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INTRODUCING CONCEPTUAL GRAMMAR

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Abstract

This paper contains an informal and sketchy overview of a new way of thinking about linguistics and linguistic processing known as conceptual grammar. Some ideas are presented on what kind of knowledge is involved in natural language, how this knowledge is organized and represented and how it is activated and acquired.

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PREFACE

The central goal of this research is the construction of a unified theory that explains the amazing capacity which people exhibit in the domain of natural language. Linguistic capacity will be interpreted in a broad sense: We will not only be interested in natural language communication itself (which includes the study of parsing, interpreting and producing), but also in other forms of linguistic behavior such as the making of linguistic judgments (e.g. deciding whether something is grammatical or not), solving linguistic problems (like in language courses: filling in words, detecting and correcting errors), editing texts, instructing other people in language, learning a language by receiving instruction or by picking it up from the environment, etc.

The theory seeks to obtain explanatory power in two ways. First we would like to have functional explanations. We will ask the question 'How does it work?' and want an answer in terms of a precise mechanistic model that is able to account for linguistic behavior. Second we would like to have deductive explanations: We will try to find universal properties of natural language communication so that we can explain a particular communication in a certain language in terms of these properties. Also we will try to find universal properties of cognition, i.e. principles of representation, activation and acquisition that all cognitive systems have in common. Then we will be able to explain natural language behavior as a particular instance of cognitive behavior.

Before we start going into details, here are some of the motivations which make me believe that the conceptual grammar approach is superior to existing approaches. Basically these motivations have to do with the following amazing results that no system reported upon in the literature has been able to obtain.

- + We need only one representation of linguistic knowledge for a variety of linguistic tasks. We mean this literally: there is only one grammar for performing such tasks as parsing, production, judgment, linguistic problem solving, etc. Thus our grammar captures the common knowledge that underlies each of these tasks and yields a stronger theory than an approach which needs to postulate different representations for each of them.

- + In addition to the fact that we need only one single representation of knowledge about the language, we need only one single method that performs the linguistic processing in all these different tasks. Again this is meant literally: the same program will perform parsing, production, judgment, problem solving, etc., each time using the same representation of knowledge.

Also here we capture an important generalization about linguistic processing because we identify what every linguistic process has in common. This theory of procedural embedding of linguistic knowledge is therefore a priori stronger than a theory which needs different methods for activating linguistic knowledge in each of these tasks.

- + Moreover the representational techniques and activation methods are uniform for all aspects of the language. In other words systems dealing with grouping and functional structures, with case, with speech acts, with the lexicon, etc. all make use of the same type of representational devices and are activated by the same methods. The difference between all these different components of the grammar lies solely in the

content of the knowledge: in the concepts used and in the constraints among the concepts. So we capture an important generalization about what is common to every linguistic system, something that is not captured by a theory that needs different data structures and procedural characterizations for each of these aspects of the language.

+ Furthermore it is possible to show (although we will not concentrate on this in the present paper) that the representation strategies and the methods for activation we will use for dealing with linguistic problems do not differ from representation strategies and methods for activation in other cognitive domains (such as the construction and recognition of real world objects or situations).

So the theory captures an important generalization on this level too: it shows what is common to many different domains of cognition. This is a stronger result than a theory which is unable to express any relation between language behavior and other cognitive behavior.

+ We believe also to have made a significant advance in the problem of language learning. Because knowledge of the language is seen as a network of concepts, the acquisition of language can be viewed as a concept-formation process. Thus all results known about this process become relevant for explaining language learning.

There are also some interesting technical results (e.g. the use of parallelism as basic process organization) but we will mention those in passing.

There are three main questions that immediately arise in our search for explanations. First of all what is the knowledge that is involved, second how is this knowledge represented and third how is this knowledge activated and acquired. In a first section we will look at the problem of what knowledge seems to be involved and how this knowledge can be represented.

1. NOTES ON LINGUISTIC KNOWLEDGE

1.1. WHAT IS CONCEPTUAL GRAMMAR

The first thesis is that there are two important tasks involved in the specification of linguistic knowledge: (i) the construction of an abstract grammar and (ii) the construction of a concrete grammar.

The *abstract grammar* consists of a set of axioms that specify the necessary and sufficient constraints on communications in natural language. One should think about these axioms as similar to the axioms of geometry: they specify in a neutral fashion all constraints on the possible entities in the domain.

For example, there might be an axiom saying that an article which plays the role of determiner in a noun-group precedes the noun that plays the role of head in the same noun-group, that the passive voice is functionally related to an occurrence of the auxiliary BE followed by a verbal element which is a past-participle, that in order to issue a command it is necessary to have a certain authority, etc.

Activation of the axioms goes by using standard proof techniques. So if we want to show that something is a valid communication given the axioms of a certain language, we construct a proof that derives a description of the communication from the axioms.

Some of the axioms might be common to several natural languages. There might even be universal axioms which characterize what it means to be a natural language communication system. I see the set of axioms of all languages as structured in a hierarchy, i.e. if we extract the common axioms between different languages we will see that languages fall into families on the basis of common axioms. Such a hierarchy might correspond with the type of hierarchies discovered by historical and comparative linguists.

Although such an abstract grammar would provide us with a satisfactory linguistic theory, there is an aspect that is not covered. An abstract grammar gives a neutral, theoretical account of the laws underlying natural language communication. But a grammar in as far as it functions in a communication system is more than that: it is knowledge. The information has to be structured in such a way that one can account for the problems of activating linguistic information. We will say that we need a grammar which is epistemologically adequate in the sense that its representation and activation schemes explain what is potentially knowable given certain constraints on resources for activating or representing the information. These constraints are that the computations must terminate, that there are severe limitations on the observations one can make (e.g. a hearer is only able to observe the external form of the communication), that the information must be accessible in limited amounts of time (to account for the speed of communication), etc.

What we need therefore is a *concrete grammar*, which is defined to be a representation of the grammar in such a way that activation and acquisition can be explained.

One way to make a concrete grammar is to use procedures, i.e. construct programs that perform a particular linguistic task, such as parsing, producing or generating. Augmented transition network grammars (Woods, 1969), specialized programming languages such as PROGRAMMAR (Winograd, 1972) or generative grammars are examples of this approach.

An alternative method, which I would like to explore, is to make a *conceptual grammar*. In a conceptual grammar the axioms are expressed as a network of concepts which is activated by a reasoner to particular tasks.

The construction of a conceptual grammar goes in two steps. First we try to identify the concepts that are used in the axioms. Some of those concepts will refer to aspects of real world objects like strings or characters or acoustic structures, such as the concepts of linear order, rising intonation, occurrence; some concepts refer to properties of linguistic entities such as plural, illocutionary force, gender; some concepts refer to descriptions of prototypical linguistic situations involving groups of entities, like functional structure, case structure, text organization, speech act configuration; still others refer to roles the entities play in those structures, such as agent, topic, predicative adjunct, etc.

Once we have identified the concepts, we have to specify their interrelationships. This will be done by associating constraints to a concept until we have an exact characterization of what the concept entails. The constraints themselves make use of other concepts or specifications of relations to real-world objects (like strings of characters). Together this system of constraints contains the same information as the axioms of an abstract grammar but now in an epistemologically adequate way.

So the main difference between conceptual grammars and other formalisms like ATN's, programming languages or generative grammars is that we do not use procedural notions like affix-hopping, transformation, deletion, push, pop, set-register, NP-movement, etc. in our characterization of linguistic knowledge. In a conceptual grammar no procedural notions appear in the description of linguistic knowledge. How the knowledge is to be used in a particular task is completely left over to the inference mechanisms. It is mainly due to this idea that we obtain the results alluded to in the preface.

Although a conceptual grammar is clearly different from most present-day approaches to formalizing grammar, it should be observed that the so called 'traditional European grammar' comes much closer to what I have in mind. These grammars do not talk about language in terms of actions constructing or analysing linguistic objects but simply in terms of linguistic concepts and relations between these concepts which are expressed as definitions. (Examples of 'traditional' grammars for English are Kruisinga (1931), Zandvoort (1945), Quirk, et.al. (1972), etc.)

On the other hand the difference with these traditional grammars and a conceptual grammar is the implication that a conceptual grammar is part of a knowledge system, i.e. that we now try to explain how understanding, producing, etc. works which was not the intention of traditional linguistics.

1.2. A SIMPLE EXAMPLE

Let us now try to do some simple examples. Much will left unexplained in doing so. The interested reader is invited to consult Steels (1978b) for an introduction to the knowledge representation language used here and Steels (1978c) for a more thorough development of some less trivial examples.

First we will try to deal with the following simple axiom: 'The article which plays the role of determiner in a noun-group precedes the noun which plays the role of head in the same noun-group.'

In order to talk about order phenomena we introduce first of all the concept of **SEQUENCE** which has two aspects a **FIRST-ELEMENT** and a **SECOND-ELEMENT**. So we set up a structure as follows

```
(SEQUENCE
  (WITH FIRST-ELEMENT)
  (WITH SECOND-ELEMENT)).
```

The relation between entities filling these two aspects is such that the first-element precedes the second-element and the second-element follows the first-element.

For example the occurrence of 'the' in 'the boy' can be described as the first-element of a sequence with the occurrence of a word boy the second-element. We will represent this as

```
(FIRST-ELEMENT SEQUENCE
  (WITH SECOND-ELEMENT (OCCURRENCE 'BOY')))
```

We will not attach constraining descriptions to the **SEQUENCE**-frame in an attempt to keep it all simple.

Now we turn to the concept of a noun-group. It has two aspects: a head and a determiner. According to the axiom there is an order constraint between fillers of these two aspects. We express this constraint using the sequence-concept introduced earlier. In particular we will say that the determiner in the noun-group can be described as the first element of a sequence of which the second element is the head of this noun-group:

```
(NOUN-GROUP
  (WITH HEAD (= THE-HEAD))
  (WITH DETERMINER
    (FIRST-ELEMENT SEQUENCE
      (WITH SECOND-ELEMENT (= THE-HEAD))))))
```

A sequence like 'the boy' satisfies the constraints given here because the occurrence of 'the' can be described as

```
(FIRST-ELEMENT SEQUENCE
  (WITH SECOND-ELEMENT (OCCURRENCE 'BOY')))
```

Notice that the noun-group specification contains no instructions or actions to obtain a certain structure, enter into a certain state, match a certain pattern, etc. The structure contains nothing but the facts and it is left to a reasoner to make sense out of them and to apply them to a particular situation.

As a second example we will look at the following axiom. 'The subject of a sentence agrees in number and person with the predicate of the same sentence.'

Assume that we start with a frame for sentence, as follows

```
(SENTENCE
  (WITH SUBJECT)
  (WITH PREDICATE))
```

We also assume that we have frames for syntactic features with aspects for the entity characterized by the feature and for the value for that feature. For example, we have a frame for **NUMBER** with the following structure:

```
(NUMBER
  (WITH CHARACTERIZED-FOR)
  (WITH VALUE))
```

Similarly for PERSON.

Now we can describe a word, such as 'we', as characterized-for NUMBER with value plural:
 (CHARACTERIZED-FOR NUMBER
 (WITH VALUE (VALUE PLURAL)))

Now we can attach agreement constraints to the subject and predicate slots of the sentence-frame. We will do this by saying that each of these slots is characterized for number and person and that the value for a feature for the subject is co-referential with the value for the same feature for the predicate:

```
(SENTENCE
  (WITH SUBJECT
    (AND
      (CHARACTERIZED-FOR NUMBER
        (WITH VALUE (= THE-VALUE-FOR-NUMBER)))
      (CHARACTERIZED-FOR PERSON
        (WITH VALUE (= THE-VALUE-FOR-PERSON))))))
  (WITH PREDICATE
    (AND
      (CHARACTERIZED-FOR NUMBER
        (WITH VALUE (= THE-VALUE-FOR-NUMBER)))
      (CHARACTERIZED-FOR PERSON
        (WITH VALUE (= THE-VALUE-FOR-PERSON))))))
```

The reader should not worry if details of these examples are not understood. The only purpose was to give some vague ideas of what is going on.

We now turn to a discussion of other issues in the description of linguistic knowledge.

1.3. THE FUNCTIONAL APPROACH

There are many different ways in which we can start asking questions about language. One approach, known as the *functional approach* has proven particularly fruitful. In a functional approach we look at language as a tool of communication and try to find what purpose each language form has in the communication. In other words we try to understand how natural language works by trying to figure out how the means realize the goals, how linguistic forms, such as roots of words, orderings, morphological variation or intonation, relate to communicative goals, like introducing a certain piece of information, invoking certain cognitive actions, establishing or maintaining a certain social relation, etc.

The functional approach is deeply rooted in European linguistic traditions (cf. Verburg [1952] for an historical overview) and remains prominent in many modern proposals such as developed by Tesnière [1959], Halliday [1976], Sgall [1969], Dik [1978], a.o.. The functional approach contrasts with the approach developed by Bloomfield [1933] and since then dominating American linguistics. This approach consists in comparing minimally different language forms (often ungrammatical ones) and postulating step by step structures and rules to account for the difference.

1.4. THE MULTIPLE VIEWPOINT APPROACH

Once the step towards a functional approach is taken it soon becomes obvious that the same linguistic expression serves a variety of different purposes at the same time: It introduces a scenario of semantic actions, specifies a number of speech acts, contributes in setting up a social interaction, establishes a number of conceptual frameworks, presents choices in these frameworks, invokes and extends large frames for whole situations and gives hints about how to access knowledge in terms of organizational clues.

It follows that we can view the structure of a natural language expression as a description of that expression from various linguistic perspectives. Each perspective highlights different aspects of the goals, the information or the organization and relates these aspects (or factors as they will be called) to properties of the linguistic form. I will call this way of organizing linguistic descriptions (and therefore also the grammar) the *multiple viewpoint approach*.

The multiple viewpoint approach contrasts with a way of structuring the language system in terms of levels: a level for morphology, a level for surface syntax, a level for "deep" syntax, one for semantics, one for pragmatics, etc., with some refinements in between. Such a method of structuring leads to a vertical division of the whole system. The grammar concentrates on giving rules for translating structures from one level (e.g. grammatical functions) into structures on another level (e.g. case relations) and only the so called surface structure has an immediate "contact" with the language forms.

In the multiple viewpoint approach there is a horizontal division of the language system. Each perspective has an autonomous grammar (a case grammar, a relational grammar, a text grammar, etc.) which relates the structural aspects to the underlying factors on the one hand and the factors to the creation or modification of knowledge structures on the other. There is no translation from one perspective into another one. At most there is consultation because of a shared factor.

For some recent examples of linguistic proposals based on a multiple viewpoint approach, see the work of Halliday [1975], Pike [1971], Lakoff [1976], etc.

1.5. THE FACTORS

In the previous paragraphs I suggested that there is a great number of factors (or speech notions, cf. Longacre [1976]) underlying the operation of the linguistic system, each providing a different perspective on the communication situation. Now I want to provide some more detail on what factors there are and what knowledge the language system has about each of the factors.

First it is convenient to classify linguistic factors into three types: *goal-based factors*, relating to what the speaker wants to accomplish with a certain communication, *content-based factors* relating to what kind of information the speaker wants to convey, and *organization-based factors* relating to recommendations about how to go about understanding a certain expression.

Let me discuss each of these types in some detail.

GOAL-BASED FACTORS

The process of understanding an expression can (at least partially) be characterized in terms of the actions that the hearer performs as a result of processing the expression. It is the task of the speaker to indicate to the hearer what kind of actions he wants to see performed. To this purpose he first makes a plan of actions, relates the linguistic forms which are

normally used to signal these actions to his plan, and transmits the signals hoping that the hearer will realize what plan is called for and consequently activate it.

(a) Semantic actions

When the actions deal with minimal changes in the knowledge structures such as referring, predicating, restricting, modifying, quantifying, etc., I will talk about *semantic actions*. Semantic actions correspond to types in intensional logic (as in Montague [1974]). They are known in the linguistics literature as grammatical functions or dependency relations (see e.g. Tesnière[1959]).

Both speaker and hearer must know what minimal actions there are, what kind of effect they are supposed to have upon the hearer, what the preconditions are and what linguistic signals are used to indicate that a certain minimal action is called for.

The interesting thing is that the speaker is not only able to signal one single action but a whole chain of teleologically related semantic actions, thus obtaining a tighter control over the understanding process. For the construction of these chains languages have standard plans available describing prototypical sequences of actions.

The grammar of semantic action plans includes information about what actions are part of the plan, what the teleological links are based on, and above all, all what the surface characteristics are that should be used for signalling this plan as a whole (e.g. certain word orderings, concord phenomena, etc.). The capability of introducing whole plans helps a lot in parsing, because as soon as the first items of the plan are recognized the complete plan might be activated. Later input will then be used to fill in the details.

Take for example the expression 'a red block'. The overall goal here could be described as drawing attention to a certain entity (supposedly in the real world). This is done by introducing a characteristic property of the entity (being a block. An element with the function determiner, here 'a', is added, to signal that the speaker wants to pick out one entity from the domain of entities to which the property block is applicable. The entity could be anonymous, if it is not yet supposed to be clear which one is meant. To make the reference more exact, one more property is introduced by means of an element with the function of attributive adjunct, namely 'red'. The goal of an attributive adjunct is to signal that the referent of its head should be applicable to the property introduced by the adjunct, in other words the block must be a red one.

Various linguistic forms are used to signal that this plan of semantic actions is to be carried out. These signals include the choice for certain parts of speech (article, adjective, noun), a certain word ordering (e.g. 'block the red' would not do), and concord relations (e.g. 'a red blocks' is ungrammatical).

Notice that some surface characteristics (such as the parts of speech) are due to the individual semantic action, some (such as ordering) are due to the plan as a whole, i.e. they indicate the relation between the individual actions.

(b) Speech acts

From a different perspective we find another class of goals, now referring to the linguistic action that the speaker intends to invoke as a result of the communication: the formulation of an answer to a question, the execution of some physical action, the storing of new information, etc.

Primitive actions from this perspective are asking a question, promising, commanding,

asserting, etc. They are known in the linguistics literature as *speech acts* (cf. Austin [1962], Searle [1969], Sadock [1974], a.o.).

Just as for minimal semantic actions, we could envisage the availability of certain prototypical plans of speech acts, although one main speech act per utterance seems to be the default case.

The grammar of speech acts concentrates on prototypical speech act situations (e.g. a question), what the various presuppositions are for that situation (I do not know the answer but the hearer may know it and I want him to tell me), when the speech act is appropriate (it must be possible to answer the question), what the effect will be on the hearer (there will be an effort to answer the question), and what the usual surface characteristics might be (inversion, use of certain intonation patterns or question words).

For example in the expression 'John, come here', a certain action is solicited from John. It is assumed that this action is wanted by the speaker, that it is possible for John to carry it out, that the speaker has authority to issue commands, etc. The linguistic form used to signal that this kind of speech act is required is known as an imperative construction.

(c) Social Interactions

Still from another perspective we find a class of goals dealing with the establishment of social interactions. (cf. Goffman [1974], Cicourel [1973], a.o.) The primitive linguistic actions from this perspective are greeting, introducing, establishing a role structure, initiating or ending a conversation, turn-taking, adhering to conversational maxims, etc. Knowledge about these factors and their relation to language is known in the linguistics literature as *communicative competence* (cf. Bernstein [1971], Hymes [1971], a.o.).

Here we could envisage that the language user has a collection of prototypical situations containing information about what kind of social interactions occur, where they occur, what the roles of the participants are, what the circumstances are, what the purpose is, what kind of actions should be performed and what the effect on language forms might be.

CONTENT-BASED FACTORS

The factors discussed so far deal with what kind of change will be carried out in the knowledge structures. Now we come to the content of the change, i.e. the information which is transmitted to the hearer.

It turns out that in order to communicate information via natural language, it is necessary to see this information through the conceptual frameworks that are conventionally established in the language. For each linguistic framework the language then provides certain means of indicating the establishment of a framework and what choices have been made within that framework.

(a) Basic frameworks

There are many different linguistic frameworks available and each framework has its own linguistic forms. Moreover several frameworks may be active at the same time, highlighting the same situation from different conceptual angles. Let me discuss three such frameworks very briefly: the lexical framework, the case framework and the framework of time. Other frameworks include the framework of space, of mood, modality, etc.

The lexical framework deals with the introduction of minimal pieces of information such as

entities, properties, relations, actions, etc. To this purpose an enormous number of prototypes are available to the language user. A prototype contains quite elaborate knowledge about a certain kind of objects. It may contain information about the conceptual aspects, examples, descriptions, a mental image, possible functions, typical parts, justification for believing that this kind of items exists, the context in which they usually occur, and so on. Connected to each prototype of a situation there is information about the implications for natural language, usually in terms of a root of a word, but a whole expression (as in idioms) may do as well.

For example if we see a chair, and we want to use the word 'chair' for it, we have to view this chair as similar to the prototype of a chair. Then we can use the root 'chair' as linguistic form to signal that there is a situation describable in terms of the prototype for chairs.

(The idea of meaning as prototype is exemplified in the current work of Fillmore [1977]).

Another framework that is mapped onto the information focuses on the roles of the participants. Prototypical situations within this framework are known as case frames (cf. Fillmore [1968], Anderson [1977], Wilks [1976], a.o.).

A case frame contains a number of semantic aspects, such as the kind of situation, the roles, the interrelations between the roles, the restrictions on participants that may fill a role, perspectives in the sense of a certain role from which the situation is approached, and a number of linguistic signals used to indicate these aspects, such as morphological variation, prepositions and word ordering (the so called surface case features).

For example in 'John sold Mary a house', we could say that a case frame is established characterizing an action with three participants John, Mary and a house. John fulfills the role of agent, Mary of beneficiary and the house is the patient. We could say that the agent has to be a person that is allowed to perform this kind of action, that Mary is a person allowed to play the role of beneficiary and that the patient must be a "sellable" object. The perspective here is fulfilled by the agent John. In this example there are no morphological variations or prepositions to signal the various case relations, instead word order is doing most of the job.

Another framework is that of time, also known as the system of tense (see e.g. Lyons [1977] where many other conceptual frameworks are extensively discussed). Within this framework it is possible to see a situation as happening in the present, past or future, to introduce a point of reference that may itself be situated in the present, past or future, to indicate that there is a connection to such a point of reference, that the action is taking place at that point itself, going beyond it, and so on. The language uses morphological variations of verbal roots and the occurrence of certain auxiliaries to indicate that a time framework is being established and what choices have been made.

For example in 'John will have been seeing Mary.', the point of reference is a point in the future (viewed from the moment in which the communication is performed). Based on this point we establish a moment before that and locate a certain situation as happening at, possibly continuing up to or at least related to this time moment. The first point of reference is established by the auxiliary will, the second point and the relation to the first one by the auxiliary have.

Note that all these frameworks are seen as language specific. Compare e.g. the tense systems of such related languages as English, Dutch, German and French. In other words each culture has its own way of dealing with reality and this is reflected in the linguistic frameworks used in the language of that culture. (cf. Wittgenstein [1971], Whorf [1964] who

called a linguistic framework a "fashion of speaking". See Schank [1975] for an opposing view although his conceptual language could be seen as part of the linguistic frameworks of English).

(b) Broader frameworks

So far the linguistic frameworks are quite local in the sense that they deal with a single object, a certain role pattern, a time configuration. But clearly much more global structures are necessary as well. It seems that there are two kinds of broader frameworks.

The first kind organizes the semantic domain in microworlds (cf. Minsky and Papert [1971]) and provides prototypes for global situations within such a microworld. Thus it has been shown that prototypes of a whole birthday party (Charniak [1972]) or a scenario for eating in a restaurant (Schank and Abelson [1977]) are relevant information structures for understanding or producing natural language. Such prototypes provide a framework for viewing a whole situation, they describe typical ways of telling about such situations, the preconditions, the usual circumstances, aspects or consequences, participants, actions, etc.

The second kind of broader frameworks deals with the different kinds of realities. There is the reality of the real world, but also the one of dreams, the literary world, the world of religion, and so on. This is what Schutz [1969] has called the "provinces of meaning". What kind of reality one is talking about or experiencing will influence the linguistic means used to do so.

LINGUISTIC ORGANIZATION

Third there is the perspective of organization. It is well known by designers of cognitive systems that accessing information is one of the main problems in systems which have a great amount of knowledge. Natural language has recognized this difficulty and provides all sorts of clues to help in accessing the necessary information at the right moment of time. This goes by providing organization of the linguistic forms according to scenarios depicting prototypical organizational structures, by introducing certain orderings, intonation patterns, etc.

(a) Micro-organization

The idea of organization is primarily reflected in well known linguistic notions such as theme/rheme, given/new, topic/focus, etc., (cf. Dahl [1969], Sgall [1973], a.o.). The speaker has the ability to point out when extra effort in accessing information structures is going to be involved or when something is supposed to be known or in the area of attention. Important points are stressed, minor details are presented weakly.

Here the prototypical situations depict the current state of the hearer's knowledge and tell what kind of actions should be performed given such a state and how these actions help streamlining the understanding process, e.g. regulate the focus of attention (cf. Grosz [1977]). The information in the prototypes concerns effects on other aspects, say, choice for a certain viewpoint role in a case frame (as studied in Halliday [1967-68] for example), or more concrete surface characteristics realizing these various organizational clues (in English usually in terms of sound structure).

(b) Macro-organization

But principles of organization go beyond these minimal concerns. The language system provides certain structural signals to indicate the organization at a macro level, e.g. by creating paragraphs, chapters or other forms of text organization (cf. Dressler [1972], Van Dijk [1977], Petofi and Rieser [1973], a.o.).

Knowledge about macro-organization could again be organized into scenarios of prototypical text structures which tell about what kind of signals there are and what is meant by the introduction of certain signals.

Note that organizational clues do indeed make the process of understanding easier. When the reader already has a plan for how the information is going to come in, he can direct his processes in a more effective way. For example knowing that a "scientific paper" plan is due, he may start reading the abstract, look around for an overview, (when impatient) skip to the end of the paper to read the conclusions, see what is in the bibliography to get an idea of the background literature, and so on.

This collection of factors is extensive, to say the least, even though I left out some groups of factors (such as emotion or social stratum) which are also known to play a role in a natural language communication. It is probably a unique feature of natural language communication that such an enormous amount of information can be transmitted with such a limited amount of signals.

2. THE REPRESENTATION PROBLEM.

From the foregoing discussion it will have become clear that knowledge about language takes two forms: on the one hand we have prototypes for aspects of situation, i.e. *frames*, and on the other hand we have descriptions of prototypical sequences of actions, i.e. *plans*. Both have sufficient properties in common to introduce a single construct as basic unit of knowledge representation. This construct will be called an *expert*.

A frame contains knowledge about a prototypical situation or action sequence. It describes the objects involved, the relations among the objects, the roles they play, what kind of objects can fulfill the roles, the conceptual aspects, examples of the situation, useful annotation such as justifications, hints about how to use or not use the information, pointers to related frames, in short all possible knowledge that can be shown to be necessary and contributing to the problem of effective inferencing.

It is important to realize that notions like prototypes, frames, plans and experts embody a holistic attitude towards the representation of linguistic knowledge : We start from whole structures and represent parts only within the context of these wholes. This contrasts with the atomistic approach where one starts with minimal elements (e.g. distinctive features, categories, minimal selection restrictions) and constructs whole structures by gradually combining these minimal elements according to certain rules.

(As regards the holistic bias experts relate to the work on frames in AI, cf. Minsky[1975], Winograd [1977], Kuipers [1975], a.o. See also the gestalts in Lakoff [1976] as an example of a parallel development in linguistics.)

The next important aspect is that frames within the same grammar are organized in a so-called generalization hierarchy, where the frames higher up in the hierarchy deal with the less specialized aspects and where there is gradual refinement when we proceed to frames lower in the hierarchy.

This hierarchy is important for three things:

(i) It is a very powerful way of capturing generalizations because common properties can be grouped together.

(ii) During activation we can start at the top of the hierarchy and work our way down to further specializations (cf. *infra*).

(iii) The generalization hierarchy is very suitable for the system during its developmental stages (cf. *infra*).

For example the frames for the prototypes in the lexical frameworks has at the top an expert dealing with the "summum genus", then the hierarchy specializes into frames for more particular prototypes. (This is by the way also the traditional way of organizing lexical knowledge, cf. Nida [1975]).

Similarly the frames for case will have a general case frame at the top with very general case relations, and almost no restrictions on the possible objects that can fulfill the roles. This case frame is then refined into more and more specific case frames and gradually the selection restrictions on the slots and the surface case features signalling the information become more specific.

Or for semantic action plans, we would start with a series of frames for very undifferentiated goals, e.g. introducing objects. Then we would gradually refine these plans , e.g. have one for introducing with proper names and one with descriptions, then one for various types of descriptions, etc.

(The hierarchy is one of the aspects of both the frames hypothesis, (cf. Minsky[1975]), and

the society of mind theory (as in Minsky and Papert [forthcoming]). There are also exciting links here to the structure of the brain (Minsky,1977) and to developmental growth (cf. infra.)

At present an abstract theory of frame-based knowledge representation has been constructed and a language has been designed that contains syntactic constructs for the representational tools contained in the abstract theory. See Steels[1978b]) for an intuitive introduction to this language. The examples given before made use of it.

3. THE ACTIVATION PROBLEM

A frame is located in a computational object known as an *expert*. An expert has the power to work according to its own scripts, in other words to be able to activate itself when the environment feels appropriate and to continue working more or less independently of but in interaction with other experts. Because a linguistic communication is something involving many types of information, several experts consider the communication each from their own viewpoint and at the same time.

One can view the whole system as a society of experts which engage in a discussion about the linguistic communication where each expert contributes his own knowledge to the whole. Actually there are many societies, one for each perspective, and presumably there is a society of supervisors that is able to establish communication between members of the individual societies. So the language system is seen as a parallel processing system, with lots of activity distributed over groups of relatively independent modules.

(In this sense the experts relate to "higher order" agents in Minsky and Papert [forthcoming], and have the actor theory of computation (cf. Hewitt [1976]) as computational foundation.)

Let me make this picture a little bit more concrete by sketching how language production and language parsing may go.

Assume that to start up *language production*, the cognitive systems provide a description of the goals, information, beliefs, etc. of a certain communication situation. Based on these descriptions experts are activated which depict prototypical situations that come as close as possible to the current situation. In other words (i) standard plans concerning semantic actions, speech acts, and social interactions are invoked that correspond to the goals of the speaker or such plans are already active and carried out further, (ii) frameworks are activated that highlight the information from various conceptual angles and existing frameworks dealing with broader conceptual structures continue exercising their influence and (iii) experts for standard situations concerning the application of organizational principles are called for.

Within each of the experts various factors are encountered that all have their own linguistic forms. The task of language production consists mainly in trying to establish coherence between these various forms by propagation of constraints (i.e. surface characteristics) until a complete output expression can be constructed. This coherence is obtained by a discussion among the experts, regulated by a so called supervising expert which collects information from many different sources and tries to assemble a whole.

Language parsing is based on the same information structures as language producing. But now the structures which describe the linguistic forms are the major source of activation of an expert. (Although it must be kept in mind that the communication situation is already for a great deal predicted by previous discourse, the social situation or frames for broader information structures, even before the first word is spoken.)

Once an expert is activated it starts considering the factors that are underlying the linguistic forms according to its knowledge, for example by looking for further evidence in the input. The main task of the parser as a whole consists again in providing coherence of factors by propagation of constraints (i.e. factors) until a complete description of the intensions of the communication situation can be constructed. This coherence is again obtained after a discussion among the experts in which they compare their results and try to gradually construct a global situation based on active prototypes, already known

information and the continuous stream of incoming linguistic forms. The plans for the various actions could then be carried out gradually and the knowledge structures would be expanded according to the intensions of the speaker.

So we see that basically the activation of linguistic knowledge goes in three steps:

(i) An expert becomes active because a small (but sufficiently relevant) portion of its descriptions match with the descriptions of the known parts of the communication situation (the goals, information, beliefs, etc. of the speaker during language production, or the linguistic forms during language parsing)

(ii) Once activated an expert tries to obtain further evidence in an attempt to satisfy more of its descriptions, or it invokes another expert which is a refinement of itself, based on more precise evidence (recall the presence of a generalization hierarchy among the experts).

(iii) Also each expert tries to establish coherence by communicating with other experts about its findings (i.e. the linguistic forms to be used in language production, or the underlying factors in language parsing). This technique is known as the propagation of constraints (cf. Sussman[1978]) and it is a central mechanism of the activation strategy.

Of course the discussion among the experts will not always go so smoothly. To this purpose so called *conflict resolution mechanisms* are introduced which relieve some of the tension in cases of severe conflict. I believe that these mechanisms are not just a feature of the processes but a substantial part of linguistic knowledge itself.

Let me briefly discuss two examples: the frame shift mechanism and the reduction mechanism.

Suppose that there is a certain communication situation and the lexical specialist has activated a prototype for the root 'poor' with meaning "having few possessions" (based on the fact that the information to be expressed deals with having few possessions).

However other experts, e.g. the one dealing with semantic actions, wants to have a root that has the function of introducer. This might for example happen in a construction like 'He gives to the ...'. Where ... has to be filled in by an appropriate linguistic form expressing someone who has few possessions. But there is no linguistic form available that is compatible with both factor values, in other words when we use the word 'poor' (as in 'a poor boy'), we have to use it with the function of an attributive adjunct and not an object. So there is a conflict.

Instead of performing backtracking in the sense of telling the cognitive systems that this situation is not realizable, natural languages use a powerful way to dynamically expand the set of available prototypes and thus resolve the conflict: *the frame shift mechanism* (cf. Steels [1978a]). It consists in actively constructing a new prototype by adding certain structural signals to indicate the shift, inheriting some of the structural properties of the factor value that caused the conflict, inheriting some of the structural properties of the factor value that is the target of the shift, etc. Methods to do this will be called *transfer frames*.

In the given example we can therefore say something like 'He gives to the poor'.

Frame shift is extremely common in natural language, each factor seems to have its own collection of transfer frames. For example we go with 'poor' from 'a poor man' to 'he gives to the poor' performing a semantic function shift from adjunct to object, with 'red' from 'a red table' to 'the red brigade' performing a meaning shift from a color to "being revolutionary" and with 'open' from 'the door is open' (state) to 'the door opened'(process) and from there to 'he opened the door'(action-process). We can perform a perspective shift as from 'John washed her clothes' to 'Her clothes were washed by John', a speech act shift in

rhetorical questions, and similarly for all other factors.

The frameshift mechanism is not only useful in production processes but also in language parsing because the "normal", i.e. unshifted usage of a certain linguistic form could be maintained unless there is a conflict forcing a shift. This turns out to be a very powerful way of implementing parsing strategies that first consider the default case before turning to more elaborated usages of certain constructions.

Another "conflict resolver" is *the reduction mechanism*. There seems to be an important maxim underlying natural language communication: be as brief as possible. The reason is obviously that if we had to make everything explicit what is contained in even the simplest language expression (such as 'Hello !') it would take hours to perform a conversation. Brevity is obtained by having the same linguistic form perform many functions at the same time, and by assuming a great amount of knowledge. But in addition there is a further mechanism available to cut down on the amount of linguistic signals to be transmitted.

The idea is that if enough information is available to get at a prototype, it is not necessary to provide all the surface characteristics that are normally occurring with this prototype. For example instead of saying 'this machine consumes more power than that one consumes power' we can (in fact should) say 'this machine consumes more power than that one'.

Reducing the amount of surface characteristics is of course not completely undetermined. For example we cannot say 'I saw milkman morning'. Instead there are certain prototypical situations where reduction is allowed, typically in cases of conjunction or comparison. These situations are laid down in so called 'reduction frames' which like demons jump up to announce that reductions are possible during language production. Note that it is necessary to institutionalize this because unlimited reductions can destabilize the language (in the Saussurian sense of 'la langue').

For the parser these reduction frames are connected to the complaint departments of the various experts. The experts complain because they do not see what they expected to see (although there is strong evidence from other sources). The experts assigned to maintain the reduction frames will in such occasions relieve the conflict.

Note incidentally that the reduction mechanism is not only no problem but also a natural thing to occur in a holistic approach. The ability of recovering reductions in humans is truly astonishing and is difficult to explain (let alone simulate) when an atomistic approach is taken.

Linguistic processing as a "discussion" among experts was suggested by several speech understanding research groups as the way to construct a global organization for the various components of a linguistic systems (such as Woods [1976] and Lesser et.al.[1975]). We have extended this metaphor to the interior mechanics of each component as well.

At the moment of writing this paper a preliminary version of a system that works along the lines sketched above has become operational.

First of all we constructed an abstract machine that is able to simulate communication among experts. Then we constructed a programming language (known as the XPRT-language) which contains the primitives for communication and construction of the experts proposed by this abstract machine. An interpreter has been designed and implemented for this language. (see Steels,1978d).

After that we started working on the construction of reasoning processes. This lead to a preliminary system that has much of the required behavior although there is still an enormous amount of problems that remain to be resolved for a first report on these results.

3.THE ACQUISITION PROBLEM

Initial experts could grow out of taking records of given situations. These records are made up of descriptions formed by innate or learned categories. Once stored the knowledge structures 'representing' the situation start functioning as a prototype for future situations, i.e. when a similar situation occurs again or rather when aspects of a similar situation are recognized, the prototype provides information to predict or reconstruct the rest of the situation at hand.

From an initial collection of prototypes several further constructive developments can be postulated. For example a new situation comes in that corresponds nicely to the prototype already available but provides some new information. In this way the original description could be expanded or refined. Or it could be that another situation comes in that conflicts at some points but corresponds to other ones. This conflict could be resolved in setting up a new prototype related to the original one by a specialization relation. And that is how the generalization hierarchy starts being developed. Or it could be that it is recognized that two prototypes have sufficient elements in common to construct a new one containing common properties and to have a specialization link to each of the original ones. Or it could be that new prototypes are constructed by analogy with existing ones, e.g. based on language regularities perceived so far, and so on.

(The relation to the Piagetian ideas about constructive growth of knowledge (such as assimilation, accomodation, etc. cf. Piaget [1975], Inhelder[1977]) should be obvious here. Much current work in AI can be seen as making these constructive principles computationally concrete, see e.g. Sussman [1975], Brown [1977], Winston [1978], a.o.).

More concretely child language development could start by preserving descriptions of global communication situations. In other words the persons involved, the subject matter, the actions resulting from saying something and of course the linguistic forms used are all part of a whole picture. When the child then sees a similar situation to the one (s)he has a prototype for, he may (try to) reproduce the linguistic form (in whole or in part) that occurred in the prototype. Or when (s)he hears the linguistic form in the context of the same situation he may predict the other aspects that are present in the prototypical situation.

Based on results in developmental psychology it is reasonable to assume that the foundation for many of the prototypes in the various perspectives have been developed before the first words are spoken, cf. Bruner [1975], Bates [1976], Sinclair [1978],a.o..

For example the child will already have a way to approach the world as a basis for the content perspective, he will know what it means to want something and that it is possible to get the thing wanted by means of communication, he will already know about fundamental concepts of organization such as focus, turn-taking and so on. The main problem as far as language is concerned is to relate these aspects to linguistic forms. In the beginning, knowledge about language might be stored as annotation of already existing structures, specifying their realization into language. (This does not mean that knowledge structures cannot be developed due to language, what I'm saying is that it does not start that way.) The main activity during "more advanced" language learning consists in finding out what the more complicated relations are between a certain linguistic form and the various prototypes within each of the linguistic perspectives.

Of course all this is far from an easy matter. A child needs about ten years before it acquires a reasonable mastery of the language system. During these ten years a very intensive problem solving process is going on that requires all the intelligence and creativity

the child can come up with.
See Sinclair [1967] for work in the same direction.

5. CONCLUSIONS

In this paper I described informally and (probably too) briefly the principles of a linguistic theory currently under development. I hope the reader has not been annoyed by the lack of detail, examples or formalisms. That will all become available in due course.

Let me end by summarizing some of the main principles guiding the development of the theory.

First of all I sketched the main thesis of conceptual grammar: the grammar consists of a network of concepts that represent information laid down in a number of axioms. These concepts refer to descriptions of prototypical linguistic situations or aspects of those situations.

Second I have opted for a functional approach which means that language is studied as a tool to establish a goal-directed communication. To understand how language works is seen as to understand how the means realize the goals.

Third the multiple viewpoint approach was introduced. Instead of dividing structures into levels, I suggested that we could isolate several viewpoints of descriptions. Each of these viewpoints highlights one aspect of the linguistic form used in the communication and is related to one aspect of the function of the communication.

Fourth I introduced several factors which underly a certain linguistic viewpoint: goal-based factors (dealing with semantic actions, speech acts and social interactions), content-based factors (dealing with basic frameworks for the lexicon, case, space, time, etc. and broader frameworks for micro-worlds and provinces of meaning) and organization-based factors (dealing with primary organizational clues such as theme/rheme, topic/focus, etc. or macro organizations such as text structures).

Fifth I introduced the "expert" conception of knowledge representation: The unit of representation is a self-contained construct called an expert that possesses a rich knowledge structure about a small subject and that is responsible and capable of regulating its own operations. Experts are organized into hierarchically organized societies. The whole system looks like a parallel processing system where activity is spread over a great number of distributed processors. All sorts of mechanisms are available to regulate activity in the system, such as climbing up and down inheritance lines in the hierarchy, communication to arrive at coherence via propagation of constraints, resolution of conflicts by mechanisms as frame shift or reduction, etc.

6. REFERENCES

[The references given throughout the paper are not meant to constitute a serious bibliography of the various subjects that were briefly touched upon, in view of the extensive literature this would be quite impossible. Instead one should see them as (loose) pointers to various areas of investigation that I consider relevant to the problems discussed.]

- Austin, J.L.(1962) How to do things with words. New York: Oxford University Press.
- Anderson, J.M. (1977) Case grammar. Towards a theory of grammatical relations. London.
- Bates, E. (1976) Language and context. The acquisition of pragmatics. New York: Academic Press.
- Bernstein, B. (1971) Class, Codes and Control I: Theoretical studies towards a sociology of language. London: Routledge and Kegan.
- Bloomfield, L. (1933) Language. London: Allen and Ulwin.
- Bobrow, D.G. and A. Collins (1975) Representation and understanding. New York: Academic Press.
- Bobrow, D.G. and T. Winograd (1977) An overview of KRL, a Knowledge Representation Language. 3-46 in: Cognitive Science I,1.
- Brown, R. (1977) Use of analogy to achieve new expertise. MIT-AI lab. TR-403.
- Bruner, J.S. (1975) The ontogenesis of speech acts. Journal of child language. 2,1-9.
- Carnap, R. (1958) Introduction to symbolic logic and its application. New York. Dover publications.
- Charniak, E. (1972) Towards a model of children's story comprehension. MIT AI lab, technical report 266.
- Cicourel, A.V. (1973) Cognitive Sociology. Harmondsworth: Penguin Books.
- Cohen, (1978) Planning speech acts. Toronto: Department of Computer Science. TR.118.
- Dahl, O. (1969) Topic and comment. Stockholm: Almqvist and Wiksell.
- Dik, S. (1978) Functional Grammar. Amsterdam: North-Holland.
- Dressler, W. (1972) Einführung in die Textlinguistik. Tübingen: Niemeyer.
- Fillmore, C. (1968) The case for case. 1-90 in: Bach, E. and M.T. Harms (eds.) Universals in Linguistic Theory. New York: Holt, Rinehart and Winston.

- Fillmore, C. (1977) Scenes-and-frames semantics. 55-82 in Zampolli, A. (1977).
- Fikes, R. and G. Hendrix (1977) A network-based knowledge representation and its natural deduction system. Cambridge, Mass: IJCAI 1977.
- Fodor, J.D. (1977) Semantics: Theories of Meaning in generative grammar. New York: T.Y. Lowell Cy.
- Grosz, B. (1977) The representation and use of focus in dialogue understanding. SRI, technical note 151.
- Goffman, E. (1974) Frame Analysis. An essay on the organization of experience. Cambridge, Mass: Harvard University Press.
- Halliday, M.A.K. (1967-68) Notes on transitivity and theme in English (3 parts). Journal of Linguistics.
- Halliday, M.A.K. (1973) Explorations in the functions of language. London: Arnold.
- Halliday, M.A.K. (1976) System and function in language. Kress, G.R. (ed.) London: Oxford University Press.
- Hewitt, C. (1976) Viewing control structures as patterns of passing messages. MIT AI Lab. memo.
- Hymes, D. (1971) On Communicative Competence. Philadelphia: University of Pennsylvania Press.
- Inhelder, B. (1977) Genetic Epistemology and developmental psychology. 332-341 in: Annals of New York Academy of Sciences.
- Kuipers, B. (1975) A frame for frames: Representing knowledge for recognition. 151-184 in Bobrow and Collins (1975).
- Lakoff, G. (1973) Derivational constraints. Seuren (ed.) Generative Semantics. Oxford University Press.
- Lakoff, G. (1976) Gestalt Linguistics. Chicago Linguistic Society.
- Lyons, J. (1977) Introduction to Semantics. Vol I and II. Cambridge: Cambridge University Press.
- Longacre, R.E. (1976) An anatomy of speech notions. Lisse: The Peter de Ridder Press.
- Minsky, M. (1975) A framework for representing knowledge. 211-277 in Winston, P. (ed) Psychology of computer vision. New York: McGraw Hill.
- Minsky, M. (1977) Neurodevelopmental epistemology. Invited papers Cambridge: IJCAI-5.
- Minsky, M and S. Papert (1977) Artificial Intelligence Progress Report.

MIT-AI lab memo 259.

- Minsky, M and S. Papert (forthcoming) The society of mind theory.
- Montague, R. (1974) Formal Philosophy: Selected papers of Richard Montague. Thomason, R. (ed.) New Haven: Yale University Press.
- Moore, R.C. and A. Newell (1973) How can Merlin understand ? in Gregg, C.(ed.) Knowledge and Cognition. Potomac: Lawrence Erlbaum Ass.
- Nida, E.A. (1975) Componential analysis of meaning. An introduction to semantic structures. Den Haag: Mouton.
- Norman D., and Rumelhart (1975) Explorations in Cognition. San Francisco: Freeman.
- Petofi, J.S. and H. Rieser, eds.(1973) Studies in Text grammar. Dordrecht: Reidel
- Piaget, J. (1975) L'equilibration des structures cognitives. Paris: P.U.F.
- Pike, K.L. (1971) Language in relation to a unified theory of human behavior. Den Haag: Mouton.
- Kruisinga, E. (1931) A Handbook of Present Day English Grammar. Groningen: Noordhoff.
- Quirk, R. et. al (1972) Grammar of Contemporary English. Harcourt Brace Jovanovich Inc., New York.
- Reddy, R. et.al. (1976) Parallelism in speech understanding. Pittsburgh: Carnegie Mellon University. Technical Report.
- Sadock, J.M. (1974) Toward a linguist theory of speech acts. New York: Academic Press.
- Schank, R.C. et.al. (1975) Conceptual information processing. Amsterdam: North-Holland.
- Schank, R.C., and A. Abelson (1977) Scripts, plans, goals and understanding. An inquiry into human knowledge structures. Hillsdale: Lawrence Erlbaum Ass.
- Schutz, A. (1967) Collected Papers: I. The problem of social reality. Den Haag: Martinus Nijhoff.
- Searle, J.R. (1969) Speech acts. An essay in the philosophy of language. Cambridge: Cambridge University Press.
- Sgall, P. et.al. (1969) A functional approach to syntax in generative description of language. Amsterdam: Elsevier.
- Sgall, P., Hajicova, E., Benesova, E. (1973) Topic, focus and generative semantics. Kronberg: Scriptor.
- Sinclair, H. (1967) Acquisition du langage et developpement de la pensee.

Paris: Dunod.

- Sinclair, H. (1978) Representation, communication et debut du langage. in press.
- Steels, L. (1978a) The frame shift mechanism in natural language. in: Proceedings of AISB-GI summer conference. Hamburg.
- Steels, L. (1978b) Frame-based Knowledge Representation. MIT-AI WP 170.
- Steels, L. (1978c) Some examples of conceptual grammar. MIT-AI WP 176.
- Steels, L. (1978d) The XPRT description system. (in preparation).
- Sussman, G. (1975) A computer model of skill acquisition. New York: American Elsevier.
- Sussman, G. and G. Steele (1978) Constraints. MIT-AI Memo 567.
- Szolovits, P. L. Hawkinson and W. Martin (1977) An overview of OWL, A language for representing knowledge. Cambridge: MIT/LCS/ TM-86.
- Tesniere, L. (1959) Elements de syntaxe structurale. Paris: Klincksieck.
- Van Dijk, T.A. (1977) Text and Context. Explorations in the semantics and pragmatics of discourse. London: Longman.
- Verburg, P.A. (1952) Taal en Functionaliteit. Wageningen: Veenman en Zonen.
- Walker, et.al. (1977) Speech Understanding Research. Stanford Research Institute.
- Whorf, B.L. (1964) Language, thought and reality. Cambridge: MIT press.
- Wilks, Y. (1976) Processing Case. American Journal of computational linguistics.
- Winograd, T. (1972) Understanding natural language. New York: Academic Press.
- Winograd, T. (1977) Five lectures on Artificial Intelligence. 521-570 in Zampolli. (1977).
- Winston, P. (1978) Learning by creating and justifying transfer frames. MIT-AI lab memo 414.
- Wittgenstein, L. (1971) Tractatus Logico-Philosophicus. London: Routledge and Kegan.
- Woods, W.A. et.al. (1969) Augmented Transition Network Grammars. CACM-69.
- Woods, W.A., et. al. (1976) The BBN Speech Understanding system. Final report. Cambridge, Ma: Bolt, Beranek and Newman.
- Zampolli, A. (1977) Linguistic Structures Processing. Amsterdam: North-Holland.

Zandvoort, R.W. (1945) A handbook of English grammar. Groningen: Wolters.

7. Acknowledgement

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