Answering Natural Language Questions via Phrasal Semantic Parsing

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Movie

1. What else movies did the director of the movie Interstellar direct?
2. How many awards did Anne Hathaway win in 2013?
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2. How many awards did Anne Hathway win in 2013?
**Interstellar (film)**

*From Wikipedia, the free encyclopedia*

*Interstellar* is a 2014 science fiction film directed by Christopher Nolan. Starring Matthew McConaughey, Anne Hathaway, Jessica Chastain, Mackenzie Foy and Michael Caine, the film features a team of astronauts who travel through a wormhole in search of a new habitable planet. Brothers Christopher and Jonathan Nolan wrote the film, merging a script Jonathan developed in 2007 with Christopher's ideas. Christopher Nolan produced the film with his wife, Emma Thomas, and Lynda Obst. Theoretical physicist Kip Thorne, whose work inspired the film, acted as scientific consultant and executive producer.
**Interstellar (film)**

*Interstellar* is a 2014 science fiction film directed by Christopher Nolan. Starring Matthew McConaughey, Anne Hathaway, Jessica Chastain, Mackenzie Foy and Michael Caine, the film features a team of astronauts who travel through a wormhole in search of a new habitable planet. Brothers Christopher and Jonathan Nolan wrote the film, merging a script Jonathan developed in 2007 with Christopher's ideas. Christopher Nolan produced the film with his wife, Emma Thomas, and Lynda Obst. Theoretical physicist Kip Thorne, whose work inspired the film, acted as scientific consultant and executive producer.
What else movies did the director of the movie Interstellar direct?
What else movies did the director of the movie Interstellar direct?
How many awards did Anne Hathaway win in 2013?
Anne Hathaway is an American actress. After several stage roles, she appeared in the 2004 sequel. Since then, Hathaway has starred in dramatic films such as "Pride & Prejudice" and "Becoming Jane," both of which are based on the novels of Jane Austen. In 2008, she won several awards for her performance in "Rachel Getting Married," including an Emmy Award for her voice-over role in "Wonderland," and a Golden Globe Award for her role in "Love and Other Drugs." She also won an Emmy Award for her voice-over role in "The Dark Knight Rises." Hathaway received a BAFTA Award and the Academy Award for Best Supporting Actress for her role in "Les Misérables." She has also received award nominations in 2012 for the Satellite Award for Best Supporting Actress – Motion Picture and the Golden Globe Award for Best Supporting Actress – Motion Picture, and in 2013 for the Critics' Choice Movie Award for Best Supporting Actress, the Screen Actors Guild Award for Outstanding Performance by a Female Actor in a Supporting Role, the BAFTA Award for Best Actress in a Supporting Role, and the Costume Designers Guild Award for Lacoste Spotlight Award.
Goal

Answer Natural Language Questions against Structured Knowledge Base
Related Work

- Semantic Parsing Based Methods
  - PCCG based
    - (Cai and Yates 2013; Kwiatkowski et al. 2013)
  - PCFG based
    - (Berant et al. 2013)

- Paraphrase Based Method
  - (Berant and Liang 2014)

- Machine Translation Based Method
  - (Bao et al. 2014)

- Information Extraction Based Method
  - (Yao and Van Durme 2014)
Semantic Parsing Based Method

Challenges:
1. Convert the question into a meaning representation
2. Ground the meaning representation into a database query

Limits of Current Semantic Parsers:
1. Search space is huge
2. Difficult to adapt to other KBs
Motivation

Meaning representation is KB-independent

[what] else movies did [the director of] [the movie] [Interstellar] [direct]
Motivation

1. Meaning representation is KB-independent

2. Separation of meaning representation and instantiation
Framework

what else movies did the director of the movie Interstellar direct
what else movies did the director of the movie Interstellar direct
what else movies did the director of the movie Interstellar direct

Parsing
what else movies did the director of the movie Interstellar direct

Parsing

Instantiation
what else movies did the director of the movie Interstellar direct

Parsing

Instantiation

```
select ?y

[ fb:m.0fkf28 fb:object.type fb:film.film
  fb:m.0fkf28 fb:film.film.directed_by ?x
  ?x fb:film.director.fim ?y
  ?y fb:object.type fb:film.film ]
```
The Transition-based Semantic Parser
  - Phrase Dependency Graph
  - The Transition-based Semantic Parsing

Grounding the Dependency Graph to the Knowledge Base

Experiments

Conclusion
**Phrase Dependency Graph**

**Node**
A phrase with a semantic label $l \in \{\text{entity, category, variable, relation}\}$

**Edge**
A **predicate-argument** dependency between phrases
- unary predicate
- binary predicate

**Example:**

```
[what] [movies] did [the director of] [Interstellar] [direct]
```

- **Node:** [what] variable, else [movies] category, did [the director of] relation, [the movie] category, [Interstellar] entity, [direct] relation

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**Introduction Outline**
The Transition-based Semantic Parser
- Instantiation
- Experiments
- Conclusions
The Transition-based Semantic Parsing

Structure Prediction

Input: a natural language question

Output: a phrase dependency graph

A pipeline framework to predict the structure

1. Phrase Detection

[what] did [the director of] [the movie] [Interstellar] [direct]

variable category relation category entity relation

2. Phrase Dependency Parsing

[what] else [movies]

variable category

[the director of] [the movie] [Interstellar] [direct]

relation category entity relation
The Transition-based Semantic Parsing

**Phrase Detection**

Sequence labeling problem

Lexical Features
The Transition-based Semantic Parsing

Phrase Dependency Parsing

Transition-based parsing

- A queue of incoming phrases
- A stack of processed phrases
- Four actions
- Multiple heads
The Transition-based Semantic Parsing

Parsing Example

Queue

Stack

Current Dependency Graph

[what] else [movies] did [the director of] [the movie] [Interstellar] [direct]

variable category relation category entity relation
The Transition-based Semantic Parsing

Parsing Example

Queue

[what] else [movies] did [the director of] [the movie] [Interstellar] [direct]

Current Dependency Graph

Stack
The Transition-based Semantic Parsing

Parsing Example

Queue

else [movies] did [the director of] [the movie] [Interstellar] [direct]

category relation category entity relation

Current Dependency Graph

Stack

[what]

variable
The Transition-based Semantic Parsing

Parsing Example

Current Dependency Graph

Queue

else [movies] did [the director of] [the movie] [Interstellar] [direct]
category relation category entity relation

Shift

Stack

[what] variable

variable
Parsing Example

Queue

Current Dependency Graph

Stack
The Transition-based Semantic Parser

**Parsing Example**

Current Dependency Graph

Queue

- movies
- did
- the director of
- the movie
- Interstellar
- direct

Stack

else

[what]

variable

Reduce
The Transition-based Semantic Parsing

Parsing Example

Queue

[variable] did [category] [relation] [category] [entity] [relation]

Current Dependency Graph

Stack
The Transition-based Semantic Parsing

Parsing Example

Queue

[movies] did [the director of] [the movie] [Interstellar] [direct]

Stack

ArcLeft

Current Dependency Graph

[what]

variable

[category] [relation] [category] [entity] [relation]
The Transition-based Semantic Parsing

Parsing Example

Queue

- [movies] did [the director of] [the movie] [Interstellar] [direct]
  - category
  - relation
  - category
  - entity
  - relation

Current Dependency Graph

- [what] variable
- [movies] category

Stack

- [what] variable
The Transition-based Semantic Parsing

**Parsing Example**

Current Dependency Graph

```
[what] variable
```

Queue

```
[movies] did [the director of] [the movie] [Interstellar] [direct]
category relation category entity relation
```

Stack

```
[what] variable
```

Shift
The Transition-based Semantic Parsing

Parsing Example

Queue

```
<table>
<thead>
<tr>
<th>did</th>
<th>[the director of]</th>
<th>[the movie]</th>
<th>[Interstellar]</th>
<th>[direct]</th>
</tr>
</thead>
<tbody>
<tr>
<td>relation</td>
<td>category</td>
<td>entity</td>
<td>relation</td>
<td></td>
</tr>
</tbody>
</table>
```

Current Dependency Graph

```
[what]        [movies]
[variable]     category
```

Stack
The Transition-based Semantic Parsing

Parsening Example

Queue
- did [the director of] [the movie] [Interstellar] [direct]
  - relation category entity relation

Current Dependency Graph
- [what] [movies]
  - variable category

Stack
- [movies] category
- [what] variable

Reduce
The Transition-based Semantic Parsing

Parsing Example

Queue

[the director of] [the movie] [Interstellar] [direct]
relation category entity relation

Current Dependency Graph

Stack

[what] variable

[what] [movies]
variable category
The Transition-based Semantic Parsing

Parsing Example

Queue
[the director of] [the movie] [Interstellar] [direct]
relation category entity relation

Current Dependency Graph
[what] [movies]
variable category

Stack
[what] variable
The Transition-based Semantic Parsing

Parsing Example

Queue

[the movie]  Interstellar  [direct]
  category    entity     relation

Current Dependency Graph

[what]  [movies]
  variable    category

Stack

[the director of]
  relation

[what]
  variable
The Transition-based Semantic Parsing

Parsing Example

Queue
- [the movie] category
- Interstellar entity
- [direct] relation

Current Dependency Graph
- [what] variable
- [movies] category
- [the director of] relation

Stack
- [what] variable
- [the movie] category

Shift
The Transition-based Semantic Parsing

Parsing Example

Queue

[Interstellar] [direct]
entity relation

Current Dependency Graph

[the movie] [the director of]
category relation

[what] [movies]
variable category

Stack

[the movie]
category

[the director of]
relation

[what]
variable
The Transition-based Semantic Parsing

**Parsing Example**

Current Dependency Graph

- **Queue**
  - [Interstellar] [direct] 
    - entity
    - relation

- **Stack**
  - [the movie] [the director of]
    - category
    - relation
  - [what] [movies]
    - variable
    - category

ArcRight
The Transition-based Semantic Parsing

Parsing Example

Queue

[Interstellar] [direct]
entity relation

Current Dependency Graph

[the movie] category
[the director of] relation
[what] variable

Stack

[what] variable
[movies] category

[the movie] category [Interstellar] entity
### Parsing Example

**Current Dependency Graph**

- **Queue**
  - [Interstellar] (entity)
  - [direct] (relation)

- **Stack**
  - [the movie] (category)
  - [the director of] (relation)
  - [what] (variable)

**Reduce**

- [movies] (category)
- [the movie] (category)
- [Interstellar] (entity)
The Transition-based Semantic Parsing

Parsing Example

Current Dependency Graph

Queue

Interstellar
direct
entity
relation

ArcRight

[the director of]
relation
[what]
variable

Stack

[what]
variable
[movies]
category

[the movie]
category
[Interstellar]
entity
The Transition-based Semantic Parsing

**Parsing Example**

- **Queue**
  - [Interstellar] [direct]
    - entity
    - relation

- **Current Dependency Graph**
  - [what] variable
  - [movies] category
  - [the director of] relation
  - [the movie] category
  - [Interstellar] entity
The Transition-based Semantic Parsing

**Parsing Example**

**Queue**
- [Interstellar] [direct]
  - entity
  - relation

**Current Dependency Graph**
- [the director of]
  - relation
- [what]
  - variable
- [movies]
  - category
- [the director of]
  - relation
- [the movie]
  - category
- [Interstellar]
  - entity

**Shift**
- Stack
The Transition-based Semantic Parsing

Parsing Example

Current Dependency Graph

Stack

Queue

- [direct] relation

Interstellar
entity

[the director of] relation

Stack variable

[what] variable

movies category

[the director of] relation

[the movie] category

Interstellar entity
The Transition-based Semantic Parsing

Parsing Example

Current Dependency Graph

Stack

Queue

ArcLeft

relation

[direct]

[the director of]

[what]

variable

movies

category

the director of
relation

the movie
category

Interstellar
entity
The Transition-based Semantic Parsing

Parsing Example

Current Dependency Graph

Queue

ArcLeft

Stack

[what] variable

[what] variable

movies

the director of

the movie

Interstellar

direct

relation

relation

relation

category

category

entity

relation
The Transition-based Semantic Parsing

Parsing Example

Current Dependency Graph

Queue

[direct] relation

Stack

[what] variable

Shift

[what] variable else [movies] did [the director of] [the movie] [Interstellar] [direct] relation

Category

Entity
The Transition-based Semantic Parsing

Parsing Example

Queue

Current Dependency Graph

Stack

[direct] relation [what] variable

[what] variable else [movies] did [the director of] [the movie] [Interstellar] [direct] relation

[direct] relation [what] variable
The Transition-based Semantic Parsing

Decoding

- incremental processing

\[ z = \arg \max_{a \in A} w \cdot f(S, Q, a) \]

where \( A = \{\text{Shift}, \text{Reduce}, \text{ArcLeft}, \text{ArcRight}\} \)

- features
  - lexical features
  - semantic features
  - structural features
Instantiation

1. Converting Phrase Dependency Graph into Structured Queries
2. Instantiating Structured Query against KB
Applying Rules

[what] did [the director of] [the movie] [Interstellar] [direct] [else movies]

rule#1

?y type movies
Interstellar type movies
Interstellar the director of direct ?x

select ?y
Interstellar the director of direct ?x
Interstellar type movies

?y
$$Q_d^* = \arg \max P(Q_d | Q_{ind})$$
Probablity Model

\[ Q^*_d = \arg \max \ P(Q_d \mid Q_{ind}) \]

\[ \overline{P}(Q_d \mid Q_{ind}) = \prod_{i=1}^{n} \overline{P}(s_{di} \mid s_{ind_i}) \overline{P}(o_{di} \mid o_{ind_i}) \overline{P}(p_{di} \mid p_{ind_i}) \]
\[ \overline{P}(s_{di}|s_{ind_i}) \overline{P}(o_{di}|o_{ind_i}) \]

Freebase Search API

\[ \overline{P}(p_{d}|p_{ind}) \]

Co-occurrence Matrix contributed by Yao
### Experiment

#### Datasets

- **Free917**
  (917 questions with annotated phrase dependency graph, 30% of the data for the final test)

- **WebQuestions**
  (5,810 question-answer pairs, with the same test split with previous work)

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free917</td>
<td>How many legal offences has lindsey lohan committed?</td>
</tr>
<tr>
<td></td>
<td>At what institutions was marshall hall a professor?</td>
</tr>
<tr>
<td></td>
<td>How many games did donovan mcnabb play in the 2008 nfl season?</td>
</tr>
<tr>
<td></td>
<td>For what country did bernard lagat play in the 2000 summer olympics?</td>
</tr>
<tr>
<td></td>
<td>What percentage of the grapes in a 1966 chateau latour grand vin are merlot?</td>
</tr>
<tr>
<td>WebQuestions</td>
<td>What is the most common language in norway?</td>
</tr>
<tr>
<td></td>
<td>What currency do they use in switzerland?</td>
</tr>
<tr>
<td></td>
<td>When olympic games 2012 opening ceremony?</td>
</tr>
<tr>
<td></td>
<td>What type of government system does saudi arabia have?</td>
</tr>
<tr>
<td></td>
<td>What countries does queen elizabeth ii reign?</td>
</tr>
</tbody>
</table>
Results

System Accuracy

<table>
<thead>
<tr>
<th></th>
<th>Free917</th>
<th>WebQuestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CY13</td>
<td>59.0%</td>
<td>-</td>
</tr>
<tr>
<td>BCFL13</td>
<td>62.0%</td>
<td>35.7%</td>
</tr>
<tr>
<td>KCAZ13</td>
<td>68.0%</td>
<td>-</td>
</tr>
<tr>
<td>BCFL14</td>
<td>68.5%</td>
<td>39.9%</td>
</tr>
<tr>
<td>Our work</td>
<td><strong>69.0%</strong></td>
<td>39.1%</td>
</tr>
</tbody>
</table>

BCFL13 and BCFL14 train the parser on Free917 and WebQuestions, respectively. Our parser is only trained on Free917.
Results

- **Training Time**
  - Our parser takes 40 minutes to train
  - PCFG-based semantic parser takes 5 days to train

- **Decode Time**
  - Time complexity of our parser is $O(n)$
  - Time complexity of PCFG-based parser is $O(n^3)$
## Results

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free917</td>
<td>Who said that one small step for man one giant leap for mankind ?</td>
<td>Neil Armstrong</td>
</tr>
<tr>
<td></td>
<td>What sport did scott anderson play in the 1992 summer olympics ?</td>
<td>field hockey</td>
</tr>
<tr>
<td></td>
<td>when was the construction of new steubenville bridge began ?</td>
<td>1979</td>
</tr>
<tr>
<td>WebQuestions</td>
<td>When did liverpool fc last win the champions league ?</td>
<td>2006 FA Cup Final</td>
</tr>
<tr>
<td></td>
<td>Who does jeremy shockey play for in 2012 ?</td>
<td>Carolina Panthers</td>
</tr>
<tr>
<td></td>
<td>What college did deion sanders jr go to ?</td>
<td>Florida State University</td>
</tr>
<tr>
<td></td>
<td>What was queen elizabeth ii childhood nickname ?</td>
<td>Lillibet</td>
</tr>
</tbody>
</table>
Error Analysis

1. The detection errors
   “harry potter and the global of fire”

2. Fail to answer the questions that imply aggregation operations.
   “where do most of people live in russia”

3. Unable to handle temporal information
   “what kind of government did the united states have after the revolution”
Conclusions

- A novel pipeline framework
  - Separate KB-independent meaning representation and KB-related instantiation
  - Easily adapt to new KBs
- A transition-based parser
  - Efficient shift-reduce parser
Future Work

- A joint model
  - simultaneously detects phrases and dependency relations
- the function phrase
  - introduce the aggregation operation
Questions?