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A new approach of attribute partial order structure diagram for word sense disambiguation of English prepositions

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ABSTRACT

To improve the accuracy of word sense disambiguation (WSD) has been a significant issue, and to visualize the structure of a dataset to discover knowledge has been an urgent demand in natural language processing. In order to fulfill these two tasks simultaneously, a new approach of attribute partial order structure diagram is proposed. The principle of attribute partial order and the approach of attribute partial order structure diagram are described. The proposed approach is testified by the WSD of the English preposition *over*, using the dataset from SemEval corpus. Two well-accepted sense inventories for fine-grained WSD of the English prepositions are adopted. The formal contexts for the fine-grained WSD of the English preposition *over* are established and the corresponding attribute partial order structure diagrams are generated and used as the models of WSD. The tested results show that the accuracies of WSD of *over* by the proposed approach are significantly higher than the ones by the state of the art system. Moreover, the proposed approach can visualize the attribute partial order structure of the dataset, which can be used for knowledge discovery.

1. Introduction

Prepositions are important devices for indicating semantic roles and relations. A preposition is a word governing a noun or pronoun and expressing a relation to another word or element. Prepositions are taken as the functional words that occur with high frequency. There are a reasonably large number of distinct prepositions and they are highly polysemous. One preposition may indicate different kinds of relations, and several prepositions may indicate the same semantic relation. Therefore, the word sense disambiguation (WSD) of prepositions is very important in natural language processing and understanding.

The computational analysis of preposition has attracted significant attention. Litkowski and Hargraves [1] developed the data for The Preposition Project (TPP) and established the SemEval-2007 corpus for WSD of English prepositions. They [2] also evaluated the SemEval-2007 preposition disambiguation task by the maximum entropy system, statistical language model and chain clarifying relationships, respectively. Tratz and Hovy [3] proposed a fast, accurate, non-projective and semantically-enriched parser, in which the preposition sense disambiguation system is believed to be the best performing system for preposition sense disambiguation. Litkowski [4] summarized the recent progress in preposition disambiguation using the SemEval-2007 datasets and used the Tratz and Hovy's [3] state of the art system to validate the effectiveness of the SemEval-2007 corpus. Tratz [5] refined the sense inventory of the SemEval corpus of English preposition. Tratz and Hovy [6] presented a supervised classification approach for disambiguation of preposition senses using linguistically motivated features. Hovy et al. [7] examined preposition disambiguation with consideration of the parameters, such as context, features and granularity by a maximum entropy classifier and they improved the result of preposition disambiguation.They [8] also presented a preliminary study on an unsupervised preposition sense disambiguation with an accuracy of 56%. Villanueva et al. [9] disambiguated prepositions in Spanish texts using the containing phrase as a context. They proposed a two steps algorithm for using frames to disambiguate Spanish prepositions. Zapirain et al. [10] examined the selectional preference for semantic role classification, demonstrating that the task is better modeled using both verbs and prepositions. Srikumar and Roth [11] studied the predicting semantic relations expressed by prepositions in terms of the arguments and the semantic types of the arguments. Smith et al. [12] presented five algorithms for the detection of the spatial relationships of the English spatial

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Nomenclatures

WSD	word sense disambiguation
TPP	the preposition project
K	a formal context
U	a set of objects
M	a set of attributes
I	a set of relation between objects and attributes
u	an object
m	an attribute
A	extent of a concept
B	intent of a concept
Ac_j	pair set corresponding to M_j
C_{ji}	new pairs after the union of sets M_j and m_i
C_{jp}	the pth pair under the constraint of M_j
U_{jp}	object set constituting pair C_{jp}
M_{jp}	attribute set constituting pair C_{jp}
C_{j+k}	the kth pair after C_j
C_{j-m}	the mth pair before C_j
C_0	the pair corresponding to the maximum common attribute
C_{mp}	the pth pair corresponding to the common attribute
C_{sp}	the pth pair corresponding to the exclusive attribute
C_{sk}	the pth pair corresponding to the exclusive attribute in the next layer
$g(s_{1i})$	the object set corresponding to the ith exclusive attribute in the first layer
w_1,w_2	w_1 is the target word for WSD; w_2 is the word related to w_1
$P(w_1, w_2)$	probability of co-occurrence of w_1 and w_2
$P(w_1)$	probability of w_1
MI_i	the ith mutual information
$j(s)$	the jth object with sense of s; it is corresponding to u in Definition 1
a_h	the hth attribute, a is corresponding to m in Definition 1
APOSD	attribute partial order structure diagram
S	similarity of the attribute patterns of two objects
X_i	attribute pattern
S_i	the ith similarity

prepositions. Boonthum et al. [13] described the general senses of prepositions and sense-case definitions. Schilder [14] proposed a compositional semantics for temporal prepositions based on the formal accounts of the temporal prepositional phrases. Ma et al. [15] proposed a system to identify the English prepositional phrases within business domain for machine translation. Alfawareh and Jusoh [16] solved the ambiguity in the preposition phrases by combining the possibility theory, fuzzy set theory and context knowledge. Elghafari et al. [17] explored the data-driven prediction of the preposition in English for the classification. Alam [18] proposed an algorithm for assigning the syntactic categories of the English preposition *over*. Yu et al. [19] proposed a new approach of rule extraction for the WSD by features of attributes. Xu et al. [20] studied the contribution of governors to the WSD of the English prepositions. Cai et al. [21] studied the identification of the Chinese preposition phrase. Bai and You [22] studied semantic role labeling of the Chinese prepositional phrases. López-Cózar proposed a technique to improve the performance of spoken dialogue systems [23]. Agerri et al. presented a streaming approach for big data for natural language processing [24].

These studies are suggestive of the importance of the prepositions and they have different focuses and merits. However, most existing approaches are single functioned, used either for classification or for knowledge discovery, and most of them are relatively low in accuracy of classification, and they cannot visualize the data structure in a dataset, therefore, their applications are limited. With the deepening of the studies in WSD, researchers are more and more interested in discovering some knowledge from the WSD models after they achieved a satisfied accuracies of WSD, such as the structure of the data, the relations between the variables, the hierarchical layers on which different variables locate and how the variables interact with each other to form a sense of a word, and so on. Therefore, it has been a challenging issue to develop a general approach which can both effectively disambiguate the word sense and visualize the data structure in a dataset in order that it can be used for different applications, such as WSD, knowledge discover, data mining and pattern recognition. For this reason, a new approach of attribute partial order structure diagram is proposed in this article. The approach is based on the principle of attribute partial order, which enables us to both effectively classify the data in a dataset and visualize the data structure. Therefore, the proposed approach can satisfy the demand of effective WSD and knowledge discovery from the WSD model.

In this paper, Section 1 introduces the research background and the motivation of the study. Section 2 describes the approach of attribute partial order structure diagram, including the theoretical foundation of the approach, calculation of some attributes and the procedures of generation of the attribute partial order structure diagram. Section 3 explains the process of WSD of the English preposition *over* by the attribute partial order structure diagram approach. Both the TPP original sense inventory and the Tratz' refined sense inventory are used for the WSD by the new approach, and the accuracies are compared with the ones by the state of the art system. Finally, Section 4 draws the conclusion of the study.

2. Attribute partial order structure diagram approach

2.1. Principle of attribute partial order

The approach of attribute partial order structure diagram is based on the principle of partial order in the theory of formal concept analysis [25,26].

The principle of partial order follows the basic principle of human being's cognition of classification of natural things. A concept is composed of attributes and objects. Attributes express the features of different objects, and the relations between the attributes show the relations between the concepts. Common attributes are the attributes commonly owned by different objects. They express the similarity of the objects, and they have more extent but less intent. While exclusive attributes express the individuality of the objects which distinct one object from the others, and they have more intent but less extent. In the cognition, we tend to put the objects with common attributes close together and to put the objects with exclusive attributes away from each other in order to classify different things (objects). The hierarchical relation of the features of attributes and objects is shown in Fig. 1. The objects with common attributes gather around the origin of the coordinate, and the objects with exclusive attributes depart from the origin. In this way, the classification is realized. The following theoretical descriptions of a formal context [26] and the attributes [27] are used in this study.

Definition 1. A formal context $K = (U, M, I)$ consists of two sets U and M and a relation I between U and M. The elements of U are called objects and the elements of M are called attributes of