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APPLICATION OF MATHEMATICAL METHODS IN
LINGUISTIC STUDIES

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Abstract

The relevance of the studied problem proceeds from the fact that in our age of scientific and technological revolutions the process of mathematisation covers all spheres of human activity, including linguistics. The purpose of the article is to develop strict methods of studying structure and semantics of the text. The leading method of our research is modelling of a linguistic object's semiotics on the basis of set theory. The results of this study include the structurally functional model of formation of text formal semantics on the basis of set theory with the use of codification of semantic-syntactic features of prepositions. This structurally functional model, focused on further development of mathematical methods used within the theory of machine translation, makes up the practical importance of our article. Our research also relates to translation programmes, which use neural network. The working principles of this network are established. The paper notes both advantages and disadvantages of applying this type of technology in machine translation. As is pointed out in our work, the most important characteristic feature of artificial neural networks is that they are not programmed. That means they can study. The ability of training is one of the principal advantages of neural networks over traditional algorithms. Technically, this training is based on finding coefficients of communication between neurons.

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Keywords: Conjunctive phrase, machine translation, preposition, set theory, supra-phrasal unit.



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1. Introduction

The problem of necessity to apply programming mathematical formalism in linguistics was studied by Serebryakov (2015), Zhukov (2007), Piotrovsky, Bektayev, and Piotrovskaya (1997), Lüttgen and Mendler (2002). The problems of applying artificial neuronets in linguistics as well as clustering method application in corpus linguistics were considered by Kozadayev (2010), and Garipov (2008b). However, in these previous studies the impact of the semantic nature of prepositions on text structure wasn't analysed on the basis of set theory.

Application of mathematical methods in linguistics is caused by two reasons. On the one hand, the development of linguistic theory and practice demands introduction of more exact and objective mathematical methods of analysis. This will allow linguists to penetrate more deeply into the mysteries of creation of language and formation of the text and other linguistic categories (Garipov, Oleynik, & Shagapov, 2016; Garipov, 2016b). On the other hand, following the use of a natural language in the people's administrative and information systems "Human-machine", linguistics is, thus, especially persistently mathematised.

In our research we consider the possibilities of the use of mathematical set theory in linguistics when determining the theoretical basis of studying languages (Hjelmslev, 2006; Likhacheva, 2015). It is well-known, that "a mathematical set" or simply "a set" is a group of objects considered as a single unit. This very concept of "a set" is not usually reduced to other smaller concepts. One of the examples of the use of set theory in linguistics is "the Venn diagram" as well as the examples of receiving any "circles of Euler" from "Venn diagrams" (Garipov & Zakharov, 2013, p. 34).

When studying the syntactic structure of a sentence within a supra-phrasal unit (SPU), it is feasible not only to identify the strict Subject-Predicate and Subject-Object structure of the sentence but also to consider the characteristics of the verbal predicate compatibility with its other possible nominal complements.

According to the theory of syntactic compatibility, the complement can be an obligatory argument, completing the predicate semantics; an optional (facultative) argument, which is not required to complete the meaning of the predicate; or an adjunct, referring to the entire predicative structure of the sentence. In other words, a sentence has a formal grammatical structure with the main parts (subject and predicate) and complements (objects, adverbials), the order of which in the sentence is determined by the syntactic rules of grammar (French grammar in our case), as well as by the referential logic parameters of its broader text (Garipov, 2016a).

The specific feature of nominal complements is that they are to a certain extent governed by the verb, and the strength of the bond between the verb and the nominal group, as well as the presence of an obligatory or optional nominal component (which determines sentential or inter-sentence function of the noun), directly depends on the verb semantics. We introduce a distinction between "complements" with intra-sentence functions and "connectors" with the function of inter-sentence connection.

The difference between complements and connectors is, probably, not only in the degree of bonding with the verb (i.e. the fact that complements are directly governed by the verb, while connectors are related to the predicative base of the sentence as a whole), but also in varying referential correlation of the corresponding prepositional nominal groups. A verbal-nominal group (including the subject and the direct object, which closely interact with each other in the sentence, and are always directly related to the verb-predicate) has been thoroughly studied. We propose now to look into the nature and specific features of the function of prepositional nominal groups in the sentence and within SPU (Zubov & Zubova, 2004).

If we characterize these prepositional phrases in terms of bonding with the verb-predicate, we should exclude the subject and the direct object from consideration, since these are always directly related to the verb. We are going to consider nominal groups usually denoted as indirect objects and adverbials. Both parts of the sentence may be directly governed by the verb or be related to the predicative base of the sentence, in the latter case they might be in a peripheral position in relation to the verb in the sentence, defining the entire sentence.

2. Problem Statement

The problem of deep study of semantics and the meaning of linguistic units remains relevant. The point is that it is not always possible to define the semantics of a particular text unit precisely. That is based on the fact that the meaning of many text units and sentences (and even word combinations) does not coincide with the lexicographical information. A reliable tool is the study of semantic information contained in the pre- and post-texts of the studied unit. This analysis makes it possible to identify new potential semantic and functional capabilities of the specified unit and, accordingly, reveal its previously unnoticed semantic and syntactic properties.

3. Research Questions

In connection with the study of the semiotics of speech (textual, syntagmatic) and language (paradigmatic) units, the following questions arise:

1. Does the value of a unit depend on the meaning of the surrounding context?
2. To what extent does the value of the studied unit depend on the semantics of the left context?
3. To what extent does the value of the studied unit depend on the semantics of the right post-text?
4. Can the sought-for unit influence the semantic information of the context?
5. What type of units can modify contextual information?

4. Purpose of the Study

The purpose of our paper is consideration of various opportunities to use new and expanded methods of linguistic analysis and simultaneous inclusion of several directions of all-linguistic research in the study of prospects of using mathematical set theory and neural networks in linguistics and translation practice.

5. Research Methods

Our study is based on the analysis of prepositional phrases by Shvedova (1954), who clearly shows (when comparing them with word combinations having a direct syntactic relationship with the verb) that prepositional phrases are not part of the sentence structure, and offers some techniques for distinguishing them from the components of the same form that have a strong bond with the governing verb, depending on the verb semantics. The verbal component most often expresses a process, and the obligatory or optional character of the governed name directly depends on the nature of the semantic group to which the verb belongs.

As for the determinants, they are such nominal groups that have weak, free connection with the sentence, and, consequently, with the verb (Shvedova, 1954). The nature of such a connection directly depends on the

actualized semantics of the preposition and the noun in the prepositional group, as well as on the verb valency realization, its obligatory or optional character in the sentence and the text.

In this context it should be mentioned that attribution of a prepositional phrase to the means of inter-sentence connection (C) will directly depend on the strength of the semantic bond (X) between the preposition and the noun in the word combination (see Table 1) and the extent of optionality of the verb valency realisation (Y), as well as on the code (K) of the coefficient, reflecting the specific type of semantic relationships between components of the nominal group:

$$C = K X/Y.$$

Another example: all the determinants are in the subset “A” (see Figure 01 below). In this case, we can use the mathematical set theory to study the extent of belonging of a prepositional phrase or determinant to the sentence structure.

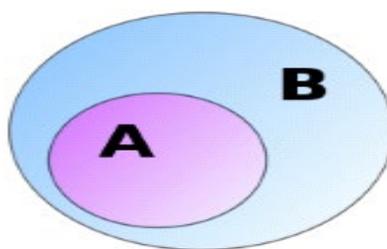


Figure 01. All the determinants are in the subset “A”

We will denote the sets of all prepositional phrases with capital letters (A, B), where “B” is the set of all intra-sentence and inter-sentence prepositional phrases, and the subset “A” includes only prepositional phrases with inter-sentence connection. Small letters (a, b) will be used to denote elements of such sets. We will denote belonging of the element “a” to the set “A” as “ $a \in A$ ” (a prepositional phrase with inter-sentence connection), but such an element, depending on (1) semantic relationships between components of nominal groups (see Table 1 below) and (2) strength of the verb valency realisation, can stay within the predicative base of the sentence (Zubov & Zubova, 2004).

The preposition is usually defined as a part of speech that expresses spatial, temporal, causal, purposive, possessive or other relationships between objects or the same relationships between objects and actions or qualities in general. Prepositions denote syntactic relationships between different forms of nouns, pronouns or their equivalents on the one hand, and verbs, nouns and pronouns on the other hand.

The preposition meaning can usually be revealed only within a particular prepositional phrase, but in the French language there are prepositions that have not yet completely lost their lexical meaning and have not lost the ability to express certain adverbial relations on their own (*à l'intérieur de* – inside something, within something). The extent of abstractness and lexical meaningfulness varies in different prepositions, though in the French language the semantics of the preposition, in general, is rather abstract (Gak, 1977). The meaning of a preposition as a connecting word is often determined by the semantics of the surrounding textual elements, but at the same time the preposition has its immanent own meaning, defining its potential combinations with certain lexical units. Therefore, it is necessary to outline its general invariant meaning, which would allow monitoring occurrences of the preposition in a variety of textual (and not always similar) situations.

The difference between the referential lexical functions and the grammatical function of prepositions is rather considerable. In the case when a preposition keeps its own lexical meaning, it has certain influence, to a greater or lesser extent, on the semantics of other words in the prepositional phrase, which can change their nature and role in the organisation of the inner structure of the sentence. On the contrary, if a preposition loses its lexical meaning, it becomes an entirely “empty” grammatical form, expressing only sentential or inter-sentence relationships.

In this connection, we can't but mention the remarks by G. Galichet, regarding the mutually conditioned relationships between the preposition and other elements of the prepositional phrase (*le double conditionnement du rapport prépositif*): either the preposition “imposes” its meaning upon the phrase elements, or relationships between two components of the phrase imply the choice and meaning of the preposition, which results in a “competition” between the preposition and other elements of the prepositional phrase. Therefore, on the one hand, there may be an absolute dominance of the preposition in a word combination; on the other hand, the absolute influence of other elements of the prepositional phrase can prevail, sometimes reducing the role of the prepositional component to naught.

All the stated above allow identifying three main types of prepositions:

1. Strong prepositions. A preposition of this type is independent of all other elements of a word combination, which cannot be connected with each other without this preposition. For example: *Il vient avec moi* (He comes with me). The sentence would be inaccurate and ambiguous without the preposition “avec”. In this case, the preposition has its own independent meaning.

2. The second – “agglutinate” – type of prepositions is characterised by its dependency on either the first or the second element of the prepositional group; otherwise, the preposition completely loses its independence under the influence from other elements of the phrase. Sometimes the preposition is attracted by the first element of the group, in which case they make up a solid linguistic unit: this often happens with the verbal phrases with the semantic structure including the notion of direction of the performed action: *compter sur* (count on), *demander à* (ask somebody).

There can be an opposite situation (i.e., the preposition is linked to the next (nominal) element), when the relationship between the elements of the prepositional phrase is represented as completed in the second, nominal element, and at the same time options for selecting the first, verbal element are very limited: *partir sur-le-champ* (to leave right away), *régler sur-le-champ* (to settle right away [“on the spot”]).

3. The third type includes weak, or “empty”, prepositions – they are a part of such prepositional phrases where simple co-occurrence of the word combination elements is sufficient in forming stable combinations without an active role of the preposition: *commencera à travailler* (to start working), *finir de rire* (to stop laughing). The prepositions of this type do not convey any semantic load – as a result of grammaticalisation. They have only structural functions (Galichet, 1972).

This process of grammaticalisation affects all types of prepositions, from lexically independent to almost totally abstract, because the process of desemantisation and subsequent falling out of the linguistic system never stops in the language. Thus, the French preposition “à” may express, among other meanings, the relationship of the “direction of movement”. In the sentence this preposition can act as an agglutinative element, losing its lexical meaning and linking the verb with an infinitive (*commencer à*), and perform only a structural function, or in some

occurrences this preposition in nominal groups is completely forced out of the structure of the sentence and functions only at the inter-sentence level:

P1: *Jamais il n'avait pas senti comme aujourd'hui le poids des ans et celui de la lèpre* (Never before had he felt such a burden of both the age and the leprosy).

P2: *A la vérité, l'atmosphère devenait étouffante* (In truth, the atmosphere was becoming stifling) (Boulle, 1978).

In the French language the process of grammaticalisation (or textual designification) has affected many prepositions. Thus, the preposition “*dans*” often expresses pure grammatical relationships in the text; thus, we can probably say that the preposition has lost its referential meaning.

However, in other cases the prepositions keep the individuality of their lexical meanings and often enter into combinations with nouns to form isolated syntagmas, which demonstrate certain independence and simply adjoin to other parts of the sentence.

It is worth noting that sometimes we can observe synonymous doubling of strong prepositions, i.e. they strengthen one another with a synonymous nuance of meaning:

Joseph prit donc le journaliste par le bras et il le conduisit jusque dans la grande galerie où se trouvaient exposées les oeuvres de ceux que Joseph appelait, ... “Les princes de la peinture modern” (Joseph took the journalist by the hand and led him to the great gallery exhibiting the works by those whom Joseph called, ... “Princes of modern painting”) (Duhamel, 1968, p. 84).

Such doubling in the use of prepositions results in strengthening the referential status of the preposition and the entire prepositional phrase, which, as an independent part of the sentence, functions only within this particular sentence and does not express any relationship with other sentences or their individual components.

In word combinations with compound prepositions, the noun stem has a referential relationship with the next component or sentence (*la galerie – les oeuvres*); the preposition indicates the established grammatical relationship (spatial in this case) in the syntagmatic combination. This leads to a kind of lexical and grammatical doubling, or strengthening the preposition in a segmented, analytic form. The analytic structure of these prepositions corresponds to the semantic and referential segmentation. In the compound prepositions formed by combining nouns or pronouns, the meaning of the whole is made up of a lexical, substantial meaning of the basic component and an additional, designative meaning of the preposition.

However, if compound prepositions are formed by prefixing a preposition to a noun (but not to a pronoun), the resulting prepositional phrases cannot combine numerous meanings due to their transparent structural and formal nature. Their grammatical functions are reduced to the lexical meanings of the nouns in their structure.

The subject definiteness of such a preposition or a prepositional phrase affects the scope of its grammatical functions. The compound prepositional phrases have a well-defined, narrow scope of meanings and possible occurrences. At the same time the meanings of simple, non-derivative prepositions in combination with non-referential nouns or pronouns (*dans ce cas, pour cela, avec ceci* – in this case, for this, with this) are the most abstract and varying to such an extent that at the inter-sentence level the functions of such prepositions are closer to those of conjunctions. The specific meanings of such prepositions weaken in textual realisation, so they turn into empty grammatical signs of objective relationships, keeping only structural functions and becoming closer to conjunctions. In other words, such prepositions are comparable with conjunctions – a part of speech that can denote lexical and

logical relationship or coordination not only between homogeneous parts of the sentence or word combinations within a syntagma or a clause, but also between sentences within supra-phrasal units.

Unlike conjunctions denoting various syntactic relationships between functionally homogeneous units of speech, prepositions usually indicate syntactic conditionality or dependence between the parts of the joined syntagmas or sentences, or the relationship between the defining and the defined, because prepositions are in anteposition in the French language. When a prepositional phrase obtains textual functions, it actualises the entire sentence, including it into the SPU structure.

The difference between traditional prepositions and conjunctions is in the fact that the former create an intra-sentence (referential and semantic) perspective in space, time and in other aspects, while the conjunctions form a purely formal (syntactic) perspective inside and outside the sentence.

There is a difference between the functions of inter-sentence conjunctions and the conjunctions connecting individual words and word combinations. The range of possible meanings (coordinating, subordinating, enumerating, contrasting, etc.) expressed by the conjunctions connecting sentences is much wider than the scope of relationships in the intra-sentence connections. We can observe certain parallels between the meanings of the inter-sentence conjunctions and those of intra-sentence prepositions: temporal, causal, purposive, comparative, quantitative, and so on. However, such conjunctions differ from traditional prepositions because, firstly, they usually do not correlate with individual words and have no effect on their semantics, and, secondly, the conjunctions do not imply the relationship of “domination – subordination” because the relationships they denote are mostly bilateral, and they connect whole sentences, including subordinate clauses. However, in many cases prepositions compete with conjunctions both in their function of inter-sentence connection and in building intra-sentence prepositional phrases, often expressing the semantic content of a whole sentence in a compressed form.

Of special interest in this context is the increased use of a prepositional modifier as an element of a noun group. The occurrence frequency of prepositional modifiers in sentence structures is often growing through their use instead of subordinate clauses, as prepositional phrases are effective and condensed alternatives expressing the same semantic content:

Pourtant, à y regarder de près, la différence sur ce point est plus apparente qu'réelle (However, on closer inspection, the difference at this point is more apparent than real) (Laffite, 1978, p. 97).

However, prepositional modifiers compete not only with subordinate clauses but also with other parts of the sentence and even with other elements of its noun group, namely, a compound noun, an extended participial modifier or a relative adjective.

For example, occurrences of prepositional modifiers with the preposition “de” are especially noticeable in partitive (*la moitié de la richesse* – half of the wealth), possessive (*la maison du père* – the house of the father), and qualitative (*le bocal en or* – a jar of gold = golden jar) meanings.

One of the reasons for such frequency of occurrences is the fact that some grammatical meanings can be expressed by different synonymous means in a noun group, but they can be expressed most clearly with a preposition.

This refers, for example, to the semantics of possession in the direct meaning of this word: belonging of a particular object to a particular person or belonging of a particular part of the object to the object as a whole (possessive adjectives and pronouns are not the subject of special consideration in our study).

Other means, such as the preposition “à”, prove to be more multivalent than the preposition “de”, because the former can also express, in particular, the meaning of the “object designation”: *le livre à papa* (the book for dad).

Other prepositional constructions formed with prepositions having specific meanings, as a rule, provide the entire group with some additional (usually spatial) meaning, going beyond the pure affirmation of a possessive relation.

Il entendait la messe dans l’oratoire de ces dames, chez la comtesse Mallet, (=l’oratoire de la comtesse Mallet), chez l’aînée des Sismondo (=l’oratoire de l’aînée des Sismondo)... (He went to the mass in the oratory of those ladies, in that of Countess Malet [= in the home chapel of Countess Male], and the elder of the Sismondos [= in the chapel of the oldest lady of the Sismondo family]) (Daudet, 2015, p. 67).

In this sentence the preposition “chez” has a complex semantic structure, including the analysed sense of possession (“belonging to a confessional organisation”) and another sense of “a place of administering various religious rites by supporters of a particular branch of Christianity”, which in this case is just additionally qualifying or even excessive.

The preposition “de” is to a certain extent irreplaceable in some nuances of its objective and subjective meanings. As the result of formal and semantic asymmetry of the sign, there is a considerable amount of homonyms and synonyms of constructions with the preposition “de”. But there are cases when the preposition “de” is practically the only possible option, such as constructions with deverbative nouns. Let’s move to Table 01:

Table 01. Types of semantic relationships between components of nominal groups

Relationship type	Code	Examples
Defining (attributive)	D	<i>classe de distribution</i> distributive class
Possessive	P	<i>membres de la classe</i> elements of this class
Subjective	S	<i>apparition du mot</i> occurrence of the word
Objective	O	<i>utilisation des textes</i> using of texts
Temporal	T	<i>soleil de juillet</i> the sun of July [during the period of July]
Spatial	L	<i>la cime du mont Gibel</i> the summit of Mount Gibel
Qualitative	Ql	<i>une grave situation des pris</i> a serious price situation
Quantitative	Qn	<i>un fond de santé</i> good health [good health capital, large amount of health, a fount of health]

6. Findings

On the one hand, combinations of such nouns with specific prepositions would result in forming subjective or objective constructions with too specific spatial semantics (as we have seen above in the case of expressing the possessive meaning with the preposition “chez”), while deverbatives are known to have tendency to express abstract verbal and nominal content.

On the other hand, the preposition “de” with its abstract semantics allows creating subjective or objective constructions with such an extent of generality of meanings of their elements, which could be difficult to be expressed with other linguistic units or constructions (subordinate or participle clauses or relative adjectives). Moreover, the meanings of the elements of the prepositional phrase can be identified without taking into account the features of the right-hand side distribution, i.e. the verbal component.

The latest achievement in machine translation is, by right, the programme using the Artificial Neural Networks (Garipov, Oleynik, & Shagapov, 2016). The main feature of neural networks is that they are not programmed, and can be studied. The possibility of training is one of the main advantages of neural networks over traditional algorithms. Technically, training consists in finding coefficients of communications between neurons. In the course of training the neural network is capable to reveal difficult dependences between the input and output data and also to execute generalisation. Some of the largest IT-companies Google and Microsoft have already introduced the Artificial Neural Networks in the developments (See Figure 02).

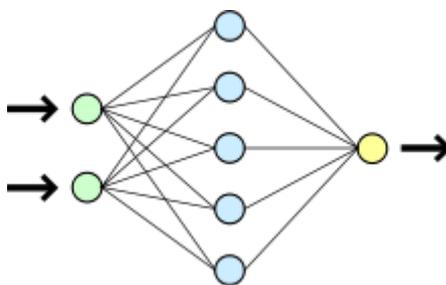


Figure 02. Artificial neural networks (2 entrance neurons, the 5th hidden neuron, and 1 output neuron)

As we see, fuzzy-neural networks carry out conclusions on the basis of the fuzzy logic device. However, the parameters of the functions of membership are configured using the NW learning algorithms.

7. Conclusion

1. For objective studying of the language it is necessary to use strict mathematical methods.
2. The most perspective is the use of the theory of sets by means of which it is possible to formalise both the plan of expression and the plan of content of any linguistic unit.
3. Formalisation of semantics of prepositions allows us to study the structure of linguistic units at a deeper level.

In the near future, special semantic-syntactic algorithm will be created, which, taking into account semantics and syntax, will change the word order in the sentence and follow all the other subtleties in an already translated

sentence. Over time, the system will develop and improve and this will allow people to communicate more freely, regardless of their language skills.

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