SYNTACTIC OPERATIONS – MODELING LANGUAGE FACULTY

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Abstract*: We further develop the self-centered model of mental representations for language with the focus on the mechanisms underlying syntactic calculus and the construction of larger meaningful* constructs *out of the basic syntactic units. We consider the inborn multimodal perception and the self-concept as an actor in an environment as the basis for concept formation and syntactic construction. Based on relevant findings in language acquisition, we investigate the perceptual, semantic, and syntactic aspects of mental apparatus. We see this apparatus as an overall system that can handle the task of conceptualization and the task of syntactic construction using the same mechanisms. Based on the argument-centered model of mental representations which involves such processing homogeneity, we show the gradual development of the complexity of syntactic formants during language acquisition.*

Keywords*: language acquisition, syntax complexity, mental operations*

ACM classification keywords*: I.2.0: Artificial Intelligence, I.2.7: Natural Language Processing*

Introduction

The discussion presented in this work is the continuation of the analysis of basic mechanisms underlying language faculty in humans [Slavova & Soschen, 2015]. Gradual formation of concepts as mental representations of the world proceeds by means of the genetically pre-determined brain systems that utilize overall brain capacity which provides the necessary mechanisms for the development of thought and language. The focal point is that a newborn has some initial Self-concept as an *actor in the environment*, the ideas stemming from the results of brain imaging studies, neuroscience, and cognitive sciences. The development of language is intrinsically linked to Proprioception, Interception, and Exteroception, namely the multimodal perception of the outside world. In addition, recent results of neuroscientific investigations show some specific inborn brain networks essential for operations responsible for the formation of mental representations and for the language faculty’s capacity to become the tool for communication. The functional and neurological interaction between self-oriented and mirror neuronal networks provides the link between mental representations of the individual *self* as a goal-oriented actor and others with respect to their actions, goals and intentions. It follows that that the entire brain, all its subnets and processes are responsible for the development of mental representations of the world in a subject as the intentional actor in the environment. We regard this factor as the principal and indispensable ingredient of the the inborn species-specific mechanism *language faculty* and subsequent development of language, the process that proceeds gradually on a par with the overall cognitive advancement of humans.

Within the Self-Centered Model of Language Faculty (SCMLF), mental operations were formally exemplified as a structure with four interacting levels: 1. The perceptual *self-centered* level functioning on the inborn processes; 2. The semantic level, where the multimodal multipath information coming from the perceptual level is encapsulated as concepts and integrated into the semantic representation of the world. The encapsulation is crucial in terms of the utilized resources: mental operations at this level work on capsules without spending extra memory resources for the entire spectrum of information coming from the perceptual level; 3. The syntactic level, or the level of mental operations that serve to interconnect concepts to form mental units (thoughts) out of a limited set of elements, the units expressed as sentences; 4. The communication level is responsible for interactions with others, thus providing a foundation for *naming-by-consensus* which takes place within a particular group.

To proceed, we concentrate on the construction of mental units and discuss the mechanism per se, its efficiency and complexity. We incorporate the recent research on language acquisition to support the proposed argument-centered model of language faculty.

Some Results from Language Acquisition Studies

The learning of language starts before birth - the newborns discriminate the prosody of their mother tongue from all other languages. Recent results confirm that the first stage of child language acquisition is highly related to multimodal perception and to basic notion about the species to which the newborn belongs. Several studies suggest that newborns are particularly sensitive to human faces. 2-month-old infants can match vowel information in face and voice [Patterson & Werker, 2003]. It was shown that pre-verbal infants possess a biologically endowed ability to map and integrate multi-modal input ([Imai & Kita, 2014], [Gogate & Hollich, 2010]) suggested that infants' perception of arbitrary word–object relations emerges from the earlier perception of suprasegmental perceptual invariance (synchrony in auditory–visual relations). A brain study [Csibra et al., 2000] demonstrated that binding-related 40-hertz oscillations are evident in the infant brain around 8 months of age, indicating the onset of perceptual binding of spatially separated static visual features. At 6 to 9 months, human infants know the meanings of many common nouns [Bergelson & Swingley, 2012]. At the age of 11 months infants are sensitive to the non-arbitrary correspondences between language and concepts and spontaneously map auditory language onto visual experience [Asano et al., 2015].

All these results suggest the inborn multimodal nature of concept formation during the first stage of language acquisition – the foundation of mental semantic description of the world. We will further relate this stage to the inherent syntactic process and its basic mental operation Ø-Merge which forms the basis for encapsulation of perceived features into a concept, a highly automatic process based on the inborn capacities of a human.

It has been shown however that concept formation and labeling are not fully developed prior to the infant's becoming an active actor in the environment. Using ERPs to observe the brain activity of 6-month-old infants, Friedrich and Friederici concluded that the infants can associate objects and words after only very few exposures, while limitations were found in the consolidation of declarative memory with regards to lexical-semantic memory [Friedrich & Friederici, 2011]. We relate this "labeling" problem to the fact that conceptual encapsulation and subsequent incorporation into the conceptual system are still not fully developed at this stage.

The second stage starts after around one year of age when the infant begins to actively demonstrate her role as an actor in the environment. At that time the process of myelination is complete and the infant starts walking and experiencing fully her surroundings. Lexical priming and semantic integration are already developed in 14-month-olds; they react with N400-like negativity for incongruous words, indicating additional effort for semantic integration, as shown by Friedrich and Friederici [Friedrich & Friederici, 2005]. Fennell and Werker also found that 14-months-old infants can already discriminate similar phonetic content having developed the initial concept representations [Fennell & Werker, 2003].

The acquisition of verbs is of special interest for the model under development. Learning to use verbs represents a task of special complexity, because verbs are abstract in a sense that they do not possess the perceptual 'tangible' properties of nouns. It has been reported that even 3-year-olds could not generalize the meaning of novel non-sound-symbolic verbs on the basis of the sameness of action [Imai et al. 2008].

Verbs convey relations between *entities* which are expressed mostly by nouns to combine nouns into larger meaningful units - sentences. The role of a verb is to express a relation between conceptualized entities, determined syntactically as arguments in a sentence. Following from that, learning of verbs contributes to sentence formation. Recent studies in language comprehension suggest the crucial importance of argument structure for the mental semantic interpretation of a sentence. In the neurocognitive "extended argument dependency model" developed by Bornkessel and Schlesewsky (2006) the online cross-linguistic comprehension consists in three hierarchically organized phases: 1) constituent structure building without relational interpretation; 2) argument role assignment via a restricted set of cross-linguistically motivated information types (e.g., case, animacy); 3) completion of argument interpretation using information from further domains. This basic architecture is assumed to be universal, with cross-linguistic variation deriving primarily from the information types applied in Phase

2 - argument role. The importance of the argument structure for the mental calculus of larger meaningful units is shown in the analyses by Friederici ([Friederici, 2011]) who discovered brain activities corresponding to language comprehension in sequential phases: 1) building initial phrase structure on the basis of word category information 2) computation of the relation between the verb and its arguments to assign the thematic roles in a sentence; 3) the final interpretation takes place, with semantic and syntactic information being taken into account and mapped onto world knowledge. In our theory, however, verbs do not 'assign' thematic roles to the nouns - for the reason that nouns are primary lexemes to encapsulate concepts - but establish, express, and describe relations between entities expressed i.e. as nouns.

As discussed in [Slavova & Soschen, 2015] the question of the actor is related to the basic categorical dichotomy animate/inanimate and to the mental projection of the self-concept onto other observed actors. Further, the most recent studies in language comprehension suggest that it is *actor-centered*. Based on the results of neurophysiological experiments, several researches in a range of typologically varied languages, ([Bornkessel-Schlesewsky, 2011], [Frenzel M. et al., 2015]) suggest that comprehension architecture is actor-centered and focused on identifying the participant primarily responsible for the state of affairs under discussion. There are also EEG evidences for a cross-linguistically valid, actor-based strategy of understanding the sentence-level meaning ([Alday et al. 2014]).

All these results suggest the key role of argument structure in mental representations and meaning formation. The research quoted supports the suggested model of the argument-based syntactic computation ([Soschen 2006 - 2008]; [Slavova & Soschen, 2007a, 2007b]), and the work that provides a formal account of the argument-based syntactic operations ([Slavova & Soschen, 2008, 2009]. We will briefly review the model under discussion to further concentrate on its aspect of 'self-centeredness', as was discussed in [Slavova & Soschen, 2015].

The Argument-Based Syntactic Calculus

Syntax is viewed in this paper as a unique subtype of recursive systems designed for the continuation of movement, thus creating the limitless meaningful strings out of a limited number of lexical tokens. Linguistic structures possess the features of other biological systems, the central factor that enters into the growth of language in the individual. The Faculty of Language is an efficient mechanism that functions in compliance with optimization requirements. To illustrate that, a functional explanation of *Syntactic Merge*, a procedure that combines lexical items into meaningful units, is discussed, and the criteria are identified that single out this particular computational system as species-specific (uniquely human). Natural Law, a physical phenomenon exemplified as the Fibonacci patterns where each new term is the sum of the two that precede it, can be observed in language, just as it is in other mental representations ([Uriagereka 1998], [Soschen 2006-2008]). These patterns share certain remarkable properties with the linguistic system: both of them are characterized by discreteness and economy. We support the idea that the same conditions account for the essential properties of syntactic trees ([Soschen 2006-2008], [Slavova & Soschen, 2007a, 2007b]); the resultant structure is a Fibonacci tree (Fig. 1.a).

Furthermore, syntactic structures in the traditional sense of Chomskyan theory (Bare Phrase Structures, XP-structures) were re-defined in terms of the finite recursive binarity; the linguistic model [Soschen 2006-2008] includes an operation Ø–merge which produces a XP (singleton set) by merging a terminal node X with Ø-operation, the process of crucial importance responsible distinguishing between *entities* X and *sets* XP. The postulation of Ø–merge has profound consequences for the general interpretation of mental processing, as it provides a rule for producing sets which are the starting point in both syntactic (i.e. sentence formation) and semantic (i.e. concept formation) processing. It is important to note that Ø-Merge, the operation responsible for constructing elementary argument-centered representations, takes place prior to lexical selection. The functional pressure of cyclic derivation to merge terms of *different types only* accounts for *the type-shift* from sets to entities and from entities to sets at each level in the tree. As a result, at some level, a construct is XP (a set); at another level, it is merged as X (entity). On a pre-linguistic level, the argument-centered mechanism builds the basic structures that underlie mental constructs on entities (E) and relations (R) between them. The three basic formants are as follows: E(R), E(R)E, and E(R)EE. When filled with lexical content, these structures appear as SV (Subject-Verb), SVO (Subject-Verb-Object), and SVOO.

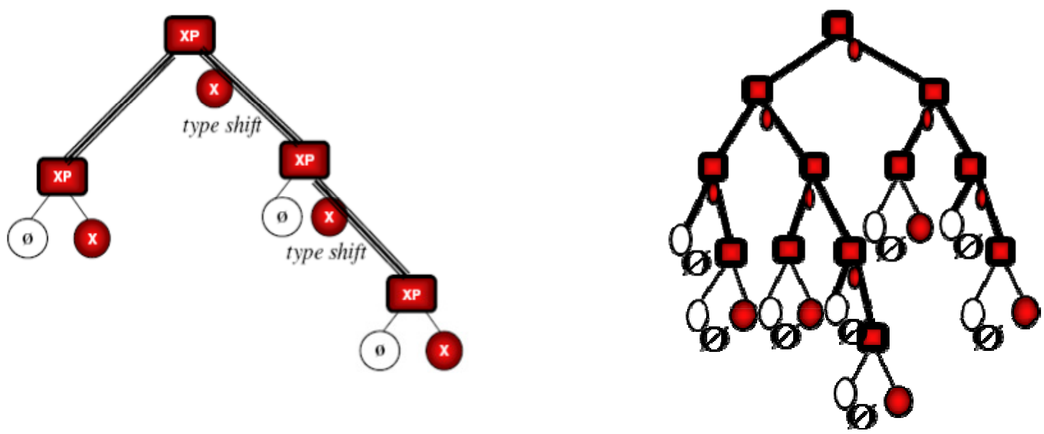
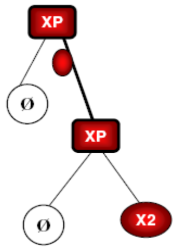
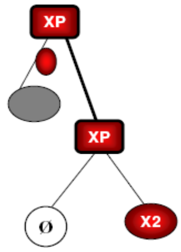


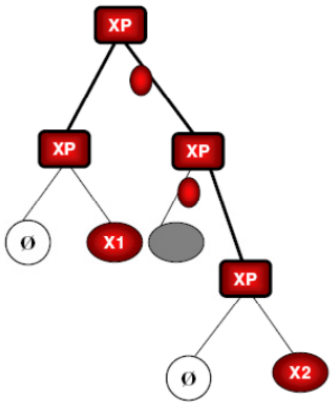
Fig 1. a. Fibonacci-based Tree



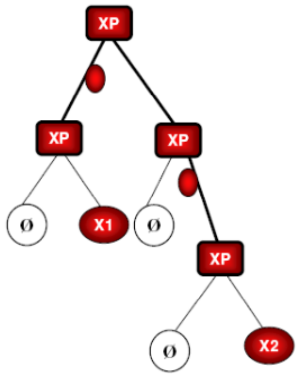
b. Infinite iteration: *Eve*, *Eve …*



c. *Eve* in *Eve laughs.*



d. Two arguments *Eve, Adam* in *Eve* saw *Adam*



e. Three arguments *Eve, Adam, apple* in *Eve gave Adam an apple*

Fig 1. The Argument-Centered Syntactic Model

The Fibonacci-based syntactic tree can be seen as an operator – it “performs” bottom-up Merge. The formal analysis of the “procedurally” possible paths of Merge on the tree has led to the four configurations, presented in figure 1.b.c.d.e. In the context of mental constructs, these paths of Merge determine the types of relations between the entities. The basic elements - entities that enter the tree are ‘transformed’ into sets to form larger meaningful units by undergoing Ø-Merge operation. The recursively applied rule adjoins each element to the one that has a higher ranking, starting with the term that is ‘Ø-merged first’. The process where Ø-merged element is type-shifted to the next level creates a single argument position made explicit by e.g. the intransitive verbs; when filled with lexical content it is expressed in sentences such as “Eve laughs” (see Fig 1). The process where the terms assume positions for each to be merged with a non-empty entity result in two argument positions, e.g. “Eve sees Adam“. The maximal argument configuration is limited to three arguments, such as in e.g., “Eve gives Adam an apple”. The resultant schemes (Fig.1 b.c.d.e.) represent all possible configurations and relations between the arguments. The Fibonacci-based tree of mental representations underlies the formation of each and every syntactic tree.

We further concentrate on language acquisition with regards of the gradual formation of these syntactic constructs and the role of ‘self-centeredness’ for its establishment.

Language Development and the Complexity of Mental Constructs

The theory in support of the syntactic-semantic convergence views mental organization as a unified apparatus that that is responsible for the ability to conceptualize, together with the ability to form the infinitely diverse meaningful strings out of a limited number of lexical tokens. Primarily, concepts appear in situations in which the child is in direct perceptual contact with a particular entity. *This process of formation of the basic mental representations involves Ø-merge of entities by transforming the memorized paths of the properties of objects into operable mental units.*

On the communication level, the process of encapsulation of these units is related to the phonological sequence accorded to the unit. When these semantic units become stable and stored as memorized paths, the child starts replicating what is said by the adult about a particular object using the memorized phonological labels for nouns; thus, the relation between the object and its label is established. Up till the end of this phase verbs are practically not used.

The focal point here is that a newborn has some initial Self-concept as an actor in the environment based on the results from brain imaging studies, neuroscience, and cognitive sciences. Following from that, the first used verbs should have Subject I (SI) as an actor.

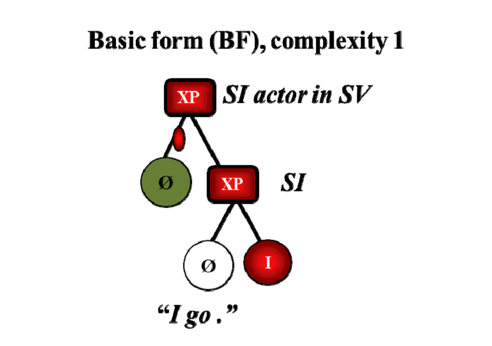
This is confirmed by the analyses of the texts in the database of child speech, CHILDES. The use of verbs starts with expressions SV where SI is understood from the context but remains unpronounced (SI is an obvious actor) as shown in the examples provided in table 1. We ascribe this mental syntactic operation the level of complexity 1 (C1) and consider it the *basic syntactic form* (BF).

The SVO argument structure appears later, the Subject is SI (see examples in Table 1). We ascribe the resultant complexity of such sentences level 2 (C2). Note that the examples for all cases of argument structure incorporate SI that appears first according to the results derived from the database of child speech CHILDES.

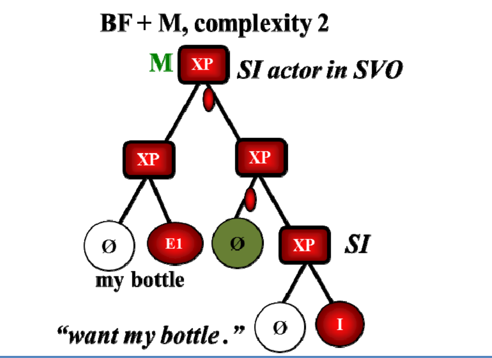
The next levels of complexity C3 and C4 are related to the introduction of the subject performing the action other than SI. The mental operations in this case include projection (Pr) of the “inborn” actor SI and are related to mirroring (Mr) of the observed action. The examples of such constructions are shown in table 1.

So far, we have introduced the complexity load 1 in mental formations for the Basic syntactic form, and obtained gradually increasing syntactic complexity of mental constructs, supported by the data derived from CHILDES database. It would follow that the complexity of structures will increase further by means of additional projections and merges.

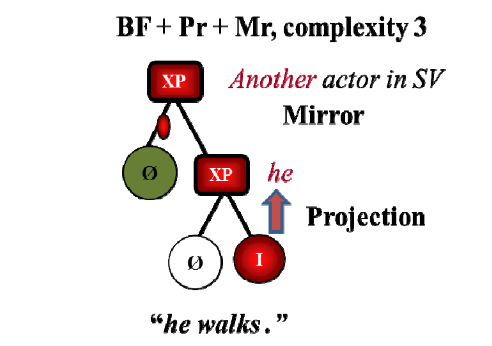
Months	Examples C1
11	go .
12	pull on hat
13	eat .
14	draw .
15	sit .
16	climb .
17	I do .



Months	Examples C2
17	want it .
17	want my bottle .
18	me pick .
18	I want my book .
19	I call this .
19	I hit doggie .
19	I cut fingers .



Months	Examples C3
18	he cry .
18	arm hurts .
18	you sit down .
18	he walks .
18	you sit down .
19	Daddy 0is [*] home . [+ SR]
19	Cuckoo barking [>] ! [+ PI]



Months	Examples C4
20	Mama read that .
22	Mommy eat cookie .
22	she brushin(g) her teeth .
22	you can hold that one .
23	<my Dad do it> [?] [>] .
23	you [//] I 0have [*] got my glasses .
24	she want a koon [: spoon] .

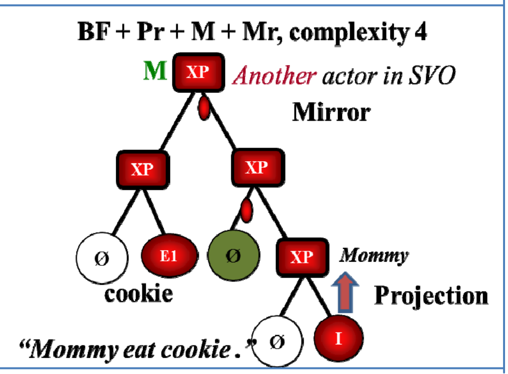


Table 1. Syntactic Complexity

The examples in table 2 show the manner of building of the syntactic construction around the basic form by means of adding Merges and Projections. This next level of sentence complexity appears later in child development within structures with SI as actor.

Months	Examples C5
23	I want you to color this xxx .
25	I don't want you to get mine .
31	I want you to put it on .
35	I don't want you to have these .
36	I want that camera to move .
42	I want you to do like this .

Table 2. Examples of complexity 5

Three-argument sentences appear around 3.5-4 years of age (Table 3); their use starts with the self-centered basic form. As shown in Fig. 2, this process corresponds to 3-entity configuration of the Fibonacci-based tree, expressed as syntactic constructions of the type e.g. SVOO ("Mama give Peter milk"). At this stage, interrelations between higher levels of abstraction and memory are prominent, and the relation between numbers and between similar objects is established. The counting procedure (rather than the list of memorized words) complies with the rules of a higher level of abstraction.

Months	Examples SVOO
40	I got two dollars to give you (.)
41	I wanna tell you something xxx back [?] . [+ PI]
41	I [/] I will tell him that .

Table 3. Three-argument sentences

Working memory is necessary to simultaneously treat the entire Fibonacci-tree (h=3) and to keep the merged intermediate results for retrieval. As shown in fig 2, the complexity load of the second merge M_2 is augmented to 2 because of the memory operations needed for it.

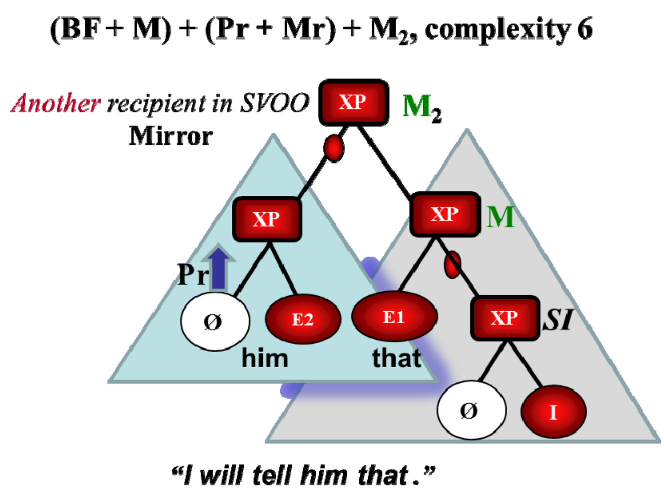


Fig 2. Examples of first use of SVOO structure, 41 months

In the studies of language acquisition, language development is measured according to the number of words in each particular expression constructed by the child. We revise this approach, and *suggest that the complexity should be measured according to the number of interrelated arguments and mental operations that start with the "projection of the actor".* We have shown how the sentences that incorporate the basic argument configurations are formed gradually developing from the basic structure to be expressed as SV, SVO and SVOO, each structure in compliance with the 'self-centeredness' principle.

Summary

In this work, we have discussed the key phases underlying the formation and development of mental representation for the language faculty in a human. During the first phase the foundation of the semantic description of the world is established, a process highly related to multimodal concept formation and encapsulation of concepts as meaningful units with labels (names of entities and their features). The second phase is related to the capacity to form larger meaningful units - the argument-centered structures - by naming relations between the entities using verbs to describe these relations. This phase gradually follows the operation of realization of the innate self-concept as an actor in the environment Subject I (SI). The development of more complex argument formants is based on the projection of SI onto other actors or objects, a process that requires the growth and utilization of neuronal networks of advanced complexity, and the established memory paths' re-use. The final and highest phase in the development of basic mental representations requires a high level of automatism for the use of antecedent phases.

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