EXPERIMENTAL SUPPORT OF ARGUMENT-BASED SYNTACTIC COMPUTATION

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Abstract: Linguistic theory, cognitive, information, and mathematical modeling are all useful while we attempt to achieve a better understanding of the Language Faculty (LF). This cross-disciplinary approach will eventually lead to the identification of the key principles applicable in the systems of Natural Language Processing. The present work concentrates on the syntax-semantics interface. We start from recursive definitions and application of optimization principles, and gradually develop a formal model of syntactic operations. The result – a Fibonacci-like syntactic tree – is in fact an argument-based variant of the natural language syntax. This representation (argument-centered model, ACM) is derived by a recursive calculus that generates a mode which connects arguments and expresses relations between them. The reiterative operation assigns primary role to entities as the key components of syntactic structure. We provide experimental evidence in support of the argument-based model. We also show that mental computation of syntax is influenced by the inter-conceptual relations between the images of entities in a semantic space.

Keywords: natural language, mathematical modeling, cognitive modeling

ACM Classification Keywords: I.2 Artificial Intelligence, 1.2.0. Cognitive simulation,1.2.7. Natural language processing - Speech recognition and synthesis.

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Introduction

We use mathematical formalism of Generalized Nets to develop a stage-simulating model of NLP. This formal approach allows a more exact representation of information flows during the stages of processing, expressed as the transitions Z_1–Z_{29} of the Net (Slavova 2004). The analyses performed on this basis suggest that information treatment consists of the operations that use two types of Long Term Memory knowledge (syntactic and semantic) in parallel. As an example, this is the case of transition Z_{27}, which expresses the stage when the system builds the syntactic structure of a sentence after its last word-form was stored in Working Memory (figure 1.). A detailed examination of the incoming information flow allows us to suggest that the procedure, running on Z_{27}, must use semantic and syntactic knowledge in parallel. We assumed that **syntactic structure is better clarified** when it receives semantic justification.

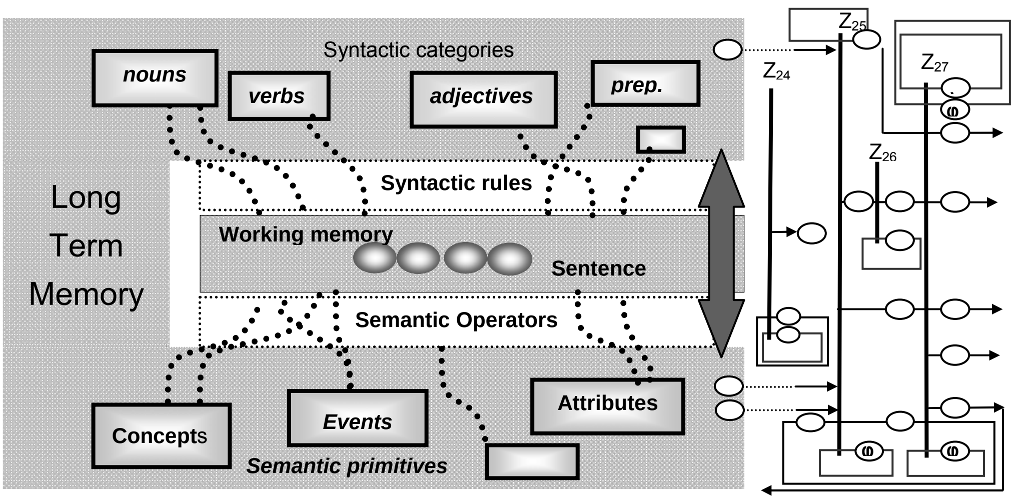


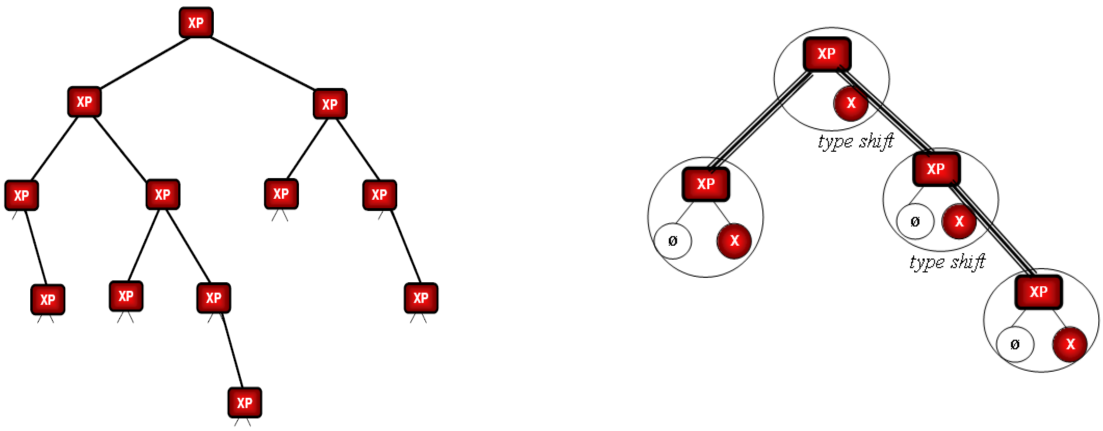
Figure 1. Information treatment of a sentence, based on language and semantics

For further analyses, the two types of knowledge stored in Long Term Memory were modeled by means of a database structure that shows the interconnection of syntactic rules, semantic primitives, and semantic operators (Slavova, Soschen, Immes, 2005). The assumption was that language units (word-forms) have images as semantic primitives such as "concepts", "attributes", "events" etc, and that grammatical rules comply with semantic operations on these primitives. This formalization of the Language as a "joint" Information System was used to study a particular language rule - secondary predication in Russian[1]. This rule was modeled by means of the formal approach described above. That led to a coherent and well-defined formal procedure and confirmed that the rule entails operations on semantic primitives.

Further efforts are put forward to obtain the proof that **semantic knowledge** and **syntax** are interrelated. The question so far is how syntax is related to operations on semantic primitives – concepts, events, attributes, etc. This is one of the most important questions in contemporary linguistics and cognitive science.

Syntax as Computation

Following one of the widely accepted linguistic theories, the key component of Faculty of Language (FL) is a computational system (narrow syntax) that generates internal representations and maps them into the conceptual-intentional interface by the (formal) semantic system (Hauser et al., 2002). There is a consensus that the core property of FL is *recursion*, which is attributed to narrow syntax. In other words, the process of mental generation of syntactic structures relies on the capacity of the human brain to perform specific operations in compliance with the principles of efficient computation. The claim in the recent theories is that this computation is based on a primitive operation that takes already constructed objects to create a new object. This basic operation, called "Merge", provides a "language of thought", an internal system to allow preexistent conceptual resources to construct expressions (Chomsky, 2006). Although these questions receive a lot of attention, there are no convincing proposals yet concerning the precise type of resources on which such computation is performed in a recursive manner to build syntactic structures.



a. Figure. 2. b.

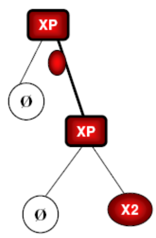
Following from the above, the study of syntactic recursion by mathematical means may provide valuable insights into the principles underlying the human language. One step in this direction was provided in Slavova and Soschen (2007). Syntactic structures, presented in the traditional sense of Chomskyan theory (Bare Phrase Structures, XP-structures), were re-defined in terms of finite recursive binary trees. The "traditional syntactic tree" does not correspond to the finite nature of a sentence; consequently, it cannot be defined recursively as a finite object. Another reason to introduce this modification is to build a structure that complies with the principles of optimization, namely with the principle of efficient growth (Soschen 2006, 2008). The tree was modified; the

[1] The linguistics theories don't provide a consistent explanation of Secondary Predication in Russian.

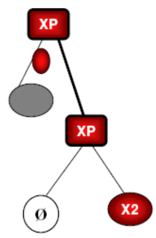
nodes related to syntactic role of verbs were discarded. The structure obtained in this way is a tree of Fibonacci (figure 2. a).

This tree can be seen as is an operator – it "performs" a bottom-up Merge (figure 2.b.), its nodes are the results of Merge. In the model under development, XPs are *sets*, Xs are 'unbreakable' *entities*, and Merge can be applied to two non-equivalent substances (the tree has ordered nodes). These formal transformations of the traditional tree result in a structure that incorporates two operations of fundamental importance in the syntactic model. The first is "Ø-Merge", operation that takes place at the point where Xs as initial substances form *singleton sets,* ready for further syntactic computation. The second is *type-shift,* which results in a transition from *sets* (XPs) to *entities* Xs and expresses a property of the dual mental representation of XP as either consisting of two separate elements or as an 'unbreakable' whole (part of a larger unit).

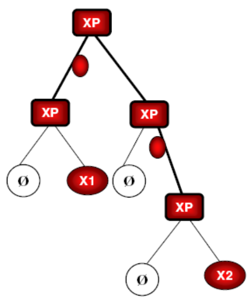
The Fibonacci-like tree shows the patterns of relating arguments (Soschen 2006, 2008). An important question is the height h of the XP Fibonacci-tree, since it refers directly to the memory, necessary for the computation. The tree is a recursive object; the same patterns of Merge are repeated at its levels. It is easy to show that merge-patterns start to reiterate when h>3 and that any tree with h>3 can perform more than one merge-pattern. We defined the tree with h=3 as the basic tree (fig. 2.b). We interpret its properties as follows: the basic tree defines the maximal number of Xs that can be merged in a procedurally unambiguous way. It could be suggested that this structure is determined in the same way as the number of nodes and relations that can be treated by the human brain within a semantically meaningful argument space.



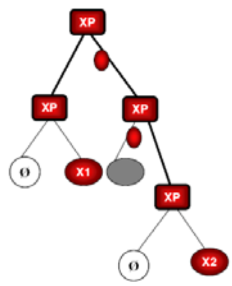
a. Infinite iteration: Mary, Mary



b. Mary in *Mary smiles*.



c. Two arguments Mary, John in Mary loves John.



d. Three arguments Mary, John, apple in Mary gave John an apple.

Figure 3.

The tree represents a bare (label-free) syntactic structure that has no lexical input; what it has are the paths that connect smaller units in order to produce a larger meaningful unit. We called the tree in (fig. 2.b) "the Argument-Based Syntactic Tree".

According to the hypothesis put forward in Soschen (2005, 2006, 2008), a general rule governing efficient growth applies in syntax in such a way that minimal syntactic constituents incorporate arguments (*agent, recipient, theme*) which are related to each other. In the Fibonacci-tree model, the type of merge configuration determines the type of relation between arguments. The maximal configuration (fig. 3.d) corresponds to thematic roles *agent*, *recipient*, and *theme*. The "syntactic meaning" of the schemes in (fig. 3) corresponds to configurations offered in (Soschen 2006, 2008).

These schemes represent all possible configurations and relations between arguments in the human theta-role Semantic Space. Carnie (2006) shows convincingly that the number of arguments in a thematic domain is necessarily limited to three, a fact that has not found an explanation in linguistics so far. The model under development suggests that the number of arguments is limited in a particular way in compliance with the principles of efficient growth, which are, in our terms, the principles of efficient computation as well.

Of importance to linguistic theory is our proposal that the argument-based model of syntax has a fundamental character. This model shows that syntax utilizes recursive calculus to connect *arguments* and express *relations* between them. The argument-based model assigns a primary syntactic role to *entities*, usually expressed as nouns. This viewpoint is in contrast with *verb*-centered models of syntax.

Our efforts are focused on the experimental evidence that supports the argument-based model. The difficulty of designing an appropriate experiment is that mental computation runs on a deep (pre-linguistic) level and cannot be captured on the lexical level by a standard experiment. One possible way to extract some information about the primary mechanisms is to force the mental system to solve ambiguities on the lexical level and to analyze the system's response.

Experimental Design

Bulgarian is the only Slavic language which, during the last 10 centuries, has undergone a transition from synthetic to analytical language. Prepositions replaced case-flections, and a suffixed definite article appeared. One interesting result of the transition is that the Genitive and Dative cases are both expressed by means of the preposition *'на'* (na). "Na" has several meanings: to, of, on. Our experiment is based on the following two meanings of "Na":

1. *Of – meaning* (whose, Slavonic Genitive)

The X	*на*	*the* Y

means "the X of the Y" i.e. "the Y's X", as in:

The X	*На*	The Y	
Къщ*ата*	*На*	Куч*ето*	
The house	*Of*	*The dog*	*The dog's house*

2. *To – meaning (to whom, Slavonic Dative)*

Subject Verb | *на* | *the* Y | means that the subject S acts To the Y. For transitive verbs, *на* assigns the syntactic role of a *Recipient*:

S Verb O		The Y (Recipient)
Той донесе стол	*На*	Директора
He brought a chair	*To*	*the director*

In the example above, Object is not marked with an article. Such sentences always have the meaning S-(V)-O-R (three arguments: agent, theme, and recipient).

When the Object is marked with an article, the sentence becomes:

Subject	Verb	*the X* (Object)	*на*	*the Y* .

and its second part fits the Genitive construction *the* X *на* *the* Y . In result, the available grammatical rules of the language assign to the noun Y two possible roles:

1. Subject Verb *the* X (Object) *to* *the Y* (Recipient). S-(V)-O-R, Resipient
2. Subject Verb *the* X (Object) *of* *the* Y (Possessor). S-(V)-O-of-P, Possessor

In such sentences, preposition *на* indicates that the noun that follows it is either Recipient (argument), or it is the object's owner/ Possessor. The difference between these two interpretations is crucial, as the basic syntactic structure of two sentences is completely different - in the former, there are three arguments, and in the latter, there are two (corresponding respectively to the trees on fig. 3.d and 3.c). In Bulgarian, all the sentences of type:

Subject Verb *the* Object *на* *the* Y.

are ambiguous: they assign two different meanings to Y - *Recipient* and *Possessor*.

In normal listening or reading-comprehension conditions, native Bulgarian speakers interpret one of these meanings depending on the context. The sentence "Mary gave the book на the boy." in the context "Mary entered holding a book and she saw a boy" is interpreted as "Mary gave the book to the boy." And, in the context "The boy left his book. Mary was asked about the book." the very same sentence is interpreted as "Mary gave the boy's book to someone else." Speakers of Bulgarian are never mistaken about the conveyed meaning. However, as our experiment has shown, they are not even aware of the existence of the two meanings. It appears that in the cognitive space such "*на*-sentence" acts as a Necker Cube – one may "see it" in either of the two ways. The context makes one of the meanings explicit, while the subjects are not aware of the other meaning. And, in fact, as is the case with Necker's Cube, if one concentrates long enough on an isolated *на*–sentence, one will discern that it has two meanings.

Our goal is to study the mechanisms of mental computation of the syntactic structure of an isolated sentence, with regard to the role of the verb and the arguments.

1. If the assumption is correct that the argument-centered computation is the key to mental operations, an isolated *на*-sentence will be constructed by assigning to Y the role of Recipient.
2. The *на*-sentences are ambiguous; if the role of *entities* (nouns in this case) is primary, semantic relations between their images in the conceptual nets will influence the final result of the syntactic computation.

Experiment

In what ways an isolated *на*–sentence is interpreted? We prepared 13 examples of *на*-sentences (Table 1). Each of these sentences has an argument that conveys either of the two meanings – Recipient (Rc) vs. Possessor (Ps). All the verbs used in the test examples are transitive and allow Recipient. All the sentences can exist as complete sentences without Possessor and without Recipient. The verbs are in the past tense, Perfective form.

Table 1.

200.Ex	Иван	Продаде	Къщата	На	баща си
	Ivan	*Sold*	*The house*	*to/of*	*his father*
201.Ex	Мария	Продаде	Колата	На	Съседката
	Mary	*Sold*	*the car*	*to/of*	*the neighbour*
202.Ex	Михаил	Продаде	Къщата	На	съседа си
	Mihail	*Sold*	*The house*	*to/of*	*his neighbour*
203.Ex	Елена	Продаде	Къщата	На	Кучето

	Elena	*Sold*	*The house*	*to/of*	*the dog*
204.Ex	Анна *Anna*	Продаде *Sold*	Ябълките *The apples*	На *to/of*	Момчето *the boy*
211.Ex	Анна *Anna*	Подаде *Gave*	Стола *the chair*	На *to/of*	Директора *the director*
212.Ex	Петър *Peter*	Донесе *Brought*	Стола *the chair*	На *to/of*	Директора *the director*
220.Ex	Мария *Mary*	Показа *Showed*	Колата *the car*	На *to/of*	Съседката *the neighbour*
221.Ex	Иван *Ivan*	Показа *Showed*	Пътеката *the wolk*	На *to/of*	Баща си *his father*
222.Ex	Петър *Peter*	Показа *Showed*	Къщата *The house*	На *to/of*	Баща си *his father*
231.Ex	Кумчо Вълчо *The Big Bad Wolf*	Продаде *Sold*	Къщата *The house*	На *to/of*	Кучето *the dog*
232.Ex	монтьорът *The fitter*	Показа *Showed*	Колата *The car*	На *to/of*	Съседката *the neighbour*

We need to find out which of the two meanings of these isolated sentences is obtained FIRST, i.e. in the most natural way. That can provide information about the mechanisms of mental computation of the basic syntax.

The difficulty in designing an efficient experiment is that when asked to explain the meaning of such a sentence, subjects usually reply by repeating the very same sentence. For them, in the first moment, the sentence has only one meaning that can be put into words in one particular way only. The subjects do exactly what they were asked to do: they express the meaning by using words. Further efforts to make them reveal the meaning make them focus on the sentence for a longer period of time. As a result, they discover that the sentence has one more meaning, and they report that the sentence can mean two different things.

This difficulty was overcome in a tricky way. We used the fact that sentence structure, including word order, is exactly the same in French. The crucial difference is that the preposition *на* is translated in French as "à" (to) for the Recipient-meaning and as "de" (of) for the Possessor-meaning.

The subjects of our experiment were the students in the masters program of the Francophone Institute for Management in Sofia, all of them fluent speakers of French. The subjects, 62 students with different backgrounds (economists, sociologists, biologists, linguists, engineers etc.), were: native speakers of Bulgarian - 39, of Ukrainian - 6, of Rumanian – 5, of Russian - 3, of Georgian – 3, of Albanian – 3, of Macedonian – 2, and of Arabic – 1. Some of the non-native Bulgarians spoke Bulgarian fluently, some were less fluent.

The statements in Bulgarian were presented in a written form to the subjects, on small separate pieces of paper, with the only instruction "Translate into French". It was done at the end of regular classes, under circumstances implying that "it is not something you should worry about, do it speedily".

Each statement was presented to 10-12 different subjects. Each subject was given 2 different statements in a random manner, while the statements did not contain the same verb or the same noun. The 23 non-native Bulgarian speakers could ask the experimenter about the meaning of Bulgarian words. There were a few questions about the meaning of "монтьор" (fitter), "тапицер" (upholster) and "пътека" (path) as well as about the corresponding French-tense of the verbs (Past-perfect forms are translated with "passé composé"). There were no questions about the meaning of *на*.

The 124 written translations of the test statements were stored in a database. Table 2 contains the proportion of the Recipient- and Possessor-meanings assigned to each statement (Of% and To%).

Table 2.

	Subject	Verb	Object	на	Y	Of%	to%	Tendency
204.Ex	Anna	Sold	The apples	To/of	the boy		**100**	Y = Recipient
202.Ex	Mihail	Sold	The house	To/of	his neighbor	29	71	Y -> Recipient
201.Ex	Mary	Sold	The car	To/of	the neighbor	30	70	Y -> Recipient
231.Ex	The Big Bad Wolf	Sold	The house	To/of	the dog	33	67	Y -> Recipient
200.Ex	Ivan	Sold	The house	To/of	his father	67	33	Y -> Possessor
203.Ex	Elena	Sold	The house	To/of	the dog	**100**		Y = Possessor
221.Ex	Ivan	showed	The path	To/of	his father		**100**	Y = Recipient
220.Ex	Mary	showed	The car	To/of	the neighbor	11	89	Y = Recipient
222.Ex	Peter	showed	The house	To/of	his father	33	67	Y -> Recipient
232.Ex	The fitter	showed	The car	To/of	the neighbor	50	50	Equivalence
211.Ex	Anna	gave	The chair	To/of	the director		100	Y = Recipient
212.Ex	Peter	brought	The chair	To/of	the director	13	88	Y = Recipient
233.Ex	The upholster	brought	The chair	To/of	the director	50	50	Equivalence

This experimental design was successful in the sense that only 4 subjects, native Bulgarian speakers, became aware that a given sentence has 2 meanings. It is interesting that some of these subjects noticed the double meaning of one of the statements that they had to translate, but not of the other. They were asked to put down the two possible translations in the order in which the meanings came to their minds, and only the first one was taken into account for further analyses.

The results in Table 2 show that, in spite of the “Necker’s cube property” of each statement, one of its possible meanings is interpreted by the subjects more often than the other. The second observation is that for some statements the preferred interpretation is the Recipient-meaning and for others – the Possessor-meaning**.** The third observation is that these changes do not depend on the verb. For one and the same verb, the interpretation “switches” from one to the other meaning. For example, as one can see in Table 2, “Sold” appears in statements varying from 100% of Recipient-meaning, to 100 % of Possessor-meaning.

Based on the available experimental data (at least ten trials for each statement from different subjects), we assume that the experiment has captured some major tendencies in the interpretation of the test statements. This experiment allows us to further explore the principles of mental operations underlying interpretation of the basic syntactic argument structure. So far, a linguistic theory that would explain the observed tendencies in obtaining some particular result, “computed” by the subjects, has not been developed. Our experiment has shown that the explanation can be provided by using the argument-oriented model derived in compliance with the principles of efficient computation.

First Analyses of Experimental Results

The experimental results show that the interpretation of the syntactic structure depends on entities (in this case, nouns). The verb itself does not predetermine the type of structure: either S-(V)-O-R (three arguments) or S-(V)-OofY (two arguments). Many of the contemporary linguistic theories mostly consider predicate-based and verb-centered syntactic structures. Actually, if the verb does not allow a recipient, the syntactic structure of the *на*-sentence is calculated as S-(V)-O of Y.

Suppose that mental calculus depends solely on the type of the verb. Then in the cases where the verb allows Rc, на would ALWAYS imply a S-(V)-O-R structure. But that is clearly not the case in the last four examples given in Table 3:

Table 3

Subject	Verb	Object	Ha	Y	of%	To%	Tendency
Anna	Sold	the apples	to/of	the boy		100	Y = Recipient
Ivan	showed	the path	to/of	his father		100	Y = Recipient
Anna	Gave	the chair	to/of	The director		100	Y = Recipient
Mary	showed	the car	to/of	the neighbor	11	89	Y = Recipient
Peter	brought	the chair	to/of	The director	13	88	Y = Recipient
Mihail	Sold	the house	to/of	his neighbor	29	71	Y -> Recipient
Mary	Sold	the car	to/of	the neighbor	30	70	Y -> Recipient
The Big Bad Wolf	Sold	the house	to/of	the dog	33	67	Y -> Recipient
Peter	showed	the house	to/of	his father	33	67	Y -> Recipient
the fitter	showed	the car	to/of	the neighbor	50	50	Equivalence
the upholster	brought	the chair	to/of	The director	50	50	Equivalence
Ivan	Sold	the house	to/of	his father	67	33	Y -> Possessor
Elena	Sold	the house	to/of	the dog	100		Y = Possessor

As it is shown in Table 3, when the verb allows a Recipient, *на* implies preferably, but not necessarily the structure S-(V)-O-R (three arguments). The noun Y selects the Rc role in most cases. If mental operations were not dependent on the calculus which relies on the arguments as primary substances, all the statements of the experiment would be with around 50% interpretation of Y as Rc and 50% - Y as Ps.

We conclude that the argument-centered representation of syntax is the key to syntactic analyses.

The next question is: if the argument S-(V)-O-R structure is calculated first, what are the reasons that lead the calculus to take another route and assign a S-(V)-O of Y structure to a similar sentence? Our assumption is that the sentence is kept in working memory (figure 1.) and that the final "solution" about basic syntactic roles is assigned to all its parts after semantic verification. If that was not true, the word order would be the key factor in the syntactic computation and the observed differences in the interpretation would not appear.

Let us analyze why the statement:

Elena	Sold	The house	*to/of*	The dog.	100% of	Y = Possessor,

is interpreted as having S-(V)-O of Y structure. The reason for that seems very clear: the noun dog is rejected as Rc of "sold". The noun takes upon itself the role of the owner of the house. If this is the right mechanism, it is sufficient to provide "the dog" with the possibility to be the Rc of the house, or to modify a noun: "Elena sold the house to a dog-buyer".

The argument-centered syntactic model attests to the fact that syntactic relations depend on the relations between concepts that exist in the semantic space. In fact, as the experimental results show, it is sufficient to replace the subject noun with the one that can be related to the dog as a buyer in a fairy tale context:

The Big Bad Wolf	Sold	The house	*to/of*	The dog	To 67%	Y -> Recipient

This result indicates that mental calculus takes into consideration not only the meaning of the noun but also the relations between the nouns. Thus:

Ivan	Showed	The path	*To/of*	His father	To	100%	Y = Recipient
Ivan	Sold	The house	*To/of*	His father	67%	Of	Y -> Possessor

The three possible arguments of both sentences correspond to concepts that exclude relations such as “fathers have paths” or “sons sell houses to their fathers”. Note that sentences reveal the relations between all the three of the arguments. The predominant meaning in the semantic space of the second sentence is ‘fathers have houses and sons operate their father’s property’.

These dependencies between the basic concepts expressed as Subject and Object are shown as two pairs of statements below:

Subject	Verb	Object	Ha	Y	of%	To%	Tendency
Mary	Showed	The car	to/of	the neighbor	11	89	Y = Recipient
The fitter	Showed	The car	to/of	the neighbor	50	50	Equivalence
Peter	Brought	the chair	to/of	the director	13	88	Y = Recipient
The upholster	Brought	the chair	to/of	the director	50	50	Equivalence

When Mary shows the car, she shows it TO the neighbor; when the fitter shows the car, there is a high probability that this is the neighbor’s car. In the semantic space, fitters operate on cars, while neighbors have cars. That same tendency is observed in the second in pair (upholsters and a director’s chair). Once again, argument structure is influenced by the inter-conceptual relations.

These examples provide evidence about the nature of the primary elements - participants in mental operations. It becomes clear that syntactic computation depends on the meaning of the nouns and inter-conceptual relations.

Conclusions and Future Work

Assumptions about how the argument structure is computed have led to the development of the argument-based model of basic syntax. We applied the methods of cognitive, information, and mathematical modeling, and linguistic theory. An experiment designed to test our ideas confirmed that the argument-centered model is the key to mental operations. The semantic role of entities (nouns) is primary in syntax. The semantic relations between the nouns’ concept-images in the conceptual nets influence the final result of syntactic computation.

The role of the noun has proven to be primary from the point of view of evolution, language acquisition, and other factors of major importance for language. The proposal that arguments (nouns) play the key role in syntax has been supported by experimental evidence. Further study requires a more precise picture of the dependencies between semantic primitives, lexical items, and syntactic rules. That will lead to an advanced modeling of the phenomenon under examination.

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