Machine Reading and Reasoning with Neural Program Interpreters

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Collaborators

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Jason Naradowsky  
(now Johns Hopkins University)
The “Classic” NLP Paradigm
In January 1880, two of Tesla’s uncles put together enough money to help him leave Gospić for Prague where he was to study. Unfortunately, he arrived too late to enrol at Charles-Ferdinand University; he never studied Greek, a required subject; and he was illiterate in Czech, another required subject. Tesla did, however, attend lectures at the university, although, as an auditor, he did not receive grades for the courses.
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What city did Tesla move to in 1880?

Prague

[Language]
+ reusable cache
+ interpretable
+ supports reasoning

[Meaning]
-misses details
-error prone
-engineering heavy

[Information Need]
In January 1880, two of Tesla's uncles put together enough money to help him leave Gospić for Prague where he was to study. Unfortunately, he arrived too late to enrol at Charles-Ferdinand University; he never studied Greek, a required subject; and he was illiterate in Czech, another required subject. Tesla did, however, attend lectures at the university; although, as an auditor, he did not receive grades for the courses.
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What city did Tesla move to in 1880?

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Would it be appropriate for me to accept court side seating tickets to an NBA event?

Rules: Entertainment

Offers of entertainment may be accepted or made where they are necessary to develop and maintain outside contacts relevant to work responsibilities… disproportionately lavish. Invitations to expensive or exclusive sporting or cultural events should not be accepted.

3. Invitations from institutions supervised by the Bank or the FCA, or from professional advisers, should not be accepted without prior agreement of an Executive Director or Governor ….
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Archiving Inbox Items

Once an inbox item has been archived it will no longer appear in the list of inbox items returned by `cape.client.CapeClient.get_inbox()`. To archive an item call `cape.client.CapeClient.archive_inbox()` with the ID of the inbox item to archive:

```python
from cape.client import CapeClient

cc = CapeClient()
cc.login('username', 'password')
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How to read and reason end-to-end?
Learning to Read and Aggregate

Which medical specialty deals with pituitary ACTH hypersecretion?
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Pituitary ACTH hypersecretion ... is a form of hyperpituitarism characterized by an abnormally high level of ACTH produced by the anterior pituitary ...
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Learning to Read and Aggregate

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Learning to Read and Aggregate

Part 1

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Learning to Read and Calculate

How many pictures were in each of the albums?

Isabel uploaded 2 pictures from her phone and 4 from her camera to Facebook. She sorted the pics into 3 different albums with the same amount of pics in each album.
Learning to Read and Calculate

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How many pictures were in each of the albums?

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How many pictures were in each of the albums?

Isabel uploaded 2 pictures from her phone and 4 from her camera to Facebook. She sorted the pics into 3 different albums with the same amount of pics in each album.
I am working for an employer in Canada since December 2017. Do I need to carry on paying UK national insurance?

If you’re self-employed
You might be able to carry on paying National Insurance if you’re:
- usually self-employed in the UK
- working abroad temporarily

If you do, you won’t have to pay social security contributions in the country where you’re working. You can check this by completing form CA9107.

Working in any other country
You’ll carry on paying National Insurance for the first 52 weeks you’re abroad if you’re working for an employer outside the EEA.
I am working for an employer in Canada since December 2017. Do I need to carry on paying UK national insurance?

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Learning to Interpret Rules

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Part 3

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Have you been working abroad 52 weeks or less?

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And Ask Clarification Questions

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Part 1: Learning to Aggregate
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Agent

Program Interpreter

Reader

Rocktäschel and Riedel NIPS 2017
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Rocktäschel and Riedel NIPS 2017
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Agent

Program Interpreter

Code
[translates questions]

Question
What is ACTH hypersecretion created by?

Reader

Rocktäschel and Riedel NIPS 2017
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Which medical specialty deals with pituitary ACTH hypersecretion?

What is the pituitary a part of?

What topic covers the endocrine system?

Rocktäschel and Riedel NIPS 2017

18
Neural Theorem Provers

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Why Program Interpreter/Theorem Prover?

Amounts the **Backward Chaining** algorithm used in **Prolog** Interpreters

- createdBy(hypersecretion, anterior pituitary)
- partOf(endocrine system, anterior pituitary)
- dealsWith(endocrine system, endocrinology)
Why Neural? Supports Soft Unification

Why Neural? Supports Soft Unification

 createdBy(hypersecretion, anterior pituitary)

dealsWith(hypersecretion, X)

partOf(endocrine system, anterior pituitary)

dealsWith(endocrine system, endocrinology)

covers(endocrine system, X)

X deals with Y if 
Y produced by Z
Z is a part of U
X covers U

Question

Agent

Program Interpreter

Code

Reader

Rocktäschel and Riedel NIPS 2017
Why Neural? Supports Soft Unification

 createdBy(hypersecretion, anterior pituitary)

 partOf(endocrine system, anterior pituitary)

 (endocrine system, endocrinology)

 X deals with Y if
 Y produced by Z
 Z is a part of U
 X covers U

 Question

 (endocrine system, X)

 Agent

 Program Interpreter

 Reader

 Rocktäschel and Riedel NIPS 2017
Learn Rules by Learning Symbol Representations

 createdBy(hypersecretion, anterior pituitary)

 partOf(endocrine system, anterior pituitary)

dealsWith(endocrine system, endocrinology)

Agent

Program Interpreter

Code

\[
\begin{align*}
X & \text{ rel32 } Y \text{ if } \\
Y & \text{ rel42 } Z \\
Z & \text{ rel51 } U \\
X & \text{ rel62 } U
\end{align*}
\]

Question

\[
\text{rel62}(\text{endocrine system, } X)
\]

Reader

Question

Which specialty deals with pituitary ACTH hypersecretion?

What is the pituitary a part of?

rel62(X, Y, if Y rel42 Z, Z rel51 U, X rel62 U)
Before Learning

- \( X \text{ rel32 } Y \) if
- \( Y \text{ rel42 } Z \)
- \( Z \text{ rel51 } U \)
- \( X \text{ rel62 } U \)

produced by

covers

deals with

is a part of

deals with
After Learning

\[
\begin{align*}
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Results on Benchmark (Rank of Correct Answer)
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<table>
<thead>
<tr>
<th>Complex Countries S3</th>
<th>Complex NTP UMLS</th>
<th>Complex NTP Nations</th>
</tr>
</thead>
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<tr>
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<td>50</td>
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<tr>
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<tr>
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<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Rocktäschel and Riedel NIPS 2017
Results on Benchmark (Rank of Correct Answer)

- Complex Countries: 48.4
- NTP S3: 96
- Complex UMLS: 86
- Complex Nations: 26

Rocktäschel and Riedel NIPS 2017
Results on Benchmark (Rank of Correct Answer)

- Complex Countries S3: 48.4
- NTP: 77.3
- Complex Countries UMLS: 96
- NTP: 99
- Complex Nations: 86
- NTP: 89
Results on Benchmark (Rank of Correct Answer)

Comparable or Better than Baselines, and interpretable

Rocktäschel and Riedel NIPS 2017
Limitations

- **Scalability**
  - Currently only works for KBs with < 10k facts (solved!)
  - Small proof depth (getting there)

- **Still requires relational representation (ongoing)**
How to create Datasets for Multihop Reading and Reasoning?
Dataset Construction Method
Dataset Construction Method

Unlabelled Text

Knowledge Base
Dataset Construction Method

Unlabelled Text — Dataset Construction Method

Knowledge Base
Dataset Construction Method

Unlabelled Text → Dataset Construction Method → Multihop Dataset

Knowledge Base
### Dataset Construction Method

| KB Triple | Entities | Documents | Instance |
|-----------|----------|-----------|----------|----------|


## Dataset Construction Method

<table>
<thead>
<tr>
<th>KB Triple</th>
<th>Entities</th>
<th>Documents</th>
<th>Instance</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
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Dataset Construction Method

What is the nationality of Jamie Burnett?

Jamie Burnett, citizenship, Scotland
### Dataset Construction Method

#### KB Triple

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What is the nationality of Jamie Burnett?
Dataset Construction Method

KB Triple
Jamie Burnett, citizenship, Scotland

Entities
Jamie Burnett

Documents
What is the nationality of Jamie Burnett?

Instance
described in
Jamie Burnett described in mentions Jamie Burnett, citizenship, Scotland

What is the nationality of Jamie Burnett?
**Dataset Construction Method**

Jamie Burnett, citizenship, Scotland

What is the nationality of Jamie Burnett?
Jamie Burnett, citizenship, Scotland

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Dataset Construction Method

KB Triple

Jamie Burnett, citizenship, Scotland

Entities

Jamie Burnett
Hamilton
Scotland

Documents

described in
mentions
described in
mentions

Instance

What is the nationality of Jamie Burnett?

Scotland
What is the nationality of Jamie Burnett?
What is the nationality of Jamie Burnett?
Jamie Burnett described in Scotland mentions Hamilton.

What is the nationality of Jamie Burnett?
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Dataset Construction Method

Unlabelled Text → Dataset Construction Method → Multihop Dataset

Knowledge Base

[Conditionally Accepted to TACL]
Dataset Construction Method

WikiHop

Unlabelled Text → Dataset Construction Method → WikiHop

Knowledge Base
Dataset Construction Method

Unlabelled Text \rightarrow Dataset Construction Method \rightarrow MedHop

Knowledge Base
Baseline Results
Baseline Results

Accuracy [%]

- WikiHop
- MedHop

- Random
- TF-IDF
- BiDAF
Baseline Results

<table>
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<tr>
<th>Accuracy [%]</th>
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<tbody>
<tr>
<td>8.333</td>
</tr>
<tr>
<td>16.667</td>
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<tr>
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</tr>
<tr>
<td>33.333</td>
</tr>
<tr>
<td>41.667</td>
</tr>
<tr>
<td>50</td>
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WikiHop

Random: 11.5
TF-IDF: 11.5
BiDAF: 13.9

MedHop

Random: 13.9
<table>
<thead>
<tr>
<th>Method</th>
<th>WikiHop</th>
<th>MedHop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random</td>
<td>11.5</td>
<td>13.9</td>
</tr>
<tr>
<td>TF-IDF</td>
<td>25.6</td>
<td>9</td>
</tr>
<tr>
<td>BiDAF</td>
<td>25.6</td>
<td></td>
</tr>
</tbody>
</table>
Baseline Results

Accuracy [%]

**WikiHop**
- Random: 11.5
- TF-IDF: 25.6
- BiDAF: 42.9

**MedHop**
- Random: 13.9
- TF-IDF: 9
- BiDAF: 47.8
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Removing Relevant Documents, Keep Answer Documents

Accuracy [%]

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<tbody>
<tr>
<td>BIDAF</td>
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<td>BIDAF doc-rem</td>
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</tbody>
</table>

MedHop

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<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIDAF</td>
<td>33.7</td>
</tr>
<tr>
<td>BIDAF doc-rem</td>
<td>30.4</td>
</tr>
</tbody>
</table>

10%
Phil’s View?

▷ Good:
  ▷ You cannot just do context matching
  ▷ We spent a lot of efforts in removing biases
  ▷ We have extra information at annotation time we don’t release

▷ Bad:
  ▷ It is still multiple choice
  ▷ Test set comes from the same process as training (kinda—see above)
Part 2: Learning to Read and Calculate

Matko Bosnjak  Tim Rocktäschel  Jason Naradowsky
How many pictures were in each of the albums?

Isabel uploaded 2 pictures from her phone and 4 from her camera to Facebook. She sorted the pics into 3 different albums with the same amount of pics in each album.
Differentiable Program Interpreters

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</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Program Interpreter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reader</th>
</tr>
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<tbody>
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Model

Program Interpreter

Stack

Heap

Reader

Bosnjak et al. ICML 2017
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<tr>
<th>Score</th>
<th>Ours</th>
<th>Seq2Seq</th>
</tr>
</thead>
<tbody>
<tr>
<td>96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>84.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>61.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bosnjak et al. ICML 2017
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</table>

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$(2 + 4) / 3$
Limitations

- Continuous relaxations difficult to train
- Hard to learn long programs
- Hard to learn with recursive function calls
- Need better understanding of SGD for networks with discrete/stochastic activations
Part 3: Learning to Interpret Rules and Ask Clarification Questions
Learning to Interpret Rules

I am working for an employer in Canada since December 2017. Do I need to carry on paying UK national insurance?

Yes

If you’re self-employed
You might be able to carry on paying National Insurance if you’re:
- usually self-employed in the UK
- working abroad temporarily

If you do, you won’t have to pay social security contributions in the country where you’re working. You can check this by completing form CA9107.

Working in any other country
You’ll carry on paying National Insurance for the first 52 weeks you’re abroad if you’re working for an employer outside the EEA.
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Have you been working abroad 52 weeks or less?

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**Generating a Corpus**

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<tr>
<th>Do I need to carry on paying UK national insurance?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you been working abroad 52 weeks or less?</td>
</tr>
<tr>
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Created ~40k instances this way
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- Great Progress in End-to-End Reading Comprehension
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