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The Language Conceptual Formation to Inspire Intelligent Systems

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Abstract: The semantic web invests in systems that work collaboratively. In this article we show that the collaborative way is not enough, because the system must 'understand' the data resources that are provided to it, to organize them in the direction indicated by the system's core, the algorithm. In order for intelligent systems to imitate human cognition, in addition to technical skills to model algorithms, we show that the specialist needs a good knowledge of the principles that explain how human language constructs concepts. The content of this article focuses on the principles of the conceptual formation of language, pointing to aspects related to the environment, to logical reasoning and to the recursive process. We used the strategy of superimposing the dynamics of human cognition and intelligent systems to open new frontiers regarding the formation of concepts by human cognition. The dynamic aspect of the recursion of the human linguistic process integrates visual, auditory, tactile input stimuli, among others, to the central nervous system, where meaning is constructed. We conclude that the human linguistic process involves axiomatic (contextual/biological) and logical principles, and that the dynamics of the relationship between them takes place through recursive structures, which guarantee the construction of meanings through long-range correlation under scale invariance. Recursion and cognition are, therefore, interdependent elements of the linguistic process, making it a set of sui generis structures that evidence that the essence of language, whether natural or artificial, is a form and not a substance.

Keywords: linguistic process; intelligent systems; cognition; recursion; conceptual formation

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1. Introduction

The vast and complex field of computational linguistics has its foundations in the information about human language that is transferred to the machine. It has been sought, through intelligent systems, to build information and meaning, just like human cognition. To make this task simpler, we compared human linguistic functioning to the linguistic functioning of artificial intelligence to show, in the end, a common structure in the language conceptual formation process: both alternatively or jointly explore logical and contextual relationships to generate meaning. This single architecture makes it clear that some limitations of intelligent systems rely on logical tasks, leaving aside the representation of the context while modeling the algorithm. The advance in systems that make use of deep neural networks is marked by the use of both axiomatic (contextual) and logical processes, which encompass the universal architecture of the linguistic process. This makes computational linguistics tools more efficient and intuitive, directing them towards the cognitive computing [1].

Software specialists, technology executives, entrepreneurs, and researchers in the field of formal sciences are increasingly interested in more interactive and intuitive intelligent systems, such as humans. This scenario is coined as the semantic web (as opposed to the documentary web) [2], which provides intelligent bots that perform tasks instead of humans. The semantic web offers patterns of behavior that express meanings, which can be observed in medicine, industrial research or even in semantic programming languages [2].

The difference in the establishment and development of the semantic web goes beyond the task of crossing over in databases. For there to be technological advancement, there is a need for a special set of definitions in algorithm design. An example of this is an experiment that aims to take advantage of data from sharing sites. Although these data are already available and categorized on the Internet, the semantic web needs to add a 'meaning' to the algorithm (that is, there must be a direction of the interpretation of the data collected through previously established rules), drawing in the algorithm a new context that was not previously foreseen. In this way, the programming is changed, that is, the 'language conception mode' is modified to give rise to a new interpretation to be performed by the intelligent system. This 'language conception mode' is responsible for the advent of interpretation through the systems. We discuss a 'mode', a 'process', which makes the content of this article somehow more theoretical and nonspecific: The conceptual formation of language configures 'evidence' prior to interpretation and 'above' it. It is the 'space' in which the interpretation will be given, its basis. It is an 'a priori' of the interpretation that, for presenting structural characteristics, is treated in this article in theoretical terms, as something capable of reducing reality to a definition, an idea organized in a certain way.

Cyber companies that deal with the semantic web want to solve real problems, not ideals or according to logical ones. Therefore, they must be given the opportunity to develop systems trained to collect data with the characteristics of the context in which they are generated, giving more consistency to the interpretability of neural networks [3]. The closer intelligent systems get to the human cognitive process, the better their performance is until they reach the state of the art.

This article deals with the structure behind the human mind's ability to generate concepts and meanings. We describe the basic elements for a system to have the characteristics of 'intelligent': it must collect data or stimuli in their 'original form', together with information provided by the context from which they were collected; it must organize these data or stimuli, relating them to pre-established rules (logical rules) of value and relationships [4] so that they become intelligible for human beings.

Explaining the point at which human cognition and the cognition of intelligent systems touch and merge leads us to make use of an argumentative approach [5], so that we can show that there is an overlap of structural aspects of human cognition in cognitive computing. A single architecture can be observed both in neurocognition [6–8] and in the field of formal sciences dealing with intelligent robotics. This architecture provides a better glimpse into what there is in common between human intelligence and cognition computing. Therefore, we can assume that mathematics expresses and explains how cognition and natural language work [5,9]. Interdisciplinary research such as the research presented in this article is very necessary, as it opens new frontiers to reflect on the same phenomenon through different perspectives of the dynamic linguistic system, be it through neuroscience or through intelligent systems, both of which are addressed in this article.

Content Description

The organization of this paper is as follows: Section 2 explains that it is not enough to build a system that operates collaboratively. It is necessary for the system to 'understand' how it should process the data resources provided to it, to replicate the essence of the human cognitive process to the algorithms. Cognitive dynamics is the subject of Section 3, in which arguments are presented to clarify that cognition is an essential element of the linguistic process—be it human or machine—and that it exhibits a universal pattern that guarantees coherence between contextual reality and the meaning taken as truth. Section 4 deals with the linguistic process in the body, under an axiomatic-logical conception of language that, being dynamic, travels through a circuit. In Section 5 we show the information circuit integrating the axiomatic characteristics of language to its logical characteristics, making the complex functioning of natural language intelligible. Section 6 describes the dynamics of the linguistic system through the recursive system, which records information as a set of stored possibilities, guiding the formulation of decisions. An elementary recursive model for language is provided. In Section 7 we explain the unique set of language structures that maintain relationships with other domains of the mind. Finally, in Section 8, we conclude that the axiomatic-logical conception of language has the necessary aspects to house recursion, making it evident that the essence of cognition, be it natural or artificial, is a process and not a substance.

2. Preliminary Remarks

The semantic web aims to build a system that operates collaboratively [2,10,11]. We, on the other hand, suggest that it is not enough that the form is collaborative. The system must 'understand' the data resources that are provided, organizing them in a certain direction indicated by the algorithm, as the cognition core of the system. The key point is the successful application of deep learning techniques, which requires skill in designing algorithms and, also, a good knowledge of principles that explain how they work [9] (p. 423). In this article, we focus on these principles. We show the essence of the human cognitive process to be replicated in the algorithms. We explain that a structural essence must be repeated by the algorithm to improve the machine learning system.

To solve heterogeneous problems brought about by semantic data, systems need to be provided with a nucleus (core) with the ability to decipher stimuli together with the context from which they arise and, also, with the ability to relate these identified stimuli, transforming them into information [5]. An organization that 'adds meaning' to the data collected is necessary for the system to mimic the human linguistic process. In order for the language conceptual process to take place, there must be, two operations: one of the axiomatic (contextual, semantic) aspects, which collects the stimuli together with the 'meaning' they have within their environment; and another of the logical aspect, which relates and organizes the data or the stimuli following a certain 'syntax' or logical order, adding a meaning previously given. It is in this previous sense given by a 'syntax' that 'well-formed' data are grouped 'correctly' [12], according to certain rules, or other criteria such as level of roughness, number of people, opacity, or brightness of points light etc. If the databases are 'structured', it means that they are represented in a 'determined' way, following a previously established rule or 'syntax' [13] (p. 17). The word 'syntax' is enclosed in quotation marks because it means 'an organization of elements according to rules given in advance'. For example, there is 'syntax' or logical organization (logical feature of language) in the sentence "A hill in a woman", following previous rules of sentence construction. However, this sentence is inconsistent, it makes no sense in the real world, escaping the context of the environment (axiomatic feature of the language). This is an example that if the 'syntax' (organization or logical resource) is detached from the axiomatic resource, the interpretation loses its consistency. The logical sequence that obeys previous rules can be represented by a sequence of numbers, lines, data of individuals, a sequence of roughness versus smoothness, etc. What we want to emphasize is that the cognitive linguistic process consists of a structure that organizes elements, interrelating them and that, if we focus only on the logical structure, this can affect the meaning in the interpretive activity.

Hauser et al. [14] argue that the language faculty requires substantial interdisciplinary cooperation. We go further by stating that the faculty of language is based on ethereal structures that connect axiomatic (contextual), logical and recursive aspects. Pinker and Jackendoff [15] suggest that it is problematic to focus on syntactic recursion and exclude other aspects related to language, making the study inconsistent. In our article, we address the structural aspects, which prevents a partial approach to the linguistic process. Foundation is related to a structure in which elements are organized and connected to each other and may include a hierarchy. While Hauser et al. [14] and Pinker and Jackendoff [15] address some elements that characterize language, in this article the relational and organizational structure of these elements in the linguistic process is discussed.

While Li et al. [11] study the characteristics of semantic data and propose the concept of a uniform knowledge graph (UKG), to apply to an Internet of Things environment; we disentangle these 'semantic data' of which the authors speak and structurally analyze them by relating them to the universal structure of language [3–5,16,17]. Therefore, we propose a structural architecture for the systems that contemplates the dynamic aspect of human cognition, which is responsible for making it more intuitive. The differential of this architecture is its dual aspect: the axiomatic feature (which is dynamic and dependent on the situational context) associated with the logical feature (static and dependent on the context previously given to the design of the algorithm). The axiomatic aspect is based on the property of repeating, within a dynamic process, a consistent pattern, which does not change its characteristics, that is, the essence of the information remains the same during the dynamic process. The logical aspect, within a dynamic process, repeats a pattern whose guidelines (or rules previously given) originate out of context.

This proposal is innovative because it conceives human cognition as a process that goes from capturing stimuli to interpreting those stimuli cognitively [3,5]. This linguistic process—where there is language there is cognition, so we use indistinctly the expressions 'cognitive process' and 'linguistic process' [18] is presented under its structural aspect to inspire and encourage approaches from different points of view for intelligent science. By addressing structures, the content of this article can be applied to cognition in any area of knowledge: image interpretation, text interpretation, number interpretation etc. In this way, this article appeals to mathematical science to interpret human language conceived as a process that encompasses brain activity. The fact of taking the linguistic process as something dynamic differentiates the content of this article from the descriptions of language assumed a priori. We are moving towards a science of the linguistic process that is also intelligent and inspired by neuroscience.

3. Cognitive Dynamics

Cognitive dynamics are complex in their design. This special section explains the strategy of adopting a criterion that leads us in the study of language and cognition through different branches of science: the argumentative method based on regressive reasoning to observe the functioning of natural language in relation to its context [5,19].

Although we are used to the apparently contradictory theories of the scientific branches, it is necessary to consider that we are observing only one phenomenon: cognition, which is an essential element of the linguistic process, be it human or machine. When it comes to a single phenomenon, we set out in search of a pattern of cognition that appears repeatedly in different disciplines, that is, something universal guaranteeing coherence between contextual reality and the meaning taken as truth. Language, cognitive computing, computer vision, intelligent systems, and robotics make use of this unique structure, which we demonstrate, by way of example, through some theories (the focus is not on theories, but on the identification of the same structure in them). Research and development in any of these areas requires knowledge of a common structure. This structure is the place where these branches meet, making possible a synergy that gives opportunity to the innovation and development of each one of them.

Modeling work in cognitive neurodynamics, for example, is grounded in neuronal correlates of cognitive and executive processes with a focus on mental faculties that include memory, language, attention, perception, reasoning, and emotion [20]. Psychological characteristics (among them emotion), intelligence, linguistic process, neurological aspects, in turn, are supported by human cognition. It is observed that there is a lot in common between human and machine, what we can call a 'generic' view of cognition, present in neural network activities, cognitive science, and behavior with a focus on 'mental action' or the 'process of acquiring knowledge and understanding' [21].

We observe that there is synergy between different elements which results from a single structure, whose role is to trigger intellectual processes, such as attention, memory, judgment, evaluation, and decision making. In this work of a new harmonic and interactive frontier, we propose that the cognitive process is particularly linked to the linguistic process under a single universal architecture. This same structure can be observed in human language/cognition and in the language/cognition of systems indifferently [3,5]. We understand that cognition is not limited to mental processes. It is 'constructed' through the linguistic / cognitive process, consisting of a structure that collects stimuli from subsystems (auditory, tactile, olfactory, visual etc.) (axiomatic feature of language) and carries them to the central cognitive system, which organizes them (according to the logic feature of language).

When the cognitive processes are methodologically divided to be studied from different contexts [20,21], notably in the fields of linguistics, biology, philosophy, neuroscience, anthropology, psychology, education, biology, logic and science of computing, there remains a 'gap' that leads to partial observations of the cognitive whole, which is described through different approaches.

Our proposed study of cognition goes deeper, as it focuses upon structure, which makes our study simpler. We look [3,5] at cognitive dynamics as a process in its entirety, in its fundamental structure and, for this reason, we can say that the study of cognition is not restricted to a scientific area or to humans only. Cognition is a structure and is also present in cognitive computing, computer vision, intelligent systems, robotics and so on.

To better explain the content of this article about the structure/mechanism that is behind the cognitive properties of the human mind and intelligent systems, we dedicate this section to randomly citing some theories to serve as examples of how the input and output processes of the cognition are 'designed'. They are compared to the architecture of the linguistic process that we present, in this article, based on the human cognitive process: the body receives (input) stimuli (perception), which go through a 'path' of information processing until they become output capabilities (intended action) [5].

The cognitive dynamics we describe does not neglect the fact that it is also connected with affections, motivation, personalities, and conscience [22,23]. The theory we have developed so far is structural. For this reason, it integrates the external and internal contexts in which human cognition occurs, and goes beyond that, also integrating significant advances in the computation of cognition.

Some authors offer clues to the field of cognitive science in intelligent systems. We look for a common denominator in them. Locke [24], in his book *An Essay Concerning Human Understanding*, describes a theory of knowledge contrary to Descartes' teachings (which gives precedence to logical reasoning), presenting arguments that knowledge becomes possible because it is related to essences characteristic of the human mind. For Locke [24] there is a 'mechanism' that reinforces the 'connection' of mental representations. Bona [25] in his thesis on Recursion in Cognition at the computational level, relates an entirely theoretical question and empirical research to provide a unified explanation of the role of recursion in the cognitive sciences to obtain a coherent understanding of cognitive issues. For the author [25] associations are not enough to make the cognitive system work, but the 'combination' of fragments. These connection or combination mechanisms are just examples of something that exists in common, operating in an underlying manner. Between Locke's studies in 1847 and Bona's thesis in 2012 [24,25], one hundred and sixty-five years passed without there being a substantial change in the subject, as both are concerned with an immutable structure of human cognition. This fact shows why this article deals with bibliographic references from 1916 and 2021 indistinctly.

There is no need for the reader to delve into theories to identify the structure defined by Locke as a mechanism that connects mental representations and by Bona as a system that combines fragments. Instead of theories, we suggest Perelman and Olbrechts-Tyteca's [19] method of argument through which the authors capture 'similarities in relationships' as the core of observation. In this Section and in Sections 2 and 3, we show similarities in how cognition works across different approaches [25–28].

Monte-Serrat and Cattani [5] present something much sought after by scientists: the biological and logical structure typical of human language in their dynamic mediation process between reality and the human mind. The linguistic functioning is taken as a dynamic process of human cognition designed to form meanings. The authors, in declaring that this process has a universal structure, describe its structure to indicate ways to improve the development of AI in specific fields of science. For this, they [5] also present an ethereal algorithmic model with axiomatic-logical elements that mimic the functioning of the human mind, adjusting them to the machine's logical-mathematical processes.

This article presents more aspects about the universal model of cognitive neurodynamics, showing how the human mind constructs meanings. The logical-axiomatic model of language, being structural, reveals a functioning of cognition with interdisciplinary application. The dynamics of language, from receiving a stimulus to its interpretation, can be applied to the concepts of computer science, intelligent science, natural sciences, and engineering.

When dealing with Neurodynamics of Intentional Behavior Generation, Robert Kozma [27] observed networked memory with mechanisms for generating and using knowledge. The author (op. cit.) makes an approach based on an intentional action–perception cycle in which knowledge is continuously created and accessed during the selection of actions and future decisions, suggesting its implementation in computational and robotic environments. Levine [29], in his chapter on "How Does the Brain Create, Change, and Selectively Override its Rules of Conduct?" explains how behaviors adapt to each context from a neural theory of the formation of rules that selectively inhibit behaviors in response to the context. The author [29] shows how the brain interacts with the sensations collected from contextual reality, forming meanings through the exchange between heterogeneous categories to produce networks under certain preferential attachments and for more optimized effects. Zhang [30], shows that the cognitive system develops interaction with the context in a more complex way, involving an integrative language in a logical chain, which is corroborated by Gandy [31] and Del-Moral-Hernadez, [32]. Charlton and Andras [33] (p. 330) affirm that the success of recruiting new information depends on the correspondence between the cognitive system and its environment, since for the authors, memories constitute descriptions (possibly compressed) of previous sets of communications in the system. The authors (op. cit.) assert that there is a correspondence between the system model and the environment itself and that it is possible to prove the inaccuracy of the communications when it is no longer rooted in the original communication.

The works of these authors mentioned in the previous paragraph establish a relationship between the axiomatic/contextual linguistic aspect (when they refer to the perception of action, response to the context, interaction with the sensations collected from the contextual reality, correspondence between cognition and the environment) and the logical linguistic aspect (when they refer to integrative language in a logical chain). The importance of apprehending language as an axiomatic-logical concept can clarify some aspects that are still obscure for the science that deals with intelligent systems. Our proposal that technicians in intelligent systems adopt the conceptual formation of language as an axiomatic and logical process in their working dynamics, which can increase the performance of their tools for the analysis of natural language. There are different perspectives in the treatment of language: this article proposes that technicians work with the integrative (axiomatic-logical) perspective of language, instead of working with the concept of natural language (which is conceptualized as the languages spoken in the world). Spoken languages (such as Portuguese, English, French, etc.) represent a limited concept of language, which clings to a set of logical rules that regulate speech and writing [34]. They disregard the context, the environment from which the information was extracted. Because they are idealized [17], spoken languages lead tools to misinterpretations. This article suggests that, in order to avoid misinterpretations by intelligent systems, the tools must adapt to the concept of language that integrates the context associated with the logical chain (axiomatic-logical concept described here). In this way, the intelligent system becomes able to meet the fundamentals of cognitive dynamics. Neuroscience researchers and technologists can use the recursive process characteristic of cognitive dynamics as a work strategy to reduce ambiguities in the construction of meaning. This prevents previously established (logical) criteria from guiding interpretation, making it disconnected from contextual reality [3].

The formation of concepts by the human linguistic apparatus is highlighted here to inspire language scholars to be aware of those elements that go beyond the generic concept of natural language, through which one idea is understood in terms of another [35]. Language, for Saussure [34], who created the science of linguistics, has two parts: langue and parole. He outlines 'language' as a system of signs, rules, and communication patterns for a particular social group. Saussure, therefore, conceives language as something autonomous in relation to reality. This limiting concept of language [34] deprives the neuroscience technologist of looking at other elements that make up cognition and interfere in the final composition of meaning.

Damasio [36] on this subject, in his book *Descartes' Error: Emotion, Reason, and the Human Brain*, questions the dualism between mind and body proposed by Descartes. The author (op. cit.) presents the somatic marker hypothesis as a mechanism in which emotions guide behavior and decision making. This author [36] brought scientific bases to reject the cleavage between reality and what human beings express about it. This phenomenon was also observed by Pêcheux & Fuchs [37] and Pêcheux [38] who showed that language cannot be separated from the context in which it is generated.

The axiomatic-logical concept of language aims to reintegrate axiomatic elements into language studies, since language is a process that has the body as a basic means for its functioning [4,17,39]. Thus, the study of language in this article takes into consideration articulating, at one time, topics in linguistics, neurolinguistics, psycholinguistics, language, cognition, which are usually studied separately.

Furthermore, we can state that mind–body integration through the linguistic process can be accurately delineated by mathematics. Instead of portraying reality under a disjunctive logic: is the state of affairs A or not-A? [38] (p. 31), mathematics can approach the contextual reality in which the information was produced by representing the body-mind integration of the linguistic process. The axiomatic-logical concept of language meets the requirement of encompassing language in its dynamic systemic complexity delineated from the input of a stimulus, until reaching the construction of a meaning.

The axiomatic-logical perspective of language reflects the cognitive dynamics bringing together:

(i) knowledge already developed by linguistic theory [6,7,34] regarding the static representations of language (study of written language with respect to phonemes, structure of sentence, syntax, grammar etc., which are related to the logical aspect of language);
(ii) knowledge that comes from psycholinguistic theory in language processing in real time (related to the representation of language in the mind, to human communication through perception, understanding, language production, which are related to the axiomatic aspect of language);
(iii) knowledge of neurolinguistic theory about the brain mechanisms that support linguistic abstraction (which is also an axiomatic aspect of language);
(iv) the theory of information proposed by Moles [26] (see Section 2) that explains the importance of the body in the linguistic process;
(v) an elementary mathematical model to describe the linguistic process integrating the previously mentioned elements.

Effects of meaning and concepts resulting from the linguistic process are directly linked to the body [25], to the experience of the senses (hearing, touch, smell, sight) that interfere in the construction of meanings through integrative functions of subsystems [8] (p. 3). The axiomatic-logical concept of language provides the elucidation of errors, misinterpretation or inadequate reaction of the listener or reader, bypassing them or explaining the origin of the error in the construction of meaning.

Our axiomatic-logical concept accounts for the dynamic character of cognition, supporting several parameters of the linguistic process [8], without discarding the regularity of syntactic restrictions (logical feature of the language), incorporated into this dynamic [40].

The nonlinear data of axiomatic-logical language are represented by recursive structures (cognitive dynamics), which are shown to be suitable for operating with language, since recursion is part of the structure of both natural and computational language. Recursion reflects axiomatic characteristics of language, by preserving stimuli and information throughout the linguistic process until they reach the central cognitive system and become 'meaning'. The word 'axiomatic' is used to express this characteristic of the linguistic structure that makes the input information remain unchanged.

4. The Linguistic Process in the Body

The study of the linguistic process carried out by the human body teaches computational linguistics the importance of recursion as an intrinsic property of the linguistic procedure [25]. Language in its axiomatic-logical conception takes human cognition as a dynamic recursive process [41,42] that mediates between the social context (where the stimuli come from) and the human mind, that processes them symbolically [26,28]. This process makes it possible for the individual to exercise the ability to understand the world by integrating it with the symbolic function in the human mind [28,43].

Abraham Moles, Doctor of Letters and Doctor of Science, worked his multidisciplinary training in cybernetics and information theory and aesthetic perception [26]. Moles' theory inspired our axiomatic-logical model of language structure [5], helping to understand the concept of communication and the communicative process (in which there is a transfer of a perception of the immediate environment). This study prompted us to look for a common framework (see Section 5) that touches the architecture of cognition, in which the same process is repeated to build information through an increasing order of instances. In this article we mathematically explain this process of meaning construction by the human linguistic system, forming the circuit of cognition.

4.1. The Cognition Working Circuit

The cognition circuit that we defend in this article is broader than the path of signals travelling through neurons. We adopted the theory of Moles [26], which conceives language as a circuit in which the perception/learning process takes place, to explain the linguistic ability to construct information so that the reality of the social context becomes intelligible to the individual. By making use of the axiomatic-logical concept of language, we take the human body as the base of operations of the linguistic process, functioning as an open system determined by the sum of the general structure of the events experienced by the organism in its environment. The axiomatic factor of language refers to the biological elements that structure language; and the logical factor, in turn, refers to the abstract symbolic process of language. Both form a linguistic interface that combines information of a biological nature with information of a logical nature, updating them to construct meanings. In this way, language is not only a system of opposition of places and values (closed circuit), but also a structure that mediates between the human mind and the social context, enabling the individual to interpret the reality that surrounds him [3,5]. This mediation may or may not be successful due to some interfering factors, whether axiomatic or logical.

4.2. The Axiomatic-Logical Foundations of Language

The construction of concepts by the linguistic process has to do with the axiomatic-logical structure of language, as explained in the previous section and in this one. The axiomatic face gives the construction of meanings a dynamic aspect, which considers the context and its constant changes. The logical feature concerns reasoning done in a chain (signal in a closed system relationship, as Moles explains, [26] (see Section 5 on the complex circuit of information).

Analyzing the previous paragraph thoroughly, the dynamics of cognition occurs through a unique structure, as explained in Sections 1–3 in which we identified a common functioning between works by different authors and different disciplines. This unique structure necessarily combines two features: the axiomatic characteristic, responsible for collecting stimuli from the context; and the logical feature, responsible for organizing these stimuli into categorized information. The dynamic of this process is recursive (see Section 6 on the dynamics of the linguistic system), which makes the cognitive / linguistic process consistent and universal. Recursion guarantees that,—on the path that the cognitive process takes between the collection of stimuli in its context (axiomatic feature) to the central cognitive system, which organizes them within a 'syntax', categorizing them and giving them sense (logical feature)—the axiomatic feature remains immutable so that the characteristics of the stimuli collected in its context are not lost along the way (cognition processing) until they are transformed into information by the central cognitive system.

The axiomatic features related to logical features compose a process that can distinguish between the body and the external world [44], since external stimuli are absorbed by inputs and interpreted by the individual (the social context plays a specific role in mental integration) [45]. This axiomatic-logical relationship is sui generis because it processes elements to lead to a final product that does not correspond to the sum of the initial features. It works under an interaction designed to give consistency to the final product: the meaning. The axiomatic-logic relationship makes the fleeting reality correspond to the 'before' and 'after' characteristic of the logical chain. It should also be considered that the production of 'noises' in this process, whether they are in the axiomatic feature (brain malformation, emotional trauma, stroke etc.) or in the logical feature (fallacy, when the conclusion does not follow from the premise; ambiguity etc.), lead to misinterpretation, over-reaction [46], aphasia [47,48] and other defects in the production of meaning.

The axiomatic foundations of language, as a dynamic process, preserve the characteristics of the original information (recursion). This involves an integrative operation between the input of stimuli in the human body and the linking of these stimuli in the logical chain that will give them meaning.

We list below some biological activities associated with brain function in the cognitive circuit to explain how the human body collects information from the context in which stimuli are generated. To better explain how the conceptual process of language takes place, we reinforce that we are referring to a dynamic process that links language to any stimuli captured by the human body and carried through subsystems to the central cognitive system [8]. This dynamic process has the role of organizing these stimuli into categories, transforming them into "meaning" [4]. The integrative language conceptual process occurs through some axiomatic (biological) activity such as:

(a) synchronization of brain functioning: Synchronization results from the connection of neurons in a network [49] (under a kernelized coupling, in sequences of oscillatory patterns [27] (pp. 130–131);
(b) blood flow: neuronal activity can be assessed indirectly through cerebral blood flow (FSC) [50]. The relationship between stimuli in language and changes in neuronal activity patterns helps to discern the specific functions of brain areas [51];
(c) interdependent subsystems linked to a central cognitive system: There is stability in neurodynamics due to a global cortical neurocognitive state [8] resulting from the interaction of different brain areas of coupling tendency (integration) and independent behavior tendency (segregation) [52]. This interaction can occur with signals from bottom to top and from top to bottom [8,32] leading to a brain organization in space-time patterns. Gangopadhyay et al. [49] suggest the adoption of a continuous time dynamic system to mimic the dynamics reported in neurobiology;
(d) mediation between real, symbolic, and imaginary kingdoms: The complex interdependence between reality and the human mind occurs through language in its role of processing symbols [28–36]. The social context interferes with the transition from sensory-motor stimuli to symbolic stimuli and has a constituent role in emotion [28,39,53–55]. Damage or malfunction of some brain regions affects cognition / language [34,36,56]. Body and mind are integrated in meaning-building operations [39,57] which are proved by altered states of consciousness [58];

(e) overlapping between interpretation, speech, and writing: Psychological and physiological components are integrated through the linguistic process, in which different time scales overlap neural activity [30]. Consciousness presents a neurodynamic that goes from vague and unconscious states to more concrete and conscious states [8] (p. 1), giving rise to the investigation of a hierarchy of linguistic structures [59] (p. 158). The sequence of mental operations can be observed by means of an electroencephalogram, which, to be successful, starts with the aligned and synchronized activity of patterns [27];
(f) interconnected mechanical processes to calculate movements, images, behaviors, decisions: The linguistic system that encompasses cognition always seeks the best result and for that it explores reality through a 'reverberatory generalization' or a 'multiple gating' [60] (p. 122), optimizing the entire system by proposing parameters decision to be made and integrating the results;
(g) symbolic system capable of producing mental representation of phenomena perceived by the individual: Natural language involves a symbolic process [28] in the formation of mental elements with semantic value (concepts, ideas, thoughts, notions, images, etc.) [4,61–63].

In addition to the biological circuit, cognition has logical aspects that organize stimuli so that they become intelligible. The logical feature of reasoning can be represented by the following premise: 'if P then Q', where 'P' imposes a truth value to establish 'Q', that is, if one statement is true, then the other will also be true [64] (p. 10). This logical sequence in the construction of meaning is dealt with by Chomsky [65], who considers that the signs of language are determined by principles (which we understand as logical principles) that are independent of the representation of language in terms of phonetic symbols; and by Pinker [7] who states that the meaning to be constructed by cognition depends on the restrictions imposed by the inputs of the logic mechanism, tying the words in order.

According to Moles [26] (p. 97), if there is a previous statement (if 'P' in the case of logical reasoning), the individual's assessment will be 'this must be interesting'. The logical feature of language offers a priori value, placing it as a hypothesis, anticipating the interpretation of meaning [4,66]. The closed circuit of logical reasoning places the elements in relation to limit the formation of meaning. Conventional language (spoken languages) symbols (English, Portuguese, African, for example) mark the intelligibility of a message and, according to Moles [26] (p. 98), this predictability of values gives the receiver the ability to interpret the meaning of what was transmitted. There is a degree of coherence, a rate of regularity, a statistical link that correlates between what happened and what will happen in time [26] (pp. 100–101).

5. The Complex Circuit of Information

To base the process of language perception on the theory of Abraham Moles [26], integrating the axiomatic and logical features, we can consider, with Moles [26] (p. 14), the individual as an open system whose behavior is determined by the sum:

(i) of a hereditary background giving the general structure of their organism;
(ii) of the events of their particular history, inscribed by conditioned reflexes and their memory in that organism;
(iii) of their current environment.

Moles [26] (pp. 19–24) and Perlovsky and Kozma [8] teach that the individual receives messages from the environment through several channels or subsystems (visual, audible, tactile for example). These messages can be of a spatial or temporal nature (speech and music are purely temporal messages, which are modulations of duration), and the spatial message is transformed into a temporal message [26] (pp. 19, 24). The linguistic process of an axiomatic-logical foundation takes external stimuli through subsystems [8,32] and carries them to a central system [67] capable of transforming stimuli into information through the symbolization process [28], which has the task of linking the information received in a logical chain, giving them meaning [5,66].

In this sense, we can conclude that the logical feature of language organizes the input signals/stimluli making them correspond [8] (p. 2) to intelligible symbols, through a complex functioning of natural language [39].

There is an inherent complexity in the linguistic process that is greater than its product [60] (p. 119). Kelso and Tognoli [52] observed that in human cognition there are elements with complementary effects of general coordination and the disintegration of individual components. It is in the sense or a dynamic process that we observe the conventional language (spoken languages) related to the logical feature of language and determined by rules and values established previously. Spoken languages are responsible for introducing some patterns in the broad linguistic process (axiomatic-logical) interfering with the operating results of stimuli coming from various input subsystems (input subsystems like visual, auditory, among others), that is, the logical feature of the linguistic process organizes these stimuli according to a logical sequence related to spoken language learning (with its logical rules/syntax) [8] (p. 3).

The stimuli coming from the environment enter the human organism through subsystems (visual, auditory, tactile, etc.) towards the central system (brain). Kozma [27] (p. 136) describes the basal state of the brain as a high/chaotic attractor upon which an activity pattern will be produced, a synchronization of neural electrical activity when completing cognitive tasks. For Kozma [27] this hypothesis can be described by the mathematical theory of chaotic roaming, which describes the trajectory of a dynamic system intermittently visiting 'Ruins of Attractors', a phenomenon that helps to interpret the main characteristics of EEG measurements. For our study in this article, it is enough to highlight the importance of this double feature of cognition (central system), in which there is a parallelism of sensations arising from the subsystems (which we call axiomatic features of the linguistic process, related to the environment) and a synchronization that produces a pattern of activity (which we call the logical feature of the linguistic process, related to the learning of rules from the spoken language).

6. The Dynamics of the Linguistic System

If we are dealing with the linguistic process as something dynamic, bringing up considerations about what recursion is essential. The dynamic aspect of the axiomatic-logical structure of natural language resides in the phenomenon of recursion [41,68,69], which integrates the input stimulus into the cognitive system that transforms it into information, under a synchrony that affects the system as a whole and continuously. This structure is capable of registering information as a set of stored possibilities, whose role is to guide the formulation of decisions [70]. This characteristic has been recognized in recurrent neural networks [71,72]. In this article we are proposing to extend these characteristics to the entire linguistic process, from the input stimulus until it is transformed into information, since recursion is what provides cognition [41,71] and this, in turn, only exists if it is continuously fed by stimuli. Both, recursion and cognition, are interdependent elements of the linguistic processing.

Studies show that the brain interprets sensory inputs [71] using internal models to make inferences [73] and, therefore, it is predictive [74]. As a result, we can say that causality is part of dynamic language modeling, as well as the dynamic vision model [68], noting that the logical characteristic and the recursion process are incorporated into the language [41,69].

The recursive aspect of speech is recognized by Lowenthal and Lefebvre [42], stating that it is necessary for language and cognition. Based on neuroimaging techniques, those authors consider the possibility of a specific brain structure for recursion extended to formal grammars. Corballis [41] states that the capacity for symbolic thinking and the recursive structure allow the generation of an unlimited number of propositional structures, making recursive thinking evolve as a prelude to language.

Bona [25] observed that both the syntactic derivations of the grammar and the analyzer's processing strategies are iterative, suggesting an algorithm defined recursively in the linguistic process. The author (op. cit.) explains that recursion applies to various constructs within the cognitive sciences (theoretical definitions, mechanical procedures, algorithms, processes, and computational structures), emphasizing that recursion is an intrinsic property of mechanical procedure and structures of language, resulting in sui generis set of structures with which other domains of the mind maintain relations.

Predictive or not, formal or not, it cannot be denied that recursion is part of the linguistic-cognitive process. Recursion is conceived as a process where one of its steps involves invoking the procedure itself. In the recursive procedure there is a set of steps based on rules which must be followed in the execution step. In order to visualize the complexity of the linguistic process, we exemplify with a text converted into categories and a sequence of classes.

The linguistic process is intended to construct meaning. Spoken language at stake symbols (whether letters, numbers, lines etc.) do not appear in a random sequence but follow rules of the environment of natural reality (axiomatic feature of the linguistic process), or previously established rules (logical feature of the linguistic process), so that those symbols establish correlations and are intelligible to the human being. This correlation in a sequence of symbols may result from a statistical dependence of self-similar elements similar to fractal physics, which present long-range correlation and imply scale invariance [75].

Once we have a temporal series, we can use the "binary map" or "recurrence plot" method [75,76] to mathematically describe the linguistic process from input of a stimulus to construction of meaning. As mentioned in the introduction section, this article deals with the 'language conception mode' responsible for the advent of interpretation by the intelligent system. Therefore, we only exemplify recursion, generically, as a 'mode' or 'process' by which the language processes concepts. This conceptual linguistic process is defined by us as an 'a priori' of interpretation, destined to 'shape' a reality, organizing it in a way that can be apprehended by the individual. The linguistic-cognitive process, therefore, being dynamic, comprises underlying rules in which an organizing principle linked to periodicity is found so that a specific order (symmetries) or hidden structures (regular patterns) can be found [75]. This explains the importance of taking recursion into account in the study of computational linguistics.

An Elementary Recursive Model for Language

If we assemble all the elements of a sentence into an algebraic set, we can assume as invariant each element that represents the partition by classes of the set, also called categories. All elements of a category have the characteristic of referring to the same subject / object. For example, given the phrase:

S = 'There's a woman on a hill, and I'm watching her with my binoculars'.

We have the following classes:

A = {a woman, her}—this class contains all elements referring to the invariant concept of 'woman'

B = {a hill}—this class refers to the concept of 'hill'

C = {I'm, my} this class contains all elements referring to the concept 'self'

D = {binoculars} this class refers to the concept 'binoculars'

E = {there's, on, and, watching, with} this class represents the axiomatic character of language, contextualizing the other elements through action and connectives.

As we can see the union of these classes gives the full set (sentence)

$$A \cup B \cup C \cup D \cup E = S$$

While the classes are pairwise disjoint, being

$$A \cap B = \varnothing \;, \;\; A \cap C = \varnothing \,, \quad B \cap C = \varnothing \,, \ldots\ldots$$

We have the *axiomatic feature* (of language) when the invariants are merged with axioms to form a self-consistent expression which reveals their contextualization, like for instance as follows:

'There's a woman' = *E A*, 'on a hill' = *E B*,

'I'm watching a hill' = *C E B*, 'a woman on a hill' = *A E B*

Obviously not all axiomatic construction are allowed because they must fulfill the rules of the *logical feature* (of language) like e.g.,

'a woman on a hill' = *A E B*—logical construction

'a hill on a woman' = *B E A*—illogical construction

Let us now take the sentence *S* and write it as a combination of the classes:

'There's a woman on a hill, and I'm watching her with my binoculars' = *S* = *E A B E C E A E C D*

$$\begin{array}{ccccccccccc} There's & a\,woman & on & a\,hill & and & I'm & watching & her & with & my & binoculars \\ E & A & E & B & E & C & E & A & E & C & D \end{array}$$

The existence of patterns or typical distributions ('a priori' of interpretation) in a temporal series can be singled out by the existence of some autocorrelation among the elements of the sequence. The autocorrelation can be computed by some classical methods, and it measures the relationship of an element with the remaining elements of the sequence. A simple method to visualize the autocorrelation is based on the indicator function and the corresponding correlation (binary) matrix as follows.

Let $S = \{x_k\}_{k=1,2,\ldots N}$ be a given sequence, and R be a given (symmetric) binary relation, the indicator function (map) is the binary map.

$$u : S \times S \to \{0,1\}$$

such that for $x_h, x_k \in S$, it is

$$u^R(x_h, x_k) = \begin{cases} 1 & \text{if } \; x_h R x_k = \text{TRUE} \\ 0 & \text{if } \; x_h R x_k = \text{FALSE} \end{cases} \tag{1}$$

The symmetric matrix

$$u_{hk} = u^R(x_h, x_k), (h, k = 1, 2, \ldots N) \tag{2}$$

whose elements are 0's and 1's, is the indicator matrix, or auto-correlation matrix. For instance, if the binary relation is

$$x_h R x_k, \text{if Mod}[x_h, k] = 0 \text{or Mod}[x_k, h] = 0 \tag{3}$$

where Mod[x,y] gives the remainder on division of x by y, the indicator matrix for the first eleven natural numbers is where the composition table is obtained by taking into account Equation (3).

Matrix (2) can be plot in 2 dimensions (Figure 1) by putting a black dot where u_{hk} = 1 and white blank when u_{hk} = 0, thus giving rise to the so-called dot-plots, recurrence plots, or binary images [75–78].

Our aim is to characterize the map (3), by some parameters of complexity multi-fractality computed on binary images of a sentence (text) similar to Figure 2.

Concerning the text analysis of recurrence, we can define the binary map as

$$x_h \; R \; x_k \;\; , \quad if \quad x_h = x_k$$

So that, with reference to the above sentence "There's a woman on a hill, and I'm watching her with my binoculars" and its corresponding conceptualization "*E A B E C E A E C D*" we have the following correlation matrix Table 1 (where empty spaces correspond to "0").

$$
\begin{array}{c|cccccccccccc}
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \iddots \\
11 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & \ldots \\
10 & 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & \ldots \\
9 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & \ldots \\
8 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \ldots \\
7 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & \ldots \\
6 & 1 & 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & \ldots \\
5 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & \ldots \\
4 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \ldots \\
3 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & \ldots \\
2 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & \ldots \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & \ldots \\
\hline
u_{hk} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & \ldots
\end{array}
$$

Figure 1. The Mod[x,y] gives the remainder on division of x by y, the indicator matrix for the first eleven natural numbers is taking into account Equation (3).

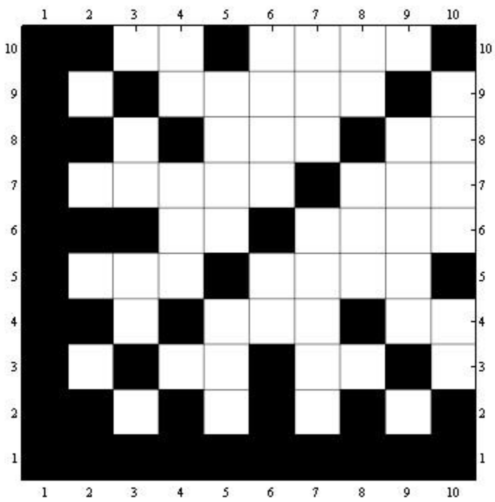

Figure 2. Binary image for the map (3) with n = 10.

Table 1. Correlation Matrix.

D											1
C						1				1	
E	1		1		1		1		1		
A		1						1			
E	1		1		1		1		1		
C						1				1	
E	1		1		1		1		1		
B				1							
E	1		1		1		1		1		
A		1						1			
E	1		1		1		1		1		
	E	A	E	B	E	C	E	A	E	C	D

So that, accordingly, we have the binary plot of Figure 3.

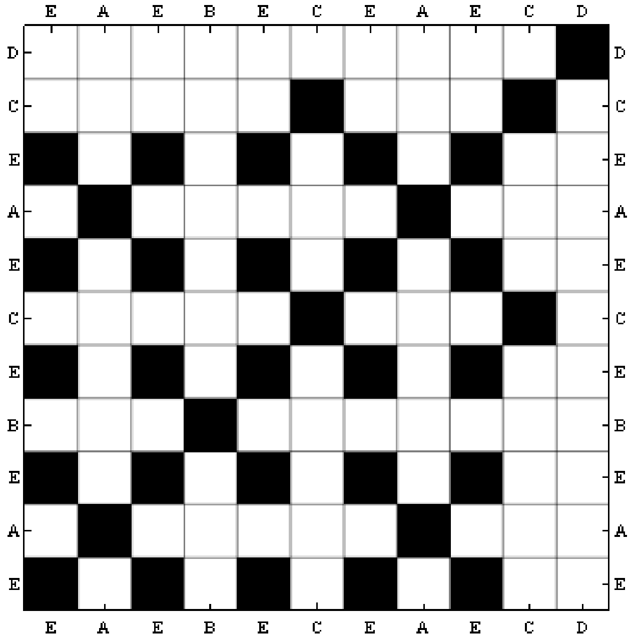

Figure 3. Binary plot for the text EAEBECEAECD.

From where it can be easily seen that there is the recurrent patch of Figure 4.

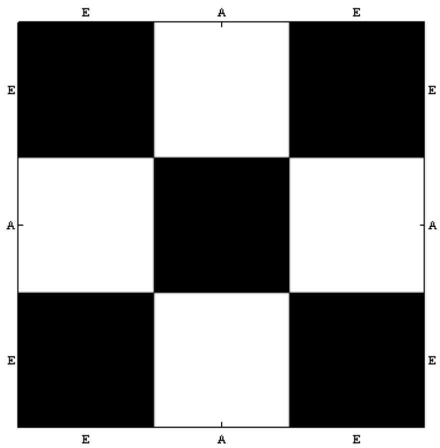

Figure 4. Recurrent patch for the text EAEBECEAECD.

An intriguing aspect of the axiomatic-logical linguistic process is that recursion appears in the logical chain (as shown in Figures 1–4), and it can also be seen in the axiomatic feature (linked to the human body, whose subsystems serve the linguistic process until reach the individual's mind). As an example, Cattani [75] shows a matrix that allows the recognition of nucleotide distribution patterns in the DNA sequence of the influenza virus, proving the recurrence of hidden symmetric geometries, underlying biological structures. The author [77] notes that even the primitive organisms that colonized the Earth had these restrictions of more evolved DNA.

7. Stimuli and Recursion in the Unique Set of Language Structures

Having seen the mathematical explanation of how typical patterns or distributions occur in a temporal series, showing autocorrelation between the elements of the sequence, it appears that this structure: (i) in the dynamic view of language [68], is capable of not only registering information as a set of stored possibilities to guide decision making [70];

(ii) it is also capable of interpreting sensory inputs [71], making inferences [73] and making predictions [74]. The linguistic process is considered the unique set of structures with which other domains of the mind maintain relations [25].

Based on these premises and considering cognition as part of the linguistic process, connected to perceptual systems, we bet that there is an 'online' process in which perceptual information is translated into symbolic language so that it can be combined with other sources of information [25] (p. 4).

In other words, there is a circuit—that is a dynamic process intended for conceptual construction, for the formation of cognition so that stimuli are intelligible to the individual—between recursion and the axiomatic-logical linguistic process that presents the following characteristics: (i) while the axiomatic feature connected to the human body collects stimuli from the environment and takes them to the central cognitive system, the logical feature is in charge of relating and organizing these stimuli according to a 'syntax' so that they become intelligible to the human being; (ii) the recursive process encompasses the dynamic aspect essential to the conceptual production of human language.

Considering both aspects (i and ii), we can say that the characteristics of the input stimuli are preserved during their journey through the subsystems of the human organism (visual, auditory, tactile etc.) until reaching the central cognitive system. Once the human mind is reached, the dynamic linguistic process takes care of transforming the stimuli into a symbolic language, through correlations established by the recursive process. It is in this way that the human conceptual language process avoids interference in the construction of meaning. For researchers and technicians who deal with computational linguistics and want to reach the state of the art in intelligent systems rejecting the ambiguity and curse of dimensionality, it is not enough to work with logically related symbols. It is essential to consider the recursive process, so that cognitive computing can mimic human cognition in its dynamics and perform its intuitiveness.

As it is known, the logical aspect of cognition is very present in the literature on the subject. We dedicate this and the following paragraphs to reinforcing the axiomatic aspect of language conceptual formation, which is less explored, but no less important. It is to be thought that changes in the subsystems themselves (problems with the visual, hearing etc.) or changes in the stimulus circuit (trauma, violence), as they are part of the linguistic process, will interfere in the construction of meaning, that is, there will be other factors that will influence the recursive process being decisive in the result of the conceptual formation. Although these factors or phenomena are researched separately, we can see some examples that show their direct interference in the meaning formation.

Livingstone [79] looks at perception in artists and finds evidence that a surprisingly large number of talented artists, including Rembrandt, can be stereoscopic, and makes use of this discovery to study the effects of this evidence on their artistic interpretation. Brady et al. [80] state that aphasia is a language deficiency resulting from brain injury that affects some or all the language modalities, such as: expression and understanding of speech, reading, and writing. For Farthing [81], the change in the meaning or in the way of interpreting the phenomena should not be merely quantitative (for example, great excitement), as it is a multidimensional phenomenon that alters the cognitive process, externalized as changes in the general pattern of subjective experiences (if there is cognition, there is language [18]. Aphasia cases or linguistic disorders are reported by patients who underwent war trauma, natural or environmental disasters [82]. Miragoli et al. [83] evaluated the narrative fragmentation in individuals with memories of child sexual abuse, stating that the traumatic effects interfered in the coherence and cohesion of the narratives of child testimonies. Mullen [32] has highlighted a connection between a history of sexual aggression with affective disorders, exaggerated reactions, and mistaken zeal, showing an imbalance in the way these individuals interpret reality.

8. Conclusions

In conclusion, it is necessary to take natural language as a process, as a whole picture integrating several elements: the linguistic system encompassing the body, the context of reality from which the stimuli were collected, the logical chaining by the central cognitive system, and the recursive process representing the dynamics of the concept construction process. This broad view of the linguistic process fits our concept of language as an axiomatic-logical process of meaning construction. Sanitizing language, removing emotion and subjectivity from it, leads us to an abstraction that, when put into practice, proves incapable of portraying reality. According to Saussure [34], who founded the science of linguistics, the construction of meaning occurs in the relationship of one word with the others. This article expands on this relational structure, showing that interpretation, the use of language by the subject, is also related to the social context [38] Foucault, [84–86], under a process that absorbs the input stimuli of the context until the formation of the meaning in the central cognitive system, thus constituting a sui generis set of structures.

The axiomatic-logical conception of language has the necessary aspects to house the recursion as demonstrated in this article. Recursion also presents itself as the underlying structure of mechanical procedures and computing structures. Considering the overlap of these characteristics of the linguistic process, making them overlap in humans and intelligent systems, guides technicians and scholars of artificial intelligence not to follow false leads, not to give importance to the sabotaging elements that bring doubts or distract with ambiguity. The axiomatic-logical conception of language by housing the process of meaning construction through recursion, organizes the elements at stake in a synchronized way, making it evident that the essence of language, whether natural or artificial, is 'a form and not a substance' [34] (p. 141).

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