Natural Language Model Re-usability for Scaling to Different Domains

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Abstract

Natural language understanding is the core of the human computer interactions. However, building new domains and tasks that need a separate set of models is a bottleneck for scaling to a large number of domains and experiences. In this paper, we propose a practical technique that addresses this issue in a web-scale language understanding system: Microsoft’s personal digital assistant Cortana. The proposed technique uses a constrained decoding method with a universal slot tagging model sharing the same schema as the collection of slot taggers built for each domain. The proposed approach allows reusing of slots across different domains and tasks while achieving virtually the same performance as those slot taggers trained per domain fashion.

1 Introduction

Recently there has been tremendous investment into the personal digital assistants by big technology companies (Sarikaya, 2015; Sarikaya et al., 2016). Apple’s SIRI, Google Now, Microsoft’s Cortana and Amazon’s Alexa are examples of such systems. Natural language understanding (Gupta et al., 2006; Tur and De Mori, 2011) is at the core of these systems providing natural communication between the user and the agent. These systems support a number of scenarios including creating reminders, setting up alarms, note taking, scheduling meetings, finding and consuming entertainment (i.e. movie, music, games), finding places of interest and getting driving directions to them. The domains supported by these systems are on the order of tens (not in hundreds) and adding new domains and experiences is a scaling problem that has not been solved yet (Tur, 2006; Jeong and Lee, 2009; El-Kahky et al., 2014; Kim et al., 2015d).

The primary reason behind this is that each domain requires potentially a new schema, intents and slots extracted from the natural language query. That, in turn requires collecting and annotating new data, which is the most expensive step in terms of time and money, and building a new set of domain specific models to support the new domains and scenarios. Slot modeling in particular is the most demanding component in terms of the difficulty of annotation and modeling.

In this study, we propose a new approach that reduces the cost of scaling natural language understanding to a large number of domains and experiences without significantly sacrificing the accuracy. The approach consists of a universal slot tagging method and a runtime technique called constrained decoding that performs the decoding according a specific schema. The proposed approach, heavily enables reusing existing slot modeling data that are collected and annotated for potentially different domains and applications, for building new domains and applications. The new domains can be expressed in terms of existing semantic schema.

The rest of the paper is organized as follows. In the next section, we talk about universal slot modeling. In section 3, we present the constrained decoding technique. We describe the experimental set up, results and analysis in section 4 followed by the conclusions and future directions in section 5.
2 Universal Slot Tagging

The first step is to build a universal slot tagger, a single model that can handle all the domains an agent (e.g. Cortana) can support. In Table 1, we show a subset of the domains that are supported by Cortana for experimentation purposes.

2.1 Universal Slot Tagger Training

To train the universal slot tagger, we consider two simple and intuitive approaches: Binary and All-in-one.

Suppose we have a combined $k$ slots across domains and also have access to the labeled data, Binary approach trains $k$ binary classifier one for each slot type. For each binary slot tagger targeting a specific slot type, the labeled data is programatically mapped to create a new labeled data set, where only the target label is kept while all the other labels are mapped “other” label. All-in-one approach simply trains a single model by aggregating queries across all domains.

2.2 Slot Tagging Ambiguity

Universal slot tagging model has an advantage, which can share schema across all domains used for training time. In spite of the advantage, there are ambiguity problems caused by combining all domains (and the underlying data) into a single model. The problems can be grouped into two categories:

- **Imbalanced training data distribution**: The amount of training data varies across domains. Universal slot model may have bias towards predicting the slots in domains with larger training data. For example, slots with less training data (e.g. app_name in MEDIACONTROL domain) could be overwhelmed by slots with large training data (e.g. place_name in PLACES domain).

- **Domain-specific schema**: In practice, the domains the system handles are not constructed at the same time. They are designed for different application back-ends, requirements and scenarios at different points in time. In other words, the semantic schema for a domain is designed without considering other domains. In ALARM domain, the slot indicating time is subdivided into sub-slots such as start_time representing starting time, duration representing duration for an alarm. In contrast, in PLACES domain, there is only a single slot indicating time (time).

3 Constrained Decoding

Slot tagging is considered as a sequence learning problem (Deoras and Sarikaya, 2013; Li et al., 2009; Xu and Sarikaya, 2014; Celikyilmaz et al., 2015; Kim et al., 2015b; Kim et al., 2015c; Kim et al., 2015a). In sequence learning, given a sample query $x_1 \ldots x_n$, the decoding problem is to find the most likely slot sequence among all the possible sequences, $y_1 \ldots y_n$:

$$f(x_1 \ldots x_n) = \arg \max_{y_1 \ldots y_n} p(x_1 \ldots x_n, y_1 \ldots y_n)$$

Here, we assume that output space in training is same as those in test time.

However, in our problem, output (slot) space in test time can be different from those in training time. At test time, we may observe different slot sequences than what is observed in the training time.

This is not an issue for the Binary approach, since we can use the output of the selected taggers needed for the new domain. We simply use general decoding approach with each of the selected taggers. Note
that a given query is run as many times as the numbers of slot types covered in a given domain.

For All-in-One technique, we consider two possible approaches: Post-Filter and Constrained Decoding. With Post-Filter, we simply provide the best hypothesis generated by the slot tagger that meets the domain schema constraints, by computing the full \( n \)-best of slots and filtering out the slot types that do not meet the target domain schema. With Constrained Decoding, given a schema \( \tilde{y} \subset y \) for the target domain, we first define a constrained lattice \( \mathcal{Y}(x, \tilde{y}) = \mathcal{Y}(x_1, \tilde{y}) \times \ldots \times \mathcal{Y}(x_n, \tilde{y}) \), as shown in Figure 1. Then, we perform the decoding in the constrained lattice:

\[
f(x_1 \ldots x_n, \tilde{y}) = \arg \max_{\mathcal{Y}(x, \tilde{y})} p(x_1 \ldots x_n, y_1 \ldots y_n)
\]

4 Experiments

In this section, we conducted a series of experiments to evaluate the proposed techniques on datasets obtained from real usage.

4.1 Experimental Setup

To test the effectiveness of the proposed approach, we apply it to a suite of 16 Cortana domains for slot tagging tasks. The data statistics and short descriptions are shown in Table 1. As the table indicates, the domains have different granularity and diverse semantics. Note that we keep domain-specific slots such as alarm_state, but there are enough shared labels across domains. For example, ALARM domain, there are 6 shared slots among 8 slots. There are 62 slots appearing more than one domain. Especially, some basic slots such as time, date.place_name, person_name, location and product appear in most domains.

4.2 Slot Taggers

In all our experiments, we trained Conditional Random Fields (CRFs)(Lafferty et al., 2001) and used \( n \)-gram features up to \( n = 3 \), regular expression, lexicon features, and Brown Clusters (Brown et al., 1992). With these features, we compare the following methods for slot tagging:\(^1\):

- In-domain: Train a domain specific model using the domain specific data covering the slots supported in that domain.
- Binary: Train a binary classifier for each slot type, combine the slots needed for a given domain schema.
- Post: Train a single model with all domain data, take the one-best parse of the tagger and filter-out slots outside the domain schema.
- Const: Train a single model with all domain data and then perform constrained decoding using a domain specific schema.

4.3 Results

For the first scenario, we assume that test domain semantic schema is a subset of training domain schema. The results of this scenario are shown in Table 2. We consider In-domain as a plausible upper bound on the performance, yielding 94.16% of F1 on average. First, Binary has the lowest performance of 75.85%. We believe that when we train a binary classifier for each slot type, the other slots that provide valuable contextual information for the slot sequence are ignored. This leads to degradation in tagging accuracy. Post improves F1 scores across domains, resulting into 86.50% F1 on average. Note that this technique does not handle ambiguities and data distribution mismatch due to combining multiple domain specific data with different data sizes. Finally, Const lead to consistent gains across all domains, achieving 93.36%, which almost matches the In-domain performance. The reason why Const performs better than Binary is that Const constrains the best path search to the target domain schema. It does not consider the schema elements that are outside the target domain schema. By doing so, it addresses the training data distribution issue as well as overlap on various schema elements.

For the second scenario, we consider a new set of test domains not covered in the training set, as shown in Table 3. The amount of training data for the test domains are limited (\(< 5K\)). These domains lack training data for the location and app_name slots. When we use universal slot tagger with constrained decoding Const yields 94.30%. On average, Const increases F1-score by 1.41 percentage points,
corresponding a 20% decrease in relative error. We believe that universal slot tagger learns to tag these slots from data available in PLACES and ENTERTAINMENT domains.

For the last scenario shown in Table 4, we assume that we do not have training data for the test domains. The Const performs reasonably well, yielding 94.48% on average. Interestingly, for the TRANSIT domain, we can get almost perfect tagging performance of 99.5%. Note that all tags in TRANSIT and TAXI domains are fully covered by our universal models, but the MEDIACONTROL domain is partially covered.

### 4.4 Discussion

By using the proposed technique, we maximize the reuse of existing data labeled for different domains and applications. The proposed technique allows mixing and matching of slots across different domains to create new domains. For example, we can tag the slots in the SHOWTIMES domain, which involves finding a movie to watch by using movie titles, actor names from the ENTERTAINMENT domain, and the location of the theater by using location, place name slots from the PLACES domain. If the new domain needs some new slots that are not covered by the universal tagger, then some examples queries could be annotated and added to the universal slot tagger training data to retrain the models. Instead of maintaining a separate slot tagger for each domain, one needs to maintain a single slot tagger. The new slots added can be used by future domains and applications.
5 Conclusions

We proposed a solution for scaling domains and experiences potentially to a large number of use cases by reusing existing data labeled for different domains and applications. The universal slot tagging coupled with constrained decoding achieves almost as good a performance as those slot taggers built in a domain specific fashion. This approach enables creation of virtual domains through any combination of slot types covered in the universal slot tagger schema, reducing the need to collect and annotate the same slot types multiple times for different domains. One of the future directions of research is to extend the same idea to the intent modeling, where we can re-use intent data built for different applications and domains for a new domain. Also, we plan to extend the constrained decoding idea to slot tagging with neural networks (Kim et al., 2016), which achieved gains over CRFs.

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