μ-Ontologies: Integration of Frame Semantics and Ontological Semantics

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Today FrameNeta-a state-of-the-art implementation of frame semantics-provides one of the best insights into lexical semantics and their interaction with the syntactic structure of the sentence. The main limitation of the current implementation is the insufficient level of formalization of frame descriptions, making it unsuitable for automatic text annotation without human supervision. Meanwhile, FrameNet usability would greatly benefit from more rigorous formalization and the consequential possibility for automatic annotation. Previous attempts at formalization have focused on enforcing strict ontological control of the semantic types for the frame fillers-despite their insignificant use-due to high ambiguity-in the actual FrameNet. We propose a different approach relying on representation of FrameNet as a 4D multidimensional ontology that allows capturing of the "precedent" knowledge encoded in the manually annotated texts, like FrameNet's full-text annotation reports. This allows both to re-create FrameNet ontology from semantically annotated texts, as well as to use this representation for semantic annotation of new texts. Further extensions of this approach with 5th dimension for anaphora annotation is discussed as an alternative for the informal semantic type mechanism of FrameNet.

1. Introduction

Today FrameNet, a state-of-the-art implementation of frame semantics (Fillmore 2003), provides one of the best insights into the lexical semantics and its interaction with the syntactic structure of a sentence. FrameNet formalizes lexical semantics by linking word senses to the *frames* or idealized situations abstracted from the concordances encountered in a text corpus. However, the main limitation of the current implementation is the insufficient level of formalization of frame descriptions, making it difficult for semantic parsing without a human supervision[1].

Meanwhile, FrameNet's usability would greatly benefit from more rigorous ontological formalization and consequential possibility for automatic semantic role labelling. Previous attempts by Scheffczyk et al. (2006) to formalize FrameNet have focused on enforcing strict ontological control on about 40 predefined *semantic types* for the *frame element* (FE) fillers and inheritance relations between the frames themselves—despite their inconsequential use (due to the high ambiguity) in the actual FrameNet.

We propose a different approach to formalization of FrameNet not relying on the predefined semantic types and frame inheritance structures, but rather on a concept of *multidimensional ontology* that allows capturing of the "precedent" knowledge encoded in the manually annotated texts, like FrameNet's full-text annotation reports[2]. This enables to enrich annotated texts with co-reference (anaphora) annotations for rich world-knowledge capturing. Additionally, unlike the approach taken by Scheffczyk et al. (2006), we do formalize in the multidimensional ontology the formal part of

[1] Although the best performing FrameNet-based semantic parser (as evaluated in the SemEval-2007 task on Frame-semantic Structure Extraction) shows promising results (Johansson and Nugues 2007), it is still in a halfway in terms of precision.

[2] *http://framenet.icsi.berkeley.edu*.

FrameNet—*lexical units* (LUs) binding to frames and subordinate valences, as well as binding of LUs to FEs in FrameNet-annotated sentences.

The proposed approach at the first glance might look similar to the statistical n-dimensional vector space approaches employed by the state-of-the-art semantic role labellers, like the one by Johansson and Nugues (2007), while in fact it differs profoundly as it is not statistically based. Multidimensional ontologies described in this paper are designed to capture exact instance level data contained in the manually annotated corpus of "precedents" in the format that can later be reused for semantic parsing of new texts. However, in this paper we are not addressing the problem of semantic parsing itself, but only introducing a method for converting an existing FrameNet-annotated text into the multidimensional ontology representation.

The central idea of our approach is to geometrically arrange (visualize) a manually FrameNet-annotated text in the multidimensional space in such a way, that all frame annotations of the text are captured by the multidimensional coordinates of "no-name" (anonymous) objects and their "no-name" relations. Such extreme multidimensional representation of manually annotated texts leads to the effect, that all rules[3] obeyed by the human annotator become exhibited geometrically as co-locations of the anonymous objects and their relations. Such co-locations can be interpreted in ontological terms as classes forming a multidimensional ontology, which in turn can be used to guide semantic parsing of new texts.

2. The concept of multidimensional ontology

Multidimensional ontology is a spatial knowledge representation approach. Ordinary ontologies (such as well-formalized OWL DL ontologies of Semantic Web) use first order logic (FOL) to define class membership of individuals (objects) and their permitted binary relations (properties). By introducing the concept of a multidimensional ontology, we are arguing that in some cases defining the class membership of individuals and their permitted relations can be more conveniently achieved through geometric means in multidimensional space, rather than through first order logic based formalisms.

More formally, by multidimensional ontology we mean a finite[4] set of *points* in the multidimensional space. These points represent classes; individuals of the multidimensional ontology are also represented as points in the same multidimensional space and must belong to some class, i.e., they must be collocated with one of the points belonging to the multidimensional ontology. Binary *relations* between the individuals are represented as directed edges connecting the two involved individuals. Unlike in FOL-based ontologies, binary relations between individuals in the multidimensional ontology have no names—only anonymous relations are permitted. Also individuals have no semantically significant names, but they do have unique identifiers—like URIs in OWL DL ontologies.

Formally, any multidimensional ontology can be reduced to OWL DL ontology, but such reduction would destroy the conceptual foundation of the original multidimensional ontology.

3. Multidimensional ontology of FrameNet

To explain the concept of a multidimensional ontology of FrameNet, we will use a human annotated sentence (Figure 1 and 2), taken from the FrameNet full-text annotation reports.

[3] Rules according to FrameNet itself and world-knowledge used for frame element disambiguation.

[4] In general, segments of infinitely many points cold be considered, but this is beyond the scope of this paper.

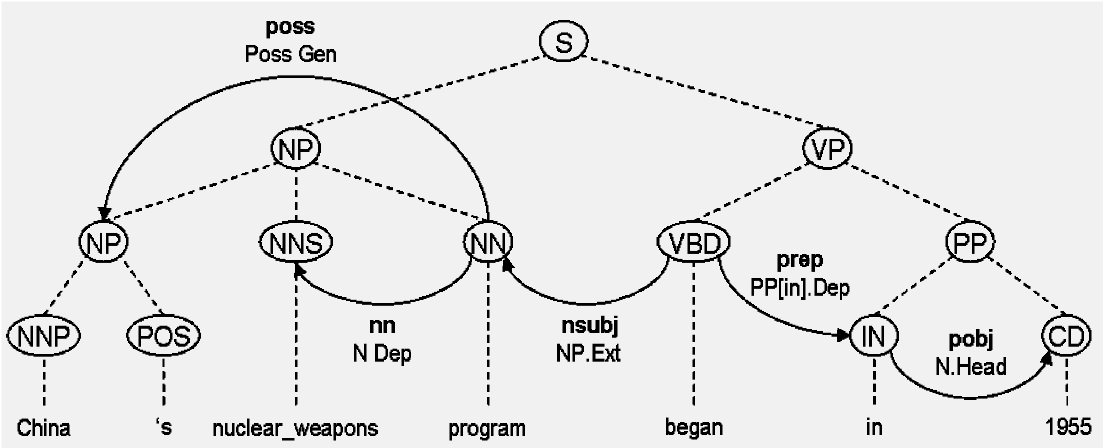

Figure 1. Parse tree of the example sentence. Both constituency (dashed) and dependency (solid) structures were acquired with Stanford parser[5]. FrameNet uses dependency links with FrameNet valences shown underneath.

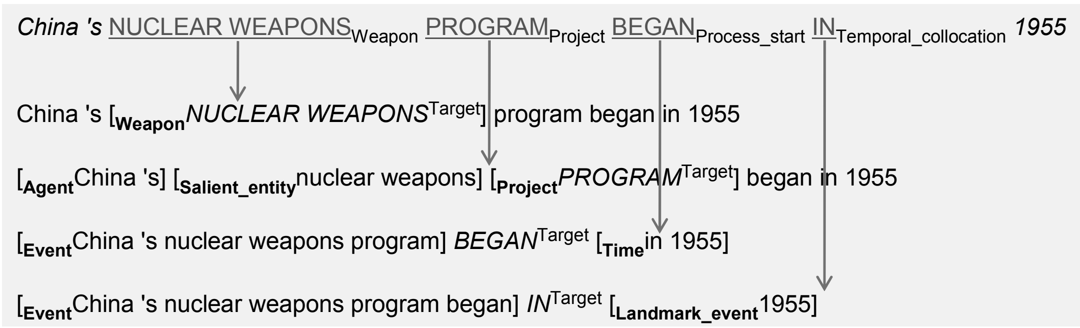

Figure 2. FrameNet full-text annotation of the example sentence.

Our initial intension was simply to better visualise the FrameNet full-text annotations along with their parse trees—the traditional visualisations shown in Figure 1 and Figure 2 seemed to be too fragmented to provide a deeper insight into the machinery of FrameNet. Our aim was to represent an annotated example in a multidimensional, geometrical manner in such a way that:

1. visualisation preserves all the information present in FrameNet annotations;
2. all the labelling occurs on coordinates of the multidimensional space, while the structure of a specific sentence is denoted only by non-labelled nodes and directed edges in this multidimensional space.

At the first glance it might appear to be a rather difficult challenge to construct such a geometric representation. It might also not be so obvious, why it would even make any sense. Nevertheless, such construction is possible and Figure 3 shows the same FrameNet full-text annotation example from Figure 1 and Figure 2, now represented as anonymous nodes and directed edges in 4-dimensional (4D) space.

[5] *http://nlp.stanford.edu:8080/parser*.

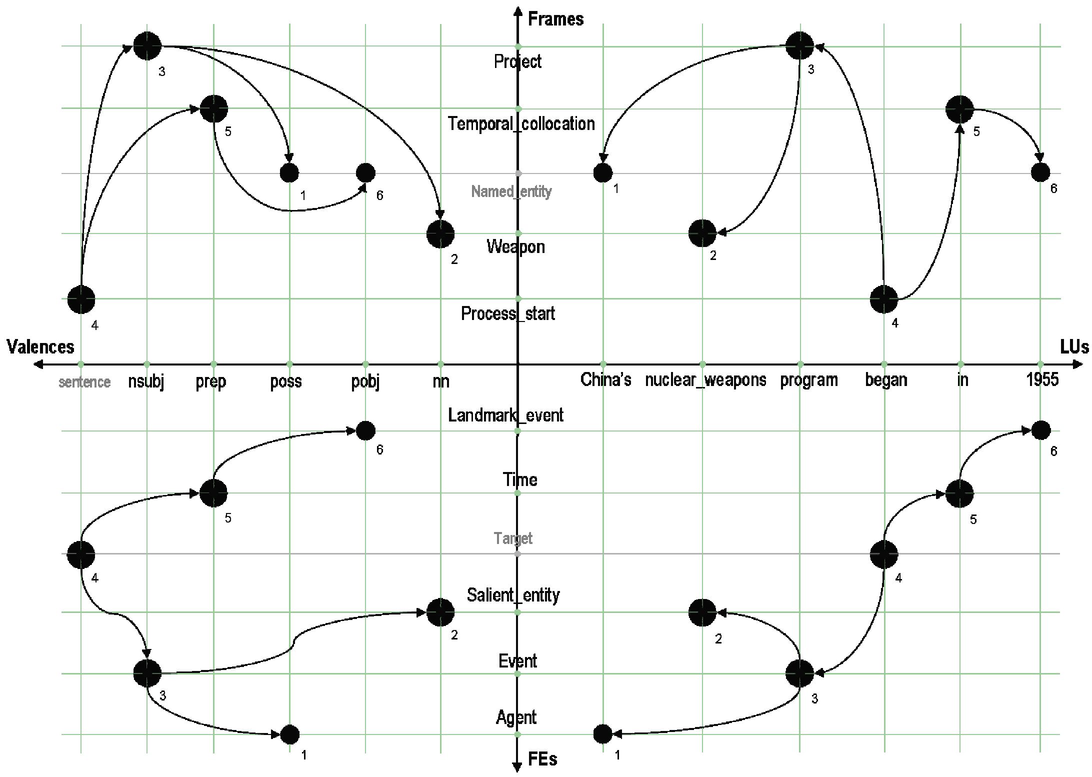

Figure 3. Four panes visualise various 2D aspects of the same 4D graph.

The 4D graph in Figure 3 contains complete annotation information from Figure 1 and Figure 2 visualised in four 2D panes—all individuals and their relations (directed edges) appear in all four panes, though they are shown from different aspects. To help grasping the concept of this multidimensional representation, a 3D view of the same 4D graph is shown in Figure 4 with one dimension missing, of course. The missing dimension is the syntactic realisations (valences) of FEs. Figure 4 effectively visualizes only data from Figure 2, but not from Figure 1, although the syntactic dependency graph coincides with that of Figure 1.

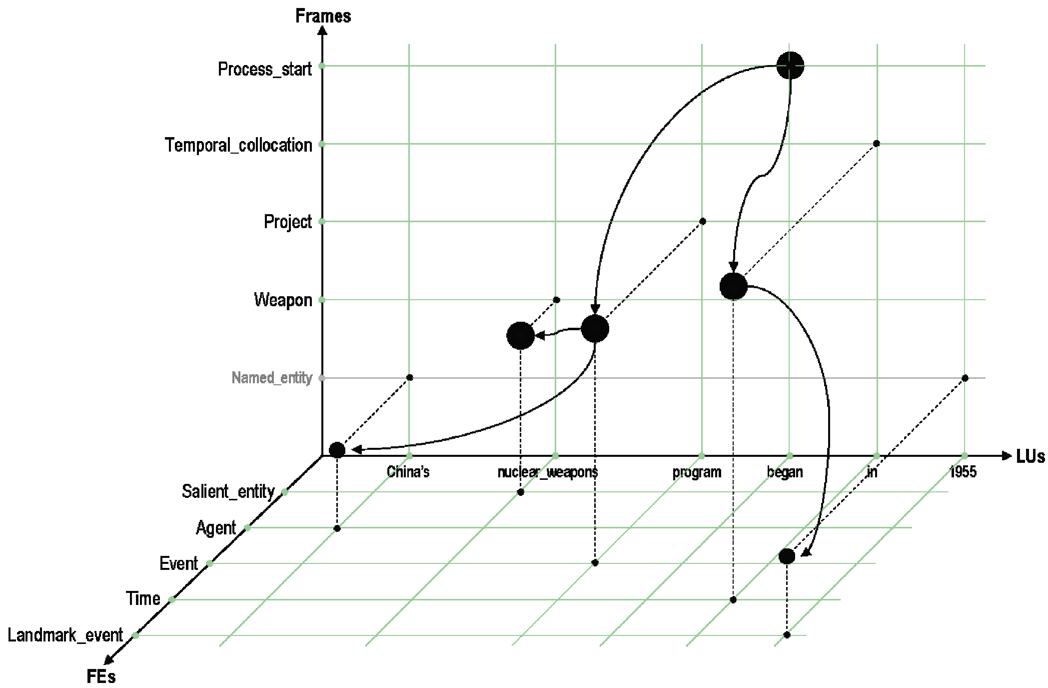

Figure 4. 3D visualisation of the full-text annotation shown in Figure 2.

In Figure 4 the non-highlighted nodes (points) depict non-target lexemes (named entities) used only as FE fillers. Lexemes serving both as FE fillers and as target lexemes invoking frames themselves are depicted by the highlighted nodes. The directed edges depict the dependency relations between the nodes. It might take some time and good 3D imagination, but eventually one should see that the information encoded in Figure 2 and in Figure 4 is, in fact, equivalent. The only discrepancy is the missing inverse dependency links in the graph—this is seldom used and in our view redundant phenomenon in FrameNet, where a FE is syntactically super-ordinate to the target lexeme (e.g., the FE "Event" of the target frame "Temporal_collocation" that is invoked by the LU "in" in Figure 2).

Assuming that by now reader has grasped the idea of the multidimensional representation of FrameNet annotations, we can finally explain also the concept of the multidimensional ontology itself. Imagine that on the four axis in Figure 3 we would have placed names of all FrameNet frames, FEs, LUs (and a lexicon of named entities appearing only as FE fillers), as well as all the valence patterns (provided by FrameNet). Next, imagine that in this 4D space we have inserted nodes and directed edges not just for one annotated sentence shown in Figure 3, but for a large corpus of FrameNet human annotated corpus. The resulting filling of this 4D space would be rather messy, but still forming a structure—nodes and edges would appear only in the sub-spaces that correspond to the corpus patterns validated by a human annotator. This 4D space is an example of a multidimensional ontology—the FrameNet ontology, where classes correspond to the points that are filled with nodes of the graphs of annotated sentences.

The described construction of the FrameNet 4D ontology from a large corpus of FrameNet annotated texts shows the appropriateness of the proposed multidimensional representation—it reflects the process through which the FrameNet itself was created by annotating a text corpus and converting the systematic relations into definitions of frames and LUs.

Of course, we can also take the readily available definitions of FrameNet frames and LUs, and create a 4D ontology directly from them. In either case such a multidimensional ontology can further be used for automatic semantic role labelling of syntactically parsed texts based on the permissible LU–frame–FE–valence mappings in FrameNet—we can construct all the possible hypothetical frame annotations for a new sentence. The only missing functionality is that the same syntactically parsed sentence might produce more than one valid semantic annotation—this is the area where world-knowledge about semantic types of FE fillers and anaphoric discourse-knowledge from surrounding sentences is currently still needed and, in general, is unavoidable. In the following section we will address this problem by adding the 5th dimension for coreferences (anaphors).

4. The 5th dimension of coreferences

Since we already have a 4D annotation, it should not be too scary to add also a 5th dimension. The role of the 5th dimension will be to enumerate all sentences (and their independent clausal parts) as they appear in the annotated text. In this way a 4D example in Figure 3 would become just a 4D view of a larger 5D graph containing 4D annotations of consecutive sentences of the annotated text.

Multiple sentences in a coherent text are typically interlinked by coreferences (anaphors) that form a discourse of actors involved in a number of situations over the time. Discourse is the essential instrument for disambiguation of alternative readings, as information contained in an isolated sentence might not be sufficient for full disambiguation[6].

An important aspect of anaphors is that they link objects and events with the same identity. Nevertheless, over time the object or event with the same identity can change significantly—compare, for example, the same person at the age of one month and at the age of 80 years. This phenomenon has been already observed by Heraclitus when he stated that "you could not step twice into the same river". To account for this phenomenon, on the 5th dimension we have to introduce a new set of involved individuals for each annotated sentence. Necessity for a new type of relations arises—"trajectory" relations, which anaphorically link individuals sharing the same identity. However, there is only one "no-name" type of relations allowed in the multidimensional ontologies. The "trajectory" relations between

[6] At least for now we would like to avoid any stochastic judgements.

sentences (or clauses) can be distinguished[7] from dependency relations within a sentence by the fact that only "trajectory" relations cross the border between the sentences in the 5th dimension.

The anaphoric coreferences annotated in the 5th dimension along with expressions like "this object is of that type" effectively can encode rich ontological world-knowledge conveyed by discourses presented in the annotated text corpus. In this paper we will not detail this aspect any more, apart from suggesting that the mentioned 5th dimension eventually could provide a possible substitute for the frame inheritance and for the semantic types of frame elements, which is notably the least formal part of the FrameNet.

5. Conclusions

The proposed formalization of FrameNet via a multidimensional ontology is different and thus complementary to the ontological semantics as proposed by Scheffczyk et al. (2006).

The proposed approach is rather universal and besides FrameNet it seems to cover well also the corpus pattern analysis approach (Hanks and Pustejovsky 2005), where valences are assigned directly to the individual word senses (instead of abstract frames) and their fillers are restricted through the Brandeis semantic ontology (Pustejovsky et al. 2006), which serves for the same purpose as FrameNet's semantic types.

Another possible extension enabled by the proposed multidimensional annotation approach is the possibility to complement text annotations with the three dimensions of space, one dimension of time, and one dimension of "observer's context". With this kind of annotation it would become possible to automatically create text-to-scene animations of the annotated text. This kind of enriched semantic annotations is in line with the rich annotations suggested in OntoNotes project (Pradhan et al. 2007) and CarSim project (Johansson et al. 2005).

Acknowledgements

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[7] Alternatively, it would not be a problem to introduce two explicitly different types of links for "dependencies" and "trajectories" and to extend the definition of the multidimensional ontology accordingly.

[8] SemTi-Kamols project at the Institute of Mathematics and Computer Science, University of Latvia. *http://www.semti-kamols.lv*.

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