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A COMPOSITIONAL APPROACH TO DISCOURSE REPRESENTATION THEORY

In a series of articles and talks[1] Hans Kamp has developed a theory of natural language interpretation that uses discourse representations. The most interesting applications of the theory are the problem of discourse anaphora to indefinites, donkey sentences and temporal processing. It seems likely that the theory can be successfully applied to a range of further questions in natural language semantics.

The theory is difficult to compare with Montague Grammar and related approaches to natural language semantics since the system Kamp presents is not a grammar in the sense of Montague (1970). The notion of a grammar in that article is a mathematically precise interpretation of the compositionality principle. Montague requires the syntax and the semantics of the grammar to be expressed as algebras. The relation between the syntactic and the semantic objects must be given as a homomorphism from the syntactical algebra to the (polynomial closure of) the semantic algebra. If a logical representation language is used in the formulation of the grammar, the relation between the syntactical objects and their representations, and between the representation and their meanings, must again be expressed as homomorphisms between the relevant algebras. In this way, the composition of both homomorphisms is itself a homomorphism between syntax and semantics. The level of representation has thereby only a secondary status in the theory: it helps to develop the grammar by making it more perspicuous, but one can in principle eliminate it in favor of the homomorphism from syntax to semantics it induces.

It is the aim of this paper to provide a version of Kamp's ideas that is a grammar in the sense of Montague. In the first part, discourse representation structures will be analysed as a formal language: i.e., a compositional interpretation will be provided. In the second part a fragment of natural language will be defined with a translation in the representation language given in the first part. The fragment is an extension and revision of the fragment in (Kamp, 1981b).

Besides comparison with more conventional approaches, there are other reasons for being interested in a compositional formulation of Kamp's ideas. Compositional treatments are supported by a simple theory of how compound expressions get their meaning: it is a function

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of the meaning of their parts. A grammar in the sense of Montague is a correlation of the possible functions with the ways in which a compound expression can be built up from its parts. Now if one considers a system that is not a grammar in this sense, it is not possible to apply this philosophical theory and one is forced to come up with new ideas. To my mind, the mentalistic interpretations[2] that discourse representation theory has given rise to can be seen as first attempts to formulate such a theory. A compound expression has a certain causal influence on a human interpreter leading him to form a representation. This representation in turn is related to reality in a way that can be captured by a truth definition. Now by itself there is no objection to speculating about the language of thought or the nature of mental representations. It is different, however, if the abandonment of compositionality would force one into such an interpretation of natural language semantics straight away.

Second, one may wonder to what extent a solution of the problem of donkey sentences outside the compositional paradigm is a solution of the problem. It is easy to give a logical translation of the sentences, but hard to do so in a compositional grammar. What Kamp provides is a systematic procedure, but not a compositional one. A compositional formulation of Kamp's theory is therefore needed to solve the problem as it arose in natural language semantics.

Last, it seems that compositional approaches have a number of practical and technical advantages. These are extensively discussed in (Janssen, 1983). One can mention here the relative ease by which properties of the grammar can be proved, extendibility, comparison with other work and incorporation of other analyses.

Initially, it may seem that Kamp's system is not so dissimilar from a classical Montague Grammar. In both systems we find a syntactic component, a level of logical representation and a model theoretic interpretation. Moreover, in both systems we find a truth definition and a way of converting syntactic objects into semantic representations. When one has a closer look, several differences emerge however.

In the first place, it is not clear how discourse representations (the representation level) are to be understood. The syntactic objects are defined as certain sets whose ultimate elements are variables and atomic formulae, and not recursively constructed by logical connectives and quantifiers out of simpler objects, as is customary. It will be necessary to impose an algebraical structure on the DRSs before the question of compositionality can be raised.

Second, the truth definition that is given for the representation language is not standard: it is essentially a top down interpretation. As in the case of first order logic, it is a non-trivial matter to rephrase the truth definition as an algebra of meanings that gives the same results. It turns out that the definition must be complicated: in particular, open DRSs, i.e., DRSs with free variables, cannot be interpreted by the truth definition.

Third, the translation process that maps discourses into (sets of) DRSs is not given by a homomorphism but by a (non-deterministic) algorithm that works top down on analysis trees. To obtain compositionality, this mapping must be completely revised. This cannot be done without a new formulation of the syntactic rules for natural language. In Section 1, the first two steps will be carried out. In Section 2, a fragment of natural language will be defined that can be interpreted in terms of the ideas developed in Section 1.

1. Discourse representation structures

One convenient way to think about discourse structures like those shown in Figures A and B[3] is as triples consisting of

(1) A finite list of atomic clauses from a previously given language L (The conditions of the top box.)
(2) A finite list of variables. (the discourse referents in the top box.)
(3) A list of ordered pairs of discourse representation structures. (The implications belonging to the top box.)

Accordingly, it is possible to define DRS_L, the discourse representation structures based on L, as follows:

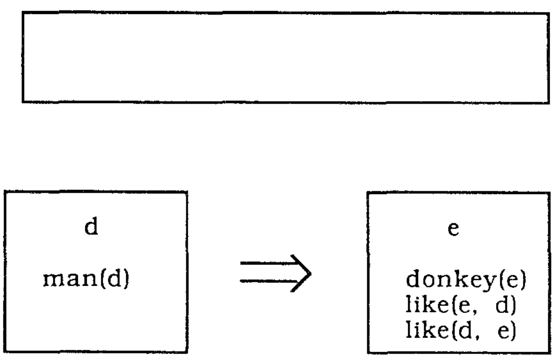

Fig. A. Every man likes a donkey that likes him.

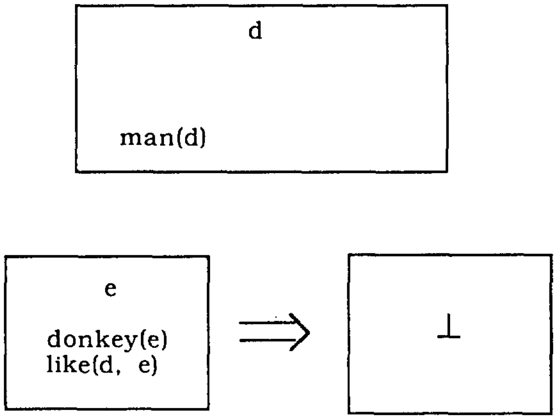

Fig. B. A man likes no donkey.

DEFINITION 1.1. DRS_L is the smallest set A such that[4] $a = \langle a_0, a_1, a_2 \rangle \in A$ iff

(1) $a_0 \subseteq \mathrm{At}_L \cup \{\perp\}$ and a_0 is finite.
(2) $a_1 \subseteq \mathrm{Var}$, a_1 is finite.
(3) $a_2 \subseteq A \times A$, a_2 is finite.

Definition 1.2 is essentially Kamp's (1981) definition of truth for DRSs using truthful embeddings. As usual, $M \vDash \phi[f]$ is used to express that ϕ is true on M if the variables in ϕ are taken as names for the values f assigns to them.

DEFINITION 1.2.0. $f \subseteq_Y g$ iff $\forall v \in \mathrm{dom}(g) - Y$ $(f(v) = g(v)$ and $\mathrm{dom}(g) = \mathrm{dom}(f) \cup Y)$.

DEFINITION 1.2.1. f is a *truthful embedding* for $a \in \mathrm{DRS}_L$ iff

(1) $a_1 \subseteq \mathrm{dom}(f)$
(2) for all $\phi \in a_0$, $M \vDash \phi[f]$
(3) for all $\langle c, d \rangle \in a_2$, for all g, if $f \subseteq_{c_1} g$ and g is a truthful embedding of c, there is an h such that $g \subseteq_{d_1} h$ and h is a truthful embedding of d.

DEFINITION 1.2.2. A is *true in* M iff a has a truthful embedding f with domain a_1.

Definition 1.2 makes it impossible for a formula to be true when it contains a variable in a position for which there is no accessible discourse marker. Such formulae are therefore all false. This is one reason to use full assignments, and to define truth in terms of satisfaction. Another reason is that algebraic treatments of the semantics of first order logic are slightly less complicated if they are based on full rather than partial assignments. In particular, the definition of conjunction is simpler. So let G be the set of total assignments of values for variables in the domain of M. I will define $[a]$, the set of assignments that satisfy a DRS a on M, and in terms of this notion, truth for a DRS a in the model M.

DEFINITION 1.3.0. $f \sim_Y g$ iff for all $v \notin Y$, $g(v) = f(v)$.

DEFINITION 1.3.1. $f \in [a]$ iff

1. for all $\phi \in a_0$, $M \vDash \phi[f]$
2. for all branchings $\langle c, d\rangle \in a_2$
   $\forall g \sim_{c_1} f(g \in [c] \rightarrow \exists h \sim_{d_1} g(h \in [d]))$.

DEFINITION 1.3.2. a is true in M with respect to f iff $\exists g \sim_{a_1} f(g \in [a])$.

'DEFINITION' 1.3.3. If every variable occurrence in a is in the scope of an occurrence of the same variable as a discourse referent, a is true on M iff $[a] \neq \emptyset$.

1.1. *An Algebra of* DRS*s*

Consider the following three operations on the set DRS_L: *merge*, *sub* and *abs* of two, two and zero places, respectively.

DEFINITION 1.4.0.

$$\begin{aligned}
&\mathrm{merge}(a, b) = \langle a_0 \cup b_0,\ a_1 \cup b_1,\ a_2 \cup b_2\rangle\\
&\mathrm{sub}(a, b) = \langle \emptyset, \emptyset, \{\langle a, b\rangle\}\rangle\\
&\mathrm{abs} = \langle \{\perp\}, \emptyset, \emptyset\rangle.
\end{aligned}$$

The system $\langle \mathrm{DRS}_L$, merge, sub, abs$\rangle$ forms an algebra, since DRS_L is closed with respect to the operations. The algebra can be generated from the set of atomic formulae, the set of variables and the empty DRS. The atomic formulae naturally correspond with the DRSs: $\langle\{\phi\}, \emptyset, \emptyset\rangle$ where ϕ is an atomic clause, the variables with $\langle \emptyset, \{x\}, \emptyset\rangle$ and the empty DRS with $\langle \emptyset, \emptyset, \emptyset\rangle$. To prove that the set B_L (the union of the DRSs listed above) is a set of generators, we must show that every DRS can be generated from it.

DEFINITION 1.5.0.

$$B_L = \{\langle\{\phi\}, \emptyset, \emptyset\rangle \mid \phi \in \mathrm{At}_L\} \cup \{\langle \emptyset, \{v\}, \emptyset\rangle \mid v \in \mathrm{Var}\} \cup \{\langle \emptyset, \emptyset, \emptyset\rangle\}.$$

DEFINITION 1.5.1. B_L^c is the smallest set such that

(1) $B_L \subseteq B_L^c$.
(2) For $a, b \in B_L^c$, merge(a, b) and sub$(a, b) \in B_L^c$.
(3) $\langle\{\bot\}, \emptyset, \emptyset\rangle \in B_L^c$.

PROPOSITION 1.1. $B_L^c = \mathrm{DRS}_L$.

Proof. Let $a \in \mathrm{DRS}_L$. By induction over the transitive closure of $\in$, we can assume that every c and d such that $\langle c, d\rangle \in a_2$ are elements of B_L^c. In that case also sub$(c, d) \in B_L^c$. So every element of $a_2 \in B_L^c$. Every element of a_0 and a_1 corresponds with an element of B_L. Merging all the indicated elements results in a. So $a \in B_L^c$. That $B_L^c \subseteq \mathrm{DRS}_L$ is immediate from Definition 1.4. So $B_L^c = \mathrm{DRS}_L$.

So it is possible to turn DRSs into an algebra in the sense of Montague's *Universal Grammar*. The next question is whether it is possible to define an algebra of semantic objects in which the algebra of DRSs can be interpreted by a suitable homomorphism.

1.2. *Semantics*

The most obvious candidate for the carrier set of the algebra of semantic objects is the power set of the set of assignments. This is the usual solution for first order logic. In Definition 1.3 we defined $[a]$ the set of assignments that satisfy a given DRS a. It turns out however, that the operation *sub* cannot be interpreted on power(G). According to Definitions 1.3 and 1.4, it should be:

$$[\mathrm{sub}(a, b)] = \{f \mid \forall g \sim_{a_1} f(g \in [a] \rightarrow \exists h \sim_{b_1} g(h \in [b]))$$

But this is not a function on the power set of assignments, since it crucially depends on the discourse referents of a and b. It is possible that $[a] = [c]$ and $[b] = [d]$ and $[\mathrm{sub}(a, b)] \neq [\mathrm{sub}(c, d)]$.[5] The solution is simple, but not very inventive: we just add the set of discourse markers to the meaning of the DRSs.

DEFINITION 1.6. $[\![a]\!] = \langle a_1, [a]\rangle$.

Meanings now are ordered pairs consisting of a set of variables and a set of assignments. The semantical algebra is easy to define:

DEFINITION 1.7. $\langle \mathrm{power(Var)} \times \mathrm{power}(G), \&, \Rightarrow, \bot\rangle$, where

(1) $x \;\&\; y = \langle x_0 \cup y_0, x_1 \cap y_1\rangle$.
(2) $x \Rightarrow y = \langle \phi, \{f \mid \forall g \sim_{x_0} f(g \in x_1 \rightarrow \exists h \sim_{y_0} g(h \in y_1))\}\rangle$.
(3) $\bot = \langle \emptyset, \emptyset\rangle$.

Towards the end of this section and in the conclusion, I will try to make this notion of meaning more acceptable from an intuitive point of view. For the while it suffices to note that it is adequate for the purpose of arriving at a compositional treatment.

PROPOSITION 1.2. The mapping $[\![\,.\,]\!]$: $\langle \mathrm{DRS}_L$, merge, sub, abs$\rangle \mapsto \langle$power(Var) $\times$ power(G), &, $\Rightarrow$, $\perp\rangle$ is a homomorphism.

1.3. *A Linear Format*

The algebraic structure for DRSs introduced above can also be exploited for a different purpose. In proving that DRS_L can be generated by B_L, we have also shown that every DRS can be represented by a polynomial over B_L in *merge*, *sub* and *abs*. For example, the DRSs in Figures A and B correspond to the following polynomials. (I use atoms and variables rather than their DRS counterparts.)

$$\begin{aligned}&\mathrm{sub}(\mathrm{merge}(\mathrm{merge}(d, \mathrm{man}(d)), \mathrm{merge}(\mathrm{merge}(e, \mathrm{donkey}(e)),\\ &\quad \mathrm{like}(e, d)))), \mathrm{like}(d, e))))\\ &\mathrm{merge}(\mathrm{merge}(d, \mathrm{farmer}(d)), \mathrm{sub}(\mathrm{merge}(e, \mathrm{merge}(\mathrm{donkey}(e),\\ &\quad \mathrm{like}(d, e))), \mathrm{abs})).\end{aligned}$$

This becomes more readable if we use infix notation and use more mnemonic symbols for the functions:

$$\begin{aligned}&(((d\ \&\ \mathrm{man}(d))\ \&\ ((e\ \&\ \mathrm{donkey}(e))\ \&\ \mathrm{like}(e, d)) \rightarrow \mathrm{like}(d, e)))\\ &((d\ \&\ \mathrm{farmer}(d))\ \&\ ((e\ \&\ (\mathrm{donkey}(e)\ \&\ \mathrm{like}(d, e))) \rightarrow \perp)).\end{aligned}$$

Having to write discourse referents by means of conjunctions is unpleasant after a while. It also turns out that we can manage with strictly local discourse referents. This allows one to abbreviate

$$d\ \&\ \mathrm{man}(d)$$

as

$$\mathrm{man}(d^*)$$

and in general:

$$d_1\ \&\ \ldots\ \&\ d_n\ \&\ R(d_1, \ldots, d_n, t_1, \ldots, t_k)$$

as

$$R(d_1^*, \ldots, d_n^*, t_1, \ldots, t_k).$$

Since merge is associative, it makes sense to omit brackets on conjunctions. We obtain thus the following logical expressions for the examples.

$$(\text{man}(d^*) \;\&\; \text{donkey}(e^*) \;\&\; \text{like}(e, d) \rightarrow \text{like}(d, e))$$
$$\text{farmer}(d^*) \;\&\; (\text{donkey}(e^*) \;\&\; \text{like}(d, e) \rightarrow \bot).$$

This language (hereafter called BL) is quite familiar: it is first order logic without quantifiers, except for a special mark that may appear on certain variables. A full definition is given in 1.8.

DEFINITION 1.8. Let L be a first order logical language (with '=', without function symbols). The set of formulae of BL is given by (1) and (2).

(1) *Terms*:

(a) Every individual constant of L is a term.
(b) For every natural number n, x_n and x_n^* are terms.

(2) *Formulae*:

(a) If P is an n-place predicate letter and $t_1, \ldots, t_n$ are terms, $P(t_1, \ldots, t_n)$ is a formula.
(b) If ϕ and ψ are formulae so are $(\phi \;\&\; \psi)$ and $(\phi \rightarrow \psi)$.
(c) $\bot$ is a formula.

Having given an interpretation for DRS_L it is not hard to find the corresponding interpretation for BL. As usual, a model M is a pair $\langle A, F\rangle$, where A is a set and F is an interpretation function for the non-logical constants.

DEFINITION 1.9.1.

$$t^g = g(t) \text{ iff } t \text{ is not a constant.}$$
$$t^g = F(t) \text{ iff } t \text{ is a constant.}$$

DEFINITION 1.9.2.

$$[\![P(t_1, \ldots, t_n)]\!] = \langle \{x_i \mid x_i^* \text{ is one of } t_1, \ldots, t_n\}, \{g \mid \langle t_1^g, \ldots, t_n^g\rangle \in F(P)\}\rangle.$$
$$[\![\phi \;\&\; \psi]\!] = [\![\phi]\!] \;\&\; [\![\psi]\!].$$
$$[\![\phi \rightarrow \psi]\!] = [\![\phi]\!] \Rightarrow [\![\psi]\!].$$
$$[\![\bot]\!] = \bot.$$

As before, definitions for truth and satisfaction can be given. It is necessary to define first what a free occurrence of a variable is, since this notion can no longer be defined by a relation between boxes.

DEFINITION 1.10.1.

$\mathrm{FV}(P(t_1, \ldots, t_n)) = \{x_i \mid x_i \text{ occurs among } t_1, \ldots, t_n\} - [\![P(t_1, \ldots, t_n)]\!]_0$.
$\mathrm{FV}(\phi \,\&\, \psi) = (\mathrm{FV}(\phi) \cup \mathrm{FV}(\psi)) - [\![\phi \,\&\, \psi]\!]_0$.
$\mathrm{FV}(\phi \rightarrow \psi) = \mathrm{FV}(\phi) \cup (\mathrm{FV}(\psi) - [\![\phi]\!]_0)$.
$\mathrm{FV}(\perp) = \emptyset$.

DEFINITION 1.10.2. x is *free in* ϕ iff $x \in \mathrm{FV}(\phi)$.

DEFINITION 1.10.3. ϕ is a *sentence* iff $\mathrm{FV}(\phi) = \emptyset$.

DEFINITION 1.11.1. $M \models \phi[g]$ iff $\exists f \sim_{[\![\phi]\!]_0} g(f \in [\![\phi]\!]_1)$.

DEFINITION 1.11.2. For sentences ϕ: $M \models \phi$ iff $[\![\phi]\!] \neq \emptyset$.

I will use BL as the representation language in the rest of this paper for two practical reasons. The first of these is that the language is compact and easily readable. The second is that it is much easier to see how two semantical representations are combined (as happens in the translations of syntactic rules in the natural language fragment), when both representations remain recognizable parts of the syntax as they do in BL, but not when they are distributed, on merging, over the separate parts of the new representation that contain the discourse markers, the atomic formulae and the implications. Those who do not like this way of proceeding are welcome to interpret the BL-formula as an instruction for building the semantic representation, rather than as the representation itself.

1.4. *BL and First Order Logic*

We now turn to a comparison of BL with first order logic. The relation is very simple.

THEOREM. BL and first order logic based on L have the 'same' formulae; i.e., there are satisfaction preserving translations in both directions.

The rest of this section is devoted to giving some parts of the proof. The complete proof is obtained by the two translation functions and an induction over the complexity of the formulae, showing that they indeed preserve satisfaction.

From BL to first order logic the translation proceeds in two steps, T_0 and T_1. T_1 is given by the following definition:

DEFINITION 1.12.

$T_1(P(t_1, \ldots, t_n)) = P(t'_1, \ldots, t'_n)$ where t'_1 is t_1 with the possible star omitted.
$T_1(\phi \,\&\, \psi) = T_1(\phi) \,\&\, T_1(\psi)$.
$T_1(\phi \rightarrow \psi) = \forall x_1, \ldots, x_n(T_1(\phi) \rightarrow \exists y_1, \ldots, y_k T_1(\psi))$ where $\{x_1, \ldots, x_n\} = [\![\phi]\!]_0$ and $\{y_1, \ldots, y_k\} = [\![\psi]\!]_0$.
$T_1(\perp) = \perp$.

To obtain a first order logical equivalent we must take the existential interpretation of the discourse referents on the top level into account. Therefore T_0 is defined by:

DEFINITION 1.13.

$$T_0(\phi) = \exists x_1, \ldots, x_n T_1(\phi) \qquad \text{where } \{x_1, \ldots, x_n\} = [\![\phi]\!]_0.$$

It is straightforward to show that

$$g \in [\![\phi]\!]_1 \qquad \text{iff } M \models T_1(\phi)[g]$$

and therefore that

$$M \models \phi[g] \qquad \text{iff } M \models T_0(\phi)[g].$$

Translating first order logic into BL is unproblematic except for one complication: existential quantification. It may be thought that existential quantifiers correspond with a discourse marker occurring in the scope of the quantifier. Though indeed the interpretation is often existential, there is no guarantee that it does remain so when combined in a larger expression. Moreover there are a number of occasions in which the scope changes when the expression becomes part of a more complex expression. In order to get the effect of an existential quantifier in a DRS we must find a formula that assigns an explicit scope to the discourse marker. This can be achieved by making it into an implication. One possibility is to use double negation $((\phi \rightarrow \perp) \rightarrow \perp)$ for this. Another possibility is the one employed below, using an implication with a trivially true antecedent, like $(\perp \rightarrow \perp)$. The binding of a specific variable can be achieved by putting a trivially true atom with the variable as a discourse marker like e.g., $x^* = x$ in the appropriate position.

This gives us the following translation function:

DEFINITION 1.14.

$T_2(P(t_1, \ldots, t_n)) = P(t_1, \ldots, t_n)$.
$T_2(\phi \,\&\, \psi) = T_2(\phi) \,\&\, T_2(\psi)$.

$T_2(\phi \rightarrow \psi) = T_2(\phi) \rightarrow T_2(\psi)$.
$T_2(\perp) = \perp$.
$T_2(\forall x\phi) = (x^* = x \rightarrow T_2(\phi))$.
$T_2(\exists x\phi) = ((\perp \rightarrow \perp) \rightarrow x^* = x \ \& \ T_2(\phi))$.

The translation maps every first order logical formula to a BL formula ϕ that has the property that $[\phi]_0$ is empty. This is as it should be: only DRSs allow the binding of a variable in ψ in a conjunction

$$\phi \ \& \ \psi$$

by an "existential quantifier" that belongs to ϕ. First order logical formulae never set up antecedents for free variables that occur later. In a sense, therefore, there are more DRSs than first order formulae. First order formulae are the subclass that set up no antecedents. For each first order formula there are arbitrarily many different DRSs that are true with respect to the same models and assignments, but that are different from it by having different sets of discourse markers. As BL-formulae, they are therefore not substitutable for each other in a BL-formula salva veritate. In order to have this property, they must have the same set of discourse markers as well.

It now holds that

$$M \models \phi[g] \quad \text{iff } M \models T_2(\phi)[g].$$

I will give one case of the induction:

$M \models \exists x\phi[g]$ iff (satisfaction).
$\exists g' \sim_{\{x\}} gM \models \phi[g']$ iff (induction hypothesis).
$\exists g' \sim_{\{x\}} gM \models T_2(\phi)[g']$ iff ($g \in [\![(\perp \rightarrow \perp)]\!]_1$ and $g' \in [\![x^* = x]\!]_1$ since both of these formula are trivially true).
If $g \in [\![\perp \rightarrow \perp]\!]_1$ then $\exists g' \sim_{\{x\}} g$, $g' \in [\![x^* = x]\!]_1$ and $M \models T_2(\phi)[g']$ iff (satisfaction BL).
$g \in [\![((\perp \rightarrow \perp) \rightarrow x^* = x \ \& \ T_2(\phi))]\!]_1$ iff (definition T_2).
$g \in [\![T_2(\exists x\phi)]\!]_1$ iff ($[\![T_2(\exists x\phi)]\!]_0 = \emptyset$).
$M \models T_2(\exists x\phi)[g]$.

This concludes the sketch of the proof.

1.5. *Quantification*

In this section, I will try to answer the question how BL manages to do without quantifiers. It is true that BL formulae have no parts (in terms of their syntax) that are quantifiers with an indication of their scope, but it is not too complicated to define existential and universal quantification as meta-notions over the syntax. The following definition does precisely that.

DEFINITION 1.15.1. A *maximal conjunction* of ϕ is an occurrence of a subformula that does not occur as a conjunct of another subformula of ϕ. (This allows a single atom or implication to be a maximal conjunction.)

DEFINITION 1.15.2. An *implication* of ϕ is a subformula of the form $(\psi \rightarrow \chi)$ where ψ is called the *condition*.

DEFINITION 1.15.3a. A starred variable x^* *belongs* to an atomic formula iff it occurs in it.

DEFINITION 1.15.3b. A starred variable x^* *belongs* to a conjunction ϕ & χ iff it belongs to ϕ or χ.

DEFINITION 1.15.4. An occurrence of a starred variable x^* is a *universal quantifier with scope* χ iff χ is an implication and x^* belongs to its antecedent.

DEFINITION 1.15.5. An occurrence of a starred variable x^* is an *existential quantifier with scope* χ *in* ϕ iff

(1) χ is a maximal conjunction of ϕ.
(2) χ is neither an implication nor the condition of one.
(3) x^* belongs to χ.

So, one could say that BL does not have syntactic parts that are quantifiers, but rather codes up a quantifier as a marked variable in the formula that would normally be its scope.

On the one hand this provides an explanation for why we had to make the meaning of both BL-formulae and DRSs a pair consisting of a set of discourse markers and a set of assignments. When we discover, assigning interpretations from the bottom to the top, that there will be a quantifier (we notice a starred variable occurrence), we still do not know what its scope will be and whether it will turn out to be a universal or existential quantifier. All that we can do at this stage is to store the information that there will be a quantifier (this is done in the set of discourse markers in the meaning). Simultaneously we keep in the set of assignments information that contributes to knowledge of the scope. Only when both the scope, and the nature of the quantifier are determined (this happens when we hit an implication or have found the maximal formula), can we use the information from both coordinates and invoke a rule that evaluates the quantifier on the scope.

It may be hard to avoid the feeling of being tricked: this style of definition seems to be unconstrained and potentially unclear. However, DRSs are not motivated as a particularly clean logical formalism, but intended as a reconstruction of the semantic contribution of natural language expressions. In natural language indefinites, we have precisely the same phenomenon: they can function both as existential and universal quantifiers and their scope is given by the linguistic context rather than by the linguistic rule that is responsible for their appearance in a sentence.

2. A FRAGMENT

The aim of this section is to formulate a fragment that has at least the coverage of the fragment in Kamp, 1981b, but is simultaneously a fragment in the style of *Universal Grammar*. It is highly fascinating to construct fragments, especially if, as here, a number of obstacles need to be overcome, but it is hard to transmit this fascination to the reader. The organisation of this section should allow one to reserve Section 2.2, which contains the actual rules, for consultation only.

2.1. *Introduction*

One way to develop a fragment for English with a compositional DRT-style semantics is to add lambda abstraction to BL. This is trivial for abstractions over individual variables, and can also be carried out for the higher types, although not as simply. More or less the same techniques as in Montague 1973 (PTQ) can then be used for combining expressions.

However, this approach seems to conflict with the general ideology of discourse representation theory, which is "naive" in the sense of Davidson. Under such an approach, one does not refer to abstract semantical entities, such as properties, properties of properties and the like in natural language semantics. Instead one tries to state semantical relations by referring to few and simple kinds of entities. It is interesting, I think to see to what extent this *naiveté* can be maintained on a compositional treatment, since it is present in Kamp's use of the DRS construction algorithm to map between syntax and semantics.

An extension to BL that is helpful and innocent is the addition of some operators. These are definable per instance in BL, but not by a schema, because clash of variables cannot be uniformly avoided. An example that will be adopted in the formulation of the fragment is the following definiteness operator:

$$D(x^*, \phi).$$

Here x is variable and ϕ is a BL-formula. The interpretation is given in (1).

(1) $[\![D(x^*, \phi)]\!] = \langle [\![\phi]\!]_0 \cup \{x\}, \{f \in [\![\phi]\!]_1 \mid \neg\exists h \sim_{[\![\phi]\!]_0} f(h \in [\![\phi]\!]_1 \text{ and } h(x) \neq f(x))\}\rangle$.

Of course

$$D(x^*, \text{boy}(x^*))$$

can be defined as:

$$\text{boy}(x^*) \ \& \ (\text{boy}(y^*) \rightarrow x = y)$$

but this cannot provide the pattern for a general definition of $D(x^*, \phi)$, since y could already occur in ϕ.

It should come as no surprise after the first part of this paper that most singular NPs can be treated: BL has the expressive power of first order logic, and almost all singular[6] NPs allow first order definition. So versions in BL of singular NPs can be given as in the following scheme (2)

(2)(a)	No man runs.	$\neg\exists x(\text{man}(x) \ \& \ \text{run}(x))$	$(\text{man}(x^*) \ \& \ \text{run}(x) \rightarrow \perp)$
(b)	A man runs.	$\exists x(\text{man}(x) \ \& \ \text{run}(x))$	$\text{man}(x^*) \ \& \ \text{run}(x)$
(c)	Every man runs.	$\forall x(\text{man}(x) \rightarrow \text{run}(x))$	$(\text{man}(x^*) \rightarrow \text{run}(x))$
(d)	The man runs.	$\exists x(\forall y(\text{man}(y) \leftrightarrow x = y) \ \& \ \text{run}(y))$	$D(x^*, \text{man}(x^*)) \ \& \ \text{run}(x)$
(e)	The man runs.	$\exists x(\text{man}(x) \ \& \ x = y \ \& \ \text{run}(x))$	$\text{man}(x^*) \ \& \ x = y \ \& \ \text{run}(x)$
(f)	One man runs.	$\exists x(\forall y(\text{man}(y) \ \& \ \text{run}(y) \leftrightarrow x = y))$	$D(x^*, \text{man}(x^*) \ \& \ \text{run}(x))$.

The difference with predicate logic is that some of the NPs introduce antecedents. In the BL version, *a*(*n*), *one* and *the* in the definitional use (2d) introduce a new antecedent. The anaphoric use of *the* (2e) is a special case: it introduces a new antecedent, but also employs an unbound pronoun that must have the same value as the antecedent. In this way, the antecedent introduced by anaphoric definites is not really new, but identical to whatever binds the unbound pronoun.

A consequence of the decision to remain within the expressive power of BL is that the only operations we can use to construct new representations from given ones in defining the semantics of natural language expressions are BL operations: conjunction, implication, absurdity, definiteness, and combinations of these. This leads to the following three differences with a system like PTQ.

The first difference is that all expressions allowed by the syntax must have a meaning that is a BL formula; it is on these that the operations are defined. In particular this means that nouns and proper names translate as formulae, just like sentences and texts. (These are the only expression types in the fragment; verbs and pronouns are introduced syncategorematically.)

The second difference is that syntactic operations do not correspond with functional application as happens in PTQ, but with schematic BL-polynomials. This departure from PTQ nevertheless falls within the framework of *Universal Grammar*.

The third difference is that it is not possible to express in a direct way, e.g., that the meaning of the NP that fills the subject place of a verb binds the variable that in the semantic representation of the verb corresponds with its subject place. This is easy using lambdas. Take a translation of the verb *walks* in (3a) and a translation (3b) of *man*.

(3a) walk(x).
(3b) man(y^*).

If we want to combine both expressions to form (4) with a possible translation (4a), it is clear that we have a problem, since in addition to conjoining the phrases we need to change the variables x and y so that they become the same.

(4) a man walks.
(4a) man(z^*) & walk(z).

In order to deal with problem we restrict the combination rule to those expressions in which the relevant variables are already the same. But then we must mark in some way that *man* translates as an expression with the variable x, and that the translation of *walks* has x as its first argument. For this reason, *man* and *walks* are not themselves expressions in the fragment. The proper expressions, as it were, wear their connection with certain variables on their sleeves. Corresponding with *man* there is a class of expressions of the form (5), with semantic representation (5a).

(5) man$^\wedge$CN$^\wedge x^\wedge\{x\}$.
(5a) man(x^*).

Here 'CN' is a label that expresses the syntactic category of the expression. The label 'x' indicates that x is the variable that corresponds with the head of the CN, and the label '$\{x\}$' contains the set of potential antecedents introduced by the expression. In the case of *man* this is just the variable that forms the second label, but there can be other variables in this label as illustrated in (6).

(6) man who owns a donkey$^\wedge$CN$^\wedge x^\wedge\{x, y\}$.
(6a) man(x^*) & donkey(y^*) & own(x, y).

Verbs do not show up in isolation either but in expressions like (7), with meaning (7a).

(7) $\text{he}_x^+ \text{ walks}^{+}{}^\frown\text{S}^\frown\emptyset$.

(7a) walk(x).

Expressions like (7) are basic elements in the lexicon. The label 'S' stands for the syntactic category, and the label '$\emptyset$' for the antecedents of this expression. For the time being, I will ignore the +-marks that sometimes appear on the verbs and the pronouns. The subscripted variables correspond with the free variables in the corresponding semantic representation.

There are a number of rules that operate on the two expressions introduced above. I will give two examples of these rules.

(S12) If $\alpha{}^\frown\text{CN}{}^\frown x{}^\frown A$ and $\beta{}^\frown\text{S}{}^\frown B$ are wfes, A and B are disjoint and δ is the first x- and +-marked pronoun in β, then bind($A \cup B$, insert(δ, $a(n) \bullet \alpha$, β), $\delta){}^\frown S{}^\frown A \cup B$ is a wfe.

T12) α' & β'.

(S14) If $\alpha{}^\frown\text{CN}{}^\frown x{}^\frown A$ and $\beta{}^\frown\text{S}{}^\frown B$ are wfes and δ is the first x- and +-marked pronoun in β, then bind(A, insert(δ, $every \bullet \alpha$, β), $\delta){}^\frown\text{S}{}^\frown\emptyset$ is a wfe.

(T14) $(\alpha' \rightarrow \beta')$.

The precise format of the rules will be explained later on, like the string operations that they employ.

Rule 12 builds indefinite terms. The syntactical operations used in the rule have the following effect. The determiner $a(n)$ is attached to *man* and substitutes the result for the pronoun he_x^+ in he_x^+ $walks^+$ to yield *a man walks*$^+$. The full expression is (8), with semantics (8a).

(8) a man $\text{walks}^{+}{}^\frown\text{S}^\frown\{x\}$.

(8a) man(x*) & walk(x).

Moreover, the rule has a number of restrictions on its application. The string operations also take care of certain side effects of the rule application. These are the following:

The first argument must have the label CN, the second label S.

The arguments should share no antecedents.

The second label on the CN must be the same variable as the subscript on one of the pronouns occurring in the second argument.

> The pronouns in the first argument should be "bound" by the antecedents in the second argument, and the pronouns in the second argument by the antecedents in the first.

These restrictions and side effects will be motivated later on.

Rule 14 introduces the determiner *every*. As a string operation, it is much the same: *every* is placed before *man* and inserted for he_x^+ in he_x^+ $walks^+$. But the side effects and restrictions are different, as is the effect on the antecedent label. Since the translation of *every man walks*$^+$ is an implication the resulting expression has an empty antecedent label as in (9).

(9) every man walks$^{+\wedge}$S$^\wedge\emptyset$.

(9a) (man(x^*) $\rightarrow$ walk(x)).

The side effects and restrictions on the rule are the following in this case.

> The first argument must have the label CN, the second label S.
>
> The second label on the CN must be the same variable as the subscript on one of the pronouns occurring in the second argument.
>
> The pronouns in the second argument must be "bound" by the antecedents of the first argument.

2.1.1. *Insertion Rules.* The use of insertion rules for entering NPs into a sentence requires some comment. In Montague Grammar, quantifying rules explain three kinds of phemomena. In the first place they form a mechanisms for binding indexed pronouns. In the second place they account for the *de re/de dicto* ambiguity in intensional contexts such as the ones set up by verbs like *believe* and *want* and by operators like *necessary* and *alleged*. And last, they take care of quantifier scope ambiguities.

We do not need the first two uses of the quantifying rules. The binding of pronouns will be a side effect of any rule that places a non-starred occurrence of a variable in the scope of a starred occurrence of the same variable. No intensional contexts are treated in this paper, but it does not seem obvious that quantifying rules should be used for explaining the ambiguity.

This leaves us with the third use. For scope ambiguities, it's hard to avoid quantification rules in a strictly compositional treatment.[7]

One cannot, however, have the same quantification rules as in PTQ. As in PTQ, their adoption would lead to a wide variety of intuitively wrong predictions. Because we do not need them here to account for pronoun binding, they can be constrained to avoid the false predictions. In PTQ this would not be acceptable, because it would be impossible to account for a range of anaphoric relations. This merely shows that theories of anaphora cannot be based on a system of quantification rules: besides the overgeneration of scope ambiguities, such systems cannot deal with Bach-Peters sentences or donkey sentences, and only awkwardly with discourse anaphora.

Counterexamples to the PTQ predictions on quantifier scope are (10) and (11).

(10) John likes no man and Mary likes Bill.

Suppose John likes Bill but Mary dislikes Bill. Then (10) is false. But it would be true if one quantified *no man* into (10a), since the result would have the predicate logical translation (10b):

(10a) John likes him_0 and Mary likes Bill.

(10b) $\forall x(\text{man}(x) \rightarrow \neg(\text{like}(j, x) \,\&\, \text{like}(m, b)))$.

Quantifying into positions in a relative clause leads to similar wrong predictions.

(11) John likes a woman who likes every man.

Intuitively, (11) does not have a reading where for every man John likes a woman who likes that man.

So that we can obtain quantifier scope ambiguities on the one hand while avoiding the overgeneration on the other we mark those pronouns in an expression which allow insertion rules to operate on them. A pronoun that fills a subject or object place[8] in a clause can be replaced by a full NP, as long as the derivation does not make the clause subordinated or coordinated. An exception here is IV and TV coordination, where the subject and/or object remain available for insertion rules.

The mechanism assumed here forbids quantification into subordinate positions. A counterargument to this claim is provided by the observation that (12) has a reading where all villagers believe something about the same cow.

(12) Every villager believes that a cow has been stolen.

It does not follow that quantification rules should be the explanation here. For in that case we would expect *every cow* in (13) to have a wide scope reading.

(13) A villager believes that every cow is stolen.

But there does not seem to be such a reading. Probably, the relevant interpretation of (12) should be explained by letting the *that*-clause have scope over the subject; this causes the proposition to be about a single cow. In (13), however, the scope of *every* is limited to the *that*-clause, so that even when the *that*-clause has wide scope over the subject, the subject is not in the scope of *every*.

The insertion of NPs is limited to main clause positions by marking those positions in the lexicon with a +-mark. Rules that subordinate or coordinate expressions erase the marks from the pronouns and the verbs. The +-mark on a verb similarly restricts the negation rule: only main clause verbs V can be replaced by the corresponding *does not* V.

Insertion is demonstrated in the derivation (14a) of (14). Rule numbers are added to the labels of the derivation tree.

(14) A man who owns no donkey loves every girl.

(14a) a man who owns no donkey loves$^+$ every girl^S^$\{x\}$, 12

man who owns no donkey^CN^x^$\{x\}$, 10   he$_x^+$ loves$^+$ every girl^S^$\emptyset$, 14

man^CN^x^$\{x\}$, 1   he$_x^+$ owns$^+$ no donkey,^S^$\emptyset$, 15   girl^CN^z^$\{z\}$, 1   he$_x^+$ loves$^+$ him$_y^+$^S^$\emptyset$, 4

donkey^CN^z^$\{z\}$, 1   he$_x^+$ owns$^+$ him$_z^+$^S^$\emptyset$, 4.

Donkey is here combined with the determiner *no* and inserted for *him*$_z^+$ before the clause is made into a relative clause. A side effect of the rule that forms relative clauses is erasing the +-marks which stops the insertion of further NPs within the clause and negation. This is illustrated in (15).

(15) a man who owns him$_z$ loves$^+$ every girl^S^$\{x\}$, 12

man who owns him$_z$^CN^x^$\{x\}$, 10   he$_x^+$ loves$^+$ every girl^S^$\emptyset$, 14

man^CN^x^$\{x\}$, 1   he$_x^+$ owns$^+$ him$_z^+$^S^$\emptyset$, 4   girl^CN^y^$\{y\}$, 4   he$_x^+$ loves$^+$ him$_y^+$^S^$\emptyset$, 4.

In this case it is not possible to insert *no donkey* in the place of *him*$_z$ to obtain another reading of (14) since it no longer has the +-mark.

2.1.2. *Pronoun Binding*. A pronoun with an index x becomes bound by an antecedent x when an expression containing the pronoun combines with an expression containing the antecedent, if certain conditions are fulfilled. So binding is not a separate rule, but a side effect of any rule that combines a phrase whose semantics contains an antecedent x with a phrase that contains a pronoun *he*$_x$, *him*$_x$, *himself*$_x$ or an anaphoric definite description of the form *the*$_x$ α, when the combination is such that the antecedent or rather the corresponding discourse marker is accessible to the variable representing the pronoun. This is not the case if we combine, e.g., (16a) with (16b) to form (16).

(16a) he$_x^+$ wins$^{+\wedge}$S$^\wedge\emptyset$.
(16b) a man rejoices$^{+\wedge}$ $x^\wedge\{x\}$.
(16) if he$_x$ wins, a man rejoices$^{+\wedge}$S$^\wedge\emptyset$.

In this case the translation of *he*$_x$ is not in the scope of the variable introduced by *a man*, as shown in (16c).

(16c) $(\text{win}(x) \rightarrow \text{man}(x^*)\ \&\ \text{rejoice}(x))$.

But (17) can be generated by giving *a man* wide scope over the implication.

(17) If he wins, a man rejoices.
(17a) $\text{man}(x^*)\ \&\ (\text{win}(x) \rightarrow \text{rejoice}(x))$.

To make binding a side effect of other rules puts a number of requirements on the syntax. Since we must be able to recognize antecedents and pronouns, it is necessary to mark expressions as setting certain antecedents. In the course of a derivation, by entering into a quantification for example, antecedents may disappear. In (18)

(18) man who own a donkey$^\wedge$CN$^\wedge$ $x^\wedge\{x, y\}$.

x and y could bind pronouns that are marked for these variables. When (18) becomes part of the expression (19),

(19) every man who own a donkey sleeps$^{+\wedge}$S$^\wedge\emptyset$.

both antecedents disappear.

But when (18) combines with another expression, y can still bind *him*$_y$ as in the formation of (20) (the donkey sentence)

(20) every man who owns a donkey beats$^+$ it

from (20a).

(20a) he$_x^+$ beats$^+$ him$_y^+$.

We saw earlier that every CN and PN is labelled by (i) a syntactic category, (ii) a single variable and (iii) a set of potential antecedents. The function of (ii) is to place an extra condition on insertion. The variable is the one that the lexical head noun of the CN introduces into the translation, as in (21), and it always belongs to the set (iii).

(21) boy who likes a girl^CN^x^$\{x, y\}$.
(21b) boy(x^*) & girl(y^*) & like(x, y).

2.1.3. *Other Conditions*. We have already met the restrictions and side effects of the rule that inserts an indefinite NP α in a sentence β. They are repeated below:

> The first argument must have the label CN, the second label S.
> The arguments should share no antecedents.
> The second label on the CN must be the same variable as the subscript on one of the pronouns occurring in the second argument.
> The pronouns in the first argument should be "bound" by the antecedents in the second argument, and the pronouns in the second argument by the antecedents in the first.

The first condition expresses the syntactic condition on the application of the rule. Another condition is that α and β do not share antecedents. If they would, we would get an unreasonable semantics for a well formed string, as in (22)

(22a) a boy whom a widow likes owns a donkey.
(22b) boy(x^*) & widow(y^*) & like(y, x) & donkey(y^*) & own(x, y).

There is nothing wrong with a semantic representation like (22b), except that it is always false. Omitting the restriction, would predict that (on some of its readings) (22a) is necessarily false. The restriction is the analogue of Kamp's requirement in the DRS construction algorithm of new variables in a number of rules. We cannot use the same notion, since when one works bottom up, the information as to what variables are used elsewhere in the tree is not available.

It is also reasonable to demand that the pronoun is the first occurrence of that pronoun which is +-marked in the sentence.

The pronoun binding that occurs as part of the rule can be described as follows:

> Any antecedent from A binds pronouns in S.
> Any antecedent from S binds pronouns in A.

The second condition allows a limited amount of cataphora, maybe too much. Potential counterexamples are arbitrarily deeply embedded pronouns in relative clauses, as in (23).

(23) The man who regrets that she was fired likes a woman.

Bach-Peters sentences with (in)definites (24a) are handled correctly, but not the corresponding ones with quantifying NPs (24c). That the latter cannot be handled derives from the DRT restrictions on anaphora from universal contexts, and is illustrated by the semantic representation (24d). Here the variable z is not bound by the starred variable z^* occurring in *mig*(z^*).

(24a) The pilot who chased it hit a mig that fired at him.
(24b) pilot(x^*) & chase(x, z) & mig(z^*) & fire-at(z, x)).
(24c) Every pilot who chased it hit a mig that fired at him.
(24d) (pilot(x^*) & chase(x, z) $\rightarrow$ mig(z^*) & fire-at(z, x)).

The conditions and side effects associated with inserting NPs of the form *every N* were given by the following list:

> The first argument must have the label CN, the second label S.
> The second label on the CN must be the same variable as the subscript on one of the pronouns occurring in the second argument.
> The pronouns in the second argument must be "bound" by the antecedents of the first argument.

Since the antecedents of the first and the second argument are not entered on the same level in the translation, it is possible to allow both arguments to share antecedents. It follows from the DRT restrictions on binding anaphora in implications that only the first argument can bind pronouns in the second. This seems to forbid cataphora completely in expressions that have an implicative translation. Sometimes, however, cataphora is reconstructed by the insertion rules as in (25). Intuitively, this seems correct.

(25) if he wins, every man rejoices$^+$

man$\hat{}\,x\hat{}\{x\}$ if he$_x$ wins, he$_x^+$ rejoices$^+$

he$_x^+$ wins$^+$ he$_x^+$ rejoices$^+$.

2.1.4. *Text and Coordination*. The fragment in the next section constructs texts from sentences (or sentence-like expressions, which may have indexed pronouns in their string representation) and common nouns and proper names. As an example consider the text (26).

(26) Harry loves a widow. He owns no donkey.

This corresponds with the expression (27), with (27a) as one of its meanings.

(27) Harry loves a widow. He owns no donkey.^TEXT.

(27a) $((\bot \to \bot) \to \text{harry} = x^* \ \&\ \text{widow}(y^*) \ \&\ \text{love}(y, x) \ \&\ (\text{donkey}(z^*) \ \&\ \text{own}\ (x, z) \to \bot))$.

(27) can be made by rule 20 from (28).

(28) Harry loves a widow. He owns no donkey.^T^$\{x, y\}$.

(28a) $\text{harry} = x^* \ \&\ \text{widow}(y^*) \ \&\ \text{love}(y, x) \ \&\ (\text{donkey}(z^*) \ \&\ \text{own}(x, z) \to \bot)$.

(28) has the analysis tree (28).

(29)

Harry loves a widow. He owns no donkey.^ T^$\{x, y\}$, 19

Harry loves$^+$ a widow^ T^$\{x, y\}$, 18 he^+_x owns$^+$ no donkey^7 S^$\emptyset$, 15

Harry loves$^+$ a widow^S^$\{x, y\}$, 11 donkey^CN^ z^$\{z\}$, 1 he^+_x owns$^+$ him^+_z^S^$\emptyset$, 4

Harry^PN^ x^$\{x\}$, 2 he^+_x loves$^+$ a widow^S^$\{y\}$, 12

widow^CN^ y^$\{y\}$, 1 he^+_x loves$^+$ him^+_y, 4.

Binding by x, the antecedent introduced by *Harry*, makes *he*^+_x into *he*, erasing gets rid of the +-mark on *owns*. The corresponding semantic tree is (30)

(30)

$\text{harry} = x^* \ \&\ \text{widow}(y^*) \ \&\ \text{love}(x, y) \ \&\ (\text{donkey}(z^*) \to (\text{own}(x, z) \to \bot)$, 19

$\text{harry} = x^* \ \&\ \text{widow}(y^*) \ \&\ \text{love}(x, y)$, 18 $(\text{donkey}(z^*) \to (\text{own}(x, z) \to \bot))$, 15

$\text{harry} = x^*$, 2 $\text{widow}(y^*) \ \&\ \text{love}(x, y)$, 12 $\text{donkey}(z^*)$, 1 $\text{own}(x, z)$, 4

$\text{widow}(y^*)$, 1 $\text{love}(x, y)$, 4.

One of the advantages of inserting NPs for subscripted pronouns is that the classical transformational grammar account of VP-coordination as conjunction reduction can be used without falling into the trap of deriving (31) from (31a–b). For this we require that the reductions under identity are limited to pronouns and verbs.

(31) Nobody likes Jane and dislikes Bill.
(31a) Nobody likes Jane.
(31b) Nobody dislikes Bill.

(31) is here derived by (32).

(32)

nobody likes Jane and dislikes Bill$\hat{}\{x, y\}$, 11

Jane$\hat{}$PN$\hat{}x\hat{}\{x\}$, 2 nobody likes him$_x$ and dislikes Bill$\hat{}$S$\hat{}\{y\}$, 11

Bill$\hat{}$PN$\hat{}y\hat{}\{y\}$, 2 nobody likes him$_x$ and dislikes him$_y\hat{}$S$\hat{}\emptyset$, 15

body$\hat{}$CN$\hat{}z\hat{}\{z\}$, 1 he$_z^+$ likes him$_x$ and dislikes him$_y\hat{}$S$\hat{}\emptyset$, 6

he$_z^+$ likes$^+$ him$_x^+\hat{}$S$\hat{}\emptyset$, 4 he$_z^+$ dislikes$^+$ him$_y^+\hat{}$S$\hat{}\emptyset$, 4.

The semantic representation of (32) under this derivation is (33).

(33) $\text{jane} = x^* \;\&\; \text{bill} = y^* \;\&\; (\text{body}(z^*) \rightarrow (\text{like}(z, y) \;\&\; \text{dislike}(z, y) \rightarrow \bot)$.

The examples in (34) give an impression of the cases which can be handled by the *coord* function, the string operation that takes care of coordination.

(34) John likes the singer and Mary likes the band.
John likes and admires himself.
John likes Bill and Mary Suzy.
John likes Bill and Mary.

2.1.5. *Proper Names and Definite Descriptions.* Kamp (1981b) treats proper names differently from other NPs. Proper names introduce their discourse referents in the highest box of the DRS under construction, whereas the other NPs introduce their referents in the current box. This is very difficult to reconstruct in a compositional treatment, since, when one works bottom up, the highest box (or its BL-counterpart) is not available. One solution would be to change the treatment of names in the semantics. This is straightforward, and is, in my opinion, the proper solution.[9]

The treatment in this paper follows another method, which has its problems. It consists in allowing proper names to be substituted not only for the first +-marked pronoun with the same variable, but also for the first pronoun with that variable in any S or T. The second possibility allows one to postpone introducing a proper name until the last possible moment in the derivation of a text. This means that the discourse referent can be at an arbitrarily high level. Though it does not put the discourse referent at the highest level automatically, it makes the prediction that coreference with a proper name is always possible, because it can always be entered at a sufficiently high level.

Substituting PNs for the first +-marked pronoun allows for cataphora in the same way as for other NPs. The conditions on this rule cannot be easily relaxed without making the wrong predictions on cataphora. For example, allowing arbitrary substitution for a pronoun with the right variable would lead to a coreferential reading for (35), which seems unacceptable.

(35) He came in and John sat down.

Counterexamples[10] to the treatment can be constructed by combining cataphora with pronoun binding out of an implication, as illustrated below.

(36) If no girl who likes him talks to Bill, he feels alone. He weeps.

To allow the cataphora *Bill* must be inserted in the antecedents of the first sentence. To allow *Bill* as an antecedent for *he* in the second sentence it must be entered outside of the implication. This would let *Bill* land on either the position of the first or the second pronoun in the sentence, but not its own place.

I do not see a way out that does not either complicate the syntax considerably or allows too much cataphora. This points in the direction of a semantic solution.[11]

Definite descriptions are here treated as similar in their binding properties to proper names. When the definite is either itself anaphoric or contains anaphors, rule 20 which transforms Ts in which all pronouns are bound into TEXTs rules out that they occur in positions where the antecedent is not available.

The translation of anaphoric definites makes them dual in nature: on the one hand they introduce a referent, (x in the example) and on the other hand they function as pronouns. This can provide an explanation for the German phenomenon (37), where the gender of a pronoun with a neuter antecedent can be influenced by an intervening definite description for the same object whose a head noun is feminine.

(37a) Ein Mädchen kommt herein. Die junge Dame hat einen schönen Hut. Sie lächelt.

(37b) Ein Mädchen kommt herein. Es lächelt.

Thus the neuter antecedent introduced by *Ein Mädchen* binds *die junge*

Dame in (37a); this in turn introduces a new antecedent, which is feminine and binds the female pronoun *sie*.

In (37b), this second antecedent is not available, so that the pronoun is neuter *es* instead.

2.1.6. *Quantification and Negation*. *Or*, *no*, *not*, *every* and *if* have in common that they bar antecedents introduced in their scope from binding pronouns outside their scope. The insertion rules allows NPs appearing in the surface scope of quantifying expressions to have wider scope than the latter. Sometimes pronoun binding enforces such readings as in (38).

(38) Every man who knows her loves a woman.
If he loses, no man rejoices.
John owns a donkey or rents it.

It is possible to translate *no* by (39b) which is logically equivalent with the translation in the fragment (39a), but makes different anaphoric predictions.

(39a) $(\alpha' \,\&\, \beta' \rightarrow \perp)$.
(39b) $(\alpha' \rightarrow (\beta' \rightarrow \perp))$.

(39b) would not allow cataphora. It seems however that one can detect, after some effort, two readings in (40).

(40) No man who knows it likes a donkey.
(40a) $\text{donkey}(y^*) \,\&\, (\text{man}(x^*) \,\&\, \text{know}(x, y) \,\&\, \text{like}(x, y) \rightarrow \perp)$.
(40b) $(\text{man}(x^*) \,\&\, \text{know}(x, y) \,\&\, \text{donkey}(y^*) \,\&\, \text{like}(x, y) \rightarrow \perp)$.

But there is only one in (41), where indeed no coreference from β to α is possible.

(41) Every man who knows it likes a donkey.
(41a) $\text{donkey}(y^*) \,\&\, (\text{man}(x^*) \,\&\, \text{know}(x, y) \rightarrow \text{like}(x, y))$.

But this is hardly a knock down argument in favour of the translation in the fragment.

2.2. *The Rules*

The Format of the Rules. In order to have a compositional formulation, it is necessary to separate the syntactic from the semantic process. It would be nevertheless be more economical to have the semantic information available in the syntactic rules.[12] The antecedent feature which is employed for the purpose of pronoun binding is semantic in nature: the set of antecedents is precisely the first coordinate of the BL-interpretation from Section 1 of this paper. The other feature which we add to the syntactic structures corresponding to common nouns is a variable. This is the variable introduced by the head noun of a (complex) common noun. In the system, it is responsible for the identity between the subject or object argument of a verb translation with the variable that is introduced by the translation of the head noun of the subject or object.

The preferred interpretation is here not categorial, as in Montague grammar. Rather there is a single set of w(ell) f(ormed) e(xpression)s that consists of labelled strings. The strings are labelled, in the case of CNs and PNs, by the category mark CN or PN, a variable, and a finite set of antecedents, again variables. In order to deal with gender agreement, we will assume that every variable comes with a sort male, female or neuter. S(entence)s and T(ext)s are only labelled for antecedents.

The function of the label TEXT without other labels is to define the set of strings recognized by the grammar: this set equals $\{\alpha\colon \alpha\hat{}\text{TEXT}$ is a wfe$\}$. If $\alpha\hat{}\text{TEXT}$ is a well formed expression, α is to be a text consisting of syntactically correct sentences without any indices or labels and that has a semantic representation that evaluates on a model as either the True or the False (cf. Section 3).

As usual, strictly speaking, the grammar assigns meanings to analysis trees, rather than to labelled strings. Annotated strings can, and usually do, have a number of meanings.

Syntactic rules now correspond to partial operations over the set of well formed expressions. We could think of the partial operations as being total since it would be possible to let a partial operation denote the improper string if the conditions associated with the operation are not satisfied. The rules are all of the form:

$$\begin{aligned}&\text{if } \alpha_1\hat{}A_1, \ldots, \alpha_n\hat{}A_n \text{ are wfes and } C_1, \ldots, C_k \text{ then}\\ &f(\alpha_1, \ldots, \alpha_n)\hat{}g(A_1, \ldots, A_n) \text{ is a w.f.e.}\end{aligned}$$

where the C_i range over conditions, and f and g are string operations. A formation of the corresponding complete operation would be explained by adding the proviso "else Λ" at the end of a rule, where Λ is the improper expression. Expressions will be of one of the forms listed below:

$$\alpha\hat{}\text{CN}\hat{}x\hat{}\{x_1, \ldots, x_n\}$$
$$\alpha\hat{}\text{PN}\hat{}x\hat{}\{x_1, \ldots, x_n\}$$

α^S^$\{x_1, \ldots, x_n\}$
α^T^$\{x_1, \ldots, x_n\}$
α^TEXT

where α is a string and x and $x_1, \ldots, x_n$ are variables.
The following are examples of lexical items:

boy^CN^x^$\{x\}$
Bill^PN^x^$\{x\}$
he$_x^+$ likes$^+$ him$_y^+$^S^$\emptyset$
he$_x^+$ likes$^+$ himself$_x$^S^$\emptyset$
he$_x^+$ walks$^+$^S^$\emptyset$.

Examples of more complex expressions are:

John likes$^+$ himself^S^$\{x\}$
the girl walks. she likes a donkey.^T^$\{x, y\}$
man whom Mary likes^CN^x^$\{x, y\}$
if Harry comes, he will be glad. he likes a widow.^TEXT.

The Lexicon. The lexical elements may be thought of as generated by the following five rules from a more conventional lexicon. The bullet (•) will be used for string concatenation.

(S1) If α is common noun, and x is a variable of the appropriate gender, then α^CN^x^$\{x\}$ is a wfe.
(T1) $\alpha'(x^*)$
(S2) If α is proper name and x is a variable of the appropriate gender, then α^PN^x^$\{x\}$ is a wfe.
(T2) $\alpha' = x^*$
(S3) If α is an intransitive verb and x is a variable, then *he*$_x^+ \bullet \alpha^+$^T^$\emptyset$ is a wfe.
(T3) $\alpha'(x)$
(S4) If α is a transitive verb and x and y are different variables, then *he*$_x^+ \bullet \alpha^+ \bullet$ *him*$_y^+$^S^$\emptyset$ is a wfe.
(T4) $\alpha'(x, y)$
(S5) If α is a transitive verb and x is a variable, then *he*$_x^+ \bullet \alpha^+ \bullet$ *himself*$_x$^S^$\emptyset$ is a wfe.
(T5) $\alpha'(x, x)$.

The other rules tend to use a number of string operations, which are defined in the next section.

String Operations.

Pronoun Binding. bind$(X, \alpha, \delta) = \beta$ iff β results from replacing every pronoun and definite article except δ in α that is marked by a variable x in X by the unmarked form of the pronoun that has the gender of x, or by the unmarked form of the article.

Example:

$$\text{bind}(\{x, y, z\}, \text{he}_x^+ \text{ loves}^+ \text{ him}_y^+, \text{him}_y^+) = \text{she loves}^+ \text{ him}_y^+.$$

Relative Clauses. relativize$(\delta, \alpha, x) = \beta$ iff β results from α by removing δ and all the +-marks, and preposing the relative pronoun that has the case of δ and the gender of x.

Example:

$$\text{relativize}(\text{him}_y^+, \text{he}_x^+ \text{ loves}^+ \text{ him}_y^+, y) = \text{whom he}_x \text{ loves.}$$

Negation. negate$(\delta, \alpha) = \beta$ iff β results from substituting does$\bullet$not$\bullet\epsilon$ for δ in α, where ϵ is the infinitival form of δ.

Example:

$$\text{negate}(\text{loves}^+, \text{he}_x^+ \text{ loves}^+ \text{ him}_y^+) = \text{he}_x^+ \text{ does not love him}_y^+.$$

NP Insertion. insert$(\delta, \alpha, \beta) = \gamma$ iff γ results from substituting α for δ in β.

Erasing +-Marks. erase$(\alpha) = \beta$ iff β is α without +-marks.

Coordination

(1) coord$(\textbf{\textit{he}}_x^+ \bullet \alpha, \textbf{\textit{he}}_x^+ \bullet \beta, c) = \textbf{\textit{he}}_x^+ \bullet$coord$(\alpha, \beta, c)$.

(2) coord$(\alpha \bullet \textbf{\textit{him}}_x^+, \beta \bullet \textbf{\textit{him}}_x^+, c) =$ coord$(\alpha, \beta, c) \bullet \textbf{\textit{him}}_x^+$.

(3) coord$(\alpha \bullet \textbf{\textit{himself}}_x^+, \beta \bullet \textbf{\textit{himself}}_x^+, c) =$ coord$(\alpha, \beta, c) \bullet \textbf{\textit{himself}}_x^+$.

(4) coord$(\alpha_0 \bullet \delta \bullet \alpha_1, \beta_0 \bullet \delta \bullet \beta_1, c) =$ erase$(\alpha_0) \bullet \delta \bullet$erase$(\alpha_1 \bullet \beta_0 \bullet \beta_1)$ iff δ is a +-marked verb, and 1, 2 and 3 do not apply.

(5) coord$(\alpha, \beta, c) =$ erase$(\alpha \bullet c \bullet \beta)$ iff α and β are nonempty strings, and 1, 2, 3 and 4 do not apply.

Coordination.

(S6) If α^S^A and β^S^B are wfes and A and B are disjoint, then coord$(\alpha$, bind(A, β, Λ), ***and***$)$^S^$A \cup B$ is a wfe.

(T6) α' & β'

(S7) If α^S^A and β^S^B are wfes, then coord$(\alpha, \beta, \textit{or})$^S^$\emptyset$ is a wfe.

(T7) $((\alpha' \rightarrow \bot) \rightarrow \beta')$.

Definites.

(S8) If $\alpha\hat{}\mathrm{CN}\hat{}x\hat{}A$ is a wfe, and y is a variable, $y \notin A$, then $the_y \bullet \alpha\hat{}\mathrm{PN}\hat{}x\hat{}A$ is a wfe.

(T8) α' & $x = y$

(S9) If $\alpha\hat{}\mathrm{CN}\hat{}x\hat{}A$ is a wfe, then $the \bullet \alpha\hat{}\mathrm{PN}\hat{}x\hat{}A$ is a wfe.

(T9) $D(x^*, \alpha')$.

Relative Clauses

(S10)[13] If $\alpha\hat{}\mathrm{XN}\hat{}x\hat{}\{x\}$ and $\beta\hat{}\mathrm{S}\hat{}B$ are wfes, XN is CN or PN and A and B are disjoint, δ is the first x- and +-marked pronoun in β, then $\mathrm{bind}(\{x\} \cup B, \alpha \bullet \mathrm{relativize}(\delta, \beta, x), \delta)\hat{}\mathrm{XN}\hat{}x\hat{}\{x\} \cup B$ is a wfe.

(T10) α' & β'.

Insertion

(S11) If $\alpha\hat{}\mathrm{PN}\hat{}x\hat{}A$ and $\beta\hat{}\mathrm{S}\hat{}B$ or $\beta\hat{}\mathrm{T}\hat{}B$ are wfes, A and B are disjoint and δ is the first x-marked nonreflexive or the first x- and +-marked pronoun in β, then $\mathrm{bind}(A \cup B, \mathrm{insert}(\delta, \alpha, \beta), \delta)\hat{}\mathrm{S}\hat{}A \cup B$ is a wfe.

(T11) α' & β'

(S12) If $\alpha\hat{}\mathrm{CN}\hat{}x\hat{}A$ and $\beta\hat{}\mathrm{S}\hat{}B$ are wfes, A and B are disjoint and δ is the first x- and +-marked pronoun in β, then $\mathrm{bind}(A \cup B, \mathrm{insert}(\delta, a(n) \bullet \alpha, \beta), \delta)\hat{}\mathrm{S}\hat{}A \cup B$ is a wfe.

(T12) α' & β'

(S13) If $\alpha\hat{}\mathrm{CN}\hat{}x\hat{}A$ and $\beta\hat{}\mathrm{S}\hat{}B$ are wfes, A and B are disjoint and δ is the first x- and +-marked pronoun in β, then $\mathrm{bind}(A \cup B, \mathrm{insert}(\delta, one \bullet \alpha, \beta), \delta)\hat{}\mathrm{S}\hat{}A \cup B$ is a wfe.

(T13) $D(x^*, \alpha'$ & $\beta')$

(S14) If $\alpha\hat{}\mathrm{CN}\hat{}x\hat{}A$ and $\beta\hat{}\mathrm{S}\hat{}B$ are wfes and δ is the first x- and +-marked pronoun in β, then $\mathrm{bind}(A, \mathrm{insert}(\delta, every \bullet \alpha, \beta), \delta)\hat{}\mathrm{S}\hat{}\emptyset$ is a wfe.

(T14) $(\alpha' \rightarrow \beta')$

(S15) If $\alpha\hat{}\mathrm{CN}\hat{}x\hat{}A$ and $\beta\hat{}\mathrm{S}\hat{}B$ are wfes and δ is the first x- and +-marked pronoun in β, then $\mathrm{bind}(A \cup B, \mathrm{insert}(\delta, no \bullet \alpha, \beta), \delta)\hat{}\mathrm{S}\hat{}\emptyset$ is a wfe.

(T15) $(\alpha'$ & $\beta' \rightarrow \bot)$.

If-clauses

(S16) If $\alpha\hat{}\mathrm{S}\hat{}A$ and $\beta\hat{}\mathrm{S}\hat{}B$ are wfes, then $if \bullet \mathrm{erase}(\alpha) \bullet \mathrm{bind}(A, \beta, \Lambda)\hat{}\mathrm{S}\hat{}\emptyset$ is a wfe.

(T16) $(\alpha' \rightarrow \beta')$.

Negation

(S17) If $\alpha\,\hat{}\,\mathrm{S}\,\hat{}\,A$ is a wfes and δ is the first +-marked verb in α, then negate(δ, α)$\hat{}\,\mathrm{S}\,\hat{}\,\emptyset$ is a wfe.

(T17) $(\alpha' \rightarrow \perp)$.

Text

(S18) If $\alpha\,\hat{}\,\mathrm{S}\,\hat{}\,A$ is a wfe, then erase($\alpha\bullet$.)$\hat{}\,\mathrm{T}\,\hat{}\,A$ is a wfe.

(T18) α'

(S19) If $\alpha\,\hat{}\,\mathrm{T}\,\hat{}\,A$ and $\beta\,\hat{}\,\mathrm{S}\,\hat{}\,B$ are wfes and A and B are disjoint, then $\alpha\bullet\mathrm{bind}(A, \mathrm{erase}(\beta), \Lambda)\hat{}\,\mathrm{T}\,\hat{}\,A \cup B$ is a wfe.

(T19) α' & β'

(S20) If $\alpha\,\hat{}\,\mathrm{T}\,\hat{}\,A$ and α contains no variable marked pronouns, then $\alpha\,\hat{}\,$TEXT is a wfe.

(T20) $((\perp \rightarrow \perp) \rightarrow \alpha')$.

3. Conclusion

Sections 1 and 2 together form a proof that there is no conflict between the assumptions of *Universal Grammar* and the theory set out in Kamp 1981b. The proof can itself be taken as an explanation of what DRT means in terms of a compositional framework. But there is a further question as to the usefulness from a logico-linguistic point of view, of both the formal language developed in Section 1 and of the fragment in Section 2. These considerations do not reflect on their status as elements in a proof or as an interpretation of DRT, but do have a bearing on the question whether DRT should be developed further in a compositional framework and whether one can be satisfied with the idea that it could be done.

An example of the latter situation is the use of Cooper stores (Cooper and Parsons, 1976). Cooper stores themselves do not fit into compositional semantics in the strict sense, but it can be shown that they reconstruct, in a systematic way, the quantifying rules of PTQ. They allow the linguist to develop a theory of syntactical derivation without bothering about quantifier scope ambiguities. Perhaps the same situation obtains here: the DRS construction algorithm could be taken as a reconstruction of a bothersome compositional formulation that one does not want to impose on the linguist when he is concerned with syntactical phenomena. My suspicion is that this is not the case. The only restriction placed on Kamp's construction algorithm seems to be that it is recursive in the given DRS and in the syntactic analysis of the sentence that is being treated. The compositional reconstruction given in this paper is essentially more constrained. It demands that the translation of an expression $f(A, B)$ is given by an operation on the meanings of A and B. So we have no proof – and it is unlikely that there could be one – that an arbitrary DRS construction algorithm can be reconstructed compositionally. What we have shown is that certain DRT analyses, notably discourse anaphora and the treatment of donkey sentences, can indeed be reconstructed compositionally. It is unproblematic to extend this to the treatments of temporal anaphora that have been given (e.g., (Kamp 1981a), (Kamp and Rohrer, 1983)). To what extent analyses of other phenomena allow a similar reconstruction is an open question.

It may be hard to recognize one's intuitions about meaning in a theory that equates meanings with pairs consisting of a finite set of variables and a set of assignments. It should be noted however, that the same holds for algebraic interpretations of first order logic to which our approach is closely related. The notion of an assignment is certainly an artefact produced in the course of developing a satisfactory and mathematically tractable semantic account of first order logic.

The intuition underlying the interpretation of a first order formula with free variables as a set of assignments is the notion of a relation. If $x_1, \ldots, x_n$ are all the free variables in $\phi(x_1, \ldots, x_n)$, $\phi(x_1, \ldots, x_n)$ can be thought of as denoting the set $\{\langle a_1, \ldots, a_n\rangle \mid M \vDash \phi(a_1, \ldots, a_n)\}$ in a model M. Universal and existential quantification over the first variable correspond with simple operations on such set: If R is an n-place relation over a set A, its universal and existential projections over the first coordinate are the following $n-1$-place relations.

$$\{\langle a_2, \ldots, a_n\rangle \mid \{a \mid \langle a, a_2, \ldots, a_n\rangle \in R\} = A\}$$
$$\{\langle a_2, \ldots, a_n\rangle \mid \{a \mid \langle a, a_2, \ldots, a_n\rangle \in R\} \neq \emptyset\}$$

Using these relations as a semantics for first order logic leads to a number of complexities in stating the meaning of conjunction, negation, and in dealing with multiple occurrences of the same variable. The reason is that the information regarding the variables is lost in passing from the formula to the set. These problems can be solved by adding various combinators to the language, but a simpler solution is really to employ analogues of the relations that maintain a connection with the variables. These are sets of assignments.

The notion of meaning for a DRS developed in Section 1 can be brought into the same relation with a relational interpretation. The set of discourse markers then corresponds with giving a number of its coordinates a special status. Let's call a relation with a number of special coordinates a *marked relation*. We then have natural universal and existential operations on the marked relation R, by letting them operate over the special coordinates, instead of over the first one. For example let R be a marked $m+k$-place relation, where the first m places are marked. The following two operations then correspond to universal and existential quantification.

$$\{\langle a_{m+1}, \ldots, a_n\rangle | \{\langle a_1, \ldots, a_m\rangle | \langle a_1, \ldots, a_m, a_{m+1}, \ldots, a_n\rangle \in R\} = A^m\}$$
$$\{\langle a_{m+1}, \ldots, a_n\rangle | \{\langle a_1, \ldots, a_m\rangle | \langle a_1, \ldots, a_m, a_{m+1}, \ldots, a_n\rangle \in R\} \neq \emptyset\}.$$

So all that changes on this level is that the quantification operations no longer operate on the first coordinate by convention, but on a given set of coordinates that is given with the relation. That it is still preferable to operate with assignments and variables has again to do with obtaining a tractable account of the other operations in the logic and of multiple occurrences of the same variable.

There is another more philosophical way in which our account of meaning can be defended. This uses two of Frege's principles. The first is the thesis that incomplete expressions do not have an autonomous meaning that can be characterised by itself, but must be characterised in terms of the contribution they make to the meanings of complete expressions. The second principle is that the meaning of an (extensional) sentence is either the True or the False.

It seems that this is also the proper way to defend the algebraic interpretation of predicate logic. The open formulae are incomplete expressions that should be characterised by the semantic contribution that they make to the interpretation of sentences, where these are the only complete expressions. Sentences in predicate logic do indeed denote the True or the False, if we equate those with the set of all assignments, or the empty set of assignments.

The same holds for our system. The fragment in Section 2 has only one kind of complete expression: the expresssions that are annotated by TEXT. The meaning of those is always one of:

$$\langle \emptyset, G\rangle$$
$$\langle \emptyset, \emptyset\rangle$$

which are the natural analogues here of the True and the False. A BL-sentence may fail to conform to this pattern, but there is a simple operation on BL-sentences that transforms them to formulae that do conform, e.g.,

$$((\phi \rightarrow \bot) \rightarrow \bot).$$

An interesting aspect of (Heim, 1982) is that it gives a different account of meaning which may be taken as an alternative to the psychological theory. Every well formed expression corresponds with a systematic change from one information state to another. As such, one may consider that a certain amount of compositionality on the level of meaning is maintained: one should be able to give a system that predicts from primitive changes associated with lexical items, and the syntactical functions that are used in constructing a compound expression, the change that is to be associated with a compound expression. Such a change can be expressed both on the representation level, and on the level of its interpretations.

It is quite straightforward to carry out this program using the present system. In the fragment, we have associated natural language expressions E with a class of semantic representations E' which are interpreted as pairs consisting of a set of discourse markers and a set of assignments. Now let D be a DRS with $\mathrm{FV}(D) = \emptyset$ – other DRSs are not really carriers of information. E' is a proper addition to D iff $\mathrm{FV}(E') \subseteq [\![D]\!]_0$, and $[\![E']\!]_0 \cap [\![D]\!]_0 = \emptyset$. This ensures that also the new information state will be a proper information state. Under these conditions $merge(D, E')$ is the new information state, a DRS that again has no free variables. In this way, we have associated a partial function from information states to information states with each interpreted expression. If we go below the level of interpreted expressions and look at the classes of meanings associated with certain strings by the system, one sees that any string corresponds with a relation between old and new DRSs. The composition of these relations is indeed capturing what happens when we keep on adding new sentences to a text: this is a series of merges of possible meanings in which all the pronouns in the new sentences are resolved from the given text. Below the sentence level, however, the situation is more complicated, and other operations besides merge are required.

In the introduction I stated that one of the aims of reconstructing Kamp's ideas in a compositional way is to eliminate the psychological interpretations which they seem to invite. Indeed, it would be possible to interpret the fragment directly so that the intermediate level of discourse representations disappears, as we can do with intensional logic in Montague grammar. Thus, there is no need for a psychological interpretation of this level: the properties of the representation language become structural properties of the definition of interpretation for natural language. But this implies that there is a difference between the way in which we characterise the interpretation of our standard logical languages and the way we have to interpret natural languages. This in its turn makes DRT relevant for psychology.

Montague grammar employs a logical formalism which is derived from a long tradition in mathematical and philosophical logic. This is sound practice: we know that a large number of problems can be described in this formalism and we would be surprised if we would find some content that cannot be adequately characterised in it.

So Montague's logical language appears to be a neutral vehicle for conveying meaning. What is revealed by donkey sentences and discourse anaphora is that the structure of languages of this type prevents their compositional treatment in natural language semantics. DRT can be seen as claiming that natural language interpretation is different from what we are accustomed to in standard logic.

The implication of this is that natural language places constraints on the structure of the logical formalisms that can interpret it: natural language is not neutral in this respect. This is a significant fact about human language which must have a psychological explanation. Since our dealings with natural language are bound to be closely related to other cognitive abilities, these constraints may have relevance for the study of human cognition, especially in the areas of human reasoning and information storage.

NOTES

[1] (Kamp, 1981b; Kamp and Rohrer, 1983), (Kamp, 1981a) and (Kamp, 1985). Very similar ideas have been worked out simultaneously by Irene Heim in (Heim, 1982).

[2] Mentalistic interpretations have until recently not reached the literature. More overtly mentalistic are (Guenthner, 1987) and my own (Zeevat, 1987).

[3] I depart from Kamp in adding the symbol $\perp$ for absurdity. This is sufficient for defining disjunction and negation.

[4] As usual, a language is a set of non-logical constants. At_L is the set of atomic formulae of a language L.

[5] In van Eijck, 1985, pp. 62–63 the meaning of a DRS is essentially a set of assignments. One would therefore expect the same problem to arise in his compositional definition of the semantics of DRSs. That it does not, has to do with the notion "part of a DRS" he employs. Under his definition, DRSs for sentences (such as the donkey sentence) that are implications have only themselves as parts. Compositionality for implications is then trivial: the identity function on meanings will do. But it is hardly what one wants, since the meaning of formulae of arbitrary complexity remains unaccounted for.

[6] The exception is "free choice" *any*.

[7] The alternatives to them that I am aware of such as Cooper storage, or the algorithm for *f*-structures in Reyle, 1985, are not compositional in the strict sense employed here.

[8] One other case, which is not in the fragment, are objects in PPs. They should be accessible for insertion as long as the verb that dominates them is the main verb of the sentence.

[9] See (Zeevat, 1987) for such a treatment.

[10] I owe these counterexamples to one of the referees of this paper.

[11] A syntactic solution would need a restriction of insertion to "a pronoun occurrence that is preceded only by occurrences of the same pronoun that it c-commands". The indexing mechanism, which in the standard case captures a notion of c-command, is not capable of expressing it globally. The only way out would be to have c-command as a recursive property defined on analysis trees. Postponed insertion is unnatural as well, since it conflicts with incrementality of interpretation. Incorporating a semantical solution for proper nouns, on the other hand, is easy. Proper names would not introduce discourse referents any more, but only antecedents. Proper name antecedents would not disappear from implications, as the normal antecedents. Such a treatment can be extended to descriptions.

[12] This is assumed in various unification based frameworks, starting with Head-driven Phrase Structure Grammar (Pollard, 1985). The compositionality issue in these frameworks is best addressed by interpreting the derivation of the integrated structure as the syntactic derivation, and checking if the projection of the derivation to its semantical coordinates can be interpreted as a polynomial in the semantic algebra. The syntax as given here becomes slightly more concise if it is expressed in the HPSG style, since the set of antecedents, and the set of discourse referents in the semantics are the same. Frameworks like HPSG allow semantic information to have a bearing on the derivation of the integrated structure. This also holds for the fragment here, since the set of antecedents, which properly belongs in the semantics, controls the pronoun binding, which belongs to the syntax.

[13] This rule stands in need of a provision that disallows multiple relatives clauses. It allows, for definites, a distinction between restrictive and non-restrictive relative clauses. For the definitional definites there is even a semantic distinction: if ϕ translates the noun and ψ the relative clause, (42a) is the restrictive, (42b) the non-restrictive version.

(42a) $D(x^*, \phi \mathbin{\&} \psi)$

(42b) $D(x^*, \phi) \mathbin{\&} \psi)$.

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