Multi-Agent Systems for Natural Language Processing

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September 5, 1998

Abstract

This paper investigates the use of multi-agent systems (MAS) for natural language processing (NLP). We have investigated two approaches for distributing linguistic knowledge among agents which interact in order to interpret a sentence: (1) a lexical-structural distribution approach; and (2) a cognitive-linguistic distribution approach. In order to test both approaches, we have developed two systems. In the first case, agents are associated with the morpho-syntactic categories of the words and behave accordingly, exchanging messages and trying to find other agents with whom they can establish associations, forming higher and higher structures until the entire sentence structure is represented. When all agents have been connected, a solution is found. The system deals with the following linguistic constructions: *topicalization, relative clauses* and *gapping*.

In the second case, agents are originally associated with levels of linguistic knowledge (morphological, syntactical and semantical). The system has been specifically used to solve *categorial ambiguity* and it is now being augmented to incorporate agents that deal with linguistic phenomena, such as *ellipsis* and *possessive pronominal reference*. The paper starts with a definition of *agents* and *multi-agent systems*; then we describe the two approaches in detail, comparing them in terms of agents organization, sub-societies construction, "agentification[1]", knowledge distribution, dictionary composition, partial results communication and systems augmentation.

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[1]Agentification is considered to be the process of identifying the entities which will constitute the agents.

1 Introduction

Until very recently most NLP systems were designed using purely sequential architectures, probably inherited from Linguistics, and whose use and maintenance are easy, but which have shown a limited performance. Over the past few years, several investigations [BS 94]; [CA 93]; [FT 88]; [SD 95]; [SMAL 80] pointed to distributed systems as a feasible alternative to traditional NLP systems, since they allow for cooperation among autonomous, specialized and distributed modules, in order to solve the problem.

The aim of this work was to investigate the use of MAS for NLP. The idea of agents as units of processing and knowledge that use their power of communication to obtain a result [DEMA 90] seemed interesting; however, there seems to be at least two different possibilities for distributing linguistic knowledge among the agents to search for a solution in the NLP field:

1. **a lexical-structural distribution:** in this case agents are associated with the words of the sentence according to a set of joining principles (a grammar). This approach, Chomyskian by nature, reveals a possibility of studying the consequences of the joining hypothesis, leading to an structural representation of the sentence.

2. **a cognitive-linguistic distribution:** here the MAS contains more powerful agents, which are usually associated with traditional linguistic processing levels (morphological, syntactical, semantical), sometimes with specific linguistic phenomena, such as ellipsis, anaphora, coordination, categorial ambiguity, and sometimes with both.

When there are agents associated with linguistic levels only, the number of agents is drastically reduced (if compared with the first approach, where there is one agent for every word of the sentence). Nevertheless, the complexity of the agents involved in the process is considerably increased.

An implementation of the cognitive-linguistic distribution approach for the French language can be seen in [SD 95].

We have investigated the two possibilities for doing natural language processing distributedly. In order to test the first type of distribution, we have designed and implemented a system where agents are associated with morphological categories, such as *verb, noun, adjective*, and so on [PAIV 96]. The agent searches, in the neighborhood, for agents to complement or be complemented by, forming higher structures such as *noun phrases (NPs)*, *adjectival phrases (AdjPs)*, *prepositional phrases (PPs)* etc. Then each new structure has to continue the process, that is a PP has to find an NP or a Verb, an NP has to find a Verb, an AdjP has to find an NP, and so on.

We have also designed and implemented a system where agents are associated to linguistic levels [SILV 97] (which is now being augmented with agents associated with some linguistic

This process may envolve the transformation of the software modules (or agents) already existent in the system in multi-agent systems and it can be seen as an internal re-arrangement of the MAS components, trying to detect situations which may need negotiations among complex societies and which can be solved by an MAS mechanism phenomena). Although both systems have been developed for Portuguese, the main ideas can be generalized to other languages.

The rest of the paper is organized as follows. In section 2 we briefly introduce agents and multi-agent systems; in sections 3 and 4 we describe, respectively, the lexical-structural and the linguistic-cognitive distribution approaches. In section 5 we compare both in terms of agents organization, sub-societies construction, further agentification possibilities, knowledge distribution, dictionary composition and systems augmentation, regarding context knowledge inclusion and new agents adding. Finally, in section 6 we present our conclusions.

2 Agents and Multi-Agent Systems

According to [BD 91], an agent is an intelligent entity able to act and understand a known environment, pursuing its goals in a rational and intentional way, according to the present state of its knowledge (internal states), that may change through cooperation with other agents in the same environment. We must take into account the following aspects: (1) capabilities, knowledge and goals related to the linguistic domain; (2) explicit communication among agents, with a common language; (3) perception of the environment and external descriptions about other agents; (4) acting capabilities; and (5) control under cooperative and individual activities.

The agents cooperative activities are determined by an autonomous behavior that is reached through the perception of the changes in the environment. The agent is able to perceive these changes using communication facilities offered, for instance, by an adequate communication protocol. There are two basic types of agents, defined according to their behavior: (1) **Reactive agents**, whose behavior is based on stimulus-response and the actions and behaviors of the other agents are perceived by changes in the environment; and (2) **Cognitive agents**, which are able to reason about the actions of the other agents, because they have an explicit representation of the environment and of the agents in the society.

In a multi-agent system, agents must interact with others in order to acquire more knowledge which will allow them to reach their goals. Besides, they have to deal with multiple, uncertain, and even contradictory sources of information. For this reason, the agent has to be able to abstract goals from the observation of the other agents behavior, and these goals can either be encoded in the algorithms or explicitly given or acquired by the context. Thus, communication capabilities are very important in the process of exchanging knowledge, goals, resources, and so on among the agents.

However, if we consider an agent as having a set of possible solutions or plans to achieve its goals, we have to take into account the fact that the agent sometimes will not to be able to derive all possible solutions, but only partial plans. In this case, the agent depends on reasoning capabilities and interaction with the environment in order to augment its knowledge. Thus, the agents need to communicate among themselves through a common communication protocol to solve any conflicting goal or information.

3 A lexical-structural distribution approach

We have explored some of the ideas presented in [SMAL 80] and [DA 94] in a MAS context [PAIV 96]. Whereas in Small and Devo and Adriaens' work each word of the lexicon is represented by a specific procedure, that is each word is a "word expert" that takes part in the global process control, in Paiva's approach there are specific agents for different morpho-syntactic categories, such as noun, verb, determiner etc. A word is considered a unit of knowledge and the compositional meaning of a sentence is obtained through the interaction among agents; they try to find other agents with whom they can establish associations, forming higher and higher structures, until the entire sentence structure can be represented. Obviously, these associations are not made at random; they are governed by attracting forces and restriction mechanisms.

The basic idea of **attracting forces** is that some words exert influence forces on others. This concept is similar to the one presented in *Dependency Grammar* [HAYS 64];[MILW 94]. Those forces are determined by the category of the word in the following way: *verbs* attract *nouns, prepositions* and *relative pronouns*; *nouns* attract *prepositions* and *determiners*; *prepositions* attract *nouns; coordinators* attract *verbs* and *nouns*; and *relative pronouns* attract *nouns* and *prepositions*.

We have used three different **restriction mechanisms**: *subcategorization* (only for verbs), *neighborhood* and *selectional restriction. Subcategorization* determines the category of the arguments that can fill a certain position in the verb matrix. So, for example, it is not enough to say that a verb can be followed by a preposition; we must restrict (or specify) the type of the semantical complement of the preposition.

Neighborhood is the mechanism that constrains the influence of the word in terms of spatial notion, and it can be seen as a weak mechanism for syntactic checking; it is the need that an agent has for another agent of a specific type in its neighborhood.

Selectional restriction specifies the possible meaning combinations that may occur between words and it can be applied to eliminate incoherent combinations.

The process of sentence interpretation, therefore, may be seen as searching for words that can either modify or be modified by others, according to attracting forces and constrained by restriction mechanisms.

As a matter of simplicity, we assume that categorial ambiguity (that is a word belonging to more than one category, such as verb and noun) was already resolved in a pre-processing phase. So if a word is associated to an agent of an specific type (based on the category of the word) we assume that this word may have several meanings, but all of them within the same morphological category.

Agents interact during the searching process through direct and broadcast message exchange; verbal agents use broadcast messages to send requirements to fill their obligatory subcategorized arguments. These requirements can be the expected position of an agent for a specific word category (or more than one category), the expected semantical category associated with the word category, or the agent type which is specified by the word category which the agent represents.

Nominal agents also play an important role in sentence interpretation; but at the beginning of the process they are all in a passive state waiting for verbal agent requirements and for other agents that will try to modify them. The agents that can modify nominal agents are those which are in the neighborhood.

The attachment phase starts when an agent finds the other it thinks it can modify and asks for attachment; it ends only when all agents are attached to some other agent.

The reasons for agents not to be attached are: (a) the sentence is ill-formed, which indicates an ellipse or a syntactic/semantic error; (b) the sentence is not ill-formed but there was some wrong attachment somewhere in the process; and (c) the sentence is a one-word sentence.

3.1 Linguistic agents level

The system is able to deal with **topicalization**, **relative clauses**, **gapping** and **coordination**. Topicalization is the movement to the beginning of the sentence of some constituent whose position is not usually there. One of the problems with **relative clauses** is the fact that the verb and its subject can be very distant in the sentence, what would make the searching process very expensive. This is treated elegantly in Paiva's system since it is the verbal agent that sends messages, looking for complements. When dealing with gapping and coordination it is difficult to detect the gap and to reconstruct the missing part of the phrase.

When a nominal agent finds itself in this situation, it may change its passive behavior and start to explore its neighborhood, looking for a verb or preposition to complement. This change of behavior is the key for gapping detection. The reconstruction is made by the creation of a new verbal agent which will act exactly as described before. When it does not find a verb or a preposition in its neighborhood, it starts looking for a coordinator agent (such as "and"); it also tries to find a verb in the previous sentence; if this is the case, a new verb agent is created and inserted in the "ill-formed" sentence. This new agent will start the search and, at the end, all agents will be attached to each other and the sentence will be considered well-formed.

4 A cognitive-linguistic distribution approach

This approach [SILV 97] is based on [SD 95], but it differs from the previous one in at least two important aspects: (1) Stefanini's does not use semantic knowledge; and (2) her model includes agents associated with pre-processing tasks (or sentence edition), which is not necessary in Silva's model since there exists a lexical-morphological agent in the system.

The linguistic agent model includes linguistic knowledge and a set of procedures to manipulate it, in order to reach its goals. The model is based on [BD 91] and it is composed of:

- domain - capabilities, knowledge and goals concerning this agent (lexical-morphological, syntactical and semantical analysis, anaphora resolution etc) and accessible to the agents internal state;

- communication capabilities - cooperation protocol;
- external descriptions - information about the capabilities of the other agents, which makes it possible to have mechanisms for social reasoning.

Two levels of implementation for the linguistic agents are complementar. One level is the own linguistic domain considered for problem decomposition in NLP, so that the linguistic levels of processing are considered "agentification" units.

The other level is what we have called cooperation layer and it is basically composed of the communication and external description modules, which are replicated for each agent in the society.

4.1 Linguistic Agents Level

The agents specific knowledge to perform processing skills and individual goals is associated to the linguistic level. At this level, capabilities include the execution of lexical-morphological analysis, parsing, semantical analysis and other functions necessary for the maintenance of the agents linguistic knowledge. Grammar, dictionaries and conceptual networks are the main attributes of each agent's speciality.

4.2 Cooperation Layer

The Cooperation Layer consists of communication and social reasoning modules. Message exchange is based on direct communication among the agents. Each agent has a mailbox for sending and receiving messages in an asynchronous mode. We have used traditional exchange message mechanisms such as <SENDER, MESSAGE, RECEIVER>, plus some primitives from KQML communication language [FF 94] for representing intentions and cooperation.

One of the agent's properties is to recognize the other agents in the society. This social capability is represented as the "other's model" (a data structure that aggregates goals, skills and identification of the other agents in the society) and it is specified in an "external description" of the agents, that is based in Sichman's proposal [SD 95].

In fact, we have simplified the original proposal because we are not concerned with the detailed description of the environment (global goals of the society, inputs and outputs, global descriptions of the interactions etc.) during the interaction among the society members, in order to solve a local problem. We have chosen to work with categorial ambiguity since it involves conflict resolution.

5 Comparing the two systems

In this section we compare both systems regarding the following aspects: agents organization, sub-societies construction, further agentification possibilities, knowledge distribution, dictionary composition and systemm augmentation.

5.1 Agents organization and phrase treatment

Whereas in Paiva's model agents are associated to word categories, in Silva's model they are originally associated to linguistic levels, (although at the moment Silva's system is being extended to incorporate other specialized agents). In Paiva's model agents associated with word categories are duplicated so that the MAS can take care of all the words of the phrase. For example, in order to deal with the phrase "a casa e o jardim" (the house and the garden) we need two *determiners*, two *nouns* and one *conjunction* agent. This duplication, derived from the type of phrase being analysed, seems to be a inherent feature of the MAS architectures which make an spatial decomposition of the problem (the decomposed object in this case being the phrase itself).

In Silva's model, on the other hand, there is no duplication of the agents (although this feature may come up when dealing with texts, instead of isolated sentences). The agents associated to the linguistic processing levels (lexical-morphological, syntactical, semantical) are organized in such a way that strongly resembles the sequential approach. The phrase treatment, whose decomposition comes from a linguistic-cognitive perspective, starts with a lexical-morphological treatment through the morphological agent, which sends its results to the syntactical agent for the construction of the derivation trees which, in turn, sends its results to the semantical agent for the construction of the semantical structure. For a very simple phrase, such as "o gato mia" (the cat mews) the system uses a succession of morphological → syntactical → semantical treatments. Nevertheless this flow becomes non sequential when certain phenomena such as ambiguity or reference are encountered.

5.2 Sub-societies construction

In Paiva's model sub-societies are dynamically built; the process is controlled by the application of attracting forces and restriction mechanisms. We can even say that it is the societies construction which guarantees the phrase treatment. For example, in "a casa e o jardim" a society is established between a determiner and a noun agent, to deal with the noun-phrase "a casa", and another similar sub-society to deal with the noun-phrase "o jardim". These sub-societies start to grow until a complete sub-society that deals with the entire sentence is found.

In Silva's model the process of building sub-societies is also dynamic; but they are built to solve some linguistic phenomena, and not to promote regular structural associations. For example, when an ambiguity at the syntactical level is detected (which may cause the generation of different structural representations for the same phrase), a sub-society composed of syntactical and semantical agents is established to solve the ambiguity.

Nevertheless, due to the small number of agents in the model, there is also a small number of possible organizations. In a phrase such as "eu o canto" (I sing it) the agents interact forming a syntactical-semantical sub-society to solve the following ambiguity: "o-determiner

+ canto-noun" or "o-pronoun + canto-verb", avoiding the generation of wrong solutions from the syntactic point of view. This is where we can evaluate the possibility of interaction among the agents. The sub-societies composition, including agents dedicated to the resolution of linguistic phenomena, is also interesting. In the phrase "Indios e agricultores delimitam suas terras" (Indians and farmers mark their land), the resolution of the possessive pronominal reference "suas" will be made by the society which contains the following agents: syntactical + semantical + anaphorical; it is the anaphorical agent which contains context knowledge, necessary for resolving references. In practice this knowledge may be internal to the agent or it may be in the ontologies stored as semantic knowledge.

5.3 Further agentification possibilities

In Paiva's model the internal agents organization, including knowledge about attracting forces and restriction mechanisms, could give rise to two agents responsible for each one of these opposed forces, and which could negotiate the construction of syntactical structures. But this representation could also be revised by a blackboard and "knowledge sources" mechanism which, although having a simpler organization, could also be used for a more sophisticated distributed configuration of the agents model.

In Silva's model there is a possibility of "agentification" inside the syntactical agent, though this fact comes more from the formalism used to implement the syntactical agent (Tree Adjoining Grammar [JOSH 85]), which contemplates negotiation phases in order to construct the syntactic tree) than the syntactic analysis task itself (other formalisms could lead to different considerations).

5.4 Knowledge distribution among the agents

In Paiva's model the agents are reasonably simple, resembling reactive agents; basically they contain grammatical knowledge. In other words the knowledge distribution is based on an structural criterion of possible associations according to word classes. Morphological and semantical knowledge are contained in a dictionary which must be complete in terms of knowledge and wide in terms of entries for words of the language; this knowledge is external to the agents.

In Silva's model the declarative and procedural knowledge spread among the agents clearly reflect the linguistic-cognitive nature of the lexical-morphological, syntactical and semantical agents. In this model agents contain dictionaries and analysers related to each of these phases. For example, the morphological agent contains a lexical-morphological dictionary, which allows for the decomposition of the words or expressions, and a lexical-morphological analyser for Portuguese phrases.

The syntactical agent contains a grammar for Portuguese, a syntactical dictionary (containing, among other items, the verbal regency) and the corresponding syntactical analyser.

The semantical agent contains a semantical dictionary based on the generative lexical semantics of James Pustejovski [PUST 95] and takes into account the generative mechanisms proposed in his theory.

Agents associated with phenomena have a much less orthodox composition, such as heuristics of the domain which is being analysed, centering and focus algorithms.

5.5 Dictionary composition

Dictionaries seem to be fundamental to the success of any model which treats natural language sentences. In Paiva's model the dictionary is an structure external to the model, which is previously consulted such that the decomposition of the sentence and the pertinent associations become possible.

In Silva's system, on the other hand, a completely different strategy is adopted. The dictionary, as well as the procedures to access them, are distributed among the agents. Every agent responsible for a linguistic level contains a dictionary structure and the respective access procedures. Nevertheless, differently from the monolithic structure available in Paiva's system, in Silva's these structures are distributed according to the knowledge needed by the agent. The number of entries in each partial dictionary may vary. For example, the syntactic dictionary contains entries for the morphological dictionary subset (that is, entries for items which show a particular behavior). Special attention must be GIVEN to the dictionaries updating. Because they are distributed, this process demands a strong coherence in order to keep the information integrity, even though the process is external to the agents.

5.6 Partial results communication

In Paiva's system, partial results are associated with a local syntactical structure (a frame) which is being built gradually. In order to allow for communication, these frames are intimately related through a global data structure with one entry for every lexical unit being treated (similar to a blackboard).

In Silva's system, there exists a communication protocol, which was implemented using KQML primitives; the cooperative learning protocol [KD 95] is based on Sian's [SIAN 91] and the communication can either be specific between two agents or through broadcast using primitives based on speech acts. The existence of a communication protocol in this model is crucial due to the agents heterogeneity.

5.7 Systems augmentation

As far as systems augmentation is concerned there exists a crucial difference between the two models. Whereas Silva's model is prepared for the inclusion of new agents in the society, through the external description of the others, in Paiva's model there should not be a need for agents inclusion, since the agents are associated with word categories that must be present at the system's conception.

Nevertheless, it is also true that in Silva's model the capability of the previous agents to collaborate with new agents in order to solve a problem and to form sub-societies may transcend the limits of social reasoning and it may demand a fine tune among the agents in the society.

6 Conclusion

There are several different approaches for doing NLP distributedly and a good survey on the subject can be find in [HA 94]. Some approaches seem more adequate for an implementation of the MAS paradigm.

Our interest in using the MAS paradigm for NLP led us to the development of two different MAS, based on Paiva and Silva's models and which are compared in this paper.

The first model (Paiva's), with a finer granularity, starts with a spatial decomposition of the sentence into words, recognizes their categories and adopts a functional treatment. Each word is treated by an agent expert in a specific word category and the goal of the system is to aggregate agents in sub-societies representing valid phrase structures until the entire sentence is represented.

The second model (Silva's), with a coarser granularity, is composed of more complex and heterogeneous agents, which are associated with linguistic processing levels (lexical-morphological, syntactical and semantical); it may areceive agents responsible for the treatment of specific linguistic phenomena, such as reference. In this system the problem decomposition is made according to a cognitive-linguistic criterion. Although the agents of the society are autonomous, the model still resembles a sequential NLP model. The benefits of the MAS paradigm become more apparent during the resolution of certain phenomena, such as ambiguity, pronominal reference etc. For simpler sentences, which do not present phenomena such as these, a sequential flow is used.

The two systems seem to be at opposite extremes. Paiva's system follows a bottom-up method during sentence treatment, whereas Silva's system uses a top-down method. Paiva sees sentence analysis as an structural problem and, as such, it is very difficult to improve the system unless the entire conception of the system is changed.

Silva, on the other hand, benefits from the possibility of growing deeper into the problem through the unfolding of the available agents and inclusion of new ones, which may lead to a conception of a more powerful MAS in terms of agents number and nature. In our opinion this is the most important advantage of the second model. Due to the heterogeneity of a MAS for NLP, we also consider fundamental the communication capabilities among the agents through a cooperative learning protocol.

As far as the sub-societies composition is concerned, Paiva's model is more dynamic and its potential comes exactly from this ability. The sub-societies formation in Silva's model is attenuated by the small number of agents involved in the process (with the aggregation of new agents, the sub-societies formation in Silva's model may become more dynamic).

As for knowledge distribution among the agents (declarative or procedural), the cognitive structure seems more adequate, with agents having knowledge about the domain they are dealing with, which seems more appropriate for a MAS paradigm. But the distribution of complex structures, such as dictionaries, may introduce the need for a synchronous updating process.

As for the manipulation or communication of intermediary results, a global data structure such as the one used in Paiva's system is fine when we intend to add new elements, such as context, to the MAS. This "mixed" model may reduce communication costs if the global structure is accessed by several agents in the society.

Finally, we should say that the reason for comparing both systems is not to choose the best model, but to shed some light on proposals for building new MAS architectures for NLP. The word type agents have a too fine granularity and are limited by a bottom-up approach; the linguist level processing agents present a poor variety of societies and the difficulties inherent to the NLP field. A model with a coarser granularity may be more interesting for a MAS whose aim is text treatment.

References

[BD 91] BOSSIER, O. and DEMAZEAU, Y., *A Distributed Artificial Intelligence View on General Purpose Vision Systems.* In: Decentralized artificial Intelligence 3, p.311-330, Elsevier Science Publishers, 1991.

[BS 94] BOITET, C. and SELIGMAN, M., *The "Whiteboard" Architecture: A Way to Integrate Heterogeneous Components of NLP Systems.* In: Proceedings of COLING'94, Vol. I, 1994.

[CA 93] CSUHAJ-VARJÚ, E. and ALEZ, R. A., *Multi-Agent Systems in Natural Language Processing.* In: K. Sikkel & A. Nijholt, eds., Twent Workshop on Language Technology 6, p. 129-137, 1993.

[DEMA 90] DEMAZEAU, Y. and MULLER, J.P., *Decentralized artificial intelligence.* In: DEMAZEAU, Y. & MULLER, J.P., eds., Decentralized A.I., 1990

[DA 94] DEVOS, M. and ADRIAENS, G. *The Parallel Expert Parser.* In: ADRIAENS, G. & HAHN, U., eds, Natural Language Processing, p. 350-375, 1994.

[FF 94] FININ, A. and FRITZSON, R., *KQML as an Agent Communication Language.* In: Proceedings of the Third International Conference on Information and Knowledge Managment (CIKM'94), ACM Press, 1994.

[FT 88] FUM, G. and TASSO, C., *A Distributed Multi-Agent Architecture for Natural Language Processing.* In: Proceedings of COLING'88, VOL. II, Budapest, 1988.

[HAYS 64] HAYS, D.G., *Dependency Theory: A Formalism and some Observations.* In: Language 40, pp. 511-525, 1964.

[HA 94] HAHN, U. and ADRIAENS, G., *Parallel natural language processing: background and overview.* In: G. Adriaens & U. Hahn, eds, Parallel Natural Language Processing. Norwood, NJ: Ablex, pp. 1-134, 1994.

[JOSH 85] JOSHI, A., *Tree adjoining grammars: How much context sensitivity is required to provide reasonable structural descriptions.* In: D.R. Dowty, L. Kartutunen and A. Zwicky, eds., Natural Language Parsing, Cambridge Press, 1985.

[KD 95] KONNING, J. and DEMAZEAU, Y., *Collaborative Learning Using DAI Interaction Protocols in a Telecommunication Setting.* In: IT&P'95: Interacting Agents, 1995.

[MILW 94] MILWARD, D., *Dynamic Dependency Grammar.* In: Linguistics and Philosophy 17, pp. 561-605, 1994.

[PAIV 96] PAIVA, D.S.D., *Um Sistema Multi-Agentes para o Processamento Distribuído de Linguagem Natural.* Master Thesis, Universidade Estadual de Campinas, Brazil, 1996.

[PUST 95] PUSTEJOVSKY, J., The Generative Lexicon. The MIT Press, 1995.

[SD 95] SICHMAN, J. and DEMAZEAU, Y., *Exploiting Social Reasoning to Deal with Agency Level Inconsistency.* In: Proceedings of the First International Conference on Multi-Agent Systems, p. 352-359, AAAI Press/The MIT Press, 1995.

[SD 95] STEFANINI, M.H.; DEMAZEAU, Y., *TALISMAN: A Multi-Agent System for Natural Language Processing* In: WAINER, J., CARVALHO, A., eds., Lecture Notes in Artificial Intelligence 991, Springer-Verlag, 1995.

[SIAN 91] SIAN, S. S., *Adaptation based on cooperative learning in multi-agent systems.* In: Decentralized A.I. 2, Yves Demazeau & Jean-Pierre Müller, eds, Elsevier Science Publishers, 1991.

[SILV 97] SILVA, J.L.T.D., *Utilização do Paradigma Multi-Agentes no Processamento da Linguagem Natural: Um Modelo Voltado à Resolução da Ambigüidade Léxica Categorial na Língua Portuguesa.* Master Thesis, Pontifícia Universidade Católica do Rio Grande do Sul, Brazil, 1997.

[SMAL 80] SMALL, S.L., *Word Expert Parsing: a Theory of Distributed Word-based Natural Language Understanding.* Doctoral Dissertation, University of Maryland, 1980.