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LEXICAL SEMANTICS IN THE SYNTACTIC STRUCTURE OF A TEXT: FORMAL REPRESENTATION AND INTERPRETATION

Abstract. In this paper we present preliminary results of investigating reusability of meaning explanations, found in existing monolingual dictionaries, for developing formal semantic representations of lexical items for large-scale NLP system. We suggest using deep syntactic representations, proposed in functional syntax (the system of syntaxeme groups), for modelling internal organisation of semantic primitives in the semantic structure of lexical items. Dictionary explanation 'formulas' of lexical items can eventually be changed to the form, where only semantic primitives are used. In this case, the deep syntactic structure of the explanation is equivalent to the semantic structure of the lexical entry. The suggested approach is consistent with procedural and interpretation models of text understanding. We show how the proposed model of sentence lexical and syntactic semantics can be used for updating extralinguistic knowledge about described situations (the situational thesaurus). The research was conducted within the project of the Ukrainian Language Information Fund of the National Ukrainian Academy of Sciences "Theoretical linguistic foundations of automatic text processing".

In a sentence, word forms are ordered linearly. Besides this linear ordering they are connected with the system of implicit surface syntactic links (or surface dependencies) and deep syntactic relations. This surface and deep syntactic structure is non-linear [1]. It can be modelled by a graph with nodes, representing word forms, and edges marked with names of surface syntactic links and deep syntactic relations. If a construction is represented by transformed structures, (e.g., *перевіряти завдання* → *перевірка завдань*; *перевірені завдання* – 'to check assignments' → 'checking assignments'; 'checked assignments'), the type of a surface syntactic link will change (an 'Object' link is transformed to 'Compositive' and 'Attributive'), but the type of the deep syntactic relation will remain the same (the relation 'action – object' in this example). In many cases the deep and the surface structures are isomorphic, but the mark-up of edges is different [2]. The names of surface syntactic links have a formal nature, and the names of *deep syntactic relations* (DSR) – a semantic nature, namely they can be correlated with certain extralinguistic concepts. On the level of DSRs "an interaction between a grammar and a lexicon takes place" [3., p.4]. Each DSR provides the context in which joined elements function and receive additional meanings, conditioned by the context (e.g., a subject, an instrument, a location of an action, etc.). This type of meanings is referred to as 'structural-semantic nomination', which differs from lexical nomination on the one hand, and from lexical syntactic nomination on the other hand (the later term denotes the type of nomination peculiar to the idiomatic expressions, e.g., *брати участь*, – 'lit.: to take part' *гострий на слово* – 'lit.: sharp on word, i.e. very critical', *дати перцю* – 'lit.: to give some pepper, i.e. to criticize or reproach somebody heavily'), where a syntactic construction is functionally equal to a lexical item [4., p.82–83].

In case of the structural syntactic nomination, individual lexemes or lexeme groups in corresponding syntactic positions become syntaxemes, expressing meanings, which are not characteristic for them in the lexical system of a language. Graphs of the syntactic structure show a name and a direction of a DSR (as a rule, from the dependent to the main component [5]). Becoming the arguments of a DRS, syntaxemes receive additional functional meanings, which are determined by the structure of the DSR. For example, DSRs 'Action – Object', 'Action – Instrument', a predicative DSR consist of a syntaxeme of an 'Action' and, respectively, an 'Object', an 'Instrument' and a 'Subject' syntaxemes. Attributive and possessive DSR consist of an 'Attributive' and a 'Possessive' syntaxemes and an abstract syntaxeme, the type of which is determined by its functioning within more complex DSRs.

The semantics of syntaxemes is traditionally considered to consist only of (1) functional, syntactically motivated meanings. We propose to distinguish two other types of syntaxeme meaning (also related to lexical meanings). These are (2) context-independent lexical classes to which belongs a syntaxeme; and (3) a lexical class, of a whole construction joined by a DSR. In case of complex syntaxemes, the meaning of type (2) is derived from smaller components in a compositional way, i.e., it can be inherited from a head component, or can be derived from properties of homogeneous heads. Meanings of type (2) and type (3) are the same, if a DSR becomes a syntaxeme within another, more complex DSR.

DSRs have two functions: creating functional positions for syntaxemes and constructing the deep syntactic structure of a sentence. The later function supposes that context-independent semantic categories of syntaxemes are taken into account, since an argument of a DSR must have strictly specified semantic properties, e.g., a lexical class. In the process of deep parsing, these properties are checked for finding arguments of DSRs. The traditional concept of a syntaxeme merges the two different aspects: functional syntactic meanings (like the 'Object' and the 'Subject') and context-independent meanings of semantic classes of the constructions (like the 'Locative', the 'Temporative', etc.). We need to distinguish them in syntactic representations. In the following example the label "B" represents the name of a DSR (if a syntactic link joins an analytical morphological form, the DSR between such components is absent. This is indicated by the label "B"). We also indicate the names of syntactic links by the label "3", if a deep syntactic structure diverges from the surface structure. The label "K" indicates the semantic class of a structure, and the label "K" – the absence of the value of the semantic class:

Коли₁-when якийсь₂-some час₃-time тому₄-ago в₅-in Києво-Могилянській₆-Kyiv-Mohyla академії₇-Academy, де₈-where читалися₉-were-read курси₁₀-courses хорватської₁₁-of-Croat мови₁₂-language, виникли₁₃-appeared проблеми₁₄-problems з₁₅-with викладачем₁₆-teacher, посол₁₇-ambassador Хорватії₁₈-of-Croatia Джуро Відмарович₁₉-Juro Vidmarovych виконував₂₀-performed ще₂₁-more й₂₂-and такі₂₃-such функції₂₄-functions – 'When some time ago in Kyiv-Mohyla Academy, where Croatian was taught, there appeared problems with a teacher, the Croatian ambassador Juro Vidmarovych performed these additional duties'.

A₍₂₋₄₎ - [*temporative.B.* {(*attributive.B.* *якийсь час*)*object.K*} *тому*] *temporative.K.*;

B₍₅₋₇₎ - [*-.B.* *в* {(*attributive.B.* *Києво-Могилянській академії*)*object.K*.}] *locative.K.*;

B₍₉₋₁₂₎ - [*subj-pred.3./action-object.B.* *читалися* {*compositive.3./attributive.B.* *курси* (*attributive.B.* *хорватської мови*)*object.K*.}] *event.K.*;

Г₍₁₃₋₁₆₎ - [*subj-pred.3./action-object.B.* *виникли* {*temporative.B.* *проблеми* (*-.B.* *з викладачем*)*comitative.K*.}] *event.K.*;

Г₍₁₇₋₂₀₎ - [*nominative.B.* {(*compositive.3./attributive.B.* *посол Хорватії*)*object.K*} (*nominative.B.* *Джуру Відмарович*)*object.K*.}] *object.K.*;

Д₍₂₁₋₂₅₎ - [*action-object.B.* *виконував*] *reinforc..B.* {(*lex.-synt.nomination* *ще й*)*particle.K*.} (*attributive.B.* *такі функції*)*object.K*.] *object.K* / *event.K.*;

E₍₈₋₁₂₎ - [*co-ref.B.* *де* <*B*>] *locative.K.*; *Є*₍₅₋₁₂₎ - [*co-ref.B.* <*B*> <*E*>] *-.K.*;

*Ж*_(2-4, 13-16) - [*event-temporative.B.* <*Г*> <*A*>] *event.K.*; *З*_(5-7, 13-16) - [*event-locative.B.* <*Г*> <*B*>] *event.K.*;

*И*_(1, 13-16) - [*co-ref.B.* *коли* <*Г*>] *temporative.K.*; *І*₍₁₇₋₂₅₎ - [*predicative.B.* <*Г*> <*Д*>] *event.K.*;

*Й*_(1, 13-25) - [*event-temporative.B.* <*І*> <*И*>] *event.K.*; *Й*_(24, 16) - [*co-ref.B.* *такі* *функції викладач* <*lex..>*]

Syntaxeme meanings are implicit on this representation, but they can be automatically explicated, since each DSR has an ordered set of functional arguments. Such representations allow modeling the interaction of syntactic and lexical semantics in the sentence.

There are two classes of models representing the sentence semantic structure. "*Atomistic semantic models*" constitute the first type. They aim to explicate "atoms of semantics" – semas, semantic primitives and their structures, which are thought to be implicitly present in the lexicon and are surfaced in certain contexts [6]. Atomistic semantic models require relating sentences with semantic representations that are invariable for all instances of sentence usage.

The second type is constituted of *procedural and interpretation models* of lexical semantics, which envisage that a text describes a process of constructing a certain mental representation of extralinguistic knowledge [7]. According to this view, language constructions do not describe the semantic content, which is created in the process of understanding a text. Instead, they control the process of understanding, accessing in a certain order the different pieces of extralinguistic knowledge, which is present prior to the process of understanding. This knowledge is amended and corrected.

Procedural and interpretation models of semantics explain more facts than atomistic models. First, they explain how the same text can have different meaning in different communicative situations: the text interacts with different structures of extralinguistic knowledge at different time, each time causing different procedural effects, building or modifying mental models in a different way. Second, they explain why in different communicative situations the same text often requires different ways of translation into another language, and why its morphosyntactic and lexical structures can be disambiguated in different ways. This means that a concrete interpretation of a text is build each time in the process of comprehension. The set of possible interpretations is open; communicants arrive to the same interpretations if there is a correspondence in knowledge that is used for text generation and understanding [8., p. 173-174].

We use the term "situational thesaurus" (ST) to refer to a formalised model of extralinguistic knowledge about some situation, where the text is used. We suggest that formalism used in the theory of programming, the object-oriented analysis, can model the structure of the situational thesaurus, which consists of *objects*, *relations* and *processes*. Objects have the *name*, the *set of attributes* and a *lifecycle* formed by *states* of the object and *the conditions on transitions from one state to another*. Among these conditions there are the conditions for creating and destroying the object. *Event generators*, *constructors* and *destructors* are processes. Objects in ST react to the events and change the states on their lifecycle, change values of their attributes and create certain relations with other objects [9]. Situational thesaurus represents extralinguistic knowledge about situations, but the problem of interaction of ST and the text is related to both to linguistic and extralinguistic knowledge.

In this model the syntactic structure of lexical items specify the sequence and arguments of procedures accessing ST. Now we see, that functional syntaxeme meanings of the syntactic structure also have to access ST. Deep syntactic labels and lexical items specify, which objects, methods and processes in the active fragment of ST are accessed. The same syntactic structures can interact with potentially infinite number of such fragments, so each time lexical items and syntaxemes have different possibilities of modifying attribute values and applying methods. This generates different contextual meanings of the same construct or text.

We have developed the described formalism for representing the syntactic structure of sentences. Now we will apply it to modelling the internal structure of lexical meaning. The meanings of content words can be represent by the DSR graph, similarly to the of syntactic structure representations: the DSR graph can connect a set of semantic primitives of a particular lexical meaning. This allows modelling lexical and syntactic semantics, as well as word polysemy and syntactic ambiguity in a consistent and homogeneous manner. Language meanings, which are expresses syntagmatically or lexically receive similar interpretation in ST.

There are different approaches to the problem of finding a necessary and a sufficient set of semantic primitives. On the one hand, there were attempts to create a semantic meta-language with a minimally sufficient number of semantic primitives, which would allow representing all possible lexical meanings by combining them [10]. On the other hand, a more productive approach for the

theory of procedural and interpretation semantics is to keep the set of "elementary lexemes" open [11] and derive it from the structure of ST, i.e., the way how the subject domain is formalised. The interaction of a text with objects, relations and processes in ST is performed through certain *key lexemes*, which can indicate names of objects, their methods, attributes, relations, etc. A same key lexeme, which is used for interaction with attributes and methods of different object, will cause different effects; the set of such effects is open, since the set of possible objects is open. Metaphoric effects occur if a key lexeme interacts with an object, which is not typical for it. In this respect the semantic meta-language is similar to the ordinary language: it does not have fixed patterns of usage, so the words in it can also be used metaphorically. This property allows creating single semantic description for each core meaning of a lexical item, and deriving its possible contextual and metaphoric meanings automatically in the process of interpreting ST [12].

Lexical meanings of semantically complex words (which are not key lexemes in semantic meta-language, i.e., they are not the names of objects, their methods, attributes or relations) can be effectively represented by the DSR structures which join the key lexemes. Further we illustrate the way of representing the semantic structure by a phrase, taken from the example given above: $A_{(2-4)}$ - [якийсь час тому] – 'some time ago'. The DSR structure of this phrase requires processing the word form "час" – 'time' first. The corresponding lexeme "час" has to be a key lexeme in ST, which activates a complex abstract object 'TIME', consisting of some 'TEMPORAL SCALE' that can be directed with marks 'PAST', 'PRESENT', 'FUTURE'. In a lifecycle of this object pointers to active events are updated by the marks from the 'TEMPORAL SCALE'. There is no destructor for the object 'TIME'. (Because of this, an expression 'to kill time' normally is not interpreted as 'annihilation of the time dimension in the universe', but it is interpreted metaphorically, in the sense of productivity of spending temporal resources by some object). Pointers on the temporal scale can be arguments in the relation '[A] earlier / later than [B]'. Procedural semantics of the lexeme "час" in this case is activation of such object. (In other usage this lexeme will interact with temporal attributes of other already active objects, but will not activate a new object and introduce it into the context).

The pronominal adjective "якийсь" – 'some' does not correspond to any key lexeme in ST. It is represented by a DSR structure of key lexemes: [*coordinative.B конкретний і { (negative.B не визначений) attribut.K }*] *attribut.K*, which is basically the representation of the syntactic structure of its possible explanation in a monolingual dictionary: "concrete and not defined". This structure consists of key lexemes, which specify an area on the TEMPORAL SCALE in the object TIME, but so far do not link any events to this area.

The adverb "тому" – 'ago/that_{dative}/because/...' is ambiguous, but in the context of the object TIME, only one of its possible meanings can produce a sensible contextual effect, which has "a chronological explanation": (*.B у минулому*)_{temporative.K} – 'in the past'. This DSR structure marks the area on the TEMPORAL SCALE, which was created on the previous stage, with the label 'PAST'.

We showed how the deep syntactic structure of a sentence could be integrated with DSR representations of explanations of semantically complex lexical items, and how this kind or representation can be used for generating contextual effects in ST. Ideally, semantic explanations for lexemes are unambiguous and consist only of clearly defined key lexemes that have only one procedural interpretation in each ST context.

This allows using ordinary "dictionary explanation" format for specifying semantic structure of lexemes. Large monolingual dictionaries for a number of languages are now freely available, formal semantic representations of lexical items can be automatically derived from these dictionaries. The proposed approach can enhance the performance and maintenance cost for NLP systems that work with representations of lexical semantics and deep syntactic structure. The semantics of a sentence is described in this approach as a procedural effect of a sentence, its potential to change a ST in the course of text interpretation at a given time in an environment of situational knowledge. Potentially infinite number of possible interpretations of each sentence and of a text in general is possible with the proposed approach, which is consistent with the procedural and interpretation models of understanding natural language.

Bibliography and notes:

- [1] *Вихованець І.Р.* Граматика української мови. Синтаксис. – К., Либідь, 1993. – С. 6, 18; *Вихованець І.Р., Городенська К.Г., Русанівський В.М.* Семантико-синтаксична структура речення. – К., Наук. думка, 1983. – С. 7. Nets of syntactic links and DSR are represented by hierarchical structures (system of constituents, dependency trees, systems of syntactic groups – *Гладкий А.В.* Синтаксические структуры естественного языка в автоматизированных системах общения. – М., Наука, 1985. – 144 с.), or by more general graphs that can have cyclic structure of edges and means for representing syntactic ambiguity of different types, e.g., logical metaoperators "OR", etc. The format, which we use in this article, – the system of syntaxeme groups – has these properties. See also: *Бабич Б.В.* Представлення та інтерпретація омонімічних семантико-синтаксичних структур // Українське мовознавство. – 1997. – Випуск 21. – С. 89-100.
- [2] Compare the view of A.M.Mukhin that units of the deep syntactic structure – syntaxemes – "are found in the positions of elementary units of the surface syntactic structure": *Мухин А.М.* Синтаксемный анализ и проблема уровней языка. – Л., Наука, ЛО, 1980. – С. 3-4. But this analysis has problems with so called "complex syntaxemes" of the type *він прийшов втомлений (втомленим) "he came tired", я побачив його сумного (сумним), "I saw him [when he was] sad"*, which can be viewed as surface transformations of two simple syntaxemes, which are the only possible units on the deep level, according to some theories. A more balanced view is that "there is no isomorphism, but there is a parallelism between surface and deep representations" – *Вихованець І.Р.* Ibid. – С. 43, a footnote.
- [3] *Золотова Г.А.* Синтаксический словарь: Репертуар элементарных единиц русского синтаксиса. – М., Наука, 1988. – С. 4
- [4] *Золотова Г.А.* Коммуникативные аспекты русского синтаксиса. – М., Наука, 1982. – С. 82-83.
- [5] *Вихованець І.Р.* Ibid. – С. 43.
- [6] The models of this type are related to the concepts of L.Witgensteins work: *Витгенштайн Л.* Tractatus logico-philosophicus; Філософські дослідження. – К., Основи, 1995. – С.8-86, which created the paradigm of logical atomism in philosophy. One of the aspects of L.Witgenstein's theory is the theory of semantics of utterances. Atomistic view on lexical semantics is adopted by the authors of the "Sense – Text" theory (*Мельчук И.А.* Опыт теории лингвистических моделей "Смысл – Текст". Семантика, Синтаксис. – М., Наука, 1974. – 315 с.; *Апресян Ю.Д.* Типы информации для поверхностно-семантического компонента модели "Смысл \Leftrightarrow Текст" // *Апресян Ю.Д.* Избранные труды. – Т. 2. Интегральное описание языка и системная лексикография. – М., Школа "Языки русской культуры", 1995. – С. 8-101). L.Witgenstein's conception is the basis of the theory of the sentence semantic structure in books: *Вихованець І.Р., Городенська К.Г., Русанівський В.М.* Ibid. – С. 30; *Pustejovsky J.* Linguistic constraints on type coercion. In: Computational lexical semantics. – Cambridge, Cambridge University Press, 1995. – P. 71-97.
- [7] Procedural and interpretation models of lexical semantics appeared later than atomistic models. Their appearance is related to criticism of the logical atomism: "Philosophical Investigations" by L.Witgenstein (*Витгенштайн Л.* Ibid. – С. 87-310), linguistic philosophy (*Austin J.L.* How to do things with words. – Cambridge, MA, Cambridge University Press, 1994. – 169 p.). Procedural semantics of P.Johnson-Laird and works of T.Winograd and F.Flores introduced the procedural and interpretation models into linguistics (cyted by translated articles: *Джонсон-Лерд Ф.* Процедурная семантика и психология значения // Новое в зарубежной лингвистике. – Вып. 23. – М., 1988. – С. 234-257.; – P. Johnson-Laird. *Procedural semantics.* Cognition, 5:189--214, 1977; *Виноград Т., Флоренс Ф.* О понимании компьютеров и познания // Язык и интеллект. – М., Прогресс, 1995. – С. 185-229. – T. Winograd and F. Flores, *Understanding computers and cognition.* Ablex, 1986)
- [8] *Бабич Б.* Інтерпретаційний семантичний аналіз тексту // Мова у соціальному і культурному контексті. Збірник наукових праць. - К., Київський університет ім. Тараса Шевченка, 1997. – С. 173- 183.
- [9] Such formalism is used in object-oriented analysis: *Шлеер С., Меллор С.* Объектно-ориентированный анализ: моделирование мира в состояниях. – К., Диалектика, 1993. – 240 с.
- [10] *Wierzbicka A.* Semantics: primes and universals. – Oxford, New York, Oxford University Press, 1996. – 500 p.; *Апресян Ю.Д.* О языке толкований и семантических примитивах // *Апресян Ю.Д.* Избранные труды. – Т. 2. Интегральное описание языка и системная лексикография. – М., Школа "Языки русской культуры", 1995. – С. 466-484.; *Шенк Р.* Обработка концептуальной информации. – М., Энергия, 1980. – 361 с.
- [11] R.Jackendoff uses similar approach in his theory of conceptual semantics (*Jackendoff R.* Conceptual semantics. In: Meaning and mental representations. – Bloomington, Indianapolis, Indiana University Press, 1988. – P. 81-97.; *Saeed J.I.* Semantics. – Cambridge, MA, Blackwell Publishers, 1997. – P. 249-259). For example, if a phrase is focused on the semantics of movement, the entity "the house" is represented as an elementary atom of meaning – *Saeed J.I.* Ibid. – С. 250. This allows keeping ST compact by giving references, but not a complete structure, to its objects in representations of lexical semantics.
- [12] H.P.Grice introduced the requirement 'not to create meanings beyond necessity' into linguistics in his work: *Grice H.P.* Logic and conversation. In: Pragmatics: a reader. Ed. by Davis S. – New York, Oxford, Oxford University Press, 1991. – P. 305-315. It is possible to show how meanings of conversational implicature are generated in our model in the process of interpreting text in ST.