ОПИСАНИЕ ЛОКАТИВНЫХ ЗАВИСИМЫХ В СИСТЕМЕ АВТОМАТИЧЕСКОЙ ОБРАБОТКИ ЕСТЕСТВЕННОГО ЯЗЫКА

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THE DESCRIPTION OF LOCATIVE DEPENDENCIES IN A NATURAL LANGUAGE PROCESSING MODEL

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The paper suggests semantic and syntactic descriptions of locative dependencies in an NLP model and focuses on the problems which locative adjuncts evoke for a system aimed at different tasks based on semantic analysis, especially at machine translation. A formal description of locative groups faces several problems. The first is the definition of locative semantic relations between words, as locative dependencies can have different meanings, such as the meanings of initial and final points (*walk [from/to the door]*), route (*walk [across the room]*), and others. Second, one has to define the set of words that can fill locative adjuncts, and the border between the locative and non-locative groups is not always distinct: *in the street* is definitely a locative, but what about *on the Internet* or *in a meeting*?
Third, the syntactic realizations of locative senses are rather numerous. On the one hand, locative adjuncts include many prepositions with different semantics—like *on, in, under, above*, etc. On the other hand, different nouns combine with different prepositions to denote the same meaning, like *in the country*, but *on the island*.
The current paper suggests a formal approach appropriate for dealing with all these difficulties.

Keywords: semantics, syntax, NLP, machine translation, locative dependencies

In memory of Taisia Shtaryova

0. Introduction

The current paper is devoted to the formal description of locative dependencies in the ABBYY Compreno model—an integral NLP model, aimed at the semantic analysis of texts in natural languages.

Presentation of space meanings in natural languages has already been widely discussed in linguistics: there are works that focus on the conceptualization and categorization of space relations in a language and works devoted to the description of lexical and grammatical units that express locative meanings, especially prepositional constructions with space semantics and predicates with the meanings of position and motion.

Locative prepositions as well as different aspects of the space category have been analyzed in the works of A. V. Bondarko, V. G. Gak ([Gak 1996, 2000]), S. Feigenbaum, D. Kurzon ([Feigenbaum, Kurzon 2002]), M. V. Vsevolodova, E. Ju. Vladimirskij ([Vsevolodova 2010; Vsevolodova, Vladimirskij 1982]), V. A. Plungian, M. V. Filipenko, D. Paillard, O. N. Seliverstova (for instance, see [Paillard, Seliverstova (eds.) 2000]), L. Talmy ([Talmy 1983]), N. Ju. Shvedova ([Shvedova 1980]), and many others.

In addition, locative groups have been much discussed in modern works on cognitive linguistics, for example in works by [Aurnague et al. 2007, Bloom et al.1996, Hickmann, Robert 2006, Levinson, Wilkins 2006, Levinson 2003, Shay, Seibert 2003, Svorou 1994, van der Zee, Slack 2003].

In this article we want to focus on the problems of dealing with locative dependencies that arise when creating an NLP model aimed at machine translation, semantic search and other tasks based on the semantic analysis of texts, as formal description of locative groups faces both semantic and syntactic difficulties.

First, one should define the set of locative semantic relations between words, as the domain of groups with space semantics includes not only groups like *on the shelf/in the street*, but also groups with the meanings of initial and final point like *walk [from/to the door]*, route (as in *walk [across the room]*), and others. Second, it is necessary to define the set of words that can be used as locatives, as it is not always clear where to make the border between locative and non-locative adjuncts, namely, whether to regard as locatives only groups like *on the table*, or groups like *on/in the Internet* and *in a meeting* as well.

Third, even locative groups like *on the shelf* may cause difficulties, as these adjuncts include quite a large number of prepositions with different semantics: *on, in, under, above*, etc., and, in addition, different nouns are combined with different prepositions to denote the same meaning, like *in the country*, but *on the island*. All these things can be problematic for a formal model, especially for the task of machine translation.

The structure of the paper is as follows: the first part gives a short description of the general principles of the ABBYY Compreno formalism that are necessary for

further discussion. The second part is devoted to the semantic part of the locative description in the Compreno model and to the problems that arise within the semantic pattern of the formalism. The third section presents the syntactic part of the description, and the conclusion summarizes the results.

1. The ABBYY Compreno Formalism

The ABBYY Compreno formalism is an NLP model, which consists of several patterns: morphological, syntactic, semantic and statistical. All of them were presented in general terms in [Anisimovich et al. 2012] and, in addition, detailed description of the semantic pattern is provided in [Manicheva et al. 2012, Petrova 2014], and the syntactic pattern is presented in [Bogdanov, Leontyev 2013, Zuyev et al. 2013]. Now the descriptions of English and Russian are available, so here we will restrict ourselves to the English and Russian material.

Lexical content is organized in the form of a thesaurus-like semantic hierarchy (SH) with a tree structure, which consists of semantic classes (SC)—language-independent nodes that are filled with lexical units in natural languages. For instance, a SC BOY is filled with *boy* in the English part of the SH and, correspondingly, *mal'chik* in the Russian part. Currently the number of universal SCs is more than 110,000. The English part of the SH includes about 130,000 English notions, and the Russian part—about 120,000. The lower the SC, the less general notion it expresses, thus the ancestors of BOY are CHILD > PERSON_BY_AGE > … > HUMAN > BEING > PHYSICAL_OBJECT.

All classes are provided with additional semantic information through semantemes (marked with a <<>> sign): for instance, people and animals have a semanteme <<Animate>>, while food and plants have a semanteme <<Eatable>> (for more information on semantemes see [Anisimovich et al. 2012]).

Semantic links between words are presented through semantic slots, or deep slots (DS): the notion of DS is close to the notion of semantic valency, but the difference is that valencies are usually associated with actant slots only, like Agent or Object, whereas under DS we understand any dependency a word can attach. For example, the verb *to walk* has an [Agent] DS for *boy* in *[the boy] walks*, [Locative_FinalPoint] for *home* in *the boy walks [home]*, and [Ch_Parameter_Speed] for *fast* in *the boy walks [fast]*. Each slot can be filled with a strict set of SCs, e.g., [Agent] is filled with classes denoting beings, organizations and countries. The model includes more than 300 DSs in total.

Syntactically, DSs are expressed through language-specific surface slots (SurfS), thus [Agent] in *[the boy] walks* is expressed through the $Subject slot, or [Agent] in *the work is done [by the boy]* is expressed through $Object_Indirect_By (SurfSs are marked with a $ sign). A more detailed description of SurfSs is provided in section 3.

There are valencies for which the description of both DSs and SurfSs causes significant problems, and the locative groups are a good example here.

Let us now consider the description of the locative dependencies in the present model and discuss the difficulties that occurred while describing them.

2. The Semantic Description of Locative Dependencies in the ABBYY Compreno Model

There are two main problems for semantic description of locatives in the formalism described above.

First, one has to define the set of locative semantic relations, as there are locative valencies with different semantics, so we introduce not only the [Locative] slot, but slots like [Locative_InitialPoint] (for the locative of initial point), [Locative_FinalPoint] (for the locative of final point), and others as well.

Second, we have to restrict the filling of the slots with the classes of locative semantics only, and this introduces the question of where one should define the border between the locatives and non-locatives: *in the street* is definitely a locative, but how should one treat *on the Internet* or *in a meeting*? On the one hand, such groups are close to the locative groups both in their semantics and in their syntactic realization, yet on the other hand, they do not denote prototypical places, so we introduce additional locative slots with similar meaning but with different filling, for example, [Metaphoric_Locative] and [Locative_Event].

According to these parameters—the semantics of the locative valency and the slot's filling—we introduce several classes of locative DSs. In the current paper we suggest a description of three classes, namely, the [Locative_Class], the [Locative_InitialPoint_Class] and the [Locative_FinalPoint_Class], which are presented in Figure 1.

[Locative_Class]	**[Locative_InitialPoint_Class]**	**[Locative_FinalPoint_Class]**
[Locative]	[Locative_InitialPoint]	[Locative_FinalPoint]
[Metaphoric_Locative]	[Metaphoric_InitialPoint]	[Metaphoric_FinalPoint]
[Locative_Event]	[LocativeEvent_InitialPoint]	[LocativeEvent_FinalPoint]

Fig. 1. Classes of locative semantic slots

[Locative] is filled with entities that can denote places in a wide sense, namely, with countries, regions, spaces, physical objects, or beings. Thus, in example (1), all constituents in square brackets can be analyzed as [Locative]:

(1) *Its priority tasks today include building relations with the compatriots* [abroad].
Your assistant is still holding 10 cards [under the table].
Only 13 rodent species are found [on the island].

As the necessary fillers are positioned in different places of the SH, it is convenient to use a distributional semanteme here to mark them—the semanteme <<Place>> has been introduced for this purpose. So the filling of the [Locative] slot does not have to include a large number of small SCs, instead, we can indicate several branches of higher levels of the SH and restrict them with the <<Place>> semanteme. For example, the ENTITY class consists of different descendants: physical objects (like *table* or *bag*), mental objects (like *idea*, *thought*, or *opinion*), abstract and scientific objects (like *formula*

or *logarithm*), countries, organizations, and so on. It is clear that not all of them can be used as locatives, so we mark with the <<Place>> semanteme only the 'locative' classes.

[Locative_InitialPoint] and [Locative_FinalPoint] are filled with the same set of SCs and denote locatives of initial and final point, respectively, as in examples (2) for the former and (3) for the latter:

(2) *Don't forget that you can shoot* [from the side].
The witness saw this [from the window of her home].

(3) *You have come* [home].
Alice is coming [to the palace of the queen].

Syntactically, all these slots usually correspond to prepositional nominal groups, which include all possible locative prepositions, and adverbs, so the syntactic realizations of the slots can be rather numerous, as one can see from the examples in (1–3).

[Metaphoric_Locative] is filled with words like *imagination*, *book*, *Internet*, *head*, *TV*, or *document* that do not denote physical space in a literal sense, but are close to the locative groups both in their semantics and in syntactic realizations, see the examples in (4):

(4) *When I get an idea I start at once building it up* [in my imagination].
And I see him [in my head].
I have to watch a baseball game [on TV].

There are fillers that are absent among the fillers of the [Locative] slot, like *imagination* or *Internet*, and there are as well classes that are present in both sets of fillers, [Locative] and [Metaphoric_Locative], like *book* or *head*. These groups can be analyzed through both DSs, although, the sense would be different: for instance, in (5a) *book* functions as a kind of informational storage, so *[in the book]* is a [Metaphoric_Locative] here, while (5b) is an example of [Locative]:

(5) *a) It is written* [in the book].
b) A dollar [in the book] *will increase the value of it*.

Unlike [Locative] fillers, classes that fill [Metaphoric_Locative] are usually used with very few prepositions: *in the imagination*, but not **under/near imagination* (of course, here we mean only their locative usage). Correspondingly, classes that fill both DSs (like *head* or *book*) also allow a full set of locative prepositions when filling the [Locative] slot and only 'default' prepositions—when filling [Metaphoric_Locative] ('default' vs 'semantic' prepositions are discussed in section 3.3 below).

As in the case with the [Locative] slot, it is convenient to mark the fillers of [Metaphoric_Locative] with a special distributional semanteme—<<MetaphoricPlace>>.

[Metaphoric_InitialPoint] and [Metaphoric_FinalPoint] correspond to [Metaphoric_Locative] in their filling, and to [Locative_InitialPoint] and [Locative_FinalPoint] in their semantics, so the former can be illustrated with examples like *Many*

details had obviously gone [from my memory], and the latter with an example like *Strange ideas come [into his mind]*.

The [Locative_Event] slot includes metonymy cases in which some event functions as a place where it occurs, for instance:

(6) *Imagine sitting* [in a meeting] *or a coffee shop.*
The artist … spent 9 years of his life [in war and imprisonment].

The fillers of the slot are classes denoting different events—*exhibition*, *rehearsal*, *parade*, *lesson*, *conference* and so on. All of them are marked with the <<Event-Place>> semanteme.

[LocativeEvent_InitialPoint] and [LocativeEvent_FinalPoint], correspondingly, have the same filling, and possess the semantics of initial and final point (as in *come [from/to the exhibition]*).

It seems reasonable to introduce three groups of locative fillers in the model for several reasons.

First, different groups of locative fillers have different syntactic realizations, namely, the fillers of [Locative], [Locative_InitialPoint] and [Locative_FinalPoint] can combine with many prepositions, like *in, at, on, under, above, near* and so on, while the fillers of metaphoric and event locatives have significant restrictions here, as shown above.

Second, different cores combine with different locatives in various ways. For example, [Metaphoric_Locative] is more typical for the verb *to read* than the [Locative] slot is, as *read [in the book/on the Internet]* is more frequent than *read [at home]*.

The following section suggests the syntactic part of the description and considers the problems bound with the syntactic pattern of the formalism.

3. The Syntactic Description of Locative Dependencies in the ABBYY Compreno Model

One of the basic elements in our syntactic module is a system of SurfSs—the syntactic positions of the constituents. For instance, the labels $Subject, $Object_Direct and $Verb in Figure 2 are SurfSs for the constituents of example (7):

(7) *The boy lives in Kiev.*

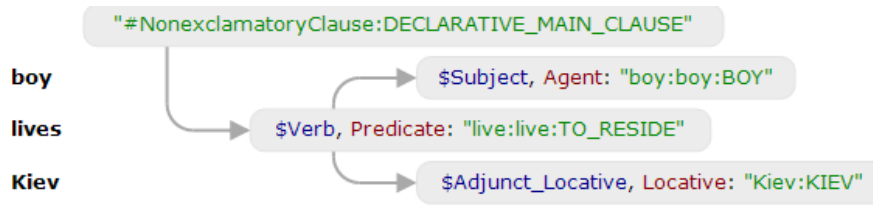

Fig. 2. Semantic and syntactic structure for example (7)

The main features of SurfSs are:

- *Government*, or the grammeme restrictions that a constituent must satisfy to be analyzed in the SurfS. For example, we can specify case forms and prepositions through grammemes, e.g., we use the grammeme of accusative case in the government of the Russian $Object_Direct SurfS.
- *Linear order* that describes the linear positions where the SurfS is allowed. For instance, the linear order for the $Object_Direct slot in English does not allow the leftmost position in a sentence, while for the $Subject slot this position is the most common.
- *Punctuation* that describes the punctuators (e.g., comma, bracket, semicolon, etc.) which are allowed in the SurfS.

If some syntactic positions share all these features, they will be reduced to one SurfS only. This reduction contributes to the productivity of the model: on the very first stage of parsing, the system builds all possible syntactic links between all words in a sentence. Each syntactic link with a child node is marked by the SurfS of the child node, so if we have fewer SurfSs, there will be fewer links generated in the analysis stage, which reduces the time necessary for the analysis.

However, the reduction of similar syntactic positions to one SurfS is not always possible. For example, when the positions have the same government but allow different linear orders such a reduction is problematic, and locative adjuncts are just the case.

3.1. Locative SurfSs. Description of the Problem

The absolute majority of Russian and English locative prepositions can be used for marking non-locative relations as well. For instance:

Russian

(8) *Таракан живет за печкой.*
Cockroach lives ZA oven.
The cockroach lives behind the oven.

(9) *Мальчик пошел за доктором.*
Boy went ZA doctor
The boy went for the doctor.

English

(10) *The book is **on** the shelf.*

(11) *Please, advise me **on** the medical training.*

As demonstrated in examples (8)–(11), the Russian preposition *za* can mark not only location but purpose as well, and the English preposition *on* can mark not only location but also theme. However, there are some syntactic differences between the locative and non-locative usage of these prepositions.

First, locatives are freely admitted in the leftmost position and this usage does not seem emphatic, as in example (12), for instance. For most non-locative groups, this position is emphatic, if admitted at all, as in (13):

(12) [In Hertford, Hereford, and Hampshire]*, **hurricanes hardly ever** happen.*

(13) *[In prepositions] *this problem is.*

Second, locatives may use other relative pronouns than non-locatives, namely, non-locative groups never use where-relativizers, whereas for locative groups this is quite normal. Compare examples (14) and (15):

(14) *The problem you advised me on. vs *The problem where you advised me.*

(15) *The city where I live.*

For these reasons we decided to introduce specific SurfSs for locative adjuncts.

3.2. Locative SurfSs and Their Government

We use the following locative SurfSs for each language: $Adjunct_Locative, $Adjunct_FinalPoint, $Adjunct_InitialPoint.

Each slot must allow nouns with specific prepositions (e.g. *to the table* for $Adjunct_FinalPoint), locative adverbs (like *below*), and adverbial pronouns (like *here* or *whence*). These instances are heterogeneous and it is not easy to cover them all in a simple description. To solve this problem we added a new grammatical category named FormOfLocativeCircumstance. It is defined for all the hierarchy, or to be more precise, for all classes that can fill locative slots, and includes the values indicated in Figure 3:

Grammemes allowed in $AdjunctLocative.
-DefaultLocativeLikeForm.
-SemanticLocativeLikeForm.
Grammemes allowed in $AdjunctlnirialPoint.
-DefaultFromForm.
-SemanticFromForm
Grammemes allowed in SAdjunctFinalPoint:
-DefaultToForm.
-SemanticToForm.

Fig. 3. Grammatical category FormOfLocativeCircumstance

The category works as follows: to indicate that a word *shelf*, for instance, can fill the $Adjunct_Locative slot with a preposition *on*, one has to indicate the preposition *on* in the DefaultLocativeLikeForm pattern of the class “shelf:SHELF”.

3.3. ‘Default’ and ‘Semantic’ Prepositions

It is possible to describe all the variety of locative adjuncts using one single pattern for each SurfS. Nevertheless, it turned out to be more convenient to split the pattern into two: ‘default’ and ‘semantic’. The ‘semantic’ pattern covers prepositions like *behind* or *near*: the semantic interpretation of their locative usage is not determined by the noun they modify, and such prepositions have exact counterparts in other languages, which can serve as translation analogues in all of the contexts (like Eng. *near*—Rus. *около*). Usually these prepositions denote peripheral spatial localizations such as AD or APUD (using the terms described in [Plungian 2000]).

The ‘default’ prepositions are quite different. They correspond to IN-Localization in the terms defined in [Plungian 2000] and form collocations with the nouns they modify. Different nouns combine with different prepositions and this choice is highly language-specific. For example, English uses different prepositions for *in the country*, *on the island* and *at the pole* while the localization denoted by the prepositions is the same.

It seems reasonable to treat the ‘semantic’ and ‘default’ prepositions differently. The ‘semantic’ prepositions can be described by one single pattern that is introduced high in the hierarchy and is very rarely modified below. This is not the case for the ‘default’ patterns—these must be described for specific lexical units.

In addition, the ‘default’ prepositions, unlike the ‘semantic’ ones, can correspond to the DSs such as [Metaphoric_Locative], as these positions denote not a real space, but a virtual one, where the localizations like APUD are simply irrelevant. One cannot talk of something near or behind the memory. This feature is not difficult to describe using two locative patterns, whereas it would be a problem for a one-pattern approach.

3.4. ‘Default’ and ‘Semantic’ Dichotomy Used for Machine Translation

The two pattern system turned out to be useful for the correct translation of locative prepositions as well. The sense of ‘semantic’ prepositions is retained through the system of transfer rules (which are discussed in [Anisimovich et al. 2012, Bogdanov Leontyev 2013]), where each preposition corresponds to a special semanteme (e.g., the preposition *under* corresponds to the semanteme <<Under>>), which demands the necessary preposition at the synthesis stage. In the case of the ‘default’ prepositions, the preposition itself is ignored, it is only the grammeme DefaultLocativeLikeForm that serves as an input for the rules. The special semanteme <<Default_Location>> is computed in this case. Using this approach we can get the correct Russian translations for the English sentences (16) and (17):

(16)	The	boy	lives	in	Kiev.	
		Мальчик	живет	в	Киеве.	

(17)	The	boy	lives	in	the	East.
		Мальчик	живет	на		Востоке.

In the English sentences (16) and (17) the single preposition *in* is used, while the Russian translations demand different prepositions—*в* and *на*. In these examples the preposition *in* is 'default', so it corresponds to the semanteme <<DefaultLocation>>. At the stage of building the output Russian structure, this semanteme will not evoke any concrete preposition but rather a link to the 'default' locative pattern—DefaultLocativeLikeForm. This pattern will assign the preposition *в* for the noun *Киев* and the preposition *на* for the noun *Восток*. Thus the resulting preposition depends only on this pattern and does not correspond directly to any preposition in the input structure.

Example (18) demonstrates the translation of 'semantic' prepositions:

(18)	The	cat	was	under	the	table.
		Кошка	была	под		столом.

Here the preposition *under* is 'semantic'. Its sense is rendered by a special semanteme <<Under>, which evokes the corresponding preposition at the synthesis stage directly, without reference to the locative patterns.

4. Conclusion

The semantic pattern of the model defines the necessary DSs for the locative valencies, sets their filling and introduces the slots in the hierarchy. The syntactic pattern provides the description of their syntactic realization, differentiating between the 'semantic' prepositions and the 'default' ones. The necessity of introducing specific SurfSs for the locative adjuncts as well as additional restrictions for them makes the work of the parser more complicated, but we believe that these difficulties reflect an objective complexity of language. Besides, such a model allows one to achieve a full and integral description of locative dependencies, as has already been done for the English and Russian locative constructions. Now the system is to be tested on a wider range of languages.

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