorical coordinations (the counterparts of the rhetorical subordinations), and adjacency pairs which are concerned with the interactional dimension of the discourse (we include question-answer pairs and request-response pairs).

- **N-ary Coordinations.** These are flat structures which can contain arbitrarily many elements, of which, at any time, only the most recent one is accessible. We include lists, monotonic lists, and narratives. To generate n-ary coordinations by means of a context free grammar, we must assign them a recursive structure: we build them up by means of binary rules which extend them to the right.

This classification is not necessarily complete, and should be the topic of more extensive discussion. But it does cover the most important structures, and brings some order into the grammar rules that we present below.

**Notation:** Category symbols have the form "cat [~t:o~t

1 The intuitive idea behind this rule is that if two adjacent dcu's can be analysed as having semantically parallel structures, they can be conjoined in a list structure. Note that there is no constraint on the category of the dcu's: the main category symbols in the right hand side of the rule are variables.

The formal criterion for the application of the rule is the existence of a semantic representation of the dcu already has the structure s(u), or can be put in that form by means of a very limited repertoire of logical equivalence transformations. (The repertoire needs to be specified in detail. It will probably at least include \( \lambda \)-abstraction.) This restriction excludes undesirable trivial values of s such as \( \lambda u.1 \) if \( u = \text{SEM1 then SEM1 else SEM2} \). The types of the \( \lambda \)-variables of \( s \) are required to be elements in a predefined hierarchy of "natural kinds" which classifies the meanings of topical entries. The value of \( s \), representing the common denominator between the meanings of the two constituents, is stored as the value of the "schema" attribute on the list-dcu.

Note that this rule often creates ambiguity. To take a simple example: if "John likes Mary" is followed by "Peter likes Mary," one can abstract out several different schema's, even without considering different choices for the types of \( \lambda \)-variables. \( \lambda P: \text{P(MARY)} \), or \( \lambda \; x: \; \text{R(x, MARY)} \), or \( \lambda \; x: \; \text{LIKE(x, MARY)} \), or \( \lambda x: \; \text{LIKE(x, MARY)} \). The last of these is the preferred one, because it is most specific. Rather than constraining the grammar rule to apply only in the most specific way to every case, we assume that a preference for the most specific rule-application is applied as a heuristic principle during the parsing process.

The "sem" attribute stores the semantics of a dcu. The operation of the \( \& \)-operator which is used here to build up the semantics is more general than logical conjunction: its arguments can have different types and have different illocutionary force operators. The semantic representation built up by \( \& \) stores the propositional content of individual utterances in a richly indexed data structure. We shall not attempt to specify this data structure in detail in the present paper. We intend that for the case of purely assertional monologues, the operation of \( \& \) reduces to logical conjunction. (The movement of reference time, for instance, will therefore not be hidden inside the meaning.

Note that the notion of "list" that we use here is more general than the one we have used in previous discussions [23]. For instance, this notion of "list" subsumes the notion of a "topic chain".

In the formula stored as the value of the "sem"-attribute of a dcu, typed free variables are used to represent unresolved anaphors, such as pronouns and disambiguated definite descriptions. The unification process which matches the "sem"-attributes of two dcu's when they are joined to constitute a list may substitute expressions for these variables and thus resolve the anaphoric references. Thus, some strong reference resolution preferences are explained as following directly from the acknowledgement of parallel structure; in this case, anaphoric elements get resolved without any search through the space of available discourse referents. This accounts for anaphoric reference to topic or attentional focus [32], as well as anaphoric reference to the corresponding element in a semantically parallel structure.

To accumulate the appropriate candidates for further anaphor resolution processes, the discourse referents (values of the "drs" attribute) of both constituent dcu's are synthesized into the discourse referent list of the list-dcu.

To extend a list-dcu to become a list with one more element, there is the following additional rule:

\[
\begin{align*}
\text{list} & \equiv \text{list} \cup \text{drs}, \text{sem}: p \land s(y) \\
\text{drsl} & \equiv \text{list}, \text{drsl}, \text{sem}: p \land s(y) \\
\text{dcu} & \equiv \text{drs}, \text{drsl}, \text{sem}: s(y) \\
\end{align*}
\]

A list can be extended by another dcu if this dcu instantiates the structure described by the schema-attribute of the list.

**Monotonic Lists:**

\[
\begin{align*}
\text{m-list} & \equiv \text{schema:s, drs} \equiv \text{drsl1} \cup \text{drsl2}, \text{sem: p & s(y)} \\
\text{drsl1} & \equiv \text{drs1, drsl2}, \text{sem: p(y)} \\
\text{drsl2} & \equiv \text{drs2, drsl1}, \text{sem: s(y)} \\
\end{align*}
\]

A list can be extended by another dcu if this dcu instantiates the structure described by the schema-attribute of the list.

\[
\begin{align*}
\text{m-list} & \equiv \text{schema:s, drs} \equiv \text{drsl1} \cup \text{drsl2}, \text{sem: p & s(y)} \\
\text{drsl1} & \equiv \text{drs1, drsl2}, \text{sem: p(y)} \\
\text{drsl2} & \equiv \text{drs2, drsl1}, \text{sem: s(y)} \\
\end{align*}
\]

2 The \( \lambda \)-function takes more than one argument, we view it as working on \( n \)-tuples, the values of \( x \) and \( y \) are \( n \)-tuples in this case.
If in a list the various arguments of the "schema"-function are elements of a linearly ordered domain, the list may be a monotonic list. To make it possible to ascertain whether a next dcu can be added to a monotonic list, such lists carry the value of the most recent argument ("last"-attribute), and their "direction" ("increasing" or "decreasing"). ("Tail" is a special constant which is not allowed as an attribute value-expression.)

m-list [schema,m, drs: dcu1 u dcu2, direction: (if x > y then incr else decr), 
lasty: s(y)] => m-list [schema,m, drs: dcu1, incr: p, lastx: sem(x)]

dcu [drs:dcu2; sem: s(y) x < y d]

A monotonic list can be extended by another dcu which instantiates the structure described by its schema-attribute, provided that the increasing or decreasing ordering is maintained. (Monotonic lists are discussed in [24].)

Rhetorical coordinations:

| Rhetorical coordinations: | (push-marker) |
|---------------------------|--------------|
| Rhetorical coordinations: | (pop-marker) |

This rule parses semantic subordinations for which the rhetorical relation involved is not overtly marked. The variable F ranges over all subordinating rhetorical relations. Since its value is not stated explicitly, it must be abduced on the basis of plausibility considerations regarding the resulting semantics. The subordinated constituent is optionally preceded by a push-marker (e.g. "like"), and optionally followed by a pop-marker.

For subordinations we need a more elaborate treatment of semantics than the one assumed in this paper. We need to distinguish between the total accumulated meaning of a discourse constituent unit and its "core meaning", which is considered in computations regarding semantic relations with other dcus. It is a characteristic property of subordination dcus's that they allow for interpretations in which the core meaning is identical to the core meaning of the subordinating constituent, without any contribution from the subordinated constituent. To represent this, we would need to assume at least two different "sem" attributes, or a more complicated structure for the value of the "sem" attribute.

Rhetorical coordinations:

| Rhetorical coordinations: | (push-marker) |
|---------------------------|--------------|
| Rhetorical coordinations: | (pop-marker) |

This rule parses semantic subordinations which involve an explicitly indicated binary coordinating rhetorical relation R ("therefore", "thus", "accordingly"). <Ref. Mann, Talmy> As in the subordination case described before, the meaning of the relation is incorporated in the semantics of the clause in which it occurs, which therefore denotes a predicate on propositions.

The function "mscg" computes the 'most specific common generalization' of its arguments in the hierarchy of value-expressions of the relevant attribute. (When there is no proper hierarchy defined on the value-expressions of an attribute, mscg degenerates into a function which yields the value of its arguments when the two arguments are equal and which yields a new free variable when they are not.)

This rule parses binary semantic coordinations which are not overtly marked as such. Therefore, the semantics of the second dcu is a proposition rather than a predicate on propositions. The variable F ranges over all binary coordinating rhetorical relations. As in the corresponding subordination case, the value of F must be computed by abduction, magic, or a similar A.I. technique.

**Topic-dominant chaining:**

| Topic-dominant chaining: | (push-marker) |
|--------------------------|--------------|
| Topic-dominant chaining: | (pop-marker) |

This rule parses semantic subordinations which involve an explicitly indicated subordinating rhetorical relation R ("for instance," "because"). The meaning of this relation is assumed to be incorporated in the semantics of the subordinated dcu; this dcu therefore has as a value of its "sem"-attribute a k-function which expresses a propositional argument. The attributes and values of a subordination are inherited from the subordinating constituent.

The subordinated constituent is optionally followed by a pop-marker (e.g. "so", "anyway"). All clue-words (push-markers, pop-markers, interruption-markers) are treated as independent units, separate from the sentences that they precede or follow.

In the formulation of the semantic subordination rule we have assumed an attribute called "index", containing reference time as well as spatial and modal index. The rule shows how the subordinated discourse constituent unit is semantically contextualized by the subordinating one.

**Top-down chaining:**

| Top-down chaining: | (push-marker) |
|--------------------|--------------|
| Top-down chaining: | (pop-marker) |

This rule parses semantic subordinations for which a next dcu can be added to a monotonic list. A monotonic list which extends a narrative is evaluated at an interval v after u. (Notation: a <i b means "a immediately precedes b").

The value of the "tense" attribute on a narrative dcu marks the reference-time of the narrative, depends on its reference-time, t of the narrative. The new accomplishments of successive events are always separated by a time-gap (though nothing is said about the size of this time-gap).

The above rules only define how to extend a narrative that is already underway. The rules for beginning a narrative are similar have been omitted for reasons of space.

Rhetorical subordinations:

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4Formulated in terms of Vendler's [34] classification, durative dcus describe accomplishments or achievements, while non-durative ones describe states or activities.

5To enhance the legibility of the rules, we will from now on leave out the description of the subordinating dcus's subordinating constituents. This occurs uniformly in the same way as in the rules given below.
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**Notes:**

- Formulated in terms of Vendler's [34] classification, durative dcus describe accomplishments or achievements, while non-durative ones describe states or activities.
- To enhance the legibility of the rules, we will from now on leave out the description of the subordinating dcus's subordinating constituents. This occurs uniformly in the same way as in the rules given below.
reertoire of logical transformations can be used to achieve this formulation, starting from formulas which correspond directly to the surface structure of the dcu’s. These limitations are to be defined in such a way that the possible values of y correspond to the constituents eligible for dominance in [8], or the forward-looking centers of [9].

The heuristics of the parsing process prefers applying rules for constructing list-structures to the rule for topic-dominant chaining. (Cf. [3].)

Adjacency Pairs:

\( \text{QA: [sem: a/b]} \)
\( \rightarrow \text{dcu} \{ \text{[mode: interrogative, sem: b]} \}
\)
\( \text{dcu} \{ \text{[sem: a/b]} \}
\)
\( \text{[pop-marker]} \)

This rule parses question/answer pairs. The semantics of a yes/no question is assumed to be a proposition; the semantics of a wh-question is assumed to be a set-denoting expression (cf. [31]). The semantics of an answer is a predicate on the question-semantics.

\( \text{RR: [sem: a/b]} \)
\( \rightarrow \text{dcu} \{ \text{[mode: request, speaker:p1, addressee:p2, sem:b]} \}
\)
\( \text{dcu} \{ \text{[speaker:p2, addressee:p1, sem:a/b]} \}
\)
\( \text{[pop-marker]} \)

This rule parses request/response pairs. Semantically, these are very similar to question/answer pairs. We have chosen to exclude "rhetorical requests" by requiring the speaker/addressee relation to flip between request and response.

Interruptions:

\( \text{dcu} \{ \text{[a]} \}
\)
\( \rightarrow \text{dcu} \{ \text{[x]} \}
\)
\( \text{[interruption-marker]} \)
\( \text{dcu} \{ \text{[y]} \}
\)
\( \text{[pop-marker]} \)

This rule allows for semantically unrelated interruptions of an ongoing discourse (cf. [26]) (10). Interruptions may be introduced by specific markers such as "Ooh!".

4. Discourse Parsing

We consider the development of a formal grammar of discourse structure, such as the one sketched in the previous section, to be the first step towards a formal account of the process of discourse parsing. We now briefly review some of the issues that would be involved in such an account.

The most important issue in discourse parsing is the necessity of semi-determinism. Spontaneous dialogue involves unpremeditated turn-taking and interruption. In order for this to be possible, there must regularly be points in an interaction at which the interpretation of utterances so far is mutually established as independent of the discourse which is to follow. Moreover, an unanticipated next utterance can intervene in a mutually understood way on the structure of the discourse so far (for instance, by abandoning a digression to pop to a previously interrupted dcu). Therefore, at points where such a move is allowed, there must also be mutual agreement on the structure of the discourse so far.

The granularity of this "unpredictability without misunderstanding" seems to be the clause or sentence level. We therefore postulate an incremental left-to-right parsing process at this level of granularity, which operates in essentially deterministic mode. In [24] we gave an informal description of such a parsing process, which processes every incoming sentence incrementally, extending an existing discourse tree to the right by node insertion. An important assumption of the parsing process as described there, is that at any point it only uses information on the right edge of the existing discourse tree. This means that the processors just need to be aware of the stock of information which corresponds to the labels on the right edge of the tree, rather than the complete details of the discourse that went before.

The inspection of the grammar rules in the previous section suggests that this grammar is compatible with the parsing strategy outlined in [24]: relevant information is always propagated up to the right edge of the tree, and dcu interpretations get propagated up without being influenced by the nature of the intervening nodes.

5. Formalisms for Discourse Grammar

The augmented context free grammar developed above should be taken as a demonstration of the possibility and utility of formal grammars for describing structural and semantic phenomena in natural language discourse. We expect that work of this kind, especially if carried out on a larger scale, will constitute a more fruitful path to new insights than approaches which are oriented towards essayistic description or unprincipled implementation.

We should not make exaggerated claims concerning the formalism we have used here. Much more work is needed before it will be clear what kind of formal framework has the best fit with the phenomena. But it is probably useful to articulate our thoughts on how the augmented context free grammar formalism compares to other formalisms that could have been used in this work.

The formalism we have used is a context free grammar augmented with attributes, which propagates feature values through term unification on value-expressions containing variables. Similar formalisms have been used for sentence-level syntax. The closest is the ACFG formalism used for the grammar of BBN’s Spoken Language System’[11] [2], which main differs in assuming a more limited syntax of attribute value expressions. Definite Clause Grammars [21], if decoupled from their commitment to Prolog programming, are also very similar.

Generalized Phrase Structure Grammar [7], as well as related theories such as HPN and LFG, share many aspects of our approach: an emphasis on context free surface structure, and the use of a unification process to enforce the desired agreement and inheritance behaviour on the values of attributes. However, these formalisms use unification on graphs rather than logical term-expressions. This probably creates additional expressive power, but it goes at the cost of ease of implementation and of conceptual clarity.

It is a major advantage of logical term unification that there is an obvious and simple semantics for it: any object which may contain variables, be it an attribute value-expression, can be viewed as an abbreviation for the set of its ground instances; applying the most general unifier to a set of terms yields a term standing for the intersection of the sets of their ground instances. Compared to the conceptual and computational simplicity of logical term unification, the graph unification formalisms used in modern linguistic frameworks are rather cumbersome. There do not seem to be good linguistic reasons for preferring graph unification.

An interesting perspective on the kind of grammar we have used follows from the realization that it can be viewed as a particular instance of an attribute grammar as defined by Knuth [16]: one in which the values of the attributes on a node are always synthesized from the values on the nodes of its immediate constituents. This raises the question whether one might want to formulate this directional dependency explicitly in an attribute grammar notation. More interestingly, it raises the question whether there are phenomena that could be more elegantly described as inheritance from a top node to its constituents, rather than the other way around. We expect such phenomena to occur if we would want to integrate more global constraints, related to people’s tasks, goals and plans, into our description of discourse.

Finally, we want to reflect on the Augmented Transition Network formulation of discourse structure that we used in previous, more informal papers [23]. ATNs do have some properties which are attractive for discourse. A looping arc which updates a register constitutes a powerful device that doesn’t have a direct equivalent in other formalisms. In the current grammar we emulate the effect of such an arc by a recursive binary structure: lists and narratives are built up by repeated extension to the right. Intuitively, one sees lists and narratives as flat structures, and we have described them in those terms in previous papers [24]. The power of ATNs thus makes it possible to account more directly for the structures that seem plausible.

The framework used in the present paper is conceptually simple, and more limited than any of its alternatives. Nevertheless, it seems powerful enough to describe the phenomena we encountered in developing the grammar presented here. Subsequent research will have to answer the question whether it is ultimately powerful enough to describe the full range of discourse phenomena in a felicitous way.

In the present discussion we have ignored what in previous work we have called the level of speech event structure, which is concerned with the structure of discourse as a social activity. [22] [23] By the same token, we have left unaddressed the fact that discourse structures may reflect the tasks, goals and plans of the discourse participants, as they would be constructed in a A.I. based approach to discourse analysis. Observations reported in [38] show (1) that speech event structure and linguistic discourse structure may be at odds with each other, and (2) that the linguistic discourse structure has the most direct semantic relevance in such cases. Though speech event structure and task structure have in fact considerable semantic relevance and must ultimately be factored in, we want to hold off on dealing with the complexities involved in this issue.

The grammar presented in this paper provides a formal characterization of Discourse Parse Trees by means of the bottom-up rules used in its construction. The problem of mating these bottom-up rules with necessary high-level, top-down rules involving phenomena occurring in the task domain or interaction is essentially the problem of plan-recognition. In an operational system, the functionality of a linguistically based discourse parser would thus be very much enhanced by an efficient Plan Recognizer of the type envisioned in "plan based" and "intention based" pragmatic discourse models. On the other hand, incorporating a discourse grammar would improve the
functionality of existing plan based models, which lack explicit mechanisms for relating sentential syntax and semantics to pragmatic plan structures.

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