THE ARGUMENT BASED COMPUTATION: SOLVING THE BINDING PROBLEM

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***Abstract**: In this paper, we further developed the argument-based model of syntactic operations that is argued to represent the key to basic mental representations. This work concentrates on formal descriptions of the observed syntax-semantics dependencies. We briefly review our up do date experimental work designed to test this hypothesis, and offer the results of our most recent experiment. The results of our experiments confirmed that semantic relations between the images in conceptual nets influence syntactic computation. The binding problem that arises when the same noun can be represented either as Subject (ex. The cat chases the mouse) or Object (ex. The mouse chases the cat), was successfully resolved.*

Keywords: Cognitive Models of Language Phenomena, Formal Models in Language and Cognition, Psycholinguistics and Psycho semantics

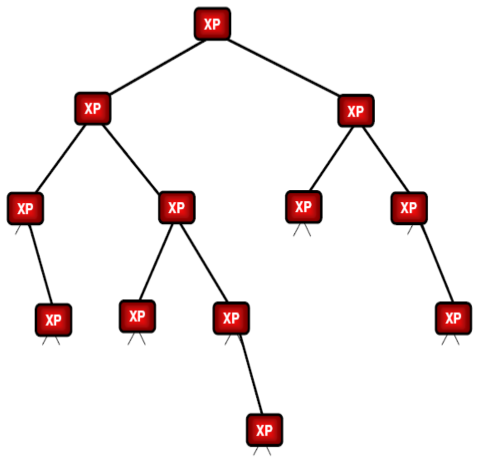
***ACM Classification Keywords**: **ACM Classification Keywords**: I.2 Artificial Intelligence, 1.2.0. Cognitive simulation*

Introduction

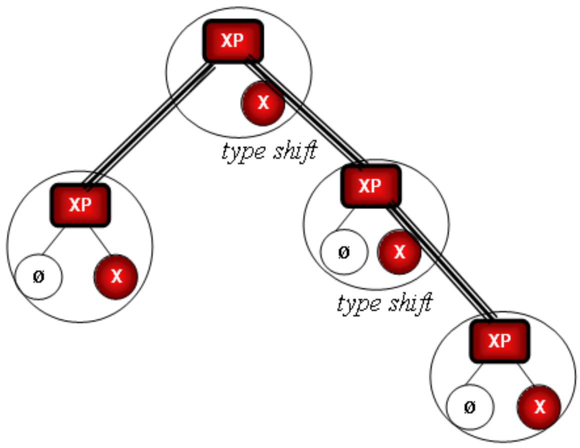
Following one of the widely accepted linguistic theories, the key component of Faculty of Language (FL) is a computational system (narrow syntax) that generates internal representations and maps them into the conceptual-intentional interface by the (formal) semantic system (Hauser et al., 2002). There 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 (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.

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 structure obtained in this way is a tree of Fibonacci (figure 1. a) that complies with the principles of optimization, namely with the principle of efficient growth (Soschen 2006, 2008).

This tree can be seen as an operator – it “performs” a bottom-up Merge (fig.1.a.); its nodes are the results of Merge. In the model under development (fig.1.b), XPs are *sets*, Xs are ‘unbreakable’ *entities*, and Merge can be applied to two non-equivalent substances (the tree has ordered nodes). We called the tree in (fig.1.b) ”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.



a.



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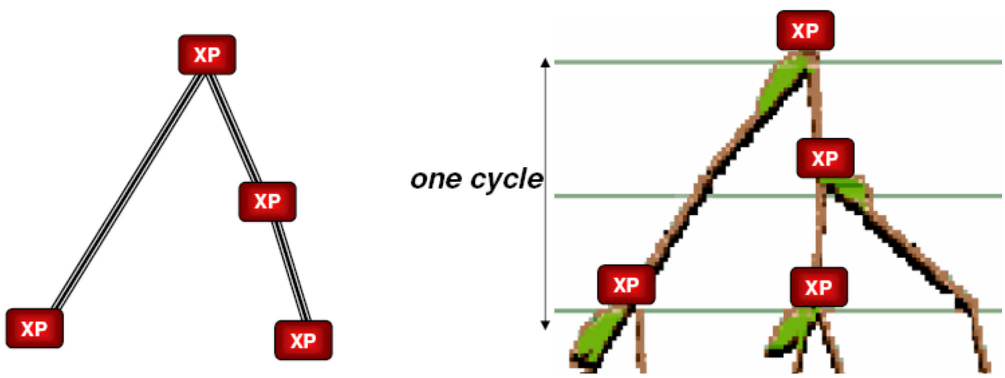

c.

Figure.1.

The question of the height of this obtained tree is deeply related to the question of the limits of human cognitive resources. This tree expresses a label-free structure that does not have lexical items; what it has are the paths of connecting smaller units in order to produce a larger meaningful unit. It could be suggested that the limits of this structure are 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 structure. The analysis has shown that the paths of merging terminal Xs that result in their final configuration, obtained at the root, are finite and well determined. The final configuration is a precise scheme that incorporates terminal Xs, which corresponds to one given path of merge.

Going back to the syntactical sense of XP, we may interpret the properties of the XP Fib trees as follows: the merge-tree defines the maximal number of XPs that can be merged into a configuration, to the root where a meaningful relation between these arguments is established. The type of configuration of merging arguments determines the type of relation between arguments. We showed what the kind of relation is set at the root of merge configuration (fig. 1.a.). The maximal configuration (fig 1.b.) corresponds to the determined in linguistics as: subject, recipient and theme and the semantic-merge pattern corresponds to the principle of efficient growth.

The argument-based model assigns a primary syntactic role to *entities*, usually expressed as nouns. This viewpoint is in contrast with the *verb*-centered model of syntax. Our efforts were further focused on experimental work in support of the argument-based model providing support for the argument-based model. In our recent paper (Slavova & Soschen, 2009) we provided experimental evidence that identifies the semantic role of entities (nouns) as primary in syntax. Our experiment was based on the fact that Bulgarian lost its case markers; the Genitive and Dative cases are both expressed by means of a preposition *'на'* (na). In Bulgarian, all the grammatically correct sentences of type:

Subject Verb Object *на* **Y**.

are ambiguous: they may assign two different meanings to Y - either that of the *Recipient* or the *Possessor*. We used 12 such double-meaning sentences and asked about 100 native Bulgarians and fluent French speakers to translate them in French, where preposition *на* is translated as "à" (to) for the Recipient-meaning and as "de" (of) for the Possessor-meaning. Only two subjects noticed the double meaning. The experimental data supported the idea that mental computation of syntax is influenced by the inter-conceptual relations between the images of entities in a semantic space. The assumption was made that the syntactic treatment includes Merge that operates on the images of the concepts. In the present paper, we call this operation "Semantic Merge" (SeM).

In the course of the experiment, the result of one of the two treatments is rejected. The assumption is that the intermediate images μ of either the Recipient scheme (fig.2.a.) or the Possessor scheme (fig.2.b.) are rejected by activating semantic relations between concepts. The experiment showed that the treatment follows the Recipient scheme (fig. 2a) even when there are no reasons to reject μZ^* as Possessor of Y^*. The explanation of this result is that the argument-based syntactic structure is "calculated" as primary. If there are no reasons to reject the result of one of the treatments, it is accepted as final.

Our conclusion is that the argument-based syntax has a fundamental character. The role of *entities* (nouns in this case) is confirmed as primary; the relations between the images of the concepts in the conceptual nets influence the final result of the syntactic computation.

We showed that the reiterative operation assigns a primary role to entities as the key components of syntactic structure. The schemes on figures 2 represent the stages of syntactic treatment with SeM for the Recipient assignment and the Possessor assignment. The images μ obtained at each step are provided in order to develop the mechanism of the treatment and to analyze it in accordance with the results of the experiments. Our assumptions concerning the ways the argument structure is computed have led to the development of the argument-based model of basic syntax.

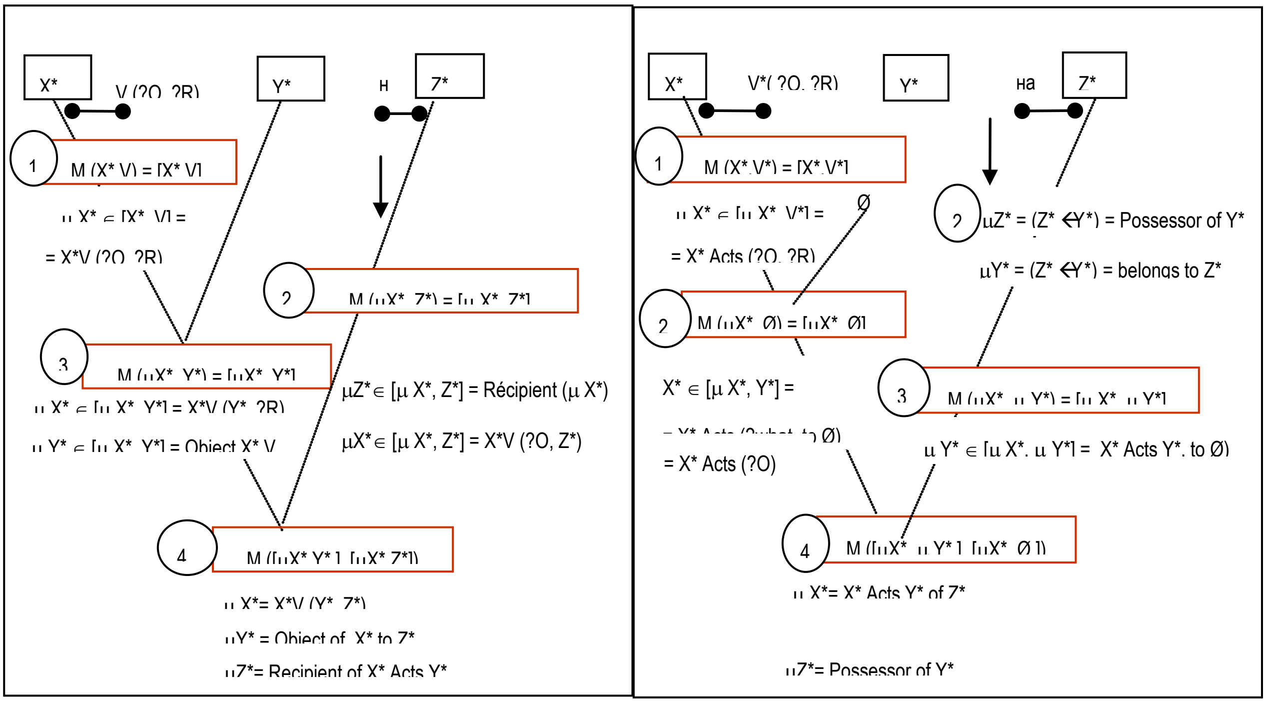

Fig 2 a) Recipient scheme b) Possessor scheme

SEMANTIC MERGE

Semantic Merge (SeM) was modeled as a binary operation, performed in sequential progression on the concepts (X*, Y* and Z*) expressed as nouns in a sentence that also includes verb V*. The general idea is that SeM complies with the principles of the argument-based syntax. The result of SeM consists of temporal semantic images μ retained in working memory up till the final stage of the syntactic treatment. The formal description of the stages obtained in the course of syntactic treatment corresponds to the experimental results. The hypothesis that syntactic rules comply with operations on semantic primitives is thus supported.

Our attention in this experiment was focused on SeM of Z* as either the Recipient or the Possessor; SeM of X* and Y* defines X* and Y* as Subject and Object of the verb V*, accordingly. The edge: *{X, Verb}* entails SeM between X* and V. The result of SeM is a pair, in which each element obtains image μ, which represents the concept in the semantic context that includes the other member of the pair. The syntactic structure begins to be assembled on the basis of the semantic information.

In the argument-based syntactic model, Subject is primary in the treatment.

$$M\,(X^*V^*) = [X^*, V]\ (\underline{?O}) \tag{1}$$

For example, image μ of the concept X* within the couple [X*V] corresponds to image of X* as Subject, performing V:

$$\mu\, X^* \in [X^*V] = X^*\ \text{Acts}\ (\underline{?O}) \tag{2}$$

In our test sentences Subject and Verb were grammatically marked. However, in the experiment presented in this paper, we analyze a language in which the grammatical rules do not always mark Subject and Object. In this experiment, the calculation of Subject vs. Object is dependent solely on the interaction of mental images of the concepts X* (Subject) and Y* (Object).

Recall that in the model offered for your consideration, the argument-centered representations are based on the primary function of the theme in respect to the agent; objects are grouped according to their primary function with respect to the participant (Soschen, 2008). This approach resolves certain problems for a neural instantiation (van der Velde & de Kamps, 2006). One of them, the binding puzzle, concerns the way in which neural instantiations of parts (constituents) can be related (bound) temporarily in a manner that preserves the structural relations between the constituents. Assume that words like cat, chases, and mouse each activate specific neural structures. The problem then would be that Noun cat and Noun mouse are bound to the role of agent and theme, respectively, of Verb chases in the sentence The cat chases the mouse and to the role of theme and agent of chases in the sentence The mouse chases the cat.” In the present theory, however, no binding by V is necessary; the semantic roles (Subject vs. Object) are determined on the basis of the interaction of the concepts X and Y*.*

A mathematical theory for semantic analysis is feasible when at some level a finite set of principles is available to determine the basic rules that underlie this interpretive part of language. The structure of a sentence is given by a recursive rule, as this provides the means to derive an infinite number of sentences using finite means. For the same reason, semantics employs recursive procedures that assign a certain meaning to a sentence based on the relations that exist between its elements.

SEMANTIC MERGE: EXPERIMENTAL PROOF

Bulgarian is an Indo-European language, a member of the Slavic branch. Bulgarian exhibits certain peculiarities that set it apart from other Slavic languages, such as elimination of Case marking and the development of a suffixed definite article. Although the Bulgarian nouns are rarely marked for Case, the word order is rather free. Thus, in a Bulgarian the sentence ‘The children have read the letter’ can be expressed as the following:

(SVO): децата прочетоха писмото. (3)

‘The children have read the letter’

(SOV): децата писмото прочетоха. (4)

‘The children the letter have read’

(OSV): писмото децата прочетоха. (5)

‘The letter the children have read’

(OVS): писмото прочетоха децата. (6)

‘The letter have read the children’

(VOS): прочетоха писмото децата. (7)

‘Have read the letter the children’

(VSO): прочетоха децата писмото. (8)

‘Have read the children the letter’.

Although SVO is the basic one, all permutations are possible; they are grammatically correct, even thought some are used mostly in poetry. According the Institute of Bulgarian at the Bulgarian Academy of Sciences, this grammatical particularity of permutation is possible because of the agreement between Subject and Verb which clarifies the role of Object.

As shown in (Fig.3), the grammatical relation between the first noun (concept X*) and verb V* vs. the relation between the second noun (concept Y*) and verb V* provide two distinct Merge-patterns. The first mental operator in this treatment is to merge nouns with V* in stages:

Stage I : Merge Subject-Verb

$$M(X^*V^*) = [X^*, V]\ (\underline{?O}) \qquad \mu X^* \in [X^*V] = X^*\ \text{Acts}\ (\underline{?O}) \tag{9}$$

or

$$M(Y^*V^*) = [Y^*, V]\ (\underline{?O}) \qquad \mu Y^* \in [Y^*V] = Y^*\ \text{Acts}\ (\underline{?O}) \tag{10}$$

Stage II : Merge Object with acting subject

$$M(\mu X^*, Y^*) = [\mu X^*, Y^*] \qquad \mu Y^* \in [\mu X^*, Y^*] = \text{Object}\ X^*\ V \tag{11}$$

or

$$M(\mu Y^*, X^*) = [\mu Y^*, X^*] \quad \mu X^* \in [\mu Y^*, X^*] = \text{Object}\ Y^*\ V \tag{12}$$

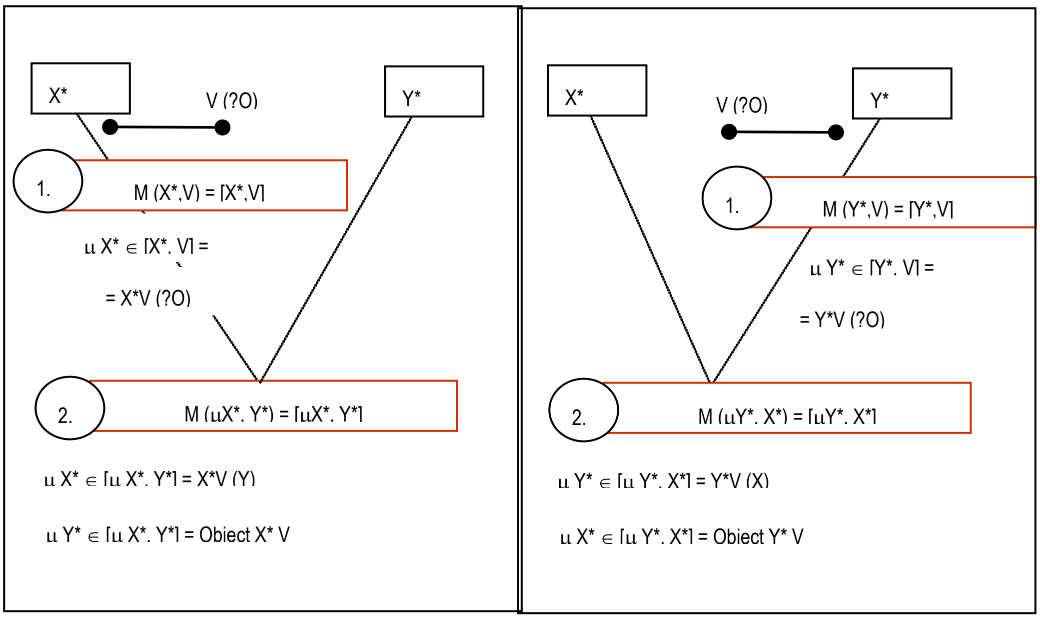

Fig 3. Stages of Semantic Merge.

The resulting mental representation μ is an image of the concept X* performing the action V. The second merge assigns to the second (‘unbound) noun the role of Object of the already obtained image μ. However, there is a problem with this approach. What will happen if the verb is in agreement with *both* nouns that represent the concepts X* and Y*?

There exists in Bulgarian a particular grammatical operation (clitic doubling) that marks Object in cases of a reverse word order, as in:

(OVS): Иван ***го*** поздрави Мария. (means : Maria greeted Ivan) (13)

*‘Ivan **him** greeted Maria’*

The clitic (го/ги) is obligatory only when the subject and the object are in the third person, and they are both either singular or plural. When the meaning is clear from the context, the clitic can be omitted, for example:

(OVS): Ролите озвучиха артистите: (followed by a list of the artists) (14)

The roles sound-screened the artists: (followed by a list of the artists)

‘The artists (from the list) sound-screened the roles’.

There are no grammatical markers that allow one to distinguish Subject from Object in the above sentence. As shown in (Fig.4), both patterns of merge are grammatically possible. However, native Bulgarian speakers do not perceive the sentence as ambiguous; it is interpreted as having OVS word order.

In this paper, we assume that both operations are semantically supported by the meaning of the concepts X* and Y*. The absence of the Accusative Case marker which canonically marks Object in Slavic languages is compensated by means of other mechanisms. The cognitive basis of these mechanisms was discussed in (Slavova & Koujumdjieff, 2009). Cognitive analytism was defined there as the phenomenon of deciding upon meaning of ambiguous phrases, where there is no marking distinction whatsoever. The decision about the function (role) of the referent is made exclusively on the basis of its place in the cognitive (mental) space.

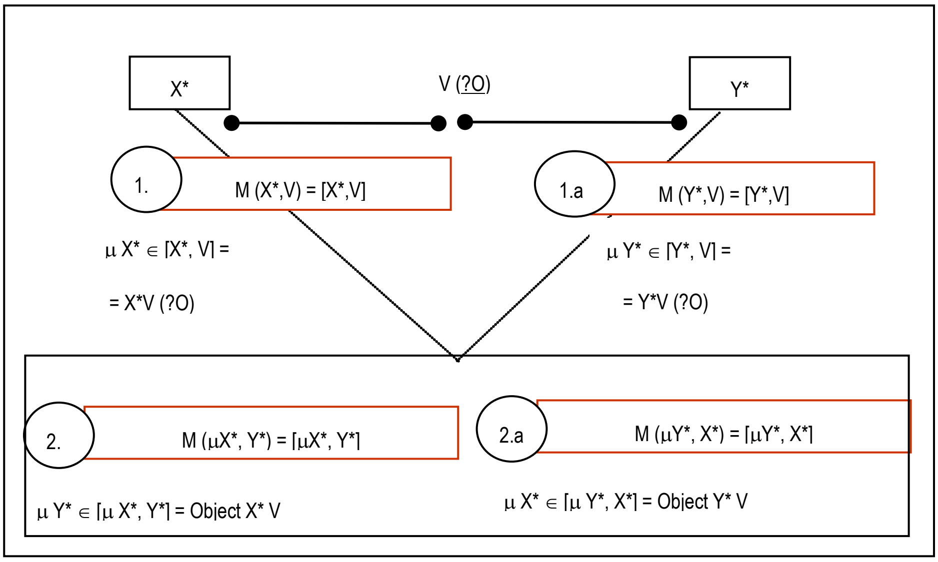

Fig.4. Double pattern of Semantic Merge.

EXPERIMENT: DESCRIPTION

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 standard experimental means. One possible way to extract information about the basic mental mechanisms is to induce ambiguity resolution on the lexical level, and then analyze the system's response.

The following experiment is based on the semantic ambiguity involved of certain Bulgarian sentences of the kind X(noun) Y(noun) V(verb). X and Y are nouns; V is in agreement with both X and Y. In this case, either X or Y can appear as Object:

$$M\ (X^*V^*) = [X^*, V]\ (\underline{?O}) \qquad \mu\ X^* \in [X^*V] = X^*\ \text{Acts}\ (\underline{?O}) \tag{15}$$

$$M\ (Y^*V^*) = [Y^*, V]\ (\underline{?O}) \qquad \mu\ Y^* \in [Y^*V] = Y^*\ \text{Acts}\ (\underline{?O}) \tag{16}$$

The following folk verses that contain sentences of the above kind were used in our experiment:

Живееше мишка, сива и красива	Живееше куче, сиво и красиво
Once upon a time there lived a mouse, grey and beautiful	*Once upon a time there lived a dog, grey and beautiful*
нейде на тавана, дето бе дивана.	нейде на тавана, дето бе дивана.
Somewhere in the attic, where the sofa was	*Somewhere in the attic, where the sofa was*
Появи се тук Котанчо, котаракът на Стоянчо.	Появи се тук Котанчо, котаракът на Стоянчо.
There appeared Kotantcho, the cat of Soyantcho	*There appeared Kotantcho, the cat of Soyantcho*
Мишката Котанчо хвана и изчезна под дивана.	Кучето Котанчо хвана и изчезна под дивана.
The mouse Kotantcho caught and disappeared under the sofa	*The dog Kotantcho caught and disappeared under the sofa*

The two sentences in the above verses (15) and (16) have identical structure X* Y* V* and ***there are no grammatical markers indicating which noun is Subject and which is Object.***

301.ex Мишката Котанчо хвана и изчезна под дивана. (17)

The mouse Kotantcho caught and disappeared under the sofa

304.ex Кучето Котанчо хвана и изчезна под дивана. (18)

The dog Kotantcho caught and disappeared under the sofa

We designed our experiment as a translation task (from Bulgarian to French). In contrast with Bulgarian, French the word order is fixed. Thus, our subjects had to assign a fixed word order to their French translations of our sentences, thus bringing out their interpretation of the same noun as either Subject or Object.

The experimenter asked the subjects to perform two tasks: 1) translate the verse (rhyming optional), 2) retell the story in two sentences. As in our previous experiment, the conditions were created where no attention was called to the ambiguity of the sentence(s).

The subjects of our experiment were 36 students with a variety of backgrounds (economists, sociologists, biologists, linguists, engineers, etc.). They were the students in the Masters program at the Francophone Institute for Management in Sofia, all of them fluent speakers of French and native speakers of Bulgarian. The Bulgarian verses were presented to them in a written form, on small separate sheets of paper.

EXPERIMENT: RESULTS AND ANALYSES

The results of the experiment confirmed once again that the relations between the images of the concepts in the conceptual nets influence the final result of the syntactic computation.

In sentences where 'the dog' appeared as the first noun and 'Kotantcho' (the cat) as the second noun, in both tasks all subjects assigned the Subject role to the first noun. All translations were structured as S V O (le chien a attrapé le chat); the word order was changed.

The dog Kotantcho (the cat) caught. (19)

the dog --> Subject caught the cat --> Object 17 (100*%)*

In sentences where 'the mouse' appeared as the first noun and 'Kotantcho' (the cat) as the second noun, in all cases of '*retell the story in two sentences'* condition the first noun was considered Object.

The mouse Kotantcho (the cat) caught. (20)

The cat --> Subject caught the mouse --> Object 12 (100*%)*

All translations were structured as S V O (le chat a attrapé la sourris); the word order was changed. The results of the translation task are as follows:

The mouse Kotantcho (the cat) caught. (21)

the cat --> Subject	caught	the mouse --> Object	16 (72,7*%)*
the mouse --> Subject	caught	the cat --> Object	4 (18,2*%)*
not clear --> Subject	caught	not clear --> Object	2 (9,1*%)*

It is clear that in the translation task the subjects were more confused as they attempted to respect the original word order. The cases which are not clear represent mot-à-mot translations, so the result in French does not make sense because of the word order. An attempt to respect the original word order is seen in a curious way in a couple of cases where the word order "subject first" is respected, but the sentences are translated in a passive form "*La sourris* ***a été*** *par Kotantcho* ***attrapée***" (The mouse has been caught by the cat).

Going back to the basic model (see Slavova, Soschen 2009) the language units (word-forms) have images as semantic primitives such as "concepts", "attributes", "events" etc, and the grammatical rules comply with semantic operations on these primitives. The detailed examination of the information flow using formal model, developed for simulating the cognitive process of natural language comprehension (Slavova 2004) has led to the suggestion that the procedures on the net must use semantic and syntactic knowledge in parallel (figure 5). Following this model, the cognitive system first assembles a fractional representation of the sentence-meaning structure (coupled words for example) and uses working memory loops for checking the semantic consistency.

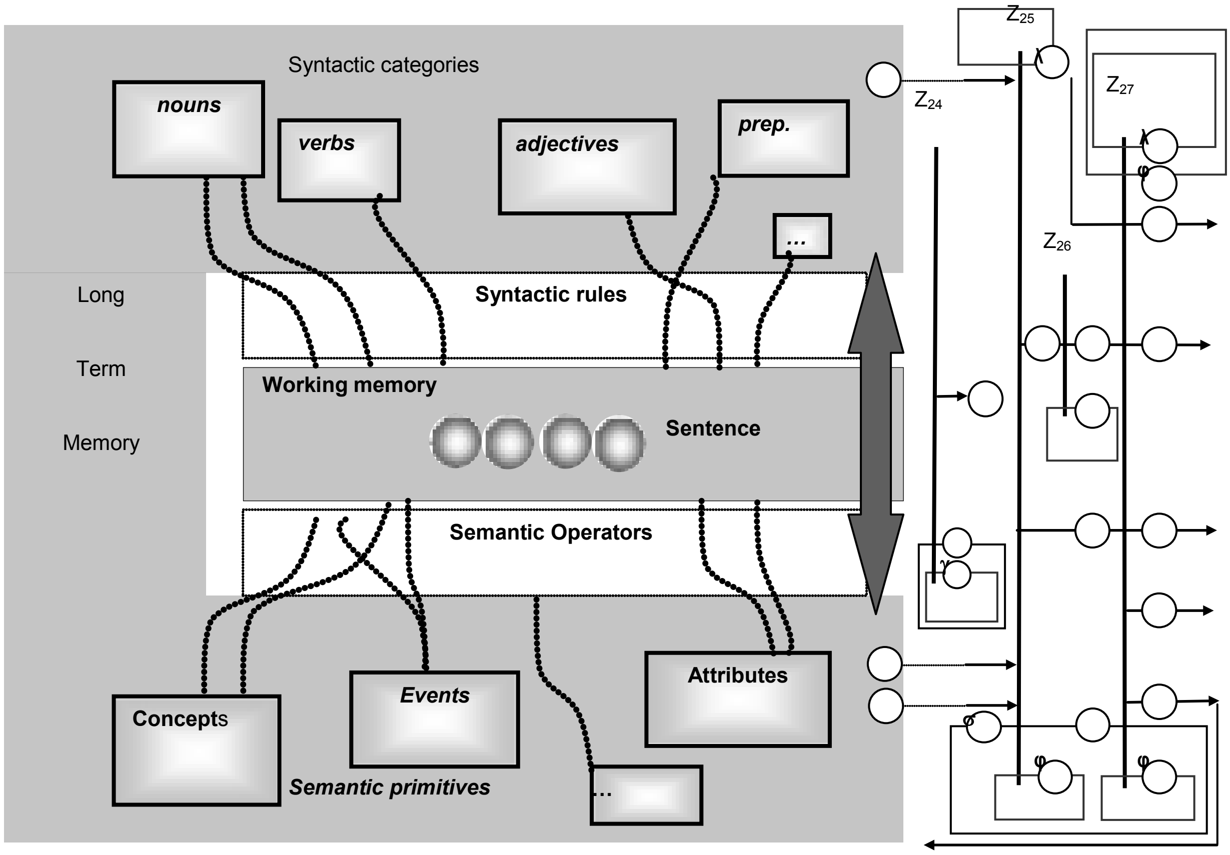

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Figure 5. Information treatment of a sentence, based on language and semantics

The grammatical features of the verb and the nouns in our sentences create two images:

Stage I Merge Subject-Verb (first noun merged with preference)

M (Y*V*) = [Y*, V] (?O) μ Y* $\in$ [Y*V] = Y* Acts (?O)

TheMouseCaught (22)

AND

M (X*V*) = [X*, V] (?O) μ X* $\in$ [X*V] = X* Acts (?O)

TheCatCaught (23)

Both images are semantically correct (as it is not "the cat flies" for example) and stored in working memory. So, both steps 1 and 1a from the merge-tree on figure 4 are performed.

Following the experiment, the result of one of the treatments is **rejected**. We suppose that this is done on the second step of the merge where object is assigned.

Stage II Merge Object with acting subject

M (μY*, X*) = [μY*, X*] μ X* $\in$ [μ Y*, X*] = Object Y* V

The Cat is the Object of TheMouseCaught (24)

AND

M (μX*, Y*) = [μX*, Y*] μ Y* $\in$ [μ X*, Y*] = Object X* V

The Mouse is the Object of TheCatCaught (25)

The rejection of (24) is done and (25) is accepted.

CONCLUSIONS

Once again, it was confirmed is that whether a particular noun is interpreted as either Subject or Object does not depend on the verb. For one and the same verb, the interpretation of a noun “switches” from one meaning to another. The analysis shows that the syntactic decision is influenced by the semantic images of the nouns themselves. The mental representation μ is an image of either the concept X* or the concept Y*, both involved in some action expressed as V. The second merge in (Fig. 4) assigns to the second (unbound) noun the role of Object of the already obtained image μ. We conclude that the operations in question are supported by the content of the concepts X* and Y* in their inter-relational semantic space.

In this work, the argument-centered approach shifts the focus from verb to the noun, from propositional to the non-propositional logic of grammar. The minimal building block that enters into linguistic computation is identified as symmetrical conjunct, or *a relation between individuals*. As a result, the true structure of language is characterized within a remarkably weak formal system, which is expected to develop into a more complex one to handle a broader range of data.

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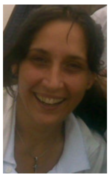

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Major Fields of Scientific Research: Cognitive modeling in linguistics, formal models of language phenomena

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Major Fields of Scientific Research general features of biological systems present in linguistic structures