Models of Natural Language Comprehension and Parsing

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Abstract

The general objective of this research is to develop cognitive models of diverse natural language comprehension phenomenon within the ACT-R cognitive architecture (Anderson, 1993). The present study constitutes an effort to investigate anaphora resolution processes in the context of the simultaneous influence of information sources such as syntax, discourse focus and conceptual. Current research is situated in the overall goal of building a student model for intelligent tutors for natural language learning.

Introduction

The literature on natural language comprehension offers many empirical results and models which are often in conflict or cover complementary aspects of comprehension without a coherent integrating view. The general objective of this research is to develop cognitive models of diverse natural language comprehension phenomenon within the ACT-R cognitive architecture (Anderson, 1993). The advantage of this approach is two fold: a) the set of architectural constraints provided by ACT-R offers a common basis for natural language comprehension models; and, b) the approach reduces the gap between natural language processing models and problem solving models. The strong separation between these last two classes of models has been supported in natural language research by the modularity hypothesis (Fodor, 1983), but many empirical results now point towards a greater interaction between interactive view between levels of representation.

This paper presents preliminary results on building models of natural language comprehension. The first section briefly presents some empirical results obtained in a text comprehension task designed to measure anaphora resolution processes. The second section presents an ACT-R model of the subjects' performance developed with ACT-R 2.0. Finally, the last section outlines some avenues of future research and model development under ACT-R 4.0.

Anaphora Resolution

A brief look at the literature on anaphora resolution from a linguistics and cognitive point of view rapidly shows that multiple factors are known to influence the process of resolving co-reference ambiguity. Anaphora resolution is known to involve a broad range of representations such as syntactic constraints (c-command, gender, number and person), discourse focus conditions (accessibility of potential referent), and conceptual representations (text and situation models). This multifaceted nature of anaphora resolution has certainly imposed a "divide and conquer" research strategy and many contributions have been made on specific representations and processes. Even when one looks only at a limited of anaphoric elements such as pronouns (see Table 1), the multiplicity of factors influencing anaphora resolution seems obvious.

Syntactic resolution Marc thinks that Paul looks at himself in the mirror. - Co-reference is determined syntacticaly -
Gender, number and person agreement Paul walks to the store with Clara. She / He wants to buy milk. - Co-reference is determined by gender, number and person agreement -
Discourse focus Paul walks to the store with Marc. He wants to buy milk. - Co-reference determined by preference for the backward focus center (Paul) -
Situation model Henry gave the ball to Marc. He wants it back now. / He plays with it now. - Co-reference determined by the coherence with the situation described -

Table 1. Examples of factors influencing anaphora resolution for pronouns.

In spite of the difficulty of studying this multifaceted process empirically, the study of anaphora resolution offers the opportunity to investigate on a small scale some basic cognitive representation and text comprehension processes. Some empirical evidences support the view that anaphora resolution processes are initiated at the moment of reading an anaphoric element but are not completed until sufficient information is provided through subsequent reading or listening (Sanford & Garrod, 1989; McDonald & MacWhinney, 1995). The data presented in this section was collected in order to investigate anaphora resolution processes in the context of the simultaneous influence of syntactic, discursive and conceptual information sources. The objective is to obtain a better characterization of the on-line resolution process. An analysis of reading time profiles shows significant differences between the kind of information sources used in resolution. The experimental material was written in French and the resolution processes involved third person singular personal pronouns.

Factors Influencing Anaphora Resolution

Previous studies on anaphora resolution have shown that the process of anaphora resolution can be decomposed into four basic mechanisms: a) application of syntactic and functional constraints, b) agreement in person, gender and number, c) focusing on discourse elements, and d) selection by inference from a situation model. The following paragraphs examine some of the main results concerning these mechanisms.

Syntactic and functional constraints on anaphora resolution. Research in linguistics has shown that the regularity of judgments regarding pronoun interpretation is determined by certain structural configurations. These structural configurations have been defined either by : A) the syntactic structure of a sentence (Chomsky, 1986); B) the semantic relationship between functions and arguments (Bach, & Partee, 1980); C) structural relationships in conceptual structures (Jackendoff, 1990), or D) a mixture of levels of representation (Reinhart, 1983; Bosch, 1983; Chierchia 1988). These structural configurations support the interpretation of a pronoun as being bound to, or blocked from a potential antecedent. Proponents of the modularity hypothesis (Fodor, 1983) tend to view this application of syntactic information as isolated from and prior to any semantic integration process (Swinney & Osterhout, 1990). In contrast, other models have proposed that discourse and semantic information are interacting freely with syntactic processing (Marslen-Wilson & Tyler,).

Agreement in gender, number and person. One important feature of pronouns is their lack of descriptive content (Bosch, 1983). Contrary to proper nouns or definite descriptions, the only information carried by pronouns is related to gender, number, and person of the potential referents. Empirical studies using English show that the information about gender, number, and person reduces the number of potential antecedents and facilitates interpretation (Frederiksen, 1981; Garnham & Oakhill, 1985). Results from Cloitre and Bever (1988) support a model of pronoun interpretation in which the pronoun has a direct access to the elements of the mental model without a representation of the linguistic properties of the noun phrases referring to these elements.

Discourse focusing. There is some empirical evidence that a set of discourse focus related constraints affects anaphora resolution, Many linguistic structures have been identified to signal discourse focus. Some studies have shown that the distance, measured in number of clauses or sentences, has an effect on the ease of anaphora resolution (Ehrlich & Rayner, 1983). However this effect has been shown to be dependent on the topicalization of noun phrases (Greenspan & Segal, 1984; Sanford & Garrod, 1981). Also amoung the discourse focus constraints is the parallel assignment strategy in which a pronoun in a subordinate clause is more easily assigned to a noun phrase of the main clause with the same grammatical function (Cowan, 1980). More global discourse structures have also an effect such as the end of episodes in narration (Garrod & Sanford, 1985), the importance of events and characters for the thematic structure of a text (Cirilo, 1981), the specificity of discourse type on the determination of global focus structures (Fox, 1987), and local discourse structures based on focus centers (Gordon & Scearce, 1995; Gordon, Grosz, & Gilliom, 1993).

Inferential selection. The information about the gender, number, and person of a pronoun is sometimes not a sufficient source of information to interpret a pronoun. Often it is necessary to infer what is the likely referent on the basis of the situation described by the text and general knowledge (Ehrlich, 1980; Frederiksen, 1981; Garnham & Oakhill, 1985; Tyler & Marslen-Wilson, 1982). Among the semantic information that has been recognized to be used in anaphora resolution is the implicit causality of verbs which creates a strong bias towards the interpretation of a pronoun as a subject of a subsequent subordinate clause or sentence (McDonald & MacWhinney, 1995; Garnham & Oakhill, 1985; Caramazza, Grober, Garvey & Yates, 1977).

Methods

Subjects. Thirty-six students speaking French as their native language enrolled in the experiment. The experiment lasted about 45 minutes including a practice session.

Design. The set of experimental texts was constructed on the basis of an experimental design which included three independent variables : a) the source of information sufficient to find a single interpretation to a pronoun, b) the reference of the pronoun of the target sentence to the discourse focus of the previous sentence, and c) the presence of the pronoun referent inside the target sentence or not. The variable source of information had four levels : A) syntactic information, B) gender information, C) inferential selection with a masculine antecedent, and D) inferential selection with a feminine antecedent. The purpose of the latter two levels of information source was to check for a gender bias when the gender feature of a pronoun was irrelevant as in the case of the pronominal form "lui" positioned before the verb.

Each experimental text was composed of three sentences describing a situation involving two or three characters. The first two sentences of the text provided the context in which the last sentence was read (target). This third sentence (target) described a new event in the situation. This sentence contained a pronoun positioned before the verb. The interpretation of this pronoun could then be completed either A) on the basis of the syntactic structure of the target sentence, or B) on the basis of the agreement between the gender marking of the pronoun and the gender of characters, or C) on the basis of the situation model constructed during reading. A test sentence was then presented to the subject who had to decide if the situation described by this test sentence was true or not of the previous short text. Table 2 shows an example of a context followed by some possible target and test sentences.

Context Line et Marc ont décidé de jouer ensemble au tennis. Elle est une joueuse expérimentée alors que Marc ne joue jamais. Target examples Un entraineur de Line lui prédit une victoire certaine. Un entraineur de Line lui prédit une défaite certaine. Un entraineur de Line le regarde sur le terrain. Un entraineur de Line la regarde sur le terrain. Comprehension test examples

Line remportera une victoire certaine. Marc remportera une victoire certaine. Line court après la balle. Marc court après la balle.

Table 2. Example of experimental material.

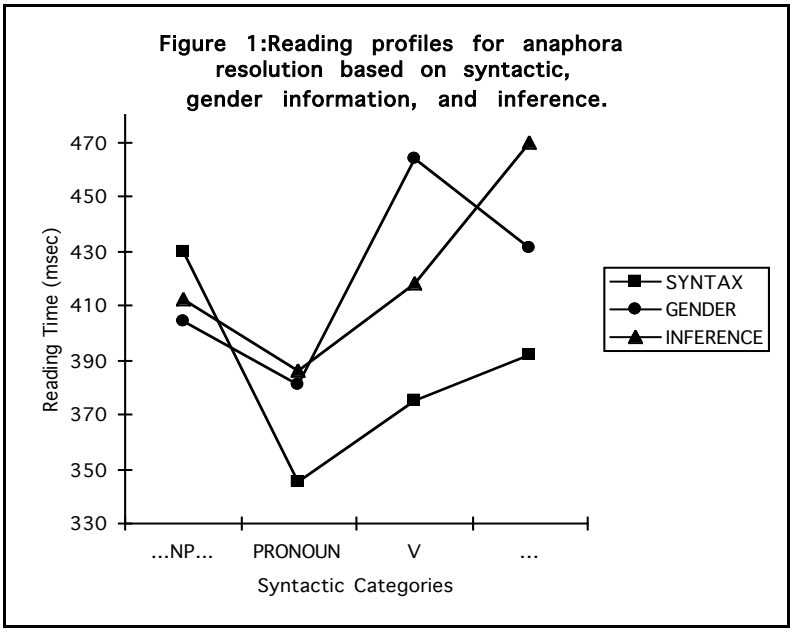
A total of 36 experimental conditions were used by crossing the experimental text and comprehension test variables. In order to control for the effect of the semantic content and individual differences in text processing, a Latin square design was used crossing the subjects, text content and experimental conditions. No subject read the same text for all the experiment conditions.

Procedures. Data on reading and decision time as well as responses given by subjects on the comprehension task were collected using Macintosh computers (Centris 610). Keyboard events were recorded by direct scanning. The words were presented one at a time in the middle of the screen in Geneva 24. The words appeared black on a white background. After reading a set of instructions, a practice session allowed the subjects to get familiar with the experimental task. The task was described to the subject as a text comprehension task. Reading was self paced and the words were presented one at a time by pressing the space bar.

Results and Discussion

The results on the reading time profiles show an interesting pattern of reading times as an indication of anaphora resolution processes. Figure 1 shows the reading time profiles for significant levels of information sources. The first result shows a sharp decrease of reading time on the pronoun location compared to the gender and inferential conditions. This longer reading time at the pronoun location seems to be an indication of the initiation of a resolution process which consists of retrieving all potential antecedents (fewer in the syntactic condition compared to the other two conditions).

The increase of reading time at the verb location in the gender resolution condition compared to the syntactic and inferential conditions suggests that even though all the information for a resolution based on gender is available at the pronoun location, it seems to occur during the verb reading time. This pattern supports Frasier's proposal (1985) that semantic integration occurs at minimal governing categories as well as the independence of lexical from grammatical processing. This implies that pronouns might provide a direct access to the mental model of the text at reading time (Cloitre & Bever, 1988) by activating potential referents but that use of their gender information is postponed until they are integrated in the thematic structure of the verb, at least in the case of non-subject pronouns. The reading time profiles also support an independent and fast syntactic resolution process because the same increase of reading time occurs between the pronoun and the verb for the syntactic condition and inferential condition. As expected, inferential process occurs at the time of reading the remainder of the verb phrase in the inferential condition. In agreement with previous research, this study supports the view that anaphora resolution processes are initiated at the moment of reading an anaphoric element but that in case of ambiguity, these processes are not completed before additional information is provided through subsequent reading or listening (Sanford & Garrod, 1989; McDonald & MacWhinney, 1995).



Modeling Anaphora resolution with ACT-R 2.0

This section describes a model of the using ACT-R 2.0 (Anderson, 1993). The description includes a specification of the chunk types in declarative memory and of the classes of productions in production memory. A third section presents the results of the simulation.

Declarative Memory

The declarative memory chunk types included in the model are the following:

- GOAL with an action name, an object, and a result slot.
- STRING with a string value, and a position slot. This memory type implements the linear position of words.
- EDGE with a string value, a syntactic category, and a length. This memory type supports a chart parsing algorithm using the length of the string (defined as a begin and an end position), and the functional syntactic categories of categorical grammar. Syntactic representations have the form of an extended categorical grammar (Bach, 1983) where semantic features are associated to basic syntactic categories. The values of the syntactic category slot are trees for which the root is a function and the branches are the domain and range of the function.
- LEXICAL-ENTRY with a string value, a syntactic information, and a semantic information slot.
- SEMANTIC-INFO with person, state, and event subtypes. This allows a simple implementation of semantic representations supporting the context as well as semantic representations being built at reading time.
- DISCOURSE-REFS and POTENTIAL-REFS hold respectively the discourse referents of the situation described by the text and the potential referents or interpretations of the pronoun.

Production memory

The model contains a set of productions that implement specific components of the resolution process as well as the organization of these processes through an implicit goal structure. The model can be analysed by grouping the productions in three classes.

A first class of productions builds edges from a string chunk and the lexicon or the active edges in declarative memory. Among these productions are the productions for left and right application of the

functions. These productions are responsible for the unification of semantic features embedded in the extended syntactic categories. For example, in categorical grammar a transitive verb would have the syntactic category "(S\N)/N". This category includes its own grammar rule and can be interpreted as a category in which the right most function "/" takes a category of type noun to its right to produce an intransitive verb of the type "S\N". The type of intransitive verb are basically the syntactic categories in which the right most function "\" takes a category of type noun to its left to produce a category of type sentence. The extended grammar formalism allows one to add features value pairs to basic syntactic categories such as S(f1:v1, f2:v2,...) and N(f1:v1, f2:v2,...). During the parsing process, syntactic constraints are applied to the pronoun to restrict possible antecedents (in the case of blocking), or specify directly the antecedent (in the case of a reflexive pronoun).

A second class of productions extracts the embedded semantic information from the syntactic categories. The model follows Frasier's proposal (1985) that syntactic information is discarded from memory and semantic information is made available for integration after minimal governing categories are constructed (N or S). The model applies this proposal strictly and does not allow semantic information to be extracted from the syntactic category at the time of reading the pronoun because pronouns positionned immediately before a verb have the category type "(S\N)/((S\N)/N)". The semantic information extraction process consists of productions for adding this semantic infomation to the chunk of potential referents.

Finally, a third class of productions performs the anaphora resolution process by focusing on the goal of determining the referent of the pronoun. This goal is decomposed into three ordered subgoals: a) syntactic resolution, b) gender resolution, and c) inferential resolution. When a unique referent can be found in the list of potential referents, the resolution process is terminated and the discourse referent chunk updated. The model predicts that the point where the relevant information is available determines the termination of the resolution process and the associated latencies.

Results of the simulation

Figure 2 presents the latencies produced by the model. The model has run with rational analysis set to true. The model fits relatively well the reading time patterns between the conditions but produces unrealistic absolute values of the latencies. The results suggest that a serial process seems to provide a correct model of anaphora resolution. The model was also developed mainly on the premiss that production efforts would account for the data but little attention has been given to the contribution of activation. This factor might account for the gap with the actual reading time values.

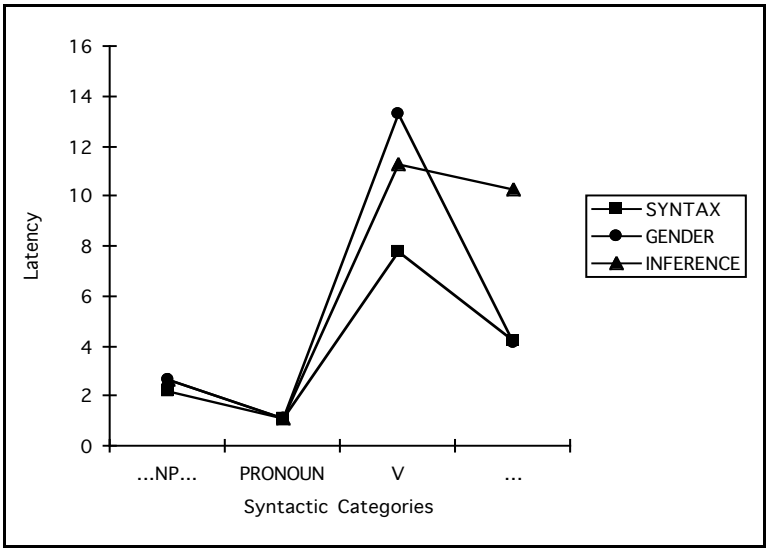


Figure 2. Latencies produced by the model.

Future Development

The general objective of this research is to develop cognitive models of natural language processing, and more specifically of natural language comprehension. This paper presented some empirical and modeling results of data on anaphora resolution. The interest of studying anaphora relies on the fact that it involves many elements of natural language processing. The literature on the subject as well as the present study indicate that it is difficult to develop a realistic model of anaphora resolution that does not include many levels of representation with there associated productions. The model presented in the previous section is an effort towards the development of a model of natural language comprehesion within the ACT-R cognitive architecture . The benefits of this approach is to offer a common basis for natural language comprehension models and also reduce the gap between natural language processing models and problem solving models.

Future developments and extensions to this work certainly involve a new implementation of the model under ACT-R 4.0. One of the immediate consequence of this change is the replacement by chunks of list structures which implemented feature structures. This change might require a change in grammar formalism an on representation of natural language structure in general. Additional work is also required to position ACT-R among other models of natural language processing. The models developed should eventually serve in intelligent tutoring systems for language learning.

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