Natural Language Question Answering over Large-scale Linked Data

Kang Liu

National Laboratory of Pattern Recognition (NLPR)
Institute of Automation, Chinese Academy of Sciences

8/30/2014   Kun Ming
Knowledge Graph: Linked Data

超过5.7亿实体
超过18亿条事实（关系）

2,653,873概念

百度知心

搜狗知立方
How to access these Linked Data

Which software has been developed by organizations founded in California, USA?

```
SELECT DISTINCT ?uri
WHERE {
    ?uri rdf:type dbo:Software.
    ?x1 rdf:type dbo:Company.
    ?x1 dbo:foundationPlace dbr:California.
}
```

SPARQL
How to access these Linked Data

Which software has been developed by organizations founded in California, USA?

SELECT DISTINCT ?uri
WHERE {
  ?uri rdf:type dbo:Software.
  ?x1 rdf:type dbo:Company.
  ?x1 dbo:foundationPlace dbr:California.
}

Linked Data

QA System

SPARQL
Which software has been developed by organizations founded in California, USA?

**Semantic Item**


**Semantic Triple**

<dbo:Software, dbo:developer, dbo:Company>
<dbo:Company, dbo:foundationPlace, dbr:California>

**SPARQL**

```sparql
SELECT DISTINCT ?uri WHERE {
  ?uri rdf:type dbo:Software.  
  ?x1 rdf:type dbo:Company.  
  ?x1 dbo:foundationPlace dbr:California. }
```
Challenges

• Manually designed patterns
  • Phrase detection rules
    • NN|NNP: Entity
    • NN: Class | Property
    • VB: Property

• Semantic item grouping patterns (syntactic patterns)
  • Verb and its arguments
  • Adjectives and its arguments
  • Prepositionally modified tokens and its objects

(?x, dbo:producer, dbo:film)
Challenges

- Manually designed patterns
  - Phrase detection rules
    - NN|NNP: Entity
    - NN: Class | Property
    - VB: Property

- Semantic item grouping patterns (syntactic patterns)
  - Verb and its arguments
  - Adjectives and its arguments
  - Prepositionally modified tokens and its objects

Can we automatically learn rules or patterns?
Challenges

Which software has been developed by organizations founded in California, USA?

• Ambiguities
  • Phrase Detection:
    • { California }, { California, USA }

• Phrase Mapping:
  • California: {California_State}, {California_Film}

• Semantic Item Grouping:
  • {dbo:Software, dbo:developer, dbo:Company}
  • {dbo:Software, dbo:foundationPlace, dbo:Company}
Challenges

Which software has been developed by organizations founded in California, USA?

- **Ambiguities**
  - Phrase Detection:
    - \{ California \}, \{ California, USA \}

- Phrase Mapping:
  - California: \{California\_State\}, \{California\_Film\}

- Semantic Item Grouping:
  - \{dbo:Software, dbo:developer, dbo:Company\}
  - \{dbo:Software, dbo:foundationPlace, dbo:Company\}

*Can we make joint inference?*
Our Solution

• Pattern Learning
  • Meta patterns
    • Not only “verb and its arguments”
    • All syntactic paths maybe possible

• Joint Inference
  • First-order logic formulas
  • Markov Logic Network

\[
p(y) = \frac{1}{Z} \exp(\sum_{(\phi_i, w_i) \in L} w_i \sum_{c \in C^{\phi_i}} f^\phi_i (y))
\]
Predicates

• Hidden Predicates

<table>
<thead>
<tr>
<th>hasPhrase(i)</th>
<th>The $i$th candidate phrase has been chosen</th>
</tr>
</thead>
<tbody>
<tr>
<td>hasResource(i, j)</td>
<td>The $i$th phrase is mapped to the $j$th semantic item</td>
</tr>
<tr>
<td>hasRelation (ri, rj, rr)</td>
<td>The semantic item $ri$ and $rj$ can be grouped together with the relation type $rr$</td>
</tr>
</tbody>
</table>

• Observed Predicates

<table>
<thead>
<tr>
<th>Describing the attributes of phrases and relation between two phrases</th>
</tr>
</thead>
<tbody>
<tr>
<td>phraseIndex(p, i, j)</td>
</tr>
<tr>
<td>phrasePosTag(p, pt)</td>
</tr>
<tr>
<td>phraseDepTag(p, q, dt)</td>
</tr>
<tr>
<td>phraseDepOne (p, q)</td>
</tr>
<tr>
<td>hasMeanWord (p, q)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Describing the attributes of semantic item and the mapping between phrase and semantic item</th>
</tr>
</thead>
<tbody>
<tr>
<td>resourceType(r, rt)</td>
</tr>
<tr>
<td>priorMatchScore(p, r, s)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Describing the attributes of relation between two semantic items in knowledge base</th>
</tr>
</thead>
<tbody>
<tr>
<td>hasRelatedness(p, q, s)</td>
</tr>
<tr>
<td>isTypeCompatible(p, q, rr)</td>
</tr>
<tr>
<td>hasQueryResult(s, p, o, rr1, rr2)</td>
</tr>
</tbody>
</table>
Predicates

• Hidden Predicates

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>hasPhrase(i)</td>
<td>The ith candidate phrase has been chosen</td>
</tr>
<tr>
<td>hasResource(i, j)</td>
<td>The ith phrase is mapped to the jth semantic item</td>
</tr>
<tr>
<td>hasRelation (ri, rj, rr)</td>
<td>The semantic item ri and rj can be grouped together with the relation type rr</td>
</tr>
</tbody>
</table>

• Observed Predicates
## Formulas

- **Hard Formulas**

<table>
<thead>
<tr>
<th>Formula</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>hf1</td>
<td>$\text{hasPhrase}(p) \Rightarrow \text{hasResource}(p, _) $</td>
</tr>
<tr>
<td>hf2</td>
<td>$\text{hasResource}(p, _) \Rightarrow \text{hasPhrase}(p) $</td>
</tr>
<tr>
<td>hf3</td>
<td>$</td>
</tr>
<tr>
<td>hf4</td>
<td>$!\text{hasPhrase}(p) \Rightarrow !\text{hasResource}(p, r) $</td>
</tr>
<tr>
<td>hf5</td>
<td>$\text{hasResource}(_, r) \Rightarrow \text{hasRelation}(r, _, <em>) \lor \text{hasRelation}(</em>, r, _) $</td>
</tr>
<tr>
<td>hf6</td>
<td>$</td>
</tr>
<tr>
<td>hf7</td>
<td>$\text{hasRelation}(r1, r2, <em>) \Rightarrow \text{hasResource}(</em>, r1) \land \text{hasResource}(_, r2) $</td>
</tr>
<tr>
<td>hf8</td>
<td>$\text{phraseIndex}(p1, s1, e1) \land \text{phraseIndex}(p2, s2, e2) \land \text{overlap}(s1, e1, s2, e2) \land \text{hasPhrase}(p1) \Rightarrow \text{hasPhrase}(p2) $</td>
</tr>
<tr>
<td>hf9</td>
<td>$\text{resourceType}(r, \text{&quot;Entity&quot;}) \Rightarrow !\text{hasRelation}(r, _, \text{&quot;2.1&quot;}) \land !\text{hasRelation}(r, _, \text{&quot;2.2&quot;}) $</td>
</tr>
<tr>
<td>hf10</td>
<td>$\text{resourceType}(r, \text{&quot;Entity&quot;}) \Rightarrow !\text{hasRelation}(r, _, \text{&quot;2.1&quot;}) \land !\text{hasRelation}(r, _, \text{&quot;2.2&quot;}) $</td>
</tr>
<tr>
<td>hf11</td>
<td>$\text{resourceType}(r, \text{&quot;Class&quot;}) \Rightarrow !\text{hasRelation}(r, _, \text{&quot;2.1&quot;}) \land !\text{hasRelation}(r, _, \text{&quot;2.2&quot;}) $</td>
</tr>
<tr>
<td>hf12</td>
<td>$\text{resourceType}(r, \text{&quot;Class&quot;}) \Rightarrow !\text{hasRelation}(r, _, \text{&quot;2.1&quot;}) \land !\text{hasRelation}(r, _, \text{&quot;2.2&quot;}) $</td>
</tr>
<tr>
<td>hf13</td>
<td>$\text{isTypeCompatible}(r1, r2, rr) \Rightarrow \text{hasRelation}(r1, r2, rr) $</td>
</tr>
</tbody>
</table>
## Formulas

- **Soft Formulas**

| \( sf_1 \) | \( \text{priorMatchScore}(p, r, s) \Rightarrow \text{hasPhrase}(p) \) |
| \( sf_2 \) | \( \text{priorMatchScore}(p, r, s) \Rightarrow \text{hasResource}(p) \) |
| \( sf_3 \) | \( \text{phrasePosTag}(p, pt+) \land \text{resourceType}(r, rt+) \Rightarrow \text{hasResource}(p, r) \) |
| \( sf_4 \) | \( \text{phraseDepTag}(p_1, p_2, dp+) \land \text{hasResource}(p_1, r_1) \land \text{hasResource}(p_2, r_2) \Rightarrow \text{hasRelation}(r_1, r_2, rr+) \) |
| \( sf_5 \) | \( \text{phraseDepTag}(p_1, p_2, dp+) \land \text{hasResource}(p_1, r_1) \land \text{hasResource}(p_2, r_2) \land \neg \text{hasMeanWord}(p_1, p_2) \Rightarrow \text{hasRelation}(r_1, r_2, rr+) \) |
| \( sf_6 \) | \( \text{phraseDepTag}(p_1, p_2, dp+) \land \text{hasResource}(p_1, r_1) \land \text{hasResource}(p_2, r_2) \land \text{phraseDepOne}(p_1, p_2) \Rightarrow \text{hasRelation}(r_1, r_2, rr+) \) |
| \( sf_7 \) | \( \text{hasRelatedness}(r_1, r_2, s) \land \text{hasResource}(\_, r_1) \land \text{hasResource}(\_, r_2) \Rightarrow \text{hasRelation}(r_1, r_2, \_) \) |
| \( sf_8 \) | \( \text{hasQueryResult}(r_1, r_2, r_3, rr_1, rr_2) \Rightarrow \text{hasRelation}(r_1, r_2, rr_1) \land \text{hasRelation}(r_2, r_3, rr_2) \) |
Formulas

- Soft Formulas

<table>
<thead>
<tr>
<th>sf1</th>
<th>priorMatchScore(p, r, s) ⇒ hasPhrase(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sf2</td>
<td>priorMatchScore(p, r, s) ⇒ hasResource(p)</td>
</tr>
<tr>
<td>sf3</td>
<td>phrasePosTag(p, pt+) ∧ resourceType(r, rt+) ⇒ hasResource(p, r)</td>
</tr>
<tr>
<td>sf4</td>
<td>phraseDepTag(p1, p2, dp+) ∧ hasResource(p1, r1) ∧ hasResource(p2, r2) ⇒ hasRelation(r1, r2, rr+)</td>
</tr>
<tr>
<td>sf5</td>
<td>phraseDepTag(p1, p2, dp+) ∧ hasResource(p1, r1) ∧ hasResource(p2, r2) ∧ hasMeanWord(p1, p2) ⇒ hasRelation(r1, r2, rr+)</td>
</tr>
<tr>
<td>sf6</td>
<td>phraseDepTag(p1, p2, dp+) ∧ hasResource(p1, r1) ∧ hasResource(p2, r2) ∧ phraseDepOne(p1, p2) ⇒ hasRelation(r1, r2, rr+)</td>
</tr>
<tr>
<td>sf7</td>
<td>hasRelatedness(r1, r2, s) ∧ hasResource(<em>, r1) ∧ hasResource(</em>, r2) ⇒ hasRelation(r1, r2, _)</td>
</tr>
<tr>
<td>sf8</td>
<td>hasQueryResult(r1, r2, r3, rr1, rr2) ⇒ hasRelation(r1, r2, rr1) ∧ hasRelation(r2, r3, rr2)</td>
</tr>
</tbody>
</table>
In which movies directed by Garry Marshall was Julia Roberts starring?
Framework

In which movies directed by Garry Marshall was Julia Roberts starring?

movies directed by Garry Marshall was Julia Roberts starring in
Framework

In which movies directed by Garry Marshall was Julia Roberts starring?

movies directed by Garry Marshall was Julia Roberts starring in

>hasCandidateResource
  "movies" "dbo:Film"
  "directed by" "dbo:director"
  "by" "dbo:publisher"
  "Garry Marshall" "dbr:Garry_Marshall"

>hasHeadPos
  "movies" "NNS"
  "directed" "VBN"
  "Garry Marshall" "NNP"

>hasDepPath
  "movies" "nsubj-­‐prep"
  "directed by" "pobj-­‐nn"

>hasResourceType
  "dbo:Film" "Concept"
  "dbo:director" "Property"
  "dbr:Garry_Marshall" "Concept"

>isTypeCompatible
  "dbo:Film" "dbo:director" "1_1"
  "dbo:director" "dbr:Garry_Marshall" "2_1"

SPARQL语句

DBpedia
Wikipedia
Word2vec
Reverb&Patty
统计信息

MLN模型
谓词和公式

问题预处理：问题类型、Focus、去除无用词等

短语检测&资源映射&特征提取

MLN联合消歧

资源映射候选
结构匹配候选

资源映射结果
结构匹配结果

构造查询图

查询图

生成查询
Framework

问题预处理：问题类型、Focus、去除无用词等

短语检测&资源映射&特征提取

资源映射候选
结构匹配候选

MLN联合消歧

资源映射结果
结构匹配结果

构造查询图

查询图

生成查询

DBpedia
Wikipedia
Word2vec
Reverb&Patty
统计信息

MLN模型
谓词和公式

In which movies directed by Garry Marshall was Julia Roberts starring?

movies directed by Garry Marshall was Julia Roberts starring in

>hasCandidateResource
“movies” “dbo:Film”
“directed by” “dbo:director”
“by” “dbo:publisher”
“Garry Marshall” “dbr:Garry_Marshall”

>hasDepPath
“movies” “directed by” “nsubj-prep”
“directed by” “Garry Marshall” “pobj-nn”

>hasResourceType
“dbo:Film” “Concept”
“dbo:director” “Property”
“dbr:Garry_Marshall” “Concept”

>hasResource
“movies” “dbo:Film”
“directed by” “dbo:director”
“Garry Marshall” “dbr:Garry_Marshall”
“Julia Roberts” “dbr:Julia_Roberts”
“starring in” “dbo:starring”

>isTypeCompatible
“dbo:Film” “dbo:director” “1_1”
“dbo:director” “dbr:Garry_Marshall” “2_1”

>hasRelation
“dbo:Film” “dbo:director” “1_1”
“dbo:Film” “dbo:starring” “1_1”
“dbo:director” “dbr:Garry_Marshall” “2_1”
“dbr:Julia_Roberts” “dbo:starring” “1_2”

>hasRelation
“dbo:Film” “dbo:director” “1_1”
“dbo:Film” “dbo:starring” “1_1”
“dbo:director” “dbr:Garry_Marshall” “2_1”
“dbr:Julia_Roberts” “dbo:starring” “1_2”

SPARQL语句
Framework

问题预处理：问题类型、Focus、去除无用词等

短语检测&资源映射&特征提取

MLN联合消岐

资源映射候选
结构匹配候选

MLN模型
谓词和公式

DBpedia
Wikipedia
Word2vec
Reverb&Patty
统计信息

资源映射结果
结构匹配结果

构造查询图

生成查询

SPARQL语句

In which movies directed by Garry Marshall was Julia Roberts starring?

movies directed by Garry Marshall was Julia Roberts starring in

> hasCandidateResource
  "movies" "dbo:Film"
  "directed by" "dbo:director"
  "by" "dbo:director"
  "Garry Marshall" "dbr:Garry_Marshall"

> hasHeadPos
  "movies" "NNS"
  "directed by" "VBN"
  "Garry Marshall" "NNP"

> hasDepPath
  "directed by" "nsubj-prep"
  "Garry Marshall" "pobj-nn"

> hasResourceType
  "dbo:Film" "Concept"
  "dbo:director" "Property"
  "dbr:Garry_Marshall" "Concept"

> hasResource
  "movies" "dbo:Film"
  "directed by" "dbo:director"
  "Garry Marshall" "dbr:Garry_Marshall"
  "Julia Roberts" "dbr:Julia_Roberts"
  "starring in" "dbo:starring"

> hasRelation
  "dbo:Film" "dbo:director" "1:1"
  "dbo:Film" "dbo:starring" "1:1"
  "dbo:director" "dbr:Garry_Marshall" "2:1"
  "dbr:Julia_Roberts" "dbo:starring" "1:2"
Framework

问题预处理：问题类型、Focus、去除无用词等

短语检测&资源映射&特征提取

MLN联合消歧

资源映射候选 结构匹配候选

资源映射结果 结构匹配结果

构造查询图

查询图

生成查询

DBpedia Wikipedia Word2vec Reverb&Patty 统计信息

MLN模型 谓词和公式

In which movies directed by Garry Marshall was Julia Roberts starring?

movies directed by Garry Marshall was Julia Roberts starring in

>hasCandidateResource
"movies" "dbo:Film"
"directed by" "dbo:director"
"by" "dbo:publisher"
"Garry Marshall" "dbr:Garry_Marshall"

>hasHeadPos
"movies" "NNS"
"directed by" "VBN"
"Garry Marshall" "NNP"

>hasDepPath
"movies" "directed by" "nsubj-prep"
"directed by" "Garry Marshall" "pobj-­nn"

>hasResourceType
"dbo:Film" "Concept"
"dbo:director" "Property"
"dbr:Garry_Marshall" "Concept"

>hasRelation
"dbo:Film" "dbo:director" "1_1"
"dbo:director" "dbr:Garry_Marshall" "1_1"
"dbr:Julia_Roberts" "dbo:starring" "1_2"
"dbr:Julia_Roberts" "dbo:starring" "1_2"

SELECT DISTINCT ?uri
WHERE
{
?uri rdf:type dbo:Film .
?uri dbo:starring res:Julia_Roberts .
}

SPARQL语句
Experiments

• Questions
  • three collections of questions from QALD
  • QALD1, QALD3, QALD4

• Linked Data:
  • DBpedia, YAGO

• MLN: thebeast toolkit
  • inference algorithm: cutting plane approach[3]
  • weights learning algorithm: MIRA
Effect of Pattern Learning

<table>
<thead>
<tr>
<th>System</th>
<th>#T</th>
<th>#Q</th>
<th>#A</th>
<th>P</th>
<th>R</th>
<th>F1</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEANNA (Yahya et al., 2012)</td>
<td>50</td>
<td>27</td>
<td>13</td>
<td>0.48</td>
<td>0.26</td>
<td>0.33</td>
</tr>
<tr>
<td>Ours</td>
<td>50</td>
<td>37</td>
<td>20</td>
<td>0.54</td>
<td>0.4</td>
<td>0.46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>POS tag of Phrase</th>
<th>type of mapped Item</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>nn</td>
<td>Entity</td>
<td>2.11</td>
</tr>
<tr>
<td>nn</td>
<td>Class</td>
<td>0.243</td>
</tr>
<tr>
<td>nn</td>
<td>Relation</td>
<td>0.335</td>
</tr>
<tr>
<td>vb</td>
<td>Relation</td>
<td>0.517</td>
</tr>
<tr>
<td>wp</td>
<td>Class</td>
<td>0.143</td>
</tr>
<tr>
<td>wr</td>
<td>Class</td>
<td>0.025</td>
</tr>
</tbody>
</table>
Effect of Joint Inference

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>PD</th>
<th>PM</th>
<th>MG</th>
<th>QA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>R</td>
<td>F1</td>
<td>P</td>
</tr>
<tr>
<td>QALD-1(Joint)</td>
<td>0.93</td>
<td>0.981</td>
<td>0.955</td>
<td>0.895</td>
</tr>
<tr>
<td>QALD-1(Pipeline)</td>
<td>0.921</td>
<td>0.972</td>
<td>0.946</td>
<td>0.868</td>
</tr>
<tr>
<td>QALD-3(Joint)</td>
<td>0.941</td>
<td>0.941</td>
<td>0.941</td>
<td>0.878</td>
</tr>
<tr>
<td>QALD-3(Pipeline)</td>
<td>0.912</td>
<td>0.912</td>
<td>0.912</td>
<td>0.829</td>
</tr>
<tr>
<td>QALD-4(Joint)</td>
<td>0.947</td>
<td>0.978</td>
<td>0.963</td>
<td>0.937</td>
</tr>
<tr>
<td>QALD-4(Pipeline)</td>
<td>0.937</td>
<td>0.967</td>
<td>0.952</td>
<td>0.905</td>
</tr>
</tbody>
</table>
## Effect of Joint Inference

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>PD</th>
<th>PM</th>
<th>MG</th>
<th>QA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>R</td>
<td>F1</td>
<td>P</td>
</tr>
<tr>
<td>QALD-1 (Joint)</td>
<td>0.93</td>
<td>0.981</td>
<td><strong>0.955</strong></td>
<td>0.895</td>
</tr>
<tr>
<td>QALD-1 (Pipe)</td>
<td>0.921</td>
<td>0.972</td>
<td>0.946</td>
<td>0.868</td>
</tr>
<tr>
<td>QALD-3 (Joint)</td>
<td>0.941</td>
<td>0.941</td>
<td><strong>0.941</strong></td>
<td>0.878</td>
</tr>
<tr>
<td>QALD-3 (Pipe)</td>
<td>0.912</td>
<td>0.912</td>
<td>0.912</td>
<td>0.829</td>
</tr>
<tr>
<td>QALD-4 (Joint)</td>
<td>0.947</td>
<td>0.978</td>
<td><strong>0.963</strong></td>
<td>0.937</td>
</tr>
<tr>
<td>QALD-4 (Pipe)</td>
<td>0.937</td>
<td>0.967</td>
<td>0.952</td>
<td>0.905</td>
</tr>
</tbody>
</table>
Ours vs. state-of-the-art

<table>
<thead>
<tr>
<th>Test set</th>
<th>System</th>
<th>#T</th>
<th>#Q</th>
<th>#A</th>
<th>P</th>
<th>R</th>
<th>F1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CASIA (He et al., 2013)</td>
<td>99</td>
<td>52</td>
<td>29</td>
<td>0.56</td>
<td>0.3</td>
<td>0.38</td>
</tr>
<tr>
<td>QALD-3</td>
<td>Scalewelis (Joris and Ferré, 2013)</td>
<td>99</td>
<td>70</td>
<td>32</td>
<td>0.46</td>
<td>0.32</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>RTV (Cristina et al., 2013)</td>
<td>99</td>
<td>55</td>
<td>30</td>
<td>0.55</td>
<td>0.3</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>Intui2 (Corina, 2013)</td>
<td>99</td>
<td>99</td>
<td>28</td>
<td>0.28</td>
<td>28</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>SWIP (Pradel et al., 2013)</td>
<td>99</td>
<td>21</td>
<td>15</td>
<td>0.71</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td><strong>Ours</strong></td>
<td>99</td>
<td>75</td>
<td>45</td>
<td><strong>0.6</strong></td>
<td>0.46</td>
<td><strong>0.52</strong></td>
</tr>
<tr>
<td>QALD-4²⁰</td>
<td>gAnswer</td>
<td>50</td>
<td>25</td>
<td>16</td>
<td>0.64</td>
<td>0.32</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>Intui3</td>
<td>50</td>
<td>33</td>
<td>10</td>
<td>0.30</td>
<td>0.2</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>ISOFT</td>
<td>50</td>
<td>50</td>
<td>10</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>RO EII</td>
<td>50</td>
<td>50</td>
<td>6</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td><strong>Ours</strong></td>
<td>50</td>
<td>26</td>
<td>15</td>
<td><strong>0.58</strong></td>
<td>0.3</td>
<td><strong>0.4</strong></td>
</tr>
</tbody>
</table>
Conclusion and Future work

• Pattern learning is needed for parsing a question over large-scale linked data

• Joint inference can effective for improving the performance of natural language question answering

• Scaled up to multiple interlinked knowledge bases
• Labeled data is insufficient to build up a robust model
• More robust solutions to find the implicit properties in questions
Thanks

Email: kliu@nlpr.ia.ac.cn

Homepage: http://www.nlpr.ia.ac.cn/cip/liukang.htm