CONTEXTUAL ADAPTATION IN LINGUISTIC ANALYSIS THROUGH THE COOPERATION OF SYNTACTIC PARSING AND SEMANTIC PRIMING

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- topical paper -

ABSTRACT - This paper focuses on the modelization 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 analyser in charge of semantic priming according to the differential compositional paradigm. We emphasize the adaptative abilities of such a cooperation, that would enhance accuracy of automatic speech understanding as well as natural language processing.

KEYWORDS - *syntax-semantics cooperation, semantic priming, compositional semantics, cognitive modelization, multi-agents system, speech understanding, natural language processing.*

1. INTRODUCTION

Language is a complex cognitive activity involving numerous contextual phenomena that can be characterized at every level of analysis. Generally speaking, linguistic cognitive functions compensates for the ambiguity of processed bottom-up information with contextual knowledge. Contextual adaptation leads thereby to a limitation of the searching space as well as a resolution of odd cases like grammatical errors which are very common in Man-Machine Communication. Pragmatic context is finally of prime importance during the understanding process.

As a result, contextual adaptation is a crucial feature for automatic systems dedicated to Natural Language Processing as well as Man-Machine Communication. Yet, classical systems based on structural methods are on the whole suffering from a lack of adaptability that could endangers their accuracy. Considering the noticeable adaptative and learning abilities of human cognition, *MICRO*[1] project is thus aimed at defining an adaptative behaviour through the modelization of several cognitive features. Our purpose, excluding all anthropomorphism, is thereby not to reach the highest accuracy but raher to propose tracks towards adaptation.

This paper focuses on the modelization of the linguistic level of analysis by means of a strong cooperation between concurrent syntactic analysis and semantic priming. We first present our cognitive approach. The global structure of *MICRO* is then described. Motivations for syntax-semantics cooperation are 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 adaptation are detailed.

[1] French acronym for "Modelisation Informatique de la Cognition pour la Reconnaissance de l'Oral".

2. REACHING ADAPTATION BY COGNITIVE MODELIZATION

Since our cognitive motivations were already described in a previous paper [2], we will namely stress on the adaptative consequences of this modelization. Three main features have been retained from recent cognitive theories: modularity, interactivity and finally the coexistence of analytic and holistic strategies.

2.1. MODULARITY AND HETERARCHY

The modular paradigm [14,24] describes cognition as the emergence of the global activity of a society of modules working in a cooperative way on their own domain of competence. Since speech and language activities involve a wide range of different kinds of knowledge, automatic understanding systems have early adopted a modular structure organized as a blackboard architecture [20]. However, the centralized control strategy of this architecture limits its adaptative power.

Every module of *MICRO* has been given a degree of complete independance to bypass this serious drawback. As a result, *MICRO* is a multi-agents system where control is distributed among the whole set of agents that are cooperating via message passing. The independance of the modules, which leads to this heterarchic architecture, is the central feature of our view of modularity in regard to adaptative considerations. Indeed, the independance of the agents enables a fast response to contextual changes, since decision modules are as close as possible to sources of adaptation.

2.2. INTERACTIVITY

Interactivity could be seen as a direct consequence of the independance of the modules of the cognitive system. In Fodor's modular paradigm [14], lower level modules are blindly working without taking into account top-down information provided by the upper modules. Hence appears a bottom-up flow of processed information, where contextual adaptation is merely limited to a filtering of ascending hypotheses.

On the opposite, interactive theories [23,12,1] militate against such a sequential description of cognitive activities. In other words, every cognitive module has a direct access to bottom-up hypotheses as well as upper contextual information. Adaptation is obviously favoured by this interactive consideration of contextual information. We have consequently provided *MICRO*’s agents with a interactive behaviour by means of a local merge of bottom-up and top-down information. A deep broadcasting of contextual information is thus achieved in the entire system.

2.3. HOLISTIC-ANALYTIC COOPERATION

At last, we took into account the functional difference between right and left side of the human brain. Cognitive science has nowadays deserted the first manicheist vision of lateralization [5]. It is nevertheless well attested that hemispheric activities are preferably specialized: on the one hand, holistic cognition, that is to say fast and global analysis, is mainly supported by the right hemisphere. On the other hand, the left hemisphere handles a so-called analytic - i.e. detailed - strategy of analysis [17]. This coexistence of concurrent strategies enables the cognitive system to parallely elaborate different opinions on the problem. Now, differential psychology has clearly shown the importance of the diversity of point of views for adaptation and development [22].

Our purpose is actually not to modelize such a complex behaviour! We however modelized a holistic analysis based on fast prosodic processings that will define anchorage points for the classical analytic strategy - from acoustic-phonetic decoding to linguistic analyses. Additional prosodic information thus consolidates the analytic strategy thereby enhancing the global accuracy of the system.

3. DESCRIPTION OF *MICRO*

Following the functional chararacterization described above, *MICRO* was implemented as a society of cognitive agents described on figure 1. Analytic and prosodic ways of analysis interfere concurrently after an acoustic[2] analysis that simulates the acoustic system. They are communicating at acoustic, lexical and pragmatic levels. Analytic agents are divided into two groups concerning phonetics and linguistic analyses. Phonetic analytic agents have already been defined in *DIRA*, a previous speech recognition system organized around a balckboard structure [8].

MICRO is developed on *MAPS*, a software environment dedicated to multi-agents structures design [3]. *MAPS*[3] basic concept is based on the distinction between two kinds of knowledge: on the one hand, the descriptive knowledge representing properties or relations on problem elements, on the other hand the operative knowledge concerning tools and strategies needed to handle descriptive knowledge. Two generic classes of agents are corresponding to those two kinds of knowledge: first of all, Knowledge Servers (KS) maintain and transmit figurative knowledge. Knowledge Processors (KP) then handle operative knowledge.

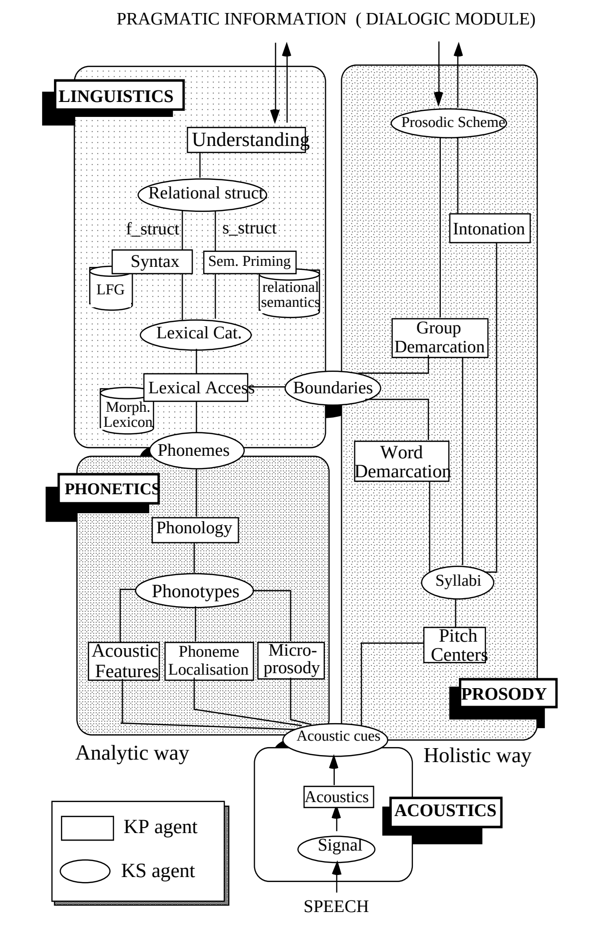

Figure 1 : *MICRO*’s architecture

Every *MAPS* agent is an autonomous entity communicating with other agents by means of message sending. Finally, agents can equally be implemented with neuromimetic or classical rule-based mechanisms.

4. FOR A SYNTAX - SEMANTICS COOPERATION

4.1. REVIEWING MORRIS' TRIPARTITION

Influenced by Morris’ tripartition [25], computational linguistics has classically been considered as a

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[2] The acoustic group actually includes reactive agents that process automatically auditive stimuli without interactive feed-back.

[3] MAPS: Multi-Agent Problem Solver.

sequential process, in agreement with Chomsky's theory on independance and preeminence of syntax in respect with semantics: at first, syntax performs a structural analysis of the sentence. Semantics then manages the transition from lexical to meaning unities, thereby filtering non-sense syntactic structures. Finally, pragmatics actualizes the elaborated meaning thanks to world knowledge.

Yet, numerous works in psycholinguistics recently question the sequential nature of the linguistic processing. For instance, Ratcliff demonstrated that people were able to operate sense-decision tasks on agrammatical sentences, thereby refuting the preeminent role of syntactic parsing [quoted in 15]. Besides, studies on the language system have presented linguistics as an integrated entity, in opposition with Morris' theory. For instance, Rastier showed interferences between syntactic cases and micro-semantic relations [27]. Likewise, Charniak [11] speaks about *Inferential Semantics* rather than pragmatics in order to express the strong merging of the latter with semantics. As a result, linguistic analysis should be seen as the processing of a set of overlapping knowledges that are equally considered.

4.2. INTEGRATION OR COOPERATION ?

Although an integrated description seems to be well motivated, a full merge of syntactic and semantic analyses is unsuitable for wide applying fields: indeed, the exhaustive definition of relations between meaning unities and syntactic structures is an impressive work (see Gross' studies [19]) that should lead to ad hoc solutions. On the contrary, integration could be conceivable with limited applying fields. Thus, the*DIAL* system [26], which is aimed at administrative information tasks, successfully uses local grammars linked to every semantic case.

Besides, a strong cooperation between several linguistics modules can achieve the same modelization. Since concurrent analyses favours adaptation, we decided to achieve part of the linguistic analysis by means of a cooperative strategy between a syntactic parsing and a semantic priming.

5. LINGUISTIC MODELIZATION

5.1. COOPERATIVE STRATEGY

MICRO's linguistic group is widely described on Figure 1. In accordance with Frazier's psycholinguistic model [16], linguistic analysis is achieved in a two-step process: parsing first and then understanding.

Recognition and parsing. Here, the Syntactic KP and the Semantic Priming KP produce concurrently relational structures of the sentence from the hypothetic words supplied by the Lexical Access KP. These relational structures are respectively:

- a functional structure (f_struct) which is computed by the application of a Lexical Functional Grammar [7]. Here is for instance the structure build by the Syntatic Kp for the sentence : "I push the left button to leave":

```
( TO PUSH
( Sub       ( I
( Obj       ( BUTTON
            ( Adj    ( LEFT
            ( Det    ( THE
( VCp       ( [IN ORDER]
            ( CpPrep ( TO LEAVE
```

- a semantic structure (s_struct) where words are linked together by semantic relations. Semantic cases [13], as well as hyperonymic ("is a") relations are common example of semantic relations. Semantic Priming KP is aimed at the building of the semantic structure: primed lexical unities are progressively linked with their priming word in the structure. Here is the s_struct of the previous sentence:

```
( TO PUSH
( Agent     ( I
( Object    ( BUTTON
            ( Property of place ( LEFT
( Goal      ( TO LEAVE
```

Psycholinguistic studies established correspondences between functional and semantic relations [4,15]. As a matter of fact, functional and semantics structures present several similarities. Relational Structure KS consequently merges coherent structures in respect with these correspondences and with pragmatic information provided by the dialog analysis. As a result, cooperation is achieved through the merging of the top-down (contextual constraints thrown to Lexical Access KP) and bottom-up (f_struct and s_struct) productions of the two linguistic KP (figure 2). However, the cooperative strategy leaves normally priority to the syntactic analysis because of the structural properties of the grammatical parsing. Thus, Semantic Priming KP usually provides the system with information that merely consolidates syntactic hypotheses. Semantic priming is however of primordial importance when analysing agrammatical sentences (§ 6.1).

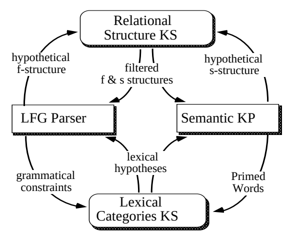

Figure 2: Cooperative strategy

Understanding. Semantic priming reflects *relationzl semantics* [10] which is only one aspect of the semantic knowledge. The parsing process indeed focuses on relationships between words, regardless of their intrinsic or contextually actualized meaning[4]. The elaboration of the complete meaning of the sentence, in respect with discourse or pragmatic context, is thus devoted to the

[4] Rastier calls *differential* and *inferential semantics* these last two aspects of semantics [Rastier 90].

understanding process. Since this paper emphasizes on the syntax-semantics cooperation, we will not further describe the understanding process.

5.2. SYNTACTIC KP

This KP is a predictive parser derived from *Ln_2_3*, a LFG parser developped in LISP language [28]. We developped a grammar including around a hundred rules that widely describe the syntax of *MICRO*'s applying field: the architectural design tasks.

5.3.SEMANTIC PRIMING KP

MICRO's semantic knowledge is completely described through the differential compositional paradigm which assumes the minimal unities of meaning to be sub-lexical entities called *semes* [18]. In opposition with referential compositional semantics [21], semes are defined in opposition to each other. Lexical meaning is thus not supported by semes, but rather by their disjunctive relations. As a result, semes are not primitives entities that warrant a minimal description of restricted domains of application. Semes are defined hierarchically, following their genericity. Consequently, *MICRO*'s semantic lexicon is described by a taxonomy of semes where taxonomic links represents hypernonymic relations. Figure 3 presents a schematic view of this lexicon[5] !

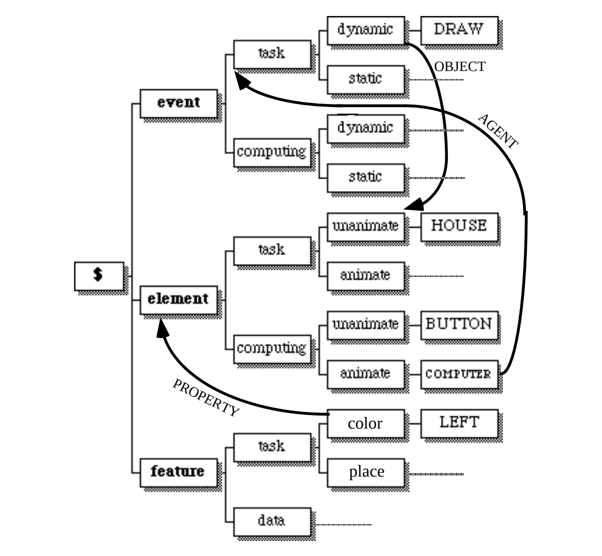

Figure 3: schematic example of semantic lexicon

The first level of disjunction of the taxonomy correspond to macrogeneric semes which divides the semantic field between three dimensions: /event/, /element/ and /feature/. The second level divide each dimension into several domains of usage. In Man-Machine Communication, one finds for instance the data-processing domain which is related to the computer use - /computing/ on figure 3 - and the task domain, which here includes architectural vocabulary.

This lexicon also includes a relational component described by several of Boguraev's semantic cases [6]. These cases, as well as taxonomic links, will be used to perform semantic priming. Those semantic relations have been characterized from similarities between the semic description of the lexemes[6] as well as from the study of priming phenomena in a large scale corpus. Thus, the sentence "Draw a white house", where for instance “to draw” primes “house” (unanimate element of the task domain) via an “object” relationship, leads to the illustrated relations.

Implementation The semantic KP is implemented as an associative memory with four hidden-layers (fig. 4):

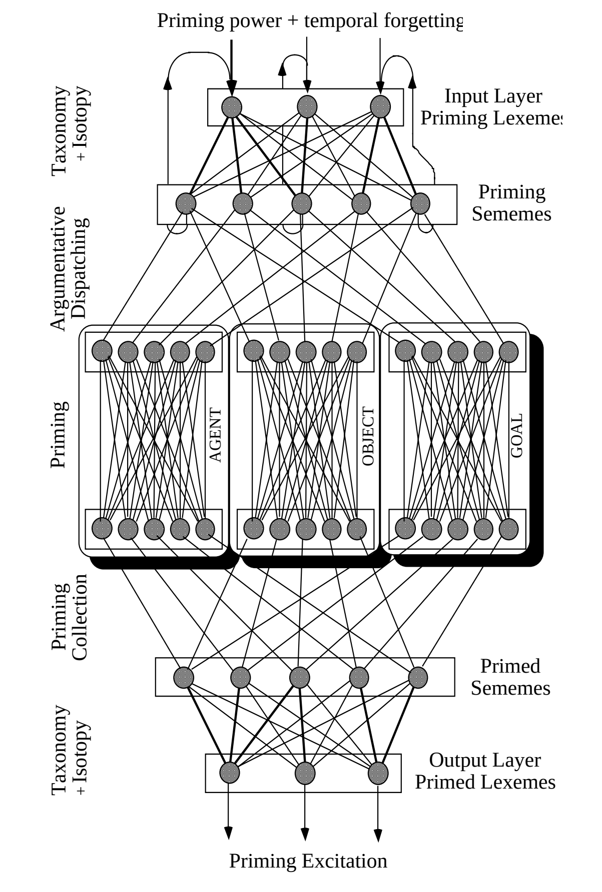

Figure 4: Structure of Semantic Priming KP

Activations received by the input layer represent the lexemic priming power. These activations are dynamically calculated: a maximal activation is provided to cell of the last analysed lexeme. Every lexemic activation is then decreased by a mechanism of forgetting, since semantic priming is syntagmatically limited. Activation is then propagated until the output layer, where collected activation represents the lexemic priming excitation: highest activated lexemes represents

[5] *MICRO*'s semantic lexicon includes 300 lexical inputs described by a taxonomy of deep 10. The illustrated lexicon is thus very oversimplified. This schematic illustration has however some virtues. For instance, the minimalization of the semantic description by the differential paradigm is here very sensible: the disjunction between /animate/ and /inanimate/ is thus enough to distinguished "button" and "computer" !

[6] Lexeme: meaning unity corresponding to a lexical entity.

this primed words. Every hidden layer has a well determined role unlike classical networks. As a matter of fact, this network is not defined by means of supervized learning but on the contrary is directly compiled from the semantic lexicon. Propagation of activation is performed through the folowing steps.

Taxonomic excitation and isotopic inhibition: the first hidden layer includes the whole sememes[7] of the lexicon, whereas input layer cells only represent the lexemes. As a result, taxonomic relations are described by the links between the two layers: an activated lexeme will then excite its hierarchic ascendants. Moreover, inhibitory links have been added between sememes of different domains. The aim of this lateral inhibition is the modelization of isotopy. Indeed, studies on Natural Language and Dialog have clearly identified a thematic redundancy of the discourse which only adresses a little evolutive part of the semantic lexicon, called *isotopy*[8]. Isotopic adaptation is thus achieved by this inhibition, therby limiting dynamically the searching space to the relevant isotopic field.

Argumentative dispatching: Priming power is then dispatched between the input layers of several internal assiociative networks. Each network corresponds to a particular kind of semantic relation (AGENT, OBJECT and GOAL on figure 4). This dispatching is absolutely necessary to establish which semantic relation actually links the priming and the primed words. Furthermore, this mechanism is useful to modelizes additional features. On the one hand, activation is not equally dispatched between the networks. Indeed, semantic relations have obviously not an equal priming power: AGENT and OBJECT cases are for instance more important for a lexeme like “to draw” than the GOAL relation. As a result, we defined argumentative structures describing the relational preference of every sememic dimension. On the other hand, numerous grammatical words intervene in the analysis by focusing the priming on a particular semantic relations. Coordinating conjunction thus focuse on previously primed relations[9] . We thus defined contextual cells, corresponding to grammatical words, that dynamically modify the overall activity of each network. These - not illustrated - cells thus achieve a powerful adaptative limitation of the searching space.

Priming: priming is then parallely performed among all the relational associative memories. Input cells of a particular network propagate their activation to the ouput cells to which they are connected.

Priming collection: this process is the reverse of the argumentative dispatching: each cell of the fourth hidden layer recovers its priming excitations among the output cells of the relational networks. Since a high priming via a particular semantic relation is more important that a global average activation, the resulting activity of the cell is calculated by a Min/Max heuristic. At the same time, most salient priming relations are memorized with the corresponding priming words.

Taxonomy and isotopy: this process is the reverse of the first one: output lexemic cells add their own activation with those of their hierarchic ascendants, thereby calculting their priming excitation. Since *MICRO* performs a wide-first strategy, the Semantic Priming KP keeps several primed words among the most salient ones. These words are connected with their most effective priming word(s) according to their most effective prming relation(s). As a result, concurrent semantic structures are provided to the Relational Structures KS that filters them in regard to the functional structures supplied by the LFG parser.

6. RESULTS ON ADAPTATION

6.1. GRAMMATICAL ERRORS

Since grammatical errors occur very frequently in Man-Machine Communication, speech understanding systems must be designed to easily bypass these difficulties. One classical solution is to implement ad hoc rules that describe exceptional erroneous structures. On the contrary, the syntax-semantic cooperation enables the system to easily analyse agrammatical sentences: since the Syntactic KP has failed, Semantic Priming KP is then in charge of providing alone the pragmatic level with a semantic structure (figure 5).

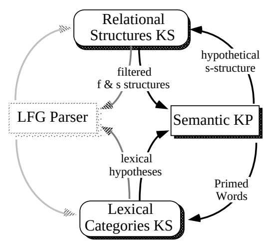

Figure 5: agrammatical sentences analysis

This strategy has been tested on a corpus on a corpus obtained by means of a "Wizzard of Oz" experiment. These tests showed that this strategy can solve the following grammatical errors:

- elisions of small words:"Move the door [on the] right"
- inversions: "The figure, I enlarge it!",
- hesitations: “I push the bu...button”
- repetitive repetitions: “I select the...the...the device”
- corrective repetitions: “Then I select the display...the window” or “I will draw...no I will colour a tree”.

[7] A sememe is a conceptual entities represented by a node of the semantic lexicon. Since semes are not primitive, sememes are dependent on the applying field. Generally speaking, lexemes can be seen as nominalizable sememes.

[8] More precisely, isotopy slowly moves in Natural Language, whereas the thematic domain keeps constant in dialogue until a breakdown is met: isotopy then jumps for instance from task to data processing domain.

[9] In the sentence “ I draw a house and...”, the conjunction focuses both on the OBJECT (“I draw a house and a tree”) and the AGENT (“I draw a house and colour it”) relations.

Since Semantic Priming KP performs an analysis without any structural information, the correct structure is obviously obtained among several erroneous ones. As a result, grammatical errors should not be too long, otherwise semantic priming proposes plenty of hypothetic structures. This drawback is nervertheless not specific to the syntax-semantics cooperation.

6.2. Combinatory explosion

We expect from syntax-semantics cooperation a sensible limitation of combinatory explosion, since semantic priming enables a consideration of semantic knowledge in parallel with syntactic parsing. Thus, we already established in a previous study concerning *DIRA* system that semantic priming can at least reduce lexical combinatory with a factor four [9].

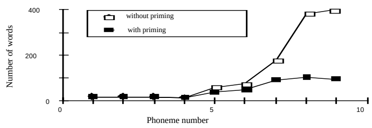

Figure 6: priming effects on lexical combinatory: analysis of the sentence “lacher la clé” (from [9]).

For instance, figure 6 shows that semantic priming reduces from 400 to 95 the lexical combinatory at the end of a French sentence analysis.

CONCLUSION

We report in this paper a cognitive approach for the linguistic level of *MICRO*, a multi-agents speech understanding system. Linguistic analysis has been partially modelized via a cooperation between semantic priming analyser and a concurrent syntactic parser. We emphasize on the influence of this generic strategy on the adaptative abilities of the linguistic analysis. Thus, the adaptative power of the syntax-semantics cooperation enables an easy analysis of agrammatical sentences as well as a limitation of combinatory explosion. Further studies will explore the benefits of the adaptative abilities of this modelization.

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