Improving Information Extraction
by Acquiring External Evidence
with Reinforcement Learning

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Information Extraction: State of the Art

• Dependence on large training sets

ACE: 300K words
Freebase: 24M relations

Not available for many domains (ex. medicine, crime)

• Even large corpora do not guarantee high performance
  ~ 75% F1 on relation extraction (ACE)
  ~ 58% F1 on event extraction (ACE)
A hard reading task for you

**Task:** Identify food carcinogens

Coffee significantly reduced ER and cyclin D1 abundance in ER(+) cells ...

Coffee reduced the pAkt levels in both ER(+) and ER(-) cells.
A hard reading task for you

**Task:** Identify food carcinogens

Coffee significantly reduced ER and cyclin D1 abundance in ER(+) cells ...

Coffee reduced the pAkt levels in both ER(+) and ER(-) cells.

Is coffee a carcinogen?
A hard reading task for machines: IE

A 2 year old girl and four other people were wounded in a shooting in West Englewood Thursday night, police said.
A hard reading task: IE (not always!)

A 2 year old girl and four other people were wounded in a shooting in West Englewood Thursday night, police said.

The last shooting left five people wounded.
Incorporate External Evidence

Traditional formulation

Our approach

extract + reason

extract

extra articles

agg.
Challenges

1. Event Coreference

| Shooter: Scott Westerhuis | NumKilled: 4 |
| Location: S.D |

| Shooter: Scott Westerhuis | NumKilled: 6 |
| Location: Platte |

Several irrelevant articles!

Inconsistent extractions
Learning through Reinforcement

Original

extract

Shooter: Scott Westerhuis
NumKilled: 4
Location: S.D

Start with traditional extraction system
Learning through Reinforcement

Original

query

extract

Shooter: Scott Westerhuis
NumKilled: 4
Location: S.D

extract

Shooter: Scott Westerhuis
NumKilled: 6
Location: Platte

Perform a query and extract from a new article
Learning through Reinforcement

Original

Platte Fire: Westerhuis Family Apparent Murder-Suicide, Officer

Shooter: Scott Westerhuis
NumKilled: 6
Location: Platte

Current

Shooter: Scott Westerhuis
NumKilled: 4
Location: S.D

New

S.D. dad killed wife, four kids with shotgun setting house ablaze and killing self: author

Shooter: Scott Westerhuis
NumKilled: 4
Location: S.D
**State**

- **Shooter:** Scott Westerhuis
  - **NumKilled:** 4
  - **Location:** S.D

- **Shooter:** Scott Westerhuis
  - **NumKilled:** 6
  - **Location:** Platte

- **Conf**:
  - 0.3
  - 0.2
  - 0.1
  - 0.4
  - 0.6
  - 0.3
RL: State

State

**New**

- **Shooter:** Scott Westerhuis
- **NumKilled:** 6
- **Location:** Platte

**Curr**

- **Shooter:** Scott Westerhuis
- **NumKilled:** 4
- **Location:** S.D

Conf

- currentConf:
  - 0.1
  - 0.2
  - 0.3

- newConf:
  - 0.3
  - 0.4
  - 0.6
  - 0.3
State

Shooter: Scott Westerhuis
NumKilled: 4
Location: S.D

Shooter: Scott Westerhuis
NumKilled: 6
Location: Platte

RL: State

Conf

0.3
0.2
0.1

currentConf

0.4
0.6
0.3

newConf

matches

1
0
0
RL: State

State

Curr

New

Shooter: Scott Westerhuis
NumKilled: 4
Location: S.D

Shooter: Scott Westerhuis
NumKilled: 6
Location: Platte

Conf

0.3
0.2
0.1

0.4
0.6
0.3

matches
1
0
0

0.65

currentConf
0.3
0.2
0.1

newConf
0.4
0.6
0.3

docSim
0.65
RL: State

State

Shooter: Scott Westerhuis
NumKilled: 4
Location: S.D

Shooter: Scott Westerhuis
NumKilled: 6
Location: Platte

Conf

currentConf

newConf

matches

docSim

context
1. **Reconcile (d)** old values and new values.
   - Pick a single value, all values or no value from new set
2. Decide how to proceed:
   - Stop
2. Decide how to proceed:

- Select next query (q)
Queries

Query templates are induced automatically

• Title of original article
• Content words having high mutual information with gold values

<title>
<title> + ( suspect | shooter | said | men | arrested | … )
<title> + ( injured | wounded | victims | shot | … )
Rewards

• Change in accuracy

Previous Values

Shooter: Scott Westerhuis
NumKilled: 6
NumWounded: 1
Location: Platte

Current Values

Shooter: Scott Westerhuis
NumKilled: 6
NumWounded: 0
Location: Platte

$$R(s, a) = \sum_{entity_j} Acc(e^j_{cur}) - Acc(e^j_{prev}) = 1$$

• Small penalty for each transition
Deep Q-Network

State space is continuous: requires function approximation

\[ Q(s, a) \approx Q(s, a; \theta) \]

Trained to maximize cumulative reward
Acquiring External Evidence

1. Select a query to search for articles on the same event

```
shooting in platte september 2015
```

2. Use base extractor to obtain values for entities of interest

```
Shooter: Scott Westerhuis
NumKilled: 6
Location: Platte
```

3. Reconcile old and new extractions

```
Shooter: Scott Westerhuis
NumKilled: 4
Location: S.D

Shooter: Scott Westerhuis
NumKilled: 6
Location: Platte
```
Related Work

• Open Information Extraction (Etzioni et al., 2011; Fader et al., 2011; Wu and Weld, 2010)
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• Slot filling (Surdeanu et al., 2010; Ji and Grishman, 2011)

• Searching for additional sources on the web (Banko et al., 2002, West et al., 2014; Kanani and McCallum, 2012)
Datasets

1. Mass shootings in the United States

<table>
<thead>
<tr>
<th>Shooter Name</th>
<th>Num Killed</th>
<th>Num Wounded</th>
<th>City</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>Train</th>
<th>Test</th>
<th>Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>306</td>
<td>8k</td>
<td>292</td>
<td>66</td>
</tr>
<tr>
<td>Downloaded</td>
<td>7.9k</td>
<td>1.6k</td>
<td></td>
</tr>
</tbody>
</table>

Downloaded

Source

Train

Test

Dev
Datasets

2. Adulteration events from Foodshield EMA

<table>
<thead>
<tr>
<th></th>
<th>Train</th>
<th>Test</th>
<th>Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>292</td>
<td>148</td>
<td>42</td>
</tr>
<tr>
<td>Downloaded</td>
<td>7.6k</td>
<td>5.3k</td>
<td>1.5k</td>
</tr>
</tbody>
</table>
Base Extraction Model

Maximum entropy model with contextual features

(Chieu and Ng, 2002; Bunescu et al., 2005)

Indirect supervision: Project database values onto articles
Baselines (1)

Simple Aggregation systems:

- **Confidence-based**: Choose entity value with highest confidence

Original

- **Shooter**: Scott Westerhuis
  - **NumKilled**: 4
  - **Location**: S.D

Extra

- **Shooter**: Scott Westerhuis
  - **NumKilled**: 6
  - **Location**: Platte

Final

- **Shooter**: Scott Westerhuis
  - **NumKilled**: 6
  - **Location**: Platte

*(Skounakis and Craven, 2003)*
Baselines (1)

Simple Aggregation systems:

- **Majority-based**: Choose entity value extracted the most from all articles on the event

Original

```
Shooter: Scott Westerhuis  
NumKilled: 4  
Location: S.D
```

```
Shooter: Scott Westerhuis  
NumKilled: 6  
Location: Platte
```

Extra

```
Shooter: Scott Westerhuis  
NumKilled: 6  
Location: S.D
```

Final

```
Shooter: Scott Westerhuis  
NumKilled: 6  
Location: S.D
```

(Skounakis and Craven, 2003)
Baselines (2)

Meta-classifier:

- Same input space $S$ and set of reconciliation decisions as RL agent.
Baselines (2)

Meta-classifier:

• Same input space $S$ and set of reconciliation decisions as RL agent.
Accuracy (Shootings)

NumKilled

<table>
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<tr>
<th>Method</th>
<th>Accuracy</th>
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</thead>
<tbody>
<tr>
<td>Maxent</td>
<td>69.7</td>
</tr>
<tr>
<td>Confidence Agg.</td>
<td>70.3</td>
</tr>
<tr>
<td>Meta-Classifier</td>
<td>70.7</td>
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<tr>
<td>RL-Extract</td>
<td></td>
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Accuracy (Shootings)

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<td>77.6</td>
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</tbody>
</table>
Accuracy (Adulterations)

Food

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxent</td>
<td>56.0</td>
</tr>
<tr>
<td>Majority Agg.</td>
<td>56.7</td>
</tr>
<tr>
<td>Meta-Classifier</td>
<td>55.4</td>
</tr>
<tr>
<td>RL-Extract</td>
<td>59.6</td>
</tr>
</tbody>
</table>
Oracle

• Given:
  • Same base extractor
  • Same set of queries
  • Agent performing **perfect** reconciliation and querying decisions.
  • Upper-bound on performance of any system given these extra articles on each event.
Accuracy (Shootings)

NumKilled

Accuracy

<table>
<thead>
<tr>
<th></th>
<th>Maxent</th>
<th>RL-Extract</th>
<th>Oracle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>69.7</td>
<td>77.6</td>
<td>86.4</td>
</tr>
</tbody>
</table>
Both reconciliation and querying
Documents are presented in round robin order from different query lists.
Reconciliation is confidence-based
Both reconciliation and querying are important and inter-linked
Evolution of Test Accuracy

Agent learns to balance all entity choices simultaneously
<table>
<thead>
<tr>
<th></th>
<th>Text</th>
<th>Shooter Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Extractor</td>
<td>A source tells Channel 2 Action News that Thomas Lee has been arrested in Mississippi ... Sgt. <strong>Stewart</strong> Smith, with the Troup County Sheriff’s office, said.</td>
<td>Stewart</td>
</tr>
<tr>
<td>RL-Extract</td>
<td><strong>Lee</strong> is accused of killing his wife, Christie; ...</td>
<td>Lee</td>
</tr>
</tbody>
</table>
### Examples

<table>
<thead>
<tr>
<th>Basic Extractor</th>
<th>Text</th>
<th>NumKilled</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Shooting leaves 25 year old Pittsfield man dead, 4 injured</strong></td>
<td>0</td>
</tr>
<tr>
<td>RL-Extract</td>
<td><strong>One man is dead after a shooting Saturday night at the intersection of Dewey Avenue and Linden Street.</strong></td>
<td>1</td>
</tr>
</tbody>
</table>

Our system finds alternative sources of information for reliable extraction.
## Adulteration Detection

### FDA Ingredient Search Engine

Search for possible adulterants or foods (use the button on the right to toggle between modes).

### Incidents

<table>
<thead>
<tr>
<th>Food Product</th>
<th>Food Category</th>
<th>Adulterant</th>
<th>Method of adulteration</th>
<th>Location</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>turmeric</td>
<td>vegetable and lentil mixes</td>
<td>colour Sudan 1</td>
<td></td>
<td>Pakistan</td>
<td>2006</td>
</tr>
<tr>
<td>turmeric</td>
<td>herbs &amp; spices</td>
<td>ash colored rice bran</td>
<td>Artificial Enhancement</td>
<td>Southeast Asia, India</td>
<td>2010</td>
</tr>
<tr>
<td>turmeric</td>
<td>herbs &amp; spices</td>
<td>lead chromate</td>
<td>Artificial Enhancement</td>
<td>Southeast Asia, India</td>
<td>2010</td>
</tr>
<tr>
<td>turmeric</td>
<td>herbs &amp; spices</td>
<td>paddy husk</td>
<td>Dilution with with a non-food-grade substance</td>
<td>Southeast Asia, India</td>
<td>2011</td>
</tr>
<tr>
<td>turmeric</td>
<td>herbs &amp; spices</td>
<td>rice</td>
<td>Artificial Enhancement</td>
<td>Southeast Asia, India</td>
<td>2015</td>
</tr>
</tbody>
</table>
Conclusion

- Alternative paradigm to improve Information Extraction, especially for low-resource domains.
- Use of Reinforcement Learning to find and incorporate external information.

_Code and data available at:_
/http://people.csail.mit.edu/karthikn/rl-ie/