From HOPE en l'ESPERANCE
On the Role of Computational Neurolinguistics in Cross-Language Studies[1]

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## ABSTRACT

Computational neurolinguistics (CN) is an approach to computational linguistics which includes neurally-motivated constraints in the design of models of natural language processing. Furthermore, the knowledge representations included in such models must be supported with documented behavior evidence, normal and pathological.

This paper will discuss the contribution of CN models to the understanding of linguistic "competence" within recent research efforts to adapt HOPE (Gigley 1981; 1982a; 1982b; 1982c; 1983a), an implemented CN model for "understanding" English to l'ESPERANCE, one which "understands" French.

## 1. INTRODUCTION

Computational Neurolinguistics (CN) incorporates initial assumptions about language processing that are often indirectly referenced in other computational approaches to language study. These assumptions focus on neural-like computational mechanisms (Ballard 1982; Feldman 1981; Gigley, 1982a; 1982b; 1983a; McClelland and Rumelhart, 1981) which subserve language behavior (Lavorel and Gigley, 1983).

Furthermore, CN approaches to different aspects of language processing include extensive use of behavioral data. Research exists within the CN paradigm along various behaviorally defined dimensions. These are at the level of phonetic speech studies that simulate speech errors (Lecours and Lhermitte, 1969; Reggia and Sanjeev, 1984), a model of aphasic language production, JARGONAUT, (Lavorel, 1982), as well as within lesionable models at a neural network level. These latter models simulate association, discrimination, and recognition of patterns employing associative network models that have been tuned or have adaptively learned to relate certain discriminations (Gordon, 1982; Wood, 1978; 1980).

There is much philosophical and linguistic discussion of the nature of the representations that exist in humans and form the basis of our cognitive function. We will not present the debate here, but instead will claim that the CN models we build include the assumption that the internal representation of concepts, words, and phonemes are given by the overall activation state of the "network" representation within the system at a moment in time. Furthermore, this means that unless activations are interpreted externally (in our case by labels so that we can talk about them), they in and of themselves reflect the "mental" representation.

To this end, CN models present time-synchronized snapshots of an interactive, parallel, distributed process that are interpreted to represent hierarchies of linguistic knowledge that can be distinguished during processing, such as a recognized word, a grammatical interaction, or even a disambiguated meaning.

Before turning to our efforts to adapt a working implementation within the CN paradigm, HOPE, into one that can process French with equal facility, l'ESPERANCE, we will present necessary background to illustrate why focusing on the "process" of language, as it can exist, based on our current understanding of brain function, contributes significantly to our increased understanding of representations which have been defined within linguistics, psycholinguistics, neurolinguistics, and AI approaches to language study.

## 2. FOCUS ON PROCESS

In developing CN models, the claim is that by focusing on process independently from representation, we gain several perspectives that are unattainable from other more usual approaches. CN models include processing which is neurally plausible. Language is seen as the behavioral result of an interactive, time-dependent process. This frees us from pre-specifying either all "correct" linguistic possibilities for constraint satisfaction at all levels of representation, or all possible errors or recognized omissions as in more flexible approaches (Hayes and Mouradian, 1981; Kwasny and Sondheimer, 1981; Lehnert, Dyer, Johnson, Yong, and Hurley, 1983; Weischeidel and Black, 1980).

We utilize what has been discovered by these other approaches to be the most likely, most plausible set of relevant features to tune our "normal" model. Through interconnections at a metalinguistic level, between recognized phonetic word representations, grammatical aspects of meaning, and specific referential meaning for disambiguated words, CN models must tune the process so that asynchronously activated instantiations at these interpretable levels which result from local contextual recognition achieve the same behavioral results that are defined within different methodologies. In other words, we use the AI preconditions or ATN states with as much corroboration from psychological, and linguistic studies as is available to tune our models for "normal" processing.

This provides an extremely valuable means of studying processing effects in neurally motivated "lesion" states that are consistent within our system, and completely defined over our model of study in a mathematical sense. This has been discussed in detail elsewhere in Gigley (1982b; 1983a; 1983b), and Gigley and Duffy (1982) and will not be repeated here.

## 3. PROCESSING ASSUMPTIONS IN HOPE

HOPE is not an acronym but was chosen as the name of the system based on the legend of Pandora's box. While raising many questions of language within a new computational perspective, it provides a first attempt to answer them as well.

The system presents an initial attempt to integrate AI and brain theory, BT, on two levels, behaviorally and within processing. HOPE uses concepts from cellular neurophysiology to define its control. Information in HOPE is encoded in a hierarchical graph which permits extensive ambiguity.

For complete detail of the model with examples in "normal" and "lesioned" states the interested reader is referred to Gigley (1982a; 1982b; 1983a). We will only highlight the processing here.

HOPE stresses the process of natural language by incorporating a neurally plausible control that is internal to the processing mechanism. There is no external evaluation made to decide what happens next. At each process time interval, there are six types of serial-order process that can occur and affect the state of the process. The most important aspect of the control is that all of the serial order computations can occur simultaneously and affect any information that has been defined in the model.

Similar control philosophies have been employed in letter perception by McClelland and Rumelhart (1981), and in the connectionist theories applied to visual processing and language parsing (Ballard, 1982; Cottrell, 1983; Feldman, 1982; Small, Cottrell, and Shastri, 1982).

The major difference in the control in HOPE is that the control process can be "lesioned" by modifying parameter settings relative to their "normal" settings to define hypothesized causes of pathological language behavior. Example "lesions" are changes in memory decay, elimination of a knowledge type, and slowing of processing relative to on-line word recognition.

Studying the results of such "lesions" and their occurrence or not in pathological behavior is used to further understanding of the behavior and to suggest evolutionary changes in the model to better its approximation to language process.

Information is presented at a phonological level as phonetic representations of words, at a word meaning level as multiple pairs of designed syntactic category types and orthographic spelling associates, within grammar, and as a pragmatic interpretation.

Each piece of information is a thresholding device with memory. It has an activity value, initially at a resting state, that is modified over time depending on the input, interconnections to other information, and an automatic activity decay scheme. In addition, the decay scheme is based on the state of the information, whether it has reached threshold and fired or not.

Activity is propagated in a fixed sense to all aspects of the meaning of words that are "connected" by spreading activation. (Collins and Loftus, 1975; Quillian, 1980/73; Small, Cottrell, and Shastri, 1982; Cottrell, 1983). Simultaneously, information interacts asynchronously due to threshold firing. This is achieved by the time coordination of asynchronously encoded serial order processes. The serial-order processes that occur at any moment of the process are context dependent; they depend on the "current state" of the system.

The serial order processes include:

1.  NEW-WORD-RECOGNITION: Introduction of the next phonetically recognized word in the sentence.

2.  DECAY: Automatic memory decay reduces the activity of all active information that does not receive additional input. It is an important part of the neural processes which occur during memory access.

3.  REFRACTORY-STATE-ACTIVATION: An automatic change of state that occurs after active information has reached threshold and fired. In this state the information can not affect or be affected by other information in the system.

4.  POST-REFRACTORY-STATE-ACTIVATION: An automatic change of state which all fired information enters after it has existed in the REFRACTORY-STATE. The decay rate is different than before firing.

5. MEANING-PROPAGATION: Fixed-time spreading activation to the distributed parts of recognized words' meanings.

6. FIRING-INFORMATION-PROPAGATION: Asynchronous activation propagation that occurs when information reaches threshold and fires. It can be INHIBITORY and EXCITATORY in its effect. INTERPRETATION is a result of activation of a pragmatic representation of a disambiguated word meaning.

It is the in interaction of the results of these asynchronous processes that the process of comprehension is defined.

The processes are independent of the knowledge representations defined and are blindly applied across all of them. This often produces unexpected but humanly interpretable results when the end state is compared with suitably defined behavioral test results.

During processing, we can study both the change in state that results over time and "how" the change occurred. Analyzing both aspects of the process is the focus of comparison between "normal" and "lesion" performance of the model. In this way we are able to study the effect of the "lesion" in a well defined linguistic context, and to make behavioral predictions that can be verified (Gigley, 1982b; 1983a; 1983b; Gigley and Duffy, 1982).

### 4. FROM HOPE en l'ESPERANCE

Given that CN approaches to natural language processing assume a neural-like control paradigm, it is possible to assume that such a paradigm will work equally well for other natural languages by simply recoding the representations into the second language surface representation, grammar, and semantic structure. We assume that the processes can be tuned to produce "normal" results as they have been for the simple English fragment demonstrated to date.

As a first attempt to determine if such a cross-linguistic adaptation is possible, we have begun to redefine the knowledge representations to encode suitable representations of French, homologous to those that HOPE includes in its present level of implementation.

The beginnings of the adaptation raised questions about language representation from a different perspective than occurs within a strictly linguistic analysis. The remainder of the paper focuses on our initial work in the adaptation (Gigley, 1984). As the research is currently underway, the discussion will raise several unanswered questions in pointing out the value of applying a CN methodology to cross-linguistic study.

In explaining the representation issues for French, we will first, briefly provide background in current linguistic research on French. This will include an overview of recent relevant psycholinguistic and neurolinguistic studies in French. Then we will present an overview of computational natural language systems for speech recognition comprehension and automatic translation into French. One issue, how to chunk French into a phonetic representation of words, along with the implications of the determined representation for our processing approach to comprehension of French, will form the basis of the discussion.

### 4.1 Word Boundaries in On-Line Comprehension of French

Because of the parallel activation of all meanings of each recognized word in HOPE, the determination of the phonetic representation of a recognized word determines the breadth of active competition among meanings for subsequent time intervals of the process. Depending on how the words are chunked, different homophone sets, sets of associated meanings for a given homophone, may arise.

For spoken English, word boundaries tend to be marked by intonation or pauses. However, for French this is not the case. Depending on the context, the ending of one word may be phonetically affixed to the following one called liason. In addition, when a content word begins with a vowel or silent h, the ending vowel of the preceding word is dropped, called elision.

The problem is particularly evident with respect to the use of articles which are very often spoken in such context. In addition, these same articles do not have the same meaning as they do in English. "Le, la, les" do not always mean "the" in the definite sense, but are often generic and mark masculine, feminine, or plural (Gross, 1977; Goffic and McBride, 1975). And furthermore, these same articles often are not translated into meaning preserving sentences in English. An example sentence demonstrating this is: Ce singe aime le cafe. (This monkey likes coffee.)

The degradation of these same morphemes has also been associated with certain types of aphasic behavior in English speaking patients, specifically in agrammatics and Broca's aphasics. French neurolinguistic studies have documented a similar degradation in the ability of agrammatic and Broca's aphasics (LeCours and Lhermitte, 1969; Nespoulos, 1973; 1981; Segui, Mehler, Frauenfelder, and Morton, 1982; Tissot, Mounin, and Lhermitte, 1973). However, only the quantity of degradation is reported. The studies discuss performance in general and have not specifically addressed to what extent and in what ways these morphemes are affected as do some of the English studies (Zurif and Blumstein, 1978; Zurif, Green, Caramazza and Goodenough, 1976).

Because of the import of articles in language processing, as briefly mentioned, how they are represented is of great interest when one wants to

use the adapted model, l'ESPERANCE, in its "lesioned" state to study the linguistic results.

Finally, to further illustrate the problems encountered in determining the phonetic representation, examples of the implications of deciding to represent the word for water, "eau," will be used. These implications are relevant to automatic speech recognition as well.

The French equivalent for "some water" is "de l'eau" which includes the generic article, le, in an elision context. Water is spoken as l'eau even though there is another article as above. The question becomes should the phonetic representation be defined as "l'eau" or as the content word in isolation, "eau?" The decision affects the homophone set association and will affect the entire across-time processing in any defined model.

Current descriptions of research in automatic speech recognition for French (Pierrel, 1982; Quinton, 1982) provide no relevant information. The MYRTILLE II system described by Pierrel (1982) stresses use of linguistic knowledge and includes phonological substitutions for the same word. The system includes alternatives for words at their junction with other words in different phonological contexts. The system described by Quinton (1982), on the other hand, is very HEARSAY-like and does not specifically address how these morphemes are handled.

Finally, the automatic translation work for French was consulted to see if there were any relevant discussions included in the systems regarding the representations of words similar to "eau". In Ariane-78, article constraints are affixed as features to content words and elision is decided in the final stage of the production of the French sentences (Boitet and Nedobejkine, 1981). The content words are specifically marked as beginning with vowels or silent "h". The final stage of the process joins the marked content word with an appropriate article to produce output words such as l'eau. This suggests that for comprehension, one would first recognize the unit "l'eau" and decompose it to the article and content word with appropriate masculine/feminine indicators (Jayez, 1982).

Initial assessment of the literature with respect to this problem has provided little evidence. The role of articles has not been studied for French to the extent that it has for English. Therefore, a pilot study with French aphasics was designed to analyze if and in what contexts these morphemes are affected.

The study includes off-line picture naming which forces use of articles in all of the above contexts, as well as on-line production of these morphemes in an attempt to determine in which way these morphemes are related to the words. Are they unified with the word in all instances or only in certain contexts?

Adapting a neurolinguistically motivated CN model for a second language can be seen to motivate a different type of question with regard to the second language than occurs when one bases the studies on English surface phenomena. This is very important because often surface phenomena are assumed to be more similar than warranted. What we claim instead is that the processing is similar, indeed universal and that we must begin to make cross-linguistic studies that assume this underlying commonality and at the same time can account for the variation at the surface level.

## 5. SUMMARY

Within developing computational neurolinguistic research which assumes that we can define cognitively based simulation models using AI methodologies which are incorporated with neural processing paradigms, we have demonstrated how one can begin to study universals of language in a new perspective.

The CN paradigm for natural language processing includes claims that new perspectives on linguistically interpretable hierarchical representations that arise in language behavior are introduced by including neurally motivated processing control as the focus of model definition and by including behaviorially defined constraints, both normal and pathological.

The issues are not whether human brains work in a universal fashion, but instead raise questions of how interpreted levels of representation, which functionally produce similar language behavior need to be represented for different languages. This processing approach includes many assumptions which are important to linguistic theory. Furthermore, it provides a way of developing specific, verifiable questions about behavior which are mathematically better defined than through other methods, because it enables one to develop a broader perspective of the questions within an analysis of the hypothesis in the context of a characterization of the "how" of the entire behavior.

By adapting HOPE for processing French, we furthermore claim that new perspectives on language universals are demonstrated. And finally, we feel that CN provides the only suitable way to begin developing a comprehensive understanding of a behavior as complex as language.

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