gefördert vom
Bundesministerium
für Forschung
und Technologie

Verbmobil
Verbundvorhaben

A Compositional DRS-based Formalism for NLP Applications

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Vm
Report 59
December 1994

December 1994

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Gehört zum Antragsabschnitt: 8.1

Das diesem Bericht zugrundeliegende Forschungsvorhaben wurde mit Mitteln des Bundesministers für Forschung und Technologie unter dem Förderkennzeichen 01 IV 101 R gefördert. Die Verantwortung für den Inhalt dieser Arbeit liegt bei dem Autor.

Abstract

This paper describes and discusses the formalism which forms the backbone of semantic processing in the VERBMOBIL spoken dialogue translation project. In the first part, the theoretical core of the formalism is presented: λ-DRT, a compositional version of Discourse Representation Theory. The main part describes the implementation of λ-DRT, as a worked out semantic representation language for the Verbmobil project, which is designed to meet the special requirements of the application. Finally, we discuss future extensions and modifications of the formalism.

Thanks

We would like to thank Chris Fox and our colleagues in the VERBMOBIL project, especially those in the semantics, dialogue and translation workpackages. The authors are solely responsible for the views expressed in this paper.

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1 λ-DRT

It has been recognized that formalisms for semantic construction which are denotationally interpreted, declarative, and compositional bear considerable methodological advantages over construction methods which lack these properties. At the same time, it has become clear that the available standard formalism for NL semantics which provides all these properties, i.e., Montague's Intensional Logic, is an inappropriate tool for several reasons, especially since it does not support semantic processing of texts and dialogues.

Various proposals have been made to address this problem. The most important among these are Discourse Representation Theory (DRT, Kamp, 1981; Kamp and Reyle, 1993) and the family of dynamic semantic approaches, among them Dynamic Predicate Logic (DPL) and Dynamic Montague Grammar (DMG) (Groenendijk and Stokhof, 1991; Groenendijk and Stokhof, 1990). DRT employs an independent representational level with Discourse Representation Structures (DRSs) and DRS Construction Rules, which is anchored in a denotational (FOL model-theoretic) semantics on the level of propositions ('weak interpretability'), and at the same time provides additional means to model context-dependent interpretation and context change. In its standard version (Kamp/Reyle), it does so, however, at the cost of declarativity and compositionality.

Dynamic semantics has been proposed as an alternative, which combines the advantages of the DRT approach with the desirable theoretical properties of intensional logic. The representations are more or less the standard predicate-logic or type-theoretic ones (which are eliminable in the sense of Montague's program). Contextual processing — as well as the truth-conditional aspect — is modelled in terms of a non-standard dynamic interpretation concept, where expressions can globally change assignment functions.

λ-DRT is a formalism which also combines basic features of DRT and Montague-style Extended Type Theory (Millies and Pinkal, 1993). In λ-DRT, the combination is on the level of representation rather than of denotational interpretation. The essential idea is to take DRSs (pairs of a set of discourse markers and a set of conditions) as basic meaning representation structures for any type of expression (except individual variables), and to derive representations of complex types by allowing λ-abstraction over DRSs. An additional ingredient in the language of λ-DRT is the merge operation $\otimes$, which combines two DRSs by taking the union of the sets of discourse markers and conditions separately, i.e.

(1) $$< \mathbf{D}_1, \mathbf{C}_1 > \otimes < \mathbf{D}_2, \mathbf{C}_2 > =_D$$
$$< \mathbf{D}_1 \cup \mathbf{D}_2, \mathbf{C}_1 \cup \mathbf{C}_2 >$$

The lexical representation of the indefinite determiner *a* in Figure 1 shows an example of this.

a'	$= \lambda P \lambda Q. < \{x\}, \{\} > \otimes P(x) \otimes Q(x)$
$date'$	$= \lambda y. < \{\}, \{date(y)\} >$
$a' \odot date'$	$= \lambda Q. < \{x\}, \{date(x)\} > \otimes Q(x)$
$fixes'$	$= \lambda y \lambda z. < \{\}, \{fix(z, y)\} >$
$(a' \odot date') \odot fixes'$	$= \lambda z. < \{x\}, \{date(x), fix(z, x)\} >$
$Brown'$	$= \lambda P. < \{z\}, \{z = b^*\} > \otimes P(z)$
$Brown' \odot ((a' \odot date') \odot fixes')$	$=< \{x, z\}, \{date(x), fix(z, x), z = b^*\} >$

Figure 1: Derivation of *Brown fixes a date*

From the outside, λ-DRT is just like standard Extended Type Theory. We can arrive at representations for complex expressions by employing Functional Application as basic composition operation, possibly followed by a sequence of β-reduction steps. To provide a more flexible composition mechanism which allows semantic construction to adhere more closely to the structures derived in many syntactic theories, we do in fact use functional composition as the basic operation. It is indicated by '$\odot$': [1]

(2) Functional Composition

$$\phi \odot \psi =_D \lambda \vec{\sigma}. \phi(\lambda \nu.(\psi(\nu)(\vec{\sigma})))$$

We call ϕ the 'functor' and ψ the 'argument' of the operation. Note that this rule is a non-standard version of functional composition. It differs in several properties from the rule $\lambda \nu. \phi(\psi(\nu))$ called 'functional composition' in categorial grammar (Steedman, 1985). First, it always binds the first argument position of the argument, instead of forming a sentence with an abstraction over that position. Second, there is no ψ with $\phi \odot \psi = \phi$ or $\psi \odot \phi = \phi$ for any ϕ. Finally, it has functional application as a special case.

Another operation, quantifier storage, is used in the manner of Nested Cooper Storage (Keller, 1988) to delay the applications of quantifiers in order to give them potentially wide scope. Quantifiers are stored on a list. The scopings of the quantifiers on this list are not specified. Putting a new quantifier on the list involves saturating an argument position in the scope with the quantifier's 'referential index', i.e. the variable which the quantifier is eventually going to bind[2].

[1] For an n-place predicate β, $\vec{\alpha}$ denotes a sequence of terms $\alpha_n \ldots \alpha_1$, such that $\beta(\alpha_n) \ldots (\alpha_1)$ is a proposition. In (2) above, $\psi(\nu)(\vec{\sigma})$ therefore is a proposition.

[2] We do not introduce a special notation for storage, but allow this operation as an alternative to $\odot$

We show in Figure 1 a short example derivation for the sentence (3) which makes use of functional composition, β-reduction and $\otimes$-evaluation.

(3) Brown fixes a date

The λ-DRT formula for the indefinite article *a* is much like its Montagovian analogue, where $\otimes$ corresponds to conjunction in predicate logic and the introduction of a discourse marker will lead to an existential interpretation of the variable. The '$\otimes$'-operator can be evaluated as soon as its arguments are instantiated. Note also that using (2) we do not need to type-raise transitive verbs. The abstraction over the verb's external argument is appended in front of the expression by the composition rule when the object applies to the verb.

λ-DRT, like DRT, is able to treat contextual connections, and at the same time it is interpreted on the propositional level. As standard extended type theory, it is declarative and compositional. A semantics, which guarantees full compositionality on the denotational level, and correctness of β-reduction, will be given along the lines of Muskens (Muskens, 1993)[3]. The main difference to Muskens style of interpretation is the commutativity of $\otimes$ (cf. (1)). However, we believe that also having a level of DRS-representation available confers a *methodological* advantage over, say, dynamic semantics, because it is more transparent and more intuitively accessible. There is a division of labor between the DRS level on which anaphoric potential and anaphoric relations are encoded, and the model-theoretic level which keeps track of propositional information. This makes the approach much more flexible and easier to modify (see Section 3).

2 The VERBMOBIL Core Semantic Formalism

λ-DRT has been employed in several NLP systems (Millies, 1993; Fischer, 1993). In the rest of the paper, we describe its implementation in the VERBMOBIL system.

In the VERBMOBIL project, the domain is translation in face-to-face dialogues. The VERBMOBIL system will provide translation for negotiation of business appointments between German and Japanese users who have only a passive knowledge of English. The system is composed of components which perform acoustic, syntactic and semantic analysis, transfer, dialogue processing and generation.

To ensure compatibility with the grammar component, a unification-based representation of the formalism is used. As in many contemporary grammar theories, such as

whenever the types match.

[3]Muskens employs a representational formalism similar to ours. We will also employ the interpretation concept of Zeevat (Zeevat, 1989).

HPSG and UCG, different levels of linguistic information are encapsulated in a single, structured unit, the *sign* (Calder et al., 1988; Pollard and Sag, 1994).

(4)
$$
{}_{\text{SIGN}}\begin{bmatrix} \textit{phon:}\ \textsc{phon} \\ \textit{syn:}\ \textsc{syn} \\ \textit{sem:}\ \textsc{sem} \\ \textit{prag:}\ \textsc{prag} \\ \textit{dtrs:}\ \textsc{dtrs} \end{bmatrix}
$$

In the following, we define and discuss the syntax of the core part of the semantic formalism. The definitions are given as typed feature structures where a type is indicated by capitals. We use the notation *listof()* to indicate that an instance must be a list of objects of the type given in parentheses. In many cases this is used to represent a set of elements.

In addition to the levels of phonological, syntactic and semantic information, our definition of a sign includes a representation of the syntactic 'daughters' and a 'pragmatic' level where the latter can specify, for example, whether the expression contains a performative verb (e.g. *vorschlagen*) or a discourse cue phrase (e.g. *nein*).

Of primary interest is the definition of the semantic level in the sign:

(5)
$$
{}_{\text{SEM}}\begin{bmatrix} \textit{lambda: listof(}\textsc{lambda\_elem}\textit{)} \\ \textit{drs:}\ \textsc{drs} \\ \textit{quants: listof(}\textsc{sem}\textit{)} \\ \textit{anchors: listof(}\textsc{anchor}\textit{)} \end{bmatrix}
$$

The *drs*, *lambda*, and *quants* feature implement λ-DRT as it has been described in the previous section. In addition, an 'anchors' list is used to represent deictic information.

The lambda list, expressing the semantic requirements of a sign, allows us to adopt the compositional approach to DRS construction based on syntactic structure, whilst retaining flexibility over the precise relationship between syntactic and semantic construction processes. Each semantic requirement *can* be correlated with the subcategorization requirements of the grammar. This approach is more flexible than the conventional approach — where semantic requirements are part of the grammatical subcategorization requirements — since there need not be a one-to-one mapping between semantic and syntactic requirements. For example, quantifiers such as *jeder* require two 'arguments' — a restriction and a scope — while there are no corresponding syntactic arguments; expletives, which make no semantic contribution, are subcategorized in some syntactic theories; certain variables which have to be bound in semantics may play no role in syntax etc.

We want to be able to represent semantic objects which take arguments of non-basic type, e.g. generalized quantifiers. The ability to represent raised types like this gives us sufficient independence from the syntactic representation of functor argument relations to provide compositional, intuitively simple and unified treatments of several difficult semantic phenomena. In the framework of a unification-based language we cannot express these types directly. However, we can represent them by allowing that the elements on a lambda-list be either basic or complex semantic objects:

(6) LAMBDA_ELEM ::= NAMED_VAR | SEM

A simple semantic object is a named variable composed of an identifier and associated sort information.

(7) $$_{\text{NAMED\_VAR}}\begin{bmatrix} \textit{ident: } \text{IDENTIFIER} \\ \textit{sort: } \text{SORT} \end{bmatrix}$$

(8) SORT ::= individual | time | event | ...

Variables bear the *ident* feature, which identifies them by a unique constant of the meta-language, because it is often necessary to establish the identity or non-identity of variables, e.g. in anaphora resolution or when looking up the information associated with variables in MARKER structures (discussed below). In addition, the sortal type of each variable is given as the value of an additional feature.

Before discussing the main component of the semantic level, the DRS, we briefly comment on the nature of anchors.

(9) $$_{\text{ANCHOR}}\begin{bmatrix} \textit{param: } \text{NAMED\_VAR} \\ \textit{discourse\_role: } \text{DISCOURSE\_ROLE} \\ \textit{constant: @domain\_model} \end{bmatrix}$$

(10) DISCOURSE_ROLE ::= speaker | hearer | ...

The main purpose of an anchor is to link a discourse marker introduced by a deictic expression (indicated by the *named_var*) to a constant in the dialogue model which performs the discourse role.

The main component in the semantics is a DRS defined as a domain of discourse markers, and a list of conditions on these markers.

(11) $$_{\text{DRS}}\begin{bmatrix} \textit{dom: listof(}\text{MARKER}\textit{)} \\ \textit{conds: listof(}\text{CONDITION}\textit{)} \end{bmatrix}$$

A discourse marker is defined as a complex structure: a named variable, a domain concept, and agreement information.

(12) $$_{\text{MARKER}}\begin{bmatrix} \textit{ref:}\ \text{NAMED\_VAR} \\ \textit{ref\_concept:}\ \textit{@domain\_model} \\ \textit{ref\_agr:}\ \text{SYNSEM\_AGR} \end{bmatrix}$$

The *ref_concept*, like several other features of the representation (e.g., *pred_concept*), is used for adding domain information about referents and predicates in the course of evaluation. Its context and relation to the core semantic information is controlled by the semantic evaluation component. The SYNSEM_AGR type specifies agreement information required for reference resolution. Minimally, this includes syntactic agreement information defined by the grammar. It can be extended to include semantic agreement information, such as the individual-collective distinction, if required for reference resolution.

Conditions on markers can be either basic or complex. A basic condition is represented as an n-place predicate, together with a concept in the domain model.

(13) $$_{\text{BASIC\_COND}}\begin{bmatrix} \textit{pred:}\ \text{PRED\_NAME} \\ \textit{pred\_concept:}\ \textit{@domain\_model} \\ \textit{inst:}\ \text{NAMED\_VAR} \\ \textit{args:}\ \textit{listof(}\text{ARG}\textit{)} \end{bmatrix}$$

(14) PRED_NAME ::= anbieten | dienstag | ...

Each predicate has a name and a referential argument which need not be realized overtly in natural language. With nouns, this argument specifies the discourse marker to which the predicate is applied[4]. With verbs, the argument specifies the discourse marker for the described event and the participants in the event are specified in a separate argument list[5].

Each *arg* in the arguments list is characterized in terms of a thematic role and a *named_var* indicating the discourse referent which plays the role.

(15) $$_{\text{ARG}}\begin{bmatrix} \textit{role:}\ \text{THEME\_ROLE} \\ \textit{arg:}\ \text{NAMED\_VAR} \end{bmatrix}$$

(16) THEME_ROLE ::= agent | theme | ...

The set of thematic roles is consistent with those defined in the domain model.

Complex conditions contain other DRSs. Disjunctions, conditionals, negation and quantifiers are treated analogous to standard definitions (Kamp and Reyle, 1993). For example, quantifiers are represented as duplex conditions: the *var* indicates the variable quantified over, *restr* indicates the restriction, and *scope* the scope of the quantifier.

[4]Thus the basic condition for a noun phrase corresponds to a one-place predicate in Predicate Logic.
[5]We assume a Davidsonian treatment of verbs and adjuncts.

(17) $\left[\begin{array}{l} \textit{qtr:}\ \text{QUANTIFIER} \\ \textit{var:}\ \text{NAMED\_VAR} \\ \textit{restr:}\ \text{DRS} \\ \textit{scope:}\ \text{DRS} \end{array}\right]_{\text{QUANT\_EXPR}}$

(18) QUANTIFIERS ::= every | most | ...

3 Extensions to Core Formalism

Beyond the basic features described in the last section, the semantic formalism must be able to represent, and a semantic construction component build, structures for a variety of phenomena frequently occurring in spoken dialogues; for example, anaphoric, elliptical and modality expressions:

(19) Ich schlage den Dienstag vor
I propose Tuesday

(20) Das paßt schlecht bei mir
That doesn't suit me

In (19) *den Dienstag* is an anaphoric definite description; in (20) *paßt* introduces a modality and *Das* is elliptical.

Elliptical phrases are represented by epsilon conditions. In the VERBMOBIL domain, once participants have established a conversational topic, they are not explicit about it in every utterance. In arranging a date for a meeting, participants may use expressions, such as *das*, which refer to abstract entities derived from earlier established events or propositions ('(participants) meeting on Tuesday'). The condition is defined as follows:

(21) $\left[\begin{array}{l} \textit{eps\_type:}\ \text{EPS\_TYPE} \\ \textit{eps\_args:}\ \textit{listof(}\text{NAMED\_VAR}\textit{)} \\ \textit{eps\_res:}\ \text{DRS} \end{array}\right]_{\text{EPS\_EXPR}}$

(22) EPS_TYPE ::= propn | event | ...

The feature *eps_type* states the type of the elliptical expression involved. *eps_args* is a list of arguments, to which the abstract antecedent has to apply. This list is empty when the expression is propositional (for example *das* above), or an argument of type *event* in case of event-type anaphora or similar constructions, and two or more in gapping cases. The result of ellipsis resolution is placed in the *eps_res* component.

Alfa conditions represent the semantics of a class of anaphoric, deictic, and other presuppositional expressions. Unlike elliptical utterances, anaphoric expressions have discourse markers as antecedents. Consequently, alfa conditions function as indicators which call for evaluation to determine the antecedent. We follow Van derSandt, 1992 where presupposition is taken to subsume anaphora. The anaphoric information in an alfa condition must be linked to previously established discourse markers; if this fails, it is projected (accommodated) at a suitable level of discourse, in which case there is a preference for accommodation as global as possible. This ensures that discourse markers for proper names and deixis will be introduced in the main DRS, and hence are fully accessible. While such a *binding and accommodation* mechanism is not part of the semantic formalism, the formalism establishes the representational means for it[6].

(23)
$$\textsc{alfa\_expr}\left[\begin{array}{l} \textit{alfa\_arg:}\ \textsc{named\_var} \\ \textit{alfa\_antec:}\ \textsc{marker} \\ \textit{alfa\_restr:}\ \textsc{drs} \end{array}\right]$$

In the definition of alfa conditions the *alfa_arg* indicates a distinguished marker, i.e., the marker that is in essence the representative for anaphoric material. The need to make a distinction between markers arises for example from expressions like *the date of a meeting*, where the discourse marker introduced by *the date* is the distinguished marker, and the information that the antecedent must be a date of a meeting forms the descriptive information that is held in *alfa_restr*. Since the latter is a DRS, it can also contain an alfa condition, which therefore allows embedded anaphoric structures; e.g. *my diary* where the alfa condition for the speaker is inside the alfa conditon of *diary*.

Modals are characterized as complex conditions. The representation differs from standard DRT in introducing additional components necessary for spoken dialogue data:

(24)
$$\textsc{modal\_expr}\left[\begin{array}{l} \textit{modal\_op:}\ \textsc{modal\_op} \\ \textit{modal\_pred:}\ \textsc{pred\_name} \\ \textit{modal\_inst:}\ \textsc{named\_var} \\ \textit{modal\_mod:}\ \textit{integer} \\ \textit{modal\_base:}\ \textsc{drs} \\ \textit{modal\_arg:}\ \textsc{drs} \end{array}\right]$$

(25) $\textsc{modal\_op} ::= \text{poss} \mid \text{nec} \mid \ldots$

[6]This mechanism is part of the semantic evaluation process.

The *modal_op* feature states whether the modality expresses a possibility or necessity. The predicate name indicates from which verb modality was introduced; for example, *passen*, *moeglich sein*, *koennen*, *in frage kommen*, *gehen*, etc. The *modal_inst* feature is the referential argument of the modal expressions and is of type *state*. The main argument of modal expressions, (*mod_arg*), is a DRS containing the proposition which is modified by the modal. The value of the *modal_mod* feature acts as an intensifier or weakener of the possibility or necessity. The scalar value of this parameter is instantiated by adverbials such as *gut* and *schlecht*. The *modal_base* is a feature which reflects the "perspective" on which the modality is based. These features are often expressed by prepositional phrases. Consider for example the representation of (20) above:

$$
\left[\begin{array}{ll}
\textit{drs:} & \left[\begin{array}{ll}
\textit{modal\_op:} & \textit{nec}\\
\textit{modal\_pred:} & \textit{passen}\\
\textit{modal\_inst:} & \textit{state}\\
\textit{modal\_mod:} & \textit{1}\\
\textit{modal\_base:} & \left[\begin{array}{ll}
\textit{dom:} & \left\langle \left[\textit{ref:}\ \boxed{1}\ \left[\begin{array}{l}\textit{ident: m1}\\ \textit{sort: top}\end{array}\right]\right]\right\rangle\\
\textit{conds:} & \left\langle\left[\begin{array}{ll}\textit{pred:} & \textit{bei}\\ \textit{inst:} & \boxed{1}\\ \textit{args:} & \left\langle\left[\begin{array}{l}\textit{role: theme}\\ \textit{arg:}\ \boxed{2}\end{array}\right]\right\rangle\end{array}\right]\right\rangle
\end{array}\right]\\
\textit{modal\_arg:} & \left[\begin{array}{ll}\textit{dom:} & \langle\ \rangle\\ \textit{conds:} & \left\langle\left[\begin{array}{l}\textit{eps\_type: propn}\\ \textit{eps\_args:}[\,]\end{array}\right]\right\rangle\end{array}\right]
\end{array}\right]\\
\textit{anchors:} & \left\langle\left[\begin{array}{l}\textit{param:}\ \boxed{2}\\ \textit{discourse\_role: sprecher}\end{array}\right]\right\rangle
\end{array}\right]
$$

The verb that expresses modality is *passen*. The proposition that is modified is the one *das* refers to (see below). The adverb *schlecht* weakens the possibility by instantiating the modal modifier parameter with 1 (the default being 3). The PP *bei mir* states the modal perspective.

4 A Worked Example

In order to exemplify the composition process, we give the semantic part of the lexical signs for *dienstag*, *den*, *vorschlage* and *ich*, and show how they combine to produce intermediate representations and, eventually, a semantic representation for the sentence *Ich schlage den Dienstag vor* in example (19). In cases where the lexical entry is a head and subcategorizes for its complements, the *subcat* list (which is part of the syntax) is also shown. This makes clear the relationship between *sem* values and *subcat* lists since, in these cases, the semantics of the elements on this list corefer with the functor, or argument, of a semantic operation.

In (26) we show the lexical entry for *Dienstag*[7].

(26)
$$\begin{bmatrix} \textit{lambda:}\ \langle \boxed{3} \rangle \\ \textit{drs:}\ \begin{bmatrix} \textit{dom:}\ < > \\ \textit{conds:}\ \left\langle \begin{bmatrix} \textit{pred:}\ \textit{dienstag} \\ \textit{inst:}\ \boxed{3}\ [\textit{sort:}\ \textit{time}] \end{bmatrix} \right\rangle \end{bmatrix} \\ \textit{quants:}\ < > \\ \textit{anchors:}\ < > \end{bmatrix}$$

The semantics of the definite article *den* in (27) specifies that the semantics of the common noun expression be established in the *alfa* DRS[8].

(27)
$$\begin{bmatrix} \textit{syn:}\ [\textit{subcat:}\ \langle [\textit{sem:}\ \boxed{5}] \rangle] \\ \textit{sem:}\ \begin{bmatrix} \textit{lambda:}\ \left\langle \begin{bmatrix} \textit{lambda:}\ \langle \boxed{3} \mid \_ \rangle \\ \textit{drs:}\ \boxed{2} \end{bmatrix}, \begin{bmatrix} \textit{lambda:}\ \langle \boxed{3} \mid \_ \rangle \\ \textit{drs:}\ \boxed{4} \end{bmatrix} \right\rangle \\ \textit{drs:}\ \begin{bmatrix} \textit{dom:}\ < > \\ \textit{conds:}\ \left\langle \begin{bmatrix} \textit{alfa\_arg:}\ \boxed{3} \\ \textit{alfa\_restr:}\ \begin{bmatrix} \textit{dom:}\ \langle [\textit{ref:}\ \boxed{3}\ [\textit{ident:}\ m3]] \rangle \\ \textit{conds:}\ < > \end{bmatrix} \otimes \boxed{2} \end{bmatrix} \right\rangle \end{bmatrix} \otimes \boxed{4} \\ \textit{quants:}\ < > \\ \textit{anchors:}\ < > \end{bmatrix} \odot \boxed{5} \end{bmatrix}$$

The lexical entry for *den* subcategorizes for a common noun. The feature structure representation is specified as the functor, the semantics of the common noun ($\boxed{5}$) is specified as the argument of functional composition. Applying the composition rule will unify $\boxed{5}$ with the first expression on the lambda-list of *den*. This has two effects: First, the variable in the common noun expression is unified with the *ref* part of the discourse

[7]In the following examples, lists are represented as < ... > in the feature structures. Note also that the scope of variables is limited to the (sign) feature structure they occur in.

[8]In the following representation, and other representations of type-raised expressions, the *lambda* list is of the form < $\boxed{n}$ | _ > indicating that it is seeking an argument which is itself seeking $\boxed{n}$ and, possibly, other unspecified arguments (as indicated by the '_').

marker introduced by the article ($\boxed{3}$). Second, the DRS of the common noun is unified with $\boxed{2}$, which forces by merging that the conditions in this DRS appear inside the *alfa* DRS containing the discourse marker. Again by the definition of functional composition, the resulting *sem* value will contain the DRS of the functor, i.e. the article.

Combining the semantics for these constituents by functional composition accordingly yields the structure in (28) for the semantics of the noun phrase:

(28)
$$
\left[\begin{array}{l}
\mathit{lambda:}\ \left\langle \left[\begin{array}{l} \mathit{lambda:}\ \langle \boxed{3} \mid \_ \rangle \\ \mathit{drs:}\ \boxed{4} \end{array}\right] \right\rangle \\
\mathit{drs:}\ \left[\begin{array}{l} \mathit{dom:}\ <\ > \\ \mathit{conds:}\ \left\langle \left[\begin{array}{l} \mathit{alfa\_arg:}\ \boxed{3} \\ \mathit{alfa\_restr:}\ \left[\begin{array}{l} \mathit{dom:}\ \left\langle \left[\mathit{ref:}\ \boxed{3}\ \left[\begin{array}{l} \mathit{ident:}\ m3 \\ \mathit{sort:}\ time \end{array}\right] \right] \right\rangle \\ \mathit{conds:}\ \left\langle \left[\begin{array}{l} \mathit{pred:}\ dienstag \\ \mathit{inst:}\ \boxed{3} \end{array}\right] \right\rangle \end{array}\right] \end{array}\right] \right\rangle \end{array}\right] \otimes \boxed{4} \\
\mathit{quants:}\ <\ > \\
\mathit{anchors:}\ <\ >
\end{array}\right]
$$

The verb *vorschlage* introduces an event variable and assigns roles to its arguments as shown in (29):

(29)
$$
\left[\begin{array}{l}
\mathit{syn:}\ \left[\mathit{subcat:}\ \left\langle \left[\mathit{sem:}\ \boxed{7} \right],\ \left[\mathit{sem:}\ \boxed{8} \right] \right\rangle \right] \\
\mathit{sem:}\ \boxed{7} \odot \boxed{8} \odot \left[\begin{array}{l} \mathit{lambda:}\ \langle \boxed{3}, \boxed{1} \rangle \\ \mathit{drs:}\ \left[\begin{array}{l} \mathit{dom:}\ \left\langle \left[\mathit{ref:}\ \boxed{6}\ \left[\begin{array}{l} \mathit{ident:}\ m6 \\ \mathit{sort:}\ event \end{array}\right] \right] \right\rangle \\ \mathit{conds:}\ \left\langle \left[\begin{array}{l} \mathit{pred:}\ vorschlagen \\ \mathit{inst:}\ \boxed{6} \\ \mathit{args:}\ \left\langle \left[\begin{array}{l} \mathit{role:}\ agent \\ \mathit{arg:}\ \boxed{1} \end{array}\right],\ \left[\begin{array}{l} \mathit{role:}\ theme \\ \mathit{arg:}\ \boxed{3} \end{array}\right] \right\rangle \end{array}\right] \right\rangle \end{array}\right] \\ \mathit{quants:}\ <\ > \\ \mathit{anchors:}\ <\ > \end{array}\right]
\end{array}\right]
$$

The entry for *ich* (not shown for space reasons) introduces a new discourse marker for *speaker* which appears in an *alfa* condition. (It must either be linked to a previously introduced discourse referent for the same speaker, or be accommodated in the main DRS.)

This marker is added to the anchor list so as to relate the referent to the *current speaker* defined in the dialogue model. Combination of *vorschlage* with the NP representations *den Dienstag* and *ich* results in (30).

(30)
$$
\begin{bmatrix}
\textit{lambda: } < > \\
\textit{drs: } \begin{bmatrix}
\textit{dom: } \left\langle \begin{bmatrix} \textit{ref: } \boxed{6} \begin{bmatrix} \textit{ident: m6} \\ \textit{sort: event} \end{bmatrix} \end{bmatrix} \right\rangle \\
\textit{conds: } \left\langle
\begin{bmatrix}
\textit{alfa\_arg: } \boxed{1} \\
\textit{alfa\_restr: } \begin{bmatrix} \textit{dom: } \left\langle \begin{bmatrix} \textit{ref: } \boxed{1} \begin{bmatrix} \textit{ident: m1} \\ \textit{sort: individual} \end{bmatrix} \end{bmatrix} \right\rangle \\ \textit{conds: } < > \end{bmatrix}
\end{bmatrix},
\begin{bmatrix}
\textit{alfa\_arg: } \boxed{3} \\
\textit{alfa\_restr: } \begin{bmatrix} \textit{dom: } \left\langle \begin{bmatrix} \textit{ref: } \boxed{3} \begin{bmatrix} \textit{ident: m3} \\ \textit{sort: time} \end{bmatrix} \end{bmatrix} \right\rangle \\ \textit{conds: } \left\langle \begin{bmatrix} \textit{pred: dienstag} \\ \textit{inst: } \boxed{3} \end{bmatrix} \right\rangle \end{bmatrix}
\end{bmatrix}
\begin{bmatrix}
\textit{pred: vorschlagen} \\
\textit{inst: } \boxed{6} \\
\textit{args: } \left\langle \begin{bmatrix} \textit{role: agent} \\ \textit{arg: } \boxed{1} \end{bmatrix}, \begin{bmatrix} \textit{role: theme} \\ \textit{arg: } \boxed{3} \end{bmatrix} \right\rangle
\end{bmatrix}
\right\rangle
\end{bmatrix} \\
\textit{quants: } < > \\
\textit{anchors: } \left\langle \begin{bmatrix} \textit{param: } \boxed{1} \\ \textit{discourse\_role: speaker} \end{bmatrix} \right\rangle
\end{bmatrix}
$$

5 Conclusion

In this final section, we comment on the status of the formalism, and mention two outstanding tasks.

The formalism contains semantic features which differ radically in status. This is due to the fact that semantic representations in VERBMOBIL serve several purposes; e.g., they constrain syntactic choice, provide input to the transfer component, and contribute to an evolving context model used by the semantic evaluation component (non-local disambiguation). Thus, there is a core part of the representation used by the compositional process of semantic construction itself and controlled by the denotational interpretation[9].

[9]Note that a unification-based implementation of λ-DRT cannot provide a complete equivalent to the

On the other hand, the formalism provides a more comprehensive data structure to encode information used by other system components. Here, our policy has been to make the formalism as flexible and redundant as possible. One example is the (thematic) role feature. We provide it, since it might be necessary for some semantic evaluation tasks (e.g., aspect determination), but we do not access arguments via roles, but instead use co-indexing between lambda variables and argument positions.

Although the formalism has been designed as flexible and extendible as possible, there are several basic requirements which have not been incorporated yet. The most important ones concern interaction with dialogue and underspecification. λ-DRT, like standard DRT, is basically a text representation formalism rather than a formalism for dialogue and discourse representation. For representing dialogues, a partitioning or classification of the semantic material is necessary, to distinguish contributions of different speakers, and different performative status of their contributions (assertion, proposal, question, etc).

The representation and processing of underspecified semantic information is partially addressed with the quantifier storage mechanism, alfa and epsilon conditions and our approach to lexical ambiguity: two readings are represented by the same underspecified lexical entry, if they do not differ syntactically or in semantic structure, and can be disambiguated by refining the conceptual information in the *pred_conc* feature. However, we have yet to extend the formalism to handle cases which emerge from incomplete or incorrect utterances in spontaneous discourse, or from the incorrect or incomplete analysis by the speech recognizer.

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handling of variables in extended type theory, but rather provides an approximation which works for many, but not all, cases.

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