Lexicons in TIL and Verb Valency Frames

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***Abstract*—The types of lexicons necessary for Transparent Intensional Logic (TIL) logical analysis will be described. We will show the algorithm for analysing the TIL verbal object as the core of a clause construction within the sentence analysis. Examples of verb frame analysis for Czech words will be presented. We also depict a way of enriching the lexicon entries as combinations of the descriptions of lexical units as they are developed within the area of lexical semantics (e.g. WordNet) with logical analysis of sentence meanings worked out within the Transparent Intensional Logic framework.**

***Index Terms*—TIL, logical analysis, verb frames.**

I. Introduction

TIL, or Transparent Intensional Logic (see [1]), is a logical system, suitable for representing meaning of natural language expressions. The system is a typed λ-calculus logic with hierarchy of types. It is a parallel to Montague's logic, however TIL is more capable of describing natural language semantics while retaining the simplicity of the basic idea. Moreover, the inference rules for TIL are well defined, thus enabling us to use constructions as an instrument for representing sentence meaning in knowledge base systems. The connection between a construction and the constructed object is fact-independent and is directed by the mechanism of typed λ-calculus. Constructions carry information about relations between the elementary parts of a language expression.

TIL objects, which are *constructed* by the sentence meaning, are typed with the objectual base that consists of the set of four basic types: o is the two-element class of truth-values (truth, T, and falsehood, F), ι is the class of individuals (universe of discourse), ω is the logical space (class of possible worlds) and τ the class of time moments (or real numbers). This yields what is called the epistemic base in TIL and represents, in fact, a framework to which now so popular ontologies can be linked. Non-basic types are classes of mappings among the members of this base and classes of constructions (higher-order types).

II. The Logical Analysis of a Sentence

For the purpose of obtaining the logical analysis of a sentence within the Normal Translation Algorithm (NTA, [2]), we describe the procedure of translation of a textual form of a natural language sentence (in Czech) into the corresponding construction of Transparent Intensional Logic, which serves as a representant of the logical meaning of the sentence.

In some cases, the resulting sentence construction is not *pragmatically anchored*, i.e. it contains free variables, which reference the pragmatic situation of the discourse as a whole. Before using such sentence in inference, the pragmatic meaning of the sentence must be acquired with filling the values of the free variables that represent personal pronouns, proper names or discourse links. However, the discourse analysis is beyond the scope of NTA and is not further discussed in this paper.

In the following sections, we concentrate on the clause construction with the usage of three lexicons:

- the lexicon of tokens
- the lexicon of verb frames
- the lexicon of functional items (prepositions, conjunctions, ...)

The content and format of these lexicons is exemplified further in the text.

A. Verb Frame Analysis

The TIL type of the object that is denoted by a verb in the finite form can be derived from the actual verb frame instantiated in the sentence. Each of the verb arguments may be assigned a different type from the *lexicon of verb frames*. In the list of verb valencies for Czech (see [3], [4]), we record the *syntactic surface structure* of the sentence constituents in contrast to their *semantic function* (in the conception of [5] the semantic function corresponds to the linguistic meaning). During the logical analysis in TIL, we need to identify yet another level of the denotation of a verb argument — its *meaning function*. On this level, we enter the construction of the TIL object represented by the corresponding NL expression.

The distinction of the three levels of verb frame representation may be demonstrated on the example of the verb 'brát' ('to take') with a valency 'někomu něco.' ('something from somebody') The three levels then can look like[1]

[1] At this level of analysis, the Agent (subject) is not processed. Its processing is postponed to the clause level analysis.

TABLE I
EXAMPLES OF A NOUN ANALYSIS.

Noun	Analysis	Description
pes, člověk *	$x \ldots \iota$: $\textbf{pes}_{wt}x$, $\mathsf{pes}/(o\iota)_{\tau\omega}$	an individual from the class of individuals — such x for which $\textbf{pes}_{wt}x$ holds
prezident *	$\mathsf{prezident}/\iota_{\tau\omega}$	an individual role
volitelnost *	$\mathsf{volitelnost}/(o\iota_{\tau\omega})_{\tau\omega}$	a property of an individual role
výška, hmotnost *	$\mathsf{výška}/(\tau\iota)_{\tau\omega}$	a quantity
výrok, tvrzení *	$p \ldots *_{\pi}$: $\textbf{výrok}_{wt}p$, $\mathsf{výrok}/(o*_{\pi})_{\tau\omega}$	a construction of a proposition from the class of constructions of a proposition
válka, smích, zvonění *	$\mathsf{válka}/(o(o\pi))_{\omega}$	a class of episodes — an activity that directly corresponds to a verb
leden, podzim *	$\mathsf{leden}/(o(o\tau))$	classes of time moments — time intervals specified by month or season.

* 'dog', 'human'; 'president'; 'eligibility'; 'height', 'weight'; 'statement', 'assertion'; 'war', 'laughter', 'ringing'; 'January', 'autumn'

1. syntactic surface structure:

   brát

       někomu$_{\text{human.NP, dat., no prep.}}$

       něco$_{\text{non-human.NP, accus., no prep.}}$

   This level reflects those properties of constituents that can be derived following the morphological and syntactical analysis of the sentence.
2. semantic function:

   brát Patient Object

   The semantic function denotes the role of the verb arguments in the activity expressed by the verb — Patient, the one that is referenced by the verb as the receiver of the verb's activity, and Object, the one that is acted with, i.e. what is taken.
3. meaning function:

   $\mathsf{brát}/(o(o\pi)(o\pi))_{\omega}\iota\iota$

       $x \ldots \iota$

       $y \ldots \iota$: s_{wt}y, $s \ldots (o\iota)_{\tau\omega}$

   On this level, we try to find the construction of the object that is represented by the corresponding constituent — $x \ldots \iota$, a specific individual, and the other $y \ldots \iota : s_{wt}y, s \ldots (o\iota)_{\tau\omega}$, an individual from a class of individuals or an individual with a specified property.

In the analysis of the verb valency frame in the NTA, we need to find the appropriate translation from the syntactic structure to the meaning function. The particular construction and type that appears in the resulting sentence analysis depends on (at least):

1. the actual *input lexical items* the constituent consists of — their analysis has to be found in the *lexicon of tokens*.
2. the *context* — the lexicon often offers more than one possible analysis of the lexical item. However, on the upper level the surrounding lexical items may provide more details to the specification of the subject and so enable to select only the appropriate analyses of the item.

The basic guide-post for the list of valencies of Czech verbs that keeps the syntactic structure of the verb valency should route the translation of a valency expression (i.e. a specification of a verb argument) in the following way:

a noun group (with/without preposition).
: A noun phrase is usually formed by a core, a noun, which is preceded by adjuncts in the form of an adjective, a pronoun or a numeral or a combination of such items. In the simplest case, the noun phrase consists of just one noun, whose analysis is found in the lexicon. Examples of common analyses of a noun are presented in the Table I.

an adverbial phrase
: The constructions of adverbial phrases usually works as a modifier of the verbal object of the verb and is not described here in detail.

a subordinate clause
: The sentence building includes the description of

analysis of relative and other subordinate clauses by means of clause combinations with the conjunction object as its functor.

an infinitive

The infinitive form of a verb in the position of a verb argument is analysed as the world-instantiated verbal object (object of type $o(o\pi)(o\pi)$) of the corresponding verb.

Following these guidelines, the current lexicon of verb frames provides the system with the information about:

- verb *lemma*
- *surface verb frame* – information about morphological and syntactic features of verb arguments
- the TIL *types of the arguments* of the verbal object
- the *schema* of the verbal object construction

An example of the current version of a lexicon entry for the verb 'brát' with valency frame 'někomu něco' (to take something from somebody) is presented in the Figure 1. In future versions, we plan to extend the lexicon of verb frames with semantic information linked to the WordNet Ontology nodes as described in the Section III.

B. The Sentence Analysis

In this stage, we have information about the logical analysis of a verb group with its arguments and adverbial modifiers. What remains to be specified, is the basic guide-post that suggests the best order in which all the partial analyses of phrases, clauses and sentence should proceed.

We suppose that the input state of the logical analysis is formed by an already disambiguated (uniquely identified) syntactic derivation tree. Hence, the logical analysis may run either after the end of the syntactical analysis of the input sentence, or as well in parallel with it, in which case the necessary procedures perform as certain contextual actions, which work over the possible combinations of the (locally) analysed constituents. The asset of such parallel approach is in its capability to prune analyses which are type-inconsistent, e.g. if the verb expects an individual as its argument, the type checking mechanism would not allow a proposition to take this place. However, the cases where such pruning may reduce the extent of the syntactic analysis are quite rare (remember, this pruning applies only on sentences which are correct in their syntax but inconsistent in the types of their constituents) or they can be substituted with the verb frame analysis only. The drawback of the parallel analysis lies also in the time and space spent on the overabundant logical analysis of those subtrees that are not part of the resulting derivation tree (i.e., in the parallel analysis, we cannot cast away any subtree that is successful "so far," even if it may be ruled out within the successive analysis).

That is why, we have chosen the logical analysis to run within the fourth group of our metagrammar actions – the actions based on derivation tree, see [6]. The process proceeds in certain (time) successive steps, which are summarized in the following paragraphs.

B.1 Lexicon of Tokens

The logical analysis starts to build the construction of the whole sentence from *inside*, i.e., in concordance with the Compositionality Principle, the meaning of the compound is constructed as the meaning of its constituents. Therefore, the first step must necessarily run in the lowest part of the derivation tree — the analysis of the input lexical items. In this step, we have not much choice other than to look up the proper analysis (analyses) of the lexical items in the *lexicon of tokens*. An example of entries in the lexicon of tokens is:

```
; lemma
peceny
; schema
O(peceny/T_PROP)

; lemma
kure
; schema
:exists:V(i/i):V(i)
  :and:[awt(O(pes/T_PROP)),V(i)]
```

Here, the word 'pečený' (roasted) is analysed as a property of individuals and the word 'kuře' (chicken) is given the analysis of an individual bearing a specific property (to be a chicken).

The lexicon can supply some wild-card values based on the grammatical category of the lexical item, but in such case we risk the possibility of incorrect type assignment (e.g. the word 'výška' (height) cannot be analysed as an individual). Hence, as a result of this part, we receive the type of each lexical item as well as a schema of its working with other (dependent) constituents (e.g. a conjunction is accompanied with the schema of the relevant clause (propositions) as its arguments). Such a lexical item that expects some arguments to be meaningful is called a *functional* lexical item.

B.2 Rule Schemata

The analysis then moves up the derivation tree, rule by rule. Each rule is supplemented with a similar schema as the functional lexical items, a schema that tells how the constituents, that correspond to the nonterminals (or preterminals) on the right hand side, combine together to

```
; lemma
brat
; encoded surface valency frame with TIL types of arguments
hPc3t{i}-hTc4t{i}
; the verbal object schema
:exists:V(v):V(v):and:V(v)=[[#0,try(#1),try(#2)],V(w)]
```

Fig. 1. Lexicon entry for the verb frame 'brát někomu něco' (to take something from somebody).

```
prep_noun_phrase -> prep noun_phrase
    agree_case_and_propagate($1, $2)
    depends($1,$2)
    add_prep_ngroup($2)
    rule_schema($@,"lwt([awt(#1),try(#2)])")

noun_phrase -> left_modif noun_phrase
    agree_case_number_gender_and_propagate($1, $2)
    depends($2,$1)
    rule_schema($@,"lwtx(awtx(#1) and awtx(#2))")
    rule_schema($@,"lwtx([[awt(#1),#2],x])")
```

Fig. 2. Examples of metagrammar rules for prepositional noun phrase and noun phrase with multiple rule schemata. The actual choice of the proper rule schema is guided by the type checking system during the running time of the analysis.

form a construction of the left side nonterminal. For an example of the rules with rule schemata see the Figure 2. The result of the application of the schema is then subject to the type checking mechanism which safeguards that the constituents typologically agree with the others in the resulting construction, i.e. that all arguments of a composition have the types needed by the corresponding function.

In this way, we form the constructions of constituents such are noun phrases or adverbial phrases up to the level of a clause.

B.3 Clause Construction

In a rule of the form '`clause → ...`', the process becomes a little more complex than to be described in one step only. In such rule, we have identified the kind of the verb group, i.e. whether it is an attributive or an episodic verb[2], active or passive voice and past, present or future tense. In groups of so called intersegments we have the candidates for the verb arguments and free adjuncts in the form of noun phrases, prepositional noun phrases, other clauses or adverbial phrases. In several successive steps, we now need to form the construction corresponding to this particular clause:

[2] *Attributive verb* ascribes a property to an entity, e.g. 'The car is red', 'He smokes'. *Episodic verb* describes an activity consisting of certain episodes, e.g. 'He is walking/running'.

1. first, we try to identify the *subject* (typically Agent) of the clause. In Czech, we can seek for a noun phrase (including a single adjectival group, optionally followed by an indeclinable word such as particle, adverb or interjection) in nominative.
   If the subject cannot be determined, we suppose that it is unexpressed[3] and supply a indefinite subject of the type of individual or a class of individuals according to the number (singular or plural) of the verb.
2. after that, we look up the *finite form verb* in the lexicon where we obtain all acceptable verb frames of this verb with the corresponding analyses (that includes the types of the verb arguments, as well).
3. what follows is a more tedious case of the procedure in point B.2 above. In order to reduce the multiplicative extent of the number of participants to be checked during this process, we run one round of pruning yet before we start to build the construction — we check all the intersegments against the available verb frames and first, score out those that with certainty cannot take part in the verb frame, and secondly, check all the possibilities (based only on the stated grammatical categories) of their fitting in place in the verb frame (e.g. we do not allow two in-

[3] In Czech, it is a frequent case when sentence subject is understood from the endings of a finite verb in the sentence.

dependent verb objects in accusative). After this, we obtain the possible verb arguments that are then type checked according to the requirements of the verb.

4. if we have linked in a relative clause or a clause with an inexplicit subject, we try to supplement it with the subject of the principal clause (i.e. if its verb and the subject agree in number and gender). Otherwise, we find the clause's subject as unexpressed.

In this way, we obtain the construction of a clause.

B.4 Whole Sentence Construction

Eventually, we process the clauses' constructions according to their conjunction. The details of their combinations in the sentence building process can be found in [2].

Thus, following these steps and the guidelines provided in the previous section, we can accomplish the logical analysis of the whole natural language sentence.

III. Word Senses and Semantic Representations

A. *Lexicalist versus Logical?*

Present approaches to semantic analysis in the NLP field typically follow two directions which do not seem to be very well integrated. The first direction can be briefly characterised as *lexicalist* and it concentrates primarily on exploration of the word senses or senses of selected word collocations (phrases). A good survey of the techniques used in this direction (with regard to the word disambiguation) can be found in [7].

The second direction, as we have explained above, may be labelled as *logical* and it pays attention mostly to the techniques that enable us to describe formally sentence meanings and build what is usually characterised as *semantic representations* of the sentences. There have been earlier attempts to explore word meanings within the Montague Grammar framework [8] where attention has been paid to the issues on how word meanings, as they are treated within generative semantics by means of decomposition analysis, can be integrated into Universal Grammar. Dowty's approach is theoretically stimulating in several ways, mainly it shows how things can be done, however, if one is looking for more applicable results that could be used in experimental NLP systems, he or she will probably not be satisfied. Though some relevant theoretical problems are addressed in [8], in a sense his analysis appears to be rather narrow because he pays attention only to English, which due to its poor morphology does not allow one to see some of the phenomena in the full extent. Take, e.g. verbal aspect — it is not a grammatical category in English (as it is the case in Czech or Russian), or the derivational morphology and lexical rules as discussed by Dowty certainly cannot be regarded general enough. Also, the version of the componential analysis dealt with by Dowty (and by generative semanticists) is interesting only from the theoretical point of view and according to our knowledge it has not been immediately used in building any existing dictionary. Further, it will become obvious that among logical approaches we rather prefer not to use Universal Grammar but TIL formalism (see above) which, in our opinion, is definitely suited better for the task.

A.1 Lexicalist View — Word Senses

In this area, the attention is essentially concentrated on obtaining plausible descriptions of the word senses or the senses of word collocations. Standardly, they are studied within the field of lexical semantics (lexicology) and the result of this effort is the information about senses of the individual lexical units as it can be found in various dictionaries. The descriptions of the word senses may take a different form depending on the type and purpose of a dictionary — starting from the classical dictionaries using definitions based on genus proximum and distinguishers, and ending, e.g., with the machine lexical databases like WordNet, where the sense descriptions are based on the synsets, Top Ontology (yielding a selected set of semantic labels (features)) plus hypero/hyponymy hierarchy.

In the following, we will refer to WordNet-like dictionaries since they can be regarded as good representatives of the description that employs extensively the semantic relations between words. As the developers of Czech WordNet, which has been built within EuroWordNet-2 project [9], we also have the positive experience with them.

Thus, within EuroWordNet-1,2 framework [10], each lexical unit is treated as a *synset* corresponding to the respective word sense. Therefore, it can be seen that each lexical unit due to its position in the respective hypero/hyponymical tree and the links given by it can be associated with a set of semantic features that can be regarded as a characterisation (or description) of its sense.

The presented approach deals preferably with word senses or senses of collocations but as far as we know, in this approach there is no complete way on how to build representations of sentence meanings or, in other words, their *semantic representations (SR)*. Thus, the issues of reference are not addressed here.

A.2 Logical View — Sentence Meanings

Logical analysis of sentence meanings takes advantage of λ-calculus formulae (see above). These formulae follow the Compositionality Principle and they yield a description of sentence meaning (its reference) in terms of the entities like extensions (in FOP) or constructions of extensions and intensions (TIL). This means that sentence like

$$\textit{John loves cars}. \tag{1}$$

can be represented as

$$\lambda w \lambda t [\textbf{Does}_{wt} John\, [\textbf{Imp}_w [\textbf{love}\, x]_w] \wedge \wedge\, \textbf{car}_{wt} x] \tag{2}$$

Thus, in TIL we get a formula which constructs a proposition stating that there is a relation-in-intension between two individuals. It should be added that TIL exploits the ramified theory of types, therefore its expressive power in comparison with FOPL appears to fulfil better the requirements that arise in realistic NLP systems.

However, in this kind of analysis, which is necessary for building reasonable knowledge representations and making inferences from them, there is something missing as well. It is obvious that we lack here the idiosyncratic lexical information that can be associated with word senses occurring in the sentence like (1) and that is certainly used in semantic analysis of (1) when it is performed by humans. Thus, we know that the expression *car* in (1) denotes an individual object (having logical type ι, which is the type of individual) but there is no way how to associate this information with the fact that typically a car is a *vehicle propelled by internal-combustion engine*. Typically, this kind of fact can be automatically retrieved from a lexical database of the WordNet type: thus we are led to a reasonable conclusion: it makes sense to attempt to combine the two mentioned ways of lexical and logical analysis and try to integrate them.

B. The Link — Lexico-Logical Dictionary (LLD)

A possible solution that would allow us to intertwine both the lexical and logical analysis of NL expressions is, in our opinion, to build a data structure that can be implemented as a dictionary of the new type. It can comprise in its entries both the lexical information about lexical units (e.g. as they are now in WordNet) and the information about the logical types that can be associated with natural language expressions.

Our preliminary analysis shows that some regular relations can be found between semantic classes of verbs [11] and the corresponding logical types, for example, the verbs denoting relation-in-intension between two individuals will certainly constitute well defined classes (transitives) whereas the verbs expressing property of an individual will clearly constitute another collection of typical verb classes (intransitives). The idea then is to explore the semantic classes of (Czech) verbs and try to find the correspondencies between them and the logical types as they are defined within TIL.

In this respect, we also have to pay an attention to the valency frames which at the first place have to be distributed according to the individual verb senses they belong to and only then the relations to the corresponding logical types can be looked for. The problem, however, is where to find the relations between the valency frames and word senses of the respective verbs (at least for Czech). One may hope that the explicit information of this sort might perhaps be found in some (really good) dictionaries but unfortunately this is not the case with the Czech ones. Thus, we face the task of building data structures for verbal lexical units that would contain the valency frames distributed according to their respective word senses, e.g. in the following form for the four senses of Czech verb *spát (sleep)*:

spát:1 i. setrvávat ve spánku (be in sleep)
valency frame: jak (Adverb of Manner): *dobře, tvrdě (well, hard*)
WordNet semantic features: BE ASLEEP, REST
logical type: $(o\iota)_{\tau\omega}$ (property of individuals).

spát:2 i. nocovat, trávit noc (stay overnight)
valency frame: kde, v čem (Place, prep. Locative): *v hotelu (in the hotel)*
WordNet semantic features: LODGE + RESIDE + OCCUPY A POSITION
logical type: $(o(o\pi)(o\pi))_\omega$ (episodic verb with adverbial modification)

spát:3 i. souložit s kým (make love with)
valency frame: s kým (prep. Instrumental)
WordNet semantic features: COPULATE + MAKE CONTACT + CONNECT TOGETHER
logical type: $(o(o\pi)(o\pi))_\omega\iota$ (episodic verb with one argument of type ι)

spát:4 být po smrti (be dead)
valency frame: kde, jak (Place, Adverb of Manner, prep. Locative): *v hrobě, tiše (in the grave, quietly*
WordNet semantic features: BE IN A STATE + BE AT REST + BE DEAD
logical type: $(o\iota)_{\tau\omega}$ (property of individuals).

The work on building this kind of data structures has already started and the first examples can be found both in Czech WordNet and other Czech lexical resources that are being prepared in NLP Laboratory at the Faculty of Informatics, Masaryk University. The starting list of Czech verbs with their surface valency frames now contains about 15 000 items [3] but they are not related to the respective senses yet. However, we have recently started adding deep valency frames to this list. At the present moment, we have enriched approximately 1.000 Czech (and English) verbs in this way.

Analogous interesting relations seem to hold between the senses of nouns, their valency frames and the logical types and their semantic features as yielded by their positions in the hypero/hyponymical trees in WordNet. As it can be seen from the examples of the verb entries presented above, the noun (as well as adjective and adverb) entries comprising both the respective lexical and logical information can be built in a similar fashion. Take, e.g. an entry for the lexical unit *hlava (head)*:

hlava:1 část těla (part of body)
valency frame: čeho, (Genitive): *hlava člověka (man's head)*
WordNet semantic features: BODY PART + PART OF A NATURAL OBJECT + ENTITY
logical type: ι (an individual) or $(o\iota)_{\tau\omega}$.

hlava:2 rozum, mysl, intelekt (nous, mind, intellect)
valency frame: na co (prep. Accusative): *hlava na počítače (a brain in computers)*
WordNet semantic features: COGNITION + KNOWLEDGE + PSYCHOLOGICAL FEATURE
logical type: $(o\iota)_{\tau\omega}$ (property of individuals).

hlava:3 vedoucí, šéf (chief, boss)
valency frame: čeho (Genitive): *hlava oddělení (head of the section)*
WordNet semantic features: INDIVIDUAL + BEING + ENTITY + CAUSAL AGENCY
logical type: $(o\iota)_{\tau\omega}$ (property of individuals) or $\iota_{\tau\omega}$ (individual role).

hlava:4 horní část motoru (hub, head)
valency frame: čeho (Genitive): *hlava kola (head of the wheel)*
WordNet semantic features: PART + PHYS.OBJECT + ENTITY
logical type: $(o\iota)_{\tau\omega}$ (property of individuals).

hlava:5 kapitola (chapter)
valency frame: čeho (Genitive), v čem (Locative): *hlava v Bibli (chapter in the Bible*
WordNet semantic features: SECTION + WRITING + COMMUNICATION
logical type: $(o\iota)_{\tau\omega}$ (property of individuals).

hlava:6 strana mince (coin side, heads)
valency frame: na čem (Locative): *hlava na desetikoruně (heads on the ten crown coin*
WordNet semantic features: SIDE + SURFACE + ARTEFACT + PHYS.OBJECT + ENTITY
logical type: $(o\iota)_{\tau\omega}$ (property of individuals).

Note that several logical types can be associated with a given noun but which type will be selected depends on the local context in which the noun can take place. In our view, it would be necessary to work not only with single nouns but with the typical collocations like *head of the department* as well.

IV. Conclusions

We have explicated the part of the Normal Translation Algorithm for logical analysis of a natural language sentence that is responsible for building a single clause construction. We have concentrated on the description of the lexicons needed for analysis of the lexical items and for analysis of particular verb frames. Several examples of existing lexicon entries have been displayed.

We have also proposed and specified a way of combining the descriptions of lexical entries in the dictionary with the respective information obtained from lexical semantic resource, namely WordNet.

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