Language to Logical Form with Neural Attention

ZHONGEN LI
OHIO UNIVERSITY

OUTLINE

• Background
  Semantic Parsing
• Models
  Seq2seq
  Seq2tree
• Experiments
  Datasets
  Results
• Contributions
• References
SEMANTIC PARSING

Transform natural language to logical form

Human friendly -> computer friendly

What is the highest mountain in Alaska?

(\text{argmax} \; 0 \; (\text{and} \; (\text{mountain}:t \; 0) \; (\text{loc}:t \; 0 \; \text{alaska}:s) \; (\text{elevation}:i \; 0))

* Example from GeoQuery
SUPERVISED APPROACHES

Induce parsers from sentences paired with logical forms

Question
Who are the male actors in Titanic?

Logical From
\( \lambda x. \exists y. \text{gender(MALE,} x) \land \text{cast(TITANIC,} x, y) \)

- **Parsing** (Ge and Mooney, 2005; Lu et al., 2008; Zhao and Huang, 2015)
- **Inductive logic programming** (Zelle and Mooney, 1996; Tang and Mooney, 2000; Thompson and Mooney, 2003)
- **Machine translation** (Wong and Mooney, 2006; Wong and Mooney, 2007; Andreas et al., 2013)
- **CCG grammar induction** (Zettlemoyer and Collins, 2005; Zettlemoyer and Collins, 2007; Kwiatkowski et al., 2010; Kwiatkowski et al., 2011)
INDIRECT SUPERVISION

Induce parsers from questions paired with side information

**Question**
Who are the male actors in Titanic?

**Logical Form**
\[ \lambda x. \exists y. \text{gender(MALE,} x) \land \text{cast(TITANIC,} x, y) \]

**Answer**
\{DICAPRIO, BILLYZANE \ldots \}

- **Answers to questions** (Clarke et al., 2010; Liang et al., 2013)
- **System demonstrations** (Chen and Mooney, 2011; Goldwasser and Roth, 2011; Artzi and Zettlemoyer, 2013)
- **Distant supervision** (Cai and Yates, 2013; Reddy et al., 2014)
IN GENERAL

Developing semantic parsers requires linguistic expertise!

• high-quality lexicons based on underlying grammar formalism
• manually-built templates based on underlying grammar formalism
• grammar-based features pertaining to Logical Form and Natural Language
• Domain- and representation-specific!
ALL PURPOSE SEMANTIC PARSING

• Learn from NL descriptions paired with meaning representations
• Use minimal domain (and grammar) knowledge
• Model is general and can be used across meaning representations

Question
Who are the male actors in Titanic?

Logical From
\( \lambda x. \exists y. \text{gender(MALE,x)} \land \text{cast(TITANIC,x,y)} \)
PROBLEM FORMULATION

Model maps natural language input $q = x_1 \cdots x_{|q|}$ to a logical form representation of its meaning $a = y_1 \cdots y_{|a|}$

\[
p(a|q) = \prod_{t=1}^{|a|} p(y_t|y_{<t}, q)
\]

where $y_{<t} = y_1 \cdots y_{t-1}$

- **Encoder** encodes natural language input $q$ into a vector representation
- **Decoder** generates $y_1 \cdots y_{|a|}$ conditioned on the encoding vector.
ENCODER DECODER FRAMEWORK

what microsoft jobs do not require a bscs?

Language to Logical Form with Neural Attention

(Kalchbrenner and Blunsom, 2013; Cho et al., 2014; Sutskever et al., 2014; Karpathy and Fei-Fei, 2015; Vinyals et al., 2015;)

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SEQ2SEQ MODEL

\[ h^l_t = LMST(h^l_{t-1}, h^{l-1}_t) \]

**encoder**
\[ h^0_t = W_q e(x_t) \]

**decoder**
\[ h^0_t = W_a e(y_{t-1}) \]

\[ p(y_t|y_{<t}, q) = \text{softmax}(W_a h^l_t)^T e(y_t) \]
SEQ2TREE MODEL

• Drawback of Seq2Seq Model: Ignore the hierarchical structure of logical forms
A SEQ2TREE decoding example for the logical form “A B (C)”

Hidden vector of the parent nonterminal is concatenated with the inputs and fed to the LSTM.

\[ p(a|q) = p(y_1y_2y_3y_4|q)p(y_5y_6|y_{\leq3}, q) \]
ATTENTION MECHANISM

• Scores computed by current $h$ vector and all $h$ vectors of encoder

• The encoder-side context vector $c^t$ is obtained in the form of a weighted sum, which is further used to predict $y_t$

TRAINING AND INFEERENCE

Maximize the likelihood of the generated logical forms given natural language utterances as input.

\[ \text{minimize } - \sum_{(q,a) \in D} \log p(a|q) \]

where D is the set of all natural language-logical form training pairs

At test time, we predict the logical form for an input utterance \( q \) by:

\[ \hat{a} = \arg \max_{a'} p(a'|q) \]

- Iterating over all possible \( a' \)’s to obtain the optimal prediction is impractical
- Probability \( p(a|q) \) decomposed so that we can use greedy/beam search.
ARGUMENT IDENTIFICATION

• Many LFs contain named entities and numbers aka rare words.

• Does not make sense to replace them with special unknown word symbol.

• Identify entities and numbers in input questions and replace them with their type names and unique IDs.

  jobs with a salary of $40000$

  jobs with a salary of $num_i$

• Pre-processed examples are used as training data.

• After decoding, a post-processing step recovers all $type_i$ markers to corresponding logical constants.
SEMANTIC PARSING DATASETS

• JOBS: queries to job listings; 500 training, 140 test instances.
• GEO: queries US geography database; 680 training, 200 test instances.
• ATIS: queries to a flight booking system; 4,480 training, 480 dev, 450 test.
SEMANTIC PARSING DATASETS

- if-this-then-that recipes from the IFTTT website (Quirk et al., 2015)
- Recipes are simple programs with exactly one trigger and one action
- 77,495 training, 5,171 development, and 4,294 test examples
- IFTTT programs are represented as abstract syntax trees; NL descriptions provided by users.

<table>
<thead>
<tr>
<th>Length</th>
<th>IFTTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.95</td>
<td>turn on heater when temperature drops below 58 degree</td>
</tr>
<tr>
<td>21.80</td>
<td>TRIGGER: Weather - Current_temperature_drops_below - ((Temperature (58)) (Degrees_in (f))) ACTION: WeMo_Insight_Switch - Turn_on - ((Which_switch? (&quot;&quot;))</td>
</tr>
</tbody>
</table>
EVALUATION RESULTS ON JOBS

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EVALUATION RESULTS ON GEO

[Graph showing accuracy rates for different models.]

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EVALUATION RESULTS ON ATIS
EVALUATION RESULTS ON IFTTT

(Quirk et al., 2015): IFTTT baselines
ATTENTION SCORE

Darker color represents higher attention score

Example: what is the earliest flight from ci0 to ci1 tomorrow
CONTRIBUTIONS

- Encoder-Decoder with Neural Networks
  Seq2Seq/Seq2Tree models perform competitively on semantic parsing

- Tree decoder
  Utilizing hierarchical structure of logical form improves performance

- Attention mechanism
  Learn soft alignments between question and logical form
REFERENCES

• For more details see Dong and Lapata (ACL, 2016)


• https://github.com/donglixp/lang2logic

• https://www.youtube.com/watch?v=JANpOGFOR_E
Thanks!

Q&A