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COMBINATION AND SELECTION IN COMPREHENSION A PROCEDURAL APPROACH TO APHASIA

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We present a procedural semantic model for sentences comprehension; it has two main parts : firstly, the meaning of a sentence is the result of combining the meanings of its constituents (this is a traditional approach); secondly, the meaning of a sentence is the result of selecting from memory a structure of general knowledge (a frame), and of filling in further specifications fitting the particular instance; this is one of the A.I. approaches of meaning. — If we assume that for each procedure there exists a distinct brain region, there must be some cases of hemispher lesions destroying one procedure and only one. We point out that everything happens as if the behavior of Broca's aphasics correspond to the removal of the "combination" procedures – and the behavior of the Wernicke's to the removal of the "selection" procedures.

In a current approach to the study of psycholinguistic phenomena, linguistic behavior is viewed as the output of brain processes. It is assumed that these outputs give insight into the underlying processes. However, there are problems to this approach, from both theoretical and experimental viewpoints.

From a theoretical viewpoint current abstract linguistic theories have been used in modelling psycholinguistic processes, namely because of their attractive formal simplicity. However, it has become more and more obvious that such theories do not provide adequate psychological models (cf. Fodor, Bever & Garrett, 1974). Thus the need for a new theoretical approach.

From an experimental viewpoint it seems impossible to observe separately the output (in other words : the behavior) corresponding to one of the several procedures which concur to linguistic abilities (indeed, every linguistic behavior brings into play several redundant procedures). It is thus difficult to check assumptions concerning a specific procedure.

Here is how we have attempted to deal with these problems. As theory is concerned, we will bring in models of comprehension introduced on Artificial Intelligence. These models fall roughly into two classes :

1. The meaning of a sentence is the result of combining the meanings of its constituents. This is a traditional approach (Cf. Katz & Fodor, or Winograd 1972).

2. The meaning of a sentence is the result of selecting from memory a structure (a frame) corresponding to a general concept and of filling

in further specifications fitting the particular instance. In this approach, the comprehension process is seen as involving primarily the use of general knowledge. The introduction of general knowledge into linguistics has been defined by Miller (1976) as "one of the more exciting branches of linguistics and psychological research". Using linguistic examples, we will show how both procedures (selection and combination[1]) may complement each other, in normal understanding.

As experimentation is concerned, we will use two kinds of aphasic behavior. We will try to show that one type of these behaviors can be understood as the result of a composition process, and the other one as the result of and only of a selection – of a schema from memory.

PSYCHOLINGUISTIC PROCESSES AND APHASIA

A psycholinguistic approach to the study of aphasia accounts for errors in pathological language by considering models of normal linguistic production. Indeed, if brain mechanisms define behavior, damage to these mechanisms will cause pathological behavior. In other words, the disfunction of a particular procedure concurring to normal linguistic production will create a given type of aphasia. It is thus appropriate to study aphasic typology by means of psycholinguistic theories – this typology will in turn help elaborate new theories of language.

Are psycholinguistic theories available for this? Until recently, the answer to this question was: "Yes, they do exist, and are derived from "strong" and well formalised linguistic theories, resulting from the linguistics explosion of the 60's". Indeed, for a long time, psycholinguistic theories dealt with the interactions between "competence", a concept of formal abstract linguistic theories, and the parameters considered secondary, because unsystematic, such as memory and motivation.

Little by little, more and more evidence pointed to the fact that psychological processes were not explained by these formal theories (Fodor, Bever, Garrett, 1974): "The discovery that psycholinguistics has a subject matter – a body of phenomena which are systematic but not explicable within the constructs manipulated by formal linguistics – is perhaps the most important result of the last decade of psycholinguistic research" (*The Psychology of Language*, p. 369).

Thus formal linguistic theories should be abandoned as models of psychological processes in favor of specifically design models. But such

[1] The terms "selection" and "combination" were key terms in Jakobson's studies of aphasia. He suggested that the two main types of aphasia (called respectively Broca and Wernicke) might reflect disturbances of one or the other of these two "poles", which, according to him, were involved in every linguistic process. We will present a rather similar suggestion, using the same keyword; but they will label two specific psycholinguistic procedures.

work is only at an embryonic stage. The recourse to formal linguistic theories was attempted in neurolinguistics too, but it was found even more inadequate in this field. Thus the feeling of failure of psycholinguistic research in aphasia. (Cf. Goodglass & Blumstein, 1973: "While small inroads have been made, the major problems of accounting for syntactic errors in terms of some models of normal syntactic processes, and of understanding the nature of word finding disorders are still unsolved" *Psycholinguistics and Aphasia*, p. 8.)

Such approaches, after Jakobson (1951), meant to reason with models of linguistic brain processes but dealt in fact with formal descriptions of language. In other words, the result of a process was confused with the process itself.

But why implicitely condemn psycholinguistic approaches to aphasia, as Fodor, Bever and Garrett (1974, preface) do (in a book where the authors state that a theory of psychological processes of linguistic abilities remains to be done): "it is the sad truth that remarkably little has been learned about the psychology of language processes in normals from over a hundred years of aphasia study". Indeed, why blame experimental observations for being unusable, when no theories are available which would make use of them?

The foundation of a psycholinguistic analysis of aphasia must precisely be a theory of psychological processes underlying linguistic abilities: normal, as well as pathological experimental data cannot be meaningful in the absence of a theory to account for them. It is now imperative to attack the problem of aphasia from a psycholinguistic viewpoint, if we believe, as Luria seems to, in his review of research in neuropsychology, that a way must be found out of the dead-end which associationist and connexionist approaches to aphasia constitute: "It is now perfectly clear that a way out of this impasse must be found, and that the essential conditions for its discovery are, first, a sufficiently precise view of the psychological structure of speech processes" (*Working Brain*, p. 305).

Let us then recall the following statement of Freud (1891) "... that the significance of the factor of localization for aphasics has been overrated, and that we should be well advised once again to concern ourselves with the functional states of the apparatus of speech..." to point out how old is the will of a functional theory of speech production-reception.

NATURAL LANGUAGE PROCESSING IN ARTIFICIAL INTELLIGENCE

Computer simulations do not claim to isomorphy with psychological processes. From a functional viewpoint however, they may constitute reasonable models of linguistic processes, because, to inputs (linguistic stimuli), they make correspond outputs in a way analogous to human behavior. Let us quote research on the following types of programs: 1. question answering; 2. machine translation; 3. information retrieval; etc.

The first attempts to computer applications in natural language were machine translation programs, which failed, because the inadequation of formal linguistic theories. Here is an example of one of the problems encountered: to translate, into English the following French sentences:

"Le camion a heurté le piéton; on l'a entendu crier"
"Le camion a heurté le piéton; on l'a entendu freiner"

syntactical rules are not enough. Information beyond dictionary definitions must be used, information such as relations between trucks and pedestrians, to decide if "I" must be translated by "him" or "it". This kind of information, which must be in memory in order to allow for any disambiguation, is in fact the general knowledge or "world knowledge" referred to in this paper.

Thus, for machine translation as well as for psycholinguistics, formal linguistic theories have proved inadequate. The same reason explains both cases of inadequacy: The lack of intervention of general knowledge in the computer system as well as for the speaker model. General knowledge is necessary in both cases to deal with semantic problems, which are the main problems in both domains. This general knowledge brushed aside by formal theories must be given a place in any theory of computational linguistics or psycholinguistics.

Some ways of integrating general knowledge in computer systems are being studied in computational linguistics. An overview of this work can be found in *Theoretical Issues in Natural Language Processing* (M.I.T., 1975) and *Computational Semantic* (1976). We will content ourselves with brief notes on the main approaches which we have attempted to use in neurolinguistics.

1. *Selection Processes in A.I. ("frame approach").* Minsky first introduced the term "frame approach" to refer to research which treated comprehension as a process of selection from memory of a schema (a frame). A lot of work in Artificial Intelligence now consists of attempts to give concrete existence to this approach. For example, in Schank's work (1975), general knowledge is used to predict the meaning of linguistic inputs: "We view the process of understanding as the fitting in of a new information into a previously organized view of the world... Input sentences set up expectations about what is likely to follow in the text. These expectations arise from the world knowledge that pertains to a given situation". Here is a summary of the assumptions underlying the frame approach: the meaning of a sentence is a semantic structure recorded in memory, selected by means of information cues taken from the sentence and its context, and filled by these cues.

2. *Composition processes.* Representations of world knowledge and the use of these representations cannot be formalized mathematically, and are difficult to implement on a computer. For *A.I.*, as for psycholinguistics comprehension was first dealth with as deductive and combinatory processes. For example, Katz (1964): "... The underlying

phrase marker of a sentence will be input to the semantic component of a grammar, which is composed of a dictionary and a projection rule. First, the dictionary will assign a set of lexical readings to each lexical item of a sentence; second, the projection rule will *combine* lexical readings" (*The Underlying Reality of Language*, p. 106). These deductive processes use lexical readings and rules of combinations of these readings. This type of processing is adequate for sentences which do not strongly require general knowledge. For instance, these processes are adequate for the description of the relative place of two objects. Winograd's program (1972) deals with a world of geometrical objects. It is based on combinatory processes acting in a syntactico-logical way. "The semantic theory must describe relationships at three different levels. First, it must define the meaning of words... The next level relates the meanings of groups of words in syntactic structures." But even in this restricted world, the meaning of a sentence depends on a whole context, which leads to the need for the intervention of general knowledge, as soon as one wishes to deal with non-trivial problems.

A PSYCHOLINGUISTIC MODEL OF COMPREHENSION PROCESSES

SELECTION PROCESSES

Both in current psycholinguistic research and artificial intelligence, it is now assumed that the use of general knowledge is a cornerstone of comprehension. Miller (1976) proposes a functional representation of lexical meaning, a representation grounded in the world knowledge of the speaker. According to Miller, the use of general knowledge is necessary for several linguistic operations, for example disambiguation or understanding of metaphors. A solution to these semantic problems would involve: 1. defining the properties, and functions of the referent of each lexical item; 2. defining, for each pair of lexical items, rules relating these syntactical, semantic and morphological properties. Miller claims that such a representation of lexical entries together with the informations associated with every pair of lexical items, encompasses the speaker's general knowledge.

Indeed, the task of semantic disambiguation requires ordinarily the use of general knowledge. In Miller's words, "We can therefore, allocate much of the disambiguation task to general knowledge and provide only an abstract and relatively vague definition in the lexical entry for a polysemous word". In Miller's model of comprehension, the input sentence is translated into a sequence of commands and pointers toward the lexical entries (in other words, into a program). This model, based on a computational analogy with a "compiler", requires the use of syntactical rules (syntactic disambiguation) to select out the proper lexical entries.

In short Miller's approach is close to a "frame" approach. The

frames which he proposes would contain : 1. information, in particular functional information, concerning the referent of the lexical entry; 2. rules relating every lexical entry to every other. – Such rules constitute the general knowledge of the speaker. Those frames are selected out by means of pointers toward the lexical entries, after syntactical disambiguation.

WHY SELECTION PROCESSES ARE INSUFFICIENT

Not every sentence requires the use of interlexical rules. Indeed, there are sentences which, to be understood, demand only somewhat loose definitions of the lexical items involved, without requiring stored knowledge linking any two items. It may be also that: a particular speaker has no association between the two items, or the relation does not exist, for any speaker; finally, syntactical and logical relationships may be primary in understanding the sentence. Examples :

a. The speaker may not have knowledge linking two particular items. For example, a medical doctor faced with the following sentence : "It is an unstable plasma" in an article on physics, will be able, knowing the context, to disambiguate the word "plasma" and to assign to it the meaning of "ionized gaz"; but he will not be able to retrieve from memory the complex schemas which – for a physicist – implicitely link "unstable" and "plasma".

b. If the lexical entries are unrelated, the corresponding sentence will be meaningless. The absence of any matching schema explains the reaction to a sentence like (cf. Chomsky) : "colourless green ideas sleep furiously" even if, with this syntactically correct type of sentence, it is possible, according to Miller's model, to define properly the pointers to lexical entries. By contrast, the sentence "green sleep colourless ideas furiously" does not allow such definition (thus, the difference of reaction).

c. If, with a particular sentence, comprehension is conditioned by items relationship in the given occurrence, then general knowledge will not be used. For example, in comprehension tests of the "Token test" type, such as: "The circle is above the square"

the answer does not depend on general knowledge concerning the relation of circles to squares. Indeed, the relation "above" is in this occurrence primary.

The above examples show that the retrieval of a schema is not always

necessary. Furthermore, in some cases, it would lead to an erroneous interpretation. Consider sentences which contradict expected schemas :

"The rat ate the cat"
"The patient cured the doctor"
"The moon and the earth bring light to the sun".

These sentences are understood properly in normal cases, but their reader is aware that they contradict normal schemas. If there is a contradiction, there must be a comparison. Thus, we must infer that two meanings have been produced and compared; in other words that there exist two different procedures used in comprehension, as each yields a different result. But if two different procedures are used in understanding the above sentences, the same must be true for the comprehension of any sentence. (Otherwise, the plausibility of a sentence would have to be checked before triggering a single procedure!)

The existence of two procedures used simultaneously in normal comprehension is reasonable from a psycholinguistic point of view (it is probable that cognitive processes are redundant). It is also logically valid, because it implies stages of verification which correspond to observed behaviors. Indeed, we saw that readers are aware of a contradiction, when reading the above sentences, which is evidenced by feedback detected for instance by means of eye tracking. A feedback must correspond to some checking. Moreover, as we will show, some pathological linguistic behaviors can be explained by postulating the loss of one or the other procedure simultaneously present in normal comprehension.

A BI-PROCEDURAL MODEL OF COMPREHENSION PROCESSES

On one hand, we will bring into play the selection procedures (of a schema from memory). On the other we will postulate another procedure which we might call a control process (but which is the only one adequate for sentences like "the circle is above the square"). It consist of syntactical operators which are applied to lexical representations. Syntactical operators and selection procedures are complementary. By "complementary", we mean that, given certain types of sentence, one of the procedures will be more efficient than the other (as we have shown by purely psycholinguistic arguments). We will thus propose the following procedural model of comprehension:

SUMMARY OF COMPREHENSION PROCESSES

a. *Comprehension is preceded by a process of syntactical disambiguation.* A preprocessing of sentence, translating it into a sequence of pointers and operators, sets up the inputs to both procedures of selection and composition : pointers towards the lexical units are indeed necessary for selecting the interlexical schemas corresponding to procedures which use general knowledge; operators and lexical entries are the

inputs of composition procedures. Let us not forget that, in order to define pointers and operators, the metaphorical compiler must resolve syntactical ambiguities, as function words must be discriminated from content words (for example : "He *will* leave of his own *will*").

b. *The process of comprehension involves procedures which select out conceptual schemas from memory.* Complex semantic disambiguations or interpretation of metaphors require the selection of "world knowledge", as we showed above. This implies the corresponding procedures to select schemas from memory.

c. *The process of comprehension involves procedures which operate by syntactico-logical composition.* Tasks defining a particular instance, logical deduction etc. are accomplished by applying operators (defined by the "compiler") to the representations of lexical items. See examples on p. 24 and some A.I. models of these processes in Winograd (1972).

d. *The procedures b. and c. yield results which can be compared.* As we already explained (see p. 25), these comparisons explain checks and feedback such as evidenced in eye-tracking experiments.

It must be noted, however, that the model we have just proposed is fundamentally procedural. It is an information processing approach of language comprehension.

FUNCTIONAL FLOWCHART

A flowchart representing the above model can be drawn using four boxes corresponding to each of the above components. These boxes process the linguistic input, using sources of information represented by the boxes in the center : lexical definitions and general knowledge. Sa and Sb represent the outputs of procedures b and c.

RELATION OF THE MODEL TO NEUROLINGUISTICS

The model proposed is based solely on psycholinguistic and logical evidence. So far, the neurological basis of the processes has been left out. If we assume that to every procedure corresponds a distinct brain implementation, there must be some cases of aphasia where the underlying hemispheric lesion has selectively destroyed one procedure and one only. One could then deduce from the behavior of the patient the exact action of this procedure. Pathology would then appear as an experimental way of showing the existence of such a procedure in the normal individual.

SELECTIVE DESTRUCTION OF SYNTACTICO-LOGICAL COMPOSITION PROCEDURES

If we assume that syntactico-logical procedures have been destroyed, then only the procedures selecting general knowledge schemas can be

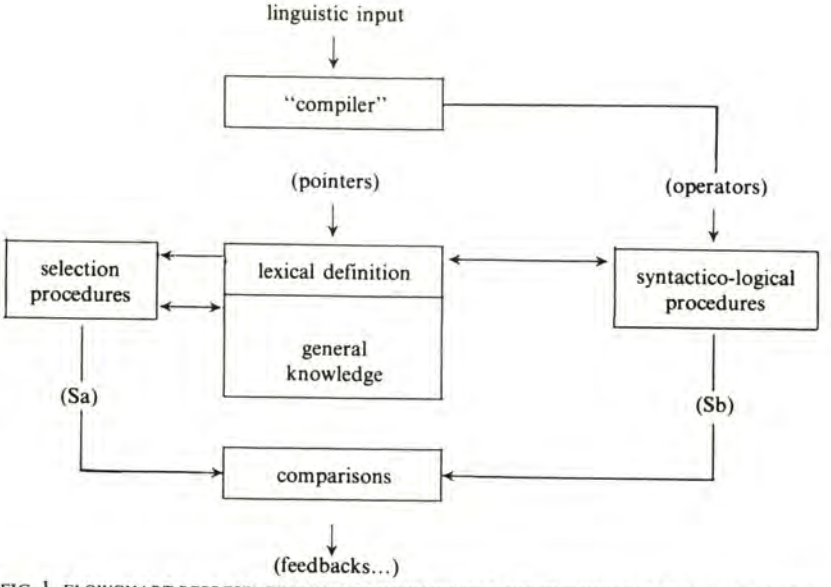

FIG. 1. FLOWCHART REPRESENTING THE COMPREHENSION OUTPUT INFORMATION PROCESSING APPROACH

used in comprehension. But for these procedures to function properly, it is necessary that the required general knowledge be available and also that the pointers to lexical entries be correctly defined. Those pointers, as we have noted before, imply a syntactic disambiguation.

Let us show then that, in the case of Broca aphasics everything happens as if their behavior corresponds rather accurately to the outputs of the postulated system, where syntactico-logical procedures have been deleted.

The following experimental data are more detailed in Andreewsky, 1974, 1975. We will also refer to the review of Zurif and Blumstein, 1976. We will use here only a few examples, the most characteristic ones, but the whole data of neuropsychological literature corroborate the following description of the comprehension behavior of Broca aphasics:

a. *Evidence for the loss of syntactico-logical procedures.* Clinically, comprehension in these patients is "relatively" good. However, they are unable to process comprehension problems based on syntactico-logical rules: they cannot answer correctly multiple choice questions of the type: "the circle is above the square" (nor any question involving syntactico-logical relations between two lexical items); they are not aware of semantic anomalies, such as "the pedestrian has run over the truck". This sentence gives rise, for instance, for one

of our patients to a comment describing normal car accidents "pedestrian, boom, coma, hospital" (this comment is in "telegraphic" style, which is the usual way of expression of these Broca-agrammatic patients).

Generally, only the usual links between lexical items are grasped. "When the agrammatic patients cannot sample from a sentence on the basis of plausibility, their comprehension fails" (Zurif, 1976).

A number of experiments have shown that agrammatic patients are not concerned with syntactical cues. For example, verb inflections are neither uttered nor understood. We have shown (Andreewsky, 1974) that those patients cannot detect any difference between sentences such as: "Yesterday, I walk"; "Yesterday, I walked"; "Yesterday, I am walking"; and cannot point out the correct sentence.

Generally, agrammatics, who do not use verb endings nor function words, in production, cannot make use of them in comprehension either. Does that mean that these patients have lost all capability for syntactical processing, as it has been claimed in the literature? If it were the case – in terms of our model –, the lexical entries required for selecting general knowledge cannot be pointed out; indeed this pointing implies a syntactic disambiguation.

b. *Evidence for syntactic disambiguation.* We have shown that such patients, who do not perform any syntactico-logical operations, *do* perform syntactical disambiguation in context (Andreewsky and Seron, 1975). If we ask such patients to read aloud syntactical ambiguities, it turns out that they are uttered or not as a function of the role of the word in the sentence: syntactically ambiguous words are uttered if and only if they are in noun (or verb) position. For example, in the following sentence: "Le car ralentit car le moteur chauffe" (The bus slows down because the motor overheats) the first occurrence of "car" is uttered, but not the second[2]. Everything happens as if the first stage of our model (i.e. pointing out the lexical entries which are the inputs of procedures selecting general knowledge) is untouched – although syntactico-logical operations cannot be performed any more by these patients as it is easy to demonstrate – and well documented in neuropsychological literature. (The loss of syntactico-logical abilities has led to the erroneous conclusion that these patients were not capable of any syntactical processing.) Utterance of syntactical ambiguities according to their functions in the given sentence fits the assumption of our theoretical model, which requires that syntactical disambiguation be done to find out, at least, the lexical entries prior to selection of general knowledge, which selection is performed by

[2] Out of context, agrammatics utter essentially nouns and verbs – without their flexion; the syntactically ambiguous French connectives (or nouns) "car" and "or" are uttered, out of context, but none of the other French non ambiguous connectives "et, ou, ni, mais, donc").

Broca-agrammatics and moreover seems to be for them the only way to sentences understanding.

DESTRUCTION OF SELECTION OF GENERAL KNOWLEDGE PROCEDURES

By contrast with Broca aphasics, Wernicke aphasics preserve in production these verb endings, functional words (connectives, prepositions, etc.) involved in syntactico-logical operations. But, on the other hand, their comprehension is seriously impaired. Assuming the loss of the selection of general knowledge provides a satisfactory interpretation of their behavior : first, the serious impairment of comprehension may be explained by this loss; experimental data provide, then, evidence that general knowledge is not embedded in the linguistic process of these patients :

1. Contrary to other types of aphasics (Derouesne, 1976) errors of recall (or repetition) are equally frequent for sentences where interlexical schemas carry information, and for "reversible" sentences where comprehension relies essentially on syntactico-logical processing : for instance, for the Wernicke aphasics, contrary to Broca aphasics (or normal patients), sentences such as : "the girl ate the pie" will lead to the same error rate as sentences such as "the motorcycle passed the car".

2. If normal subjects (cf. Miller, 1969) are given words to categorize, the sorting is a function of characteristic features (animate/non animate, human/non human, etc.) and of the properties of the referents (for example, animals are classified as "ferocious", "edible", etc.). Wernicke aphasics proceed differently : they seem only concerned with personal relation to the referents. For example, one of our patients – a cook – put in the same category "dogs", "table" and "bread", because "all three are found in my restaurant".

3. Experimental results of Goodglass and Baker (1976) demonstrate the same: to three groups of subjects (normals, Broca and Wernicke) a target object is shown while a list of words is uttered. The subjects must push a button if the word uttered appears to bear a semantic association with the target object. The relation of the referent of a word to the target object can be of many different kinds. For example, if the object is an orange, we will have : the superset class (fruit), an attribute (juicy), an element of the same category (apple), a functional context (breakfast) or an associated function (eat). The Wernicke's (in contrast with the Broca's and the normals) are not able to grasp "any kind of association" between the target object and any functional context or associated function; when comparing two functionally related concepts, here also, the Wernicke's demonstrate their inability to retrieve any linking knowledge between them.

CONCLUSION

The model of sentence comprehension proposed in this paper appears very useful: it does account for psycholinguistic phenomena of the comprehension process; it also accounts, in a logical way, for the comprehension behaviors of Broca and Wernicke aphasics; it can include more detailed models of specific procedures, such as those for syntactic disambiguation or relation retrieval between two items. We claim that in psycholinguistic and neurolinguistic research, it is necessary to construct explicit models in order to understand experimental data – so numerous in these fields. It also helps to design experimentations with the aim of checking a specific model – otherwise, the data cannot, in general, be used for anything else but a statistical description of themselves.

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