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Language and cognition

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ABSTRACT

What is the role of language in cognition? Do we think with words, or do we use words to communicate made-up decisions? The paper briefly reviews ideas in this area since 1950s. Then we discuss mechanisms of cognition, recent neuroscience experiments, and corresponding mathematical models. These models are interpreted in terms of a biological drive for cognition. Based on the Grossberg–Levine theory of drives and emotions, we identify specific emotions associated with the need for cognition. We demonstrate an engineering application of the developed technique, which significantly improves detection of patterns in noise over the previous state-of-the-art. The developed mathematical models are extended toward language. Then we consider possible brain–mind mechanisms of interaction between language and cognition. A mathematical analysis imposes restrictions on possible mechanisms. The proposed model resolves some long-standing language–cognition issues: how the mind learns correct associations between words and objects among an astronomical number of possible associations; why kids can talk about almost everything, but cannot act like adults, what exactly are the brain–mind differences; why animals do not talk and think like people. Recent brain imaging experiments indicate support for the proposed model. We discuss future theoretical and experimental research.

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1. Nativism, cognitivism, evolutionism

Complex innate mechanisms of the mind were not appreciated in the first half of the last century. Thinking of mathematicians and intuitions of psychologists and linguists were dominated by logic. Considered mechanisms of logic were not much different for language or cognition; both were based on logical statements and rules. Even fundamental Gödelian theory (Gödel, 1931/1994) establishing the deficiency of logic did not move thinking about the mind away from logic.

Contemporary linguistic interests in the mind mechanisms of language were initiated in the 1950s by Chomsky (1965). He identified the first mysteries about language that science had to resolve. "Poverty of stimulus" addressed the fact that the tremendous amount of knowledge needed to speak and understand language is learned by every child around the world even in the absence of formal training. It has seemed obvious to Chomsky that surrounding language cultures do not carry enough information for a child to learn language, unless specific language learning mechanisms are inborn in the mind of every human being. This inborn mechanism should be specific enough for learning complex language grammars and still flexible enough so that a child of any ethnicity from any part of the world would learn whichever language is spoken around, even if he or she is raised on the other side of the globe. Chomsky called this inborn learning mechanism Universal Grammar and set out to discover its mechanisms. He emphasized the importance of syntax and thought that language learning is independent of cognition. This approach to language based on innate mechanisms, is called *nativism*.

Chomsky and his school initially used available mathematics of logical rules, similar to rule systems of artificial intelligence. In 1981, Chomsky (Chomsky, 1981) proposed a new mathematical paradigm in linguistics, *rules and parameters*. This was similar to model-based systems emerging in mathematical studies of cognition. Universal properties of language grammars were supposed to be modeled by parametric rules or models, and specific characteristics of grammar of a particular language were fixed by parameters, which every kid could learn from a limited exposure to the surrounding language. Another fundamental change of Chomsky's ideas (Chomsky, 1995) was called *the minimalist program*. It aimed at simplifying the rule structure of the mind mechanism of language. Language was modeled in closer interactions to other mind mechanisms, closer to the meaning, but stopped at an interface between language and meaning. Chomsky's linguistics still assumes that meanings appear independently from language. Logic is the main mathematical modeling mechanism.

Many linguists disagreed with separation between language and cognition in Chomsky's theories. Cognitive linguistics emerged in the 1970s to unify language and cognition, and explain

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creation of meanings. Cognitive linguistics rejected Chomsky's idea about a special module in the mind devoted to language. The knowledge of language is no different from the rest of cognition, and is based on conceptual mechanisms. It is embodied and situated in the environment. Related research on construction grammar argues that language is not compositional, not all phrases are constructed from words using the same syntax rules and maintaining the same meanings; metaphors are good examples (Croft & Cruse, 2004; Evans & Green, 2006; Ungerer & Schmid, 2006). Cognitive linguistics so far has not led to computational linguistic theory explaining how meanings are created. Formal apparatus of cognitive linguistics is dominated by logic.

Evolutionary linguistics emphasized that language evolved together with meanings. A fundamental property of language is that it is transferred from generation to generation, and language mechanisms are shaped by this process. (Christiansen & Kirby, 2003; Hurford, 2008). Evolutionary linguistics by simulation of societies of communicating agents (Brighton, Smith, & Kirby, 2005) demonstrated the emergence of a compositional language.

2. Cognition, dynamic logic, and the knowledge instinct

Consider a seemingly simple experiment. Close your eyes and imagine an object in front of you. The imagined image is vague, not as crisp and clear as with opened eyes. As we open eyes; the object becomes crisp and clear. It seems to occur momentarily, but actually it takes 1/5th of a second. This is a very long time for neural brain mechanisms – hundreds of thousands of neural interactions. Let us also note: with opened eyes we are not conscious about initially vague imagination, we are not conscious about the entire 1/5th of a second, we are conscious only about the end of this process: crisp, clear object in front of our eyes. The explanation of this experiment has become simple after many years of research that have found out what goes on in the brain during these 1/5th of a second.

2.1. Instincts, emotions, concepts

Explaining this experiment requires us to consider mechanisms of concepts, instincts, and emotions. We perceive and understand the world around due to the mechanism of concepts. Concepts are like internal models of objects and situations; this analogy is quite literal, e.g., during visual perception of an object, a concept-model of the object stored in memory projects an image (top-down signals) onto the visual cortex, which is matched there to an image projected from the retina (bottom-up signal; this simplified description will be refined later; see Grossberg (1988)).

The mechanism of concepts evolved for instinct satisfaction. The word instinct is not used currently in the psychological literature; the reason is that the notion of instinct was mixed up with instinctual behavior and other not very useful ideas. We use the word instinct to denote a simple inborn, non-adaptive mechanism described in Grossberg and Levine (1987). Instinct is a mechanism of the internal "sensor", which measures vital body parameters, such as blood pressure, and indicate to the brain when these parameters are out of safe range. This simplified description will be sufficient for our purposes, more details could be found in Gnadt and Grossberg (2008) and Grossberg and Seidman (2006) and the references therein. We have dozens of such sensors, measuring sugar level in blood, body temperature, pressure at various parts, etc.

According to instinctual–emotional theory (Grossberg & Levine, 1987), communicating satisfaction or dissatisfaction of instinctual needs from instinctual parts of the brain to decision making parts of the brain is performed by emotional neural signals. The word emotion refers to several neural mechanisms in the brain (Juslin & Västfjäll, 2008); in this paper we always refer to the mechanism connecting conceptual and instinctual brain regions. Perception and understanding of concept-models corresponding to objects or situations that can potentially satisfy an instinctual need receive preferential attention and processing resources in the mind.

Projection of top-down signals from a model to the visual cortex primes or makes visual neurons to be more receptive to matching bottom-up signals. This projection produces imagination that we perceive with closed eyes, as in the closed–open eye experiment. Conscious perception occurs, as mentioned, after top-down and bottom-up signals match. The process of matching for a while presented difficulties to mathematical modeling, as discussed below.

2.2. Combinatorial complexity, logic, and dynamic logic

Perception and cognition abilities of computers still cannot compete with those of kids and animals. Most algorithms and neural networks suggested since 1950s for modeling perception and cognition, as discussed in Perlovsky (2006a), faced difficulty of combinatorial complexity (CC). Rule systems of artificial intelligence in the presence of variability has grown in complexity: rules have become contingent on other rules, and rule systems faced CC. Algorithms and neural networks designed for learning have to be trained to understand not only individual objects, but also combinations of objects, and thus faced CC of training. Fuzzy systems required a fuzziness level to be set appropriately in different parts of systems, also degrees of fuzziness vary in time, an attempt to select efficient levels of fuzziness would lead to CC.

These CC difficulties were related to Gödelian limitations of logic, they were manifestations of logic inconsistency in finite systems (Perlovsky, 2000). Even approaches designed specifically to overcome logic limitations, such as fuzzy logic and neural networks, encountered logical steps in their operations: neural networks are trained using logical procedures (e.g. "this is a chair"), and fuzzy systems required logical selection of the degree of fuzziness.

To overcome limitations of logic, dynamic logic was proposed (Perlovsky, 2000, 2006a; Perlovsky & McManus, 1991). In the next section we summarize the mathematical description of dynamic logic, here we describe it conceptually. Whereas logic works with statements (e.g. "this is a chair"), dynamic logic is a process from vague to crisp, from vague statement, decision, plan, to crisp ones. It could be viewed as fuzzy logic that automatically sets a degree of fuzziness corresponding to the accuracy of learning models.

Dynamic logic corresponds to the open–close eye experiment: initial states of models are vague. This experiment was recently performed with much more details using brain imaging. Bar et al. (2006) used functional Magnetic Resonance Imaging (fMRI) to obtain high spatial resolution of processes in the brain, which they combined with magneto-encephalography (MEG), measurements of the magnetic field next to the head, which provided high temporal resolution of the brain activity. Combining these two techniques the experimenters were able to receive high resolution of cognitive processes in space and time. Bar et al. concentrated on three brain areas: early visual cortex, object recognition area (fusiform gyrus), and object information semantic processing area (OFC). They demonstrated that OFC is activated 130 ms after the visual cortex, but 50 ms before object recognition area. This suggests that OFC represents the cortical source of top-down facilitation in visual object recognition. This top-down facilitation was unconscious. In addition they demonstrated that the imagined image generated by top-down signals facilitated from OFC to cortex is *vague*, similar to the closed–open eye experiment. Conscious perception of an object occurs when vague projections become crisp and match the crisp and clear image from the retina, and an object recognition area is activated.