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ARTIFICIAL INTELLIGENCE AND AGENTIVE COGNITION: A LOGICO-LINGUISTIC APPROACH

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Abstract
Every agent (animal or human) perceives and reacts to its own environment according to its own psychophysical structure and organization. This is true for machine intelligence as well as for any other agent. Machine intelligence must perceive and react to its environment according to its own cognitive organization, which requires a linguistic model. We claim that we need a logico-linguistic ontology for the construction of the agentive character of machine intelligence.

1. *Introduction*

Intelligence is not a single phenomenon, and it includes various ranges of cognitive capacities such as perception, learning, reasoning, problem solving, memory, understanding, etc. Having one of these cognitive capacities cannot be a proof of intelligence. It is the high-order interaction of these capacities that lead us to accept the presence of intelligence. Developing reasoning and rationalizing techniques for machine intelligence requires constructing higher-level cognitive structures. In Artificial Intelligence (AI), a linguistic model is a higher-level cognitive organization. We adopt Wittgenstein's well-known statement to an understanding of AI: "The limits of machine linguistic capability mean the limits of a machine's agentive world."[1] The investigation of machine agency and its limits can be pursued only by

[1] The original statement is "The limits of my language mean the limits of my world" (Wittgenstein 1922: § 5.6). In machine intelligence, we have to pay attention to the agentive character of thought and cognition which can be constructed by a logico-linguistic model. In AI, we do not need to make a claim about the mental activity (or content) of thinking. Language may not have any role in a human being's mental activity. This is a controversial issue, however. In our view, language must have a constitutive role in the formation of agentive cognition in machine intelligence. In AI, language does not have only a communicative function but it also has a constitutive role in machine cognition.

paying attention to linguistic and logical models. All cognitive structures can be analyzed and described in terms of agency; and agency (in machine intelligence[2]) can be described in terms of a linguistic model. Therefore, language is regarded as an element of higher-level cognitive organization in which all environmental data can be situated in an agentive condition.

Cognition is the essential source of agency. Sense data, perception, learning, and memory are the basic elements of cognition. There are obviously structural and organizational differences between human and machine cognition. Because of these differences, we need to seek an alternative model to find a way to construct a relation between cognition and agency. A logico-linguistic model is a necessary constituent of machine cognition because only a logico-linguistic model can allow cognitive processes to be *agentified*. Language is the only means machine intelligence has to *objectify* (*agentify*) the external world. The way machine intelligence achieves this depends on the linguistic-based model. In AI, language is not a mere attachment of words to objects or ideas; rather, language enters into the cognitive process itself.

There is a correspondence between the logico-linguistic structure and machine cognition. Machine cognition should be considered in terms of three variables: environment, agent, and logico-linguistic structure. These variables form three kinds of interaction. Firstly, environment is what forms an agentive structure. Secondly, both agency and logico-linguistic structure are viewed as things that are formed by the environment. Thirdly, the logico-linguistic structure is considered to be something that is formed by the environment and something that determines the form of agency. As a result of these interactions, language is not a determined state, but an agentive activity. We split cognition into two natures, namely a *what* and a *how*. *What* an agent does and thinks depends on his cognitive potentialities and skills. However, the logico-linguistic structure is the agentive *how* of thought and cognition. For human beings, cognitive skills and thought may have inner forms (e.g., cognitive modules), but for machine intelligence, the logico-linguistic structure is the formal guide to thought and cognition. For instance, time, space, and matter are the most fundamental abstract notions that an agent uses in interpreting experiences. For human agents, these abstract notions can have inner sources (i.e. biologically-based structures or causal powers).[3] However, for machine intelligence, a logico-linguistic model can

[2] The term "machine intelligence" will be used in a 'robotic' sense viewed from an agentive perspective. For instance, when we use the term "the behavior of machine intelligence", we refer to agentive robotic performance.

[3] For instance, Searle (1997: 103) considers biological structure to be the source for the explanation of cognition: "What sorts of systematic explanation should we and can we seek in cognitive science for perception, rational action and other forms of cognition? In broad

be the only source for the construction of these abstract notions that bring about an agentive experience of the world because biologically-based structures cannot be the target system for modeling certain abstract notions such as time, space, and matter. In AI, the fundamental analysis of experience is not through direct statements about perception itself but rather through statements about how a logico-linguistic structure *functionalizes* experience in machine intelligence. In other words, a logico-linguistic model can bring agentive aspects of cognition into the interpretation of experience and show how these patterns can be traced in the *grammar* (logic). The forms of machine cognition are controlled by strict laws relating to the patterns that are an intricate systematization of the machine's logico-linguistic structure. Machine cognition follows a network of tracks laid down in a logico-linguistic model for machine intelligence.

For human beings, thought and language can be seen as two distinct systems and the relation between these systems can be gradual or relational.[4] But for machine intelligence, thought and cognition are systems in which a logico-linguistic model must be the basic constructive element. We do not claim that there is no pre-linguistic thought; but we do claim that all mental, cognitive, intelligent, and thoughtful activity of machine intelligence must depend on a logico-linguistic model. Therefore, there is no pre-linguistic mental and cognitive state in machine intelligence. That is to say, in AI, language is a logical structure, which has a supra-individual status. In AI, language and logic are studied, not as some sort of abstract phenomenon but as constitutive elements of agentive machine cognition. In other words, we are interested in the manner in which language is embodied in cognitive capabilities such as perception, memory, learning, and cognition. Language is a cognitive medium between machine intelligence and the environment. In AI, language can occupy a middle position between the sensation of objects and the perception of the environment because language is a mediatory tool for attributing a functional role to the sense data. When we study language in AI, we are not studying only words; we are also studying how certain data can be embodied in a logico-linguistic model in order to make statements about environmental factors. Every language structures cognition in its own way and thereby forms the elements of cognition that are specific to this given language because grammar has a determinative role in the formation of cognition. Cognition is not a mere mental state but must be relative to the

outline I think the answer is reasonable clear: We are looking for *causal explanations*, and our subject matter is *certain functions* of biological organ, the human and animal brain."

[4] For instance, ethno-linguistics is an academic field that studies the relational degree between language and thought.

particular language one speaks. Therefore, language can impose upon machine intelligence a particular (an agentive) way of thinking about the world. In other words, logico-linguistic rules can determine a manner of thinking and a mode of agency for machine intelligence.

A higher-level cognitive organization is important as a means to process data and regulate behavior in the light of those data. Cognition, in machine intelligence, cannot be constructed without at some point alluding to language. We do not claim that thought is impossible without language; but we do claim that in AI the nature of thought and cognition must make reference to language at some point. Cognition is propositional in AI; that is to say, knowledge can be formulated in a linguistic model.[5] Therefore, language is the only form of mental representation that can be used in machine cognition.

Language is a creative, formal structure that forms experience for machine intelligence. That is to say, language is classificatory, and it organizes elements of experience. Machine intelligence can experience the world through language. The notion of "experience" can be situated in machine intelligence in terms of linguistic structure. In the human mind, experience may not have a direct correspondence with linguistic categories but there is an abstraction and elaboration in the linguistic process that makes experience cognitively meaningful for the human mind.[6] Certain cognitive processes (such as thinking and perception) can take on a specific form when they are employed in a linguistic model. Normally language does not necessarily mediate between us and the world but it must mediate between the machine information processing and the surrounding environment in order to provide experience in

[5] In AI, knowledge and cognition presuppose propositional attitudes in general because understanding something requires an attribution of properties to particulars and holding claims to be true or false of them in the first place.

[6] Sapir claims that the formal nature of language is the constructive element of human experience: "Language is a self-contained, creative symbolic organization, which not only refers to experience largely acquired without its help but actually defines experience for us by reason of its formal completeness and because of out unconscious projection of its implicit expectations into the field of experience. . . . [Language] categories are, of course, derivative of experience at last analysis, but once abstracted from experience, they are systematically elaborated in language and are not so much discovered in experience as imposed upon it because of the tyrannical hold that linguistic form has upon our orientation in the world" ([1931]: 128). In addition to that, Britton (1971: 28) specifies the relation between language and experience by referring to the governing role of syntax: "Grammatical relationships continue another kind of organization to be found in language, and as such affect the way we represent experience in speech and thought. Aspects of our experience are habitually represented as nouns while others are represented as verbs: their further relations are governed by rules of syntax."

machine intelligence.[7] Many philosophers consider language to be a criterion for discussing the distinction between humans and animals.[8] Language is an agentive construction system for human experience. The representational role of language helps us to make classifications and organize our representations of experience. What happens around us does not form our experiences. What forms our experience is the gradual construction of what happens around us. Language is the essential element for this successive construction, since language has a significant role in the representation and organization of the information that we receive from the world. Waters and Tinsley (1982: 270) mention the significant role of language for experience:

> Language plays important roles in the selection and encoding of information from the environment, the organization of information and experience,, the representation of knowledge about the environment, the individual, and their interactions. In all of these areas, there are developmental trends that suggest that language's role as a

[7] Davidson forms an analogy between language and sense organs. In our opinion, this analogy is true for the role of language in machine intelligence: "Language is not an ordinary learned skill; it is, or has become, a mode of perception. However, speech is not just one more organ; it is essential to the other senses if they are to yield propositional knowledge. Language is the organ of propositional perception. Seeing sights and hearing sounds do not require thought with propositional content; perceiving how things are does, and this ability develops along with language. Perception, once we have propositional thought, it is direct and unmediated in the sense that there are no epistemic intermediaries on which perceptual beliefs are based, nothing that underpins our knowledge of the world" (Davidson 1997: 22).

[8] For instance, according to Britton (1971:14–15), language is only one way of representing what is in the world. He states: "The ability to speak and to reason are, of course, highly characteristic features of human life, distinguishing man from the other animals, but the point is that we have to dig beneath them to get to the root of the matter since both are dependent upon the ability to generate and use symbols, the ability to create representations of actuality. The world we respond to, in fact, the world towards which our behavior is directed, is the world as we symbolize it, or represent it to ourselves. Changes in the actual world must be followed by changes in our representation of it if they are to affect our expectations and, hence, our subsequent behaviour." Chomsky interprets the Cartesian understanding of language and he mentions that Descartes did not consider language in terms of his mechanistic theory. According to Chomsky, Cartesian philosophy attributes a special role to human language that differentiates man from animal. He states: "[Descartes] arrived at the conclusion that man has unique abilities that cannot be accounted for on purely mechanistic grounds, although, to a very large extent, a mechanistic explanation can be provided for human bodily function and behavior. The essential difference between man and animal is exhibited most clearly by human language, in particular, by man's ability to form new statements which express new thoughts and which are appropriate to new situations" (Chomsky 1990: 71).

> representational system increases with age, becoming more important in the cognitions and behavior of the individual.

What makes language so valuable for AI is not just that it represents words in communicative actions. Language must have a cooperative function that provides an appropriate medium to mediate between environmental data and cognition. The realization of this kind of cooperative function requires constructing a specific linguistic model in AI. We propose an *Onto-heuristic* model for use in our search for a cognitive correlation between language and thought. This cognitive correlation includes some specific programming techniques.[9] However, we will not describe this technique fully here because this technique requires an engineering study. We will set up the methodological principles for constructing a cognitive correlation between language and thought. We have to mention that these methodological principles are suitable only for machine intelligence. We do not have any claim on an explanation for the relationship between language and thought in human cognition. We do not seek any direct empirical demonstration of the linguistic structures involved in human thinking because we see human and machine cognition as different mechanisms. We do not wonder whether linguistic representations have any real function in human thought. However, we wonder about the possibility of constructing a linguistic model (namely, an *onto-heuristic* model) that provides operations that can transform environmental data that will yield a solution (or experience) when reapplied to the environmental situation. Cognitive science makes an empirical study of the material structure (i.e.,the brain) that carries out man's high-level cognitive organization. Cognitive scientists use their empirical data for a direct examination of the brain structure, and their models are used to understand its nature and function. To the contrary, the onto-heuristic model does not set out to study the language functions in the brain but it is intended to be a scientific model of brain functions responsible for language. It intends to construct a system of rules and principles that functionalize and transform environmental data into an agentive cognition related to the behavior of machine intelligence.

A linguistic model has a mediating role in a machine's behavioral system. In what we will call an onto-heuristic model, we will propose a parallel process with language and thought. In this process, environmental data (cognition) may initially be considered independent of language but they progressively come under the control of a linguistic model. The linguistic and

[9] The onto-heuristic model does not make any contribution to the decision of the adequacy of any linguistic theory, such as structuralism or generative grammar, by making it part of a competence model for machine understanding.

logical aspects of environmental data gain further significance in the higher-level organization of cognitive processes. In AI, we do not equate language and thought but we argue that whether or not thought has an independent representational content in the human mind, it can nonetheless be functionalized[10] only in a linguistic model because a linguistic model is the proper way of situating (describing) environmental data in a formal manner.

Following up on these statements, we think it is best to start the analysis of the correlation between language and thought.

2. *The Correlation between Language and Thought in Machine Intelligence*

In the history of philosophy, there exist various ideas about the relationship between thought and language.[11] The basic issue related to this relationship is whether thought is independent of language, or whether thought, to the contrary, necessarily depends on language. Since Darwin's theory of evolution was put forward, language has been seen as a part of nature. Language is considered to be a tool used by man to acquire adaptive capabilities in the environment. This idea presupposes that language, as a part of nature, can be examined in terms of physical and psychological laws. Kuczaj and Hendry (2003: 242) analyze the relationship between language and thought from an evolutionary point of view:

> Darwin's speculations on the evolution of language and thought emphasized the necessity of some form of "highly developed" cognitive abilities for language to emerge, and the subsequent role of language in expanding these abilities into even more sophisticated cognitive powers. In Darwin's view, cognitive abilities and linguistic structure coevolved as a natural consequence of continued efforts to communicate more effectively. Theoretically, then, any species that possessed sufficient basic cognitive abilities and communicative needs might evolve increasingly complex cognitive and communicative powers as cognition and language reciprocally influence one another's evolution.

[10] Sapir (1921:14) describes language as primarily a pre-rational function for human thought.

[11] Lund (2003: 10) classifies these various ideas under four main groups: "1-The language we speak determines or influences the way we think. 2-The way we think determines the use of language. 3-Language and thought are independent but gradually become interdependent during infancy. 4-Language and thought are independent."

Frege, the founder of modern logic, defends a regulative idea in which he unifies language and thought. According to Frege (1918: 20), "The thought, in itself immaterial, clothes itself in the material garment of a sentence and thereby becomes comprehensible to us. We say a sentence expresses a thought." The early Wittgenstein equates language and thought. Wittgenstein (1979: 82) sees thinking as a kind of language and, therefore, a logical picture of the proposition. In modern psychology, the relationship between language and thought has become a part of scientific study, especially in developmental psychology. For instance, Vygotsky (1972) made certain observations on children's linguistic and cognitive developments. After making these observations he reached the following conclusion: "The relation of thought and word is not a thing but a process, a continual movement back and forth from thought to language and from word to thought" (1972: 186). Vygotsky and his followers in Soviet psychology (especially, Luria) defended the idea that language can emerge in cognitive systems and that language subsequently interacts with them. This interaction endows cognitive systems with a developmental capacity. Therefore, language and thought are interdependent and this interdependency is the source of certain cognitive and behavioral developments. Davidson mentions the interdependence of language and thought from a philosophical point of view in which he claims that it is not possible to argue for the primacy of language to thought and vice versa. Davidson (1975: 10) states:

> It is redundant to take both patterns as basic. If thoughts are primary, a language seems to serve no purpose but to express or convey thoughts; while if we take speech as primary, it is tempting to analyse thoughts as speech dispositions. . . .But clearly the parallel between the structure of thoughts and the structure of sentences provides no argument for the primacy of either, and only a presumption in favour of their interdependence.[12]

According to Dummett (1991), language has a priority over thought but this priority is not structural. In other words, he thinks that the only way for an analysis of thought depends on the analysis of language. This idea gives an explanatory priority to language. Dummett (1989: 196) states: "thought, by its nature, cannot occur without a vehicle, and that language is the vehicle whose operation is the most perspicuous and hence the most amenable to a systematic philosophical account." Carruthers (1996) goes one further step

[12] Although Davidson defends the interdependence between language and thought, in his article "Rational Animals", he argued that it is impossible for non-language-users to have beliefs and propositional attitudes.

and gives language a constitutive role.[13] Fodor and Pylyshyn (1988: 37) see language as a paradigm of systematic cognition.

The above-mentioned ideas involve significant notions and methodological principles for constructing a linguistic model in AI but none of them are sufficient for machine intelligence. In our opinion, using the linguistic relativity hypothesis (i.e., Whorf-Sapir Hypothesis) is the best way to understand the correlation between language and thought from the AI point of view. There are three main reasons for this viewpoint: First, in AI, thinking and cognition are best understood instrumentally (functionally), not as the ultimate representational content. The principles of the linguistic relativity hypothesis provide this functional analysis of the correlation between language and thought. In other words, the linguistic relativity hypothesis gives an AI researcher a way to situate cognitive systems, such as experience, cognition, understanding, and thought, into a linguistic model. Second, as mentioned earlier, machine cognition should be based on a linguistic model. This specification should include the construction of a special formal structure (i.e., grammar) that controls (operates) the environmental data. The linguistic relativity hypothesis can be helpful in meeting such a specification. Third, although language has such distinct aspects as semantics and syntax, the cognitive analysis of meaning and cognition should depend on a model which unites these two aspects in a specific linguistic model. The linguistic relativity hypothesis provides methodological principles that make such a unification possible.

2.1. *The Linguistic Relativity Hypothesis*

The linguistic relativity hypothesis proposes that the way we perceive and think about the world is shaped by language. There are two versions of the

[13] The constitutive role of language, described by Carruthers, is a mediatory function between thought and language. He states: "It is one thing to maintain that thoughts (or some thoughts) can only achieve the status of consciousness through being formulated in (inner or outer) natural language. It would be another, much stronger, thing to maintain that there are some thoughts which can only exist at all through the possibility of being formulated, consciously, in such language. And it is one thing to maintain that language has a role in our cognition distractive of conscious thinking. But it would be another, much stronger, thing to maintain that language is constitutive of the very existence of (some of) the thoughts which we actually employ in that form of thinking" (1996: 122).

linguistic relativity hypothesis.[14] The strong version sees language as a determining factor for human thought and the weak version considers language as a tool that has certain effects on human thought. In the former, language is a necessary constituent for thought but in the latter, language is only one of the dominant factors in human thought. In ethno-linguistics, many studies examine the role of language as either having a determinant role or an influential role in human thought but what makes the linguistic relativity hypothesis special for a linguistic model in AI is its specific emphasis on the role of grammar in thought. In other words, the linguistic relativity hypothesis gives an AI researcher an opportunity[15] to analyze the notion of "thinking" in morphological and syntactical forms. A specific emphasis on grammar is mentioned by various philosophers and linguists. For instance, Whorf (1956: 212) states:

> It was found that the background linguistic system (in other words, the grammar) of each language is not merely a reproducing instrument for voicing ideas but rather is itself the shaper of ideas, the program and guide for the individual's mental activity, for his analysis of impressions, for his synthesis of mental stock in trade. Formulation of ideas is not an independent process, strictly rational in the old sense, but is part of a particular grammar, and differs, from slightly to greatly, between different grammars. We dissect nature along lines laid down by our native languages. The categories and types that we isolate from the world of phenomena we do not find there because they stare every observer in the face; on the contrary, the world is presented in a kaleidoscopic flux of impressions which

[14] In his article "Linguistic Relativity", Lucy (1997: 294) describes the general characteristics of the linguistic relativity hypothesis and he gives the reason for different interpretations of the hypothesis: "There are a variety of specific linguistic relativity proposals, but all share three key elements linked in two relations. They all claim that certain properties of a given *language* have consequences for patterns of *thought* about *reality*. The properties of language at issue are usually morphosyntactic and are taken to vary in important respects. The pattern of *thought* may have to do with immediate perception and attention, with personal and socio-cultural systems of classification, inference, and memory, or with aesthetic judgment and creativity. The reality may be the world of everyday experience, of specialized contexts, or of ideational tradition. These three key elements are linked by two relations: Language embodies *an interpretation* of reality and language can *influence* thought about reality. The interpretation arises from the selection of substantive aspects of experience and their formal arrangement in the verbal code."

[15] According to Lucy (1996), the relation between linguistic structure (grammar) and cognitive systems can be analyzed in a scientific manner. He states: "it is important that there can be a clear analytic distinction between linguistic categories and cognitive categories so that the influence of the former on the latter can be detected and identified" (1996: 264).

> has to be organized by our minds — and this means largely by the linguistic systems in our minds.

Greenberg follows the line of Whorf and he states: "The general notion is that the grammatical categories of a language determine or at least influence strongly the general manner of conceiving the world of those who speak it" (1963: 138). In his studies, Lee focuses on the grammatical categories that are the reflection of culture. He (1938: 89) states: "Grammar contains in crystallized form the accumulated and accumulating experience, the *Weltanschauung* of a people." Slobin proposed the phrase "thinking-for-speaking",[16] which he used to shows the role of grammar in spatial and temporal cognition. According to Slobin (2003: 161), "The semantic domain is encoded by *special grammatical construction* or *obligatory lexical selections* in at least some of the languages under comparison." Gumperz and Levinson (1999: 27) see grammatical categories as the source of specific ways of thinking. Parisi and Antinucci (1976: 8) see grammar as a part of man's mental capacity and they attribute a regulative role to language in human cognition, stating that "grammar is not a theory of what people do but a set of prescriptions about what they *should* do." Von Kutschera (1975: 242–243) attributes an ontological function to linguistic structure, stating, "[I]t is only with the help of language that we apprehend the world, the things, distinctions, properties and relations within it; and we apprehend them in a particular way with a particular language: Every language contains a view of the world [*Weltansicht*] and its structure, a distinctive ontology." Quine (1970: 15) also mentions the role of grammar in the way that we perceive the world, stating "How we depict the native's view of the world depends on how we construe his words and grammar, and how we construe his words and grammar depends on what we take to be his view of the world." Language is not just a collection of terms or lexical meanings. Grammar is the most general characteristics of language. There are many empirical studies that show the effect of grammar on our ways of thinking.[17]

[16] Slobin (1999: 76) describes 'thinking-for speaking' as follows: "In my own formulation: the expression of experience in linguistic terms constitutes thinking for speaking — a special form of thought that is mobilized for communication. Whatever effects grammar may or may not have outside of the act of speaking, the sort of mental activity that goes on while formulating utterances is not trivial or obvious, and deserves our attention. We encounter the contents of the mind in a special way when they are being accessed for use. That is, the activity of thinking takes on a particular quality when it is employed in the activity of speaking."

[17] There is much affirmative evidence for the linguistic relativity hypothesis. For instance, see Boroditsky 1999, 2001; Bowerman 1996; Carroll and Casagrande 1958; Davidoff et al 1999; Imai and Gentner 1997; Levinson 1996; Lucy 1992; Slobin 1996. However, we will not advance any solid ethno-linguistic evidence that bears on the linguistic relativity hypothesis,

If we apply this hypothesis to AI, grammar influences thought in certain cognitive contexts. Languages have different effects on cognition because of their various syntactic structures. For instance, to learn how to encode space alters the nature of one's spatial cognition. The same spatial relationships are represented in different grammatical forms in different languages.[18] Grammatical differences cause different types of considerations related to similar acts. Grammar gives us a world view we use to interpret data in the environment. Therefore, machine intelligence can gain a capability of representing environmental data by using a proper linguistic structure (grammar). We can make use of a linguistic structure (grammar) as a tool that provides an understanding of the environment. In machine intelligence, certain behavioral and cognitive processes can be ruled by a specific linguistic structure embodied in a linguistic model (i.e., the onto-heuristic model). The procedure used to follow these rules should include a specific method that shows how to encode environmental data utilizing linguistic structure peculiar to machine intelligence.

2.2. *The Regulative Role of Grammar in Thought and Cognition*

Grammar is an essential part of the cognitive capabilities of human agency. Grammar can always be a part of psychological and cognitive inquiry. Grammar is the formative element in the way language shapes thought. It can be seen as the source of many cognitive functions. "The multiple function of language is reflected in linguistic structure [grammar]; this is the basis for the recognition of the ideational (including logical), interpersonal and textual functions" Halliday (1975: 165). Wittgenstein's notion of grammar can give us a general idea about the ontological and epistemological significance of grammar in human mental acts. According to Wittgenstein (1958: § 496),

nor will we attempt to examine the literature on the subject. Our concern is rather with the implications of the linguistic relativity hypothesis in an onto-heuristic model in machine intelligence. See Lucy (1999) for a detailed analysis of empirical studies in the linguistic relativity hypothesis.

[18] See Munnich and Landau (2003) for a detailed analysis of the effect of grammar on spatial language.

grammar has a special status that relates language to the world.[19] In addition, grammar internalizes[20] the "use of a word" in language; that is to say, we do not need an extra-linguistic status in order to define the meaning of a word. "The place of a word in grammar is its meaning," and "it is grammatical rules that determine meaning (constitute it)" (Wittgenstein 1974: § 23, § 133). Grammar governs the actual use of the sign and its appropriateness within a given situation. Wittgenstein also attributes a special status to grammar that gives an autonomous character to language: "the connection between 'language and reality' is made by definitions of words, and these belong to grammar, so that language remains self-contained and autonomous" (1974: § 55). Grammar has a *special*[21] use in Wittgenstein's philosophy. The use of the term grammar varies in Wittgenstein's works and includes such expressions as "grammar of a proposition" (Wittgenstein 1958: § 353), "grammar of a word" (1958: 18), "grammar of an expression" (1958: § 660), "grammar of a state" (1958: § 572) etc. which divergent uses of grammar refer to the constructive role of grammar. What does grammar construct? There are various answers to this question: grammar constructs "norms of representation" (Glock 1991: 77), "rules of the usage of linguistic science," "meaning of a sign" (Specht 1969: 146), "essence" (*Ibid.*: 178), "the harmony between thought and reality" (Wittgenstein 1967: § 55), "our form of representation" (1958: § 122),"relations organizing our language use" (Guignon 1990: 665), "designation the way we look at things" (Hacker 1972: 147), "limits of sense" (O'Neill 2001: 3), "judgments of truth and falsity" (1974: 88) etc. Although they seem to have different approaches to and

[19] O'Neill (2001: 3) interprets the status of grammar in Wittgenstein's philosophy as follows: "the grammar of our language is that set of rules which determines the bounds of sense, and the status and nature of this delimitation of meaningfulness is clearly an issue that is primary importance for a proper understanding of the use of language, and of how it enables us to speak of 'reality'. By coming to an understanding of the status of grammar, we come to understand all that there is to know about how our language relates to our world."

[20] Like Wittgenstein, Chomsky (1968: 6) sees grammar as an internalized system that is active in language use: "The person who has acquired knowledge of a language has internalized a system of rules that relate sound to meaning in a particular way. The linguist constructing a grammar of a language is in effect proposing a hypothesis concerning this internalized system."

[21] It is a typical discussion in the philosophy of Wittgenstein whether he uses the term "grammar" in a non-standard sense. Most of Wittgenstein's commentators deny the idea that he uses the term "grammar" in a technical and non-standard way. Although these discussions are not the issue of this essay, it is important to mention that here we use the word "special" in order to indicate that Wittgenstein's use of the term "grammar" differs from the traditional use. However, this difference does not mean that Wittgenstein has a terminology which is special to him and out of ordinary usage.

various descriptions of the constructive role of grammar, all answers refer to the fact that grammar is autonomous in "our way of thinking", understanding, meaning, truth, and language. Wittgenstein attributes a regulative status to grammar that is active in our factual judgments. This regulative status is described by Forster as follows:

> They [all *other* features of our experience] essentially depend on grammar for their essential form-specifically, in the sense that grammar both constitutes all of the concepts which articulate our factual judgments and regulates which (combinations of) factual judgments it is appropriate for us to make and which not-in essential part have their source in our minds as well (2004:15–16).

From the Wittgensteinian point of view, we may conclude that in AI, a thing becomes an *object* when it has a place in a machine's linguistic structure. Cognition and other mental states can be given to machine intelligence by the dynamic information-processing of the machine's linguistic structure. If we can find the right programming strategy, syntax can generate semantic constraints.

Another reason that we attribute a regulative role to grammar for the correlation between language and thought is its formal completeness.[22] In AI, this formal completeness can be the source of procedural data encoding, modulating inputs, control mechanisms, rule-based representations, idealized information, etc. Therefore, we need to make sure that the programming principles of linguistic structure (grammar) and logic are developed simultaneously in a unified model.[23] In machine intelligence, the relationship between logic and language is not situated in a limited area in which logical regularity is examined in the foundations of linguistic structures.[24]

[22] Here, we use the term "formal completeness" in the sense that language has a standardized form. For instance, Sapir (1949: 153) uses the term "formal completeness" in the sense that: "By 'formal completeness' I mean a profoundly significant peculiarity which is easily overlooked. Each language has a well defined and exclusive phonetic system with which it carries on its work and, more than that, all of its expressions, from the most habitual to the merely potential, are fitted into a deft tracery of prepared forms from which there is no escape. These forms establish a definite relational feeling or attitude towards all possible contents of experience, in so far, of course, as experience is capable of expression in linguistic terms."

[23] There exists a close relation between logic and grammar. For instance, Kant mentioned this close relation as follows: "grammarians were the first logicians". See Mirella (1987) for a detailed analysis of logic and grammar in Kant's philosophy.

[24] We claim that a linguistic model, specific to machine intelligence, can embody an agentive cognition in which language provides certain rules for a discovery procedure. Therefore, a linguistic model is essential for a machine to provide rules for testing whether a given

Grammar should be seen as a cognitive faculty that generates cognition. Langacker states: "the rules of grammar are responsible for fully describing cognitive structures — a grammar is then a theory of cognition, not just a theory of language" (1976: 231). In addition to that, Chomsky (1980: 90) mentions the role of grammar in knowledge of language and cognitive systems: "What we loosely call 'knowledge of language' involves in the first place knowledge of grammar — indeed, that language is a derivative and perhaps not very interesting concept — and beyond that other cognitive systems that interact with grammar." The way grammar generates cognition depends on competence and generative rules. We can look at competence as a tool for constructing a high-level organization in machine intelligence. According to Haugeland (1985: 215), "*[C]ompetence* is the ability to achieve goals by making rational decisions in the light of knowledge and perception. The point, in other words is to 'rationalize' the system's behavior, relative to its circumstances, by interpolating just the right mental structure to do the job." Linguistic competence is an autonomous computational process that guides machine intelligence through the acquisition and use of language.[25] Parisi and Francesco (1976:13) conceive grammar as a scientific model of linguistic competence:

> Insofar as linguistic competence is considered a part of man's cognitive competence, the science concerned with language — whether it is called linguistics, or the psychology of language, or psycholinguistics — is part of a science of the mind, intended as the system of higher functions of the human organism. Hence, the grammar poses problems and advances hypotheses concerning the relations between linguistic competence and the cognitive competence of which it is a part.

Competence and generative rules are the subjects of certain linguistic theories. For instance, Chomsky is one of the leading linguists who formulated

condition is appropriate for its agentive acts. Cooper (1978: 8) emphasizes the importance of a linguistic theory: "By insisting that a theory of language tell[s] how to make detailed language descriptions, one ensures that the theory has a proper regard for the place of observation and evidence in the scientific process, as well as an adequate conceptual apparatus within which meaningful empirical hypothesis can be framed."

[25] Chomsky's dichotomy of competence/performance presupposes an epistemological principle in which language is not a social entity, but belongs to the agent's activity. In that sense, the linguistic competence and performance, as an agent's cognitive potentiality and activity, can be grasped in an ideal (i.e. computational) competence (i.e. a programming logic in AI).

the rules of generative grammar.[26] According to Katz and Postal (1964), the generative role of grammar reflects the creative and productive aspects of language. The semantic and cognitive values of environmental data can be determined by a rule-governed linguistic structure in machine intelligence.[27]

2.3. *Language in Machine Intelligence*

Language has always been one of the main issues in AI. By the mid 1960s, AI researchers had studied question answering systems, machine translation, machine understanding of natural language, and story analysis to mention only a few.[28] These studies are concerned with a cognitive system that

[26] Lyons (1975: 124) describes the generative characteristics of syntax by referring to its "interpretative" feature: "The syntax falls into two parts: the rules of the *base* and the *transformation*. It is the base 'component' that generates the deep structure and the transformational component that converts these into surface structure. The transformational component is therefore 'interpretative' in much the same way as the phonological and semantic rules are; and all the 'creative' power of the system is located in the base."

[27] Montague's and Davidson's formal and compositional approaches to natural language are good examples that show the way to relate grammar to the semantic and cognitive values of environmental data. Kempson (1990: 7) describes their formal and compositional approaches to natural language as follows: "The assumption that Davidson and Montague shared. . . is that natural languages do not have uniquely defining characteristics of any interest, but are interpreted systems of the same type as formal, constructed languages, and are characterisable by the same descriptive techniques. In particular, the interpretation of natural languages is identical to that of formal languages, a relation between expression of the language and the nonlinguistic entities which they refer to or denote." From an AI point of view, the studies of Montague (1974) are very valuable in order to show how syntactic structures can embody logical and semantic structures. Moravcsik (1990: 119) states that Montague's studies are very significant because his studies are not "merely the technical achievement of assigning appropriate semantic interpretations to traditional syntactic categories. . . .but the philosophically significant claim that the grammatical rules of a natural language can be seen as serving primarily semantic interests and being motivated by these."

[28] A historical and philosophical analysis of these studies can be found in Wilks (1974 and 1977). In our opinion, a philosophical analysis of AI studies on natural language should include the theory of meaning in information theory. The theory of meaning in cybernetics has an effect on linguistic models in AI. Shannon, the founder of the information theory, did not give any significant role to the concept of "meaning" in his information theory. However, MacKay (1969: 92) claims that "the theory of information has a natural, precise, and objectively definable place for the concept of meaning." In Cybernetics, the main object is "to provide a technical equivalent for the term 'meaning' where it is in fact used, not to legislate as to where it should be used" (1969: 89). Sayre sees cybernetics as a significant tool for explaining the origins of language: "man's consciousness is not limited to processing information from his sense receptors, and that his flexibility is extended by his linguistic capabilities. To explain the origin of language from the cybernetic viewpoint is to explain its contribution to the control of behaving organism, for which it has been favored by natural selection" (1976: 188).

can understand and produce meaningful utterances. In addition, some researchers have attributed an explanatory role to AI for research in natural language.[29] For instance, Goodwin and Hein (1982) claim that AI is a psychological tool to study language in use. They state: "AI's engagement in natural language research is based on a desire to understand what kind of cognitive organization enables humans to communicate with each other" (1982: 283). In a classical AI program, an utterance is analyzed in terms of a model based on a symbolic representation.[30] Some AI researchers consider this model to represent an essential function of human cognition. The general idea behind these studies is to correlate symbolic representations with semantics and the world. However, every AI researcher accepts nowadays that these studies have not reached a satisfactory result.[31] According to Bickhard and Terveen (1995), the failure of these studies shows the significance

[29] On the one hand, Wilks (1977: 71) believes that AI has the following benefits for linguistics : "(i) emphasis on complex stored structures in a natural language understanding system; (ii) emphasis on the importance of real world; (iii) emphasis on the communicative functions of sentences in context; (iv) emphasis on the expression of rules, structures, and information within an operational/procedural/computational environment." On the other hand, in their article "On Some Contributions of Artificial Intelligence to the Scientific Study of Language" Dresher and Hornstein criticize the idea that AI has an explanatory role in linguistics. They state: "there exists no reason to believe that the type of AI research into language…could lead to explanatory theories of language. This is because first, workers in AI have misconstrued what the goals of an explanatory theory of language should be, and second, because there is no reason to believe that the development of programs which could understand language in some domain could contribute to the development of an explanatory theory of language" (1976: 377).

[30] Weizenbaum is one of the AI researchers who defends the classical view in AI. He states: "There are many problems, all having to do with enabling the computer to understand whatever messages are impressed on it from the world outside itself. The problem of computer vision, for example, is in many respects fundamentally the same as that of machine understanding of natural language. However, the machine is made to derive information from its environment, it must, in some sense, 'understand' it; that is, the computer must somehow be able to extract the semantic content from the messages that impinge on it, in part from their purely syntactic structure" (1976: 184).

[31] The failure of language studies in AI has had negative effects on the development of AI research. For example, after the failure of developing a Russian-English machine translation system, the American government cut most of the funds that could be used by AI researchers. According to Goodwin and Hein (1982: 262), AI researchers learnt many things from research in the 1970s: "One of the lessons AI has learned during the last ten years of research on natural language concerns the inadequacy of certain rigid divisions, such as syntax vs. semantics, external language vs. internal language, linguistic knowledge vs. common sense knowledge. Although there are many good reasons for these dichotomies, they seem to be inadequate with respect to process models of linguistic behavior." In addition to that, Walczak (2002) makes an analysis of a technique used in artificial intelligence for natural language processing. In his analysis he mentions the significance of empirical and background

of real-world knowledge in language processing. They (1995: 240) state, "Knowledge of both the physical and social worlds and the conventions of language interaction was crucial in building systems that could use language in human-like ways." Dresher and Hornstein (1976: 321) discuss the reasons behind this failure, stating, "[A] more sophisticated view of language, involving not only a dictionary and grammar but also full semantics and total knowledge of the world, was required if computers were to deal with natural language with any success at all." According to Wilkins (1989: 1979), to study the language faculty as an isolated and independent entity is incorrect because language is not free from the influence of real-world knowledge.

AI research in natural language shows that there is not a full cooperation between linguists and AI researchers; they propose different methodologies for understanding natural language. Linguists develop theories in order to explain the nature of language and the syntax-semantics interface. However, AI researchers develop models that provide computers with a language-processing capability. Linguists see language understanding as a scientific issue but AI researchers see language understanding as an engineering project. There are many studies emphasizing the differences between linguistic theories and AI models of language understanding. For instance, Raphael (1976: 196) stated the following about the difference between a linguist and an AI researcher who is studying language: "The linguist is primarily interested in how to translate from the strings of words of natural language to some representation of their meaning, whereas the computer scientist is primarily interested in making use of the data in the meaning representation to control some program." Wilks (1977: 69) goes one step further and claims that AI is "a quite independent source of insight into the workings of natural language, centering on the notion of the use of large structured entities for the representation of language: entities that represent our knowledge of the real external world." According to Winograd (1977: 172), "a program is not a theory, even if it is totally a correct model." Schank and Wilensky (1977) give performance theories priority in linguistic models of AI. They defend the idea that performance theories simplify the problems that AI works on. They state: "almost every AI model of language use is an ideal user. The basic difference is that we have thought that the problem of how people use language to communicate was too fundamental to be eliminated from the study of language, or to be relegated to some secondary role" (1977: 135). AI has developed original methodological principles different from theories in linguistics. Winograd is one of the leading figures in developing computer systems for understanding natural language. In his well-known study,

knowledge. He states: "current artificial intelligence models are developed to be computationally tractable and to facilitate the programming of solution, but ignore epistemological validity" (2002: 396).

Understanding Natural Language, he describes the general scope and principles of AI in modeling language understanding:

> We must deal in an integrated way with all of the aspects of language — syntax, semantics, and inference. The system contains a parser, a recognition grammar of English, programs for semantic analysis, and a general problem solving system. We assume that a computer cannot deal reasonably with languages unless it can understand the subject it is discussing. Therefore, the program is given a detailed model of a particular domain. In addition, the system has a simple model of its own mentality. It can remember and discuss its plans and actions as well as carrying them out. . . .Knowledge in the system is represented in the form of procedures, rather than tables of rules or lists of patterns. By developing special procedural representations for syntax, semantics, and inference, we gain flexibility and power. Since each piece of knowledge can be a procedure, it can call directly on any other piece of knowledge in the system (1972: 1).

There are various methodological principles used in modeling language understanding in AI. These methodological principles can be classified in two groups: computational and connectionist ones. In the computational paradigm, AI researchers try to build an algorithm in which a sentence can be generated by the syntactic structure. They use techniques from computational linguistics.[32] One of the basic characteristics of the computational approach is its emphasis on syntax rather than on semantics. However, the connectionist approach focuses on the ability of a machine to learn sentence understanding in which multiple sources of information from both syntax and semantics are interconnected.[33] Plaut (2003: 146) describes the connectionist perspective of language understanding in which “performance is not an imperfect reflection of some abstract competence, but rather the behavioral manifestation of the internal representations and processes of actual language users: Language is as language does. The goal is not to abstract

[32] See Bott (1975) and Wilks (1988) for the general principles of computational linguistics and its relation to AI. According to Goodwin and Hein (1982: 251), the computational paradigm is a “constructive explanation which tells how to implement the process as a program on an idealized computer.”

[33] There are various studies using connectionist techniques in modeling natural language. For instance, see, McClelland and Kawamoto 1986, Seidenberg 1997, Tanenhaus and Trueswell 1995, St. John and McClelland 1990, and McClelland et al 1989.

away from performance but to articulate computational principles that account for it." In addition, the connectionist model is effective in encoding compositional relationships between linguistic elements. (Elman 1996: 528)

The cognitive theory that is used in order to understand natural language is different from the theory that is used in AI. Therefore, in AI, a theoretical model includes specific techniques peculiar to machine intelligence. These specific techniques include acoustical, phonetic, phonemic, lexical, syntactic, and semantic elements. The *acoustical* element is about the transmission of an utterance (the sound as an input consisting of waves) through the air to a machine. The sound as an input is analyzed as alternative energy units at different frequencies. This analysis provides segmentation and labeling of the input (sound) that gives the machine a possibility of characterizing the input as a *phonetic* element. The *phonetic* element gives the machine an ability to distinguish the various inputs (speech sounds). The *phonetic* element is related to the *phonemic* element which is about the letters in an alphabet; and they are brought together in the *lexical* element which is about words and grammatical components such as plurals and past tense. In the *lexical* element, the sequences of words and their morphological forms are related to the *syntactic* element, which is about phrases, clauses, and sentences. The *semantic* element is the interpretation of the *syntactic* element in terms of environmental data and knowledge of the world.

The elements of a specific technique in machine intelligence, described above, are about the control system of processing data in what we call an onto-heuristic model. This control system includes certain procedures such as how an input (speech signal) can be combined into larger units, how these units can generate words, how these words are used in phrases; how environmental data can be integrated into phrases, etc. However, certain methodological principles should be explained first in order to construct these specific techniques. These methodological principles in machine intelligence are related to developing a linguistic model that is structured and formal enough to support natural language processing in machine intelligence. Therefore, the methodological principles that we propose in an onto-heuristic model do not claim any cognitive and psychological reality that is true for the human mind. We do not claim that the human mind uses the same natural language processing developed in an onto-heuristic model. We divide the general methodological principles of an onto-heuristic model into four groups: *Agentive semantics, grammaticalization, mappings, and second language acquisition*.

2.3.1. *Agentive Semantics*

In machine intelligence, meaning is simply a relational[34] and heuristic term. The relational and heuristic character of meaning can be studied in an agentive system. The agentive patterns of machine intelligence have a great significance for the formalization of elements of meaning and cognition. From the AI point of view, to understand the meaning of a sentence, one needs the ability to recognize environmental data (input-speech signal) in an agentive context, or as Fetzer put it "The theory of meaning presupposes the theory of action" (1990: 82). We carry this idea one step further and claim that in AI language should be considered as a communicative action system in which an operation (information processing of an utterance) or data transformation (sound) is organized in terms of agentive situations and potential goal definitions. When an agentive situation is constructed in a linguistic model, machine intelligence handles communicative interactions in accordance with the environmental data and the goal. A communicative action in AI has three functions: the scope of potential goals, the formation of communicative interaction in terms of environmental data, and the generative association between actions and environmental data.

A communicative action system is basically a procedure for operating on the environmental data that defines the agentive situation in terms of the goal. The environmental data are an essential element of all agentive systems, and they both define the prior conditions for machine intelligence and organize the use of cognitive systems in machine intelligence. The productivity of a communicative action system is dependent on the diverse elements of environmental data. In addition, the knowledge of the environmental data under which machine intelligence holds sentences true is central to machine understanding which aims at constructing a communicative action system that could react practically and reasonably to utterances with requests about an agentive knowledge of the world. This agentive knowledge is important for the truth conditions that machine intelligence uses in the interpretation of an utterance. Agency provides the opportunity not only to know about the world but also to define it.[35] In other words, an agent is not only an observer but also interacts with the world (and reality) in a number of ways. There is a difference between the knowledge of an observer and the knowledge

[34] McDonough (1993: 127) mentions the relational characteristics of meaning: "Meaning is 'relational' in the sense that the very identity of the meaning of an utterance is determined by its 'relations' to items in the environment of the linguistic subject."

[35] Moravcsik (1990: 226) mentions the role of agency as follows: "our concepts, and hence the meanings assigned to descriptive words, are influenced by the fact that humans are necessarily agents and not just observers of reality."

of an agent. Itkonen (1978: 193–194) emphasizes this difference in terms of language theory: "our knowledge of events and regularities is observer's knowledge, whereas our knowledge of actions and rules is agent's knowledge... man's relation to his action is not empirical, but conceptual. Actions must be understood and known by those who perform them." In machine intelligence, this knowledge can be based on the linguistic structure. Therefore, the cognitive systems of machine intelligence are basically linguistic in their modes of functioning.[36]

Agency is not simply the source of the potential goal definitions of machine intelligence but rather a distinct methodology that provides an account of the linguistic background of cognition and thought.[37] Linguistic knowledge might interact with other cognitive systems such as learning, perception, and cognition. However, the nature of the interaction would itself depend on a syntactic domain. Therefore, the syntactic structure can be an element of computational cognition. Rapaport (1995: 59) expresses a parallel view:

> *The linguistic and perceptual "input"* to a cognitive agent can be considered as a syntactic domain whose semantic interpretation is provided by the agent's *mental model* of his or her (or its) sensory input. (The mental model is the agent's "theory" of the sensory "data".) The *mental model*, in turn, can be considered as a syntactic structure of thought whose semantic interpretation is provided by the *actual world*. In this sense, a person's beliefs are true to the extent that they correspond to the world.

Another reason that we need an agentive system for a linguistic model is that language is an open system,[38] and we need to develop a methodology in which machine intelligence can operate[39] in various (and potential) contexts.

[36] See Geodecke (1976) for a detailed analysis of consciousness and cognitive systems in relation to linguistics.

[37] Davidson (1975: 9) sees the linguistic background as a criterion for thought: "a creature cannot have thoughts unless it is an interpreter of the speech of another."

[38] Vandamme (1976: 81) uses the term "open system" for language in two senses: "'New permitted combinations with permitted elements can be constructed' and 'New permitted elements can be introduced'. This means that it will always be possible to introduce new differentiations if the community wants it."

[39] Bickhard and Terveen (1995: 238–239) interpret the operative function of language into four groups: "First, the meaning of utterances are inherently context dependent, since, in general, the results of an operator depends on the operand(s) it is applied to.... Second, the meaning of an utterance *type* is taken to be its operative power, rather than the result of

In an agentive system, we need to use a constructive world model.[40] In our opinion, grammaticalization is the proper method to use in order to form a constructive world model for an agentive system in machine intelligence.

2.3.2. *Grammaticalization*

Natural language understanding requires a system of rules that governs the acoustical, phonetic, phonemic, lexical, syntactic and semantic abilities of machine intelligence. Machine understanding implies mapping the *acoustic* element into *semantic* representations by using a linguistic structure.[41] In the machine's natural language processing, semantics cannot be autonomous i.e., independent of syntax, and, more particularly, that a semantic theory for a language is tied to a grammatical structure for that language. In a linguistic model, the essential function and classification of a word can be established in the syntactic structure. Words may be categorized in various ways including traditional ones such as verb, noun, and adjective. This categorization is meaningful and functional only in a syntactic order. The information (meaning) that lexical items contain does not have any semantic function unless it is represented in a proper grammatical structure. Therefore, grammar is

an utterance of an *instance* of that type. . . .Third, the fact that utterances operate on situation conventions, together with people's need to coordinate their situation conventions, offer a way of aaounting for phenomena like presupposition and implicature. . . Fourth, . . . the ontology of th person is largely social and, because the social is largely linguistic, the ontology of the person is massively linguistic".

[40] Ontological semantics is one of the theories which aim at developing a constructive world model for natural language processing in a computer. See Nirenburg and Raskin (2004) for a detailed description of the theory of ontological semantics. For instance, hakia (www.hakia.com) is a search engine that uses an alternative method. This method is based on the theory of ontological semantics. Nirenburg and Raskin (2004: 10) define the theory of ontological semantics as follows: "Ontological semantics is a theory of meaning in natural language and an approach to natural language processing which uses a constructed world model, or ontology, as the central resource for extracting and representing meaning of natural language texts, reasoning about knowledge derived from texts as well as generating natural language texts based on representations of their meaning."

[41] This linguistic structure is an internal symbolic representational system and has a priority in the communicative action of machine intelligence. Sloman and Cohen (1986: 65) see the internal symbolic system as a primary element: "Meaning and understanding are often assumed to be essentially concerned with communication between language users. . . .this is a mistake, since understanding an external language is secondary to the use of an internal symbolism for storing information, reasoning, making plans, forming percepts and motives, etc."

a functional tool for discovering semantic representations and their understanding in machine intelligence. For instance, Winograd (1973: 178) mentions the functional role of grammar in the process of understanding: "On our system, the sequence of actions is represented explicitly in the set of rules. The process of understanding an utterance is basic to the organization of the grammar."

In machine intelligence, the structure of language determines the organization of a semantic network; and a semantic network determines an associated world-view. A linguistic model in AI, therefore, characterizes semantic patterns in terms of a grammatical form. We propose four main typologies categorized into two groups: The first group includes *form* (*status*) and *content* (*mode*); and the second group includes the specific (*mode*) and the general (*status*). In an onto-heuristic model, the *general form* (*syntax*) determines and constructs a *specific content* (*semantics*). The typological perspective has a methodological significance for machine intelligence because a framework (model) is needed for an agentive perspective, for control, delimitation and rationalization of the data for a cognitive orientation and style. For machine intelligence, this is a matter of forming cognition that comes from a detailed comparison of environmental data. At that point, there is a need for heuristic help in determining the presence of typologies.

In an onto-heuristic model, we leave *content* aside, aiming at accounting for the *form* (the syntactic structure) of data independent of its semantics. Only after doing that can we give a semantic interpretation of the syntactic structure by using linguistic (particularly lexical) techniques. We call this technique *grammaticalization*.[42] We consider grammaticalization to be an AI-specific technique in which the functional and operational rules of syntactic structure are adequate to decide the meaningfulness of a natural language. This specific technique is different from the cognitive models that

[42] Here, we use the term *grammaticalization* differently from the term "grammaticalization" used in historical linguistics. Hopper and Traugott (2003: 1) give the classical definition of the term grammaticalization as follows: "The term 'grammaticalization' has two meanings, one to do with a research framework within which to account for language phenomena, the other with the phenomena themselves. In this respect the term 'grammaticalization' resembles not only other terms in linguistics such as 'grammar,' 'syntax,' and 'phonology,' but the terminology of all higher-level concepts in scholarly disciplines. As a term referring to a research framework, 'grammaticalization' refers to that part of the study of language change that is concerned with such questions as how lexical items and constructions come in certain linguistic contexts to serve grammatical function or how grammatical items develop new grammatical functions."

take the human mind as a target system.[43] Grammaticalization is an AI technique used to get a machine to perform linguistic and certain cognitive tasks in an agentive context. Grammaticalization is, then, the set of rules used by machine intelligence to decide whether or not an utterance is meaningful in natural language. Grammaticalization is a syntactic process in which machine intelligence receives cognition and semantic representation from the source of the rules of syntactic structure, described in accordance with a system of formal logic. Grammaticalization is the name of a linguistic technique in which it is always possible to represent semantic units as syntactic items by using a theory of logical form. The prime concern of grammaticalization is to determine how to represent (map) the meanings of sentences in a system of inference rules (syntactic derivations). Grammaticalization provides machine intelligence with a computational procedure for interpreting and processing sentences in accordance with the goal and environmental data.

A system of a formal logic is required in grammaticalization because we need the inference rules of logic in order to transform the syntactic order of a grammar into the semantic representation of an utterance.[44] In other words,

[43] Wilks (1972: 47) mentions that "the construction of a system for determining meaningfulness in no way implies that human beings make use of such a system in their brains or minds when they make judgments about meaningfulness."

[44] Rudolf Carnap is the first person who analyzed the logical character of syntactic structures. He advanced the term *logical syntax* in which he developed a formal theory of the linguistic forms. He claimed that logic is a part of syntax. He ([1937]: 2) stated: "the logical characteristics of sentences (for instance, whether a sentence is analytic, synthetic or contradictory; whether it is an existential sentence or not; and so on) and the logical relations between them (for instance, whether two sentences contradict one another or are compatible with one another; whether one is logically deducible from the other or not; and so on) are solely dependent upon the syntactic structure of the sentence. In this way, logic becomes a part of syntax, provided that the latter is conceived in a sufficiently wide sense and formulated with exactitude. The difference between syntactical rules in the narrower sense and the logical rules of deduction is only the difference between *formulation rules* and *transformation rules*, both of which are completely formulable in syntactic terms." Fodor (1975: 210) finds logical forms a useful tool for linguistics (especially for grammatical rules): "a system of formal logic can serve as a very useful starting point in thinking about how to represent meaning in linguistic descriptions. By considering the ways in which the logical system both is and is not suitable as a model for linguistic description we may be led to some general conclusions about the kind of semantic representation that is required." Tomkow (1980: 82) considers the formative role of logic in the syntactic structure: the "syntax, a definition of sentence-type for a language, requires a theory of logical form for that language." In addition, Harman (1975: 291–292) describes the main features of logical form for natural languages into four groups: "1-A theory of logical form must assign forms to sentences in a way that permits a (finite) theory of truth for the language. . . 2-A theory of logical form should minimize novel rules of logic. In practice, this means that rules of logical implication should be kept as close as possible to the rules of ordinary (first order) quantificational logic. . . . 3-A theory of logical

a system of formal logic is a tool for a syntactic derivation (grammaticalization) in the semantic representations. A system of formal logic includes the inference rules used to construct syntactic derivations, but it does not necessarily construct one type of interpretation for the semantic representation. Therefore a logical theory of semantic representations is needed. This theory can be computational and has the task of formulating and operating rules according to the fuzzy systems. The theory of fuzzy sets is a promising application in linguistic models. The fuzzy systems include linguistic data and their causal relations. Promising results have been observed in the control process in industrial applications.[45] In a fuzzy system, a linguistic variable is represented as a syntactic unit and the set of linguistic values (i.e., semantic representations) is characterized by syntactic rules forming possible semantic values.[46] The rules of grammar are the set of orders used by machine intelligence in deciding whether or not an *acoustic* element is part of a natural language. A *parser* is an operative tool giving machine intelligence a capability to analyze the linguistic data (input). A parser[47] is a functional element for creating the link between the lexical morphology and

form should minimize axioms. Other things equal, it is better to account for obvious implications by rules of logic alone than by rules of logic plus nonlogical axioms. 4-A theory of logical form should avoid ascribing unnecessary ontological commitments to sentences of the language.”

[45] See e.g. Verbruggen and Babuska (1999).

[46] Here, the term *linguistic variable* indicates a variable in which words or sentences have a value in terms of numbers. Zadeh (1975: 199) gives an example in order to explain what he means by *linguistic variable* in fuzzy logic: “For example, *Age* is a linguistic variable if its values are linguistic rather than numerical, i.e., *young, not young, very young, quite young, old, not very old, and not very young* etc., rather than 20,21,22,23.... In more specific terms, a linguistic variable is characterized by a quintuple ($\mathcal{X}$, $T(\mathcal{X})$, U,G,M) in which $\mathcal{X}$ is the name of the variable; $T(\mathcal{X})$ is the *term-set* of $\mathcal{X}$, that is, the collection of its linguistic values; U is a universe of discourse; G is a *syntactic rule* which generates the term in $T(\mathcal{X})$; and M is a *semantic rule* which associates with each linguistic value X its *meaning*, $M(X)$, where $M(X)$ denotes a fuzzy subset of U. The meaning of a linguistic value X is characterized by a *compatibility function*, $c : U \rightarrow [0, 1]$, which associates with each u in U its compatibility with X. Thus, the compatibility of age 27 with *young* might be 0.7, while that of 35 might be 0.2. The function of the semantic rule is to relate the compatibilities of so-called *primary* terms in a composite linguistic value — e.g., *young* and *old* is *not very young and not very old* — to the compatibility of the composite value. To this end, the hedges such as *very*, *quite*, *extremely etc.*, as well as the connectives *and* and *or* are treated as nonlinear operators which modify the meaning of their operands in a specified fashion. The concept of a linguistic variable provides a means of approximate characterization of phenomena which are too complex or too ill-defined to be amenable to description in conventional quantitative terms.”

[47] Harder and Togeby (1993: 470) describe the role and the significance of a parser in the syntactic structure: “An important feature of a classical grammar and parser is its seriality; it only takes one step at a time, and all steps made by the machine are ordered in a sequence.

the semantic network. A parser is a logical operator that is based on the principle of compositionality. Parsing is also a procedure used for language acquisition. "Parsing simply means executing a series of tree building and token shifting grammar rule actions" (Berwick and Weinberg 1984: 204). In a linguistic model, all concepts are inter-defined and inter-defining. Therefore, we need a formal world model, or ontology, that generates a network system, including relational and configuration possibilities of a lexical item with other items. This network system is a set of interrelated vocabularies. Strawson (2004: 111) divides the necessary components of a set of interrelated vocabularies into four groups:

> We need, first, what might be called an ontological vocabulary. We need, second, a semantic vocabulary, or vocabulary for naming semantic types of elements and even for describing individual elements. Third, we need a functional vocabulary for naming the kinds of combination or relation into which elements may enter in sentences. Fourth, and finally, we need a vocabulary of formal devices.

In AI and linguistics, there are several theories that try to situate semantic representations in the syntactic structures. Rapaport's theory of *syntactic semantics*, is the most promising approach for machine understanding. Rapaport (1988: 81) defends the idea that "although a certain kind of semantic interpretation is needed for understanding natural language, it is a kind that only involves syntactic symbol manipulation of precisely the sort of which computers are capable, so that it is possible in principle for computers to understand natural language." We, like Rapaport, claim that *syntax suffices*; in other words, syntax is sufficient for machine intelligence to understand

That means that options in the grammar are computed by backtracking. If the grammar allows a choice between, say, two word classes in one position, the machine first computes one option until the analysis is finished or fails; then backtracks to the point of choice, and then it computes the second option until the analysis is finished." In addition, According to Rapaport (1988: 89) the use of parsers is the proper method for natural language processing in a computer: "It is fairly easy to have a productive *parser* for a natural-language-understanding system. I am not claiming that the problem of natural-language *understanding* has been solved, but we seem to be on the right track with respect to parsers for natural language *processing*, and, at any rate, we know the general outlines of what a suitably robust parser should look like. What's needed, however, is *generative* productivity: the ability to *ask* new and relevant questions and to *initiate* conversation. To be able to generate appropriate utterances, the system must have the capability to *plan* its speech acts, and, so, a planning component must be part of a natural-language-understanding system. Such a planning component is probably also needed for parsing, in order to be able to understand *why* the speaker said what he or she did."

natural language. According to Rapaport (2003: 399), syntax suffices in a unified system including syntactic and semantic domains:

> Semantics can be turned into a study of relations within a single domain among the markers and their interpretations. This is done by incorporating (or "internalizing") the semantic interpretations along with the markers to form a unified system of *new* markers, some of which are the old ones and others of which are their interpretations. Hence, syntax *can* suffice for the semantical enterprise... In particular, syntax suffices for the semantics needed for a computational cognitive theory of natural-language understanding and generation.

The unification of the domains of syntax and semantics is possible only in an agentive system because "a relation between a syntactic domain and a semantic domain can be understood only by taking an independent, external, third-person point of view" (Rapaport 1995: 64). In other words, in AI, the correspondence between semantics and syntax can be established only from an agentive[48] point of view. Moreover, the third-person (agentive) view allows for the correspondence between cognition and the external world (Rapaport 2002: 4). In our opinion, the idea that *syntax suffices* is a challenge to the Chinese Room Argument (CRA)[49] because it shows that the semantic domain, which is supposed to be the source of "understanding" in the CRA, can be represented (situated) in the syntactic domain; and only the third-person view has an active role in understanding. Syntactic and semantic domains are interdependent. That is to say, there is no intrinsic difference between them. Rapaport (1999: 110) describes the relative aspect of syntactic and semantic domains:

> A given domain can be either syntactic *or* semantic, depending on one's interests: Typically, we understand one domain (the "syntactical" one) in terms of an antecedently understood domain (the "semantic" one). E.g., a computer process that implements a program plays the role of semantic domain to the program's role as syntactic

[48] Rapaport mentions the role of agency for his theory. For instance, he (2003) describes his theory of syntactic semantics in terms of cognitive agents: "[Syntactic semantics] is a holistic conceptual-role-semantics that takes the meaning of an expression for a cognitive agent to be that expression's "location" in the cognitive agent's semantic network of (all of) the cognitive agent's other expressions."

[49] According to Rapaport (2000), the theory of syntactic semantics is a proper methodology in order to pass the Turing Test and he defends the possibility of machine understanding against the Chinese Room Argument.

> domain. The same program, implementing an algorithm, plays the role of semantic domain to the algorithm's role as the syntactic domain.

The first-person view, defended by Husserl, Nagel and Searle, has supported the idea that the human mind is about the semantic domain and a machine cannot simulate it. However, in our opinion, grammaticalization and parallel methods (such as syntactic semantics) can establish an agentive model in which environmental and linguistic data can be embodied in a formal structure and the cognitive systems (such as experience, understanding, perception, memory, learning, thought, and cognition) of machine intelligence can be formed in terms of syntactic structures (the rules that can operate on inputs).

2.3.3. *Mappings*

The mapping between the syntactic and the semantic domains is a central issue when discussing a machine's cognitive capability of processing and understanding meaning. A mapping between environmental data and a syntactic structure is central to an understanding of language and cognitive construction in machine intelligence. Fauconnier (1997: 3) describes mapping as a powerful tool to attain cognitive skills:

> [mapping] yields general procedures and principles for a wide array of meaning and reasoning phenomena, including conceptual projection, conceptual integration and blending, analogy, reference, and counterfactuals; and it provides us with insights about the organization of cognitive domains to which we have no direct access.

In a linguistic model for machine intelligence, mapping operations and principles can be constructed.[50] A mapping is an especially significant functional tool for gaining spatio-temporal cognition.[51] In AI, in order to gain

[50] In this paper, we will only discuss the structural principles of the mapping. The technical aspects (i.e., programming, control process and organization) are out of its scope.

[51] Syntactic structure is an operative tool for machine intelligence to construct and interpret spatial settings. Here are some elements for the mapping of spatial settings in a linguistic model: "*Space Builders*: A space builder is a grammatical expression that either opens a new space or shifts focus to an existing space. Space builders take on a variety of grammatical forms, such as prepositional phrases, adverbials, subject-verb complexes. . . .*Names and Descriptions* either set up new elements or point to existing elements in the discourse construction. They also associate such elements with properties. . . .*Tenses and moods* play an important role in determining what kind of space is in focus, its connection to the base space,

knowledge of a specific domain, the function of other domains and their corresponding information should be used. For instance, environmental data can be mapped out in a linguistic model in order to visualize them as an external reality. This is a *constructive perception* totally different from human cognitive processing. The mapping of the environmental data, in which computational (syntactic and logical) elements have operative and functional roles, helps machine intelligence to gather the particular (biological, physical computational) data in a unified agentive cognition. Mappings in AI also allow environmental data to be recognized in terms of agentive and computational functions. The mapping of different domains also gives machine intelligence a creative capability. There are many specific mapping techniques. The *Pragmatic function mapping* is one of them and it can be used in AI's programming strategy. Fauconnier (1997: 11) e.g. describes it as follows:

> The two relevant domains, which may be set up locally, typically correspond to two categories of objects, which are mapped onto each other by a pragmatic function. For example, authors are matched with the books they write, or hospital patients are matched with the illnesses for which they are being treated. This kind of mapping plays an important role in structuring our knowledge base and provides means of identifying elements of one domain via their counterparts in the other. Pragmatic function mappings will often be responsible for semantic change over time.

Mappings, therefore, may be of great value to help us construct cognitive systems in machine intelligence as they indicate possible ways of situating environmental data into semantic representations.

2.3.4. *Second Language Acquisition*

AI researchers have always been interested in the language acquisition process of children and the way it gives them a fluent control of their native language. In AI, language acquisition is seen as a process of generative

its accessibility, and the location of counterparts used for identification. *Presuppositional constructions*: Some grammatical constructions, for example, definite descriptions, aspectuals, clefts. . . .[are] introduced in the presuppositional mode; this mode allows the structure to be propagated into neighboring spaces for the counterparts of the relevant elements. *Transspatial operators*: The copula (*be* in English) and other "copulative" verbs, such as *become*, *remain*, may stand for connectors between spaces." (Fauconnier 1997: 40–41).

orders.[52] A computer model of language acquisition idealizes a child's capability of language learning. In *Aspects of the Theory of Syntax*, Chomsky describes the conditions for the language learning capability:

> A child who is capable of language learning must have (i) a technique for presenting input signals; (ii) a way of representing structural information about these signals; (iii) some initial delimitation of a class of possible hypothesis about language structure; (iv) a method for determining what each hypothesis implies with respect to each structure; (v) a method for selecting one of the hypothesis that are allowed by (iii) and are compatible with the given primary linguistic data (1965: 30).

The computational implementations of the language learning ability in the psychological development of children do not have any impact on a linguistic model in AI since the linguistic model of machine intelligence uses an internal task-operation that includes specific techniques (such as grammaticalization) peculiar to machine intelligence. A second language acquisition model is needed that transforms the natural linguistic data into the internal language[53] of machine intelligence. In AI, second language acquisition is a part of the mapping technique in which we are not concerned with how

[52] A *Language acquisition device* (LAD) is considered to be a subsystem for discovering generative orders. Rumelhart and McClelland (1996: 508) describe the three basic assumptions of the idea of LAD: "[1] The mechanism hypothesizes explicit inaccessible rules. [2] Hypotheses are rejected and replaced as they provide inadequate to account for the utterances the learner hears. [3] The LAD is presumed to have *innate* knowledge of the possible range of human languages and, therefore, is presumed to consider only hypothesis within the constrains imposed by a set of *linguistic universals*." In addition, The Marcus parser operation is a classical language acquisition model for computers. Berwick and Weinberg (1984: 202) describe the general characteristics of the Marcus parser: "The Marcus parser divides into two parts, a grammatical rule interpreter (plus stack and input buffer data structures) and a set of grammar rules comprising the operating rules of the machine. To model acquisition we start with a 'bare' interpreter having no grammar rules. The machine learns these rules. As input data the program takes just grammatical sentences, so-called positive evidence, and a rudimentary initial ability to characterize words as objects, actions and unknown. These restrictions aim at a minimal psychologically plausible acquisition model."

[53] The term "internal language" refers to the organizational system that represents environmental data in terms of specific items developed for machine intelligence. Suppes (1991: 376) finds internal representation a useful tool for the robotic machine learning of natural language: "[internal language] is itself a language of a higher level of abstraction, relative to the concrete movements and perceptions of the robot. There are several other internal language modules. . . . It has been important to us that most of the machine learning of a given natural language can take place through simulation of the robot's behavior just at the level of the language of the internal representation."

acquisition is facilitated but rather how a linguistic input is internalized (in terms of a linguistic model) in machine intelligence.

3. *Conclusion*

We have introduced the main methodological principles of the higher-level cognitive organization of machine intelligence. We have shown that there is a close relationship between language and cognition.[54] We have claimed that this relationship can be modeled in terms of principles inspired by computational linguistics and the linguistic relativity hypothesis. We have defended a *syntactocentric*[55] idea in which we have considered grammar as an algorithm that generates cognition. In other words, grammatical rules help in the study of the fundamental laws of machine cognition. When we, therefore, consider the role of linguistic structures in machine intelligence, we are not studying words phrases or sentences but, rather, how semantic data can be used in the construction of machine intelligence.

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REFERENCES

Berwick, Robert C. and Weinberg, Amy S. (1984). *The Grammatical Basis of Linguistic Performance: Language Use and Acquisition*, Cambridge, Massachusetts: The MIT Press.

[54] For instance, Lehman et al describe language as a transducer. They (1996: 491) explain the role of language in cognition by referring to the linguistic relativity hypothesis: “Language and cognition share a structure, which we call the *situation model*. By delivering a nonlinguistic representation of the situation to the task, language has its effect on cognition through the encoding of their shared model and through any subsequent structures added to the long-term memory based on that encoding. The transducer paradigm supports a form of the Weak Whorfian Hypothesis: Language influences cognition, but does not determine it. Language’s effects are pervasive, just because its encodings provide the starting points for thought.”

[55] The term “syntactocentrism” is used by Jackendoff (1997: 15) in order to indicate the generative component of the computational system.

Bickhard, Mark H. and Terveen, Loren (1995). *Foundational Issues in Artificial Intelligence and Cognitive Science*, Amsterdam: Elsevier.

Boroditsky, L. (1999). "First-Language Thinking of Second-Language Understanding: Mandarin and English Speakers' Conception of Time", *Proceedings of the Cognitive Science Society*, 21, pp. 84–89.

Boroditsky, L. (2001). "Does Language Shape Thought? Mandarin and English Speaker's Conception of Time", *Cognitive Psychology*, 43, pp. 1–22.

Bott, M.F. (1975). "Computational Linguistics" in *New Horizons in Linguistics*, ed. John Lyons, Middlesex: Penguin Books, pp. 215–228.

Bowerman, M. 1996. "The Origins of Children's Spatial Semantic Categories: Cognitive Versus Linguistic Determinants." In *Rethinking Linguistic Relativity*, Eds. John J. Gumperz and Stephen C. Levinson, Cambridge: Cambridge University Press, pp. 145–76.

Britton, James (1971). *Language and Learning*, London: The Penguin Press. Mirella, Capozzi (1987). "Kant on Logic, Language, and Thought" in *Speculative Grammar, Universal Grammar and Philosophical Analysis of Language*, eds. Dino Buzzetti and Maurizio Ferriani, Amsterdam: John Benjamins Publishing Company, pp. 97–147.

Carnap, Rudolf [1937]. *The Logical Syntax of Language*, Illinois: Open Court Publishing Company, 2002.

Carroll, John B. and Casagrande, Joseph B. (1958). "The Function of Language Classification in Behavior" in *Readings in Social Psychology*, eds. Eleanor E. MacCoby et al, New York: Holt, Reinehart & Winston, pp. 18–31.

Carruthers, Peter (1996). *Language, Thought and Consciousness*, Cambridge: Cambridge University Press.

Chomsky, Noam (1965). *Aspects of the Theory of Syntax*, Cambridge, Massachusetts: The MIT Press.

Chomsky, Noam (1968). *Language and Mind*, New York: Harcourt Brace Javanovich.

Chomsky, Noam (1980). *Rules and Representations*, New York: Columbia University Press.

Chomsky, Noam (1990). "Linguistics and Descartes" in *Historical Foundations of Cognitive Science*, ed. J.-C. Smith, Dordrecht: Kluwer Academic Publishers, pp. 71–79.

Cooper, William S. (1978). *Foundations of Logico-Linguistics: A Unified Theory of Information, Language, and Logic*, Dordrecht: D. Reidel Publishing Company.

Davidoff, J. et al (1999). "Colour Categories in a Stone-Age Tribe", *Nature*, 398, pp. 203–204.

Davidson, Donald (1975). "Thought and Talk" in *Mind and Language*, ed. Samuel Guttenplan, Oxford: Clarendon Press, pp. 7–23.

Davidson, Donald (1982), "Rational Animals", *Dialectica*, 36, pp. 317–327.

Davidson, Donald (1997). "Seeing Through Language" in *Thought and Language*, ed. John Preston, Cambridge: Cambridge University Press, pp. 15–27.

Dresher, B. Elan and Hornstein, Norbert (1976). "On Some Contributions of Artificial Intelligence to the Scientific Study of Language", *Cognition*, 4, pp. 321–398.

Dummet, Michael (1989). "Language and Communication" in *Reflections on Chomsky*, ed. Alexander George, New York: Basil Blackwell, pp. 192–212.

Dummett, Michael (1991). "The Relative Priority of Thought and Language" in *Frege and Other Philosophers*, ed. Michael Dummett, Oxford: Oxford University Press, pp. 315–324.

Elman, Jeffrey (1996). "Grammatical Structure and Distributed Representations" in *Readings in Language and Mind*, eds. Heimir Geirsson and Michael Losonsky, Oxford: Blackwell Publishers, pp. 526–558.

Fauconnier, Gilles (1997). *Mappings in Thought and Language*, Cambridge: Cambridge University Press.

Fetzer, James H. (1990). *Artificial Intelligence: Its Scope and Limits*, Dordrecht: Kluwer Academic Publishers.

Fodor, Janet Dean (1975). "Formal Linguistics and Formal Logic" in *New Horizons in Linguistics*, ed. John Lyons, Middlesex: Penguin Books, pp. 198–214.

Fodor, Jerry and Pylyshyn, Zenon (1988). "Connectionism and Cognitive Architecture: A Critical Analysis", *Cognition*, 28, pp. 3–71.

Forster, Michael N. (2004). *Wittgenstein: On the Arbitrariness of Grammar*, Princeton, New Jersey: Princeton University Press.

Frege, Gottlob [1918]. "The Thought: A Logical Inquiry" in *Readings in the Philosophy of Language*, ed. Peter Ludlow, Cambridge, Massachusetts: The MIT Press, 1007, pp. 9–30.

Geodecke, Robert (1976). "Linguistic Ontology", *Philosophy Today*, 20, pp. 157–166.

Glock, H.J. (1991). 'Philosophical Investigations section 128: thesis in philosophy and undogmatic procedure', in *Wittgenstein's Philosophical Investigations*, ed. Sluga, H. and Stern, D., London, New York: Routledge, pp. 69–88.

Goodwin, James W. and Hein, Uwe (1982). "Artificial Intelligence and the Study of Language", *Journal of Pragmatics*, 6, pp. 241–280.

Greenberg, Joseph (1963). "Language and Linguistics" in *Behavioral Sciences Today*, ed. Bernard Berelson, New York: Basic Books: pp. 126–138.

Guignon, C. (1990). "Philosophy after Wittgenstein and Heidegger", *Philosophy and Phenomenological Research*, 50, pp. 649–672.

Gumperz, John J. and Levinson, Stephen C. (eds.) (1999). *Rethinking Linguistic Relativity*, Cambridge: Cambridge University Press.

Hacker, P.M.S. (1972). *Insight and Illusion*, Oxford: Clarendon Press.

Halliday, M.A.K. (1975). "Language Structure and Language Function" in *New Horizons in Linguistics*, ed. John Lyons, Middlesex: Penguin Books, pp. 140–165.

Harder, Peter and Togeby, Ole (1993). "Pragmatics, Cognitive Science and Connectionism", *Journal of Pragmatics*, 20, pp. 467–492.

Harman, Gilbert (1975). "Logical Form" in *The Logic of Grammar*, eds. Donald Davidson and Gilbert Harman, Belmont, California: Dickenson Publishing Company, pp. 289–307.

Haugeland, John (1985). *Artificial Intelligence: The Very Idea*, Cambridge, Massachusetts: The MIT Press.

Hopper, Paul J. and Traugott, Elizabeth Cross (2003). *Grammaticalization*, Cambridge: Cambridge University Press.

Imai, M. and Gentner, D. (1997). "A Cross-Linguistic Study of the Early World Meaning: Universal Ontology and Linguistic Influence", *Cognition*, 62, pp. 169–200.

Itkonen, Esa (1978). *Grammatical Theory and Metascience: A Critical Investigation into the Methodological and Philosophical Foundations of 'Autonomous' Linguistics*, Amsterdam: John Benjamins B.V.

Jackendoff, Ray (1997). *The Architecture of the Language Faculty*, Cambridge, Massachusetts: The MIT Press.

Katz, Jerrold J. and Postal, Paul M. (1964). *An Integrated Theory of Linguistic Descriptions*, Cambridge, Massachusetts: The MIT Press.

Kempson, Ruth M. (1990). "The Relation Between Language, Mind, and Reality" in *Mental Representations: The Interface between Language and Reality*, ed. Ruth M. Kempson, Cambridge: Cambridge University Press, pp. 3–25.

Kuczaj, Stan A. and Hendry, Jennifer L. (2003). "Does Language Help Animal Think?" in *Language in Mind: Advances in the study of Language and Thought*, eds. Dedre Gentner and Susan Goldin-Meadow, Cambridge, Massachusetts: The MIT Press, pp. 237–275.

Lacgacker, Ronald W. (1976). "Semantic Representations and the Linguistic Relativity Hypothesis", *Foundations of Language*, 14, pp. 307–357.

Lee, Dorothy Demetracopolou (1938). "Conceptual Implications of an Indian Language", *Philosophy of Science*, 5, pp. 89–102.

Lehmen, Jill Fain et al. (1996). "The Role of Language in Cognition: A Computational Inquiry" in *Readings in Language and Mind*, eds. Heimir Geirsson and Michael Losonsky, Oxford: Blackwell Publishers, pp. 489–507.

Levinson, S.C. (1996). "Frames of Reference and Molyneux's Question: Cross-Linguistic Evidence" in *Language and Space*, eds. P. Bloom,

M. Peterson, L. Nadel, and M. Garrett, Cambridge, Massachusetts: The MIT Press, pp. 109–169.

Lucy, John A. (1992). *Grammatical Categories and Cognition: A Case Study of the Linguistic relativity Hypothesis*, Cambridge: Cambridge University Press.

Lucy, John A. (1996). *Language Diversity and Thought: A Reformulation of Linguistic Relativity Hypothesis*, Cambridge: Cambridge University Press.

Lucy, John A. (1997). "Linguistic Relativity", *Annu. Rev. Anthropol.*, 26, pp. 291–312.

Lucy, John A. (1999). "The Scope of Linguistic Relativity: An Analysis and Review of Empirical Research" in *Rethinking Linguistic Relativity*, eds. John J. Gumperz and Stephen C. Levinson, Cambridge: Cambridge University Pres, pp. 37–69.

Lund, Nick (2003). *Language and Thought*, London: Routledge.

Lyons, John (1975). "Generative Syntax" in *New Horizons in Linguistics*, ed. John Lyons, Middlesex: Penguin Books, pp. 115–139.

Mackay, Donald M. (1969). *Information, Mechanism and Meaning*, Cambridge, Massachusetts: The MIT Press.

McClelland, J.L. and Kawamoto, A.H. (1986). "Mechanisms of Sentence Processing: Assigning Roles to Constituents of Sentences" in *Parallel Distributed Processing: Explorations in the Microstructure of Cognition, Vol. II: Psychology and Biological Models*, eds. J.L. McClelland and D.E. Rumelhart, Cambridge, Massachusetts: The MIT Press, pp. 272–325.

McClelland, J.L. et al (1989). "Sentence Comprehension: A Parallel Distributed Processing Approach", *Language and Cognitive Process*, 4, pp. 287–335.

McDonough, Richard (1993). "Linguistic Creativity" in *Linguistics and Philosophy*, eds. Rom Harré and Roy Harris, Oxford: Pergamon Press, pp. 125–162.

Montague, Richard (1974). *Formal Philosophy*, New Haven: Yale University Press.

Moravcsik, J.M. (1990). *Thought and Language*, London: Routledge.

Munnich, Edward and Landau, Barbara (2003). "The Effects of Spatial Language on Spatial Representation: Setting Some Boundaries" in *Language in Mind: Advances in the study of Language and Thought*, eds. Dedre Gentner and Susan Goldin-Meadow, Cambridge, Massachusetts: The MIT Press, pp. 113–155.

Nirenburg, Sergei and Raskin, Victor (2004). *Ontological Semantics*, Cambridge, Massachusetts: The MIT Press.

O'Neill, Martin (2001). "Explaining 'The Hardness of the Logical Must': Wittgenstein on Grammar, Arbitrariness and Logical Necessity", *Philosophical Investigations*, 24, pp. 1–29.

Parisi, Domenico and Antinucci, Francesco (1976). *Essentials of Grammar*, New York: Academic Press.

Plaut, David C. (2003). "Connectionist Modeling of Language: Examples and Implications" in *Mind, Brain, and Language*, eds. Marie T. Banich and Molly Mack, New Jersey: Lawrence Erlbaum Associates, Publishers, pp. 143–167.

Quine, W.V. (1970). "Philosophical Process in Language Theory", *Metaphilosophy*, 1, pp. 2–19.

Rapaport, William J. (1988). "Syntactic Semantics: Foundations of Computational Natural-Language Understanding" in *Aspects of Artificial Intelligence*, ed. James H. Fetzer, Dordrecht: Kluwer Academic Publishers, pp. 81–131.

Rapaport, William J. (1995). "Understanding Understanding: Syntactic Semantics and Computational Cognition", *Philosophical Perspectives*, 9, pp. 49–88.

Rapaport, William J. (1999). "Implementation is Semantic Interpretation", *The Monist*, 82, pp. 109–130.

Rapaport, William J. (2000). "How to Pass a Turing Test", *Journal of Logic, Language and Information*, 9, pp. 467–490.

Rapaport, William J. (2002). "Holism, Conceptual-Role Semantics, and Syntactic Semantics", *Minds and Machines*, 12, pp. 3–59.

Rapaport, William J. (2003). "What Did You Mean By That? Misunderstanding, Negotiation, and Syntactic Semantics", *Minds and Machines*, 13, 397–427.

Raphael, Bertram (1976). *The Thinking Computer: Mind Inside Matter*, San Francisco: W.H. Freeman and Company.

Rumelhart, David E. and McClelland, James L. (1996). "On Learning the Past Tenses of English Verbs" in *Readings in Language and Mind*, eds. Heimir Geirsson and Michael Losonsky, Oxford: Blackwell Publishers, pp. 507–526.

Sapir, Edward (1921). *Language*, New York: Hartcourt, Brace and Co.

Sapir, Edward (1931). "Conceptual Categories in Primitive Languages" in *Language in Culture and Society: A Reader in Linguistics and Anthropology*, ed. D.H. Hymes, New York: Harper & Row, 1964, p. 128.

Sapir, Edward (1949). *Selected Writings of Edward Sapir in Language, Culture and Personality*, ed. David G. Mandelbaum, Berkeley: University of California Press.

Sayre, Kenneth M. (1976). *Cybernetics and the Philosophy of Mind*, London: Routledge & Kegan Paul.

Schank, Roger C. and Wilensky, Robert (1977). "Response to Dresher and Hornstein", *Cognition*, 5, pp. 133–145.

Searle, John R. (1997). "The Explanation of Cognition" in *Thought and Language*, ed. John Preston, Cambridge: Cambridge University Press, pp. 103–126.

Seidenberg, M.S. (1997). "Language Acquisition and Use: Learning and Applying Probabilistic Constraints", *Science*, 275, pp. 1599–1603.

Slobin, Dan I. (1996). "Two ways to travel: Verbs of motion in English and Spanish" In *Grammatical constructions: Their form and meaning*, eds. M.S. Shibatani and S.A. Thompson, Oxford: Clarendon Press, pp. 195–220.

Slobin, Dan I. (1999). "From 'Thought and Language' to Thinking for Speaking"' in *Rethinking Linguistic Relativity*, eds. John J. Gumperz and Stephen C. Levinson, Cambridge: Cambridge University Pres, pp. 70–96.

Slobin, Dan I. (2003). "Language and Thought Online: Cognitive Consequences of Linguistic Relativity" in *Language in Mind: Advances in the study of Language and Thought*, eds. Dedre Gentner and Susan Goldin-Meadow, Cambridge, Massachusetts: The MIT Press, pp. 157–191.

Sloman, Aaron and Cohen, L. Jonathan (1986). "What Sorts of Machines Can Understand the Symbols They Use?", *Proceedings of the Aristotelian Society, Supplementary Volumes*, 60, pp. 61–95.

Specht, E.K. (1969). *The Foundations of Wittgenstein's Late Philosophy*, translated by D.E. Walford, Manchester: Manchester University Press.

St. John, M.F. and McClelland, J.L. (1990). "Learning and Applying Contextual Constrains in Sentence Comprehension", *Artificial Intelligence*, 46, pp. 217–257.

Strawson, P.F. (2004). *Logico-Linguistic Papers*, Burlington: Ashgate.

Suppes, Patrick (1991). *Language for Humans and Robots*, Oxford: Blackwell Publishers.

Tanenhaus, M.K. and Trueswell, J. (1995). "Sentence Processing" in *Handbook of Perception and Cognition: Language*, eds. P. Eimas and J.L. Miller, New York: Academic Press, pp. 217–262.

Tomkow, Terrance A. (1980). "What is Grammar", *Canadian Journal of Philosophy*, 6, pp. 61–82.

Vandamme, Fernand J. (1976). "Language, Logic and Thinking" in *Universalism versus Relativism in Language and Thought*, ed. R. Pinxten, The Hague: Mouton, pp. 69–84.

Von Kutschera, Franz (1975). *Philosophy of Language*, Dordrecht: D. Reidel Publishing Company.

Verbruggen, H.B. and Babuska, Robert (eds.) (1999). *Fuzzy Logic Control: Advances in Applications*, Singapore: World Scientific

Vygotsky, Lev (1972). "Thought and Language" in *Language and Thinking*, ed. P. Adams, Harmondsworth: Penguin Education.

Walczak, Steven (2002). "A Context-Based Computational Model of Language Acquisition By Infants and Children", *Foundations of Science*, 7, pp. 393–411.

Waters, Harriet S. and Tinsley, Virginia S. (1982). "The Development of Verbal Self-Regulation: Relatinships between Language, Cognition, and Behavior" in *Language Development*, ed. Stan A. Kuczaj, New Jersey: Lawrence Erlbaum Associates, Publishers, pp. 251–277.

Weizenbaum, Joseph (1976). *Computer Power and Human Reason*, San Francisco: W.H. Freeman and Company.

Whorf, Benjamin Lee (1956). *Language, Thought and Reality: Selected Writings of Benjamin Lee Whorf*, ed. John B. Carroll, Cambridge, Massachusetts: The MIT Press.

Wilkins, Wendy (1989). "Linguistics, Learnability, and Computation" in *The Computer and the Brain: Perspectives on Human and Artificial Intelligence*, eds. Jean R. Brink and C. Roland Haden, Amsterdam: Elsevier Science Publishers, pp. 197–207.

Wilks, Yorick Alexander (1972). *Grammar, Meaning, and the Machine Analysis of Language*, London: Routledge & Kegan Paul.

Wilks, Yorick (1974). "One Small Head – Models and Theories in Linguistics", *Foundations of Language*, 11, pp. 77–95.

Wilks, Yorick (1977). "Methodological Questions About Artificial Intelligence: Approaches to Understanding Natural Language", *Journal of Pragmatics*, 1, pp. 69–84.

Wilks, Yorick (1988). "Reference and Its Role in Computational Models of Mental Representations" in *Meaning and Mental Representations*, eds. Umberto Eco, Marco Santambrogio, and Patrizia Violi, Indianapolis: Indiana University Press, pp. 221–237.

Winograd, Terry (1972). *Understanding Natural Language*, New York: Academic Press.

Winograd, Terry (1973), "A Process model of Language Understanding," in *Computer Models of Thought and Language*, eds. R. Schank and K.M. Colby, San Francisco: W.H. Freeman & Co., pp. 152–186.

Winograd, Terry (1977). "On Some Contested Suppositions of Generative Linguistics About the Scientific Study of Language", *Cognition*, 5, pp. 151–179.

Wittgenstein, Ludwig (1922). *Tractatus Logico-Philosophicus*, London: Routledge, 1961.

Wittgenstein, Ludwig (1958). *Philosophical Investigations*, G.E.M. Anscombe (trans.), Oxford: Blackwell.

Wittgenstein, Ludwig (1967). *Zettel*, G.E.M. Anscombe and G.H. von Wright (eds), G.E.M. Anscombe (trans.), Oxford: Blackwell.

Wittgenstein, Ludwig (1974). *Philosophical Grammar*, Rush Rhees (ed.), Anthony Kenny (trans.), Oxford: Blackwell.

Wittgenstein, Ludwig (1979). Notebooks: 1914–1916, New York: Basil Blackwell.