ON MENTAL REPRESENTATIONS: LANGUAGE STRUCTURE AND MEANING REVISED

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Abstract: *Based on results from recent studies in neuroscience, cognitive science, brain imaging and psychology, we develop a model of language faculty. We suggest that the entire brain, all its subnets and processes are responsible for the formation of mental representations of the world, obtained gradually by the subject as an actor in the environment. We assume that mental representations are developed using inborn cognitive mechanisms for creating internal information units operated on a continuous bases for the internal 'language of thought' and the external 'language of communication'. We consider that the underlying mental processing is self-centered and uses inborn operations such as 'projection of the actor' and 'mirroring'. We discuss the four levels of cognitive apparatus related to the language faculty (perceptual, syntactic, semantic, and communicative). Language development relies on species-specific mental operations that comply with the general laws of efficient growth in biological systems, the laws that account for both the effective reiteration of the minimal meaningful unit in syntax and the semantics of concept formation.*

Keywords*: brain activity, fMRI, language, semantic space, concept, syntax, semantics*

ACM classification keywords *I.2.0: AI General I.2.7: Natural Language Processing*

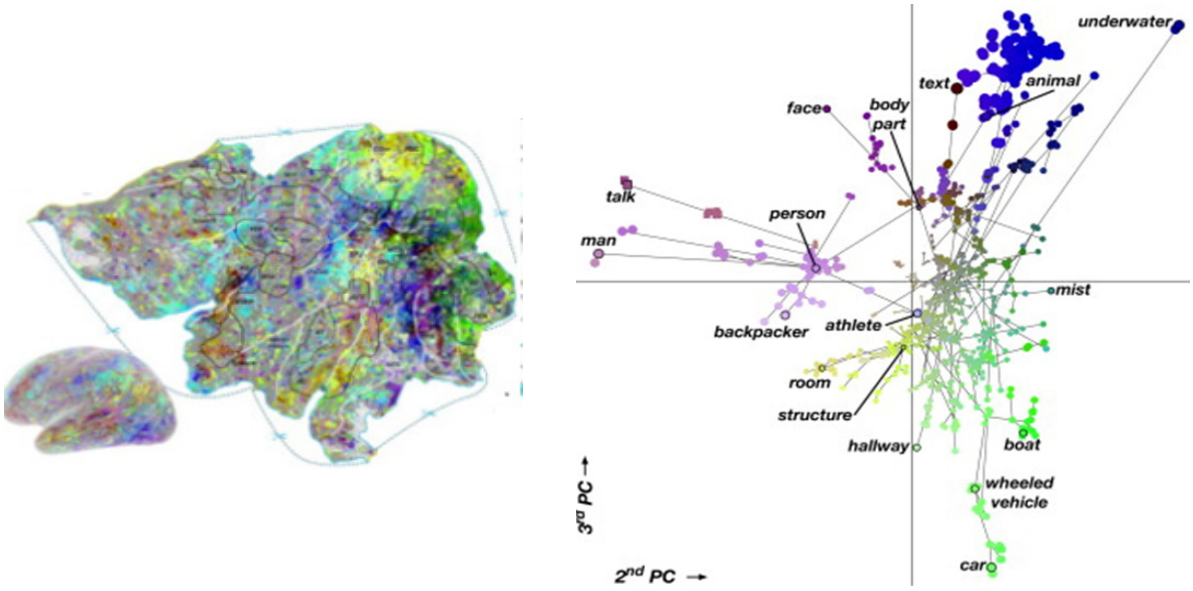
Language: Syntactic Module and Semantic Space

We don't know why language "happens" in humans. This question is related to semantic space and operations that human can perform mentally but other species cannot.

It was shown in a recent fMRI study that the detailed brain activations are practically identical for 5 humans presented with the same object and/or action [Huth et al., 2012]. The authors found that the brain groups the perceived 1,705 entities and events into categories within a continuous space, organized into broad gradients across the cortical sur-face (Fig. 1.a). This brain activation is shared across different individuals. *We consider this overall brain activity evoked by the same perceived objects to be an overall brain representation - image of the world in the joint brain-space.*

Having analyzed individual and group variance and performed Principle Component Analysis (PCA) of fMRI data, it was found that 4 Principle Components (PC) are common across individuals. The sixth to ninth PC-axes explain more "personal" variance, suggesting that while the subjects share broad aspects

of brain activations, the finer-scale representations are *subject-specific*. A projection of the internal organization of this brain-activation fMRI data is shown in Fig. 1.b., where the axes are obtained by means of PCA. The points show clear clustering of the overall brain-activations in response to the perceived objects and actions. What is of great consequence for our analysis is the existence of brain activations (points in Fig. 1.b.) which show that certain objects cause a specific activation positioned farther from other points: "man (human being)", "face", "body", "animal", "text", "underwater" and "car".



a) b)

Fig. 1. Huth A.G. et al. (2012) [1].

a) Activations represented across the cortical surface, left hemisphere;

b). Projection of the brain activations corresponding to the perceived objects and actions, plot after P**C**A of fMRI data.

Huth and colleagues projected the data from brain activations on Word Net graph. The 4D fMRI clusters are shown with different colors in Fig. 2, where the nodes are language units and the vertices correspond to "is a" relation showing Word Net semantic categories. The first PC discriminates across moving objects such as "person," "vehicle," and "animal", and stationary objects such as "sky," "city," "building," and "plant". The analysis of the similar brain activation appearing on the rest of the axes (3D, fig. 2.b.) highlights the following categories [Huth et al., 2012]:

- Humans, human body parts, communication verbs ("gesture" and "talk");

[1] we used color reversed figures because of the printing specificity, please see the original figures in the source, http://www.sciencedirect.com/science/article/pii/S0896627312009348#gr4

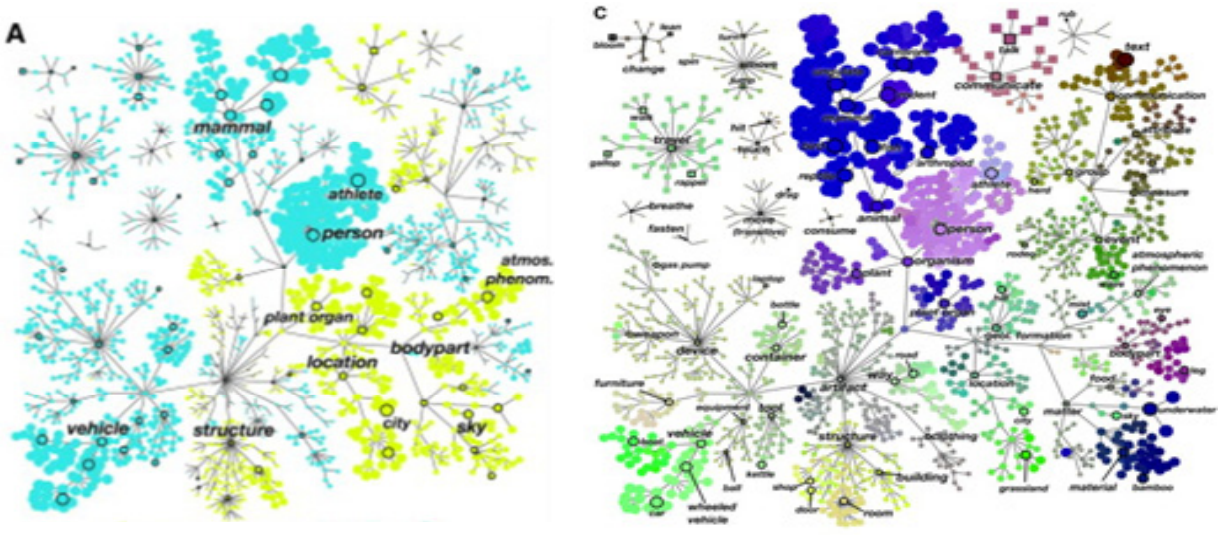
- Animals (related to action verbs, the first PC);
- Inanimate objects such as "vehicles", movement verbs (e.g., "run"), outdoor categories (e.g., "hill," "city," and "grassland"), and paths (e.g., "road");
- Indoor categories (e.g., "room," "door," and "furniture").

This has suggested three main points, important for our approach:

1. The brain-activation categories are related to features that come from the observed behavior: objects are strongly discriminated following their capacity to move by themselves - human beings and animals appear together with *movement verbs*, including transitive verbs as a sub-cluster. Further, another type of actions appears – communication verbs, where "human" and "talking" are related (but animals are not included).

2. The brain-activation image of inanimate objects used for transportation such as "vehicle" and "boat", together with "city" and action verbs such as "travel" and "walk" show similarity, which suggests that these categories are inferred by *personal experience* regarding the object in question. The ***first person*** point of view is further confirmed by the existence of the *indoor category* that includes "door", "furniture", "laptop" and "bottle".

3. The following observation supports the hypothesis developed in the present work: Verbs that comprise about 10% of all the words in a language do not have as clear and strong brain-activation image as nouns; thus, *verbal activation is always related to "noun" categories.*



a) b)

Fig 2. Huth A.G. et al. (2012). **(**Projection onto the WordNet graph)

a) First PC, discriminating across moving objects,

b) The second, third, and fourth PCs, similar colors are for points close in the FMRI space, (see analysis in the text).

All in all, the results of Huth and colleagues show that the manner in which mental representations are grouped are only partially coincide with the organization of words into categories, such as those derived following the explicitly defined human knowledge about the underlying nature of the world.

Mental Representations and Meaning

The terms 'mental representation' and 'meaning' have a variety of interpretations in psychology, philosophy, and cognitive sciences, where each definition cannot be used out of a particular context. To tackle this problem *we define a mental representation as a distinguishable mental state that complies with the underlying inherent rules of mental function for information processing in the brain*. In our theory, mental representations of objects are in fact information units which exist if there is a distinguishable brain image corresponding to each of them. The individual mental representations are shared on the most informative 4 dimensions of the fMRI entire-brain signals where subject-dependent differences appear to be small. This allows the subjects to "comprehend" each other, sharing the same mental basis for representing the world.

Our claim is that mental representations appearing in the "semantic fMRI space" are formed from "*the first-person point of view"*. This brings into question the notion of "self-reference" which is another mystery yet to be if not resolved fully but at least better understood.

Our general assumption is that mental representations arise due to the necessity on part of the subject to act in a particular way in order to survive and function adequately in the environment (following Lawrence Barcalou [Barsalou, 2003]). These representations are similar for different individuals because they depend on the same operational basis for representing the world. *The species-specific mechanism in-wired in humans as a unique mental capacity, empowers a person with the ability to gradually develop a mental representation of the world in interaction with the environment and with others.* This common basis allows each individual to operate synchronically on mental representations within their mental space and to communicate by sharing information. The inter-functioning types of communication of relevance are the internal language of thought and the external language of communication, both intrinsically inter-connected and co-functioning on a continuous basis. Within the model of 'group cognition' the subjects have practically identical neurological mechanisms for perception and action resulting in similarity of each particular mental representation.

Following the analysis proposed by Barsalou and colleagues [Barsalou et al., 2003], a grounded concept arises because of multimodal sensory-perceptual input and previous experiences and actions of the individual. This is in line with the neuron network model proposed by van der Velde that exhibited the stages in the evolution of an organism, where neural circuits mediate between perception and action, and a grounded representation in neurons arises when the neuron input is moderated by

feedback loops, thus causing the auto-moderated circulation inside the system, exhibited as brain circuits and areas involved in the formation of a particular mental representation [van der Velde, 2015].

In this work, we offer the model of mental processing in which the subject's brain gradually builds up a mental representation that has *meaning* if the perceived information is of importance for the subject's survival-oriented behavior in the environment. We call such a representation a Concept. Concepts are gradually formed representations of the world that comprise the over-all brain picture which is coherent with the perceived world and the individual self-centered mental representation of it. *This gradual mental formation is genetically predetermined and is in fact the system of the brain that utilizes its overall capacity and provides the essential mechanisms to develop both the internal (thought) language and the external (communication) language.* Further, we assume that a newborn has the initial self-concept 'the actor in the environment'. We take under consideration the following capacities of the newborn:

1. ***Proprioception***. The brain integrates its overall sense of body position, its movements and acceleration from the signals received by the proprio-receptors situated in the skeletal muscles and joints, and from the vestibular system. The categories "animate"/"inanimate" are formed due to the discriminating capacities of receptors that rely on proprioceptive information which allows the perceiving subject to know that she is "animate" [Dellantonio et al., 2012]. The fetuses are proprioceptive months before birth and can suck their thumbs, rub their eyes, touch their ears, toes and feet. This process determines the categorical dichotomy "animate"/"inanimate" as more basic than other analogous categories such as "living"-"non-living" and provides correspondence to categories in the mental fMRI-space (section 1).
2. ***Interception***. The brain integrates the perception of pain, hunger, etc. The facts that pain is integrated during gestation and that the neonates can experience and respond to painful events are well documented and confirmed in a number of medical and brain studies ([Santos et al., 2001]; [Efrat, 2012]; [Mikos, 2014]; [Knauer, 2014]; [Sinkey et al., 2015]).
3. ***Exteroception***. The multimodal perception and synchronization of modalities occurs prior to birth. A developing fetus auto-generates sensory information which is used to guide neurogenesis. Patterned, spontaneous activity is observed in developing neural circuits, in-cluding the retina, cochlea, spinal cord, cerebellum and hippocampus. Prior to acquiring the capability to transform physical stimuli into patterns of neuronal activity, the developing sensory organs generate bursts of action potentials that convey key information for sensory circuitry assembly ([Blankenship & Feller, 2010]; [Bonetti& Surace, 2010]).

All of the above suggests that a neonate has a certain initial self-concept as an actor in a particular environment.

Most recent results in neuroscience have identified some specific inborn brain networks crucial for the operations responsible for generating mental representations of the world and language capacity.

Default Mode Network (DMN) is a network of brain regions that are active when the individual is not focused on the outside world. In children the regions of DMN are largely local and organized by their physical location, while in adults the DMN is highly connected despite the physical distance of the brain regions. The DMN corresponds to task-independent introspection, or self-referential thought, activated when the task-positive network (TMN, corresponding to goal-oriented action) is at rest.

Mirror Neuron System (MNS) has been identified in primate species and birds. Mirror neurons are active when an agent performs an action, and when it observes that same action being performed by another agent. It was shown that the imitation of sounds in birds' songs and human babies' babbling is related to this network. MNS creates an agent-independent connection between an actor and an observer [Rizzolatti & Sinigaglia, 2010]. Using fMRI, Molnar-Szakacs and colleagues [Molnar-Szakacs et al. (2006)] investigated the ability of the human MNS to represent sequences of action and suggested that MNS could be foundational to support language evolution in an individual. Based on meta-analysis of 125 fMRI studies, Molenberghs and colleagues [Molenberghs et al., 2012] discovered that an extensive brain network has mirror properties, located not only in the areas that show mirroring in the macaque such as the inferior parietal lobule (considered language-related anthropologically), but also in Broca's area and the adjacent ventral premotor cortex, the primary visual cortex, cerebellum and parts of the limbic system. MNS is deeply involved in the brain structures and related not only to action, but also to emotions – [Kim et al., 2007] found that the imagery of emotional facial expressions elicited activation in the amygdala (unconscious emotions). Assuming that the brain activation patterns for unconscious emotions are generated by conveying the current interoceptive and proprioceptive state of the body to the brain, [Shafir et al., 2013] showed that motor imagery and observation of emotional behavior activate MNS, and this causes the individual similar emotional effects.

MNS and DMN are interconnected. Recently, the functional and neurological interaction of the self-oriented network and mirror neurons has become the focus of attention in neuro-studies. It was found on the basis of fMRI results, that a unique network (fronto-parietal structures - part of MNS) underlies self-face recognition, and that certain DMN voxels react with higher signal intensity to the images of "other" than to the images that are "self-like" [Uddin et al., 2005]. Connolly and Haxby [Connolly & Haxby 2012] defined regions in which observation of the mammals produced activity associated with viewing animate objects, while bugs produced patterns similar to those for inanimate objects. Furthermore, Molnar-Szakacs and Uddin found that DMN and MNS are related via common hubs. In addition, a number of studies show that the newborns are attentive and sensitive to human voices as well as to human faces [Molnar-Szakacs & Uddin, 2013]. These results suggest the existence of a mental operation related to ***projection*** of the ***self-concept*** onto other biological species, and supports the importance of the component "motion" in the fMRI-brain-activation space discussed in section 1.

The overall mechanism responsible for the brain functioning still remains a mystery; however, the most recent advances in neuroscience add significantly to the clarification of some global interactions that provide a neuro-scientific support for the self-centered representation model of the world. Following the results of the studies discussed in the above, we propose that a MNS-DMN interconnection provides the link between the mental representation of self as a goal-oriented actor and mental representations of others in terms of their actions, goals and intentions. Analyzed jointly, these results lead us to the assumption that the functions of MNS and DMN are comprised of two interconnected processes – a ***projection*** coming from the subject's perspective about the goal of the action, and ***mirroring*** of the action itself (as confirmation feedback).

The idea that language faculty is dependent on the global brain function is discussed in a number of brain impairment studies. Cahana-Amitay and Albert [Cahana-Amitay & Albert, 2014] propose to adopt a component process framework to language processing; the neural basis of language is related to neural multi-functionality consisting in incorporation of nonlinguistic functions into language models of the intact brain, thus reflecting interaction among neural networks subserving cognitive, affective, and praxis functions, with neural networks giving rise to language. Several studies in the domain of cognitive science show similar reasoning, for example Gogate and Hollich explain language development through general perceptual processes, thus providing a model and analysis of the ways the conceptual word mapping is rooted in the interactions between the infant and the physical world [Gogate & Hollich, 2010].

The conclusion is that the entire brain, all its subnets and processes are responsible for the formation of mental representations of the world obtained by the subject as an actor in the environment. The global cognitive interconnection of parts is the mandatory ingredient for language development, on a par with the overall cognitive growth in the newborn.

Language Faculty: the Components of S-C Model

The Subject I (SI) forms a mental representation of the world obtained utilizing the outside sources via individual perception-sensation; the SI has an initial self-concept as *actor in the environment*. The inside information sources aid the SI to acquire information about the objects' functioning via perception-sensation and by employing diverse mechanisms of self-cognition. Consequently, mental representations are simultaneously self-centered and coherent with the world and with the SI embedded in it, guiding the subject's actions, decisions, and overall behavior in the environment. The world's mental representations are gradually developed by the entire brain that makes use of the in-wired cognitive mechanisms and rules to create the internal information units and perform mental operations on them for the internal 'language of thought' and the external 'language of communication'. In the process, these elements are merges into larger meaningful units. Here we consider the following four levels of cognitive apparatus underlying language faculty (fig. 3):

1. ***Perceptual level,*** as was previously discussed, is a self-centered device; the mechanisms underlying this level are utilized to generate concepts while affected in a top-down manner by the upper levels. This level known to have a high plasticity is related to feelings and emotions; it can be either conceptualized or not, depending on the impact of higher levels.
2. ***Semantic level*** is where multi-modal multipath information coming from the perceptual level is encapsulated as concepts to form the basis of the semantic description of the world. The encapsulation is important from the point of view of the utilized resources: mental operations work on capsules economizing memory resources for the entire spectrum of information coming from the perceptual level.
3. ***Syntactic level*** is the level related to mental operations running on concepts in the process of building larger meaningful units out of the basic elements. This level is also self-centered and related to concept formation, 'projection of the actor' and 'mirroring'.

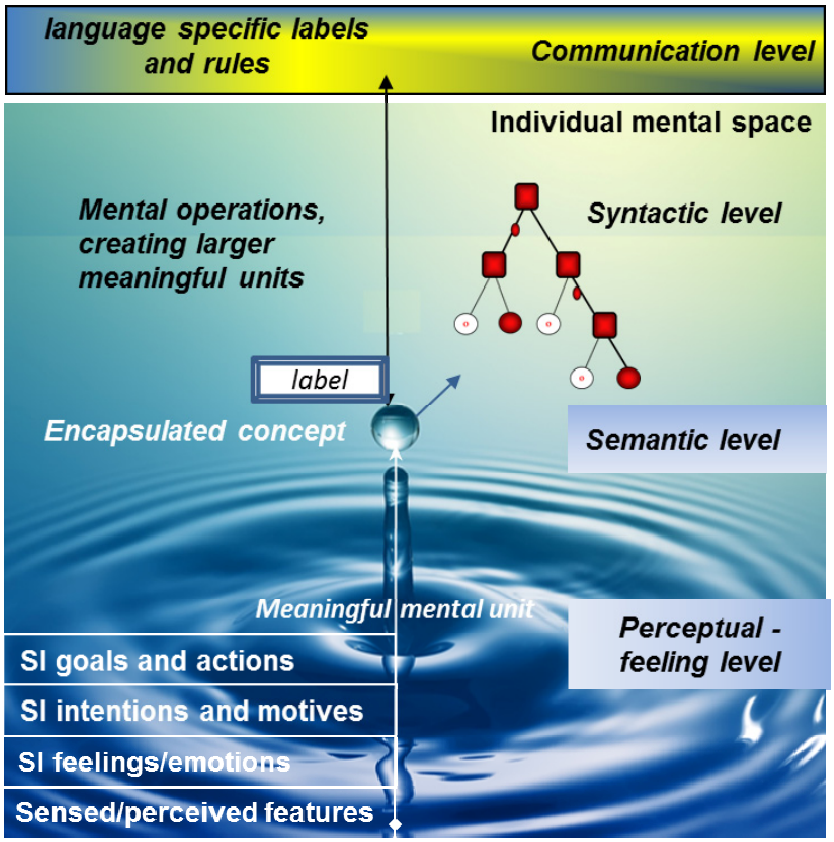


Fig.3. Levels of cognitive apparatus underlying language faculty. The levels 1-3 are present in the individual mental space, the details to be discussed in the following paper dedicated to the issue at hand.

The recursive syntactic process relies on a species-specific mental operation responsible for the efficient growth in biological systems, responsible for the reiteration of the basic meaningful unit in

syntax ([Soschen, 2006, 2007, 2008], [Slavova & Soschen, 2008, 2009]). It was shown in a number of studies that higher species, in particular the non-human primates, can encapsulate concepts and assign labels but cannot conceptualize actions, that is, cannot use verbs. This operability is assumed to be dependent on the structure of relations which determines the complexity of a cognitive task (see e.g. [Halford et al.,1998]).

4. ***Communication level*** is related to the communicative interaction with others. At this level the operational units comprise the ingredients of a human language as a communication tool. The prosody, gestures, and lexemes appear as labels for the concepts and mental communication-oriented operations. The language rules of various kinds that result in e.g. building a grammatically recognizable sentence are related to mental operations on concepts.

The model offered in this work parallels the individual development of language faculty according to the stages of gradually increased language-task complexity. The basic concepts are formed as the reaction to environment guided by self-preservation, survival and related factors.

Around 1 year of age, human infants start naming objects using sound combinations. The information-coding role of a sound is that it serves to distinguish the labels that are given to the objects referred to in the perceived world. Meaningful prosody and phonemic formation play an important role in the development of communication. However, concepts are still formed at the self-centered/object-only level with the purpose to communicate self-related attitudes, such as for example a feeling of discomfort. Concept formation and subsequent naming proceeds by consensus (all agree that a dog is a dog, not a cat). The basic semantic operation is responsible for the naming-by-consensus, which occurs within a particular group and thus accounts for the existence of a considerable number and diversity of human languages. Naming is the primary mode of communication, followed by the two-word expressions.

The next step is the syntactic-semantic convergence that accounts for the ability to form both the concepts and the infinitely diverse lexical strings (clauses, simple and complex sentences, etc.) out of a limited selection of lexical tokens. A sentence as a meaningful unit is encapsulated to be treated further as the information unit. A sentence can be formed without using names for actions (verbs): a one-word sentence frequently implies a certain associated action or situation, e.g. 'kitty' meaning 'Here is a kitty'. An action does not have a concrete meaning without the agents' participation. A verb as a function has no value before the values of the arguments are given. Nouns are primary in the construction of a meaningful sentence as the information unit.

According to the model proposed in [Berwick R. et al. 2013], each linguistic expression is assigned interpretation at two 'interfaces'. A sensory-motor interface connects the mental expressions formed by syntactic rules to the external world, via language perception and production. A conceptual-intentional interface connects these same mental expressions to semantic-pragmatic interpretation, reasoning, planning, and other activities of the internalized 'mental world'.

The problem with this analysis is that it is not clear in which way a meaning unit formed 'by syntactic rules' is incorporated in the semantic space. It is obvious that such a system calls for the 'actors', which in its turn requires the involvement of working memory and trained pathways. The only way to reconcile the existing differences that arise from postulation of two separate mechanisms (that necessitate two sets of independent operations for each) is the elimination of the syntax-semantic interface. This can be achieved by developing the overall system that can handle the task of conceptualization using the same mechanisms that handle the syntactic construction of limitless meaningful strings.

Summary

In the formation and expansion of mental representations, self-consciousness and self-orientation are primary. Based on the recent studies that attest to the functional and neurological interaction between self-oriented network and mirror neurons, it was suggested that the MNS-DMN interconnection provides the link between the representation of self as 'goal-oriented actor' and the mental representations of others in terms of their actions, goals and intents. We also discussed the key levels of mental representations that participate in the development of conceptualization: perceptual, semantic, syntactic, and communicative. The 'self-orientation' implies recognition of the existence of 'self', which is essential for the development of conceptualization in humans, and represents its starting point. We consider the following inborn capacities: the multimodal perception as the basis for concept formation, the self-concept as an actor in an environment belonging to a particular species. In this model self-orientation is primary as it predetermines concept formation as well as syntactic operations which are based initially on the SI as an actor.

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