Transformation-based Learning for Semantic parsing

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Abstract

In this paper, we present a semantic parser that transforms initial naive semantic hypothesis into correct semantics by using an ordered list of rules. These rules are learned automatically from the training corpus with no prior linguistic knowledge. We show that TBL parser is competitive to the state-of-the-art semantic parsers on the ATIS and TownInfo tasks.

Index Terms: spoken language understanding, semantics, natural language processing

1. Introduction

Semantic parsing is important part of a spoken dialogue system [1]. The goal of a semantic parsing is to map natural language to formal meaning representation - semantics. Such semantics can be either defined by a grammar, e.g. LR grammar for GeoQuery domain [2] or by frames and slots e.g. TownInfo domain [3]. In Table 1, it is shown an example of the frame and slot semantics from ATIS dataset. Each frame has a goal and set of slots. Each slot is composed of a slot name, e.g. "from.city", a slot equal sign, e.g. "=" or "!=", and slot value, e.g. "Washington". As dialogue managers commonly use semantics in the form frames and slots, our approach learns how to directly map from natural language into frame and slot semantics.

A dialogue system needs a semantic parser which is accurate and robust, easy to build, and fast. First, a parser presented in this paper performs comparable to the state-of-the-art semantics parser and it can deal with ill formed utterances. Second, it does not need any handcrafted linguistic knowledge and it can learn from data which is not semantically annotated at the word-level. Finally, it learns a compact set of rules which results in limited number of operation per semantic concept.

In our approach, we adapt transformation-based learning (TBL) [4] to the problem of semantic parsing. We attempt to find an ordered list of transformation rules to improve a naive semantic annotation.

In the next section, we describe previous work on mapping natural language into formal meaning representation. Section 3 presents an example of TBL based semantic parsing, discusses templates for transformation rules, and describes the learning process. Section 4 compares TBL parser to the previously developed semantic parsers on ATIS [5] and TownInfo [6] datasets.

2. Related work

In Section 4, we compare performance of our method with the four existing systems that were evaluated on the same dataset we consider. First, Hidden Vector State model [7, 8] have been used to model an approximation of a pushdown automaton which has semantic concepts as non-terminal symbols. Consequently, a deterministic algorithm was used to recover slot values. Second, automatic induction of combinatory categorical grammar [9] have been used to map sentences to lambda-calculus. They show that their technique produces the state-of-the-art performance on the Air Travel Information (ATIS) dataset [5]. However, apart from using the lexical categories (city names, airport names, etc) readily available from the ATIS corpus, they also need considerable number of handcrafted entries in their initial lexicon. Third, Markov logic networks [10] have been used to extract slot values by applying ideas of a Markov network to first-order logic. In this approach, weights are attached to first-order clauses which represent relationship between slot names and their values. Such weighted clauses are used as templates for features of Markov networks. Finally, support vector machines [6] have been used to build a semantic trees by recursive calling classifiers to estimate probabilities of production rules using a linear kernel and word based features.

what are the lowest airfare from Washington DC to Salt Lake City		
GOAL	=	airfare
airfare.type	=	lowest
from.city	=	Washington
from.state	=	DC
to.city	=	Salt Lake City

Table 1: Example of frame and slot semantics from ATIS [5] dataset.

There has been also done a large amount of research into mapping natural language to semantics that is not directly comparable because it uses either different corpora or different meaning representation. Transformation techniques [2] have been used to sequentially rewrite an utterance into semantics. However, our approach differs in the way how the semantics is constructed. Instead of rewriting an utterance, we transform initial naive semantic hypothesis. As a result, we can use input words several times to trigger transformations of the semantics. This extends our ability to handle non-compositionality phenomena in spoken language. Support vector machines and tree kernels [11] have been used to integrate knowledge contained in the gold standard dependency trees to capture long-range relationship between words.

3. Transformation-based parsing

This section describes the transformation-based parser. First, we give an example of the parsing algorithm. Second, we detail locality constrains for transformation rules. Third, we describe templates used to generate rules for the inference process. Finally, we detail the learning process.

3.1. Example of Parsing

The semantic parser transforms initial naive semantic hypothesis into correct semantics by applying transformations from a sequence of rules. Each rule is composed of a trigger and a transformation and a trigger initiates a transformation of a hypothesis. We demonstrate the parsing on an example. Think of the utterance: *"find all the flights between Toronto and San Diego that arrive on Saturday"*

First, the goal "flight" is used as the initial goal because it is the most common goal in the ATIS dataset and no slots are added in the semantics. As a result, the initial semantics is as follows:

GOAL = flight

Secondly, the rules whose triggers match the sentence and the hypothesis are sequentially applied. Generally, rules add slots, delete slots, and substitute slots.

trigger	transformation
"between toronto and"	add slot "from.city=Toronto"
"and san diego"	add slot "to.city=San Diego"
"saturday"	add slot "departure.day=Saturday"

After applying the transformations, we obtain the following semantic hypothesis.

GOAL	=	flight
from.city	=	Toronto
to.city	=	San Diego
departure.day	=	Saturday

The trigger "and Sand Diego" is example of non-compositionality, in which the words in an utterance do not have a one-to-one correspondence with the slots in the semantics. The word "and" indicates that the city "San Diego" is slot value of the slot "to.city".

As the date and time values are associated with the "departure*" slots most of the time in the ATIS dataset, the parser learns to associate them with the "departure*" slots. The incorrect classification of the word "Saturday" is a result of such generalization. However, TBL method learns to correct its errors. Therefore, the parser also applies the error correcting rules at later stage of parsing. For example, the following rule corrects the slot name of the slot value "Saturday".

trigger	transformation
"arrive"	substitute slot from "departure.day=*" to "arrival.day=*"

In this case, we substitute the slot name with the correct name. The final semantic hypothesis is as follows.

GOAL	=	flight
from.city	=	Toronto
to.city	=	San Diego
arrival.day	=	Saturday

3.2. Locality constrains

So far we considered an utterance as a bag of words and no notion of locality was considered. For example, before we perform the substitution of the slot "departure.day" to "arrival.day", we should test whether word "arrive" is in the vicinity of the slot. The reason is that we do not want to trigger the substitution of the slot "from.city=Toronto" to "to.city=Toronto" because the parser can also learn the rule as follows.

trigger	transformation
"arrive"	substitute slot from "from.city=*" to "to.city=*"

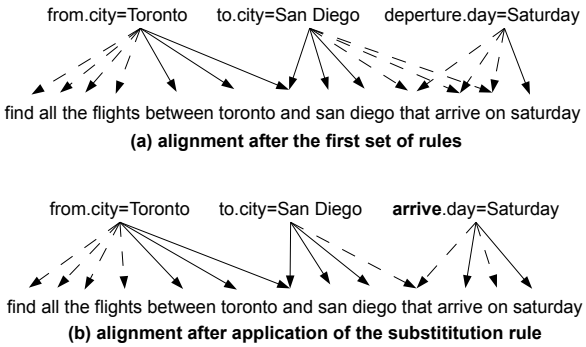

Figure 1: Alignment between words and the slots in the example utterance.

One way to deal with this problem is to constrain triggers performing substitution to be activated only if they are in the vicinity of the slot's lexical realization. We track the words from the utterance, which were used in triggers. Every time we apply a transformation of a slot, we store links between the words which triggered the transformation and the target slot. Such links are called as direct alignment.

In Figure 1 (a), we see the alignment between the words and the slots in the example utterance after applying the first set of rules. The full lines denote direct alignment created by the add-transformations. The dashed lines denote derived alignment - alignment computed from the direct alignment. Because no rules were triggered by words "find all the flights" and "that arrive on" those words could not be aligned directly to any of the slots, we have to derive such alignment. To compute derived alignment, first we order the slots so that the slot aligned with the left-most word is the first and the ordering results in minimum instances of direct alignment crossing. Then, every unaligned word is aligned with the nearest left and the right slot. In Figure 1 (a), the phrase "find all the flights" can be aligned to the slot "from.city=Toronto" only. The phrase "that arrive on" can be aligned to two slots "to.city=San Diego" and "departure.day=Saturday".

In Figure 1 (b), we see the alignment after applying the substitution. We can see change in the alignment of the phrase "that arrive on". First, the word "arrive" is aligned to the slot "arrival.day=Saturday". Second, the word "on" must be aligned to the same slot as the word "arrive", otherwise the derived alignment would cross the direct alignment. There is no change in the alignment of the word "that".

3.3. Rule templates

In the previous section, we presented several rules which add, substitute, or delete slots. These rules were selected by a learning algorithm from a large set of all potential rules. Such rules are generated from a set of templates for triggers and transformations.

A trigger questions an input utterance, an output semantics, or both. In our method, a trigger contains one or more conditions as follows: the utterance contains n-gram N, the utterance contains skipping[1] bigram B, the goal equals to G, the semantics

[1] In a skipping bigram, one or more words are skipped between two

contains slot S.

If a trigger contains more than one condition, then all conditions must be satisfied. A transformation performs one of the following operations: substitutes a goal to G, adds a slot S, deletes a slot S, substitutes a slot S. A substitution transformation can substitute a whole slot, a slot name, a slot equal sign, or a slot value.

3.4. Improving disambiguation of long-range dependencies

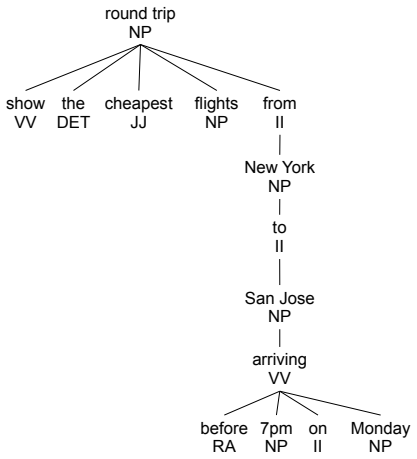

Figure 2: Dependency tree of the sentence "Show the cheapest flights from New York to San Jose arriving before 7pm on Monday" generated by the RASP parser [12].

Besides simple n-grams and skipping bigrams more complex lexical features can be used. Kate [11] used gold standard word dependencies to capture long-range relationship between words. At its simplest, dependency trees are one of the most concise way to describe language syntax. Essentially, each word is viewed as the dependent of one other word, with the exception of a single word which that is the root of the sentence. Kate showed that word dependencies significantly improve semantic parsing because long-range dependencies from an utterance tend to be local in a dependency tree. For example, the words "arriving" and "Monday" are neighbours in the dependency tree but they are four words apart in the sentence (see Figure 2).

Instead of using gold standard word dependencies [11], we used dependencies provided by RASP dependency parser [12]. First, some pre-processing had to be done so that the RASP parser was able accurately parse sentences with unknown named entities such as "New York". Secondly, we generated new n-gram features from dependency trees. We however note that the RASP was used off-the-shelf and more accurate dependencies could be obtained by adapting the RASP parser to the ATIS and TownInfo domains.

3.5. Learning

The main idea of transformation-based learning is to learn an ordered list of rules which incrementally improve initially assigned naive semantic hypothesis (see the algorithm in Figure 3) and the initial assignment is made based on simple statistics. The semantics with the most common goal is used as initial

words. For example, ('arrive',*,'Boston') is a skipping bigram which skips one word.

1. ASSIGN INITIAL SEMANTICS TO EACH UTTERANCE
2. REPEAT AS LONG AS THE NUMBER OF ERRORS ON THE TRAINING SET DECREASES
   - (A) GENERATE ALL RULES WHICH CORRECT AT LEAST ONE ERROR IN THE TRAINING SET
   - (B) MEASURE NUMBER OF CORRECTED ERRORS BY EACH RULE
   - (C) SELECT THE RULE WITH THE LARGEST NUMBER OF CORRECTED ERRORS
   - (D) APPLY THE SELECTED RULE TO THE CURRENT STATE OF THE TRAINING SET
   - (E) STOP IF THE NUMBER OF CORRECTED ERRORS IS SMALLER THAN THRESHOLD T.

Figure 3: Rule learning algorithm.

semantics. The learning is conducted in a greedy fashion and at each step TBL chooses the transformation rule that reduces the largest number of errors in our hypothesis. Number of errors includes number of goal substitutions, number of slot insertions, number of slot deletions, number of slot substitutions. The learning ends when no rule that improves the hypothesis beyond the pre-set threshold can be found.

As in the previous work [9, 6, 10], we make use of database with lexical realizations of some slots, for example city and airport names. Since the number of possible slot values for each slot is usually very high, the use of such database results in more robust parser. In our method we replace lexical realizations of slot values with category labels in the input utterance, e.g. "i want to fly from CITY". Similarly, we replace slot values in the semantics.

4. Evaluation

In this section, we evaluate our parser on two distinct corpora, and compare our results with the state-of-the-art techniques and handcrafted rule-based parser.

4.1. Datasets

In order to compare our results with previous work [6, 7, 9, 10], we apply our method to the Air Travel Information System dataset (ATIS) [5]. This dataset consists of user requests for flight information, for example "find flight from San Diego to Phoenix on Monday". We use 5012 utterances for training, and the DEC94 dataset as development data. As in previous work, we test our method on the 448 utterances of the NOV93 dataset, and the evaluation criteria is the F-measure of the number of reference slot/value pairs that appear in the output semantic (e.g., from.city = New York). He & Young detail the test data extraction process in [7].

Our second dataset consists of tourist information dialogues in a fictitious town (TownInfo). The dialogues were collected through user trials in which users searched for information about a specific venue by interacting with a dialogue system in a noisy background. These dialogues were previously used for training dialogue management strategies [1, 3]. For example, utterance "I would like a Chinese restaurant?" represented as

GOAL	=	inform
food	=	Chinese
type	=	restaurant

Parser	Prec	Rec	F
TownInfo dataset with transcribed utterances:			
TBL	96.05	94.66	95.35
STC	97.39	94.05	95.69
Phoenix	96.33	94.22	95.26
TownInfo dataset with ASR output:			
TBL	92.72	83.42	87.82
STC	94.03	83.73	88.58
Phoenix	90.28	79.49	84.54
ATIS dataset with transcribed utterances:			
TBL	96.37	95.12	95.74
PCCG	95.11	96.71	95.9
STC	96.73	92.37	94.50
HVS	-	-	90.3
MLN	-	-	92.99

Table 2: Slot/value precision (Prec), recall (Rec) and F-measure (F) for the ATIS and TownInfo datasets.

The TownInfo training, development, and test sets respectively contain 8396, 986 and 1023 transcribed utterances. The data includes the transcription of the top hypothesis of the ATK speech recogniser, which allows us to evaluate the robustness of our models to recognition errors (word error rate = 34.4%). We compare our model with STC parser [6] and the handcrafted Phoenix grammar [13] used in the trials [1, 3]. The Phoenix parser implements a partial matching algorithm that was designed for robust spoken language understanding.

For both corpora are available databases with lexical entries for slot values e.g. city names, airport names, etc.

4.2. Results

The results for both datasets are shown in Table 2. The model accuracy is measured in terms of F-measure of the slot/value pairs. Both slot and the value must be correct to count as correct classification. We report precision, recall, and F-measure (harmonic mean of precision and recall).

Results on the ATIS dataset show that our method with F-measure 95.74% is competitive with respect to Zettlemoyer & Collins' PCCG model [9] (F-measure=95.9%). Note that PCCG model makes use of considerable large number of handcrafted entries in their initial lexicon. In addition, our method outperforms STC, MLN and HVS parsers. Concerning the TownInfo dataset, Table 2 shows that TBL produces 87.87% F-measure, which represents a 3.28% improvement over achieved by the handcrafted Phoenix parser and it is competitive with respect to STC model on TownInfo dataset - TBL's performance is only 0.76% lower compared with the STC model.

Table 3 shows contrast between the full system and the system without features extracted from dependency trees and the system without using locality constrains. Experiments were carried out on the ATIS development dataset. The results show that if the dependency tree features are removed or the locality constraints are not used, the performance of our method degrades.

As is typical for TBL methods, the number of learned rules is considerably low. There are 17 dialogue acts and 66 slots in ATIS dataset and the total number of rules is 372. This results in 4.5 rules per semantic concept on average. In TownInfo dataset, we have 14 different dialogue acts and 14 slots and the total number of rules is 195. The average number of rules per semantic concept is 6.9.

Parser	Prec	Rec	F
ATIS development dataset:			
Full TBL	93.95	93.70	**93.82**
Without loc. constrains	XX.XX	XX.XX	XX.XX
Without dep. tree features	92.78	92.04	92.41

Table 3: The ablation studies on the ATIS development dataset.

5. Conclusion

This paper presents novel application of TBL for semantic parsing. Our method learns sequence of rules which transforms initial naive semantics into correct semantics. It significantly differs from the method presented by Kate et al [2] where they were rewriting utterance and replacing its words with semantic concepts.

Our method was applied to two very different domains and it was shown that it performs competitive on both datasets with respect to the state-of-the-art semantic parsers. On ATIS dataset, our method outperforms STC, MLN and HVS by 1.27%, 2.75%, and 5.44% respectively. We also show that our method outperforms the handcrafted Phoenix parser by 3.28% on ASR output on the TownInfo dataset.

6. References

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