Event Structure Representation in Ontological Semantics

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Abstract - *The present work focuses on representation of event types in Ontological Semantics. As a systemic resource for knowledge-based Natural Language Processing, Ontological Semantics strives to represent the results of human language processing ability. This work suggests that event structure representation is indispensable to this task, noting the use of event structure in semantic representations of natural languages. It proceeds with offering possible ways of incorporating event structure into an ontological semantic system, and consider the advantages of using an event-structural treatment of predicates for semantic interpretation of ambiguous sentences, including implicature.*

Keywords: event structure, ontology, computational semantics, telicity, resultative.

1 Ontological Semantics as a Resource for Natural Language Processing Applications.

The main difference between Ontological Semantics and other approaches to Natural Language Processing lies in the fact that Ontological Semantics is fundamentally a resource for use in various applications. In the present paper we focus our attention on one aspect of this resource: representing the event structure of the predicate, which plays an indispensable role in human language processing. Ontological Semantics, assuming the "weak AI" approach, aims to build resources, which would be maximally applicable for reproducing the results of human language processing ability, for use in any practical applications; the applications themselves are beyond the scope of the paper, although they are mentioned briefly in the concluding section.

We propose the framework of ontological semantic processing/text meaning representation through the ontology as a possible solution for this problem. The ontological semantic approach to natural language processing as such consists of using both language-independent static knowledge sources (the ontology, fact database) and static language-dependent sources (lexicons, onomasticons, morphological processor, syntactic processor, etc.), as well as dynamic processing algorithms. In summary, the dynamic algorithms (which include the tokenizer, syntactic, ecological and morphological analyzers) process the text and match the lexical items in the text with appropriate ontological concepts through the lexicon-ontology connections, ultimately leading to text meaning representation, or TMR. As a language-independent semantic concept hierarchy, it can then be used (with appropriate follow-up processing) for machine translation, data mining, information extraction, question answering, text summarization, etc.

1.1 Predication in Ontological Semantics: Events as fundamentals of Text Meaning Representation.

The main function of all static and dynamics sources of ontological semantics is construction and manipulation of TMR, or text meaning representation. The TMR is constructed by means of processing a natural language text with the analyzer, and using the available lexicon (or lexicons) and ontology in order to construct representations of predicates, centered around sentence-level predication. Thus, the verbs in the sentence serve as "crystallization points" for the rest of the information contained in the sentence. The process is described in detail in Raskin & Nirenburg (2004). In the present paper, I focus mainly on what information the static resources (ontology and lexicon) need to contain in order to best facilitate TMR creation, and how that information is introduced in the templates for lexical items or ontological concepts. The way Ontological Semantics system is constructed, the semantic representations in the lexicon and the ontology are complementary, and there is no clear-cut distinction as to whether a particular piece of semantic meaning needs to be represented in either one – outside, of course, the non-proliferation requirement for ontological representation.

As will be obvious from the templates for various parts of speech described below, predication serves as the central point for creation of text meaning representation using the static resources of ontological semantics. Each sentence is processed based on its propositional structure, where predication plays a central role. Both primary (in English, predication expressed by the main verb) and secondary predication (e.g. adjectival description of objects, use of resultatives and depictives, etc.) serve as sources of "crystallization" for the rest of the sentence, when possible candidates for filling in propositional templates are checked against the possible meaning representations for the TMR template, and the best candidates are chosen to fill each meaning-slot in the TMR.

Raskin and Nirenburg (2004: 212) describe the process as follows:

> The initial big step in semantic analysis is building basic semantic dependencies for the input text. Proceeding from the lexical, morphological and syntactic information available after the preprocessing stage for a textual input, on the one hand, and an empty TMR template, on the other, we establish the propositional structure of the future TMR, determine the elements that will become heads of the TMR propositions, fill out the property slots of the propositions by matching case role inventories and selectional restrictions on sets of candidate fillers.

Note that the templates and rules for all representations in the lexicon and ontology are driven by the need to eventually establish the basic semantic dependencies, and this is the reason for which we strive to represent the semantics and semantic valency of each word and expression as thoroughly at possible. While the procedure for building semantic dependencies uses the specifications offered in static resources as defeasible constraints (especially when the basic procedure returns no result), those constraints are still the main resource for the construction of TMR, and should be expressed thoroughly.

2 Event structure in linguistic research.

I propose a general addition to the structure of the acquisition of verbs, which would cover event structure. The change provides for more rigorous processing of sentential propositional structure. This rigorous description can be achieved by categorizing verbs into event structure types with corresponding syntactic-semantic processing templates.

The fundamental purpose of the ontological description of the semantics of lexical entries lies in the closest possible "description" of a real-world event. That involves pre- and postconditions, effects, end-points, etc. There is a vast body of theoretical work in event structure (Pustejovsky 1991 and 1995, Levin 1993, Ramchand 2003 etc.). While some of the above-mentioned approaches are purely syntactic, and others tend to a more cognitive-based description, they all converge on the distinction of event types, even if they differ in the final inventory of those types. The reasons for introducing event structure into computational NLP models include the following:

1) Event structure has to be present in the original conceptual structure (for humans, see O'Bryan, 2003, for discussion) or text meaning representation (for machines) in order to allow for lexical item selection (or morphology – this parameter varies between languages, but never actually disappears even in Russian, where aspect and event structure are very closely connected).

2) Since event structure information is "under the word-level" for many languages (or can be traced only in morphology, like in Finnish and Bangla), in order to construe a non-conflicting cross-linguistic ontology, consisting of semantic primitives, it's instrumental to allow for basic event phases 'inceptive phrase', 'main phrase of the process', and 'resultant phrase'.

3) The event-structural information of the word can be exposed by allowable verb frame alternations, i.e. it is testable. This provides for much higher reliability in ontological acquisition. For example, in English, causativisation and middle alternation expose, respectively, the absence of Initiator argument, and the co-indexing of Undergoer and Resultee argument roles. As such, the event structure of the verb is predictive of its syntactic behavior and allows one to track arguments of the verb with much higher efficiency, as compared to, for example, Case analysis constrained by encyclopedic (ontological) information.

4) Event structure is psychologically relevant. We do know that humans are remarkably good at detecting the presence of the RP, and judging the affectedness of the Undergoer/Resultee, as has been shown by research on telicity/transitivity comparison (Erin O'Bryan 2003, Folli and Harley 2006). Thus, any Text Meaning Representation (TMR) should necessarily carry the information about affectedness of the arguments by the verb-denoted process, and the information as to whether the process has already reached its logical conclusion(see Wilbur, in press,

and Grose et al, 2004, for discussion of Signed Languages, and Bertinetto 2001, van Hout 2000, and Hovav and Levin 2002, for discussion of spoken languages). Yet, this is impossible without introducing the event structure of the verb, as I demonstrate further.

5) Event structural information is computationally relevant. The entire event/argument structure is represented by the combination of event structure of the verb, and quantification/Case of its arguments. However, argument quantification alone (sometimes surfacing as strong-weak case alternations, such as Accusative vs. Partitive, as per van Hout 2003) is not sufficient to account for the judgments that humans make: it is a part of event structure, and inseparable from it. Therefore, in order to connect the information provided by the arguments to the original CS/TMR, it is imperative to account for the event structure (provided by the verb) that these arguments participate in.

Taking into consideration the recent advances in research on event structure in human languages, I would like to suggest the following schema for event description for use in this work.

The typical event type taxonomy, described in the above-mentioned literature, deals with 4 event types: state (S), process (P), accomplishment (a process terminating in a state, P **à** S), and achievement (a state change S **à** S). From the point of view of real-world knowledge, it is important to retain the information as to whether the final state was achieved ("He almost climbed the mountain"), in what state the affected entity (or Undergoer, using Ramchand's terminology) of the event exists after the event itself is completed ("He painted the house red"), and whether the event itself has a completion point (is telic) and a result or not (cf. "I wiped the table clean" vs. "I wiped the table for 5 minutes").

Processes and states, from the point of view of event structure, are not very different – they are homogenous events, with the exception of one of them being static (state), and the other one being dynamic. Accomplishments and achievements, as non-homogenous events, on the other hand, are more complex and share several important traits:

- they consist of more than one part, the initial state or process being a necessary precondition for the resultant state;
- they can be telic complete or incomplete;
- when telic and complete, they result in a certain state for the Undergoer of the event, which is sometimes overtly specified in the sentence ("wiped the table clean"), and sometimes only inferred (e.g. table being clean would be an implied result of wiping it, unless specified otherwise : "She wiped the table, but it was still dirty").

I suggest the following extensions to the ontological semantics treatment of the verbs:

1) differentiating between processes and states on one hand, and accomplishments and achievements on the other;

2) using explicit templates (provided below) for rigorous treatment of accomplishments and achievements. These templates allow one to keep track of what goes on before (using the ontological concepts of PRECONDITION-OF and PRECONDITION) and after the state change (using the concepts of EFFECT and more rarely OUTCOME), and thus allow the processing system to both "remember" and "imply" the result of achievement and accomplishment event types.

I would like to make a disclaimer here: I am not suggesting that the event structure encoded by the verb is singly responsible for expressing the result end-point. In fact, considering possibilities of verb frame alternations (Levin 2003), it's important to take into account the predicate in its entirety. For instance, Filip (2000) and Van Hout (2000) note that only quantified noun phrases can serve as end-point themes: "I ate the fish" (telic) vs. "I eat fish every day" (altelic). Also, the 'path PP or a location /goal', when present in the structure of the verbal phrase, can facilitate a "change of state", or "telic" reading, e.g. 'John ran to the store' (telic, PP describes goal) vs. 'John ran along the river' (atelic, PP describes path). Among syntactic-based approaches, most notable ones are Van Hout (2000) and Borer (2004), who go as far as suggesting a feature [+ telic] to be checked only by quantified noun phrases.

Given the above, I maintain that while quantization (for languages such as English) or use of grammatical case (for languages like Finnish and Russian) are important for processing event types, in any semantics-based approach to natural language processing they can be relegated to the stage of dynamic (phrasal) analysis, and processed on a language-specific basis. However, the event structure as pertains to verbs, especially the homogeneous/non-homogenous event dichotomy, needs to be present in the static resources, and in some cases raised to the level of ontological representation.

3 Ontological Semantics and Implicature Processing: the Use of Event Structure.

One of the useful consequences of the thorough event-structure-based semantic description of the predicates is the fact that such description is necessary for processing one of the types of implicature. Consider the following example: “I downloaded the file”. In order for a complex processing to take place, the system has to “know” not only what the process of downloading is, but also what it entails – in our case, a change of state from “lack of possession” of the file to “possession”, with the agent owning the file as a result of this event. If this information is available to the system, it can appropriately keep track of “the file” for use in script-based processing of situations. A template for complex events which would contain this information is sufficient to cover the notions of both telicity and resultativity.

The achievement of the end-point (in general terms), or the realization of the existential modality of the EFFECT (in ontological terms) can, of course, be modified or blocked in a sentence all together. For example, in processing the sentence “I almost downloaded the file”, the idea of incompleteness of the action, contributed by the adverb “almost”, renders the verb phrase non-complete from the point of view of telicity, and marks the “possession” EFFECT of the event unrealized. Thus, the use of event-based verbal templates allows for a more thorough semantic processing at later stages.

3.1 Verb templates in the lexicon and their modifications.

I give a schema-like generalized version of a verbal template, before proceeding to explain how event structure can be represented in the lexicon or the ontology:

```
(lexical-item
(lexical-item-V1 (cat V)
(synonyms "")
(anno  (def "")
(ex "")
(comments ""))
(syn-struc
(subject ((root $VAR1) (cat N)))
((root $VAR0) (can V))
(object ((root $VAR2) (cat N)))
(pp-adjunct ((root prep) (cat PREP)(obj ((root root)))))
)
(sem-struc (CONCEPT
(slot (facet filler)) // optional, used for case roles, etc.
(slot (value value))  //optional, used for scalar or binary property
)))
```

The head of the entry (line 1) is the lexical item itself. Since some lexical items have more than one meaning, and span more than one part of speech, all of these senses are united under one word. The second line tells what part of speech is described in this part of the entry. This is followed by the synonyms field (synonyms), including synonymic expressions, and annotation field (anno), containing definition (def), examples (ex), and comment field, which for verbs includes an indication of transitivity.

Syntactic structure (syn-struc) introduces the possible argument structure of the entry. For English, we rely mainly on word-order, in order to specify the syntactico-semantic connections. The words surrounding the verb (which is always given a 0-label, $VAR0), are assigned variable numbers. It does not really matter what those are, so long as the variables introduced in the syntactic structure are referenced and specified in the semantic structure as well. Usually, they are fit into the argument structure using case role assignment – i.e. each of the possible arguments introduced in the syntactic structure is specified for its case-role, licensed by the verb, in the semantic structure field. Most typical case roles are AGENT (or PATIENT, for non-agentive verbs) and THEME for transitive verbs; others are used as necessary.

Syntactic structure allows for both direct and indirect (prepositional) objects, as shown above.

The semantic structure of the lexical entry for the verb is determined by the event type, as discussed below; overall, there is one major concept to which the entry is connected and further specified by the use of other ontological slots.

I have incorporated the event-type structure information of the verbs in the Digital Identity Management domain into their semantic descriptions. As noted above, the process/state distinction is extant in ontological semantics, so for both of the simple event types I have used the basic structure.

In the semantic structure part of the entry, verbs of the English lexicon can be tied to various ontological concepts: EVENTs (the most frequent connection), PROPERTY, or can be mapped to MODALITY (e.g. the verb “to try”) or ASPECT (e.g. “to begin”).

Templates for Non-homogenous Event Types. Non-homogeneous events, i.e. accomplishments and achievements, can be captured by means of ontological semantics in various ways. One of the ways already employed was the use of aspect: i.e. a non-homogeneous event can be interpreted as a beginning or ending of a process or state, for example:

```
(log-out
(log-out-V1 (cat V)
(SYNONYMS “sign off” “log off” “log out”)
    (anno  (def "to terminate a session on a computer, for which authorization is required")
```

(ex "I logged myself out and left the lab.") (comments ""))

```
(syn-struc
((subject ((root $VAR1) (cat N)))
(root $VAR0) (cat V)))
(sem-struc (ACCESS-COMPUTER-NETWORK
(ASPECT (PHASE FINISH))
(AGENT (value ^$VAR1))))
))
```

As you see, even the aspect can be a part of verbal semantics (coded by morphological and 'lexical choice' means in Russian, but by syntactic means in English). However, if we do end up with aspectual marker on a non-homogeneous event like 'log-out' (e.g. "I'm logging out; it takes a while on these computers"), then the analyzer would be in an unnecessary loop as to the interpretation of a conflicting double aspectual representation in the TMR. To avoid this, and to facilitate deep semantic representation, I invoke the "event-switch tracing" mechanism of language processing.

There are several event-relation concepts in the ontology, useful for relating events to each other in a causative manner (relations between initiation, main phase, and resultant phase in event structure are based on a caused-by relationship). They are located in CONDITION-OF-CHANGE and INVERSE-CONDITION-OF-CHANGE branches. Both CAUSED-BY and PRECONDITION from the first branch tie together two simple events; in the case of *CAUSED*-BY, one event has to be an immediate cause of the other, PRECONDITION identifies an event that is a necessary condition for the occurrence of another.

From the second branch, EFFECT is defined as "the result of a causing act, state change, force application, etc."; PRECONDITION-OF is "the relation that describes a state or property that sets up the precondition" (so it can be used with both predicative types of concepts in the ontology). They are the inverse of CAUSED-BY and PRECONDITION, respectively. OUTCOME, from the same branch, is only applicable to psych verbs, because it connects an event with a mental object only.

I selected PRECONDITION (process or state that begins the event) and EFFECT (end-state) as default (and most general, semantically) ontological connections for the main phase and Resultant Phrase, respectively, in non-homogeneous events. Other above-mentioned concepts can be used when the semantics of the verb requires it – specifically, I reserved the CAUSED-BY for atelic verbs marked as causative (not a class in English, but found in Finnish and Russian).

Since we are not forced to mark process/state distinction in the template (this information is provided by ontological items chosen for the main and resultant state), this approach is intended to treat both accomplishments (and in many cases for these, the end-point for the telic process is provided externally by the direct object) and achievements (verbs expressing changes from one state to another). Examples for both are given below.

First, consider this representation of the example given at the beginning of this section. The verb denotes a change of state, e.g. from being online to offline. Here is how the entry is treated:

```
(log-out
(log-out-V1 (cat V)
(synonyms "sign off" "log off" "log out")
  (anno (def "To enter into a computer the command to end a session.") (ex "After you are done working, log out to avoid a derf.") (comments ""))
 (syn-struc
 ((subject ((root $VAR1) (cat N)))
 (object ((root $VAR2) (cat N) (opt +)))
 (root $VAR0) (cat V)))
 (sem-struc (CHANGE-EVENT
(EFFECT (sem BE-OFFLINE))
     (PRECONDITION (sem BE-ONLINE)
(AGENT (value ^$VAR1)))
(THEME (value ^$VAR2))))
))
```

For an accomplishment, e.g. "to type" vs. "to type a letter", we need to specify a syn-struc that, in the presence of an object, would culminate the event in a resultant state for the object. That is, while technically speaking, the object is optional for the verb, the type of event in the presence and in the absence of the direct object is different. Without the object, the event is a process; with the object, the event is an accomplishment (telic, requires an object):

```
(TYPE
(TYPE-V1 (cat V)
(anno (def "To write (something) with a typewriter; typewrite. ")
(ex "I type 50 words a minute.")
(comments "intransitive variant"))
 (syn-struc
((SUBJECT ((root $VAR1) (cat N)))
(root $VAR0) (cat V)
 (sem-struc
(TYPE (AGENT (value ^$VAR1)))
(AGENT (value ^$VAR1))
(TYPE-V2 (cat V)
(anno (def "To write (something) using a keyboard; typewriter")
(ex "He typed the letter using a word processor.")
(comments ""))
 (syn-struc
```

((SUBJECT ((root $VAR1) (cat N)))
(root $VAR0) (cat V)
(OBJECT ((root $VAR2) (cat N))))))
(sem-struc (PRODUCE
(AGENT (value ^$VAR1))
(THEME (value ^$VAR2))))
(MANNER (sem TYPE)))
))

Above, I described the use of lexicon templates in order to specify the event type. However, as I noted above, the information about semantic structure of an entry can be divided between the ontological concept that the lexical item is connected to, and its lexical template in the lexicon. Thus, when the ontological item that the verb is connected to is sufficiently specific in describing the event structure (i.e. has inherited the explicit event structure description from a parent node), we would not need to specify this further in the lexical template. For example, the verb "update" does not need event type specification in the lexicon, because the ontological item it is tied to, UPDATE, already contains the necessary information; cf. lexical and ontological entries given below:

(UPDATE
(UPDATE-N1 (cat N)
(anno (def "Information that updates something.")
(ex "news update")
(comments ""))
(syn-struc ((root $VAR0) (cat N)))
(sem-struc (INFORMATION
(ADD-TO (THEME (sem INFORMATION))))
(UPDATE-N2 (cat N)
(anno (def "An updated version of software.")(ex "news update") (comments ""))
(syn-struc ((root $VAR0) (cat N)))
(sem-struc (SOFTWARE
(THEME-OF (sem UPDATE))))
(UPDATE-V1 (cat V)
(syn-struc
((subject ((root $VAR1) (cat N))) (root $VAR0) (cat V)
(object ((root $VAR2) (cat N) (OPT +)))))
(sem-struc (UPDATE
(AGENT (value ^$VAR1))
(THEME (value ^$VAR2))))
))

(UPDATE
(DEFINITION (value ("to change smth (information, software) to a newer version")))
(INSTRUMENT (sem (OBJECT)))
(IS-A (value (CHANGE-EVENT)))
(EFFECT (OWN (AGENT (sem (HUMAN) RELAXABLE-TO (ORGANIZATION))
(THEME (sem (INFORMATION SOFTWARE) relaxable-to (object)))
(PRECONDITION (LACK (AGENT (sem (HUMAN) RELAXABLE-TO (ORGANIZATION)))
)

From the standpoint of an engineering application, like an ontology, it does not matter very much at what level the distinction is made for the event type, as long as this information can be accessible for processing at some point in the computation. As ontological frameworks strive to attain the level of the functional equivalency to human language processing, event structure information is indispensable to the task. As shown above, for our purposes the distinction for event-structure type can be specified in the lexical entry or in the ontological concept. Within the ontology itself, the requirement for event-type distinction can be made at a higher or lower level. The distinction between event types would be made at the point of TMR creation, which brings together both the lexical and ontological information. As long as there are no pushing memory-size or processing-time requirements, the distinction can be made at any level and still be processed accurately and give the user the same advantage, including temporal entailment processing.

4 Significance of proposed approach to domain acquisition.

The main point of theoretical significance of the present work lies in the application of event-structure theory to the static resources of any ontology, and the proposed mechanism of refining the grain size of lexical description and enhance the descriptive power of Ontological Semantics, and any other ontology-based approaches to NLP.

The goal of any ontological acquisition project is to collect new data for the system (in our case, in a specific domain of knowledge), combining linguistic theory and practice to render adequate resources for the use in natural language processing. While the entire project is primarily lexicographical in nature, the peculiarity of this particular work is that the approach is computational in nature, and can only be evaluated in terms of its applicability to natural language texts.

s such, the project has several possible audiences. The linguistic community can benefit from the evaluation of theoretical applicability of well-established and emerging theories through computational semantic approach to natural language processing. On the other hand, the computer scientists, working on the natural language processing tasks, benefit from the resource, which offers a thorough ontological semantic representation of the vocabulary.

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