AUTOMATIC ADAPTIVE UNDERSTANDING OF SPOKEN LANGUAGE BY COOPERATION OF SYNTACTIC PARSING AND SEMANTIC PRIMING

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ABSTRACT

This paper focuses on the modelling of the linguistic level of *MICRO*, a multi-agents speech understanding system largely inspired by cognitive models. It describes the cooperation between, on the one hand a syntactic parser using a Lexical Functional Grammar, and on the other hand an semantic analyser. The semantic analysis is achieved through a mechanism semantic priming carried out by a incremental associative network. We emphasize the adaptive abilities of such a cooperation, particularly in case of ungrammatical utterances, which are very common in spoken language.

I. INTRODUCTION

Language is a complex cognitive activity involving numerous contextual phenomena. Generally speaking, linguistic cognitive functions compensates for the ambiguity of processed bottom-up information with contextual knowledge. As a result, contextual adaptation is a crucial feature for Human-Machine Communication. Considering the noticeable adaptive abilities of human cognition, *MICRO* dialog system is aimed at modelling several cognitive features that should enhance accuracy.

This paper focuses on the modelling of *MICRO*'s linguistic level of analysis through a strong cooperation between concurrent syntactic analysis and semantic priming. We first present our cognitive approach. The global structure of *MICRO* is then reviewed. In the third part, the realization of the linguistic level of *MICRO* is then described: we emphasize the cooperative strategy and the semantic priming. Finally, results on the understanding of ungrammatical utterances are detailed.

II. COGNITIVE APPROACH

Three main features have been retained from recent cognitive theories [1]: modularity, interactivity and finally the coexistence of analytic and holistic thoughts.

2.1. Modularity and Heterarchy

The modular paradigm [8] describes cognition as the emergence of the global activity of several modules working in a cooperative way. Since spoken language analysis involves the consideration of numerous heterogeneous knowledge, dialog systems early adopted a the modular structure of blackboard architectures. However, the centralized control of this architecture was limiting its adaptive power. A central feature of modularity was lacking: the independence of the modules, which is nowadays fulfilled by multi-agent systems. As a result, *MICRO* is achieved as a society of independent cooperative agents.

2.2. Interactivity

In the cognitivist paradigm, lower level modules are blindly working without considering top-down information [6]. Contextual adaptation is then limited to a filtering of ascending hypotheses. On the opposite, interactive theories [9] claim that every cognitive module has a direct access to bottom-up hypotheses as well as upper top-down information. Adaptation is obviously favoured by this early consideration of contextual information. Thus, *MICRO*'s agents, which communicate via message passing are interactive entities.

2.3. Holistic-Analytic Cooperation

We also took into account the functional difference that exists between Human cerebral hemispheres. Indeed, hemispheric activities are preferably specialized: on the one hand, holistic (fast and global) analysis is mainly supported by the right brain. On the other hand, the left hemisphere handles analytic (detailed) cognition [3]. This coexistence of concurrent thoughts enables the cognitive system to parallely elaborate different opinions. Now, differential psychology has clearly shown the auto-adaptive power of this cooperation [7].

We then have defined a holistic way of analysis based on fast prosodic processings. Additional prosodic information thus aims at consolidating the classical analytic strategy (from acoustic-phonetic decoding to linguistic analysis), thereby enhancing accuracy.

Besides, MICRO also models a local holistic-analytic cooperation at the linguistic level. Our paper describes this linguistic cooperation.

III. DESCRIPTION OF *MICRO*

Figure 1 illustrates MICRO's architecture., with its two ways of analysis: analytic on the left and holistic on the right. They interfere concurrently after an acoustic analysis that simulates the auditory system. They are communicating at acoustic, lexical and pragmatic levels.

Analytic agents are divided into two groups concerning phonetics and linguistic analyses, whereas the prosodic group includes the whole holistic strategy.

MICRO is developed on *MAPS*, a software environment dedicated to multi-agents structures design [2]. MAPS is based on the distinction between two kinds of knowledge. On the one hand, descriptive knowledge represents problem elements; on the other hand operative knowledge concerns tools and strategies needed to handle descriptive knowledge. Two generic classes of agents are corresponding to those two kinds of knowledge: Knowledge Servers (KS) maintain and transmit figurative knowledge whereas Knowledge Processors (KP) handle operative knowledge. MAPS agents are autonomous entities that communicate via message sending.

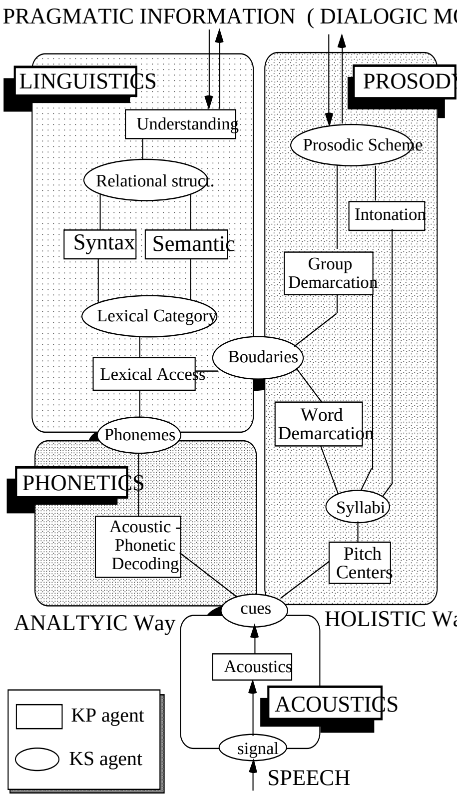

Figure 1: MICRO's architecture

IV. SYNTAX - SEMANTICS COOPERATION

4.1. Understanding ungrammatical utterances

Spoken language is by nature ungrammatical. Indeed, natural conversations frequently present ungrammatical sentences that are however still understandable. One can find problems of inversion, correction, hesitation, repetition or elision, that dialog systems should overpass.

Methods classically used in Natural Language Processing can not thus be transposed towards Human-Machine Communication, since they are based on detailed syntactic parsing. On the opposite, dialog systems perform stochastic analyses (bigrams models) which are well adapted to speech recognition. However, the structure of language handled by these methods is too poor to authorize the analysis of spontaneous speech.

As a result, we propose to merge these antinomical approaches by the cooperation between a syntactic parser and a semantic analyser. This idea is obviously as old as *SHRDLU* . Syntax was however given a specific role in Winograd's system. On the opposite, we claim the priority of semantics in clause analysis, even if we also emphasize on the structural properties of syntax (especially while driving clauses articulation).

4.2. Description of the linguistic agents

The linguistic group is made of two concurrent KPs - a syntactic parser and a semantic analyser - that are cooperating via two KSs which respectively performs lexical access and relational structure merging (figure 2). These KSs aim at solving conflicts between the two analysers and adapting the cooperative strategy in case of ungrammatical sentences.

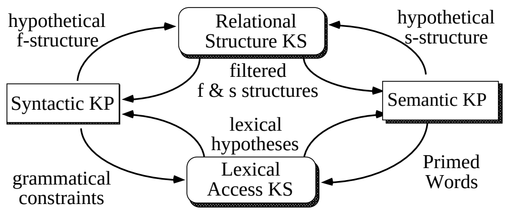

Figure 2: Cooperative strategy in the linguistic group

Syntactic Parser - This module follows the formalism of Lexical Functional Grammar. It is a predictive analyser derived from *Ln_2_3* parser that was developed at INSERM [10]. It provides the lexical access stage with syntactic constraints and the upper understanding processes with a functional structure (f_struct). This structure describes the superficial relations inside the sentence thanks to the following syntactic functions:

SUJ subject
OBJ object
OBL-x essential prepositional complement
ADT adverbial phrase
COMP infinitive complement
XADT noun
THEME relative pronoun in the relative clause
DET determiner, demonstrative

Here is for instance the f_struct of the sentence: "we place a wide window in this bedroom".

```
( PRED  to move <(SUJ),(OBJ)>
( OBJ   ( PRED  window
( DEF   ( PRED  a
( XADT  ( PRED  wide
( SUJ   ( PRED  we
( ADT   ( PRED  in <(OBJ)>
( OBJ   ( PRED  bedroom
        ( DEF   this
```

Semantic Primer - This KP aims at performing a predictive analysis, regardless of grammatical problems, by means of a mechanism of semantic priming. On the whole, semantic priming is a cognitive process where words are calling other ones according to meaning associations. We distinguish two kinds of priming.

One the one hand, *relational priming* seeks to satisfy deep relations in the sentence through an analysis of the predicative structures of uttered words. Semantic cases [5] are common examples of these relations. We defined the following cases through the analysis of a large corpus:

AGT	Agent	
OBJ	Object	
REC	Recipient or dative	
OWN	Metonymy and possession	
DES	Destination	
LOC	Location	
SCE	Source	
WAY	Way	
BUT	Goal	
INS	Instrument	
ATT	Attribute	
MOD	Modal	
ACT	Activity	
TPS	Time	
REF	Reference	
TAG	Case specifier	(not a real case)

On the other hand, isotopic *priming* focuses on words that present meaning similarities with the previous ones. This semantic likeness mainly reflects the global thematic redundancy of the discourse (isotopy). Actually, we distinguish two isotopic fields : the task domain and the computing domain.

As a result, the semantic analyser supplies the other modules with two kinds of information. On the one hand, primed words constrain lexical access. On the other hand, the semantic KP provide the upper levels with a *semantic structure* (s_struct) that describes the deep semantic relations of the sentence. Here is the s_struct of the sentence: “We place a wide window in this bedroom”:

```
( PRED  to place
( AGT   ( PRED  we
( OBJ   ( PRED  window
        ( ATT   ( PRED  wide
                ( REF   ( PRED  the
( LOC   ( TAG   ( PRED  in
        ( PRED  bedroom
        ( REF   ( PRED  this
```

The semantic KP is implemented as an incremental associative network made up of four layers (figure 3). The input layer, which grows during analysis, represent the priming power of previously uttered words. Activities are then propagated until the output layer, where highest excited cells correspond to primed words. Unlike connectionist networks, each layer has a well determined role. Indeed, the network is not defined by means of supervised learning but on the contrary is, for the time being, statically compiled from a semantic lexicon. Propagation involves the following steps:

Temporal forgetting and isotopic inhibition - Input activities are dynamically calculated: the last analysed word receive a maximal activation, whereas other cell activities are decreased regularly by a mechanism of forgetting. Moreover, lateral inhibitory links model the isotopic influence.

Argumentative dispatching - Priming powers are then dispatched between several internal networks that correspond to specific relations (agent, object and goal on figure 3). Furthermore, numerous grammatical words, such as coordinating conjunctions, intervene in the analysis by focusing the priming on a restricted set of semantic cases. Consequently, several contextual cells, corresponding to grammatical words, modify the overall activity of the case-based networks.

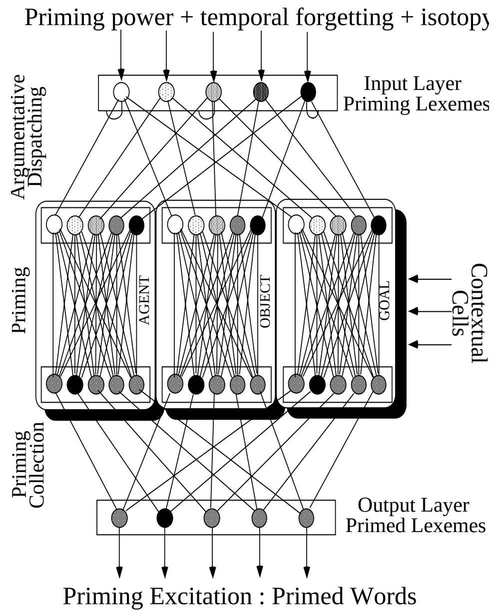

Figure 3 Structure of Semantic Priming Agent

Priming - Relational priming is performed in parallel among the case-based networks. Activities are propagated according to the relational links of the semantic lexicon.

Priming collection - Finally, the cells of the output layer recover their activities among the corresponding output cells of the sub-networks. Most activated cells correspond to primed words. Primed words are connected with their most effective priming word(s), according to their most effective priming relation(s), thereby building concurrent hypothetical semantic structures.

4.3. Cooperative strategy

The cooperative strategy is achieved by the merging of the top-down (lexical constraints) and bottom-up (f and s structures) productions of the two analysers (fig.2).

Lexical Constraint Merging - The LFG parser and the semantic primer constrain in parallel lexical access, thereby defining two sub-sets of the lexicon. The Lexical Access agent merges these sub-sets with the phonemic information supplied by the phonetic group. Furthermore, the prosodic group provide additional holistic information on word demarcations. On the whole, the Lexical Access KS gives the best confidence to semantic information.

Structure Merging - As illustrated on our examples, there are some similarities between functional and semantic structures. Thus, Relational Structure KS aims at merging f and s structures with respect to these correspondences. This structure comparison is worked out every time a relation is characterized: the KS considers if the same words are related in the two structures, and if the relations are compatible. Here is for instance the table of compatibility defined for the subject syntactic function:

Syntax	Semantic	Example
SUJ	AGT	We draw a table
	REC	The house was given a roof
	OBJ	The bedroom is well placed

V. RESULTS

5.1. Linguistic covering of the semantic primer

Our aim was to provide the semantic primer with a large covering of the clause structure. At present, it is able to analyse the following kind of regular clauses, without any syntactic knowledge:

- declarative clauses "I move it inside the kitchen"
- WH-questions "Where is the upper floor ?"
- imperative clauses "Erase the second room"
- passive voice "The doorstep is now drawn"
- infinitive "I want you to draw the bathroom"
- negation "Do not remove the bathtub"
- coordination "Remove the table and the chair"

5.2. Combinative explosion

The semantic analysis involves a quite moderate perplexity, as shown by the following experiment where the semantic KP was disconnected from the LFG parser. This experiment has been carried out by providing the semantic primer with written sentences taken from a Wizard of Oz corpus (natural speech) of 37 sentences, including 167 semantic relations.

number of primed words / lexicon size	20,9 %
rank of the correct word / lexicon size	16,0 %
percentage of correct words at rank 1	58.7 %

Only one fifth of the semantic lexicon is primed in average after each word. The focusing power of grammatical words intervene greatly in this limitation of the perplexity. The following table shows the decrease of combinatory in case of prepositionally based priming.

consideration of grammatical words	rank of correct word \ lexicon size	% of correct words
YES	15,4 %	100 %
NO	25,2 %	67,2 %

Finally, we expect the coexistence of semantic and syntactic constraints to sensibly limit perplexity. We already established with a previous system that semantic priming can reduce perplexity with a factor four [4].

5.3. Grammatical errors

The cooperative strategy ignores the LFG parser when it fails in case of ungrammatical utterance. The semantic KP is then in charge of providing alone the pragmatic level with a relational structure (figure 5). Obviously, the semantic primer is not able to parse alone sentences during a long time. Consequently, we plan to solve grammatical problems that do not overreach the clause borders. However, most errors of performance occur inside these boundaries.

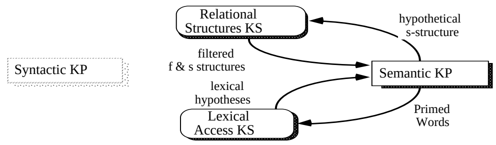

Figure 5: ungrammatical sentences analysis

Since it does not consider syntax, the semantic primer can solve gracefully most of the introductory errors:

- elisions "Draw (a) small room"
- inversions "Now, in the bathroom, draw a bathtub"
  "The stairway, I want to enlarge it"
- repetitions "Remove the little ... the little window"
- hesitations "Colour in red the the...eeh...roof"
- corrections "Draw two chairs...no three armchairs"

Grammatical errors are thus handled without any specific mechanism. As a result, there is no real influence of syntactic errors on perplexity:

kind of clause	% primed words	rank of correct word / lexic size	correct words at rank 1
incorrect	19.8 %	16.0 %	59.1 %
grammatical	22.0 %	16.7 %	58.3 %

CONCLUSION

We report in this paper a cooperative approach for the linguistic level of *MICRO*, a multi-agent dialog system. Linguistic analysis has been modelled via the cooperation between a semantic analyser and a concurrent syntactic parser. Unlike classical systems, semantic analysis is an independent process with respect to syntax, what enables the analyses of ungrammatical sentences which are very common in spontaneous speech. Our aim is thus to give an early and dominant role to semantics in case of local dependencies analysis, whereas syntax is only given priority to solve clause articulation.

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