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Linguistically motivated knowledge representation

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LINGUISTICALLY MOTIVATED KNOWLEDGE REPRESENTATION

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Any system which is to be able to process natural language data in a communicatively adequate way will need a vast data base containing sources of different types of knowledge. This paper presents a typology of these knowledge sources, and argues that most of the relevant knowledge types can be represented in the form of predicate frames and predications as defined by the theory of Functional Grammar (FG). The paper further develops an interactive bottom-up and top-down model of interpretation, and illustrates how this model can be used in utilizing knowledge sources in the interpretation of natural language data.

1. INTRODUCTION

As a linguist I am interested in systems which can handle natural language data in a communicatively adequate way. Let us call such systems Natural Language Users (NLUs). We know millions of NLUs that are extremely good at their task, but whose internal structure and functioning are only fragmentarily understood. These are *human* NLUs (HNLUs). On the other hand we have systems whose internal wiring and processing are fully understood, but who are, as yet, not very good at handling natural language data. These systems may be called *computational* NLUs (CNLUs).

I think it is a very interesting enterprise to try and teach CNLUs to become ever better NLUs, thus approaching HNLUs in their capacity of processing natural language data.

There is no doubt a great variety of jobs for which proficient CNLUs could be used. My personal interest, however, lies in the theoretical side of the matter. A CNLU which is proficient in any aspect of natural language processing can, in that aspect, be regarded as a model of the HNLU. Building a CNLU may thus teach us how the HNLU might work, in the same way as any operational model of any empirical phenomenon may make us understand something about the real-life properties of that phenomenon. Constructing a CNLU is thus one road towards insight into the properties of HNLU.

Note that for such a program to be interesting, it is immaterial whether or not it will ever be possible to construct a CNLU with the same capacity and facility for handling natural language data as the HNLU. Either this is possible, in which case we must certainly do it; or it is not possible, in which case by seeing how far we can get, we can find out why it is impossible.

2. MINIMAL REQUIREMENTS ON CNLU

The following minimal requirements will have to be imposed on any CNLU:

(i) CNLU must be able to analyse NL expressions;

(ii) CNLU must be able to interpret the content of these expressions in the light of the knowledge which it already possesses;

(iii) CNLU must be able to produce NL expressions which tie in with the context in a communicatively adequate way.

These minimal requirements on CNLU may be represented as in Figure 1:

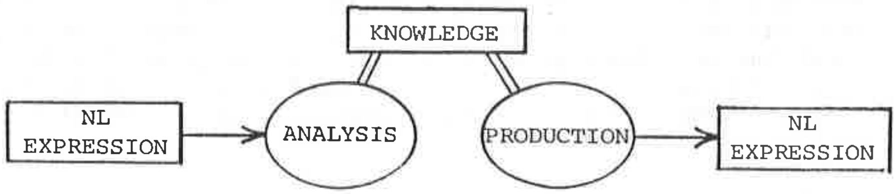

FIGURE 1
Minimal components of CNLU

Any CNLU will thus have to contain one or more components in which that knowledge is stored which is required for analysing and producing linguistic expressions. This paper concentrates on the following questions relevant to the knowledge component of CNLU:

(Q1) The question of knowledge *typology*: what distinct types of knowledge are involved in processing linguistic expressions ?

(Q2) The question of knowledge *representation*: how can these different types of knowledge be represented in the system ?

(Q3) The question of knowledge *utilization*: how are these different kinds of knowledge mobilized and used in the actual processing of linguistic expressions ?

With respect to these questions the following theses will be defended:

(T1) The adequate processing of even the simplest NL expression requires knowledge of a great variety of types.

(T2) Most of this knowledge can be represented in a linguistically motivated way. More specifically:

a. knowledge can be represented by structures which contain the lexical contentive predicates of the natural language involved;

b. the form of these knowledge representation structures can be derived from the theory of Functional Grammar (FG) in the sense of Dik (1978a, 1980a) and later publications.

(T3) In processing linguistic expressions, knowledge is utilized in an interactive way, involving continuous parallel top-down and bottom-up processing.

3. KNOWLEDGE REPRESENTATION

The standard assumption in Artificial Intelligence and Cognitive Science in general is that knowledge should be represented in some language-independent code, consisting of structures (trees, graphs, networks) filled with language-independent elements which symbolize the most fundamental conceptual distinctions that human beings make. Thus, even though one may use English words in conceptual representations, there is typically a footnote warning the reader that these English words are but a makeshift device, doing temporary service for the 'real' conceptual elements of which conceptual structures are assumed to consist.

Thus, when Lindsay and Norman (1977: 395) propose the semantic network given in Figure 2 for the English sentence:

(1) Patrick is cooking supper for Cynthia

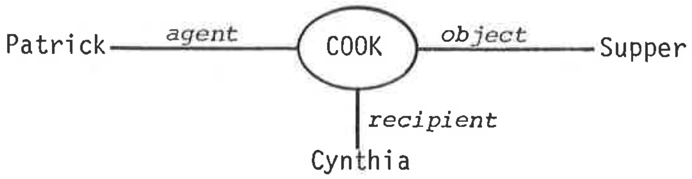

FIGURE 2.
Semantic network for sentence (1)

they hasten to add the following comment (*ibid.* 390):

> 'Obviously, we do not believe that the propositions and concepts in memory are specified by verbal descriptions of this sort ... Actually, the propositions themselves are probably decomposable into a rich, interlocking structure of more fundamental concepts.'[1]

It is clear what motivates this abstract view of the knowledge representation code. The idea is that human intellectual capacities are the same, no matter what language they speak. How, then, could one develop a general insight into human reasoning if one were to stay within the limits of a single natural language ? And how could one account for the possibility of translating from one language to another, *salva significatione*, if there were no language-independent conceptual code mediating between source and target language ?

In spite of its initial plausibility, however, the idea that knowledge is represented in a language-independent code raises a number of questions which throw doubt on its feasibility. Consider the following points:[2]

(a) In practice, even those who firmly believe in the language-independent code always use words of some specific language in giving their examples of conceptual structures. Apparently, NL expressions are quite efficient means for representing knowledge.

(b) Every competent speaker has a solid knowledge of at least one natural language, providing him with a theoretically unlimited repertory of linguistic expressions in which almost any conceivable content can be expressed. Suppose that he also possesses a language-independent code for representing knowledge. Then, for any expression in his native language, there must be some 'shadow expression' in the conceptual language, into and out of which the NL expression must be translated whenever knowledge is stored or utilized. This would certainly not seem to be a very efficient organization of human symbolic competence.

(c) If there is one common conceptual language for all mankind, why are the actual natural languages so different from each other ? One would, in that case, expect them to be more direct mappings of the universal underlying conceptual structures. Why should natural languages hide rather than reveal the underlying conceptual organization in terms of which human reasoning is supposed to operate ?

(d) Translatability is hardly ever complete. Not only the linguistic organization, also the conceptual structure may differ from one language to another. Thus, it is doubtful whether translatability could be accounted for in terms of identity of the underlying conceptual code across languages. It is probably better accounted for in terms of partial equivalences between the actual surface expressions of different languages.

For these various reasons I will assume that conceptual representation is less language-independent than it is often assumed to be. More specifically, I will assume that knowledge representations consist of structures which are organized around the actual content words of the language in which the knowledge is expressed. This means that the structure given in Figure 2, as an approximation of the semantic structure of (1), can at the same time be seen as an approximation of the knowledge contained in (1). The main objection to the structure of Figure 2 is that it is insufficiently detailed to do justice to the full content of (1).

The most obvious counter-argument to this view is the following: it is clear, one would say, that such notions as 'cook' or 'supper' are not elementary conceptual notions. How, then, can structures in which these items occur capture the conceptual richness of sentence (1) ? To this counter-argument we can reply with a counter-question: it is also clear, we would say, that such notions as 'square' or 'triangle' are not elementary concepts of Euclidean geometry. Nevertheless, no-one would think of replacing these notions by their definitions in any context in which they occur. It is precisely the fact that 'square' and 'triangle' are *defined* concepts of geometry which allows them to be used in higher-order geometrical conceptualizations. In the same way, complex notions such as 'cook' and 'supper' can be used in higher-order linguistic conceptualizations, since they can be defined in terms of more elementary concepts of the same language.

As for translatability, sentence (1) is a good illustration of point (d) above. This sentence is rather difficult to translate even into a closely related language like Dutch. First, the proper names *Patrick* and *Cynthia* have no direct counterparts in Dutch. Second, English *cook* overlaps, but is not coextensive with its closest equivalent in Dutch, *koken*. For example, *cook breakfast* or *cook a steak* cannot be directly translated with *koken*. On the other hand, *koken* does all the work that is done by *boil* in English. Third, there is no direct counterpart to English *supper*. This word depends on the custom of having a (potential) evening meal distinct from dinner; this custom does not exist in Dutch society. It is therefore impossible to translate (1) into Dutch without either adding or subtracting elements of content, as compared to the original.

There are good reasons, then, for assuming that knowledge representations contain the actual content words of the natural language in which the knowledge is expressed. There are also good reasons, however, for assuming that knowledge representation structures are more abstract than the actual linguistic expressions of any one language. These reasons are the following:

(i) Some linguistic expressions are synonymous in the sense of embodying the same knowledge, presented in different ways. Consider:

(2) a. Patrick kissed Cynthia
    b. Cynthia was kissed by Patrick

In these two sentences much the same event, consisting of Patrick's kissing Cynthia, is presented in two different ways. The differences of presentation may be contextually motivated, but they are not essential to the knowledge of what happened. We would thus like to have a form of knowledge representation in which the differences between (2a) and (2b) may be disregarded. This means that we need a knowledge structure which is more abstract than either (2a) or (2b), and which can capture the common core of information contained in these two linguistic expressions. There is empirical psychological support for such a more abstract level in that a person informed of the event in question through (2b), and later asked to recall what happened, may well respond with (2a) without even noticing that he presents the information in a different way. Conversely, a person informed through (2a) may later report the event in the form of (2b) in a context in which in some sense the focus of attention is on Cynthia rather than on Patrick.

(ii) Some linguistic expressions are ambiguous or homonymous in the sense of having different possible interpretations which relate to quite different knowledge structures. For example:

(3) Patrick didn't like Cynthia's kissing him

For determining the knowledge imparted by this expression, it is rather essential to know whether *him* refers to the same person as *Patrick*, or to some quite different person in the context or situation. The ambiguity of the expression must therefore be resolved at the level of knowledge representation.

(iii) Certain elements which are essential to the grammatical form of the expression are quite immaterial to the knowledge embodied in the expression. Consider the following pairs:

(4) a. the man vs. Patrick
b. fox-es vs. ox-en

At first sight the definite article *the* is essential for expressing the definiteness of the noun phrase *the man*; however, *Patrick*, though lacking the article, is just as definite as *the man*. This implies that 'definiteness' will play a role in knowledge representations, but that the definite article as such will not figure in such representations. Similarly, the difference between the endings *-es* and *-en* is essential for grammatical correctness, but makes no difference for the 'plurality' which is relevant at the level of content.

I conclude from this discussion that knowledge representation structures must on the one hand be concrete enough to accomodate the actual content words of a language, on the other hand sufficiently abstract to capture synonymies, resolve ambiguities, and disregard conceptually irrelevant details of grammatical expression. It is here that Functional Grammar comes in.

4. SOME ELEMENTS OF FUNCTIONAL GRAMMAR

Functional Grammar is a general theory of the grammatical organization of natural languages, based on a functional view of the nature of language. A view, in other words, in which a natural language is regarded as an instrument used for communicative purposes.

FG seeks to make itself sensitive to criteria of typological, pragmatic, and psychological adequacy. Typological adequacy is achieved to the extent that the theory is applicable to languages of any arbitrary type; pragmatic adequacy means that the theory should make one understand how it is that linguistic expressions with given structural properties can be used with specific communicative effects in natural language interaction; and psychological adequacy implies that a grammar developed according to FG specifications should be a good candidate for incorporation into operational models of natural language users.

One test for the overall adequacy of FG, then, is to see to what extent this theory can be used in constructing CNLU. For one thing, this means that we are in need of a procedural reinterpretation of the rules and principles of FG, which have so far been developed mainly on the basis of the criterion of typological adequacy. The underlying assumption is, however, that those principles which are most adequate for generalizing over languages of many different types at the same time stand the best chance of capturing the basic psychological and communicative mechanisms which govern the ways in which natural languages are used.[3]

There is obviously no room here for giving a full description of the FG model as it has been developed so far. For this, I must refer to the relevant literature. Here, I will concentrate on those aspects of FG which would seem to be most essential to the present discussion. From this point of view, the basic structure of the FG model can be represented as in Figure 3:

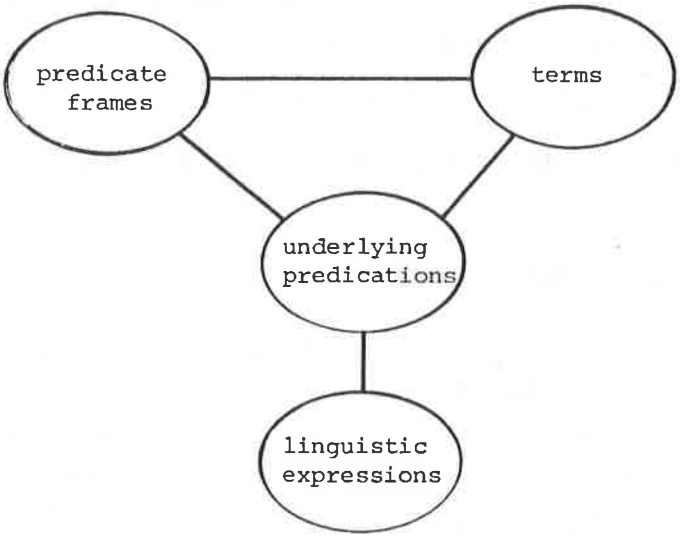

Figure 3.
Simplified outline of FG

Reading Figure 3 from bottom to top, we can say that a linguistic expression is analysed in terms of an underlying predication, which can in turn be taken apart into predicate frames and terms, where these terms can again be analysed as built up from predicate frames. Reading from top to bottom, we can say that underlying predications can be formed from predicate frames and terms, and can then be mapped onto linguistic expressions.

The underlying predication is thus in a sense the central level of linguistic description according to FG. A predication basically consists of a predicate, applied to an appropriate set of terms. Content-wise, the predication designates a set of state of affairs; states of affairs can be divided into a number of distinct types such as Action, Process, Position, State, depending on a number of semantic parameters.

Terms are expressions by means of which we can refer to entities in some world. Terms range from simple words to phrases of great complexity:

(5) a. John

b. the best friend of my father

c. an interesting person I met in Paris when I went there to attend the funeral of my uncle

We thus need rules of term formation with certain recursive properties. These rules must allow for the incorporation of all sorts of predicates and predications within the structure of complex terms.

Predicates are expressions which designate properties of, or relations between entities. Each predicate is contained in a *predicate frame*, an abstract 'open' structure which specifies the syntactic and semantic 'valency' of the predicate, i.e., its syntactic and semantic combinatory possibilities.

I shall now illustrate the working of the FG model through an analysis of sentence (1):

(1) Patrick is cooking supper for Cynthia

I do so by first presenting the fully specified underlying predication of this sentence, and then showing how this predication can be built up from predicate frames and term structures. For lack of space I will not say very much about the rules which define the mapping of underlying predications onto linguistic expressions, although these are obviously quite important for the feasibility of the full model.

In order to be able to specify the underlying predication of (1), we must first know in what context (1) is presented and, in connection with this, what intonation and stress contour it has. I shall assume the following context:

(6) A: For who on earth is Patrick cooking supper ?

B: Patrick is cooking supper for CYNTHIA.

This contextualization is important for determining the *pragmatic functions* of the constituents. When the sentence is produced in context (6A), we say that *Patrick* has the pragmatic function of Topic, and *Cynthia* that of Focus. Pragmatic functions are used to code the informational values of constituents, and have their influence on the form and order in which these constituents are presented in linguistic expressions.

The fully specified predication underlying (6B) can now be given as follows:

(7) $$\text{DECL}\ \{\text{PresProgr cook}_V\ (\text{d1x}_i\text{: Patrick}_{pN}(x_i))_{AgSubjTop}\ (\text{d1x}_j\text{: supper}_N(x_j))_{GoObj}\ (\text{d1x}_k\text{: Cynthia}_{pN}(x_k))_{BenFoc}\}$$

This predication is constructed around the basic predicates *cook*, *Patrick*, *supper*, and *Cynthia*, which are contained in the lexicon, each in their own predicate frame:

(8) a. cook_V (x_1: <human> (x_1))$_{Ag}$ (x_2: <food> (x_2))$_{Go}$

b. Patrick_{pN} (x_1:<human, male> (x_1))$_{\emptyset}$

c. supper_N (x_1: <meal> (x_1))$_{\emptyset}$

d. Cynthia_{pN} (x_1: <human, female> (x_1))$_{\emptyset}$

cook is specified as a two-place verbal (V) predicate, taking a first argument (x_1) in the semantic function Agent, and a second argument in the semantic function Goal. The semantic functions specify the roles that the arguments play in the state of affairs designated by the predicate frame, just as in the semantic network of Figure 2 above. The possible arguments to be inserted into the argument slots are restricted by the selection restrictions <human> and <food>, which indicate that we may expect terms indicating a human being in the Agent slot, and indicating some kind of food in the Goal slot.

Note that the predicate frame, as stored in the lexicon, provides us with a wealth of information concerning the semantic and syntactic valency of a predicate such as *cook*. From the production side, starting with a predicate frame such as (8a) gives us a blueprint for the further elaboration of our predication. From the interpretation side, as soon as we have been able to identify the verbal predicate *cook* in any one linguistic expression, we can retrieve (8a) from the lexicon and use it to derive a rich set of predictions concerning the further constituent types which may be expected to occur in that expression.

In (8b), *Patrick* is defined as a one-place predicate of type proper noun (pN), applicable to male human arguments which take $\emptyset$ semantic function. This will be interpreted in such a way that the predicate *Patrick*, applied to human males, designates the state of having the name 'Patrick'. (8c-d) are similar.

It is to be noted that each predicate frame in the lexicon will be provided with a meaning definition, in which the predicate is paraphrased in terms of combinations of semantically less complex predicates of the language. The form and function of these meaning definitions will be exemplified in section 7 below.

Nuclear predicate frames such as (8a) can be extended with positions for *satellite* terms, which provide different types of information relevant to the state of affairs designated by the nuclear predicate frame. In the case of (8a), since *cook* designates an Action (witness Agent function), the predicate frame can be extended by a position for a Beneficiary (= the being for whose benefit the Action is performed)[4]. This leads to extended predicate frames such as:

(9) $\text{cook}_V\ (x_1: \text{<human>}(x_1))_{Ag}(x_2: \text{<food>}(x_2))_{Go}(x_3: \text{<animate>}(x_3))_{Ben}$

We now need terms to fill in the three term positions opened up by (9). Terms are formed from predicate frames and term operators through rules of term formation. Term formation constructs an infinite variety of term structures, all built on the schema:

(10) $(\omega\ x_i: \text{pred}_1(x_i): \text{pred}_2(x_i): \ldots : \text{pred}_n(x_i))$

in which ω indicates one or more term operators such as 'd' (definite), 'i' (indefinite), '1' (singular), etc.; x_i is the term variable symbolizing the intended referent; and each 'pred(x_i)' indicates some predication open in x_i (i.e. with x_i as a free variable). These open predications, also called *restrictors*, are stacked onto each other through the relation ':' ('such that'), and thus progressively restrict the possible values of the intended referent x_i. Thus, a term such as *the clever pink panther* would get the following underlying term structure:

(11) $(\text{d1}x_i: \text{panther}_N(x_i): \text{pink}_A(x_i): \text{clever}_A(x_i))$

'definite singular entity x_i such that x_i has the property panther such that x_i has the property pink, such that x_i has the property clever'

For the construction of predication (7) we need the following terms:

(12) a. $(\text{d1}x_i: \text{Patrick}_{pN}(x_i: \text{<human, male>}(x_i))$

b. $(\text{d1}x_j: \text{supper}_N(x_j: \text{<meal>}(x_j))$

c. $(\text{d1}x_k: \text{Cynthia}_{pN}(x_k: \text{<human, female>}(x_k))$

These three terms are compatible with the selection restrictions imposed on the term positions of the extended predicate frame (9), and can thus be inserted into these term positions.[5]

The resulting predication is now further specified by a number of grammatical operators, and by syntactic and pragmatic functions. The predicate operators Pres and Progr specify the Tense and the Aspect of the predication. The syntactic functions Subject and Object determine the perspective through which the state of affairs designated by the predication will be presented. Subject assignment to the first argument, as in (7), has the semantic effect of presenting the Action from the point of view of the Agent, and the formal effect of triggering the rules which will map (7) onto an active rather than a passive construction. The pragmatic functions Topic and Focus define the informational status of the relevant constituents, as determined by the context (6A). Finally, the predication operator DECL (declarative) specifies the illocutionary value of the predication, and opposes it to INT (interrogative) or IMP (imperative) predications.

Underlying predications such as (7) are meant to contain everything that is needed to retrieve the semantic content of the predication on the one hand, and to specify the form of that expression on the other. Note that underlying predications are not considered to be linearly ordered. (7) could therefore be just as well presented in a two- or even three-dimensional format. This means that, apart from minor details, the structure of Figure 2 is contained in (7) as a proper subpart. (7) simply gives much more information on the semantic and syntactic properties of sentence (1) than the structure of Figure 2.

The underlying predication is connected to the linguistic expression by formal rules, which have so far been given in the form of *expression rules*, which take the underlying predication as input and deliver the linguistic expression as output. Evidently, it should also be possible to reverse this mapping and define procedures which, given a linguistic expression, will derive the underlying predication. There is no room here for specifying these mappings. For the production side, they have been worked out in some detail for a fragment of English grammar in Dik (1980b). Kwee (1979) has written a program in Algol68 which can be taken as proof that an effective procedure for the construction of underlying predications and for mapping these onto linguistic expressions can in principle be formulated.[6]

Note, finally, that underlying predications such as (7) are language-dependent in the sense that they are constructed around the English predicates *cook*, *Patrick*, *supper*, and *Cynthia*. They are (to a high degree) language-independent, however, in that the general structure of the predication, the semantic, syntactic, and pragmatic functions, as well as the grammatical operators used in building up this structure, are largely the same across languages.

This implies, first, that underlying predications of this type have those properties which we found to be desirable for knowledge representation structures in section 3 above. Second, that underlying predications of this type are good candidates for providing the input (and the output) for translating linguistic expressions into other languages. This latter theme, however, will not be further developed within the context of the present paper.

5. A TWO-WAY MODEL OF INTERPRETATION

One central capacity of any understanding system (hence also of CNLU) is its ability to assign interpretations to data. In general terms, an interpretation can be defined as the attribution of some higher-level significance to certain lower-level data. For example, we may interpret certain disturbances in air pressure as representing a person singing a song; we may interpret certain data on voice quality and transmission as indicating that that person is no one else than our fiancée who is presently taking a shower in the bathroom; we may interpret the words and the melody of the song as representing *Jealous Guy* by John Lennon; and we may interpret her singing that song then and there as an indirect criticism for us having taken her to task for seeing too much of our friend Patrick.

Note that I take 'interpretation' to be a relative concept: data A may be used as material for arriving at interpretation B = I(A); and data B may then be used for arriving at higher-level interpretation C = I(B) = I(I(A)).

How do understanding systems arrive at an interpretation of given data ? According to a naive view of interpretation, this work about in the way depicted in Figure 4:

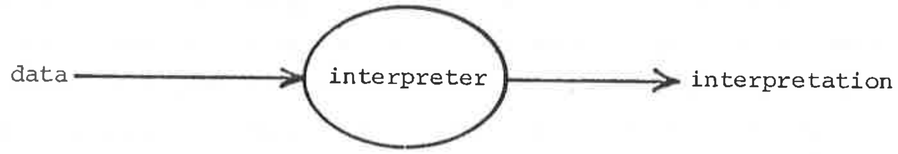

Figure 4.
A naive model of interpretation

According to this model, the interpretation would be a direct function of the data, mediated by the interpreter. This model works only 'bottom-up', from the data to the interpretation. It cannot be correct, for the following main reasons:

(i) we may arrive at correct interpretations of incomplete, mutilated, incorrect, or even absent data;

(ii) we may arrive at unequivocal interpretations of ambiguous data;

(iii) we may arrive at incorrect interpretations of complete, undisturbed, and correct data.

All these facts show that the interpretation model of Figure 4, according to which we derive interpretations from data, gives only one part of the story. Another part, which is certainly just as important, is that we impose interpretations on data. The former activity is the bottom-up part of interpretation; the latter activity constitutes the top-down part. In order to get at a full understanding of interpretation, we must assume that bottom-up and top-down activities are carried out in a parallel, interactive fashion.

This could be achieved by an interpretation model of the form sketched in Figure 5. This model is a particular elaboration of ideas set forth in Lindsay and Norman (1977) and owes much to their lucid exposition of the psychology of perception and pattern recognition.

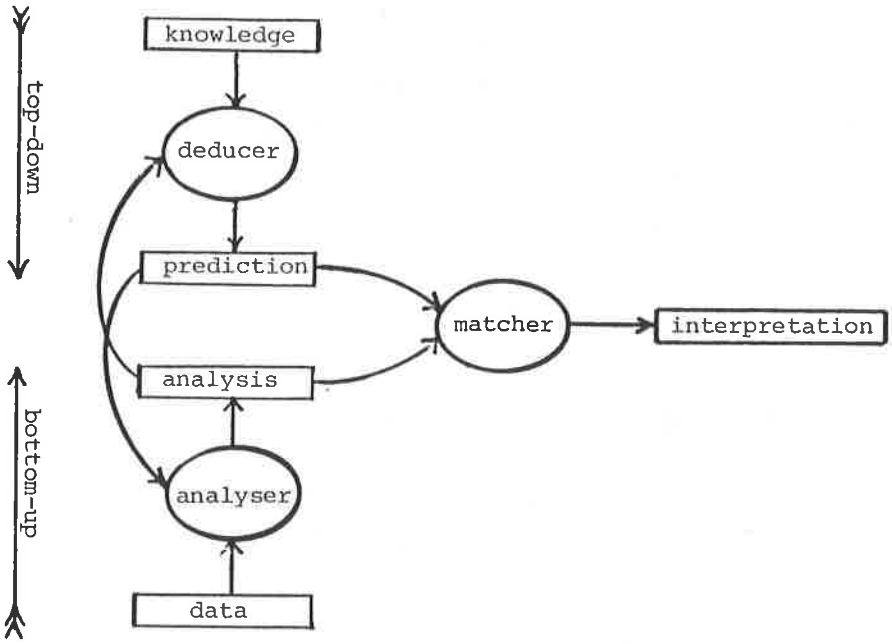

Figure 5.
A two-way interactive
interpretation model

This interpretation model consists of a bottom-up and a top-down component which provide each other with continuous feedback. The bottom-up component consists of an Analyser that scans the data and yields tentative analyses of these data. The top-down component consists of a Deducer which derives predictions concerning what the data might represent from the knowledge which the system already possesses. The predictions are fed into the Analyser so as to help it in making sense of the data; the tentative analyses are fed into the Deducer, so as to help it in deriving further and more accurate predictions. The system is monitored by a Matcher which, using certain criteria of sufficient fit, decides at which point prediction and data analysis are sufficiently consonant with each other. At that point, the interpretation is decided on.

Suppose this interpreter is to make sense of the following data:

(13) ɇ7ɇø/ɗńŧ

On the assumption that the Analyser works from left to right through the data,[7] it may come up with tentative interpretations such as:

(14) blank? e? l? e?

As the analysis comes in, it is sent to the Deducer which immediately starts searching the system's knowledge for words which might match the analysis. At the point indicated in (14) it may come up with such predictions as *elegy*?, *elevate*?, *element*?, *elephant*?, ... These predictions are sent to the Analyser, which will soon come up with *elephant* as the only prediction matching the data. The Matcher will then decide that (13) may be interpreted as representing *elephant*, even though one letter is missing and all the others are mutilated by slashes.

Note that this whole process may be speeded up by presenting the data in a more extensive context, as in:

(15) Yesterday in the zoo I saw an e̸l̸e̸p̸/a̸n̸t̸

In such a context the Deducer will itself eliminate such predictions as *elegy*, *elevate*, *element*, ... since they do not match the predictions already established on the basis of the information contained in the preceding context. In extreme cases, heavily mutilated data will then be sufficient to arrive at the correct interpretation without any apparent effort. On the other hand, data that are difficult to predict in a given context may well get incorrect interpretations, as in:

(16) Yesterday in the zoo I saw an e̸l̸e̸v̸a̸t̸o̸r̸

where the last word might well be incorrectly interpreted as representing *elephant*.

We will now go on to consider how knowledge representation and knowledge utilization could be integrated into the interpretation model of Figure 5, so as to result in a system which can make full sense of natural language data. In order to be able to do so, we will first have to consider the question of what different *types* of knowledge are involved in natural language processing.

6. TYPES OF KNOWLEDGE INVOLVED IN NATURAL LANGUAGE PROCESSING

We saw in section 5 that 'interpretation' is a relative concept: noises may be interpreted as sequences of speech sounds, these may be interpreted as sequences of words, these again as representing predications, and these, finally, as representing certain communicative intentions of the speaker, and certain communicative implications for the addressee.

In the present context I will take strings of words as given data for the higher levels of interpretation. In interpreting strings of words we make use of a great variety of knowledge sources. At least the following distinct types of knowledge would seem to be involved in natural language interpretation:

(17) 1. Long-term knowledge
   1.1. Linguistic
      1.1.1. Lexical
      1.1.2. Grammatical
      1.1.3. Pragmatic
   1.2. Non-linguistic
      1.2.1. Referential
      1.2.2. Episodic
      1.2.3. General
2. Short-term knowledge
   2.1. Textual
      2.1.1. Referential
      2.1.2. Episodic
      2.1.3. General
   2.2. Situational

These various types of knowledge can be defined in the following way. Note that in using the term 'knowledge' to cover all these types, we take the term in a very wide sense, as more or less equivalent to 'information'.
Short-term knowledge is knowledge which the system derives from what it perceives in the actual communicative situation. Long-term knowledge is knowledge which the system possesses independently of the particular communicative situation. This distinction more or less coincides with the psychological division of memory into long-term and short-term memory (LTM and STM).

Linguistic long-term knowledge is knowledge concerning the properties of the language involved. It is divided into knowledge of the forms and meanings of the lexical elements (lexical knowledge), knowledge of the rules and principles through which lexical elements can be combined with each other into linguistic expressions (grammatical knowledge), and knowledge of the conventions which govern the use of linguistic expressions in communicative situations (pragmatic knowledge).

Non-linguistic long-term knowledge is knowledge concerning the world around us, and knowledge of other worlds, whether real (such as worlds-in-the-past) or potential/imaginary (such as worlds-in-the-future or worlds existing only in dreams or fantasies, or by hypothesis). This non-linguistic long-term knowledge may be divided into knowledge of entities, such as persons, things, locations (referential knowledge), knowledge of states of affairs in which these entities have been, are, will be or could be involved (episodic knowledge), and knowledge of general rules, principles, and laws that are judged to apply to entities, states of affairs, and worlds (general knowledge).

Short-term knowledge is either derived from the verbal input (the text) fed into the system in the given communicative situation (textual knowledge), or from other data perceived or experienced in that situation (situational knowledge). Textual knowledge can again be divided into referential, episodic, and general knowledge. General short-term knowledge consists of general rules and principles which are overtly mentioned in the text.[8]

Long-term knowledge can, in terms of the interpretation model of Figure 5, be equated with the 'knowledge' from which the Deducer derives its predictions. Short-term knowledge can be seen as the 'analysis' which the Analyser comes up with on the basis of the raw input data. We can thus combine our knowledge typology and the interpretation model into one integrated model of linguistic interpretation, as represented in Figure 6 (see next page).

One new element in that integrated model is the Evaluation component. This component evaluates the interpretation which the system arrives at with respect to its retention value. If the interpreted information is judged sufficiently important for later use, it is integrated into the system's long-term knowledge. If not, it is discarded and forgotten. Note that even information which has been integrated into LTM may later turn out to be forgotten. But if the information is discarded right away, there has never been any effort to retain it. If it is forgotten from LTM, it is forgotten in spite of the original intention to retain it.

The distinction between linguistic and non-linguistic knowledge is made on the basis of what the knowledge is about (about the language or about the world); this does not exclude that even non-linguistic knowledge is represented in verbal form. In fact, I will assume that all knowledge either takes the form of perceptual images or of verbal predications. Images are perceptual pictures of the entities and states of affairs they stand for. They can be evoked or even constructed through mental operations, and 'seen' through 'the mind's eye'. Images must be assumed to play an important role in the recognition of perceptual entities, even though very little is known about their actual operation (cf. Lindsay and Norman 1977: 411 ff.).

Saying that all knowledge is either perceptual or verbal implies that there is no room for 'concepts' or 'ideas' apart from those which can be captured by either images or verbal predications or combinations of these. This imposes strong constraints on possible cognitive systems, and may thus be a useful methodological guide, even if it should turn out to be untenable in the end.

Note, finally, that the prototypical form of natural language use is that which takes place in direct communicative interaction between speaker and addressee. This means that language users not only get several forms of internal feedback as specified in the interpretation model, but may also get external feedback (or ask for such feedback) from their communicative partner.

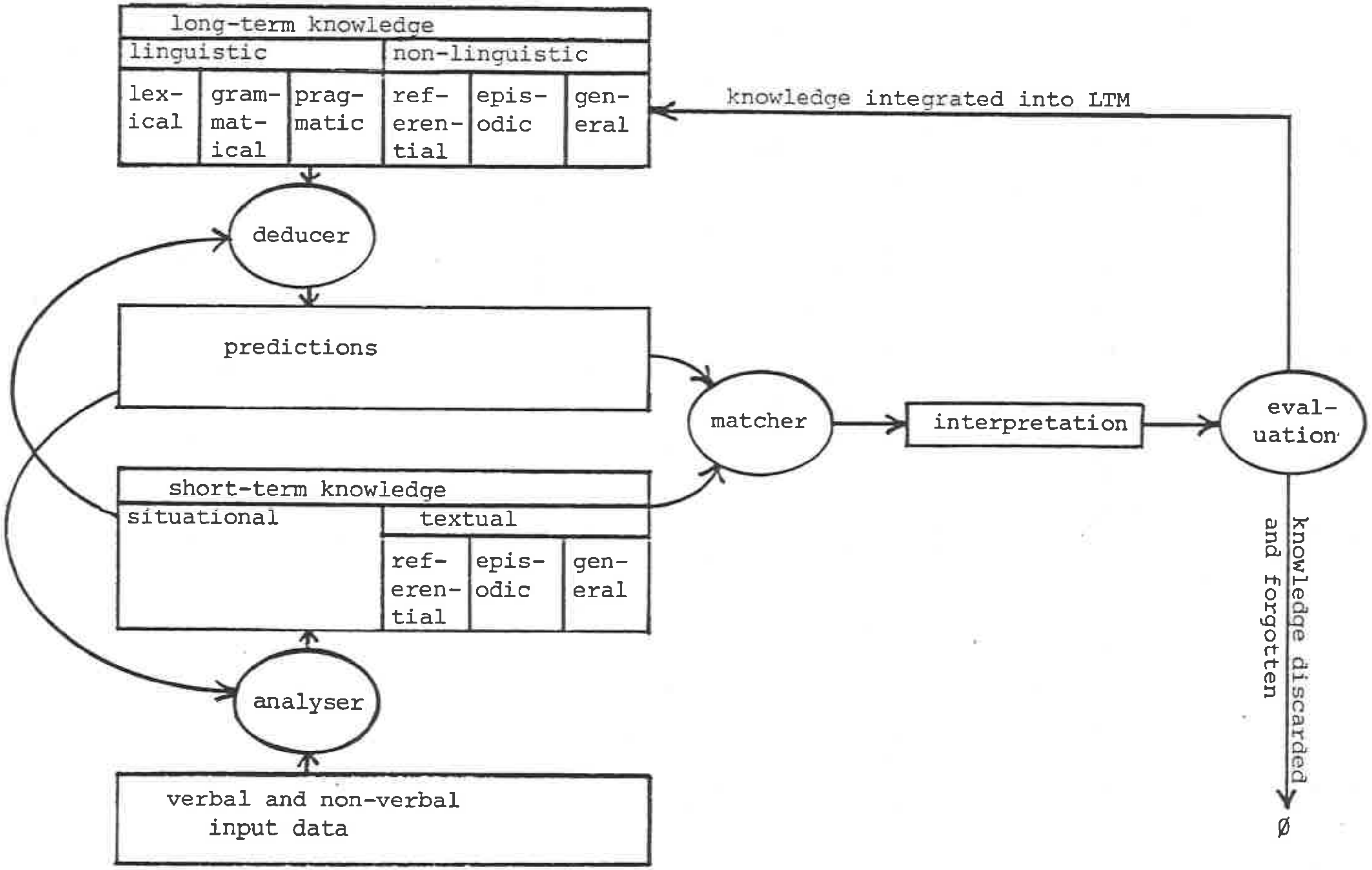

Figure 6.
An integrated model of
linguistic interpretation

7. ILLUSTRATION OF THE INTERPRETATION MODEL

In this section I will illustrate the operation of the interpretation model of Figure 6 by discussing the interpretation of the following simple text fragment:

(18) S: John's wife is pregnant. The baby is due in August. If it is a boy, Mary would like to call him after me.
A: Well, 'Peter Parker' doesn't sound too bad.

Our main question will be: what steps must A take in interpreting S's text, so as to be able to have his reply accepted as a coherent and rational reaction to that text.

I first define the long-term knowledge which A must possess if he is to be able to interpret S's text.

(I) Lexical knowledge.

A must be assumed to know the predicate frames of all the lexical elements which occur in S's text. Each of these predicate frames will be provided with a *meaning definition* in which the meaning of the predicate is paraphrased in terms of combinations of other, less complex predicates of the language.

(L1) $\text{John}_{pN}(x_1\text{: <human, male>}(x_1)) =_{def}$
$\text{'John'}(d1x_i\text{: name}_N(x_i)\text{: }\{(x_1)_{Poss}\}(x_i))$

Comment: to apply the predicate *John* to some human male x_1 is to say that the name that x_1 possesses is *'John'*.

(L2) $\text{wife}_N(x_1\text{: <human, female>}(x_1))\ (x_2) =_{def}$
$\text{married}_A\ (x_1) \text{ and } (x_2)$

Comment: to say of some human female x_1 that she is *wife* of x_2 is to say that x_1 and x_2 are married.

(L3) $\text{pregnant}_A(x_1\text{: <female>}(x_1)) =_{def}$
$\text{Prosp have}_V\ (x_1)\ (ix_i\text{: child}_N(x_i))$

Comment: to say of some female x_1 that she is *pregnant* is to say that she is going to have one or more children. Prosp(ective) is an aspectual operator which in English can be expressed as 'be going to'.

(L4) $\text{due}_A(x_1)(x_2)_{Temp} =_{def}$
$\text{expect}_V(Gx_i)(x_3\text{: }|\text{arrive}_V(x_1)(x_2)_{Temp}|(x_3))$

Comment: to say that some x_1 is *due* at a time x_2 is to say that one expects an event x_3 consisting in x_1 arriving at x_2. (Gx_i) stands for a 'generic term'; | and | enclose an embedded predicate frame.

(L5) $baby_N(x_1\text{: <child> }(x_1)) =_{def}$ recently $born_A(x_1))$

Comment: to say of some child x_1 that it is a *baby* is to say that x_1 was recently born.

(L6) $August_{pN}(x_1\text{: <month>}(x_1)) =_{def}$

'August'$(d1x_i\text{: } name_N(x_i)\text{: } \{(x_1)_{Poss}\}(x_i))$

Comment: see (L1).

(L7) $boy_N(x_1\text{: <child>}(x_1)) =_{def} male_A(x_1))$

Comment: to say of some child x_1 that it is a *boy*, is to say that it is male.

(L8) $Mary_{pN}(x_1\text{: <human, female>}(x_1)) =_{def}$

'Mary'$(d1x_i\text{: } name_N(x_i)\text{: } \{(x_1)_{Poss}\}(x_i))$

Comment: see (L1).

(L9) $like_V(x_1\text{:<animate>}(x_1))(x_2) =_{def}$

$find_V(x_1)(x_3\text{: } |pleasant_A(x_2)|\ (x_3))$

Comment: to say of some animate x_1 that it *likes* some x_2 is to say that x_1 finds something x_3 which consists in (x_2) being pleasant.

(L10) $call_V(x_1\text{:<human>}(x_1))_{Ag}(x_2)_{Go}$ after$(x_3) =_{def}$

$give_V(x_1)_{Ag}(d1x_i\text{: first } name_N(x_i)\text{: } \{(x_3)_{Poss}\}(x_i))_{Go}\ (x_2)_{Rec}$

Comment: to say that some human x_1 *calls* some x_2 *after* some x_3 is to say that x_1 gives the first name that x_3 possesses to x_2.

(L11) $Peter_{pN}(x_1\text{:<human, male>}(x_1)) =_{def}$

'Peter'$(d1x_i\text{: } name_N(x_i)\text{: } \{(x_1)_{Poss}\}(x_i))$

Comment: see (L1).

Apart from (L1)-(L11) we need definitions for the pronouns *it*, *he*, and *I*. I will here assume that these pronouns have the status of *basic terms* (terms not derived from predicates), and can be defined as follows:

(L12) $(d1x_i\text{: } it_{Pro}(x_i)) =_{def} (d1x_i\text{: -S, -A, -male, -female } (x_i))$

Comment: applying the pronoun *it* to some referent is to say that that referent is a non-Speaker, non-Addressee, non-male, and non-female entity.

(L13) $(d1x_i\text{: } he_{Pro}(x_i)) =_{def} (d1x_i\text{: -S, -A, male } (x_i))$

(L14) $(d1x_i\text{: } I_{Pro}(x_i)) =_{def} (d1x_i\text{: S } (x_i))$

(II) Grammatical knowledge.

A must possess the grammatical knowledge which is required to be able to map incoming linguistic expressions onto underlying predications, and to map underlying predications onto linguistic expressions. This knowledge will be taken for granted here.

(III) Pragmatic knowledge.

The pragmatic knowledge will consist of a number of 'default assumptions' or *implicatures* that A may assume will hold in verbal interaction, unless there are explicit indications to the contrary. Such implicatures might include the following:[9]

(P1) On Sincerity: If S uses a construction of the form DECL(p), then S believes that p is true.

(P2) On Relevance: If S uses a construction of the form DECL(p), then S believes that A may want to know p.

(P3) On Coherence: If S presents new information to A, then, if A can 'anchor' this new information in information he already possesses, he is expected to do so.

(P4) On Topical Continuity: Each new linguistic expression produced by S may be expected to contain a term referring to some entity which is already present in A's (long-term or short-term) referential knowledge or can be constructed on the basis of that knowledge.

(IV) Non-linguistic referential knowledge.

A has long-term knowledge of a number of entities:

(R1) x_{320} = (d1x_{320}: John Parker$_{pN}$(x_{320}))

(R2) x_{67} = (d1x_{67}: Mary Parker$_{pN}$(x_{67}))

(R3) x_{45} = (d1x_{45}: Peter Brown$_{pN}$(x_{45}))

(R4) x_{203} = (d1 next x_{203}: month$_N$(x_{203}): August$_{pN}$(x_{203}))

(V) Non-linguistic episodic knowledge.

(I1) married$_A$ (x_{320}) and (x_{67})

(VI) Non-linguistic general information.

A possesses a huge amount of general non-linguistic knowledge, much of which will be taken for granted by S as being available to A. At least the following items of general knowledge are relevant to the interpretation of (18):

(G1) When two persons are married, one of them is male, the other female.

(G2) When a child is born, it (normally) receives its father's family name. Its parents give it a first name of their own choice.

(G3) Pregnancy of the human female takes about nine months.

Note that the knowledge specified under (III) and (VI) should again be thought of as represented in the form of predications.

We shall now consider how A can utilize the long-term knowledge specified in (I)-(VI) above in interpreting S's text in (18).

In interpreting this text, A's Analyser will continuously scan the data for information, and will send any tentative analysis to his Deducer, which will exploit his long-term information to make maximum sense of the data, i.e. to derive the richest possible predictions on what the significance of the data might be. The Analyser builds up short-term knowledge based on the communicative situation and on the text.

As for the situational knowledge, we assume that A can connect his picture of the Speaker to his long-term referential knowledge (R3). Thus:

(19) $S = x_{45} = (\text{d1}x_{45}\text{: Peter Brown}_{pN}(x_{45}))$

We further assume that S and A have been talking for some time about x_{320}, which is contained in A's long-term referential knowledge by (R1). This means that x_{320} is already present in A's short-term referential knowledge at the moment at which (18) starts off.

A now starts interpreting (18): *John's wife is pregnant*. His grammatical knowledge allows him to reconstruct the underlying predication:

(20) $\text{DECL\{Pres pregnant}_A(\text{d1}x_i\text{: wife}_N(x_i)(\text{d1}x_j\text{: John}_{pN}(x_j))\}$

Note that A will be able to infer DECL from intonation and word order, Pres from the form *is* rather than *was, will be*. He will further be greatly helped by predicate frame (L3), from which, given the word *pregnant*, he can deduce that he is to look for a single argument indicating some female entity. The phrase *John's wife* perfectly fits this expectation. By (P3) and (P4) A will now try to integrate (20) with the knowledge which he already possesses. He will identify x_j with the x_{320} which is already present in his short term referential knowledge. By (L2) he knows that, in order to identify x_i, he must look for the female person who is married to x_{320}. By (I1) he knows that this must be x_{67}, present in his long-term referential knowledge by (R2), and there identified as *Mary Parker*. A will thus add x_{67} to his short-term referent record, and simplify (20) to:

(21) $\text{DECL\{Pres pregnant}_A(x_{67}))\}$

What does (21) say about Mary Parker ? Here A can use (L3) to derive:

(22) $\text{DECL\{PresProsp have}_V\ (x_{67})(\text{i}x_i\text{: child}_N(x_i))\}$

This adds a third (potential) referent to the short-term referent record: x_α =

'the future child of John and Mary Parker':

(23) x_α = (dl future x_α: $child_N(x_\alpha)(x_{320}$ and $x_{67}))$

Note that this referent comes in through the lexical meaning of the predicate *pregnant*. This referent has presumably no counterpart in A's long-term referential knowledge. A can now go on with *The baby is due in August*. He will reconstruct the underlying predication as:

(24) DECL{Pres $due_A(dlx_i: baby_N(x_i))(dlx_j: August_{pN}(x_j))_{Temp}$}

Again, he will try to anchor the content of this predication in his available knowledge. What baby x_i ? By (L5) he knows that a baby is a recently born child, which allows him, by (P4), to identify x_i with x_α from (23). As for x_j, A knows by (L6) that this indicates a month named August; since the child in question is still to be born, this must be a future month August; and from (G3) A can deduce that x_j must be the next month of August, i.e. x_{203} by (R4). He will thus add x_{203} to his short-term referent record, and simplify (24) to:

(25) DECL{Pres due_A $(x_\alpha)(x_{203})_{Temp}$}

Note that 'August' will not be further referred to in (18). It is, however, a potential referent in the further course of the interaction, and therefore it must be stored by A. By (L4), A can now develop (25) into:

(26) DECL{Pres $expect_V$ $(Gx_i)(x_j$: $|arrive_V(x_\alpha)(x_{203})_{Temp}|(x_j))$

A's short-term referent record now contains x_{320}, x_{67}, x_α, and x_{203}. And his short-term episodic knowledge could be paraphrased as:

(27) x_{67} (Mary Parker) is going to have x_α (a baby), expected to arrive in x_{203} (next August)

He now takes in the next bit of information *If it is a boy, Mary would like to call him after me*. Let us start with the conditional:

(28) DECL{$(x_i$: $|\{(ilx_j: boy_N(x_j))\}$ $(dlx_k: it_{Pro}(x_k))|(x_i))_{Cond}$ ...

This structure defines a Condition x_i, consisting of 'it being a boy'. Since *a boy* here appears in predicate position, A will not interpret this phrase as referential. He will have to decipher *it*, however. From (L12) he knows that this pronoun refers to some non-Speaker, non-Addressee, non-male, and non-female entity. There are two candidates for this reference in his referent record: x_α (the baby-to-be), and x_{203} (the next month of August). From (L7) he knows, however, that the predicate *boy* applies to children, not to months.

Therefore, *it* may be identified with x_α. The conditional opens up a world in which, by (L7), the property 'male' is assigned to x_α. Within this hypothetical world, x_α may be further specified as x_α', the potential male future child of Mary Parker.

A can now analyse the last part of S's statement into the predication:

(29) $$\ldots \text{Pot like}_V(\text{d1}x_i\text{: Mary}_{pN}(x_i)) (x_j\text{: }|\text{call}_V(x_i)_{Ag}(\text{d1}x_k\text{: he}_{Pro}(x_k))_{Go}\text{ after}(\text{d1}x_l\text{: I}_{Pro}(x_l))|(x_j))\}$$

This predication says that some entity x_i (Mary) would (Potential) like something x_j where x_j consists in x_i calling 'him' after 'me'. Without displaying all the individual steps, let us note that x_i will be identified with x_{67} by (P4), x_k will be identified with x_α', and x_l will be identified as $S = x_{45}$ = Peter Brown, by (19).

The identification of 'him' as x_α' is non-trivial, since the pronoun could in principle also refer to x_{320} = John Parker. However, x_α' has just been established in the conditional. Moreover, A knows from (L10) that to call a person after another person is to give a name to that person, and from (G2) that parents give a first name to their children when they are born. From (L1) he knows that John Parker already has a first name. From these various facts, the identification given above is certainly the most probable.

From (L9) A knows that to like something is to find something pleasant; From (19) he knows that the Speaker's first name is 'Peter'. Given all this knowledge, A could further develop (29) into:

(30) $$\text{Pot find}_V\,(x_{67})\,(x_i\text{: }|\text{pleasant}_A(x_j\text{: }|\text{give}_V(x_{67})_{Ag}(\text{d1}x_k\text{: name}_N(x_k)\text{: 'Peter'}(x_k))_{Go}(x_\alpha')_{Rec}|(x_j)|(x_i))\}$$

In other words, Mary Parker would find some x_i to be the case, where x_i is some x_j being pleasant, where x_j is for her to give the name 'Peter' to her potential male baby child.

Since A knows, by (G2), that the potential baby boy will get the family name *Parker*, he may conclude that if all these conditions would come true, the boy's name would be *Peter Parker*. This is what allows him to coherently reply the way he does in (18).

8. DISCUSSION

Let us now return to the three theses (T1)-(T3) formulated in section 2 above.

As for (T1), I have distinguished, in section 6, ten distinct types of knowledge involved in natural language interpretation; in section 7 I have illustrated how these different types of knowledge might be exploited in a operational model of CNLU.

As for (T2), I have shown how these different types of knowledge can, to a large extent, be represented in the form of predicate frames, predications, and term structures as specified by the theory of Functional Grammar. This suggests that, indeed, much of our knowledge may be coded in structures which contain the actual content predicates of our language.

As for (T3), finally, the interactive parallel bottom-up and top-down interpretation model sketched in sections 5 and 6 would certainly seem to be a powerful device for explaining a number of phenomena well-known from linguistic experience, but very difficult to account for by less sophisticated devices.

The example of section 7 has made it clear that the interpretation of even a single text fragment such as (18) is an extremely complicated matter, involving a continuous to and fro between the incoming data and the interpreter's long-term knowledge. Complexity, however, can hardly be used as a criticism against the model. We simply have to accept it as an empirical feature of natural language use.

The interesting question rather concerns the feasibility of explicitly formulating every single step in the interpretation process in such a way that it can be turned into an effective algorithmic procedure of the kind that can be programmed into a model of the natural language user. The example of section 7 does not even approach such an algorithm, since it glosses over many points of detail which would have to be made explicit in order to make it fit for automated execution. I do not see any principled reason, however, why a further elaboration of the interpretation model sketched in this paper could not yield an effective component of the computational natural language user CNLU.[10]

NOTES

1 Note that 'probably' builds in a hedge which ties in with a certain hesitation of the authors elsewhere in the book. Thus on p. 486 they suggest that perhaps decomposition is only partial, and applied only where it is needed for understanding.

2 For more extensive discussion of these points, see Dik 1978b.

3 The need for such a procedural reinterpretation of FG was advocated by De Schutter and Nuyts 1983 and Nuyts 1985.

4 FG distinguishes Beneficiary ('do something *for* Mary') from Recipient ('give something *to* Mary').

5 In (7) I have left out the selection restrictions. It is not quite clear whether and under what conditions these should be retained.

6 Weigand at al. 1985 sketch a system which takes in linguistic expressions and derives FG-like predications.

7 This left-to-right processing is probably an unnecessary assumption. In actual word recognition, more holistic procedures might be more effective.

8 In the illustration given in section 7, general short-term knowledge will play no role. By this type of knowledge I mean the short-term knowledge which A may derive from a statement such as: *Children are cute, aren't they ?* In such a statement, S does not describe an episode, but rather a general rule with respect to which he asks for A's confirmation.

9 On the status of such pragmatic conventions, see Searle 1969, Grice 1975, and Levinson 1983.

10 In a general sense, beyond the actual details of this paper, I have drawn much inspiration from Clark and Clark 1977, Lindsay and Norman 1977, and Winograd 1983. These works contain a lot of useful ideas for the further elaboration of CNLU. More specifically, the development of (partial) models of this kind would seem to fit in nicely with the 'computational paradigm' as advocated by Winograd as one of the available routes towards gaining more insight into the workings of the natural language user.

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