Mapping Ontologies Using Ontologies: Cross-lingual Semantic Role Information Transfer

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Abstract

This paper presents the process of enriching the verb frame database of a Hungarian natural language parser to enable the assignment of semantic roles. We accomplished this by linking the parser's verb frame database to existing linguistic resources such as VerbNet and WordNet, and automatically transferring back semantic knowledge. We developed OWL ontologies that map the various constraint description formalisms of the linked resources and employed a logical reasoning device to facilitate the linking procedure. We present results and discuss the challenges and pitfalls that arose from this undertaking.

Keywords: linked resources, ontology, verb argument frames

1. Introduction

Semantic role labeling (SRL) – identification of the semantic arguments of verbs and their classification into semantic (thematic) roles – is an important step in making sense of natural language sentences, enabling further applications such as semantic search, question answering etc. (Palmer et al., 2010). This paper details the process of enriching the verb frame database of a novel, psycholinguistically motivated Hungarian natural language parser (detailed in Section 1.1.) with semantic role information. We accomplished this by linking the verb frame database to available external linguistic resources such as VerbNet (Schuler, 2014) and WordNet (Fellbaum and Miller, 2006) in order to transfer as much semantic role information as possible. The linking was achieved by mapping the different constraint description formalisms of the source and target resources using two OWL ontologies and by employing the Racer OWL reasoner (Haarslev et al., 2012).

1.1. The parser

Our parser is based on ANAGRAMMA, a computational text understanding approach which does not follow the parsing algorithms that are well-established in language technology, but uses some of the principles of human sentence processing set forth in (Pléh, 1989). This performance-based algorithm processes linguistic input in a parallel way from left to right. Each parsing step uses a trigram window where the first of the three tokens is processed, sometimes with the help of the two following tokens.

The basic unit of processing is a (written) word. We may also think of the series of input words as a clock signal coordinating the work of the processing threads. The first thread is morphological analysis, but for the sake of simplicity – and because our focus is on syntactic processing – we conceptualize this process as a monolithic one, which provides the lemma of the input and those linguistic and non-linguistic features which serve as the basis for further processing. Some of these features belong to the so-called "demand" class, which create threads that look for suitable features that may satisfy them, while others belong to the so-called "supply" class, which may satisfy the demand created by already existing or future threads (Sass, 2015).

Frequently occurring structures may enter the analysis with their full internal structure already in place. Multi-word expressions (proper nouns, conversation formulae, idioms, etc.) are processed in a similar way, but they do not have internal structures but behave as if they were written in a single word. In computer science we may refer to such solutions as caching, but the process is also well known in psycholinguistics: in human language comprehension we call it holistic processing. Further details about the parser can be found in (Prószéky and Indig, 2015).

2. Related Work

Semantic role labeling was pioneered by (Gildea and Jurafsky, 2002). CoNLL-2005 introduced a shared task to evaluate Semantic Role Labeling approaches (Carreras and Màrquez, 2005). (Palmer et al., 2010) gives an in-depth overview. A recent work (Ku et al., 2015) boosts SRL with grammar and semantic type related features extracted with the help of a Chinese Treebank and Propbank.

There are several resources that link together structured linguistic databases for NLP applications. VerbNet, which we refer to in this paper is linked to PropBank, WordNet, FrameNet and OntoNotes Sense Groupings in the Unified Verb Index (Loper et al., 2007), and a number of projects developed VerbNets for other languages (see, e.g., (Pradet et al., 2014) for French and (Scarton and Aluısio, 2012) for Brazilian Portuguese) by exploiting the cross-linguistic relevance of Levin's verb classes (Levin, 1993). UBY (Gurevych and Wirth, 2012) is a large-scale lexical-semantic resource based on the Lexical Markup Framework (LMF) and combines various resources for English and German (WordNet, FrameNet, VerbNet, Wiktionary, OntoWiktionary). BabelNet (Navigli and Ponzetto, 2012) is a multilingual encyclopedic dictionary and a semantic network which connects concepts and named entities in a very large network of semantic relations by integrating resources such as WordNet, Wikipedia, OmegaWiki, Wiktionary and Wikidata. The Linked Open Data concept brings together many other different semantic and linguistic ontologies via semantic web technologies such as RDF links (e.g. (Schmachtenberg et al., 2014)).

3. Resources

The verb frame database that was the starting point of our project originates from the MetaMorpho Hungarian-to-English rule-based machine translation system (Prószéky and Tihanyi, 2002). It contains more than 30,000 verb frame patterns that represent the various possible argument configurations of over 17,000 Hungarian verbs. Each frame pattern contains a verb with lexical and morphological restrictions on it, and the part-of-speech, semantic, morphological and (optionally) lexical restrictions that describe the verb's argument positions. Some argument positions are optional (are not required to be present in the sentence for the verb frame matching to hold).

As an example, the following verb frame entry for "ábrándozik" (*to dream*) describes the equivalent of the English verb frame "somebody dreams about something": `HU.VP = SUBJ(human=YES) + TV(lex="ábrándozik") + COMPL#1(pos=N, case=DEL)`. Here, the first argument position (`SUBJ`, for subject) is restricted to phrases that have the `human` semantic property, while the second argument position (`COMPL#1`, for complement) is required to be a noun phrase in the *delative* case.

There are 27 binary semantic properties, representing semantic classes, and 54 further morphological and other grammatical features describing restrictions on the argument positions in the whole database. The verb elements of each verb frame entry are described by 6 grammatical features.

Since the verb frame database originates from a MT system, each entry describing a Hungarian verb frame also has an English translation equivalent. This English verb frame contains the equivalent English verb and argument positions equivalent to the Hungarian argument positions (and optionally more slots that constitute the semantically equivalent VP in English). The English equivalent of the verb frame shown above for "ábrándozik" is `EN.VP = SUBJ + TV(lex="dream") + COMPL#1(prep="about")`. This shows, for instance, that the argument slot (`COMPL#1`), which is expressed by a delative case marker in Hungarian, is expressed by a prepositional phrase headed by "about" in English.

Our central idea was to use the English verb frame equivalents to link the MetaMorpho (MMO) Hungarian verb frame database to an English verb semantic resource *at the argument level* in order to transfer thematic role information. We focused on VerbNet (VN), a high-quality and broad-coverage online verb lexicon for English (Schuler, 2014), (Loper et al., 2007). It is organized into hierarchical verb classes extending Levin's classes. Each verb class in VN contains syntactic descriptions and selectional restrictions on the arguments, whose thematic roles are also described. Continuing our example, the Hungarian verb frame entry for "ábrándozik" can be mapped to the following VN frame entry for its English translation, "dream" (which belongs to the `wish-62` VN verb class):

```
NP V NP
Experiencer V Theme<-sentential>
```

By using the mapping between Hungarian MMO, English MMO and English VN arguments in the linked entries, we can infer that the thematic role of the `SUBJ` argument of the Hungarian verb "ábrándozik" in the above verb frame is *Experiencer*, while the other argument (`COMPL#1`) is a *Theme*.

In VN, in contrast to the flat list structure of MMO, verbs are grouped into classes according to the similarity of their frames, and each class may contain multiple frames that are valid for all verbs in the class. The class hierarchy means that subclasses inherit properties from the higher classes and may specify them further. See details on Figure 1.

Description	**Number of verbs**
Verbs in VerbNet	6,343
Has no frame (only mentioned in other resources)	2,057
Has frames, possible to link to	4,286
Verbs occurring in only one class	2,957

Table 1: Verbs in VerbNet

Multi-word verb lexemes (phrasal verbs) are represented differently in MMO and VN. This presents a problem when establishing candidate links by looking up the same verb in the two resources. The number of phrasal verbs covered was determined using one of the most complete resources available, Princeton WordNet (Fellbaum, 1998). Details are in Table 2.

Description	**No. of verbs**
Number of verbs in WordNet	7,440
Number of phrasal verbs in WordNet	1,410
Number of phrasal verbs in VerbNet	404
Number of verb stems from phrasal verbs in VerbNet	223

Table 2: Phrasal verbs in WordNet and VerbNet

There is a ratio of about 1 to 10 between the number of verb frames and unique verbs in MMO, as seen in Table 3. This is due to various idiomatic and other intricacies, which produce several different frames for the majority of verbs. This phenomena affects little more than the third of the rules. On the other hand, during the development of MMO it was not a goal to achieve good recall on the English side of the verbs. It was enough to keep the lexical coverage high on the Hungarian side and optimize the translation equivalents for the target language for precision, which presents a problem for linking.

Our investigations showed that 42% of the verbs in MMO are listed in multiple classes of VN. Consequently, in addition to the VN frames, the VN classes corresponding to MMO frames also had to be disambiguated. For a brief overview of MMO verbs see Table 3.

Description	No.
Number of verb frames	30,292
Number of unique English verb stems	3,505
Number of verb stems that are not in VerbNet	920
Verbs treated as misspelled or unknown by the spell checker	143
Idiomatic or otherwise restricted English verb frames	10,694
Idiomatic or otherwise restricted Hungarian verb frames	8,347

Table 3: Verbs in MetaMorpho

4. Linking the Resources

We used multiple knowledge sources such as WordNet and our ontologies (see Section 4.2. for details) to ensure that Hungarian verb frame entries in the MMO database are linked precisely to those entries in VN that correspond to them both syntactically and semantically, and all incorrect links are eliminated.

First, we took English verbs contained by the resources and filtered out those that do not appear in both of them. Using this filtered verb set we created all possible connections between frames with identical English verbs, and used this maximal mapping as our baseline. In the subsequent steps we tried to reduce the number of incorrect links by applying different constraints on the mapping in an iterative development style.

In a given MMO–VN mapping the mappings of specific MMO entries can be categorized into the following 5 types:

(i) There might not be any linked VN entry.

(ii) Unambiguous (one-to-one) mapping: there is only one link, which can be either
   (iia) correct or
   (iib) incorrect.

(iii) Ambiguous (one-to-many) mapping: there are more than one links, and they either
   (iia) include the correct mapping (if it exists) or
   (iib) not (possibly because it does not exist).

Because of the different granularity and level of completeness of the two resources the baseline contained a large number of entirely unsatisfactory mappings of the types (iib) and (iiib). In particular, there were many verb frames that could be found only in one of the resources, in spite of the fact that the verb itself was present in both of them. It was part of our goal to identify these entries to ease later processing.

Before applying our constraints on the baseline mapping we further reduced the number of entries by selecting only those frames from MMO that do not have optional arguments and do not require reordering of the arguments.

To determine the real-life occurrence frequencies of various MMO verb frame types, we used the Verb Argument Browser (VAB) ((Sass, 2009), (Sass, 2008)), a resource derived from the 180-million word Hungarian National Corpus (Váradi, 2002). The VAB contains analysis of 18.3 million finite verb clauses in which the finite verb and the heads of the nominal phrases that are either arguments of modifiers of the verb are annotated. We mapped the case markings of the VAB argument nominals to MMO verb frame terminology: nominative case=SUBJ, accusative case=OBJ, other case markings or postpositons=COMPL. Using these labels we counted the occurrences of each different verb frame type in the corpus. As you can see in Table 4, the top 4 types account for 88% of all verb occurrences in the corpus. Based on this, we only considered the intransitive, mono-transitive (object or complement with non-accusative case marking) and ditransitive (object and complement) frames in the further stages.

Type	Occurrences	%
`SUBJ TV OBJ`	5,535,334	30.22%
`SUBJ TV COMPL#1`	4,501,736	24.57%
`SUBJ TV OBJ COMPL#1`	3,859,952	21.07%
`SUBJ TV`	2,465,005	13.46%
(13 more types)	1,957,700	10.68%
Total:	18,319,727	

Table 4: Verb frame type occurrences in the Hungarian National Corpus

On this reduced set we successively applied our different constraints and checked the differences between the mappings before and after each application. In applying and fine-tuning each constraint our goal was to filter out ambiguous and incorrect links keeping as many good connections as possible.

4.1. Filters

The first constraint that was used to filter the links in the baseline mapping required the number of arguments of the linked MMO and VN frames to be equal. This step required some conversion, because in VN prepositions are treated as separate elements of the verb frames whereas in MMO prepositions are properties of the argument slots.

A further constraint checked whether the Hungarian side of the MMO entry had a similar meaning to that of the English verb on the VN side. The satisfaction of this constraint could be checked only for a small fraction of the links since the available mappings between MMO and Hungarian WordNet, on the one hand, and Hungarian WordNet and Princeton WordNet, on the other, are incomplete. We also checked whether the two sides of the MMO entry correspond to the same synset in WordNet.

Restrictions on the argument slots of prepositional verb phrases provided an additional constraint for filtering, as the prepositional restrictions had to be compatible for each argument position of the linked verb frames. The two resources represent prepositional restrictions differently: while VN uses boolean combinations of preposition classes, MMO frames always specify concrete prepositions. Consequently, compatibility could be checked by testing whether the preposition required by the MMO entry is a member of the VN entry's preposition class combination.

The last two filtering constraints required the syntactic and semantic restrictions in the linked MMO and VN entries to be compatible. The formalisms in which the two resources describe these restrictions were so different and, especially in the case of semantic selectional restrictions, so complex that it became necessary to introduce explicit formal representations of their logical relations in the form of two manually created OWL ontologies. For a brief overview of the number of verbs linked by the application of the aforementioned filters see Table 5 in Section 5.

4.2. The Ontologies and the Reasoner

The syntactic restriction ontology. In contrast to VN, which relies on a rich repertoire of more than 40 binary features to describe syntactic restrictions, MMO's descriptions of English frames make use only of 4 attributes: *clause-type* with 6 possible values, *tense* with 3 possible values, and the binary *poss*(essive) and *num*(ber). The syntactic restriction ontology we created represents all syntactic VN features and all possible syntactic MMO attribute–value combinations by OWL classes, and encodes their logical relationships by equivalence axioms. For example, the axiom `genitive≡poss_YES` expresses the fact that VerbNet's *genitive* feature is equivalent to MMO's *poss*:*YES* attribute–value pair. Although a large number of the axioms state simple equivalences between syntactic VN features and specific MMO attribute–value pairs, some axioms are quite complex: VerbNet's *sentential* feature, for instance, could be expressed only as a disjunction of 7 different MMO attribute–value pairs.

The semantic restriction ontology. Both VN and MMO describe selectional restrictions on verbal argument positions in terms of boolean combinations of a small number of semantic categories that are organised into ontologies. However, the two ontologies are very different: both of them contain categories that are difficult to relate to those of the the other ontology (e.g., MMO's *punct* (punctuation) or VN's *communication*), and they interpret seemingly identical categories strikingly differently (e.g., in MMO's categorisation events can be *abstract*, while VN considers *event* and *abstract* to be disjoint categories).

In view of these differences, we decided to represent the logical relationships between the selectional categories of the two systems in a single, manually created semantic restriction ontology that contains both original ontologies, together with a number of bridging concepts and axioms (see Figure 1). The bridging concepts are high-level concepts taken from the EuroWordNet top ontology (Vossen et al., 1998), which served as a starting point for the development of the VN selectional ontology (Schuler, 2005, 35). They are organizational devices that help expressing logical relations between MMO and VN categories in a succinct and conceptually clear form. For instance, although both ontologies contain several functional categories such as *drink* (MMO) or *vehicle* (VN), neither of them had EuroWordNet's general *function* category. Adding this concept to the OWL ontology enabled expressing generalisations about functional categories (e.g., that they are all subcategories of VN's *concrete* category). Since neither MMO's nor VN's selectional restriction ontology has a detailed documentation clarifying the intended interpretation of all categories they use, in the case of many categories bridging axioms were added on the basis of a careful analysis of their actual usage in the resources.

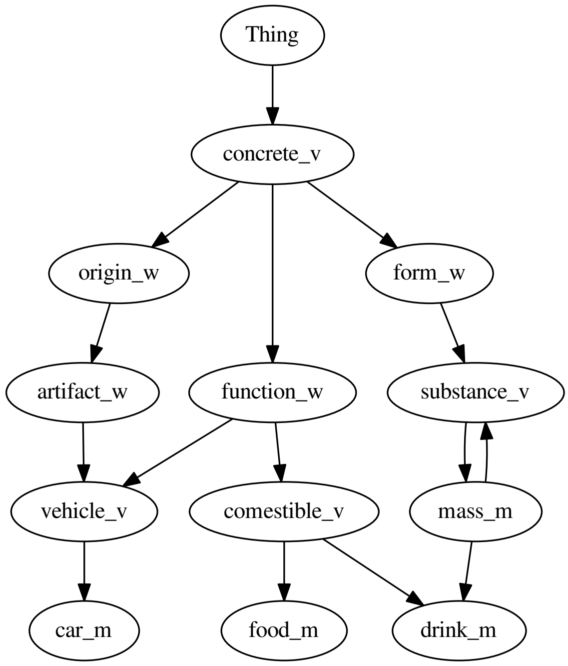

Figure 1: A fragment of the semantic restriction ontology. The source ontology of each class is indicated by a suffix added to its original name: v=VerbNet, m=MetaMorpho, w=EuroWordNet top ontology.

The ontology represents bridging concepts and selectional categories by OWL classes whose names follow a uniform naming scheme that encodes their source (VN, MMO or EuroWordNet) by suffixes. It contains all classes of the VerbNet and MMO selectional restriction ontologies (29 and 47 classes, respectively) and 15 classes from the EuroWordnet top ontology. There are no named individuals or properties, and the 129 logical axioms are limited to stating that one of the `subClassOf`, `equivalentClass` or `disjointWith` relations holds between certain boolean combinations of classes.

The reasoner. The two restriction ontologies described so far reduced the problem of determining the compatibility of MMO and VN selectional restrictions to a reasoning problem: two restrictions are compatible if and only if the restriction ontology does not imply that the corresponding (typically complex) ontology classes are disjoint. The general solution to this problem required the introduction of a reasoner software component into our system. Since the two ontologies consist only of boolean axioms, a simple propositional reasoner would have been sufficient, but because of its maturity and excellent support of the OWL format we used the open source version of the Racer OWL reasoner (Haarslev et al., 2012), which the system accessed via the OWLlink client-server protocol (Liebig et al., 2011).

Description	No. of linked entries (unambiguous/ ambiguous)
Baseline set	431 / 26,560
Possible reordering needed	291 / 12,664
The lengths of MMO Hungarian and English sides are not equal	285 / 12,347
Mono- and ditransitive constructions	267 / 10,146
Equal no. of arguments both in MMO and VN	2301 / 7,745
WordNet mapping	2181 / 6,858
Prepositional restrictions	2929 / 4,610
Ontology (semantic restrs)	2967 / 4,455
Ontology (both)	2733 / 3,286

Table 5: The number of links after subsequent filters

Description	No. of linked entries (unambiguous/ ambiguous)
Baseline set	100% (9) / 98.38% (183)
Possible reordering needed	100% (9) / 98.38% (183)
The lengths of MMO Hungarian and English sides are not equal	100% (9) / 98.38% (183)
Mono- and ditransitive constructions	100% (9) / 98.38% (183)
Equal no. of arguments both in MMO and VN	100% (114) / 96.29% (78)
WordNet mapping	100% (101) / 97.14% (68)
Prepositional restrictions	90.43% (104) / 79.62% (43)
Ontology (semantic restrs)	90.98% (111) / 76.59% (36)
Ontology (both)	92.59% (100) / 70.83% (17)

Table 6: Precision and number of links after subsequent filters with regard to the gold standard

5. Results

To measure the performance of our system we created a random sample of 400 MMO entries from the output of the last filter. Ambiguous entries and unambiguous ones were treated equally. The sample was processed by two independent annotators and unified by a third one. The sample contained 90 MMO entries that had no corresponding entry in VN, and were therefore removed. The remaining entries constituted our gold standard.

Since the gold standard was not representative of the whole MMO database and we considered only those entries from each test set that were in the gold standard, only the precision of the results could be assessed reliably. We checked each filter's output in the following way: if an MMO entry was unambiguously mapped and the mapped VN entry was identical to the one specified by the gold standard then it was considered correct, otherwise it was incorrect. In the ambiguous case set containment was used instead of equality: if the correct VN entry was in the set of linked entries then the mapping was considered correct, otherwise it was incorrect.

The final mapping (see Table 5) that was produced by our procedure contained four times more unambiguous links than the baseline, while the number of ambiguous links was radically reduced. The precision of the filters described in Section 4.1. (see Table 6) was nearly perfect in the case of those unambiguously mapped MMO entries for which the gold standard specified a valid corresponding VN entry.

6. Discussion

A number of issues made the linking of MMO and VN entries more than a trivial exercise. Some of these obstacles arose from inherent problems in the used resources.

First, the MMO verb frame database was not conceived as a general-purpose resource for NLP applications, but rather to support a specific MT system. As a consequence, the lexical coverage of verbs in the English side is low, compensated by paraphrase-like translations, which are hard to look up in a lexical resource such as VerbNet. The English MMO verb frames also include a large number of idioms or semi-compositonal structures (one or more of the arguments are bound lexically, eg. *take part in sg., make room for sg.* etc.), which are totally absent from VerbNet. Furthermore, while the features used for specifying selectional restrictions in the Hungarian verb frames fare well within the original MT system, the lack of a strict and formal system presents challenges when mapping to another feature system.

Second, VerbNet has recursive, complex selectional restriction feature expressions, which are hard to process (4.2.). Even though VN is an elaborate resource, the semantic features and categories used in the syntactic frames are not well documented or come from vaguely documented resources, which sometimes makes their interpretation difficult or a work of guessing.

We found VN to be sometimes incomplete, for example, the only intransitive frame for "knock" (class `sound_emission-43.2`) marks the subject *Theme*, while we believe a frame with an *Agent* subject exists in English ("Somebody knocked.").

Finally, WordNet presents some problems of its own. Its noun hypernym hierarchy, which is very useful as a taxonomic network, represents a level of granularity which does not reflect general (domain-independent) language use, making graph distance-based inferences difficult. The differences between the data formats of various WordNet resources (Hungarian WN and different Princeton WN versions) also presented challenges.

7. Future Work

The linking of MMO and VN entries was implemented in a unification-based framework, in which the relevant features of the entries were represented by attribute–value matrices, and links were created between all MMO and VN entries for which the corresponding AVMs could be successfully unified. Since semantic restrictions were considered unifiable if and only if they were consistent according to the semantic restriction ontology, the linking process did not take into account the semantic similarity of these restrictions: all entry pairings with consistent semantic restrictions on the corresponding argument positions were treated as equally acceptable as far as semantic selectional restrictions go.

This approach had some problematic consequences, for instance, the linking procedure could not distinguish restriction pairs in which one of the restrictions is empty (these are always consistent) from the ones consisting of two similar concepts, such as *comestible_v* and *food_m*. In order to solve this problem, we plan to introduce a numeric similarity measure for semantic selectional restrictions, and modify the linking algorithm to link only those entry pairs for which this similarity measure has a sufficiently high value.

In the long run, we also plan to transform the MMO verb frame database into a VerbNet-like resource, in which verbs will be organized into a hierarchy of Levin-style classes, and verb frames will be described at the level of these classes instead of listing all valid instances of the generalizable, common patterns. Although this transformation will undoubtedly involve a large amount of manual work, we expect that a useful starting point can be provided by a suitable unsupervised clustering of the current MMO verb frame descriptions.

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