Machine Reading and Reasoning with Neural Program Interpreters

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Bloomsbury AI

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Matko Bosnjak

(UCL)

Tim Rocktäschel

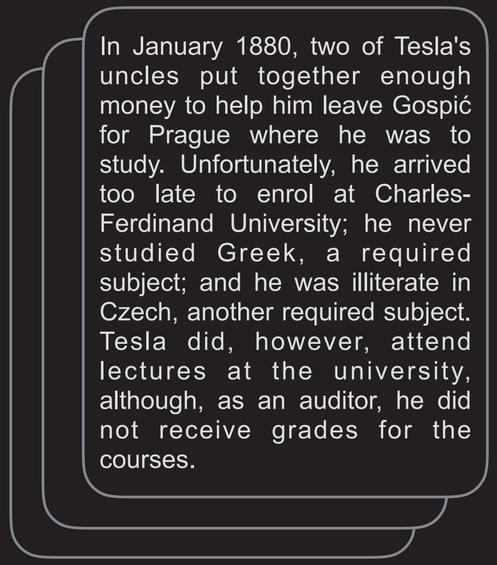
(now at Oxford)

Jason Naradowsky

(now Johns Hopkins University)

The “Classic” NLP Paradigm

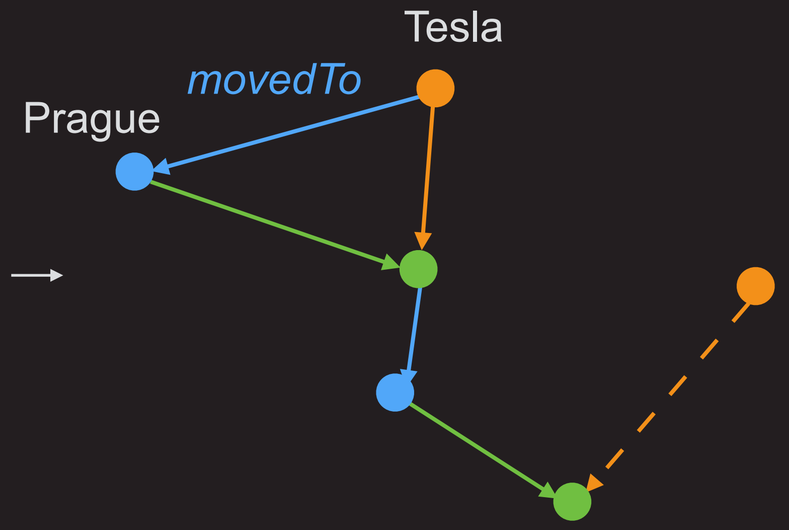
The “Classic” NLP Paradigm



[Language]

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.



[Language]

[Meaning]

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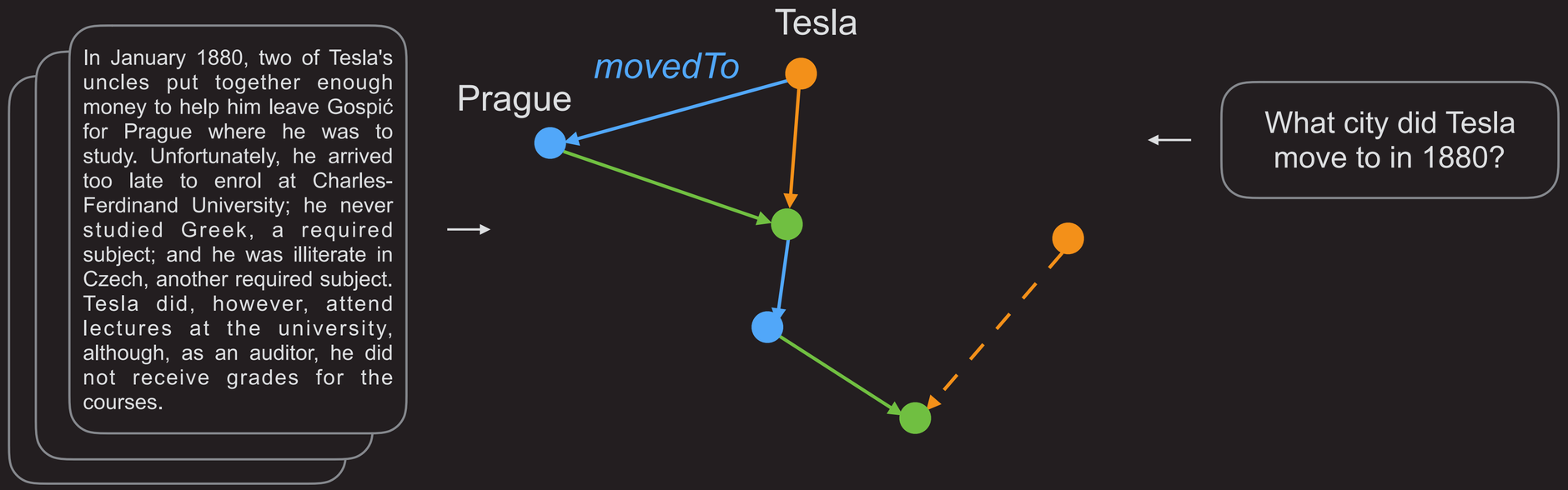

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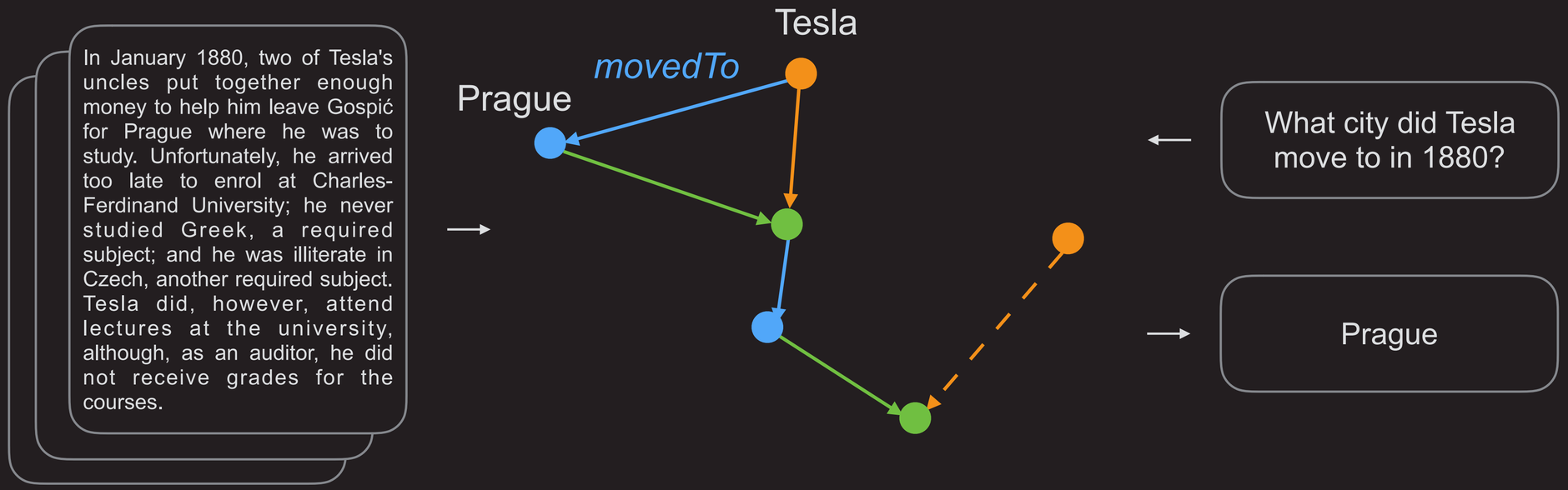

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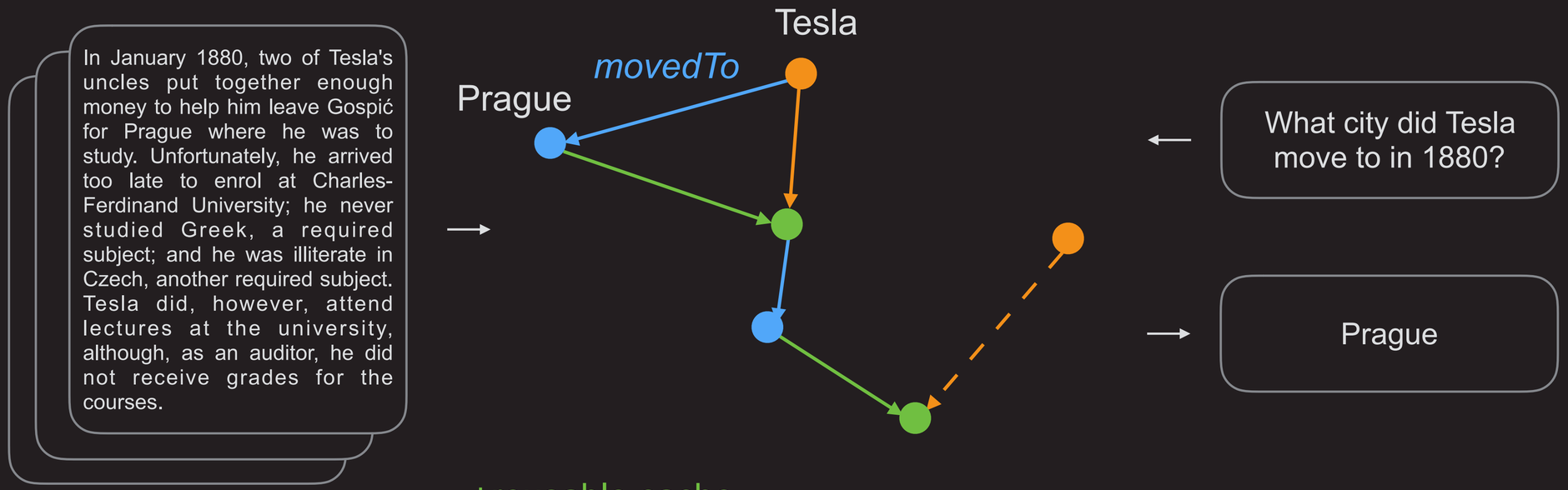

[Language]

+reusable cache
+interpretable
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[Meaning]

[Information Need]

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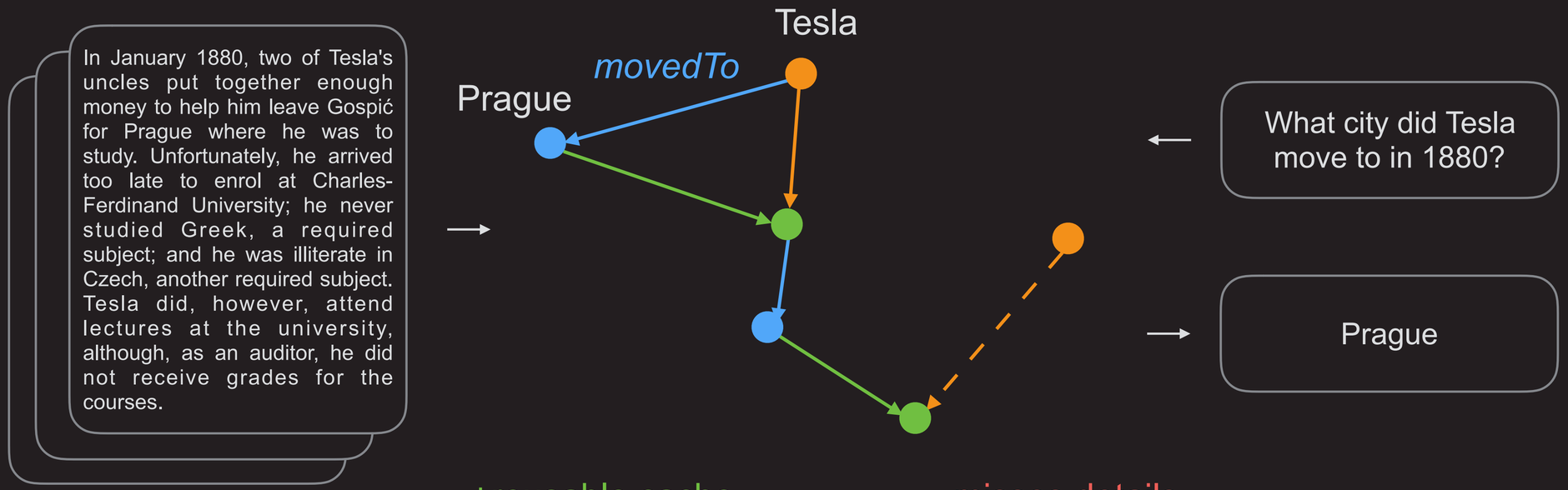

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“Should we separate meaning from language?”

Chris Manning
@AKBC 2013

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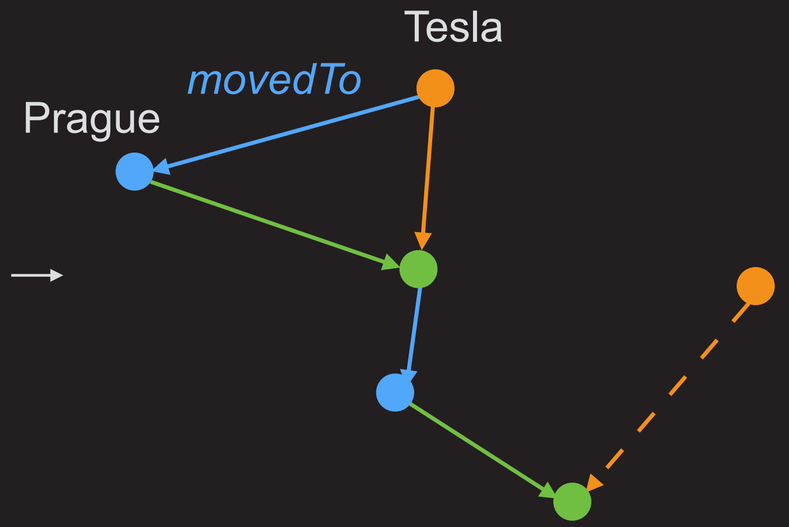

What city did Tesla move to in 1880?

Prague

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“Should we separate meaning from language?” **[Maybe not?]**

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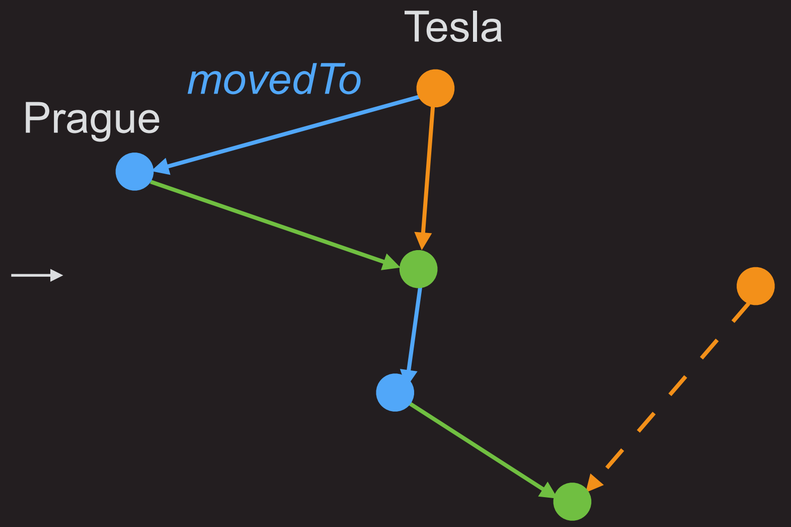

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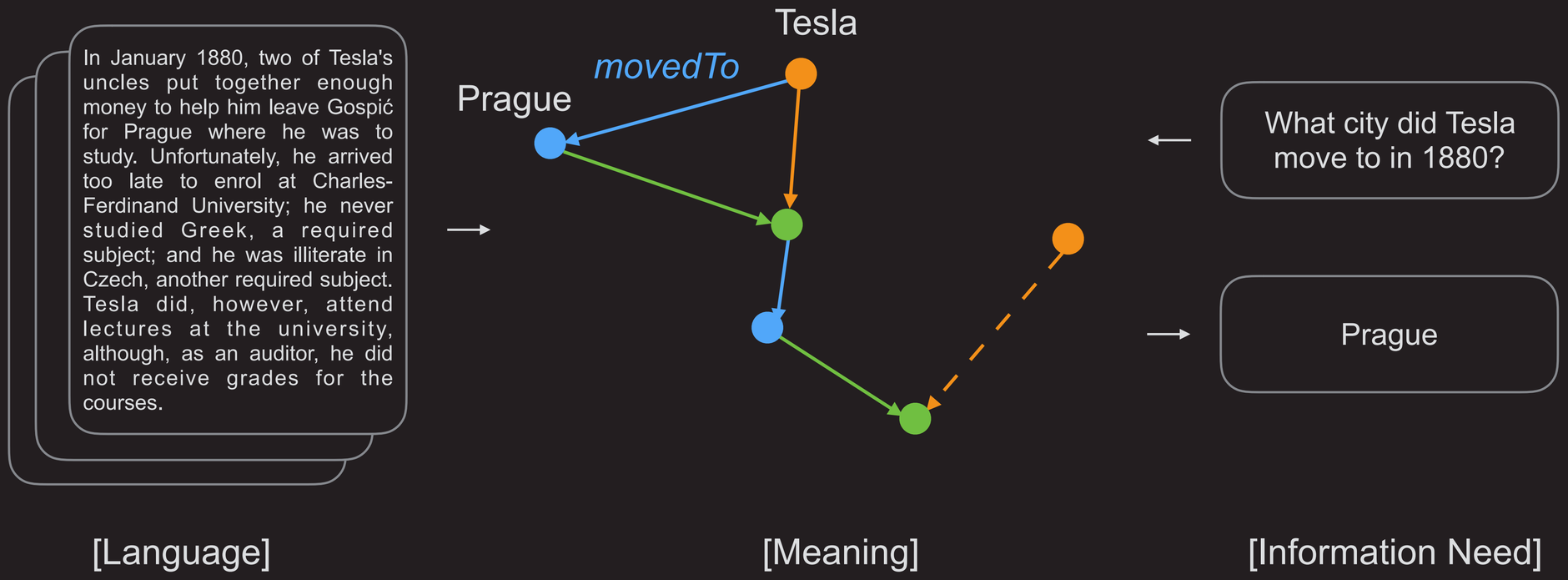
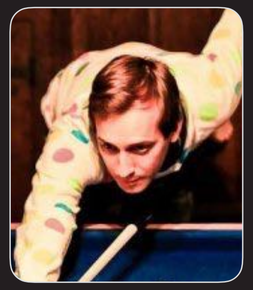
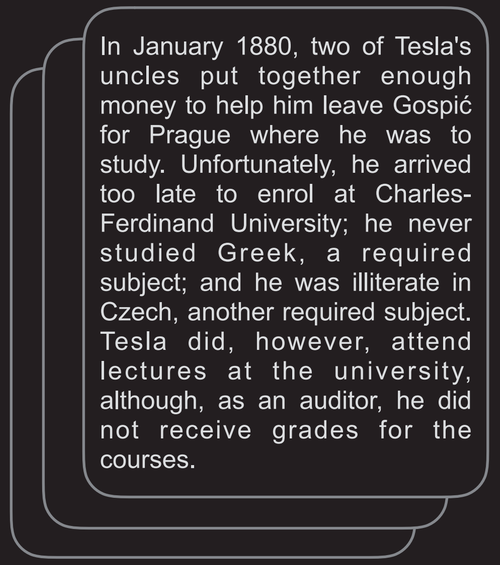




End-to-End Reading and Comprehension

(Hermann et. al 2015, Seo et al., 2016, Rajpurkar et al., 2016, Weissenborn 2016…)



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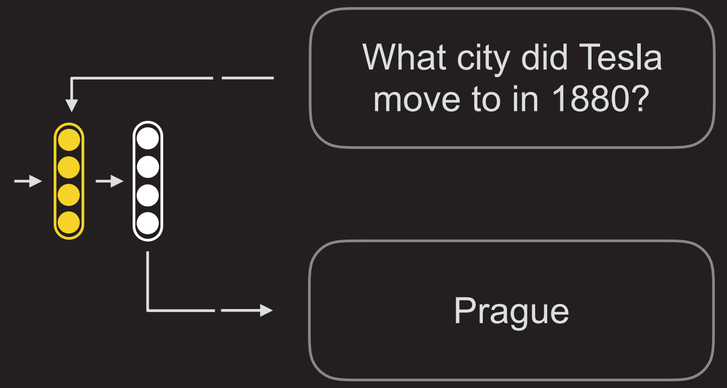

[Information Need]

Machine Reading & Comprehension

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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Machine Reading & Comprehension

Which function do I call for storing items in cape?

...

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:

```
from cape.client import CapeClient

cc = CapeClient()
cc.login('username', 'password')
cc.archive_inbox('4123')
```

Machine Reading & Comprehension

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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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NIPS 2017, TACL 2018

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

How many pictures were in each of the albums?

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Learning to Read and Calculate

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ICML 2017

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?

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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ONGOING

Pontus Stenetorp

Johannes Welbl

Tim Rocktäschel

Part 1: Learning to Aggregate

Neural Theorem Provers

Which medical specialty deals with pituitary ACTH hypersecretion?

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Reader

Rocktäschel and Riedel **NIPS 2017**

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Program Interpreter

Code

[translates questions]

Question

Reader

Rocktäschel and Riedel **NIPS 2017**

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[translates questions]

Question

What is ACTH hypersecretion created by?

Reader

Rocktäschel and Riedel **NIPS 2017**

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What is the pituitary a part of?

Reader

Rocktäschel and Riedel **NIPS 2017**

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[translates questions]

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Reader

Rocktäschel and Riedel **NIPS 2017**

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[translates questions]

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Vectors Correspond to Interpretable Rules

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Agent

Program Interpreter

Code

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

Question

What topic covers the endocrine system?

Reader

Catch: Currently only Works on Relational Data

dealsWith(**hypersecretion**, X)

createdBy(**hypersecretion, anterior pituitary**)

partOf(**endocrine system**, **anterior pituitary**)

dealsWith(**endocrine system**, **endocrinology**)

Agent

Program Interpreter

Code

```
X deals with Y if
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```

Question

covers(**endocrine system**, **X**)

Reader

Rocktäschel and Riedel **NIPS 2017**

Why Program Interpreter/Theorem Prover?

dealsWith(**hypersecretion**, X)

createdBy(**hypersecretion, anterior pituitary**)

partOf(**endocrine system**, **anterior pituitary**)

dealsWith(**endocrine system**, **endocrinology**)

Agent

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

Why Neural? Supports Soft Unification

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Question

covers(**endocrine system**, **X**)

Reader

Rocktäschel and Riedel **NIPS 2017**

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```
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Question

(**endocrine system**, **X**)

Reader

Learn Rules by Learning Symbol Representations

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createdBy(**hypersecretion, anterior pituitary**)

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Agent

Program Interpreter

Code

```
X rel32 Y if
  Y rel42 Z
  Z rel51 U
  X rel62 U
```

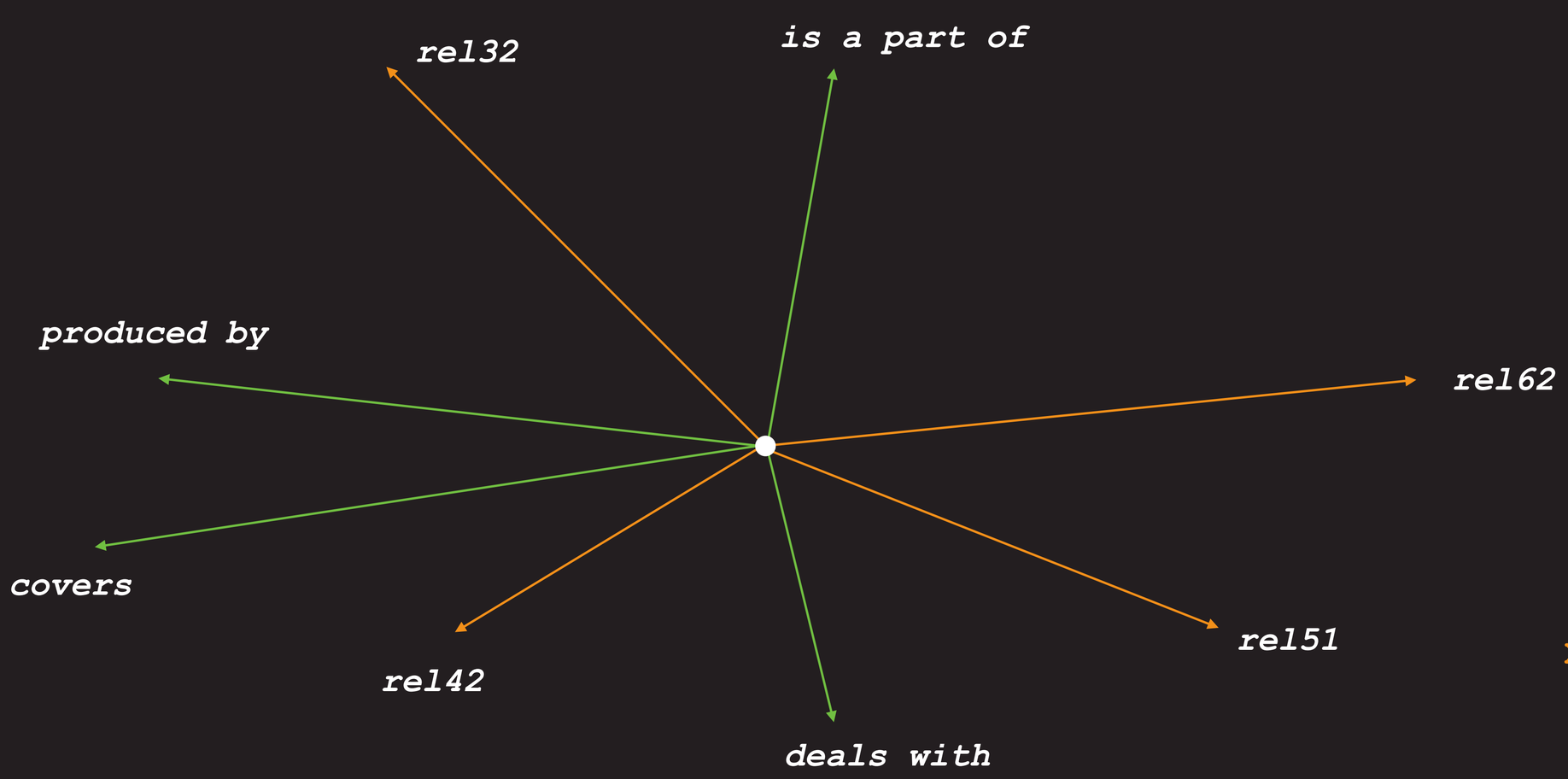
Question

rel62(**endocrine system**, **X**)

Reader

Rocktäschel and Riedel **NIPS 2017**

Before Learning

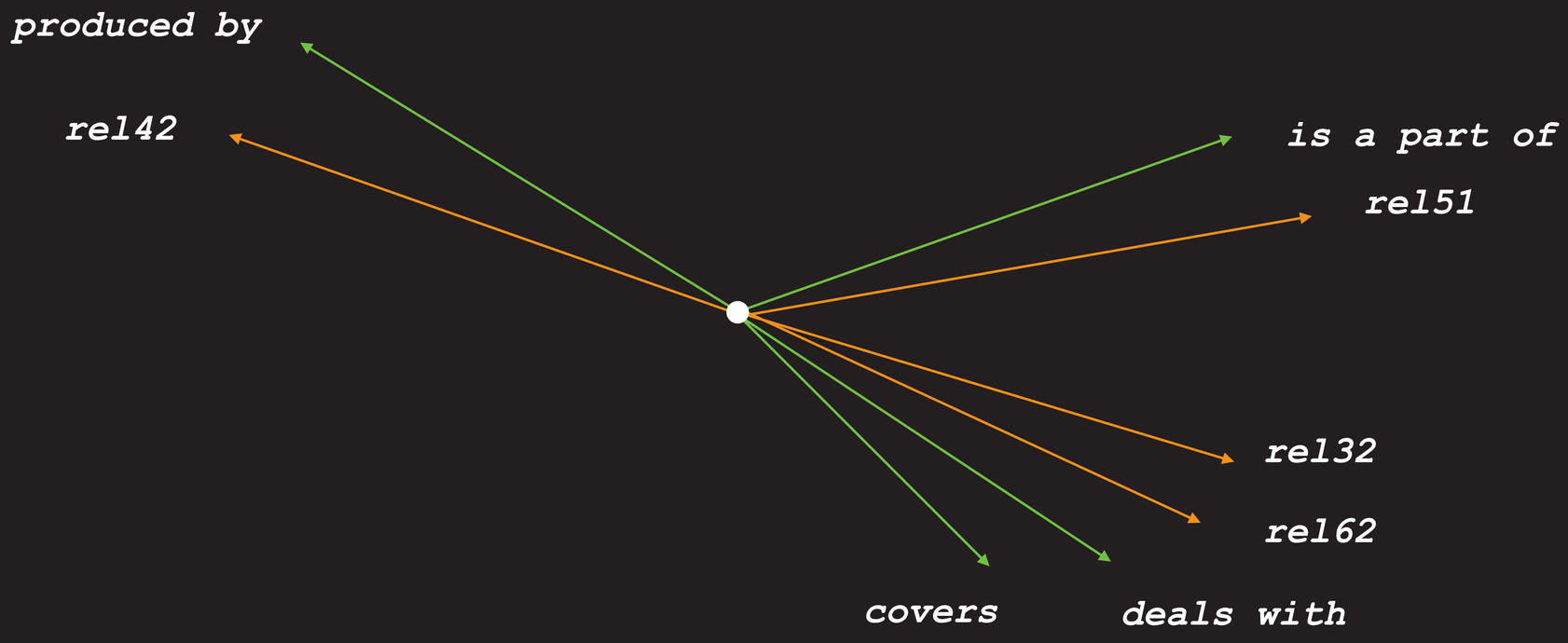


X rel32 Y if
Y rel42 Z
Z rel151 U
X rel62 U

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

After Learning

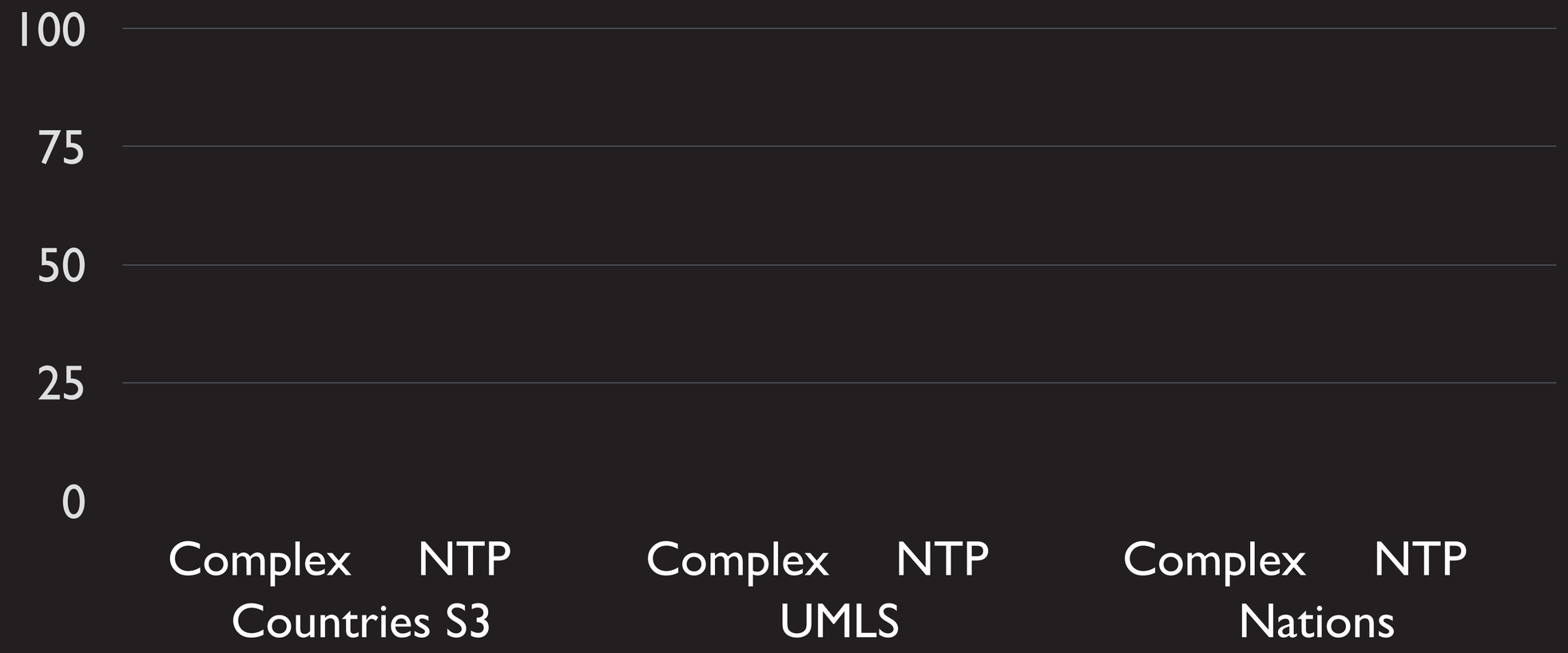
X *rel32* Y if
  Y *rel42* Z
  Z *rel51* U
  X *rel62* U



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

Results on Benchmark (Rank of Correct Answer)

Results on Benchmark (Rank of Correct Answer)



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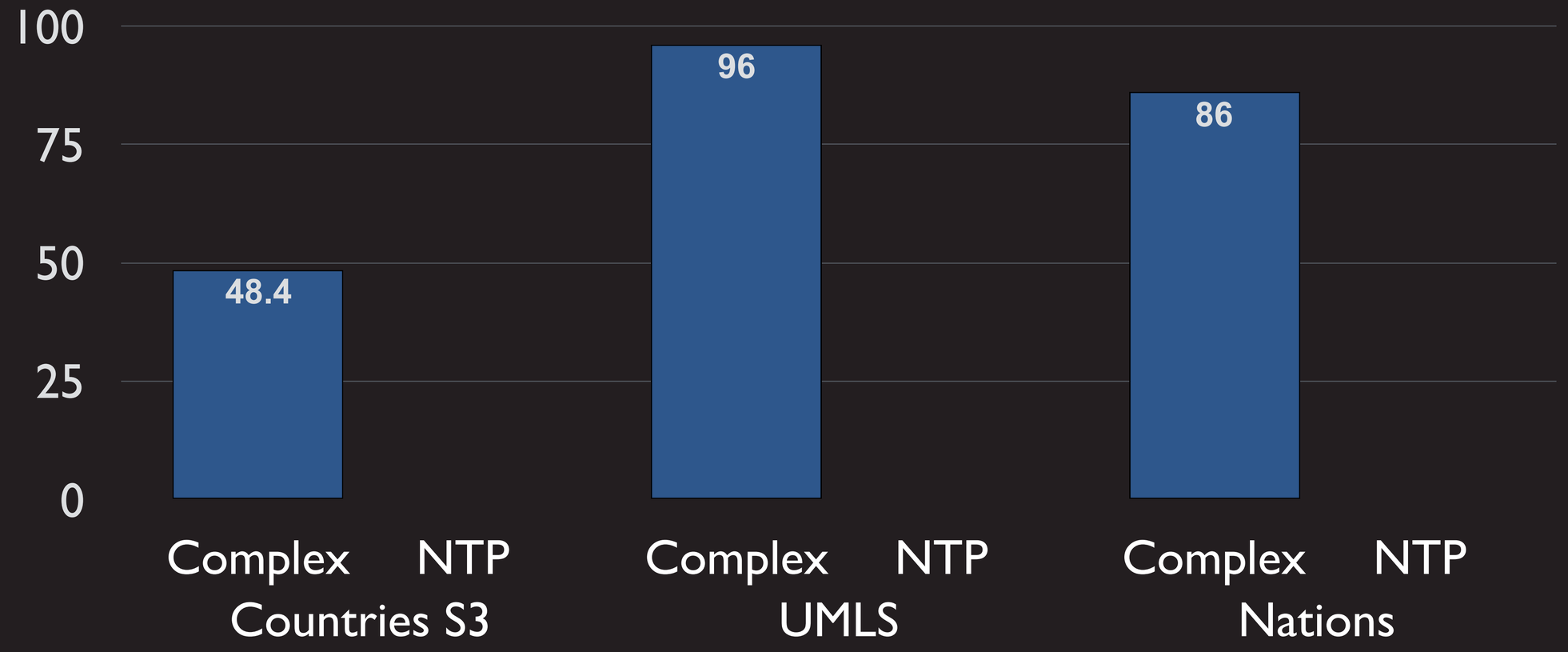

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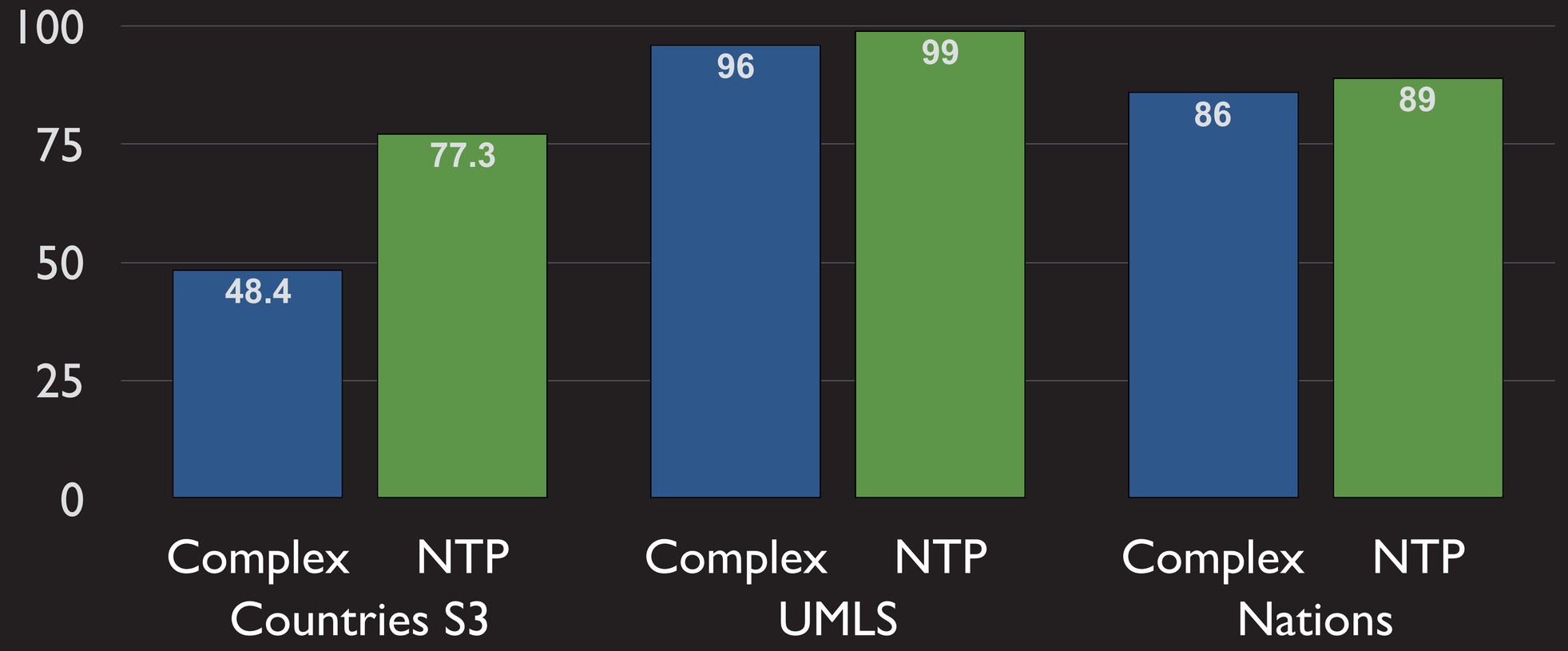

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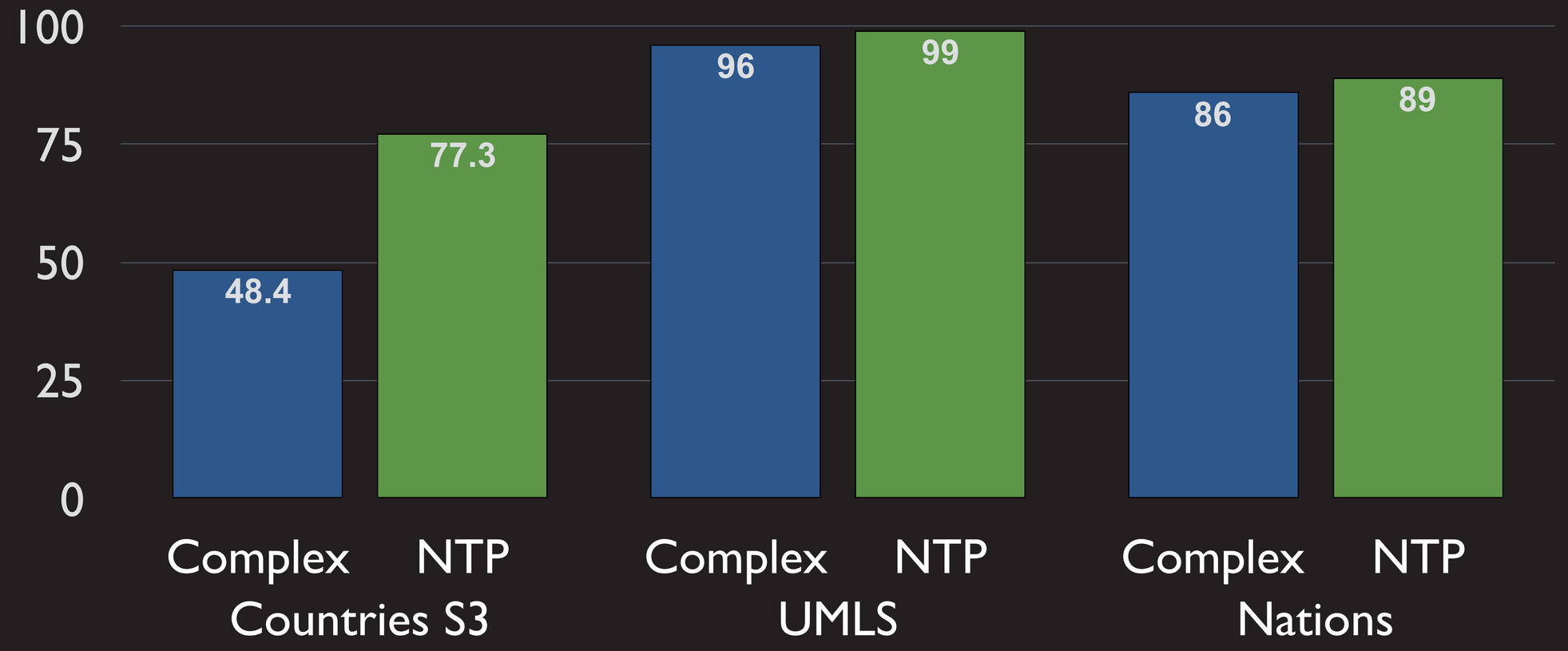


*Comparable or Better than Baselines, and **interpretable***

Limitations

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

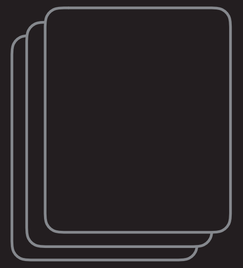
Pontus Stenetorp

Johannes Welbl

How to create Datasets for Multihop Reading and Reasoning?

Dataset Construction Method

Dataset Construction Method



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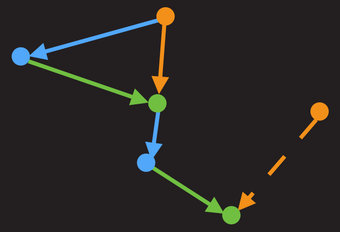

Knowledge Base

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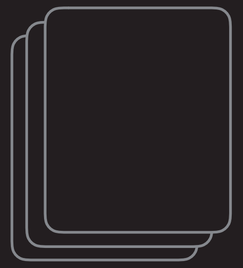

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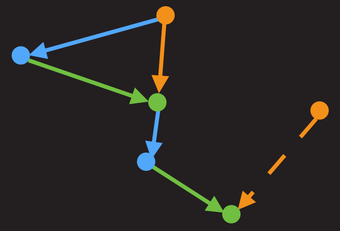

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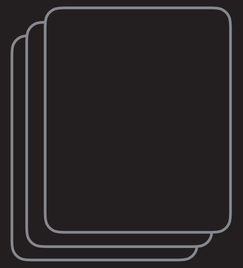

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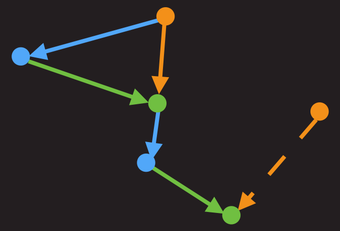

Knowledge Base

Dataset Construction Method

Multihop Dataset

Dataset Construction Method

KB Triple **Entities** **Documents** **Instance**

Dataset Construction Method

KB Triple **Entities** **Documents** **Instance**

Jamie Burnett, citizenship, Scotland

Dataset Construction Method

KB Triple | **Entities** | **Documents** | **Instance**

What is the nationality of Jamie Burnett?

Jamie Burnett, citizenship, Scotland

Dataset Construction Method

KB Triple

Jamie Burnett, citizenship, Scotland

Entities

Documents

Instance

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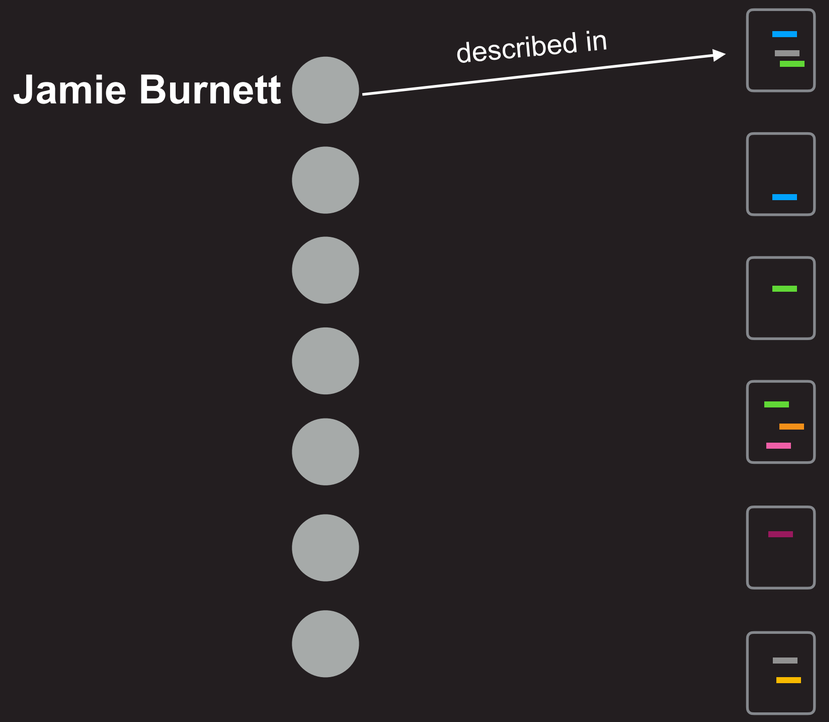

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What is the nationality of Jamie Burnett?

Dataset Construction Method

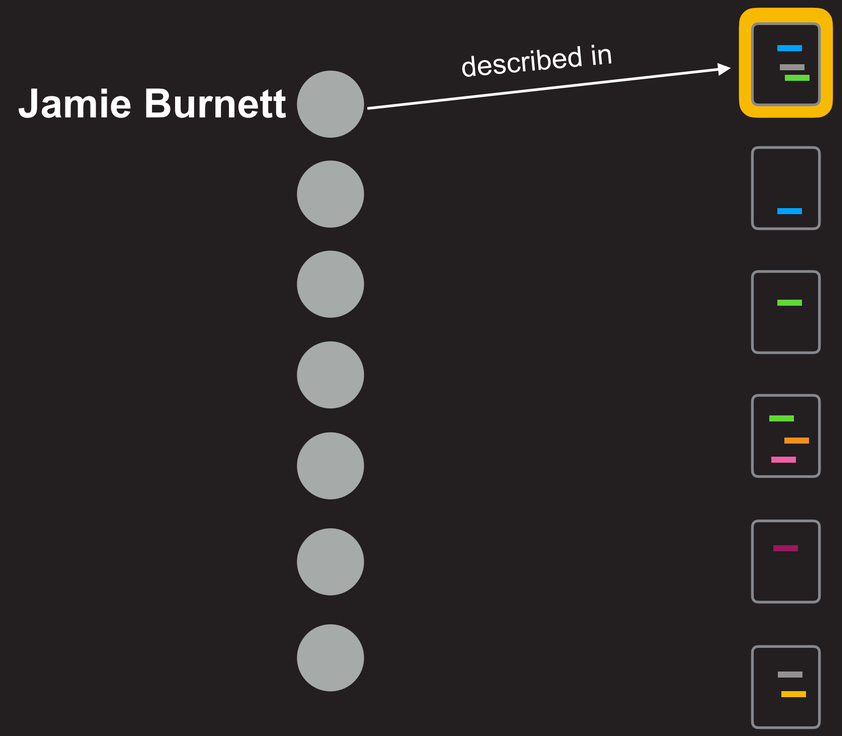
KB Triple

Jamie Burnett, citizenship, Scotland

Entities

Jamie Burnett

Documents



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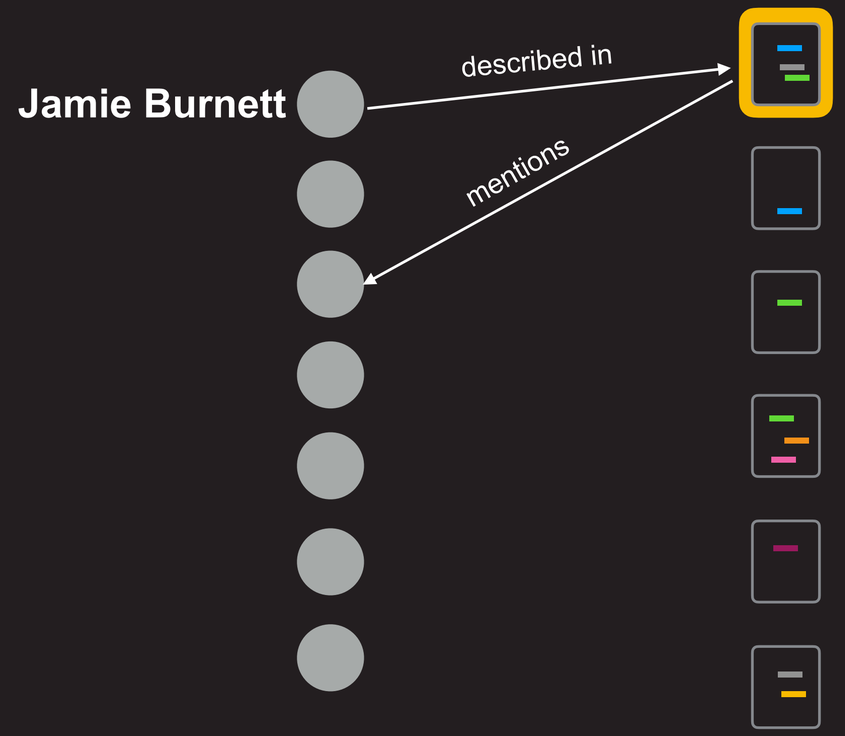


Instance

What is the nationality of Jamie Burnett?

Dataset Construction Method

KB Triple

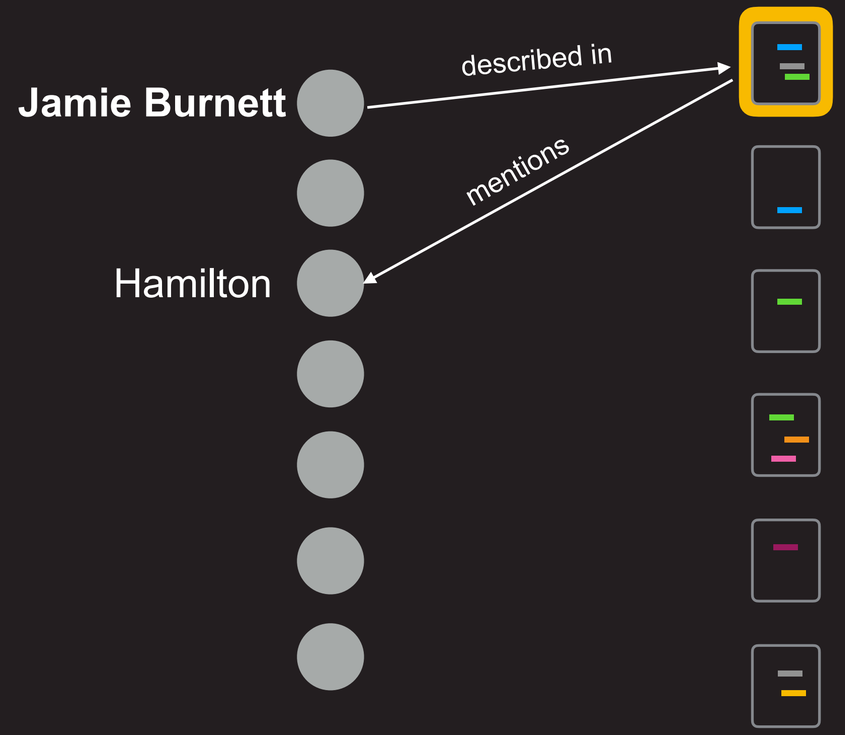
Jamie Burnett, citizenship, Scotland

Entities

Jamie Burnett

Hamilton

Documents



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Dataset Construction Method

KB Triple

Jamie Burnett, citizenship, Scotland

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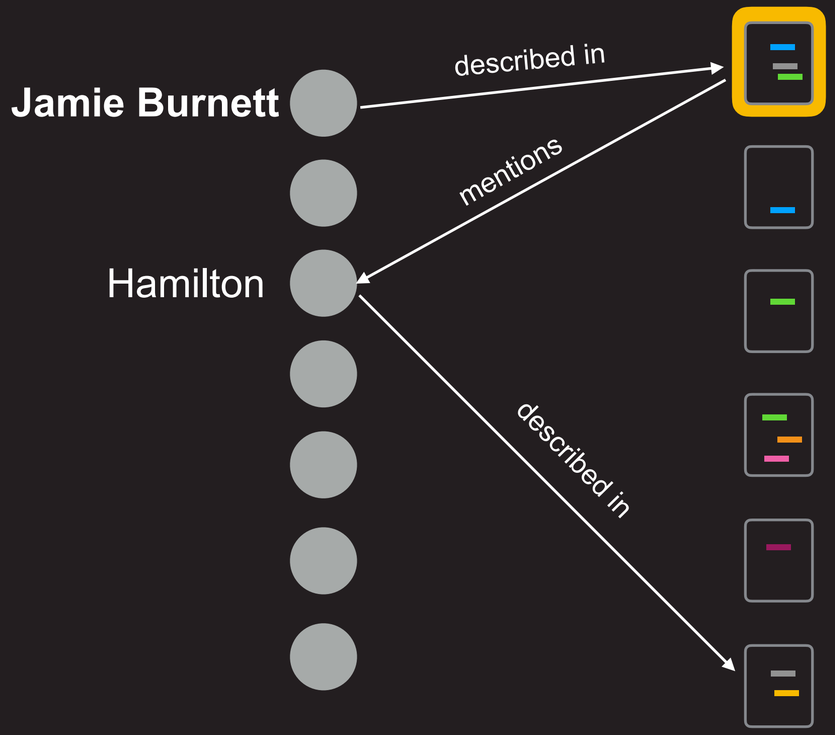

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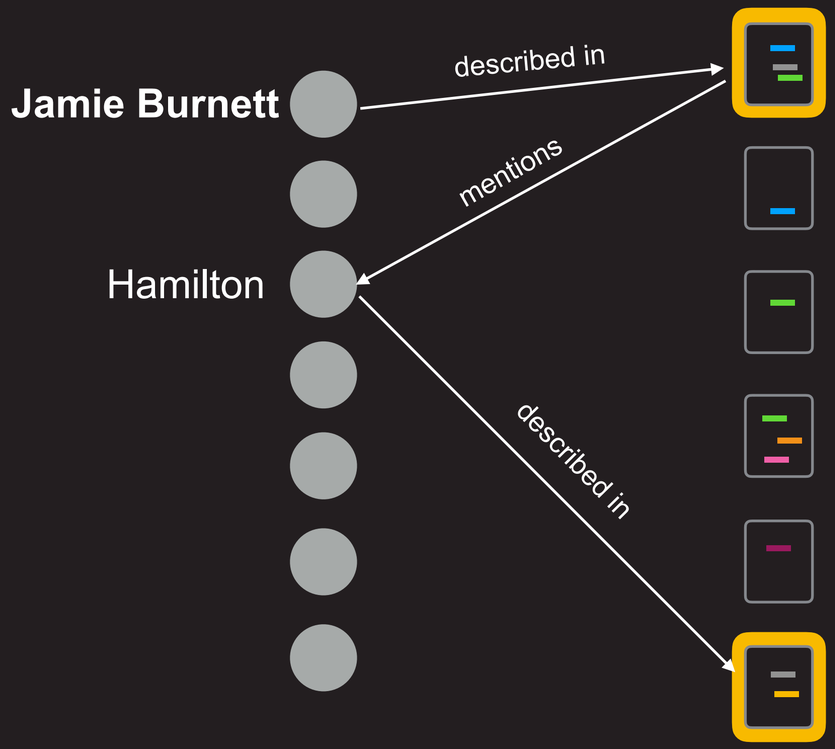

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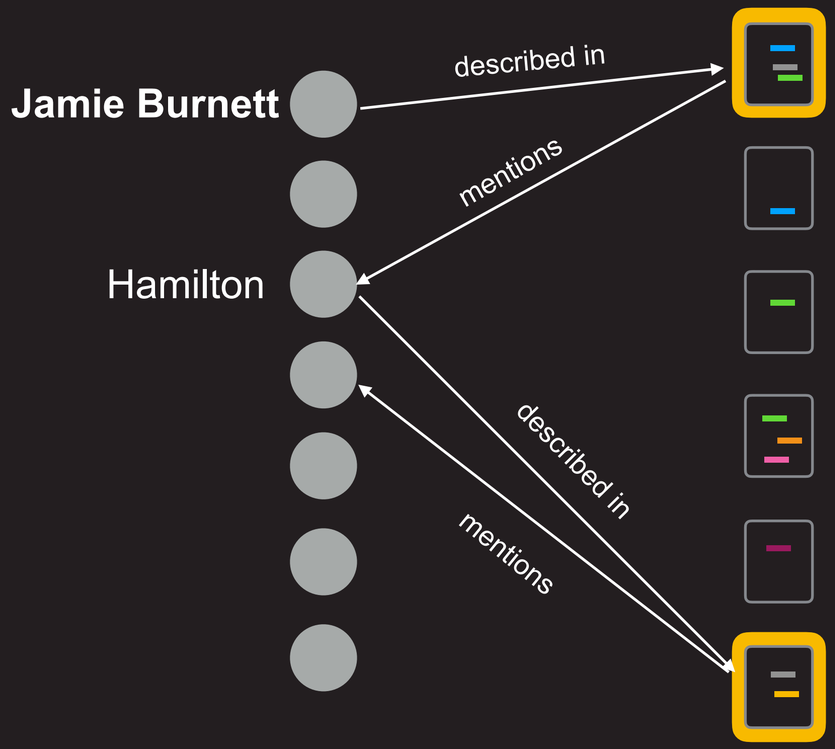

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Scotland

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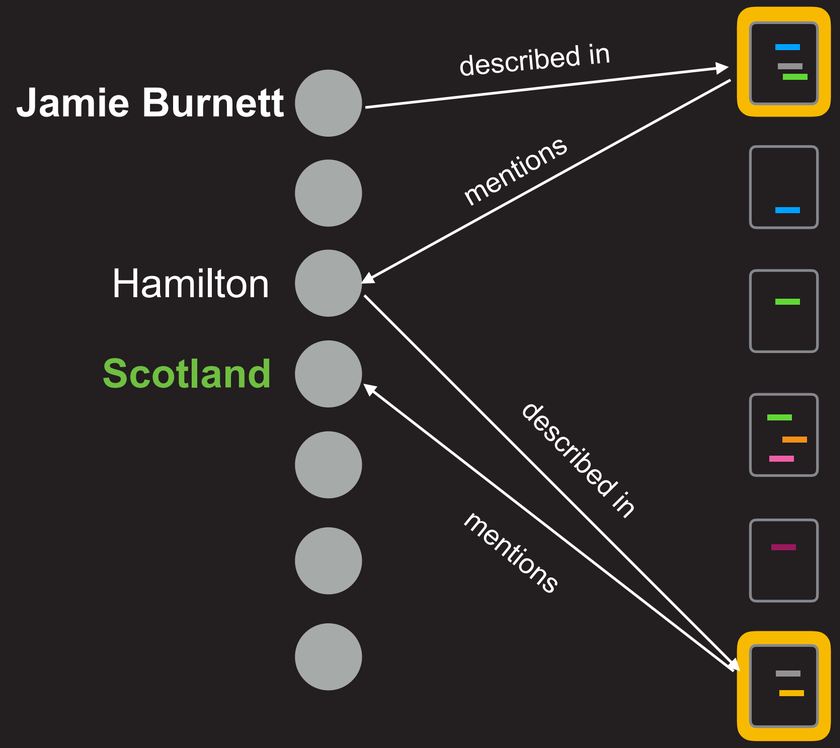

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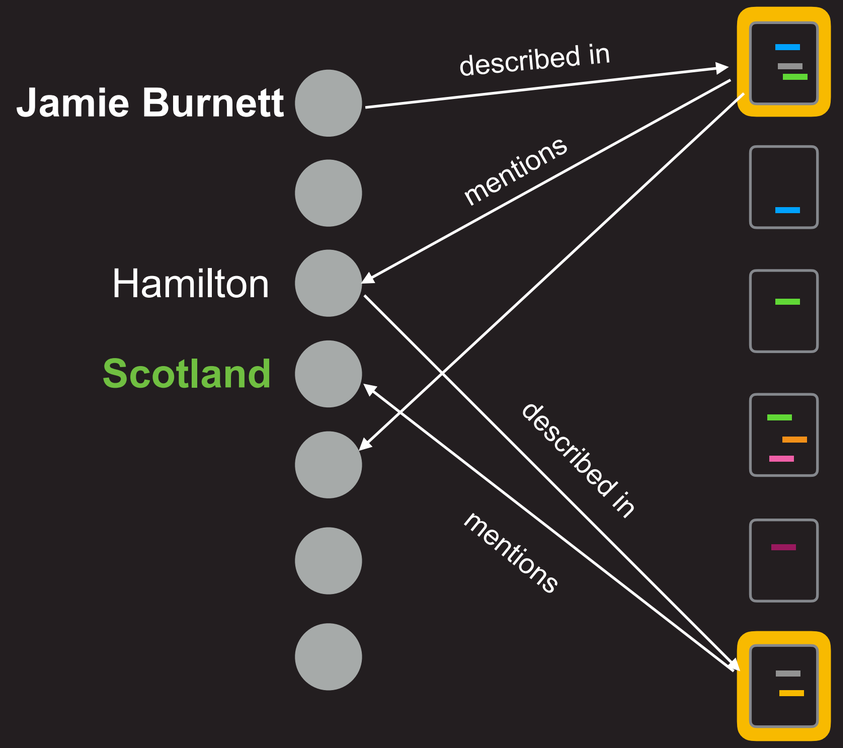

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Jamie Burnett, citizenship, Scotland

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Scotland

Yixing Open

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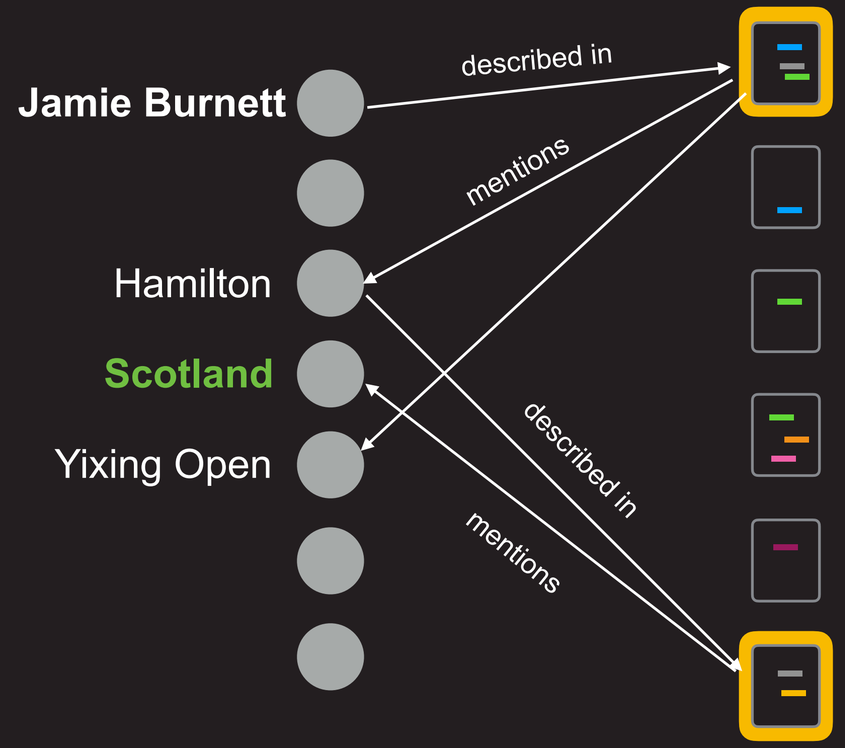

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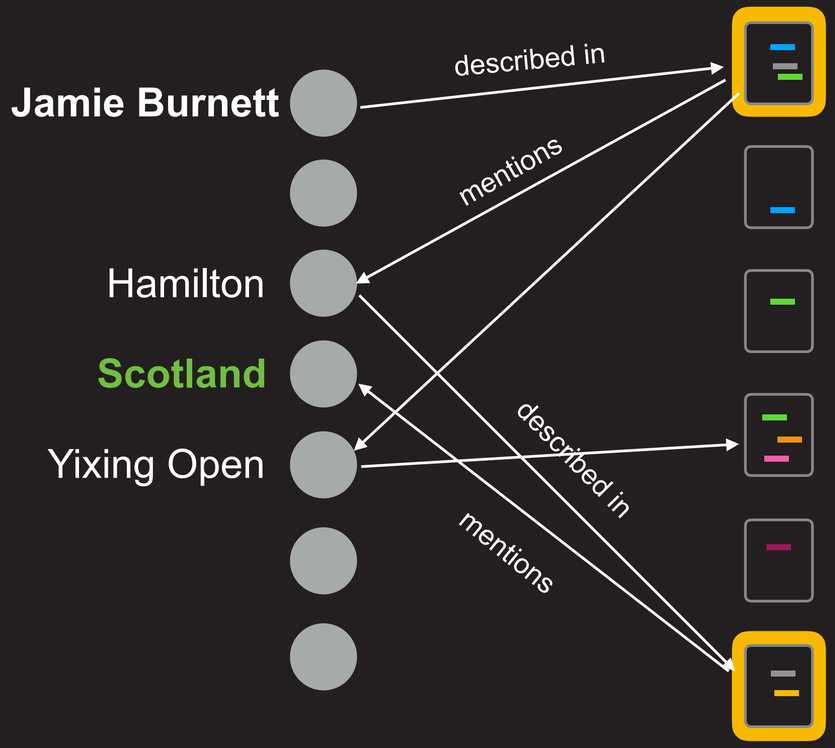

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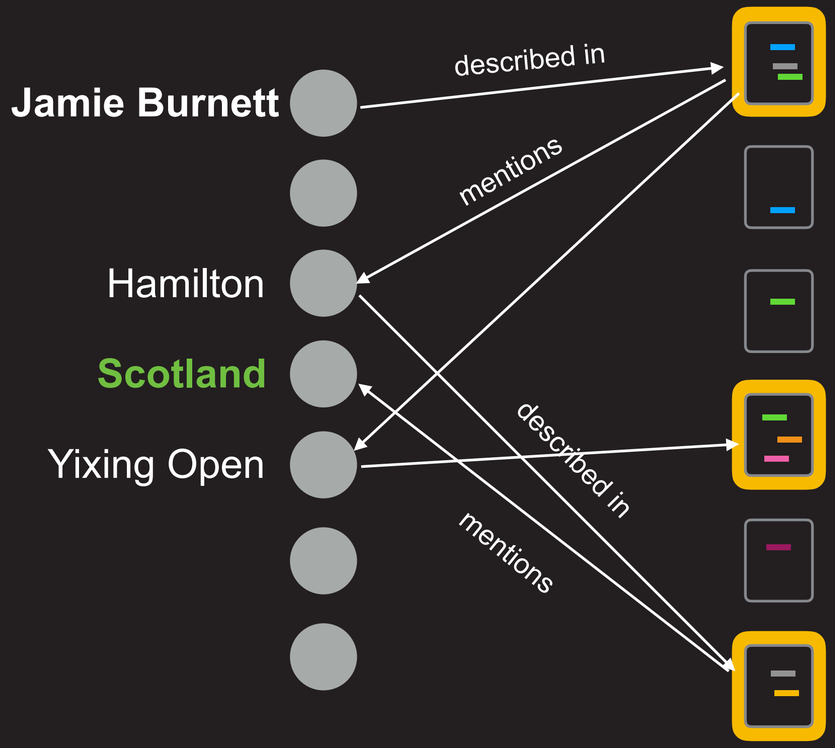

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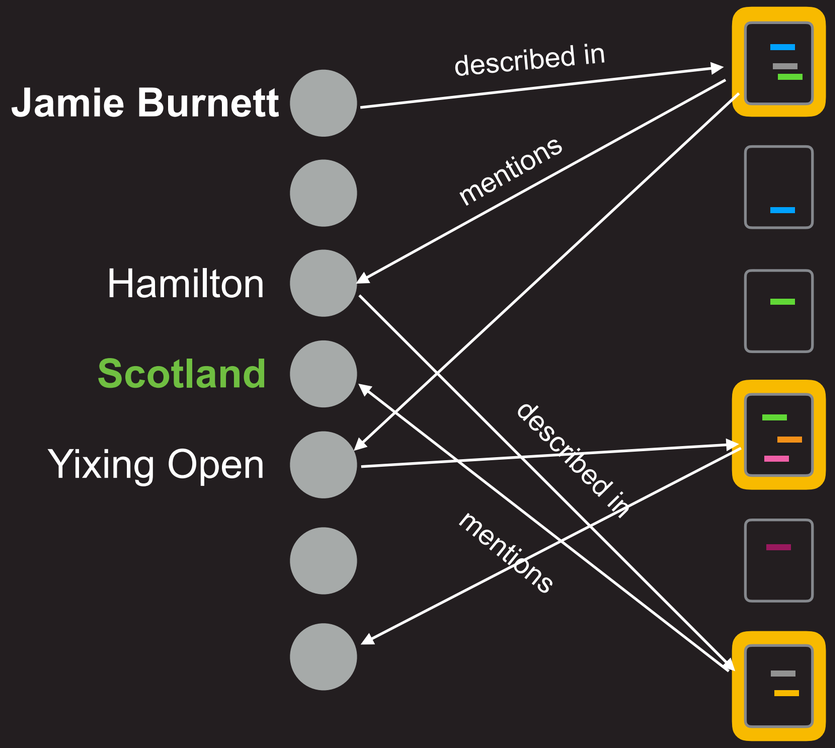

Instance

What is the nationality of Jamie Burnett?

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KB Triple

Jamie Burnett, citizenship, Scotland

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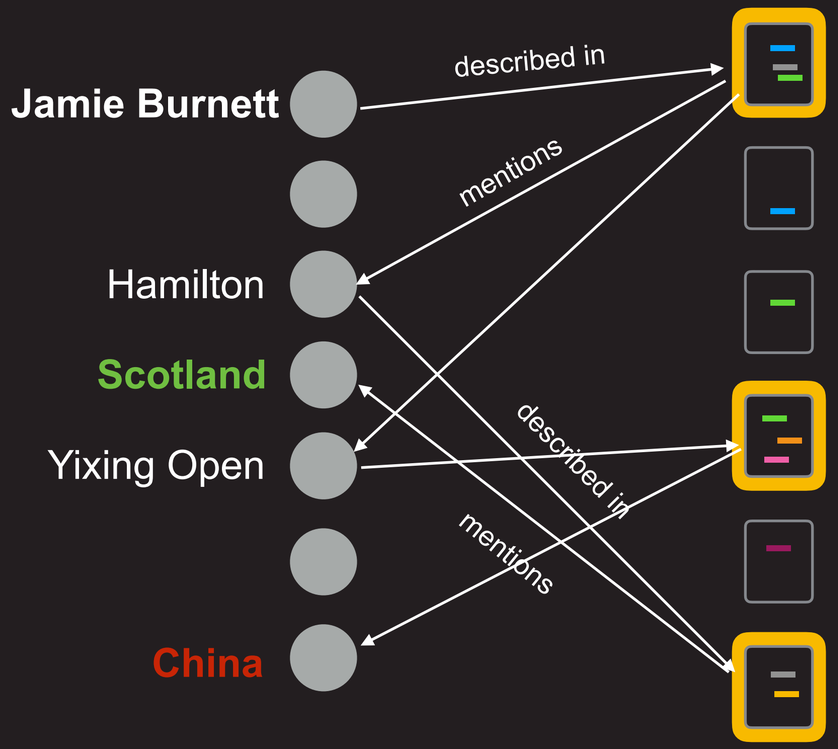
Documents



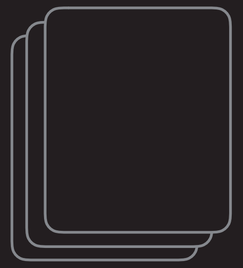
Instance

What is the nationality of Jamie Burnett?

Scotland

China

Dataset Construction Method



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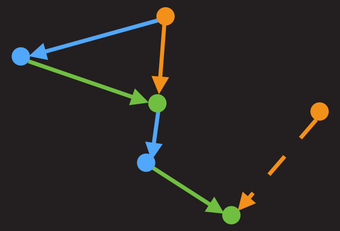


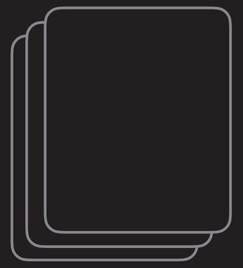
Knowledge Base

Dataset Construction Method

Multihop Dataset

[Conditionally Accepted to TACL]

Dataset Construction Method



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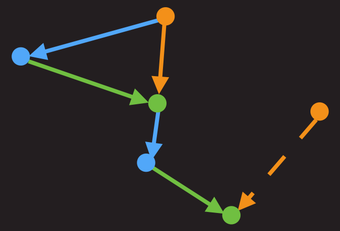
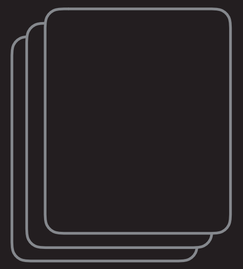
Dataset Construction Method

WikiHop



Knowledge Base

Dataset Construction Method



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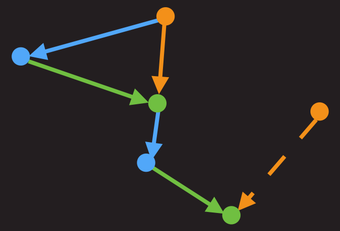
Dataset Construction Method

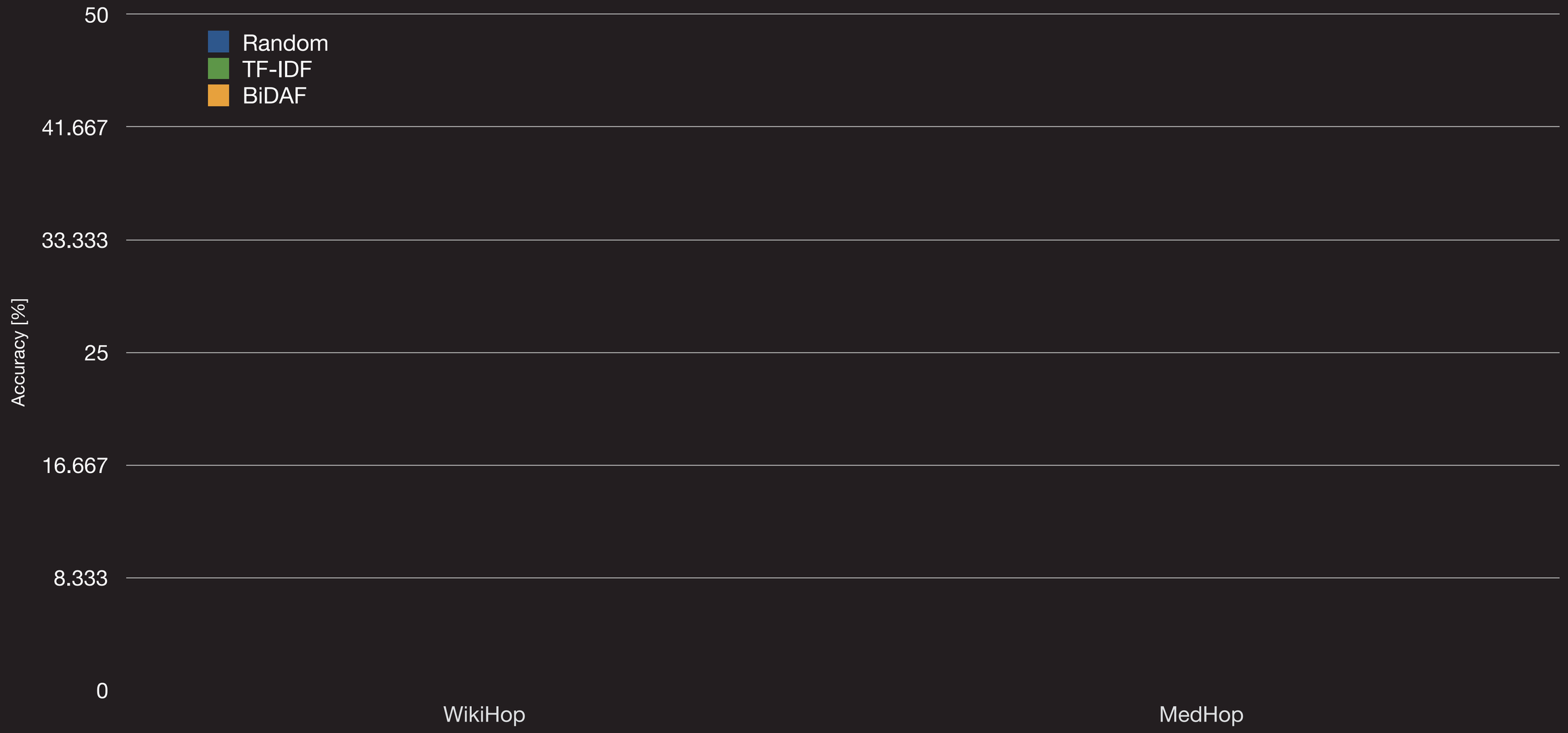
MedHop



Knowledge Base

Baseline Results

Baseline Results



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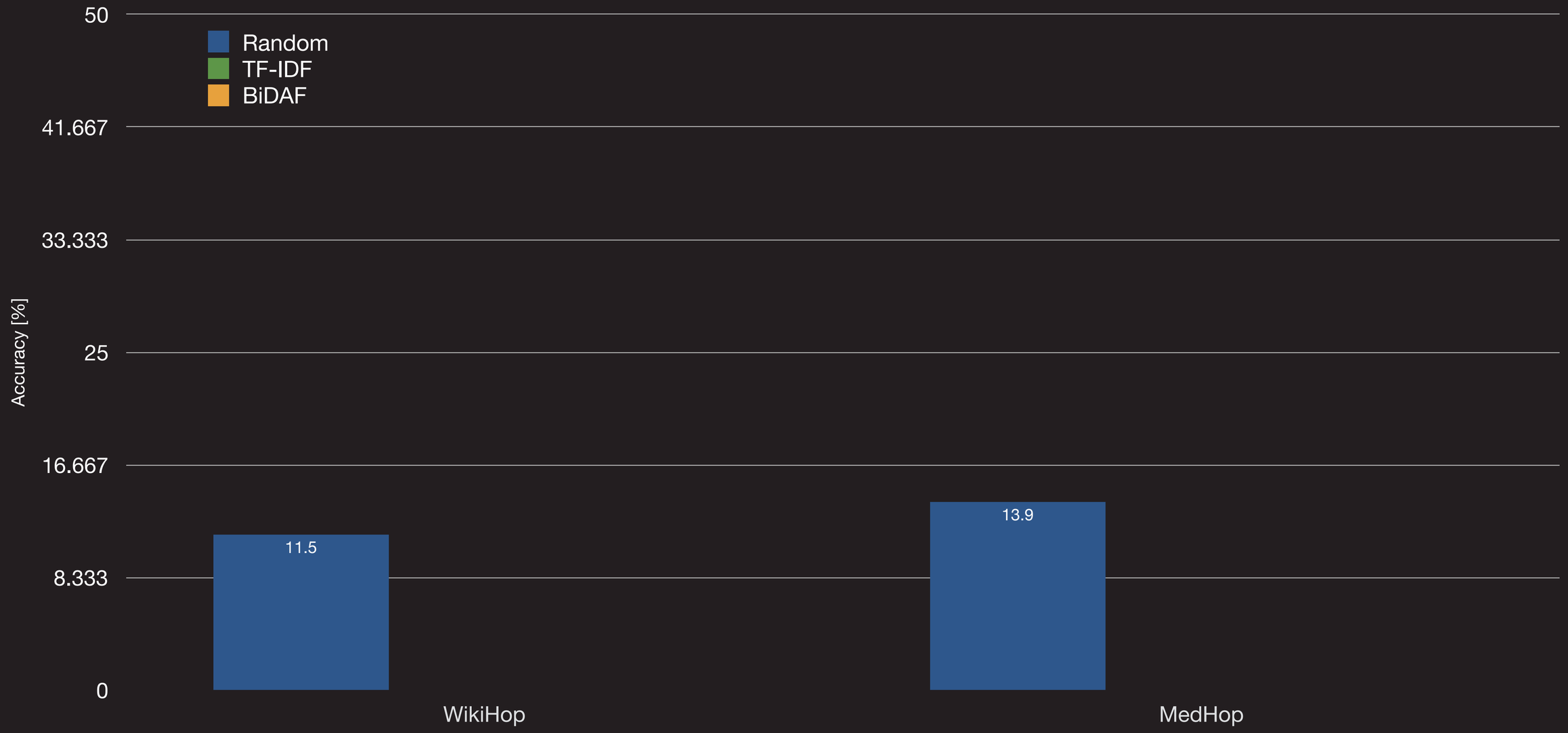

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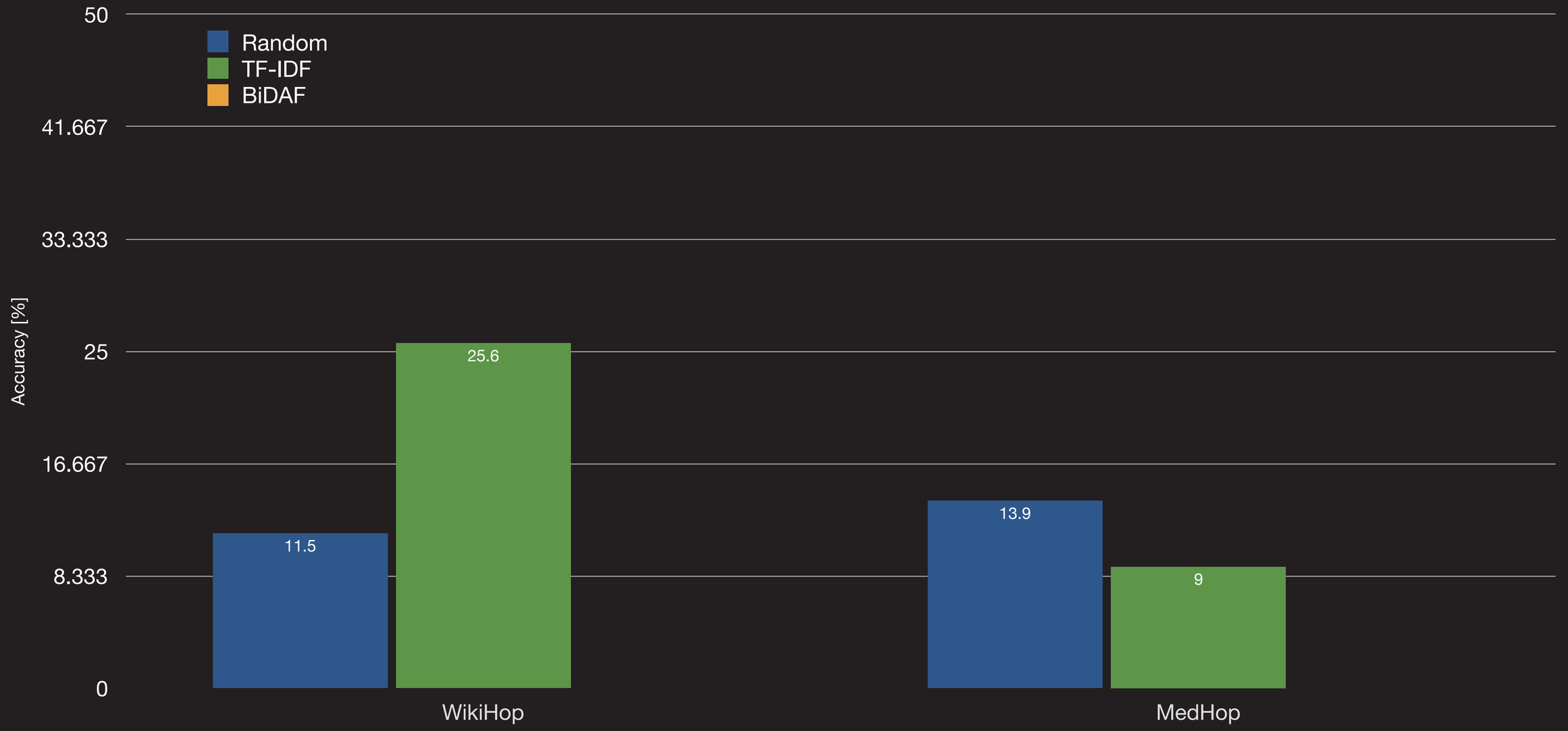

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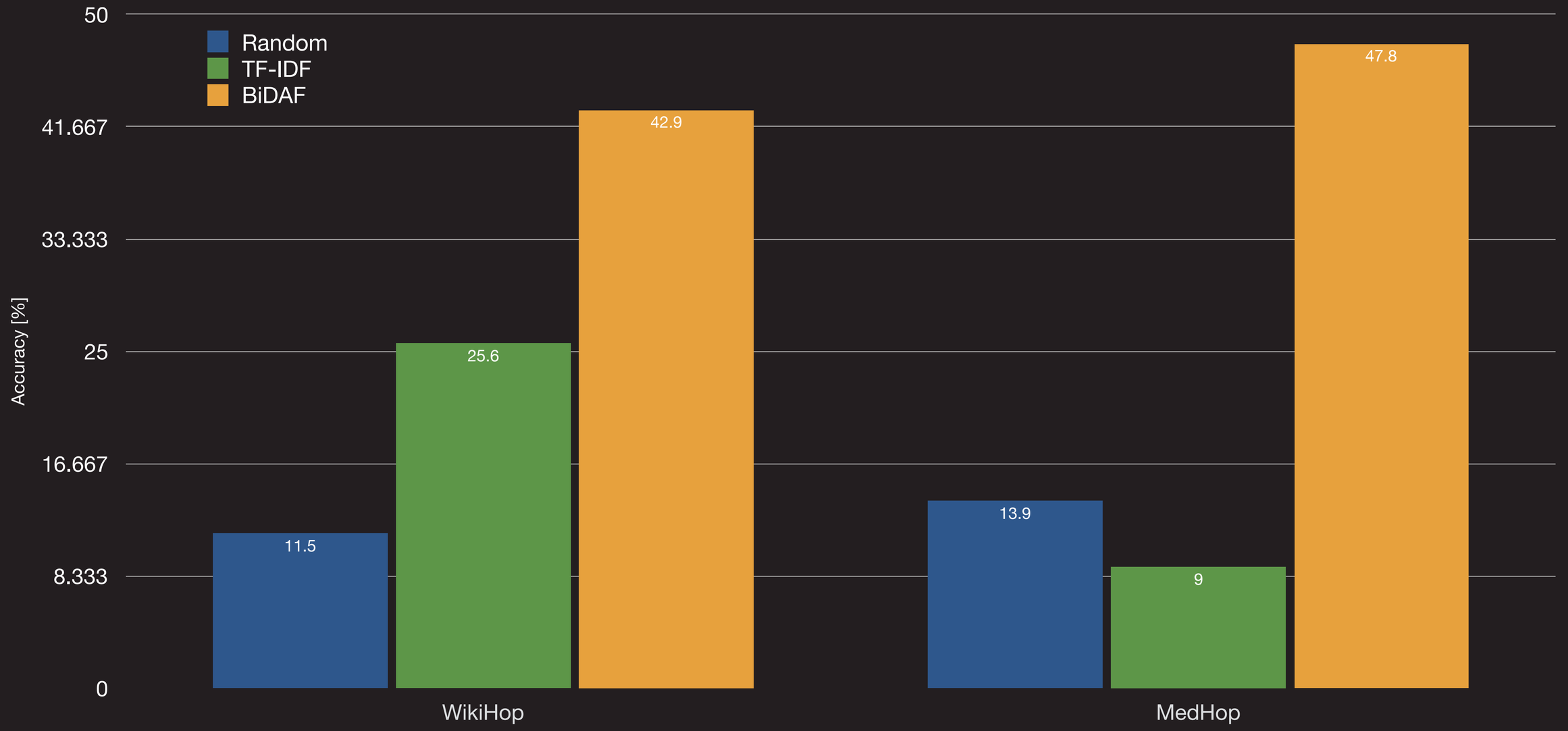
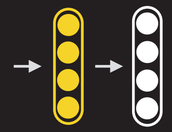


Reduction to Traditional Machine Comprehension

Which medical specialty deals with pituitary ACTH hypersecretion?

Endocrinology



Pituitary ACTH hypersecretion ... is a form of hyperpituitarism characterized by an abnormally high level of ACTH produced by the **anterior pituitary** …

A major organ of the **endocrine system**, the **anterior pituitary** is the glandular, anterior lobe that ...

The endocrine system is ... ... The field of study dealing with the **endocrine system** and its disorders is **endocrinology**, a branch of internal medicine.

Reduction to Traditional Machine Comprehension

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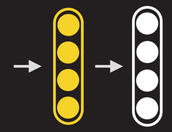

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Do Neural Reading Models Aggregate?

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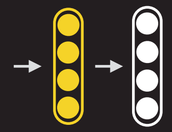

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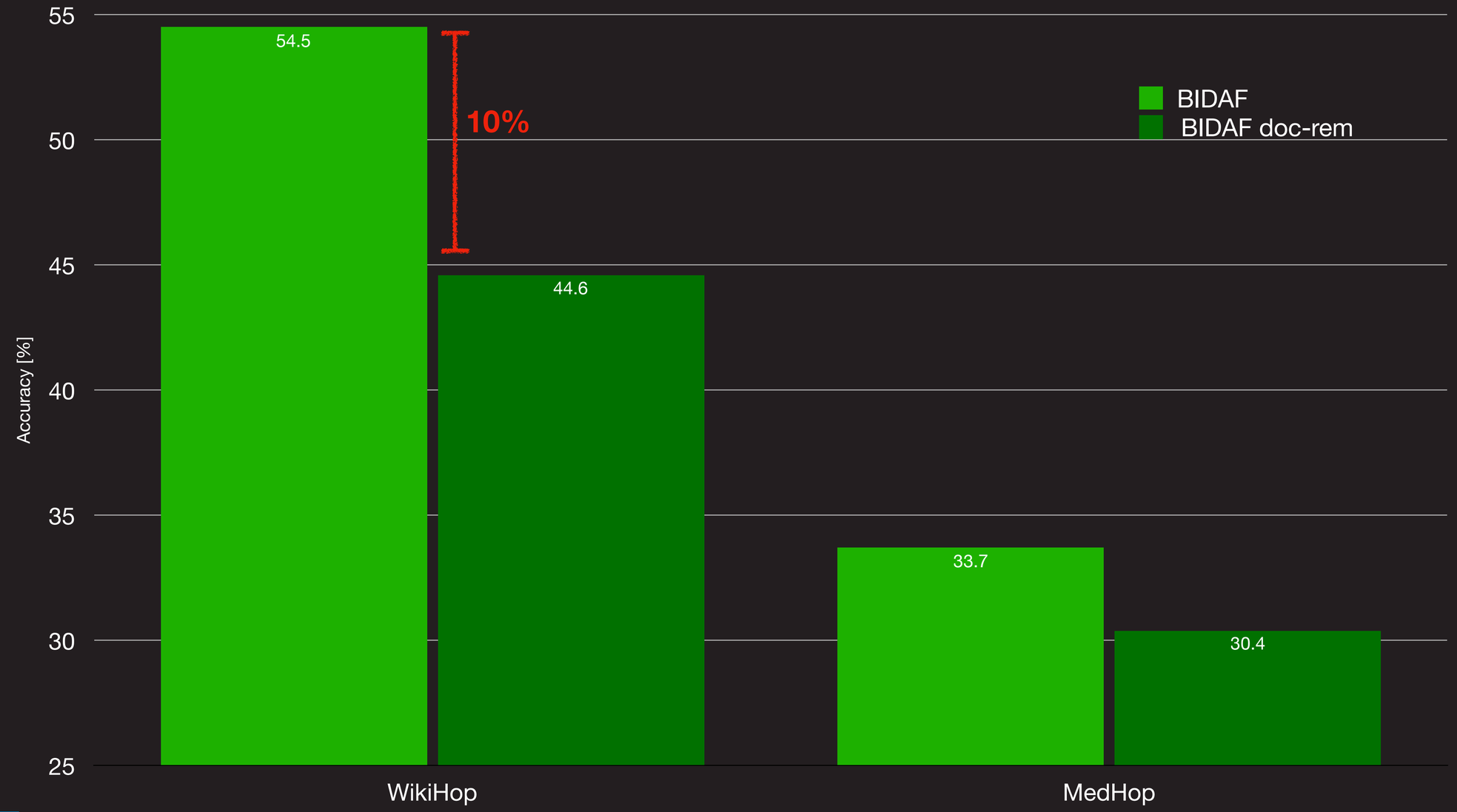
Removing Relevant Documents, Keep Answer Documents



TACL 2018
QAngaroo
Reading Comprehension with Multiple Hops
Paper
Dataset Download
Dataset Distribution under CC BY-SA 3.0

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)

Matko Bosnjak

Tim Rocktäschel

Jason Naradowsky

Part 2: Learning to Read and Calculate

Machine Reading and Reasoning: Math

How many pictures were in each of the albums?

2

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

How many pictures were in each of the albums?

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Model

Program Interpreter

Reader

Bosnjak et al. **ICML 2017**

Differentiable Program Interpreters

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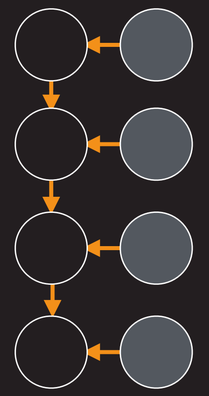

Bosnjak et al. **ICML 2017**

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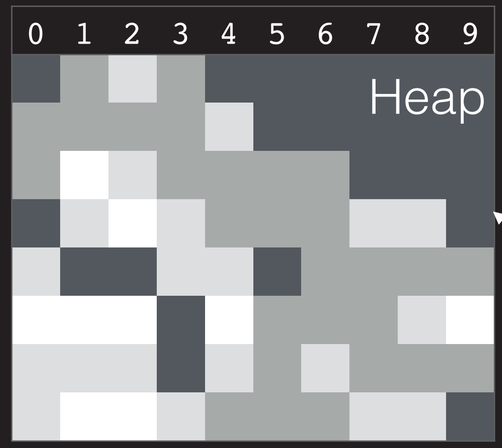
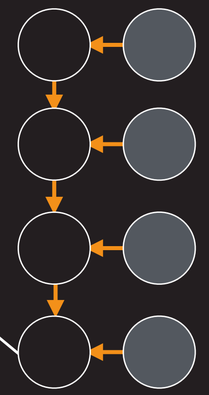
Program Interpreter



Reader



Bosnjak et al. **ICML 2017**

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Model

Program Interpreter

d

0 1 2 3 4 5 6 7 8 9

Stack

3

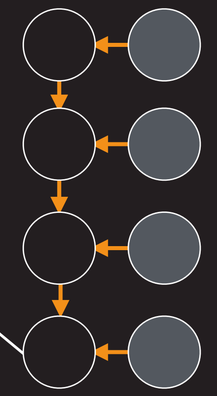
4

2

0 1 2 3 4 5 6 7 8 9

Heap

Reader



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Differentiable Program Interpreters

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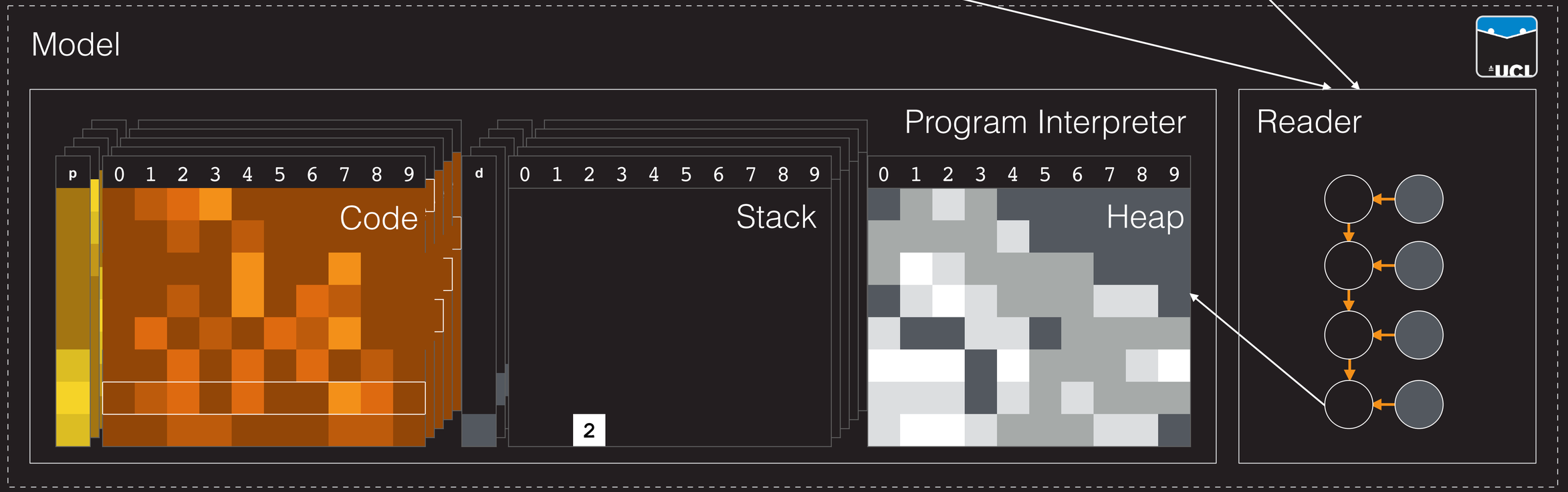

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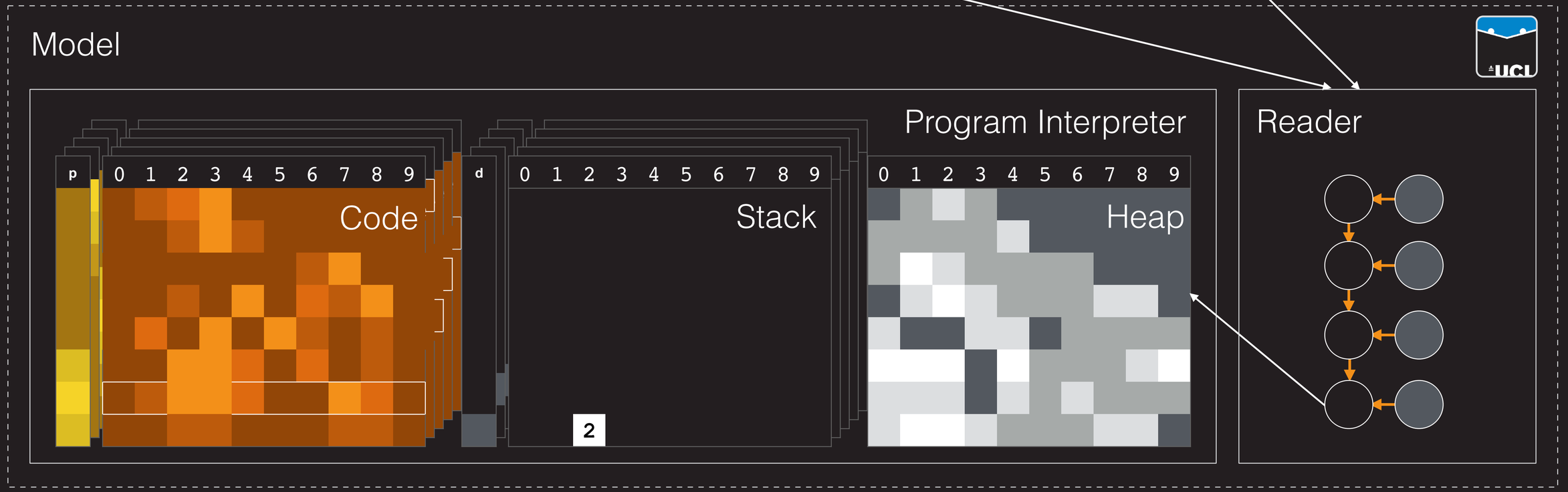

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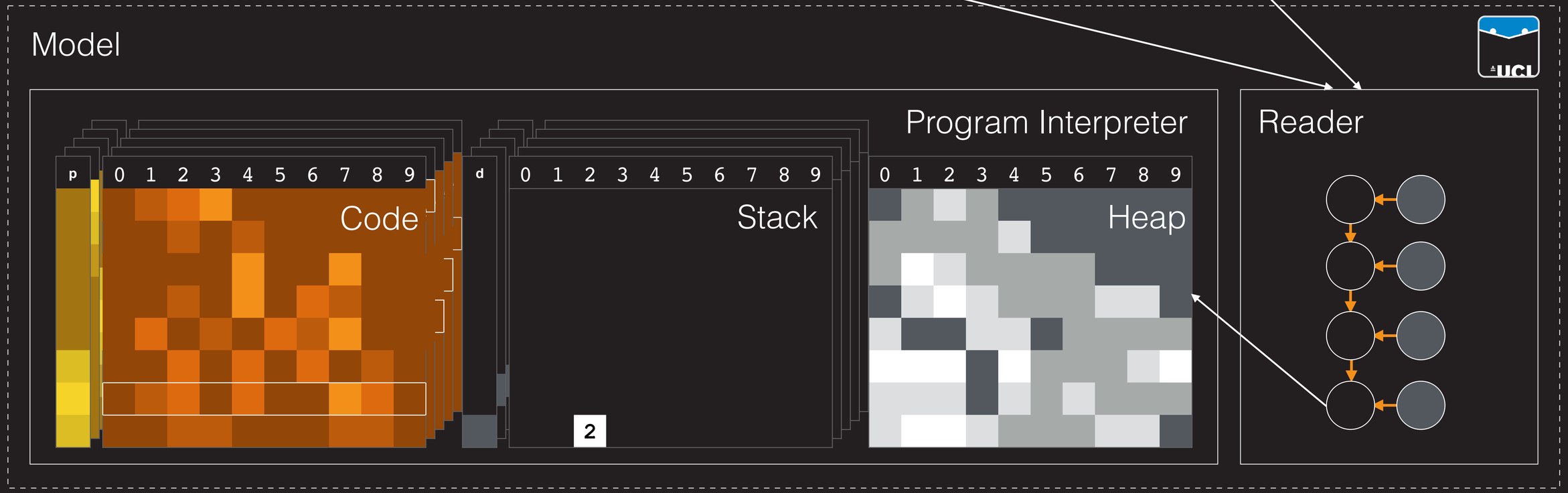

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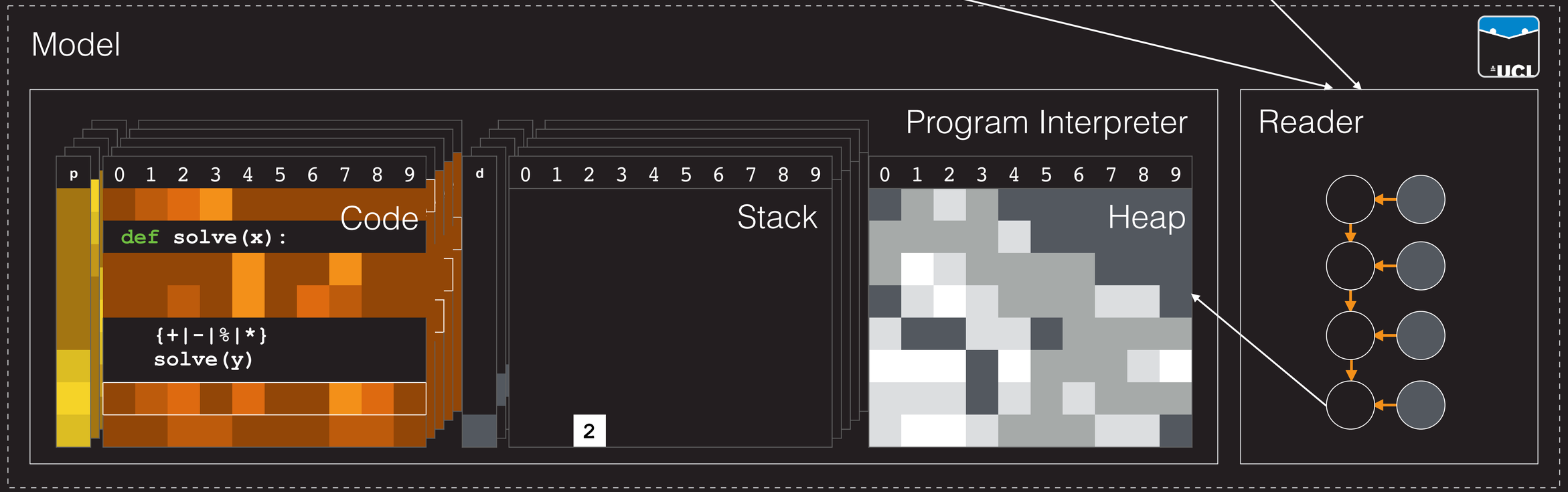

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Results on Math Problems (Accuracy)

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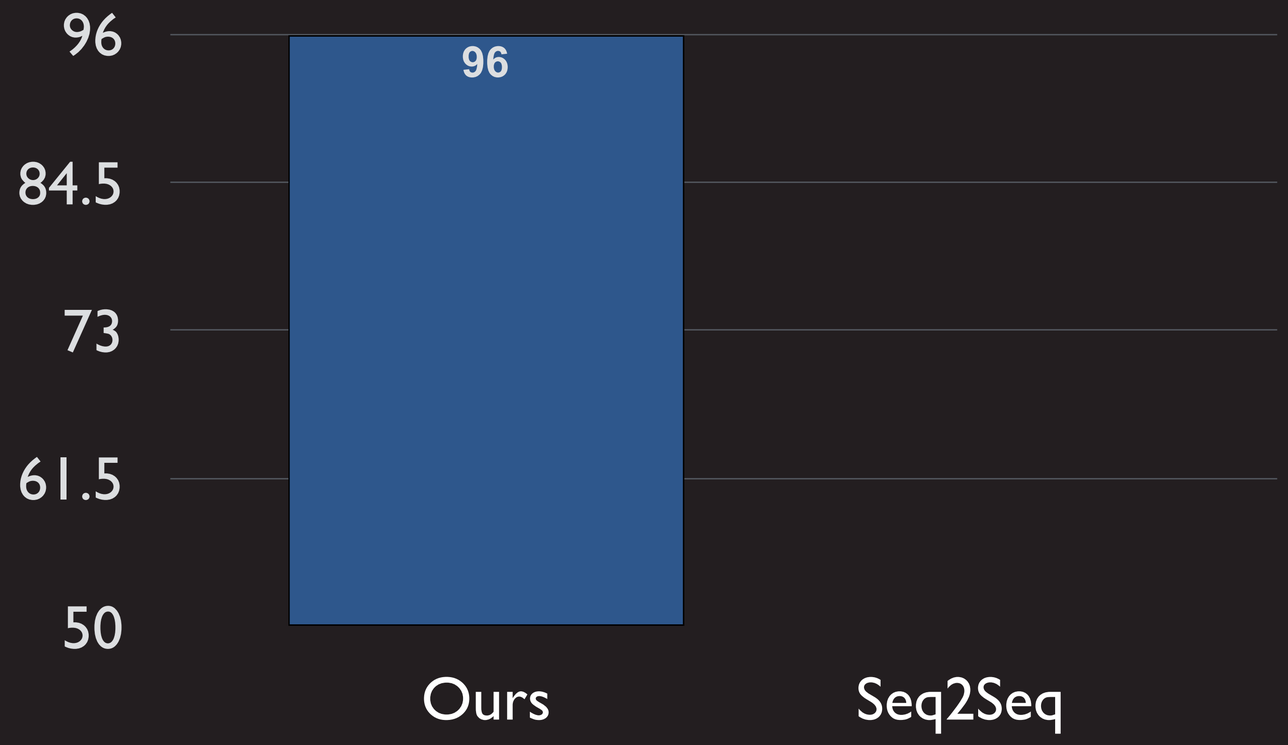

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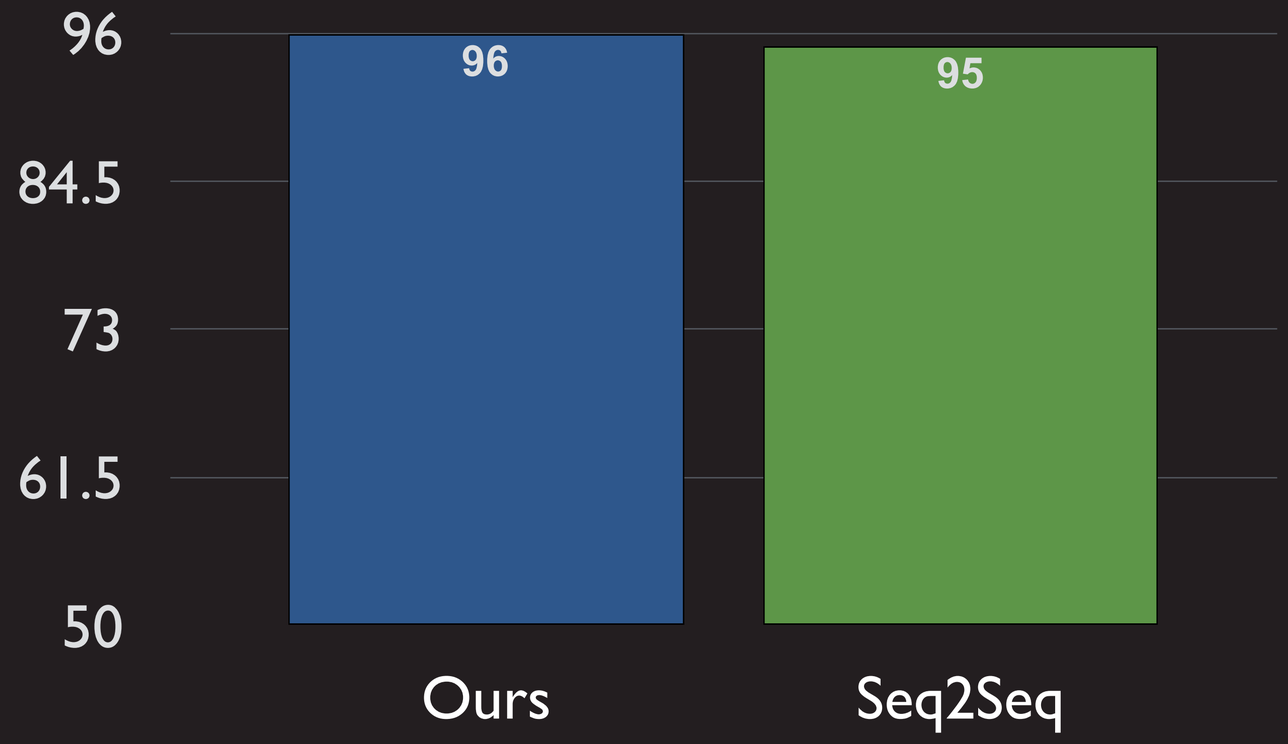

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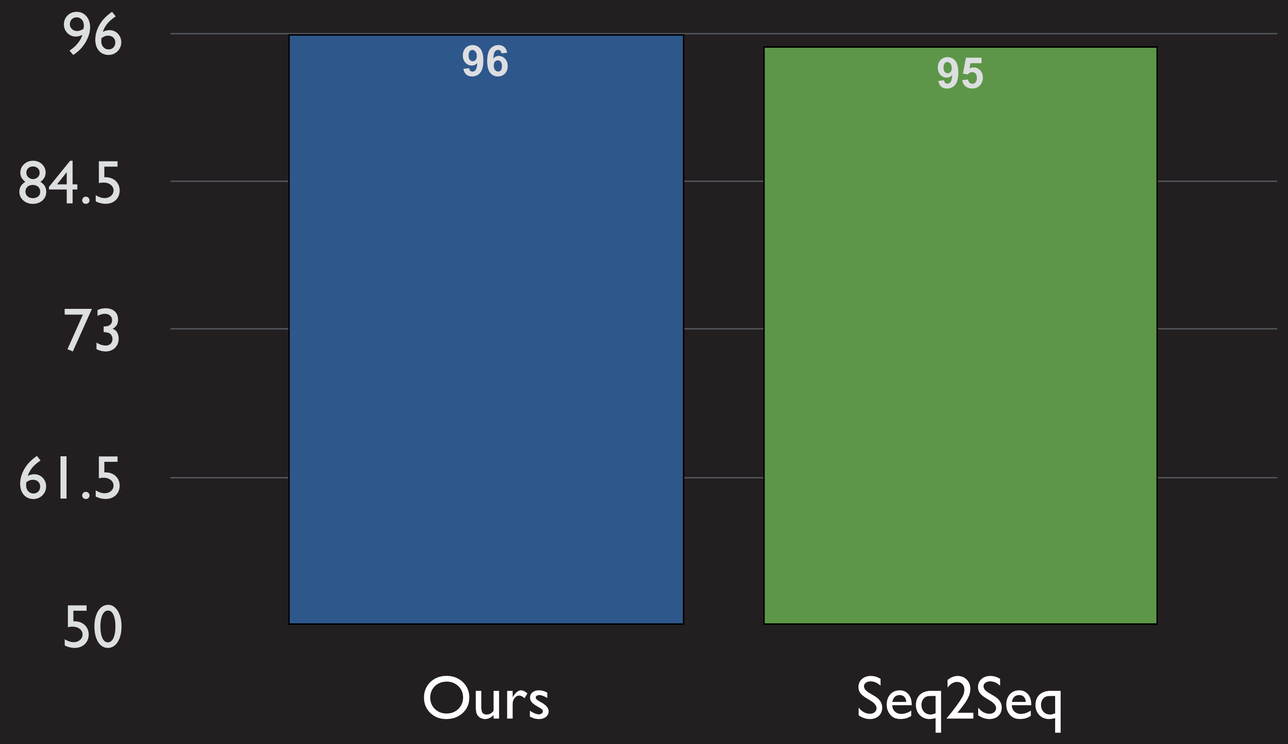

Seq2Seq solves simpler problem

How many pictures were in each of the albums?

(2 + 4) / 3

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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

Tim Rocktäschel

Guillaume Bouchard

Marzieh Saeidi

Max Bartolo

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.

And Ask Clarification Questions

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

Have you been working abroad 52 weeks or less?

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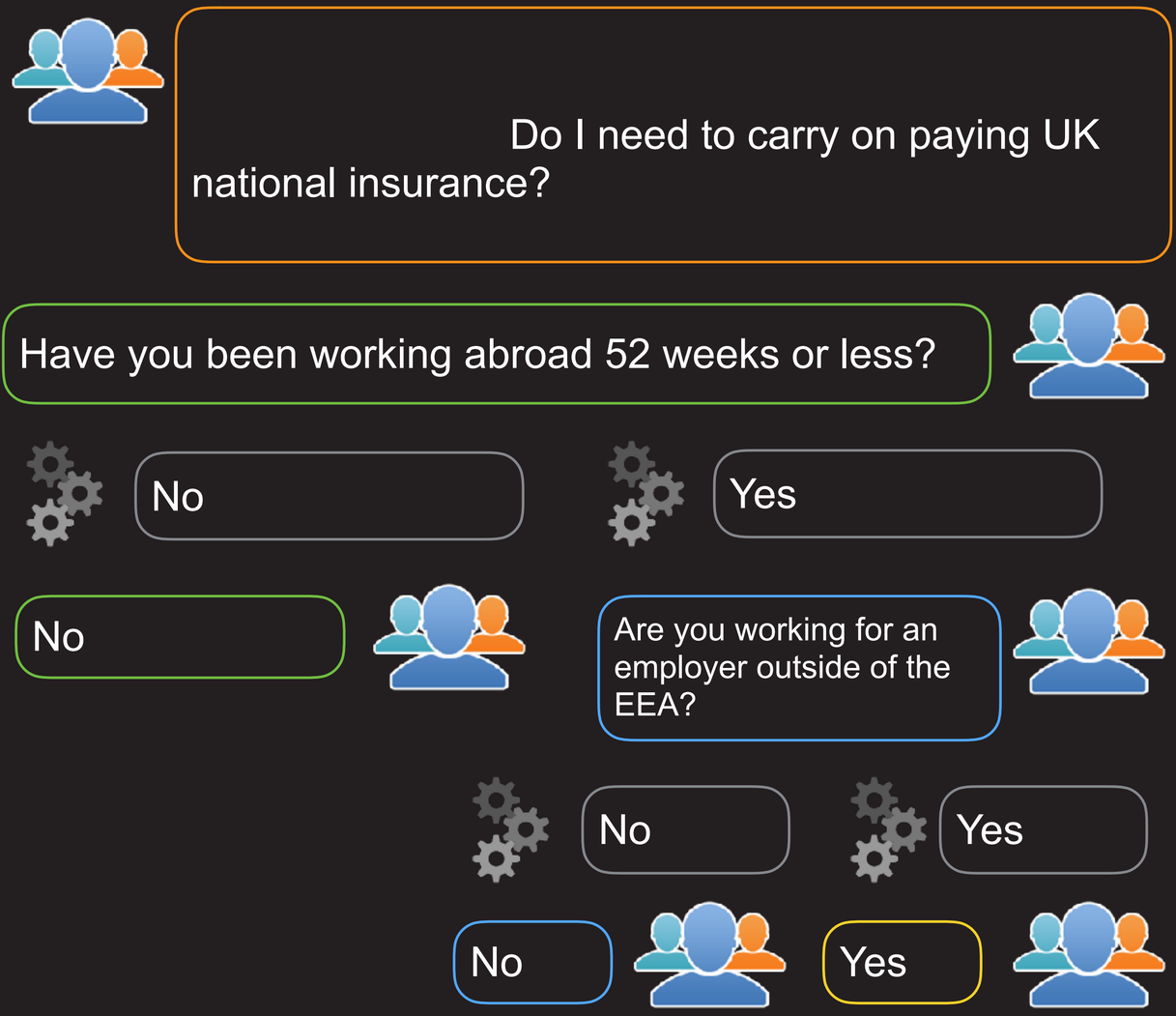

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Created ~40k instances this way

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Were you laid before earning at least the lower earnings limit?

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Seq2Seq with attention
(to your needs)

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