Interpreting the predicate-argument representation for the needs of the Thetos translator

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Abstract

In our work on the system Thetos translating texts in the Polish language into sign language, trying to significantly improve the quality of translations, we have recently decided to take into account the meaning of sentences, syntactic groups (SGs) and individual words they are composed of, what we previously ignored. In the paper we describe the work on a two-level SG-model of semantics. The first level is a predicate-argument (P-A) representation, which expresses relations between the syntactic tree root, which is a verb SG, and its arguments. The currently added second level allows to express semantic relations that exist between terms occurring in separate arguments, as well as relations hidden inside the syntactic relations that bind components of individual SGs. We give examples of rules for interpreting syntactic relations in several SG types, as well as interpreting semantic relations that occur between different elements of the P-A structure.

Keywords: NLP, Polish Sign Language, semantic processing, semantic relations, interpreting relations, Thetos system

1. Introduction

For many years our research team has been working in the domain of NLP in the framework of the *Thetos* project. Its practical goal is to build and consequently develop a program (called *Thetos*) for translating Polish texts into the Polish Sign Language. The Thetos program is the main field of application and verification of our work results. The results have been reported in a number of papers.

One of the main parts of the *Thetos* program is a translator from written Polish into an intermediary language called Thel. Thel is used to express in a textual form a sign language equivalent of the input utterance. The main component of Thel utterances are Polish words, which denote the sign language signs.

The translation in *Thetos* is rule based. It is performed according to the classical processing scheme:

Text-Morphology-Syntax-Semantics-
Syntax-Morphology-Text,

where on the semantic analysis stage the predicate-argument (P-A) structure of a single statement is being shaped. The resulting semantic representation of the text consists of the sets of semantic representations of individual sentences. The individual processing stages are performed by the respective processors: *Polmorf* (Suszczańska and Lubiński, 2001), *Polsyn* (Suszczańska et al., 2009), *Polsem* (Romaniuk et al., 2011), and *Polin* (Romaniuk et al., 2014).

Carrying out the translation, we assume that the construction of P-A structure and the semantic units in different languages are similar. It is confirmed, for example, by Fillmore's works for English, Apresjan's for Russian, etc.: in spite of the different formalism, these "building blocks", which organize the sense of utterance, appear to be similar. Despite the fact that PSL is a language clearly different from Polish, our observations of the semantic structure of utterances in PSL show that it is identical to the semantic structure of the corresponding utterances in Polish. So if we have the P-A structure for input language sentences, we will have the P-A structure for the target language.

What remains then to be done is "only" to generate a sentence in PSL in accordance with the principles of PSL syntax; we do not consider here the final stage of translation, where takes place the rendering of gestures. The difficulty is that PSL has neither compound sentences, nor complex syntactic constructions, including ellipses of different kinds. All the meanings of complex constructions have to be transmitted through a series of simple sentences that are to be complete. So the P-A structure for a sentence in Polish almost always can not be directly moved to P-A structure in PSL. Hence the need for transformation, interpretation. One of the main requirements in this is that you can not change the meaning of the transmitted message.

Until recently, the translation did not take into account the meaning of sentences (neither syntactic groups, nor individual words, which the groups are comprised of). In most cases the quality of such translation can be considered satisfactory, however there are cases where the effects of such simplification are poor. In this situation we decided to extend the scope of the semantic analysis. In the extended version, the semantic analysis is aimed at discovering the meaning of syntactic structures provided by the syntactic analysis – in our model they are syntactic groups (SGs) and relations, which exist between them. During the analysis not only the P-A structure is shaped but also both its arguments and relations are interpreted.

In this paper we discuss problems of semantic interpretation of selected elements of the syntactic representation, which we encountered in the early stages of the development of our SG-based model of semantics.

The paper is neither a full description of the model, nor a technical report on its implementation.

We should notice that all our research in this direction is done on the information science ground and is based on the work of leading specialists in the field of semantics, both IT professionals and linguists. We think it impossible to mention all the sources.

2. SG-model of semantics – general premises

The aim of the research being reported is "understanding" of the content of utterances. Adducing Z. Vetulani (Vetulani, 2004), for "understanding" we assume a form of translation from a natural language into some artificial, formalized one, whose units are used to store the meanings contained in syntactic structures. In addition, the formal structures of the semantic representation of the text should be convenient for further processing. With us, the formal structures mentioned above are a model of semantics. Since the semantics of a language is an extensive subject of research, it makes sense to speak of only modeling a small semantics fragment, and this is also in our case.

At elaboration of our model for semantics we are basing on the fact that the semantics and syntax of a language are strictly connected each to other. We assume the thesis that an SG is a language component unit that serves for conveying the content at the semantic level. According to this thesis we examine the topology of the syntax representation graph, and by this – the meaning of SGs (a sentence is an SG too!) and mechanisms, which are used for transmitting their content. We also examine the influence of SG types and syntactic relations between SGs on this transmitting; in order to model the semantic structure of the sentence on the basis of its syntactic structure we try to semantically interpret SGs and syntactic relations.

3. Basic predicate-argument structure

The premise of our study on modeling the semantics was the following reasoning: A model of semantics should define semantic phenomena that reflect the desired level of reading comprehension in this segment of the language, which was adopted in the analysis. Starting from these assumptions (usually determined empirically), you can build a system of semantic units representing the content of the sentence, and next – of the text.

Our SG-model of semantics is divided into two levels, the first of which uses a P-A representation, and the other its extension. Both are the place to record semantic units essential for conveying the content, and to set relations that hold between them.

The P-A representation in the base version is a tree whose root is a predicative element, nodes (except the root) – the elements that are root's arguments, and edges – the relations that bind the predicate with its arguments. According to that, the semantic structure of the sentence can be written in the form of a multi-argument relation

$$p(a_1,a_2,..,a_n),$$

where p is predicate, a_i, $i=1,2,..n$, is predicate's argument, i is argument's position, and there is some fixed *a priori* function r_i, which corresponds to each position.

In the SG semantic model the P-A representation mirrors the roles of strongly consistent SGs. The idea of using this formalism in our work arose from the observation of similarity of syntactic and semantic representation. In order to obtain the P-A structure it is sufficient to lay the semantic graph over the syntactic one, to define new, semantic roles for SGs including the verb SGs (VG), which is meant as the predicate, and to note new, semantic relations while transforming the representation; the *Polsem* analyzer has been built according to these rules. The naturalness of this transformation is based also on semantic aspect of SGs, founded in the very principles of the syntax formalism – Syntactic Groups Systems (SGS) (Gladkij, 1985; Gladkij and Melčuk, 1979). With the development of operations on a set of semantic units helpful was the fact that the SGS formalism is built on a strictly described mathematical basis, so it gives the ability to use formal mathematical apparatus for further studies of the text structure properties.

It is known that the predicate's arguments can be characterized by their type: referential, attributive or sentential (Vetulani, 2004). The role of referential arguments is played by NGs (noun SGs), GIMs (pronoun SGs) and a part of PGs (preposition SGs). Attributive arguments are PSs (adverbial SGs), MODs (modifier SGs), and the remainder of PGs. The number of arguments and argument types depend on the predicate features and are defined in the semantics grammar. One of such grammars is defined in (Grund, 2000). In the algorithms, which determine the semantic structure of the sentence, we also use the grammar (Bach, 2004), which is an adaptation of Fillmore's case grammar (Fillmore, 1968). Apart from ACTION (predicate), there are 16 roles taken into consideration, including AGENT (action's executor), OBJECT, INSTRUMENT, etc. (Romaniuk et al., 2011). We realize that this list neither includes all the P-A relations in any language, nor is required in full at any processing system, including the system *Thetos*. The list is experimental, designed to carry out the research, including the transfer of space-time relation elements in Polish to the corresponding structures of the Polish Sign Language.

4. Extension of the P-A structure

The P-A representation only expresses semantic relation between VG, the root of the parse tree, and other strongly consistent SGs. This formalism does not allow for expressing relations between terms contained in different arguments, e.g. between the AGENT and the GOAL of its operation, or between the OBJECT and the PLACE, although this information is implicitly contained in the P-A structure. The same can be stated about semantic relations hidden in internal syntactic relations that hold between component SGs.

To represent such specific relations we introduce a second level of our model. At this level, we use a set of binary relations taking the form $\#r_i(a_i,p)$, where p represents some term referred to by another term represented by a_i. Such units can easily make up a system, next, it is easy to search for synonymous equivalents for these units, to compare the sets of relations for different sentences, and in particular, to analyze various relations of the same term. In addition, it is easy to capture the units that require fulfillment of missing components, or relations that go beyond the boundaries of sentences, for example, when looking for answers to questions or when analyzing anaphoric relations (see e.g. (Kulików et al., 2004)). It should be mentioned, that the notation based on binary relations *mutatis mutandis* is also used for the first, P-A level of our model. In that case individual relations have the form $\#r_i(a_i,p)$, where p is simple predicate, and a_i is i-th predicate's argument. Both forms, the tree-like and binary relation based are equivalent, and the latter is more convenient for definition and implementation.

In our model the binary relations that belong to the second level arise in effect of semantic interpretation of P-A structure elements and syntactic relations recorded in those elements. In this model part we distinguish two types of semantic units: semantic elements and semantic relations. Semantic elements are notions, which represent the meaning of SG or semantic constants. Semantic relations arise during interpretation of SGs and their internal relations. A kind of semantic relations are situational relations, which arise during interpretation of relations between the predicate and its arguments.

It is obvious that an unrefined conversion of syntactic representation in the semantic one as outlined above, is not sufficient to understand the content of a sentence, and the more – of the text. Additional operations are necessary for transformation of semantic units, and their semantic interpretation (for example, a logical derivation, reasoning, etc.). There is an obvious requirement: no operation can change the original semantics.

And yet a few words on the composition of semantic relations: they are indecomposable (elementary) or decomposable. Decomposable relations can be reinterpreted in order to obtain elementary units. In view of this, the P-A relations are decomposable ones. Semantic elements are the alphabet of the model and are contained in dictionaries. As to semantic and situational relations, some of them are discussed in the next sections.

To recap: we are building a two-level semantic model, which is based on the mechanisms provided by the modified and completed SGS formalism. At the first level of modeling the P-A structure is built, the task of the second modeling level is an interpretation of semantic elements of the P-A structure, both at the semantic and syntactic level. At both levels of the description of semantics the formalism of binary relations is adopted.

5. Interpreting relations – introduction

The purpose of SG interpretation is to detect the semantic representative in it and to determine both its meaning and the content of the SG as a whole. The semantic representative defines the meaning of the group. Each SG has also a syntactic representative, which not always coincides with the semantic one. An important role in determination of the latter is played by the type of SG and by interpretation of internal syntactic relations in the SG. Semantic interpretation rules for the PS, PG, NG and VG groups are briefly described in (Romaniuk et al., 2011).

Functional relations of syntactic representation serve as the basis for generating P-A relations. Other syntactic relations, internal to SG, also used to deliver the content. The purpose of those internal relation interpretation is to find their mapping into relations between semantic representation units. In other words, the semantic interpretation should give an answer to the question whether for a particular relation of syntactic representation there exists a mapping into a semantic relation, and if so, how this relation can be interpreted. In order to find the mappings we formulated several rules. The first rule is:

R1. Semantic relation involves arguments of specific types. □

Some other rules are discussed in the following sections. We use the notational convention, according to which the relations on the first semantics level are written in capital letters, on the second level – in small, with double '#' sign preceding the relation name.

For the record it should be mentioned that SGs, with which we deal with in the graph, are tagged. In this part of the model, which relates to molding the P-A structure, mostly the 4th, 3rd, and also 0th level SGs (SG^4s, SG^3s, and SG^0s) are examined, and in the part, which complements this structure, SG^0s through SG^3s are under examination.

6. Interpreting internal relations of 1st level NG groups

6.1. Interpreting relations in attributive groups

At the beginning let's analyze the internal relations of 1st level NG groups (NG^1). Between the components of an attributive group (GAT) and its parent noun there occur syntactic relations #attr, #n_attr (after *numeric attribute*) or #q_attr (after *quantor attribute*). Note that these relations may also exist between the elements of GAT; consider for instance the NG group *te nasze trzy najlepsze studentki*[1] (*these our three best students*) and its component GAT *te nasze trzy najlepsze* (*these our three best*). In many cases the GAT's representative is an adjective or an ordinal number. For the purposes of research a classification system for GATs was adopted, containing the semantic classes *color, shape, quantor, number, membership, question, size,* and *property*. Our semantic dictionary of adjectives contains dozens of entries extracted from test examples. The specificity of GAT is that if a GAT component belongs to a specific semantic class then it is the basis for generating in the parent NG the relation `##class_name(A,B)`, where `class_name` is an identifier – entry in the above-mentioned list of classes for GAT, `A` is the GAT component, and `B` – the parent NG representative. This is reflected in the rule R2.

R2. If in NG^1 the `#attr` relation occurs then between NG's arguments there exists a relation determined by the name of the semantic class of the attribute. □

Application of the rule R2 is illustrated by Example 1.

Example 1. In effect of an automatic analysis of the NG group *mały zielony zeszyt* (*little green notebook*) two syntactic relations are generated: `#conf(mały, zielony)` and `#attr(zielony, zeszyt)`. The relation #conf belongs to the set of compound relations, which cannot be directly interpreted: such relation should be first decomposed into one or more elementary relations, which are already suitable for interpreting. After transformation of the conformity relation `#conf`:

```
#conf(mały,zielony)
 => #conf(mały,#attr(zielony,zeszyt))
 => #attr(mały,zeszyt)
```

[1] a part of an elementary NG phrase given by Melčuk in (Jordanskaja and Melčuk, 1988).

we will get two relations to be interpreted: #attr(zielony, zeszyt) and #attr(mały, zeszyt). If in the semantic dictionary to the entry *mały* the feature *size* is assigned, to *zielony – color*, and to *zeszyt – inanimatedness* (*impersonalness*), then according to the rule R2 the interpretation of these relations is: ##color(zielony, zeszyt) and ##size(mały, zeszyt). □

Another group of rules, which describe semantic relations that exist in attributive groups, applies to the cases connected with determination of a number of things. The main rule in this group is the rule R3.

R3. The semantic relation ##number binds a term with a numerical constant. The constant is a number in a digital format, possibly with a comparison or equal sign: '<' , '>' , '='. The relation is generated during the interpretation of NG^1 according to respective (three) sub-rules. □

Due to the lack of space, we skip a more extensive discussion of this issue.

6.2. Interpreting relations in questions

Some observations concerned phrases containing questions. In this respect, the rule R4 was formulated.

R4. The semantic relation ##question may require re-interpretation. For this purpose, interrogative words are divided into semantic classes, which depend on the type of the question. The effect of re-interpretation for individual classes is determined by sub-rules. □

The sub-rules indicated in the rule R4 involve in the first place the questions built with the words *jaki* (*what/what kind*) and *ile* (*how many*). In this paper, they are labeled R4.1 and R4.2.

R4.1. A question with *jaki* in NG^1 refers to the attributes *color*, *shape*, *belongingness*, *size* and *property*, and generates five indecomposable relations binding the term and these attributes. □

For example, in NG *jaki zeszyt* (*what notebook*) syntactic relation #attr(jaki,zeszyt) is converted into semantic relation ##question(jaki,zeszyt), which generates five relation templates corresponding to the attributes mentioned in the rule R4.1:

```
##color(?X,zeszyt),
##shape(?X,zeszyt),
##belongingness(?X,zeszyt),
##size(?X,zeszyt),
##property(?X,zeszyt).
```

By "?X" we denote here the unknown, the value of which is to be found in the semantic representation. The answer to the question may be one or more of the relations from this list, binding the same term in the semantic representation of the text with a known first argument. For example, in the semantic representation of NG given in Example 1 and complemented by R4, the answer will be the relations ##color(zielony,zeszyt) and ##size(mały,zeszyt).

R4.2. A question with *ile* (*how many*) in NG^1 refers to a numeric constant and produces the relation ##number(?X, A), where A is a term. The answer to this question will be the same relation for the same term with the first argument filled by a numeric constant. The answer is searched in the set of binary relations – semantic representation of the analyzed text. The number of output responses, if any, may be greater than one. □

7. Interpreting relations between terms in 2nd level NG groups

In the second level NG groups there are relations, which at the semantic level are interpreted as semantic relations between terms. At the syntactic level, there are 38 possible relations, including the following: #attr, #obj2, #obj3, #obj4, #obj5, #ident, #attributive, #comparative.

The same syntactic relation in NG^2 can be interpreted differently depending on the semantic context of the representative of NG. Interpretation requires the development of semantic dictionaries of nouns, as well as rules for combining the semantic features for each of the interpreted syntactic relations. For this, the interpretation is highly dependent on pragmatics, i.e. the subject area of the text being analyzed and the requirements for the level of understanding.

We will demonstrate it with an example of the relation #obj2(B,A), where A and B are NGs. The relation is a kind of syntactic assignment and means that A is a parent group, B is a group depending on the group A, the dependence type being #obj2. This relation can be semantically interpreted in several ways, among which we have chosen the following seven: A *is a part of* B, B *is a part of* A, B *belongs to* A, B *consists of* A, A *is an attribute of* B, A *is an object of activity of* B, A *is an activity attribute of* B. Choosing the right interpretation depends on many factors, including the grammatical, semantic and pragmatic properties of relation arguments. In order to explain it clearer we'll make use of two examples.

Example 2. Syntactic analysis of the group NG *pelerynka dziewczynki* (*girl's cloak*) gives the word *pelerynka* (*cloak*) as the representative of the NG; between the components of it there occurs the relation:

#obj2(dziewczynka,pelerynka),

which means that in the given context the word *dziewczynka* in the syntactic structure is a modifier of the word *pelerynka*. □

Example 3. In the three NGs: *pelerynka z jedwabiu* (*cloak of silk/silk cloak*), *pelerynka z kapturkiem* (*cloak with hood*) and *pelerynka z Gliwic* (*cloak from Gliwice*) the relations #attr(PG, NG_i) occur. After a trivial transformation of the relation: #attr(PG+NG_i,NG) ⇒ #attr(NG_i,NG), we get a new list of relations:

```
#attr(jedwab, pelerynka)
#attr(kapturek, pelerynka)
#attr(Gliwice, pelerynka)
```

At the syntactic level these relations are interpreted in such a manner, that the words *jedwab*, *kapturek* and *Gliwice* are modifiers for the word *pelerynka*. As we can see, the translation of internal relations #attr in Example 3 and #obj2 in Example 2 are very similar to each other. Of course, in the semantic level each of these four NGs is to be interpreted differently. For example, the feature *personalness* for *girl* and *inanimatedness* for *pelerynka* can be used as a basis for the hypothesis that the relation B *belongs to* A may occur between them:

##belongingness(dziewczynka,pelerynka);

the feature *material* for *jedwab* (*silk*) and *inanimatedness* for *pelerynka* (*cloak*) can be considered as a basis for interpretation of the #attr(A,B) as A *is an attribute* of B:

##property(jedwab, pelerynka);

the interpretation of *miasto* (*city*) as *place* for *Gliwice* uniquely transforms #attr(Gliwice,pelerynka) to:

##place(Gliwice, pelerynka).

On the other hand, interpretation of `#attr(kapturek, pelerynka)` is ambiguous if the feature *inanimatedness* is assigned to *kapturek* (*hood*) as well as to *pelerynka* (*cloak*) – then to interpret `#attr` both rules can be used: `A` *is a part of* `B` and `B` *is a part of* `A`. The ambiguity can be resolved by assigning to the word *kapturek* additional feature *part*, what allows to identify the relation `##part(kapturek, pelerynka)`. □

8. Interpreting relations between elements of P-A structure

The relations discussed in the previous section involved elements located in the peripheral parts of the parse tree. In this section, we will discuss the relations that exist between elements situated at the root of the parse tree and its immediate vicinity. In the semantic model they correspond to the predicate and its arguments. The rule R5 applies here.

R5. The interpretation of the relation between the predicate and its arguments requires additional transformations, resulting in identified relations between semantic elements of different arguments of the P-A structure. □

To solve the problem, a method of translating the P-A relations into situational relations of the semantic representation was proposed. The importance of relations being generated depends on the semantic features of the predicate, enclosed in its semantic environment model (otherwise known as valence model) denoted μ_{ACTION}, and the type and semantic features of arguments; in our case μ_{ACTION} is limited to μ_{VG} only.

To carry out experiments, we used the VG semantic classes: *movement*, *state*, *ownership*, *contact*, *emotions and mental states*. At the very outset, an inadequacy of these classes turned out. From the *movement* class the *displacement* class has been extracted, which in turn has been divided into *AGENT's displacement*, *OBJECT's displacement*, and *displacement of AGENT and OBJECT in the same time*; from the *state* class the *place* class has been extracted, etc. Due to the lack of space we do not provide the full list of semantic classes for verbs, used in our experiments.

Our method allows to determine relations that bind:

- two terms found in different referential arguments,
- two terms, one of which is in a referential argument, and the second – in an attributive one,
- a term and a semantic constant, which is defined in a specialized dictionary[2],
- two semantic relations,
- a semantic relation and a semantic constant.

In our experiments we also tried to refine the list of semantic relations. As the basis, the descriptions taken from the database *Semsyn* were adopted as well as Apresjan's rules of mutual interaction of content (semantic modification) (Apresjan, 1967; Apresjan, 1974; Apresjan, 1980). From the *OBJECT displacement* class, verbs semantically close to the word *rzucać (throw)* were extracted. For this new class of predicates, on the basis of patterns and semantic interpretations of *Semsyn* a list of possible arguments was prepared. This is however a separate topic, which in this publication will not be elaborated.

[2] The contents of this dictionary is highly dependent on the subject domain of the analyzed text, that is, on pragmatics, and more specifically, on the extra-linguistic requirements for the modeled level of understanding of the text. For experimental purposes, in this dictionary the words: *możliwie*, *prawdopodobnie*, *szybki_ruch (possibly, probably, quick_motion)* were placed.

9. Final remarks

Looking at the results of conducted experiments we can formulate the following conclusions:

1. The proposed method of interpretation of the P-A sentence structure is used to reveal semantic relations that are hidden in it.
2. The method can be used to achieve a satisfactory level of "understanding" the text.
3. Semantic interpretation of syntactic relations complements the scope of semantic analysis.
4. The level of understanding is highly dependent on the semantic classification of predicates and their arguments in the P-A structure.
5. Semantic classification depends on the requirements of pragmatics of text and needs an in-depth development of semantic models, primarily establishing a list of semantic relations in the modeled text domain.

Polish Sign Language does not contain complex structures, which in the spoken Polish and in many other natural languages appear in abundance. We are dealing with a fairly common situation, when the translation should convey the content of input utterance, without being suggested by its syntactic structure. Interpretation of semantic structures allows to recount the utterance in the form of single sentences that reflect the original content.

Experimental works started a few years ago and proceed with variable intensity; we are still near the beginning of the road. In the first place it is planned to carry out experiments on the interpretation of the relations of time and space, as well as catching the emotional load bearing structures, which is important due to the specific nature of the target language. Some examples waiting for automated processing were given in (Romaniuk et al., 2011). Current results in a demo version are available on our Linguistic Analysis Server *LAS* (Kulikow, 2003) website at http://las.aei.polsl.pl/las2/.

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