Linguistic Neuroprogramming

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Abstract: This article aims to summarize how the organization of knowledge and memory in the cerebral cortex, the dynamics of the perception-action cycle and the integrative functions of the prefrontal cortex bear on the integration and programming of human language.

Key words: cognits, syntax of action, hierarchy in cortex, hierarchy in language, perception-action cycle, cross-temporal contingencies, prefrontal cortex.

Late in evolution, one particular brain structure and one particular cognitive function undergo enormous development: the first is the prefrontal cortex and the second is language. As this article argues, the two are intimately related. In the human, the prefrontal cortex reaches the size of almost one-third of the entire cortex; especially striking is the exponential evolutionary growth of prefrontal fibers and connections, well beyond the growth they reach in the large apes. At the same time, precisely because of that extraordinary growth in cortical connectivity, the primitive communication ability of the ape becomes language in the human. Thus, the question of the evolutionary continuity or discontinuity of either prefrontal function or language becomes moot. There is indeed a quantitative progression from animal to man in the development of the function of the prefrontal cortex and in the ability to communicate cognition and emotion; but the progression is so large and "sudden", and exponentially so steep, that for all practical purposes both are step functions, qualitatively new and uniquely human.

That does not mean that the mechanisms of language construction and the role of the prefrontal cortex in them are totally new in the human and unprecedented in evolution. They are not. In fact, the spoken (or written) language is a complex and purposeful form of behavior, organized and extended in time much as any other complex and aim-directed behavior in man or animal. Therefore, the *principles* of language construction and the role of the prefrontal cortex in it apply to all forms of complex serial behavior. They do not basically differ between the human and other mammalian species.

However, we cannot treat language programming quantitatively, as has been done with animal behavior. The reasons are many, but can be summarized as follows: (a) All propositional language is essentially *new* and irreducible to generic algorithms, and so are the plans and schemas of behavior in which the prefrontal cortex specializes; (b), new language is *multi-factorial*, the result of many neural and psychological influences, some of which are unconscious and imponderable; and (c), the cognitive functions of the prefrontal cortex that make language (e.g., planning, attentional set, working memory and decision-making) are *probabilistic* and obey Bayesian rules.

It may be argued that normal propositional language is programmable and, like machine language, quantifiable. Indeed machine language is quantifiable (i.e., digitized, by definition), lineal, and deterministic in its conveyance of meaning. But machine language is not real language—this one with practically infinite recursive capability, novelty and spontaneity. The application of logic to machine language does not make it any more human. Furthermore, in this article I am not dealing with "Neurolinguistic Programming," as advanced by Bandler and Grinder (Dilts et al., 1980) in a theoretical approach that was based on quasi-magical reasoning and poor data.

In a famous paper entitled *"The problem of serial order in behavior,"* Harvard psychologist Karl Lashley (1951) uses language as an example of the temporally integrative *syntax* of goal-directed action. He attributes theoretically that role to the cerebral cortex, and even proposes that within the cortex there must be an "agent of order." Today we know that that "agent" is the prefrontal cortex. But in Lashley's time, we did not know nearly as much as we know now about (1) the organization of knowledge and memory in the cerebral cortex, (2) the dynamics of the perception-action cycle, which is essential for speech, and (3) the integrative functions of the prefrontal cortex in language. The purpose of this article is to summarize how these three interrelated subjects bear on the integration and programming of human language.

1. COGNITIVE ORGANIZATION IN THE CEREBRAL CORTEX

As far as we know (reviews in Fuster, 2009, 2010), all memory and all knowledge are stored in an immense organization of widely distributed, overlapping, and interactive neuronal networks of the cerebral cortex named cognitive networks or *cognits*. A cognit is thus a unit of memory or knowledge; it is made of all the cortical neuron assemblies that have been simultaneously excited by learning or life experience. The simultaneous excitation of two nerve cells or cell groups that are connected with one another by nerve fibers will modulate their synaptic contacts, in such a manner that, afterwards, the excitation of one will lead to the activation of the entire network, the entire cognit. This is the essence of memory acquisition and recall. A new sensory experience can not only tie together the cells representing the sensory components of that experience, but also can tie together those cells with other cells in old, preexisting cognits with which the new experience has relations of association or similarity. In this manner old cognits expand with new experience; in other words, new experience updates, expands, strengthens and modifies old memory. This is in the essence of learning, including the learning of language.

A given cognit, that is, a memory or item of knowledge, is not made of synapses of equal strength. The strongest will be synapses that connect the most salient and repeated experiences. These will form the core of the cognit. The weakest will be synapses that link the cognit with other more distant or softer experiences with which that cognit maintains more distant connections, in time and in brain space. Therefore, the core of a cognit is surrounded by a penumbra of weaker associations which may play a critical role in the rehabilitation of a memory when its core has been destroyed by trauma, disease or aging.

Cognits, old and new, share network nodes in common. These are made of cell assemblies with heavy associations that represent common features of several cognits (for example, the yellow color in the canary, the emblematic rose of Texas or the taxi cab in Barcelona). It follows that a neuron or group of neurons practically anywhere in the cortex can be part of many memories or items of knowledge.

With life experience, learning and rehearsal, cognits self-organize in the cerebral cortex, where they establish connections with other cognits. The cortical organization of knowledge, which incorporates the new cognits as they are formed, is hierarchical; in reality, there are two hierarchies, one in posterior cortex for perceptual cognits acquired through the sense organs and the other in anterior, frontal, cortex for executive cognits acquired through movement or motor systems (Figure 1).

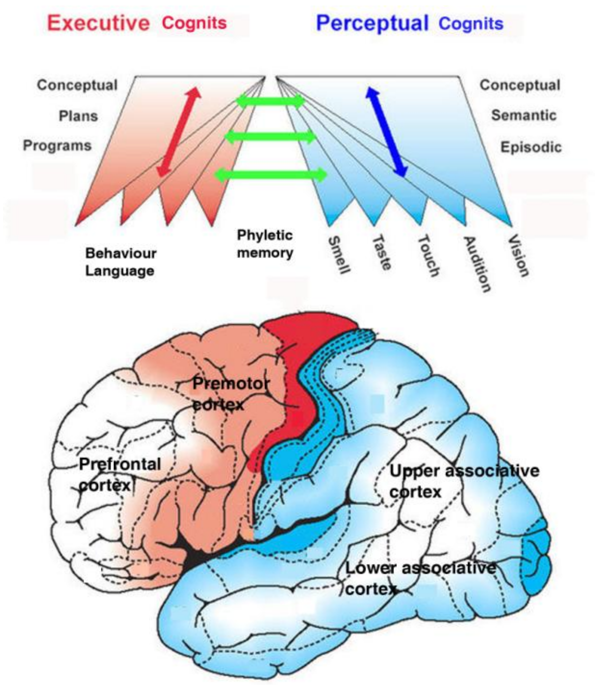

Figure 1. Diagram of the hierarchical organization of memory networks (cognits) in the human cortex. *Lower figure:* The posterior cortex is shaded blue to white from primary sensory to association areas, the frontal cortex red to white from primary motor to prefrontal cortex. Primary sensory and motor areas are marked in *darker blue* and *red*, respectively. *Upper figure:* Gradients of development and hierarchical organization of cortical cognits, with the same color code as in the map below. Bidirectional arrows symbolize: *blue*, perceptual cortico-cortical connectivity; *red,* executive cortico-cortical connectivity; *green*, reciprocal connectivity between posterior and frontal cortices, essential for the perception-action cycle (below). As they grow upwards in the hierarchy, cognits become more widespread and represent progressively more abstract memory and knowledge.

The simplest, most concrete perceptual cognits are formed and have their roots in the lower layers of the perceptual hierarchy, in or near sensory cortices, which I call "phyletic" memory or memory of the species. I call these structures "memory" because they contain the evolutionary and genetic adaptive memory of the species in dealing with the sensory world in which we live. All individual memory enters the organism through phyletic memory before it finds its appropriate level in the hierarchy. Likewise, in frontal cortex, there is a hierarchy of executive networks with a base and root in phyletic motor memory, the motor cortex. At the top of both hierarchies, in posterior association cortex and in prefrontal cortex, are the cognits representing the most conceptual and abstract aspects of perceptual and executive memory/knowledge, respectively.

It is important to note that many, perhaps most, cognits are heterarchical, in that they contain information from various hierarchical levels of abstraction. It is also important to note that both hierarchies (perceptual and executive), at all levels, are interconnected "horizontally," which explains the existence of mixed, perceptual-executive cognits. As we will see, these are functionally critical in the perception-action cycle and in speech. In fact, for the structuring of language, the entire cortical organization of cognition is critical, because it contains the information that all language utilizes. The concepts of "language areas" and "language modules" are outmoded. It is impossible to separate language content from speech function. The cortical infrastructure is the same for both. That means that neuroprogramming is inseparable from the neural structure of knowledge.

Finally, all cognits have lexical connections. Among the many associations (synaptic contacts) that form them are the associations with phonetic sounds and graphic symbols; those lexical associations are parallel to the cognitive hierarchies. Their collateral organizations for associated words are also to some extent heterarchical, because at their lower levels they incorporate word sounds and at the highest levels the words for abstract concepts. The two lexical organizations, perceptual and executive, as a whole, constitute the brain's *semantic system,* which, like the cognitive hierarchies, is distributed throughout the cerebral cortex.

2. CORTICAL DYNAMICS OF THE PERCEPTION-ACTION CYCLE

Animals adapt themselves to their environment by means of sensory and chemical receptors, motor systems and the autonomic nervous system—for visceral control and emotions. Lower animal species do their adjustment to the environment by reflex arcs through simple receptors and motor effectors. Those reflexes may be conditioned, that is, modified by behavioral learning. In any case, adaptive reactions, whether innate or conditioned, are immediate and automatic, without much regard for their implications in terms of the past or the future.

In higher animal species, the adjustment is much more elaborate and extends considerably in time, backwards and forwards. Changes that have occurred in the past modulate and influence new actions, while these acquire a temporal perspective into the future. In the pursuit of a goal, sensory systems inform motor systems, which will implement the appropriate actions toward that goal. These actions will produce changes in the environment, which in turn will be analyzed by sensory systems, which will modify the actions, and so on until the goal is reached. This cybernetic circling of influences back and forth through the environment and the nervous system is what we call the perception-action (PA) cycle.

Also in higher animals, the PA cycle is supplemented by an important new set of connections: internal fibers, inside the brain, from effector (motor) systems to sensory systems (Uexküll, 1926). These "backward" internal connections, close an internal cycle that parallels the external PA cycle and provide the latter with a future dimension. Thus, thanks to that internal cycle, the PA cycle becomes future-oriented and, therefore, not only adaptive but also preadaptive. It predicts future events and adjusts to them before they happen. That capacity to predict is largely based on past memory and knowledge (Fuster and Bressler, 2015). Here is in summary what that backward internal cycle does: (a) it prepares sensory systems (attentional perceptual set) for the expected consequences of ongoing action, (b) it prepares motor systems (attentional executive set) for impending action, (d) it helps store in working memory the information which is going to guide that action to its goal, and (e), because of those prospective functions (a-d), the internal cycle plays a critical role in decision-making. These cognitive functions assist the prefrontal cortex to mediate cross- temporal contingencies and to establish order in a given goal-directed sequence of actions (Figure 2). Both are essential for the structuring of the spoken language.

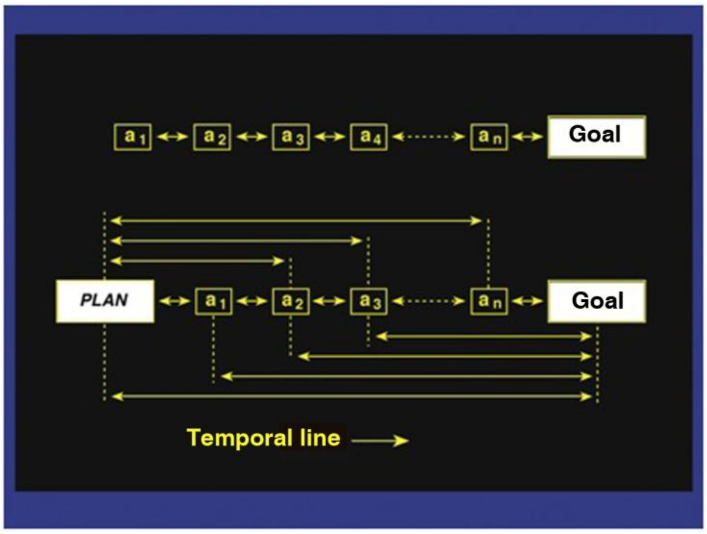

Figure 2. Succession of acts ($a_1 \ldots a_n$) in a plan toward its goal. Two-way arrows represent cross-temporal contingencies. Some of them link individual acts to each other, while others link individual acts to the plan or the goal of the action, and still others link the plan to the goal. In the upper figure is a chain of habitual or instinctual acts, where each act is strictly contingent on the immediately previous one and the succeeding one without cross-temporal contingencies between them. The prefrontal cortex is needed for integration of the lower sequence, not the upper one. If we substitute words for acts, we have the structure of a piece of spoken language, where the cross-temporal contingencies are grammatical and syntactic.

Now we can illustrate, however schematically, the PA cycle running through the environment and the cerebral cortex (Figure 3).

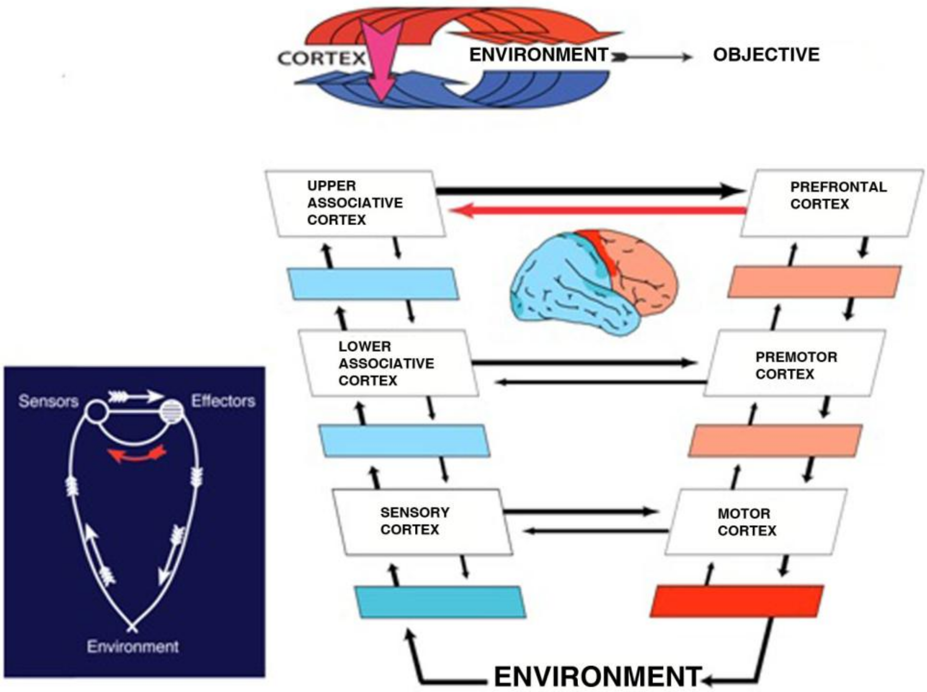

Figure 3. *Upper figure*: Schematic diagram of the PA cycle (thick blue arrows through perceptual hierarchy, and red arrows through action hierarchy). The *internal* cycle is indicated by a vertical *pink* arrow. That intra-cerebral circuit (indicated by red arrow in Uexküll's schema *below left*, and also by red arrow *below right,* from prefrontal cortex to superior associative cortex) is essential for future-oriented cognitive control functions (section 3). *Lower right*: General cortical circuitry of the PA cycle. Unlabeled rectangles represent cortical areas intermediate between labeled areas or sub-areas of the latter. The perceptual cognitive hierarchies are depicted on the left, the executive hierarchy on the right. The major connectivity of the cycle runs through thick arrows. Thin arrows mark intra-cortical feedback connections.

The figure shows the cerebral pathways that mediate the performance of a series of consecutive actions toward a goal. Each turn of the cycle involves the feed-forward action of the cycle toward the goal, the sensory feedback from the effects of the action on the environment, the matching in the cortex of those effects with regard to the plan and the goal, and the correct preparation of the next action. All actions require the cognitive control of the prefrontal cortex for the mediation of cross-temporal contingencies and for the future-oriented functions of attention set, working memory, decision-making, and inhibitory control of interference.

The purpose of the previous section (1) and of this one (2) has been to outline the principles of the cortical organization of memory and knowledge, including semantic and lexical knowledge, which is to play an essential role in the structuring of the spoken language. The important point of both sections is to set the neural stage for the dynamic principle that *the syntax of speech is a special case of the syntax of goal-directed action* (words in language). This is most evident when applying the PA cycle to the spoken or written language. Each semantic expression, whether it is a word, a sentence or a piece of discourse, is a turn of the cycle. It is an action informed by knowledge (semantics and lexicon in posterior cortex) that the subject executes upon the environment (the listener or the written page). That action produces certain effects on the environment that the subject, via sensory feedback, analyzes in association cortex to inform the next semantic expression; that next expression is informed not only by the sensory effects of the previous one but also by internal feedback (internal PA cycle). This internal feedback contains "efferent copies" of the output (listening internally to oneself) and predictive signals from the prefrontal cortex (next section).

The spoken dialog between two persons is a vivid example of two PA cycles *interlocked* with each other; the environment in this case is the interlocutor. The goal is mutual understanding or the convincing of the interlocutor. Each speaker will mobilize his/her own PA cycle, which will guide the dialog to that goal assisted by memory, knowledge and reasoning as well as by the effects of one speaker's pronouncements on the thinking and speech of the other speaker.

3. THE PREFRONTAL CORTEX IN LANGUAGE

The prefrontal cortex contributes to language two fundamental qualities: the syntax and the future tense. Both derive from the role of this cortex in the PA cycle and in its control of prospective, that is predictive, cognitive functions.

In the same manner as with coordinated goal-directed actions, the prefrontal and posterior association cortices, at the top of the PA cycle, coordinate the execution, the programming, of the spoken language. By mediating cross-temporal contingencies, that is, by integrating words across time, the prefrontal cortex, which is the highest stage of the executive cortical hierarchy, takes a leading role in the creation of language and its meaningful expression. The prefrontal cortex has the unique ability to *propositionise* (Jackson, 1958); that is the ability to construct new meaningful statements. Interestingly, the vocable “propositionise,” originated by the neurologist Jackson, implies two properties of language that intimately relate it to prefrontal function: one is novelty and the other, more subtle, is the intention of future influence on the environment—the interlocutor, the reader or the audience. Let us briefly consider the two properties, novelty and future, which, in addition to the previous two sections, place language fully within the purview of the prefrontal cortex.

In 1970, Noam Chomsky, in a public lecture (Peck, 1987), declared the following: “*Language is a process of free creation; its laws and principles are fixed, but the manner in which the principles of generation are used is free and infinitely varied. Even the interpretation and use of words involves a process of free creation.”* The key to novelty in language is that, with a limited set of rules, one can construct a practically infinite variety of expressions, given that the semantic material to which those rules are applied is practically infinite. Because the language code (the lexicon) is a relational code, based on relations (associations) between words, and because words are represented in neuronal assemblies in widely differing cortical locations, the creative power of speech resides in the combinatorial power of those assemblies and the material they represent, which is practically infinite.

What is finite, as Chomsky maintains, is the set of rules that make the spoken language an orderly goal-directed activity. These rules are generally well defined; in the case of language, they are called grammar. (This is not the place to discuss Chomsky’s concept of “universal grammar”). Like all forms of goal-directed activity and the material they work with (cognits), the grammar of language is *hierarchically organized*, as are also the performance of manual tasks and music making. The hierarchical organization of a goal-directed activity such as those depends essentially of (1) a neurally defined schema of the action, a high-level cognit of the plan or program and its objective, most probably in anterior prefrontal cortex, and (2) a series of temporally ordered sub-routines controlled by that “umbrella” cognit and leading to the goal. The control of the sequence consists basically of the mediation of cross-temporal contingencies by the prefrontal cortex engaged in the PA cycle.

Modern neuroimaging of human subjects during the execution of behavioral tasks, spoken language and music making, provide increasing evidence of the hierarchical dynamics of these activities in the prefrontal cortex. A recent review of the relevant studies has recently been published (Jeon, 2014). Figure 4 nearby, from that review, represents the structure of the executive hierarchies of both speech and music. The figure shows not only the commonality of the hierarchical principles of that structure for the two activities, with its nesting of subroutines and recursion, but also the theoretical and empirical neural basis for the serial mediation of cross-temporal contingencies from plan to goal in the prefrontal cortex.

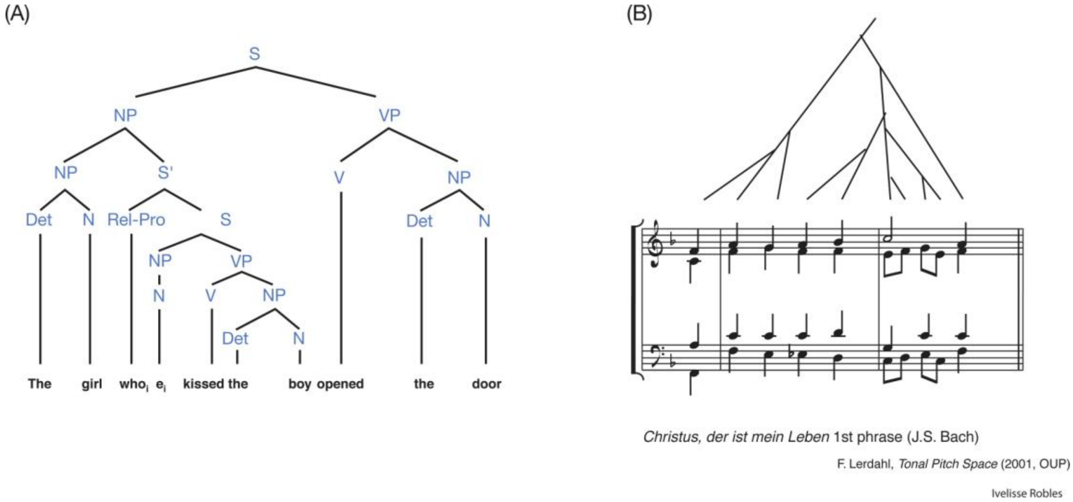

Figure 4. Similarities in hierarchical structure between language and music. (A) An English sentence. The syntactic tree depicts the hierarchical relations among words and phrases. Abbreviations: S, sentence; NP, nounphrase; VP, verbphrase; S', sentence modifier [relative clause]; N, noun; V, verb; Det, determiner; Rel-Pro, relative pronoun. (B) A phrase from a composition by Johann Sebastian Bach. The phrase is overlaid by a syntactic tree depicting the hierarchical pattern of tension and relaxation embedded in larger scale motions. (From Patel, 2003, slightly modified by Jeon, 2014, with permission).

The second fundamental property of prefrontal dynamics, which is eminently applicable to language, is its future quality. That, too, comes from elementary biology. The prefrontal cortex is the part of the organism that preadapts the nervous system to the environment; as such, it predicts future events—including the organism's own actions—and adapts the organism to them before they take place (Fuster, 2014 Fuster and Bressler, 2014). The essence of our argument is that the dorsolateral prefrontal cortex supports four cognitive-control functions that are future-oriented and play a critical role in the PA cycle and in the mediation of cross-temporal contingencies. All four are critical to the spoken language and rely on interactions between that cortex and other cortices (containing memory and knowledge of the past), as well as with sub-cortical structures:

(1) *Planning,* to self-predict trains of goal directed actions.

(2) *Attentional set*, to prime selectively sensory and motor system for anticipated inputs or actions.

(3) *Working memory*, to retain an item of information *for* an anticipated action.

(4) *Decision-making*, to choose one among several alternative actions.

These functions, the essence of so-called *cognitive control*, constitute what makes the prefrontal cortex a preadaptive brain structure. Inasmuch as preadaptation implies prediction (from Latin, *praedicere*, to foretell), it is essential to all language that refers to future action. More generally, the prefrontal cortex can be construed as the maker of the future of the organism and the foundation of its creative power.

The four aforementioned functions are predictive of a more or less distant future. In the human brain, that future extends much more distantly than in lower animals. For this reason, the human PA cycle can extend to years and decades, containing countless shorter cycles, each with its programmed subroutine. But the predictive power of those functions is solidly based on the past and updatable (Fuster and Bressler, 2014 in press). In that sense future action and language are subject to Bayesian probability (Jaynes, 1986). Their effects on the environment (e.g., the interlocutor) are based on past hypotheses that are modifiable by new experience, and liable to retest and modification.

In former times, the spoken language was relegated to two discrete areas of the cerebral cortex of the left cerebral hemisphere: one posterior, in the temporal-parietal region, dedicated to the understanding of the meaning of language (Wernicke's area), and the other anterior, in the in ferior prefrontal cortex, dedicated to the articulation of language (Broca's area). Today we know that the two areas in question represent only two relatively small portions of the cognitive cortex and the PA cycle, although dramatic speech disorders (aphasias) can result from their lesion.

The latest evidence from neuropsychology and neuroimaging, however, implicates in speech practically the totality of the neocortex (the last cortex to develop phylogenetically in evolution, and ontogenetically in the individual), including the cortex of the right hemisphere. To the best of our knowledge (Section 1), that evidence is attributable to the widespread distribution of cognitive networks (cognits), those countless networks that are involved or can be involved in language. As a consequence, a large variety of speech disorders can result from disease or trauma of the cerebral cortex in numerous locations.

4. SUMMARY AND CONCLUSIONS

To sum up, large portions of the cerebral cortex participate in the neural structure and dynamic programming of the spoken language. The syntax of language is a special case of the syntax of action. Essentially, the anatomical structure of language consists of a large mass of widely distributed, overlapping and interconnected networks of cortical neurons that represent the memory and the knowledge acquired by life experience. These networks or cognits contain lexical content and associations. Perceptual cognits, with information acquired through the senses, are hierarchically organized mainly in posterior (temporal and parietal) cortex, whereas executive cognits, with information acquired through action, are hierarchically organized mainly in frontal cortex. In any planned and goal-directed sequence of actions, such as speech, practically the entire cortex engages in the PA cycle, which is the cybernetic interface between the organism and its environment. The dorsolateral prefrontal cortex, at the hierarchical summit of the PA cycle, controls its progress toward the goal by four cognitive functions that mediate cross-temporal contingencies, that is, integrate those contingencies in the time domain: planning, attentional set, working memory, and decision-making. All four of these functions are cognitively anchored in the past but have a future orientation. By circular interactions between prefrontal cortex and posterior cortex, they establish syntactic order in the language sequence and guide it to its objective.

5. REFERENCES

DILTS, R., GRINDER, J., DELOZIER, J., AND BANDLER, R. (1980) *Neuro-Linguistic Programming: Volume I: The Study of the Structure of Subjective Experience*. Cupertino, CA: Meta Publications.

FUSTER, J.M. (2014). The prefrontal cortex makes the brain a preadaptive system. *Proceedings of the IEEE* 102, 417-425.

—— (2009). «Cortex and memory: emergence of a new paradigm». *Journal of Cognitive Neuroscience*, 21:2047-2072.

—— (2010). «El paradigma reticular de memoria». *Revista de Neurología,* 3:50. Suppl 3:S3-10.

FUSTER, J.M., AND BRESSLER, S.L. (2014) Past Makes Future: Role of pFC in Prediction. *J. Cognitive Neuroscience* 1-17. (electronic).

JACKSON, J.H. (1958). *Selected Writings*. New York: Basic Books. Pp. 119-212.

JAYNES, E.T. (1986) *Bayesian Methods: General Background. Maximum-Entropy and Bayesian Methods in Applied Statistics*. Cambridge: Cambridge Univ. Press.

JEON, H-A. (2104) Hierarchical processing in the prefrontal cortex in a variety of cognitive domains. *Frontiers in Systems Neuroscience*, 8, 223-233.

LASHLEY, K.S. (1951) The problem of serial order in behavior. In *Cerebral Mechanisms in Behavior,* L.A. JEFFRESS. (ed.). New York: John Wiley & Sons, pp. 112-146.

PATEL, A. (2003). Language, music, syntax and the brain. *Nature Neuroscience*, 2003

PECK, J. (ed.). (1987). *The Chomsky Reader*, New York: Pantheon Books.

UEXKÜLL,J.V. (1926). *Theoretical Biology*. New York: Harcourt, Brace & Co.