Semantic Parsing on Freebase from Question-Answer Pairs

EMNLP
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Semantic Parsing

Who did Humphrey Bogart marry in 1928?
Semantic Parsing

Who did Humphrey Bogart marry in 1928?

semantic parsing

Type.Person $\sqcap$ Marriage.(Spouse.HumphreyBogart $\sqcap$ StartDate.1928)
Who did Humphrey Bogart marry in 1928?

semantic parsing

Type.Person △ Marriage.(Spouse.HumphreyBogart △ StartDate.1928)

execute logical form

Mary Philips
Who did Humphrey Bogart marry in 1928?

semantic parsing

Type.Person ⊓ Marriage.(Spouse.HumphreyBogart ⊓ StartDate.1928)

execute logical form

Mary Philips

Motivation: Natural language interface to large structured knowledge-bases (Freebase, DBPedia, Yelp, ...)

Semantic Parsing
Statistical semantic parsing

Supervision: manually annotated logical forms

What's California's capital?  Capital.California
How long is the Mississippi river?  RiverLength.Mississippi
...
Statistical semantic parsing

Supervision: manually annotated logical forms

What’s California’s capital?  Capital.California
How long is the Mississippi river?  RiverLength.Mississippi

Limitations:

• Requires experts — slow, expensive, does not scale!
• Restricted to limited domains
Weakly supervised parsers

Supervision: question/answers pairs

*What’s California’s capital?*  
Sacramento

*How long is the Mississippi river?*  
3,734km

...
Weakly supervised parsers

**Supervision:** question/answers pairs

- What’s California’s capital? Sacramento
- How long is the Mississippi river? 3,734km
- ...

**Advantage:** obtain from non-experts!

[Clarke et al. 2010; Liang et al. 2011]
Weakly supervised parsers

**Supervision**: question/answers pairs

- *What’s California’s capital?* Sacramento
- *How long is the Mississippi river?* 3,734km

**Advantage**: obtain from non-experts!

<table>
<thead>
<tr>
<th>Dataset</th>
<th># word types</th>
</tr>
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<tbody>
<tr>
<td>GeoQuery</td>
<td>279</td>
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<tr>
<td>ATIS</td>
<td>936</td>
</tr>
<tr>
<td>KM-NP</td>
<td>158</td>
</tr>
</tbody>
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[Clarke et al. 2010; Liang et al. 2011]
Scaling to large knowledge-bases

Unsupervised systems with no training

• Unger et al., 2012; Yahya et al., 2012
Scaling to large knowledge-bases

Unsupervised systems with no training

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Distant supervision (on a small set of KB predicates)

• Krishnamurthy and Mitchell, 2012
Scaling to large knowledge-bases

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Parser trained from question/logical form pairs

- Cai and Yates, 2013
Scaling to large knowledge-bases

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Parser trained from question/logical form pairs

- Cai and Yates, 2013

**Our goal**: Training a parser from question/answer pairs on a large knowledge-base
Challenge: mapping text to the KB

What languages do people in Brazil use
Challenge: mapping text to the KB

What languages do people in Brazil use

- Exhaustive enumeration is intractable [Liang et al. 2011]
Challenge: mapping text to the KB

What languages do people in Brazil use

- Exhaustive enumeration is intractable [Liang et al. 2011]
- String matching is not precise [Yahya et al. 2012]
Challenge: mapping text to the KB

- Exhaustive enumeration is intractable [Liang et al. 2011]
- String matching is not precise [Yahya et al. 2012]
- String matching has coverage issues

What languages do people in Brazil use
Contributions

What languages do people in Brazil use
Contributions

Type.HumanLanguage
Type.ProgrammingLanguage
alignment
What languages do people in Brazil use

Alignment: lexicon from text phrases to KB predicates
Contributions

Alignment: lexicon from text phrases to KB predicates

Bridging: Use context to generate KB predicates
Semantic parsing

- Setup
- Alignment
- Bridging
- Composition
- Dataset creation
- Experiments
Setup

Input:

• Knowledge-base $\mathcal{K}$
• Training set of question-answer pairs $\{(x_i, y_i)\}_{i=1}^n$

What are the main cities in California? SF, LA, ...
Setup

Input:

- Knowledge-base $\mathcal{K}$
- Training set of question-answer pairs $\{(x_i, y_i)\}^n_1$

*What are the main cities in California?* SF, LA, ...

Output:

- Semantic parser that maps questions $x$ to answers $y$ through logical forms $z$

$countries\ \text{in}\ \text{Asia} \Rightarrow Type.\text{Country} \sqcap ContainedBy.\text{Asia}$

$\Rightarrow China, \ Japan, \ Israel, \ ...$
Freebase knowledge graph
Freebase knowledge graph

BarackObama

Person

Type
Freebase knowledge graph

Barack Obama

Person

Type

Politician

Profession
Freebase knowledge graph

Barack Obama
- Type: Person
- Date of Birth: 1961.08.04
- Place of Birth: Honolulu
- Profession: Politician
Freebase knowledge graph

BarackObama
Person
Type Politician
Profession
DateOfBirth 1961.08.04
PlaceOfBirth Honolulu
ContainedBy Hawaii

Person
Type
DateOfBirth
Profession
Politician
Freebase knowledge graph

Barack Obama
- Person
  - Type: Politician
  - Date of Birth: 1961.08.04
  - Profession: Politician

Honolulu
- City
  - Contained By: Hawaii
  - Type: City

Hawaii
- Contained By: City
Freebase knowledge graph

Barack Obama
- Person
  - Type: Politician
  - Profession
  - Date of Birth: 1961.08.04
  - Place of Birth: Honolulu, Hawaii, United States

United States
- Contains: United States

Hawaii
- Contains: Hawaii

Honolulu
- Type: City

Person

Politician

City
Freebase knowledge graph

- **BarackObama**
  - **Person**
  - **Type**: Politician
  - **Profession**: Politician
  - **DateOfBirth**: 1961.08.04
  - **PlaceOfBirth**: Honolulu
    - **Type**: City
    - **ContainedBy**: UnitedStates
  - **USState**: Hawaii
    - **Type**: State
    - **ContainedBy**: UnitedStates
  - **Event8**: Marriage
    - **Type**: Event
  - **Spouse**: MichelleObama
    - **Type**: Person
Freebase knowledge graph

- **Barack Obama**: Person, Type (Politician), Profession (Politician), DateOfBirth (1961.08.04), PlaceOfBirth (Hawaii, ContainedBy (UnitedStates, ContainedBy (UnitedStates, City (Honolulu))), Event8 (Marriage), Spouse (Michelle Obama, Type (Female), Gender (Female), StartDate (1992.10.03)).
Freebase knowledge graph

BarackObama
- Person
- Type: Politician
- Profession
- DateOfBirth: 1961.08.04
- PlaceOfBirth: Honolulu
  - Type: City
  - ContainedBy: UnitedStates
    - Type
    - Event8
      - Type: Marriage
      - StartDate: 1992.10.03
      - Spouse: MichelleObama
        - Type: Person
        - Gender: Female
        - StartDate: 1992.10.03
        - Spouse: BarackObama
          - Type: Person
          - PlaceOfBirth: Honolulu
          - DateOfBirth: 1961.08.04
          - Profession: Politician
          - PlacesLived: 9
Freebase knowledge graph

- **BarackObama**: Politician, Profession, DateOfBirth 1961.08.04, PlaceOfBirth Honolulu, USState Type UnitedStates, ContainedBy City Hawaii

- **MichelleObama**: Spouse, Gender Female, StartDate 1992.10.03, Event8 Marriage

- **Event3**: PlacesLived Chicago, Event8 Marriage

- **Event8**: Spouse MichelleObama, Gender Female, StartDate 1992.10.03

- **Hawaii**: ContainedBy USState UnitedStates

- **UnitedStates**: ContainedBy City Honolulu

- **Chicago**: Location

- **Person**: DateOfBirth 1961.08.04, Profession Politician
Freebase knowledge graph

MichelleObama
- PlacesLived
- Spouse

Event21
- Type
- Location

Event8
- Gender
- StartDate
- Marriage

UnitedStates
- Type
- ContainedBy
- ContainsBy

Hawaii
- Type
- ContainedBy

Chicago
- Type
- Location

Event3
- Type
- DateOfBirth
- Profession

BarackObama
- PlaceOfBirth
- Person

1961.08.04
- DateOfBirth

1992.10.03
- StartDate

Female
- Gender

MichelleObama
- Spouse

UnitedStates
- ContainsBy

Honolulu
- City
Freebase knowledge graph

41M entities (nodes)
19K properties (edge labels)
596M assertions (edges)
Logical forms are graph templates

\[ \text{Type.Person} \sqcap \text{PlacesLived.Location.Chicago} \]
Logical forms are graph templates

Type.Person ⊓ PlacesLived.Location.Chicago
Logical forms are graph templates

Type.Person ⊓ PlacesLived.Location.Chicago

```
  o
 / \
|   |
Type PlacesLived

Person ? Location

Chicago
```
Logical forms are graph templates

Type.Person ⊓ PlacesLived.Location.Chicago

Person

MichelleObama

Gender

Female

1992.10.03

StartDate

Event8

BarackObama

PlaceOfBirth

Hawaii

1961.08.04

DateOfBirth

Profession

Politician

City

Event3

Person

UnitedStates

ContainedBy

Hawaii

MichelleObama

Spouse

1992.10.03

StartDate

Event3

PlacesLived

Chicago

Location

UnitedStates

ContainedBy

UnitedStates

BarackObama

PlaceOfBirth

Honolulu

UnitedStates

ContainedBy

UnitedStates

BarsackObama

Profession

Politician

City

MichelleObama

Spouse

1992.10.03

StartDate

Event3

PlacesLived

Chicago

Location

UnitedStates

ContainedBy

UnitedStates

BarsackObama

Profession

Politician

City

BarsackObama

Profession

Politician

City

BarsackObama

Profession

Politician

City

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Politician

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City

BarsackObama

Profession

Politician

City
Logical forms are graph templates

Type.Person ⊓ PlacesLived.Location.Chicago

Person

O

Type

PlacesLived

??

Location

Chicago

MichelleObama

Gender
Female

1992.10.03

StartDate

Event8

Spouse

UnitedStates

PlaceOfBirth

Honolulu

USState

Type

Hawaii

ContainedBy

11

Event3

PlacesLived

BarackObama

Location

Chicago

ContainedBy

UnitedStates

Type

City

DateOfBirth

1961.08.04

Profession
Politician

Type

Event21

Locations

MichelleObama

Type

Female

NYC

Ingredient

Event8

Type

Marriage

StartDate

BarackObama

Location

NYC

Type

City

DateOfBirth

1961.08.04

Profession
Politician
Semantic parsing

- Setup
- **Alignment**
- Bridging
- Composition
- Dataset creation
- Experiments
Alignment

What languages do people in Brazil use?
Alignment: text phrases

ReVerb on ClueWeb09 [Thomas Lin]:

(Barack Obama, was born in, Honolulu)
(Albert Einstein, was born in, Ulm)
(Barack Obama, lived in, Chicago)
... 15M triples ...
Alignment: text phrases

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• Entities are linked to Freebase
Alignment: text phrases

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• Entities are linked to Freebase
• Hearst patterns used for unaries
Alignment: text phrases

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... 15M triples ...

- Entities are linked to Freebase
- Hearst patterns used for unaries

15,000 text phrases
Alignment: KB predicates

Freebase:

(BarackObama, PlaceOfBirth, Honolulu)
(Albert Einstein, PlaceOfBirth, Ulm)
(BarackObama, PlacesLived.Location, Chicago)

... 600M triples ...
Alignment: KB predicates

Freebase:

(BarackObama, \text{PlaceOfBirth}, Honolulu)
(Albert Einstein, \text{PlaceOfBirth}, Ulm)
(BarackObama, \text{PlacesLived.Location}, Chicago)

... 600M triples ...

Binaries: paths of length 1 or 2 in the KB graph
Alignment: KB predicates

Freebase:

(BarackObama, PlaceOfBirth, Honolulu)
(Albert Einstein, PlaceOfBirth, Ulm)
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... 600M triples ...

Binaries: paths of length 1 or 2 in the KB graph

Unaries: Type.x or Profession.x
Alignment: KB predicates

Freebase:

(BarackObama, PlaceOfBirth, Honolulu)
(Albert Einstein, PlaceOfBirth, Ulm)
(BarackObama, PlacesLived.Location, Chicago)

... 600M triples ...

Binaries: paths of length 1 or 2 in the KB graph

Unaries: Type.x or Profession.x

60,000 KB predicates
Alignment: match phrases and predicates

\[ \text{born in} \{\text{Person, Location}\} \rightarrow \text{PlacesLived.Location} \]

- (RandomPerson, Seattle)
- (MichelleObama, Chicago)
- (BarackObama, Honolulu)
- (BarackObama, Chicago)
Alignment: match phrases and predicates

\[
\begin{align*}
grew up in & \quad \text{[Person, Location]} \quad \text{DateOfBirth} \\
born in & \quad \text{[Person, Date]} \quad \text{PlaceOfBirth} \\
marrried in & \quad \text{[Person, Date]} \quad \text{Marriage.StartDate} \\
born in & \quad \text{[Person, Location]} \quad \text{PlacesLived.Location}
\end{align*}
\]

- (RandomPerson, Seattle)
- (BarackObama, Honolulu)
- (MichelleObama, Chicago)
Alignment: match phrases and predicates

Lexicon: Mapping from phrases to predicates with features
Alignment: match phrases and predicates

Lexicon: Mapping from phrases to predicates with features

Alignment features

- phrase-count: 15,765
- predicate-count: 9,182
- intersection-count: 6,048
- KB-best-match: 0
Semantic parsing

- Setup
- Alignment
- **Bridging**
- Composition
- Dataset creation
- Experiments
Bridging

Often predicates are not expressed explicitly:

- *What government does Chile have?*
- *What is Italy’s language?*
- *Where is Beijing?*
- *What is the cover price of X-men?*
- *Who did Humphrey Bogart marry in 1928?*
Bridging

Often predicates are not expressed explicitly:

- *What government does Chile have?*
- *What is Italy’s language?*
- *Where is Beijing?*
- *What is the cover price of X-men?*
- *Who did Humphrey Bogart marry in 1928?*

**Alignment:** build coarse mapping from raw text

**Bridging:** use neighboring predicates / type constraints
Bridging 1: two unaries

Type: University

BarackObama

Which college did Obama go to?

alignment

19
Bridging 1: two unaries

Type.University ⊓ Education.Institution.

BarackObama

Which college did Obama go to?
Which college did Obama go to?
Bridging 2: event modifiers

Marriage.Spouse.Madonna

join

Madonna

join

Marriage.Spouse

2000

Who did Madonna marry in 2000

alignment

join

Who did Madonna marry in 2000

alignment
Who did Madonna marry in 2000?

Marriage. (Spouse. Madonna □ StartDate. 2000)

features

- br-popularity: 7.11
- br-inject: 1
- br-startdate: 1
Semantic parsing

- Setup
- Alignment
- Bridging
- **Composition**
- Dataset creation
- Experiments
One derivation

\[
\text{Type.City} \sqcap \text{PeopleBornHere.BarackObama}
\]

what \hspace{1cm} \text{Type.CityTown} \hspace{1cm} \text{was} \hspace{1cm} \text{PeopleBornHere.BarackObama} \hspace{1cm} ?

\[
\text{city} \hspace{1cm} \text{BarackObama} \hspace{1cm} \text{PeopleBornHere}
\]

\[
\text{Obama} \hspace{1cm} \text{born}
\]
One derivation

Type.City ⊓ PeopleBornHere.BarackObama

what Type.CityTown was PeopleBornHere.BarackObama BarackObama peopleBornHere.

Alignment

city BarackObama PeopleBornHere

Alignment Alignment Alignment

Obama born
One derivation

Type.City $\cap$ PeopleBornHere.BarackObama

what Type.CityTown was PeopleBornHere.BarackObama

Alignment

join

city BarackObama PeopleBornHere

Alignment

Alignment

Obama born
One derivation

Type.City \(\cap\) PeopleBornHere.BarackObama

intersect

what Type.CityTown was PeopleBornHere.BarackObama

join

Alignment

city BarackObama PeopleBornHere

Alignment

Alignment

Obama born
One derivation

Derivations are constructed using an over-general grammar
Model

Candidate derivations: $\mathcal{D}(x)$
Model

Candidate derivations: $\mathcal{D}(x)$

Model: distribution over derivations $d$ given utterance $x$

$$p(d \mid x, \theta) = \frac{\exp(\phi(x,d) \cdot \theta)}{\sum_{d' \in \mathcal{D}(x)} \exp(\phi(x,d') \cdot \theta)}$$
Model

Candidate derivations: $D(x)$

Model: distribution over derivations $d$ given utterance $x$

$$p(d \mid x, \theta) = \frac{\exp(\phi(x,d) \cdot \theta)}{\sum_{d' \in D(x)} \exp(\phi(x,d') \cdot \theta)}$$

Features:

- Alignment and bridging
- Lexicalized
- Syntactic
- Denotation
Model

Candidate derivations: $D(x)$

Model: distribution over derivations $d$ given utterance $x$

$$p(d \mid x, \theta) = \frac{\exp(\phi(x,d) \cdot \theta)}{\sum_{d' \in D(x)} \exp(\phi(x,d') \cdot \theta)}$$

Features:
- Alignment and bridging
- lexicalized
- syntactic
- denotation

Training (estimating $\theta$):
- Stochastic gradient descent (AdaGrad)
Semantic parsing

- Setup
- Alignment
- Bridging
- Composition
- **Dataset creation**
- Experiments
WebQuestions: getting questions

Strategy: breadth-first search over Google Suggest graph
WebQuestions: getting questions

Strategy: breadth-first search over Google Suggest graph

Where was Barack Obama born?
WebQuestions: getting questions

Strategy: breadth-first search over Google Suggest graph

Where was Barack Obama born?

Where was _ born?

Google Suggest
Barack Obama
Lady Gaga
Steve Jobs
WebQuestions: getting questions

Strategy: breadth-first search over Google Suggest graph

Where was Barack Obama born?

Where was _ born?

Google Suggest

Barack Obama
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Where was Steve Jobs born?
WebQuestions: getting questions

Strategy: breadth-first search over Google Suggest graph

Where was Barack Obama born?

Where was _ born?

Google Suggest
Barack Obama
Lady Gaga
Steve Jobs

Where was Steve Jobs born?

Where was Steve Jobs _?

Google Suggest
born
raised
on the Forbes list
WebQuestions: getting questions

Strategy: breadth-first search over Google Suggest graph

Where was Barack Obama born?

Where was _ born?

Where was Steve Jobs born?

Where was Steve Jobs _?

Where was Steve Jobs raised?
WebQuestions: getting questions

Strategy: breadth-first search over Google Suggest graph

Where was Barack Obama born?

Where was _ born?

Where was Steve Jobs born?

Where was Steve Jobs _?

Where was Steve Jobs raised?

Result: popular web questions
WebQuestions: getting questions

Strategy: breadth-first search over Google Suggest graph

Where was Barack Obama born?

Where was Steve Jobs born?

Where was Steve Jobs raised?

Result: popular web questions

Answers were obtained through crowdsourcing (AMT)
Dataset comparison

Free917 [Cai & Yates, 2013]: 917 examples, 2,036 word types

What is the engine in a 2010 Ferrari California?
What was the cover price of the X-men Issue 1?

• Generate questions based on Freebase facts

WebQuestions [our work]: 5,810 examples, 4,525 word types

What character did Natalie Portman play in Star Wars?
What kind of money to take to Bahamas?
What did Edward Jenner do for a living?

• Generate questions from Google ⇒ less formulaic
Semantic parsing

• Setup
• Alignment
• Bridging
• Composition
• Dataset creation
• Experiments
Results on Free917

Differences:

- We train from answers only, CY13 uses logical forms
- We use 12K binary predicates, CY13 used 2k binary predicates
Results on Free917

Differences:

- We train from answers only, CY13 uses logical forms
- We use 12K binary predicates, CY13 used 2k binary predicates
- Kwiatkowski et al. obtain larger improvement
Impact of alignment and bridging

Conclusions:

- **Bridging** more important for Free917
- **Alignment** more important for WebQuestions
Impact of alignment and bridging

Conclusions:

- **Bridging** more important for Free917
- **Alignment** more important for WebQuestions

Test accuracy on webQuestions: 35.7
Summary

Learning from question-answer pairs
Summary

Learning from question-answer pairs

Scaling up via alignment/bridging [EMNLP 2013]
Summary

Learning from question-answer pairs

Scaling up via alignment/bridging [EMNLP 2013]

Paraphrases

Compositionality
All data and code:

http://www-nlp.stanford.edu/software/sempre/
All data and code:

http://www-nlp.stanford.edu/software/sempre/

Thank you!