

# Machine Reading and Reasoning with Neural Program Interpreters

▶ Sebastian Riedel

 @riedelcastro

# Collaborators



**Johannes Welbl**  
(UCL)



**Pontus Stenetorp**  
(UCL)



**Matko Bosnjak**  
(UCL)



**Tim Rocktäschel**  
*(now at Oxford)*

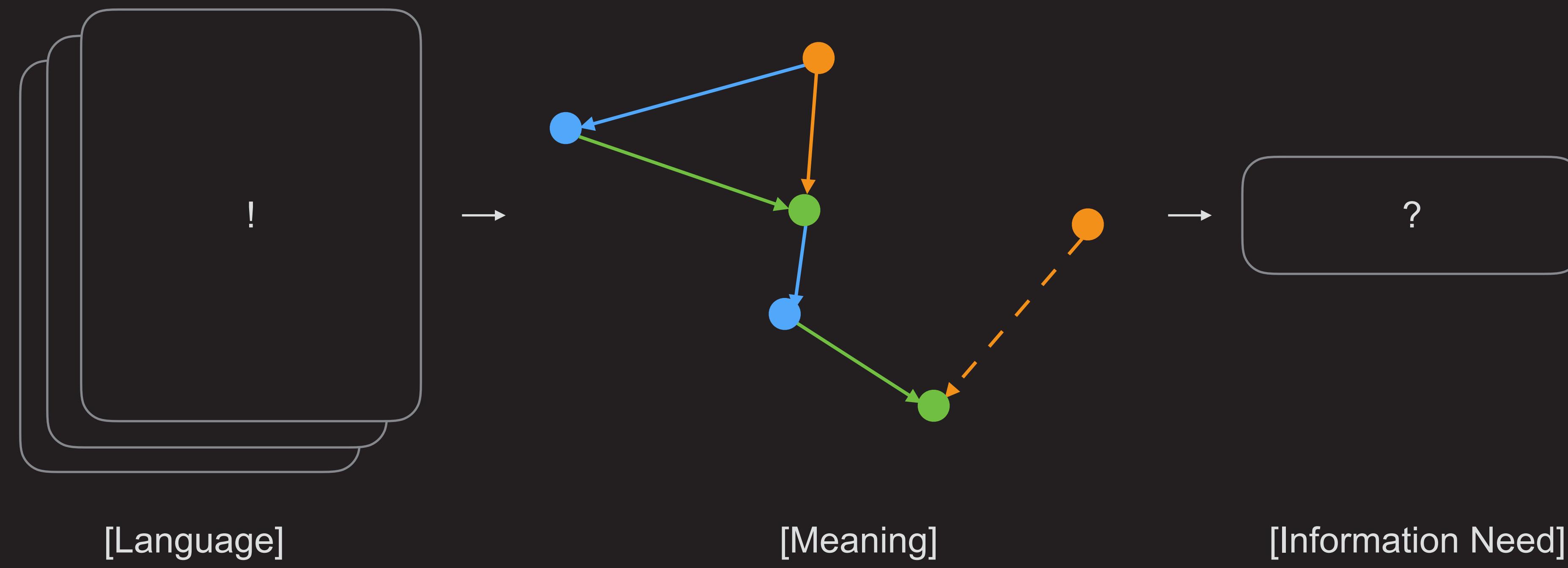


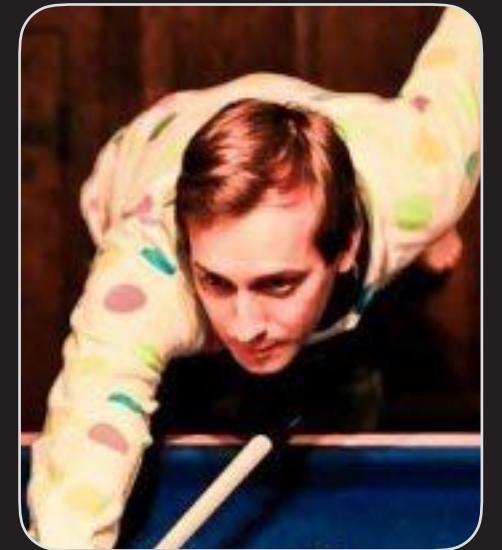
**Jason Naradowsky**  
*(Johns Hopkins University)*



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

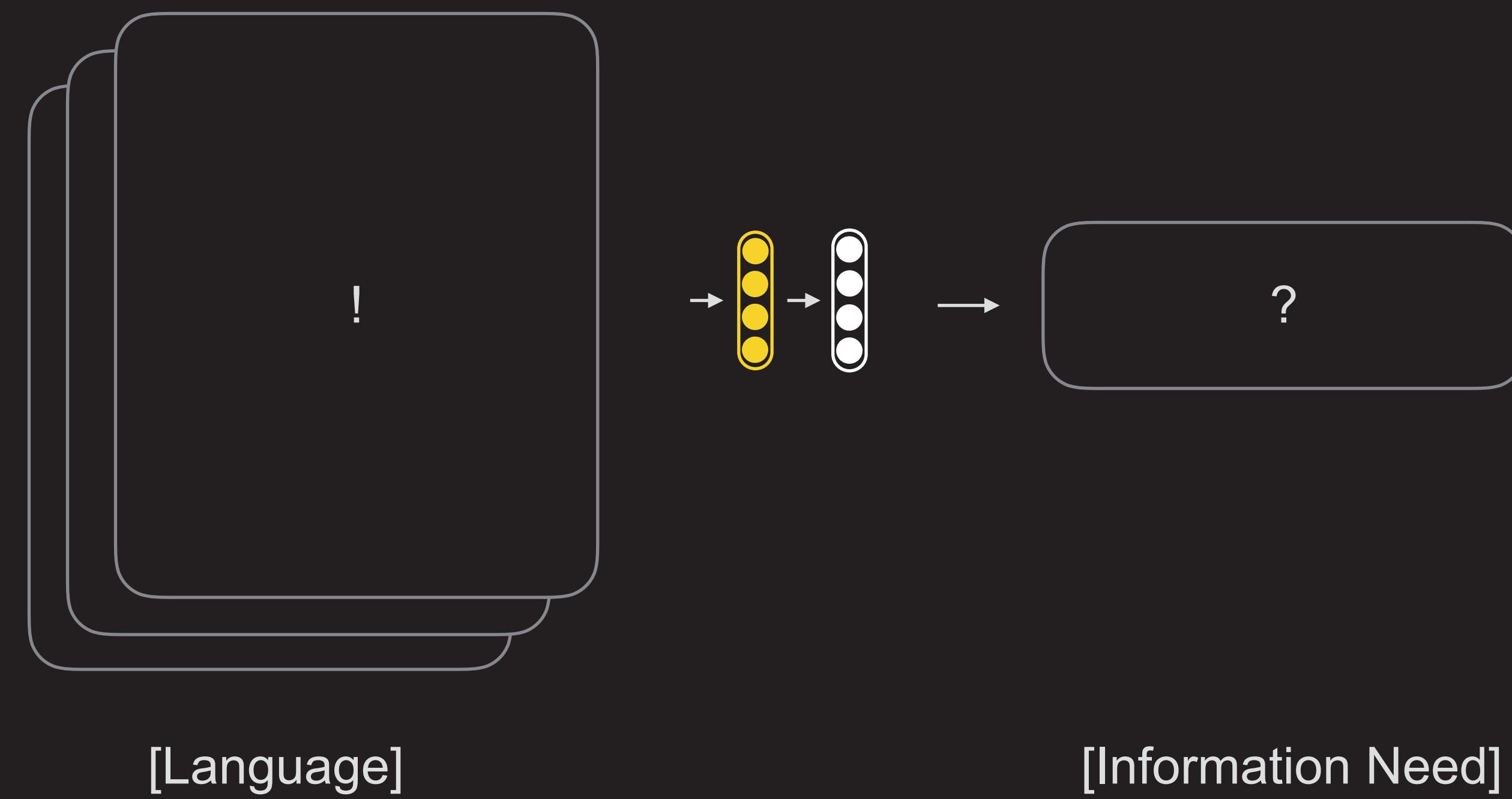
Chris Manning  
@AKBC 2013





# End-to-End Reading and Comprehension

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

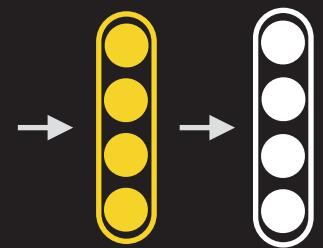


# Machine Reading



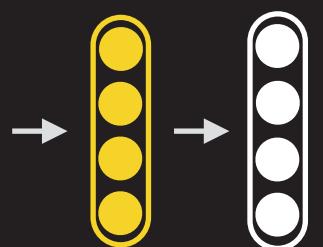
What city did Tesla move to in 1880?

Prague



Why was he unable to enroll at the university?

arrived too late to enroll



**Nicola Tesla**

...

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 enroll 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.

# How to read and reason?

# Machine Reading and Reasoning



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.

# Machine Reading and Reasoning



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.

Can we learn this end-to-end?



Johannes Welbl



Pontus Stenetorp

# Part 1: A Read & Reason Dataset

The background of the image is a photograph of several kangaroos in a green, grassy field. In the foreground, two kangaroos are clearly visible, facing the camera. Behind them, several more kangaroos are blurred, creating a sense of depth.

# QAngaroo

## Reading Comprehension with Multiple Hops

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[!\[\]\(b8a72a3753dcf585f9661ac843b3f6db\_img.jpg\) Paper](#)[!\[\]\(e462f608b89f421f9d905728e26f6429\_img.jpg\) Dataset Download](#)

Dataset Distribution under [CC BY-SA 3.0](#)

# A Single Instance

What is the nationality of Jamie Burnett?

▶ Candidates:

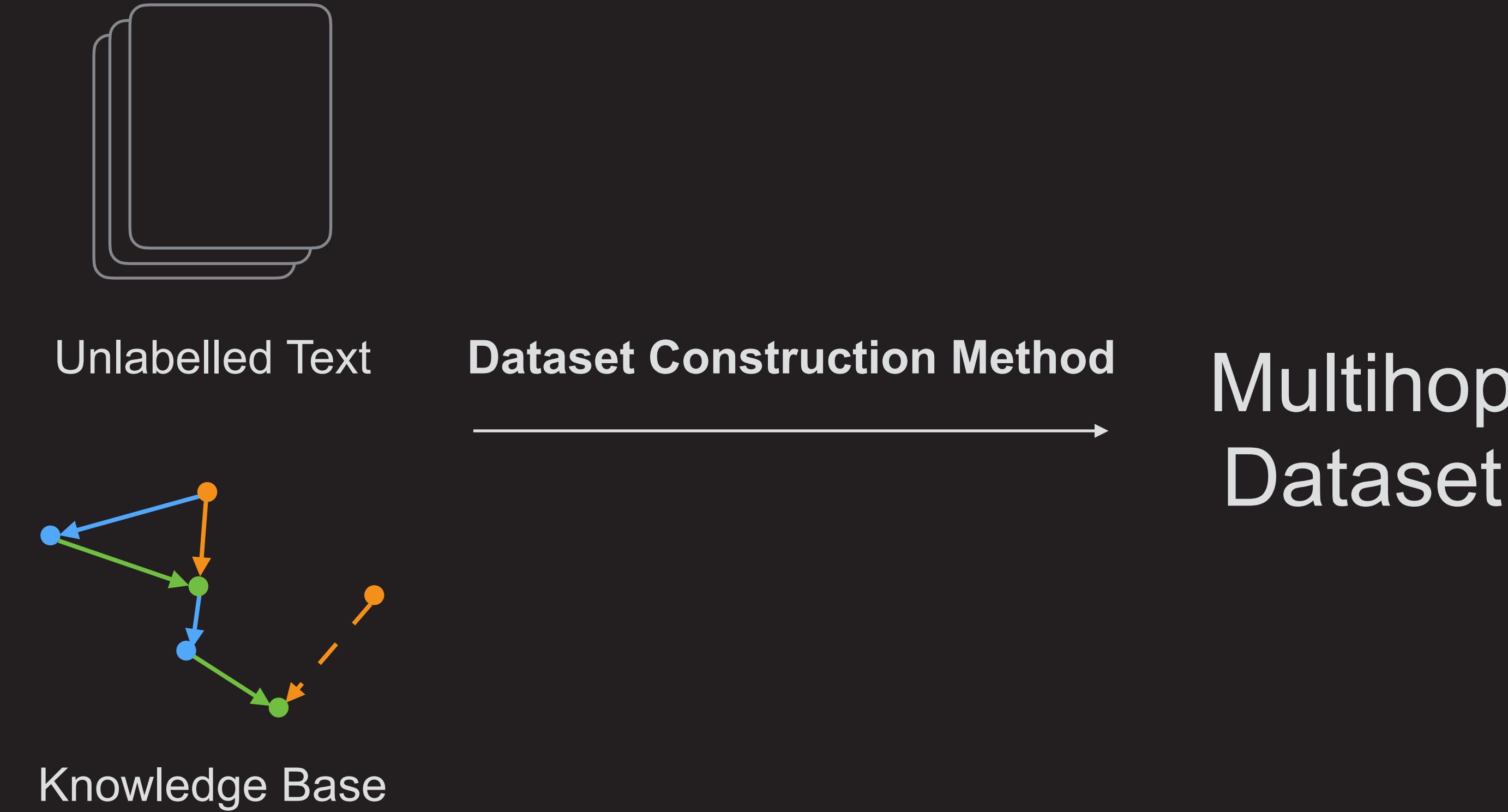
- ▶ **Scotland (correct)**
- ▶ **China (incorrect)**
- ▶ ...

Jamie Burnett (born 16 September 1975 ) is a professional snooker player from Hamilton, South Lanarkshire...He began the 2014/2015 season with a quarter-final showing at the Yixing Open...

...Hamilton is a town in South Lanarkshire, in the central Lowlands of Scotland...

The Yixing Open was a professional minor-ranking snooker tournament that took place at the Yixing Sports Centre in Yixing, China.

# Dataset Construction Method



# Dataset Construction Method

KB Triple

Jamie Burnett, citizenship, Scotland

Entities

Jamie Burnett

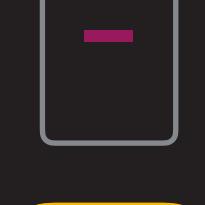
Hamilton

Scotland

Yixing Open

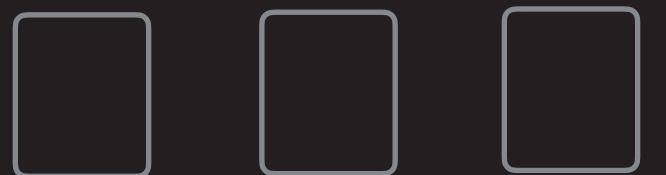
China

Documents



Instance

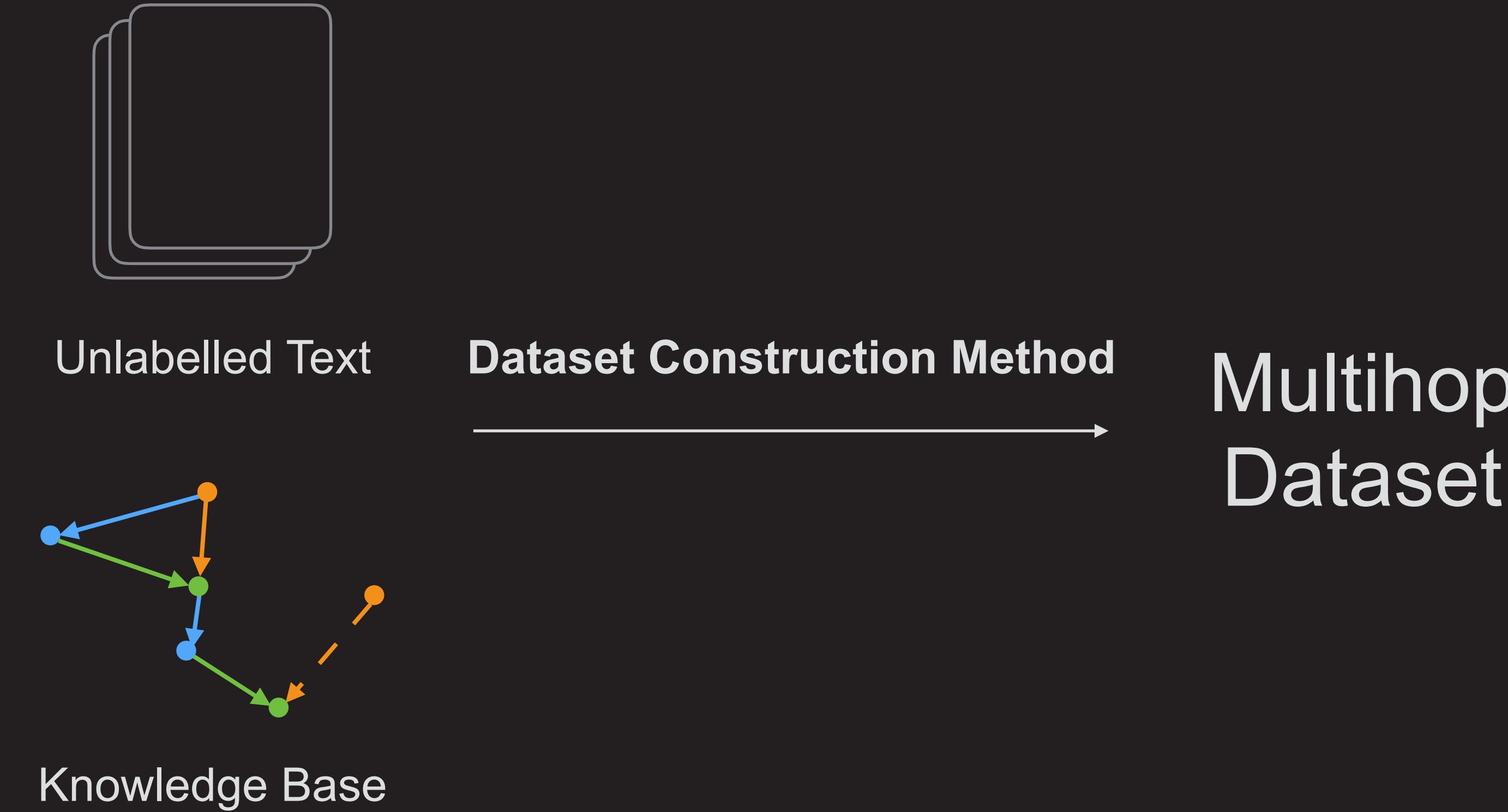
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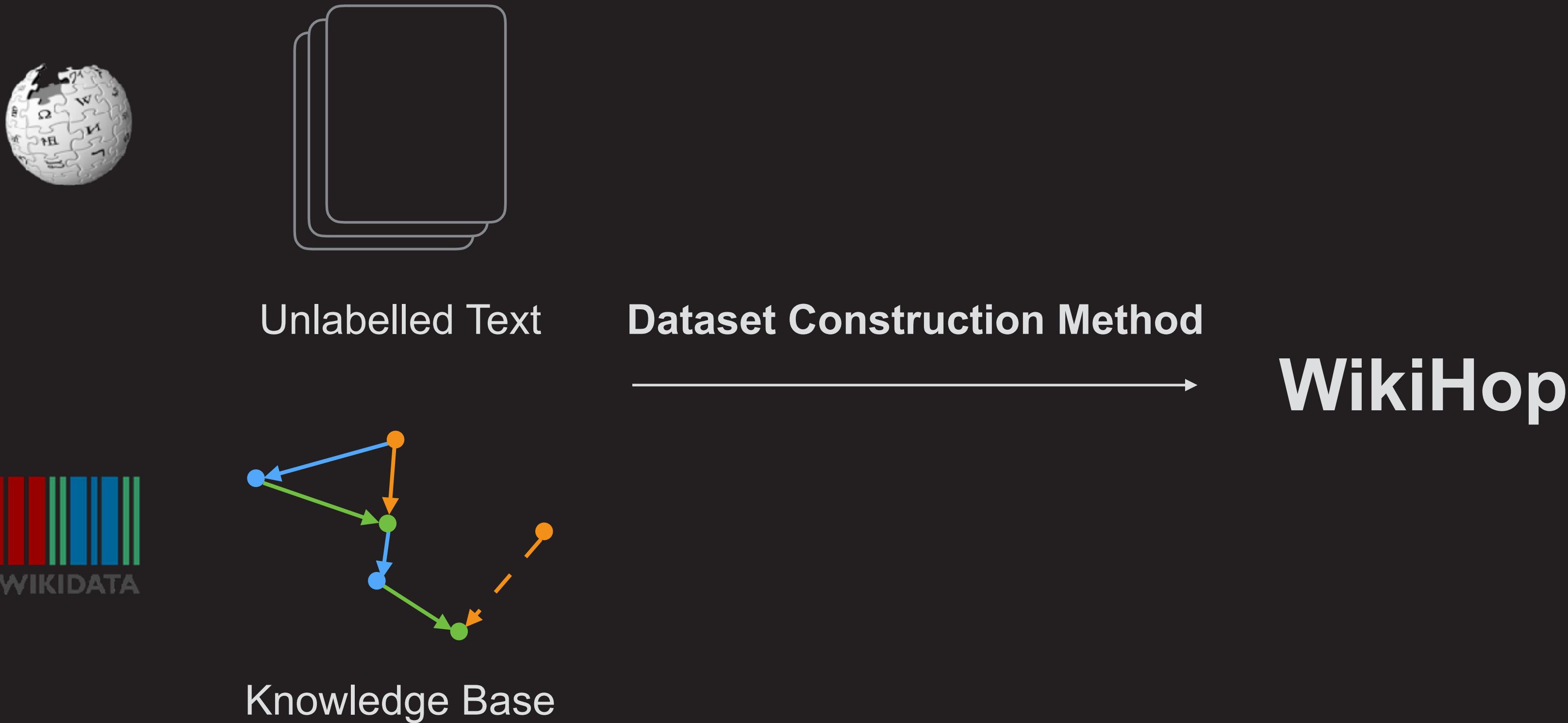
Scotland

China

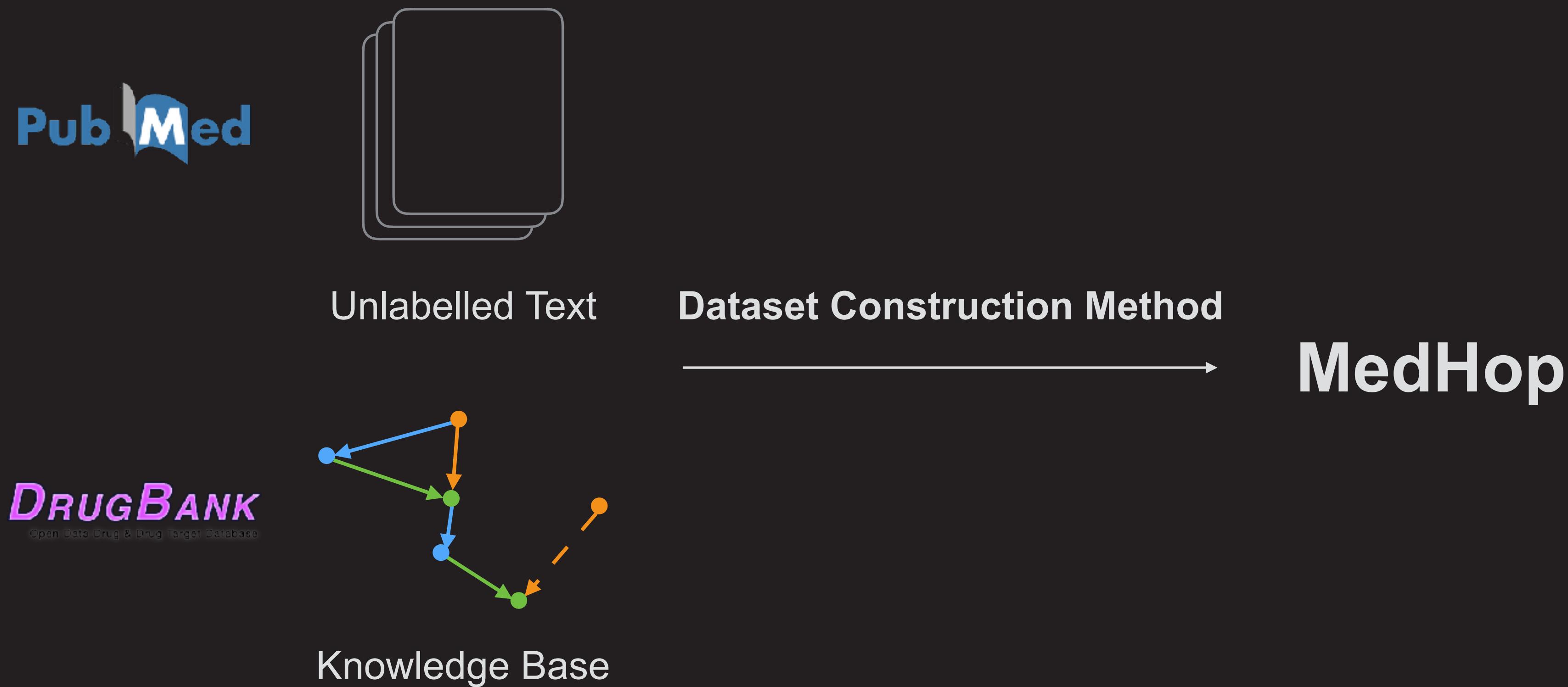
# Dataset Construction Method



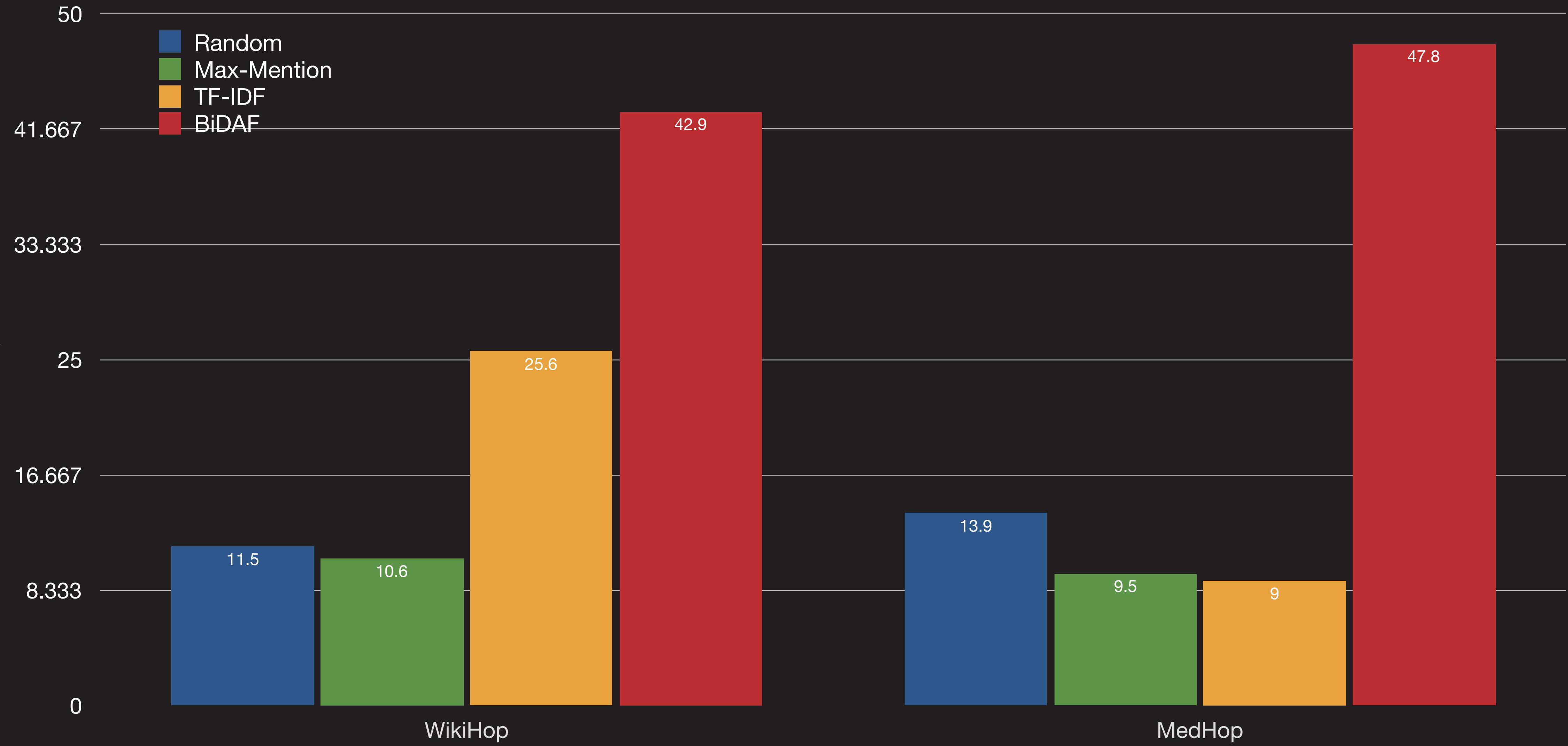
# Dataset Construction Method



# Dataset Construction Method



# Baseline Results

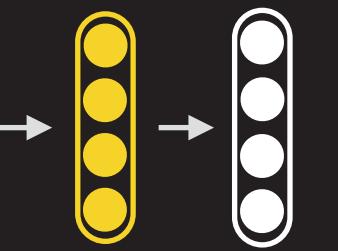


# Reduction to Traditional Machine Comprehension



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 ...

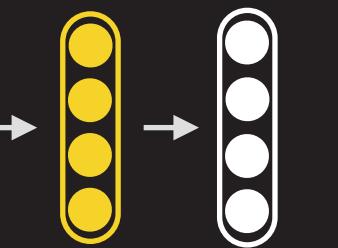
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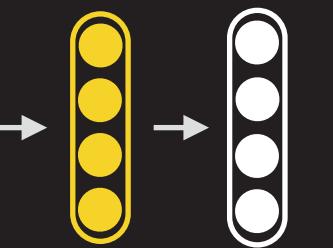
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# Does BiDaf Aggregate?



Which medical specialty deals with pituitary ACTH hypersecretion?

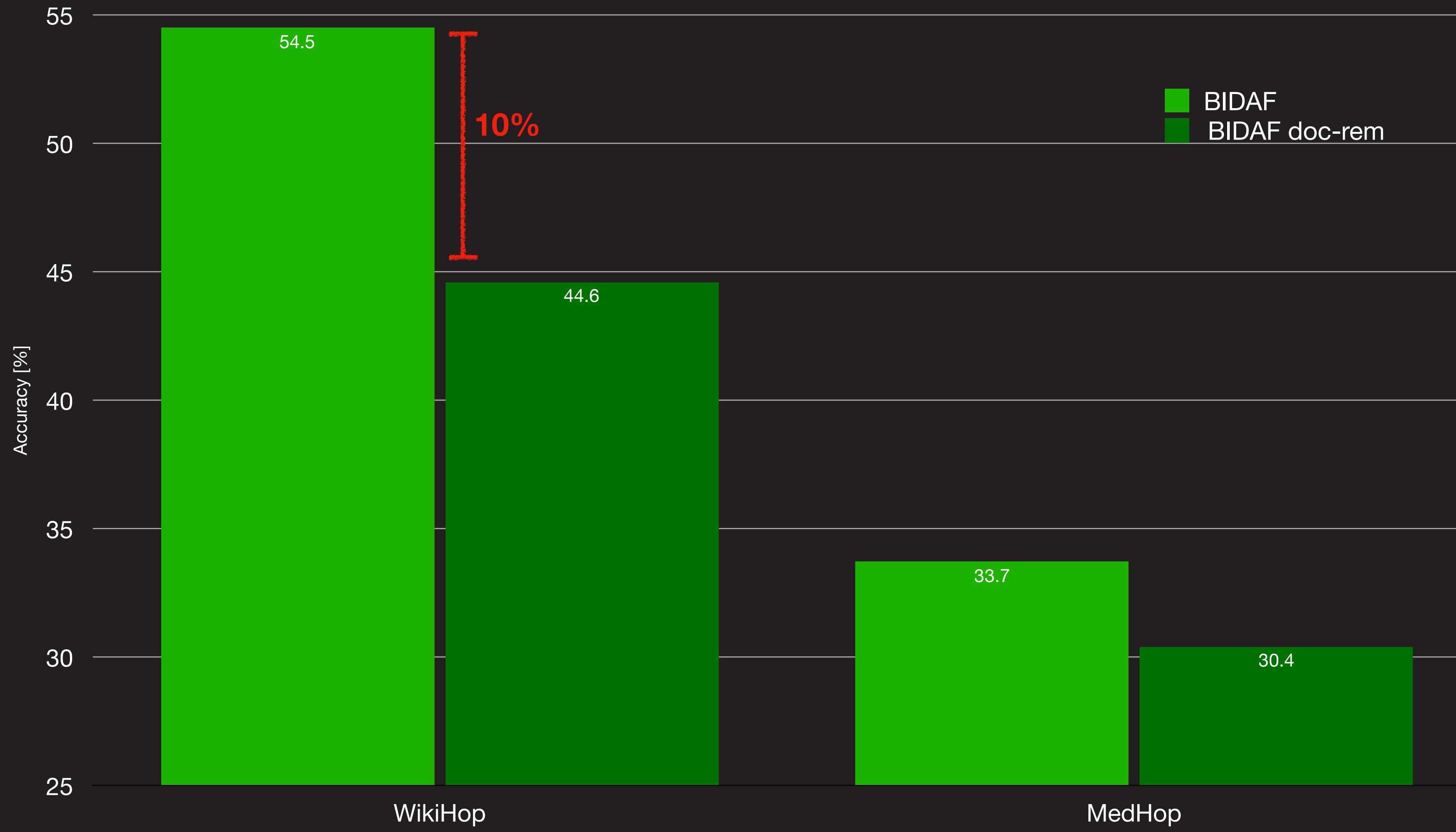
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A major organ of the **endocrine system**, the **anterior pituitary** is the glandular, anterior lobe that ...

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# Removing Relevant Documents, Keep Answer Documents





**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



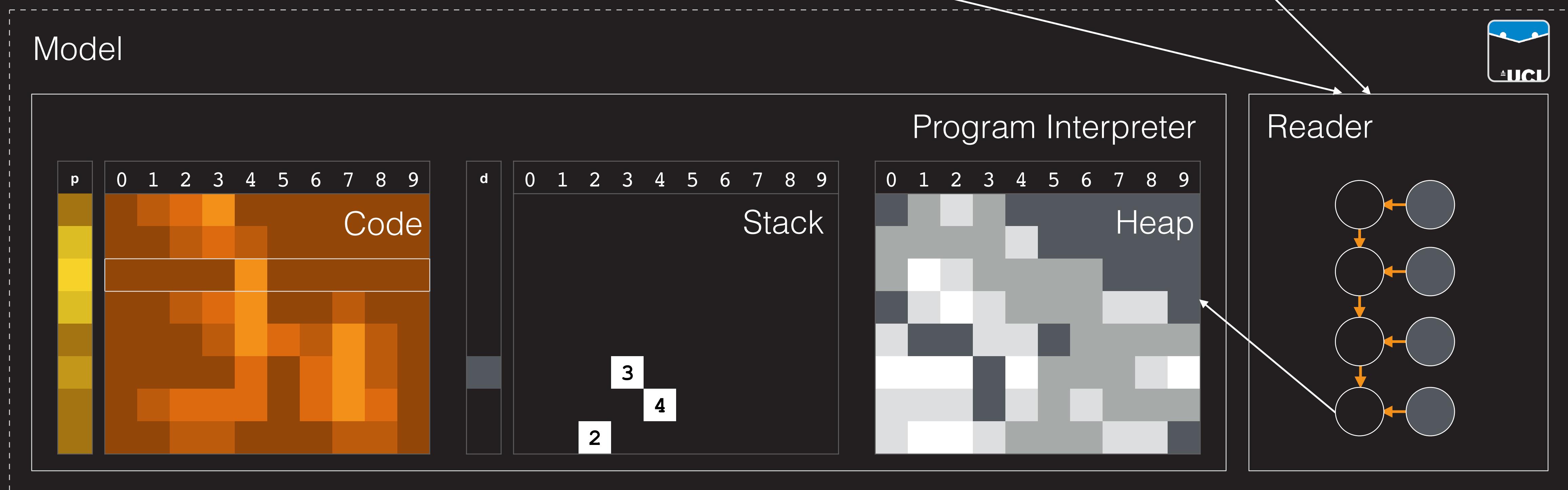
Isabel uploaded **2 pictures from her phone** and **4 from her camera** to facebook. She sorted the pics into **3 different albums** with the same amount of pics in each album.

# Differentiable Program Interpreters



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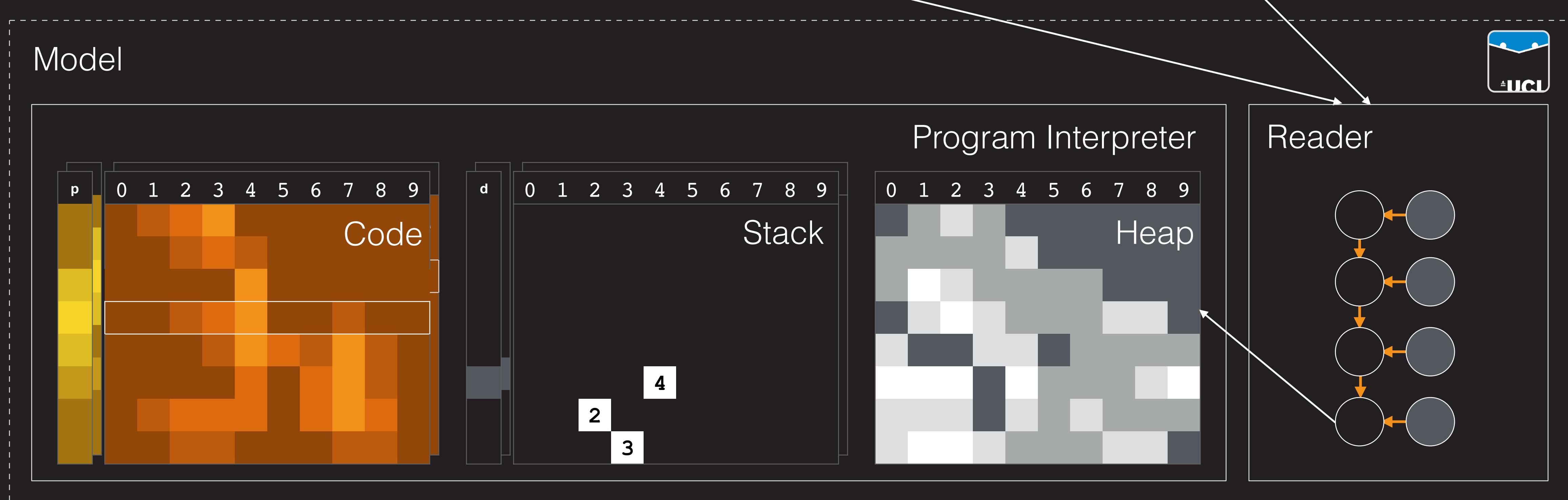


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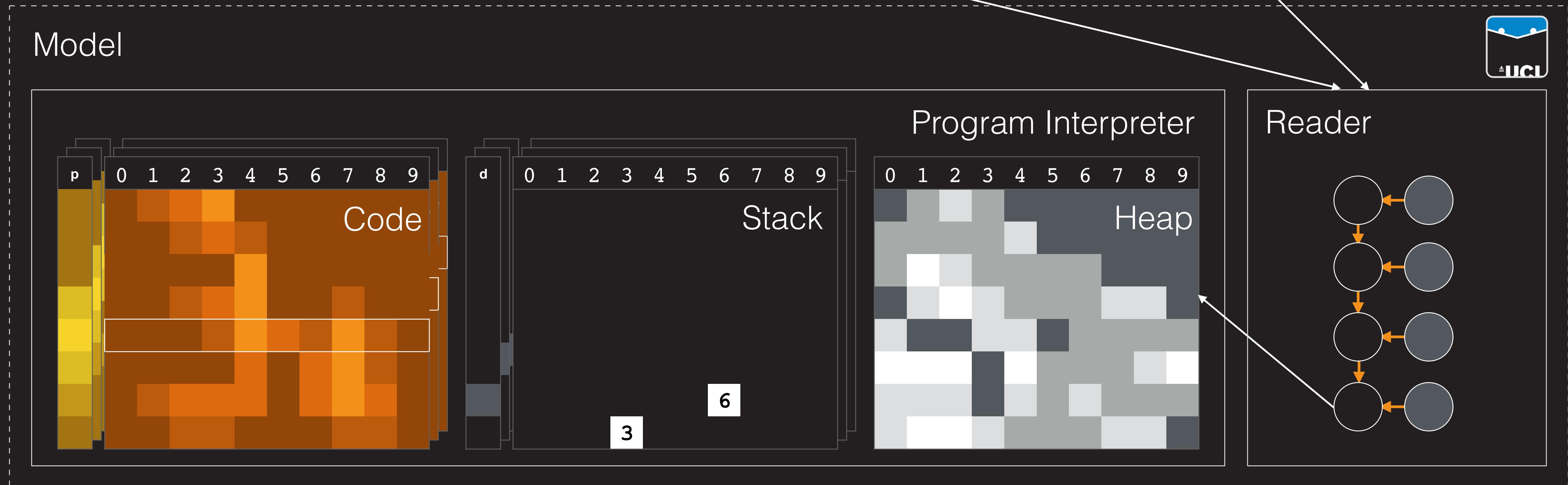


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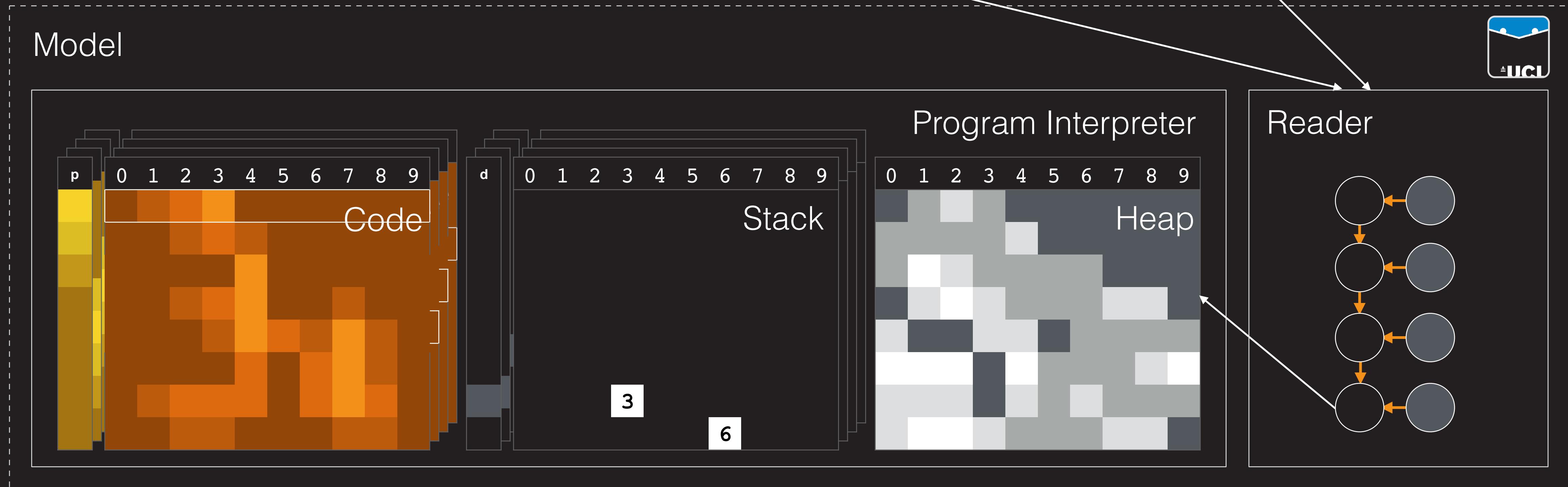


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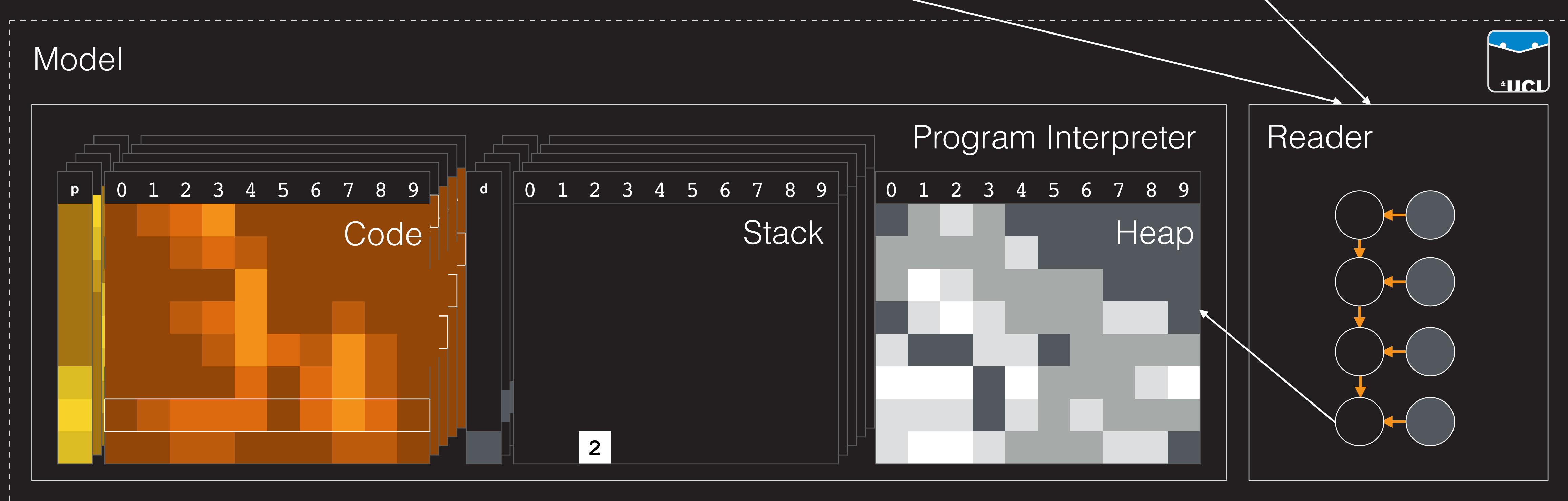


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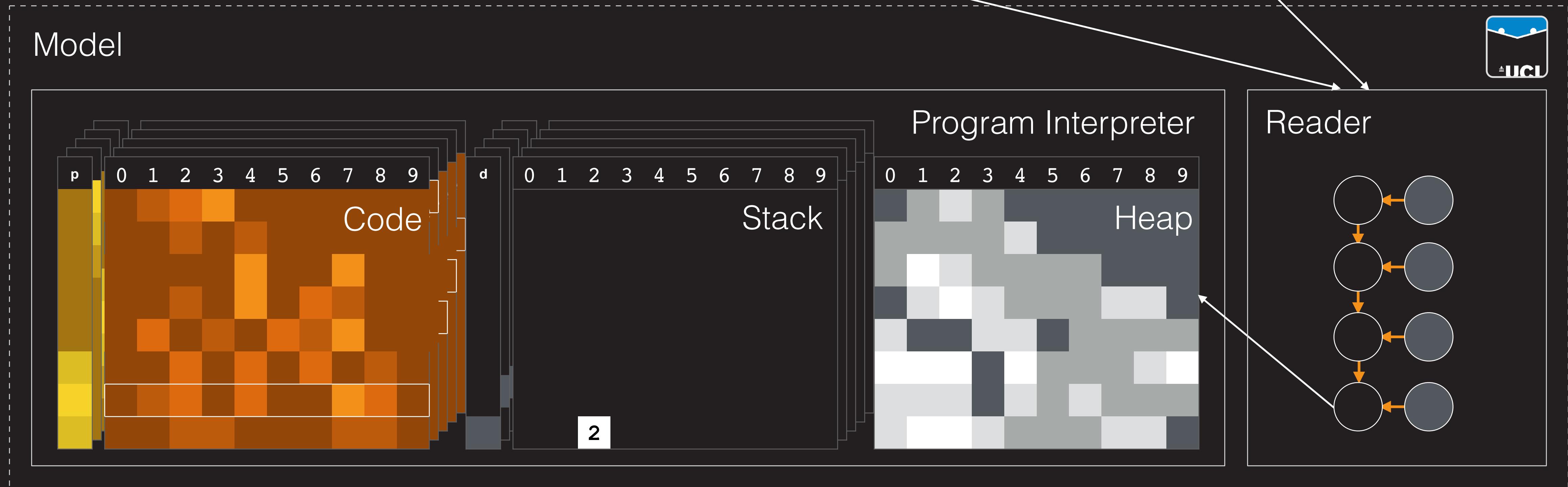


# Training



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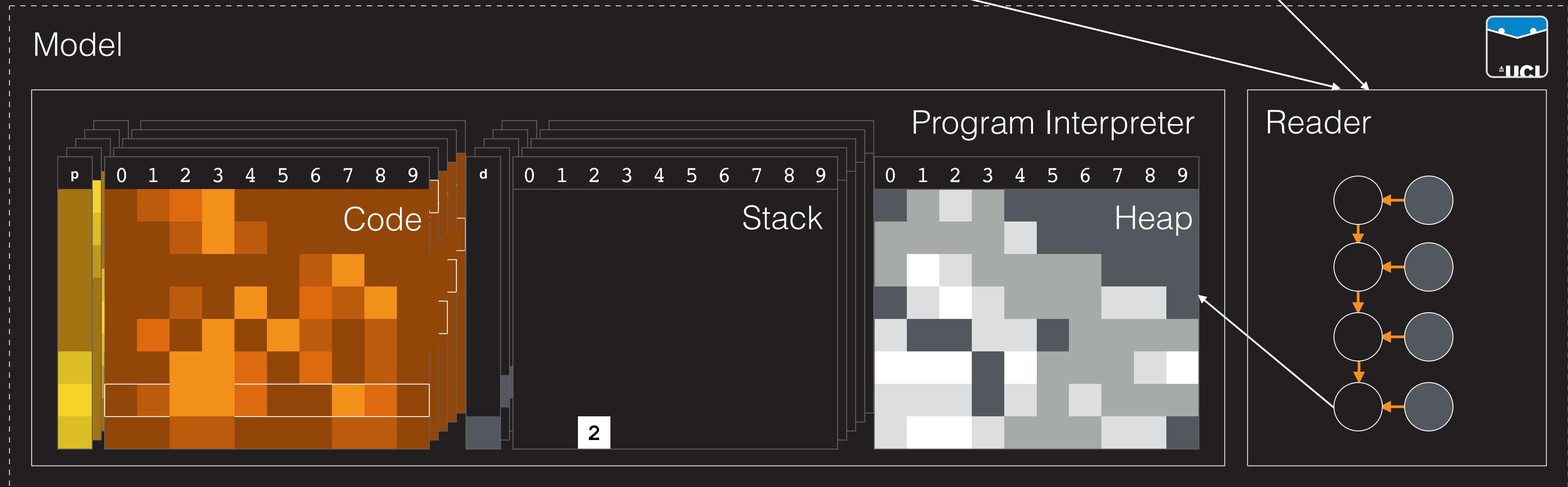


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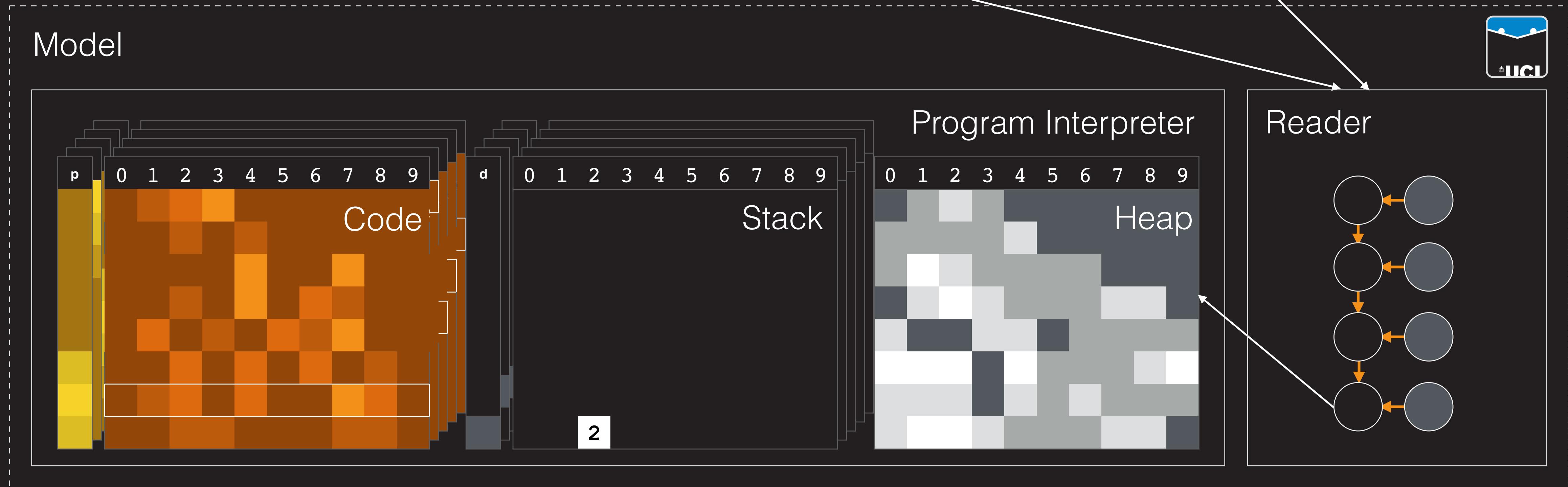


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# Training



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## Model



# Program Interpreter

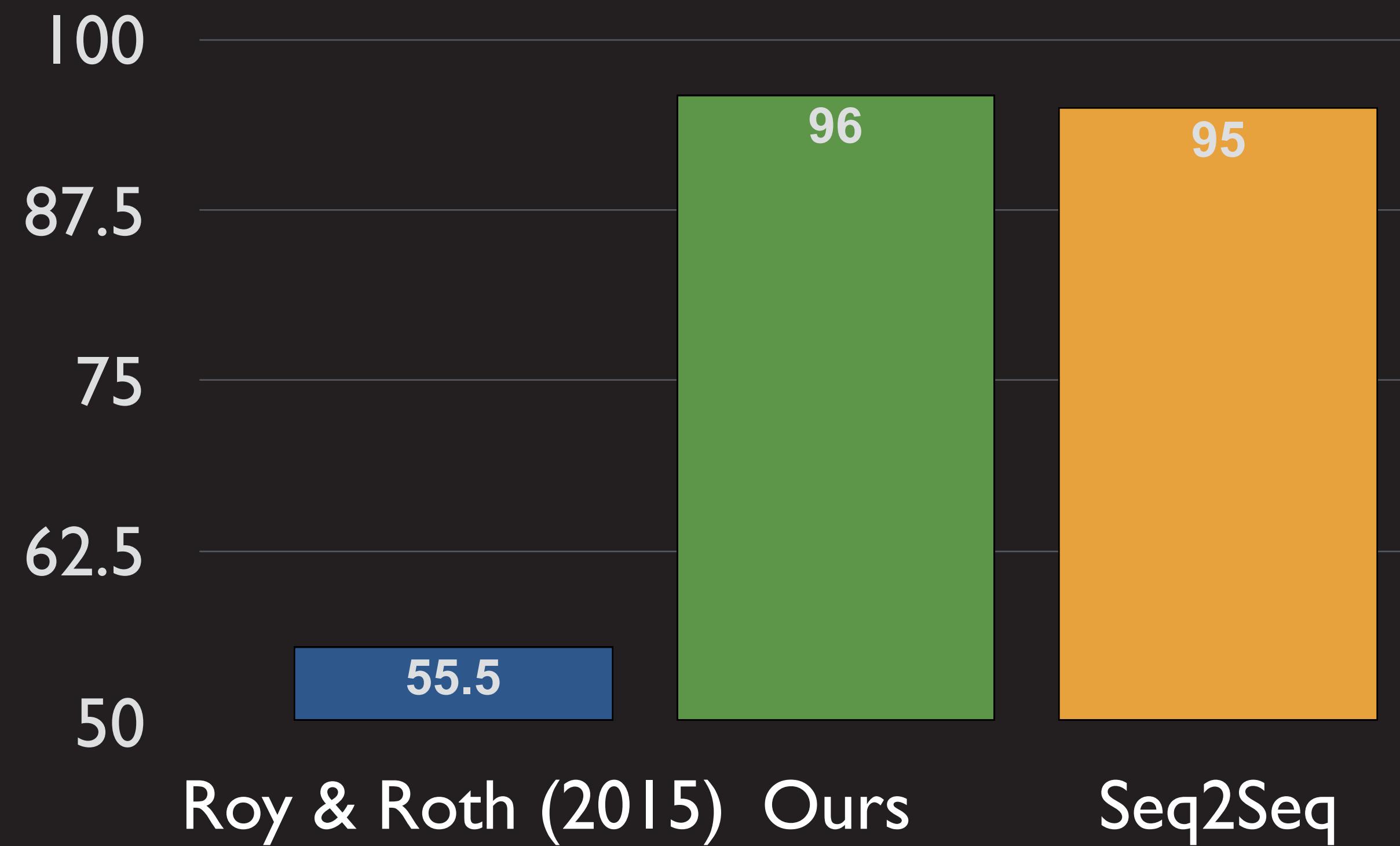
# Reader

# Stack

# Heap

2

# Results on Benchmark (Accuracy)



*Seq2Seq solves simpler problem*



How many pictures were in each of the albums?

$$(2 + 4) / 3$$

# Limitations

- ▶ Continuous relaxations difficult to train
- ▶ Hard to learn long programs
- ▶ Hard to learn with recursive function calls
- ▶ Need better gradients in presence of discrete variables



**Tim Rocktäschel**

# Part 3: Learning to Aggregate

# Neural Theorem Provers



Which medical specialty deals with pituitary ACTH hypersecretion?

**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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# Neural Theorem Provers



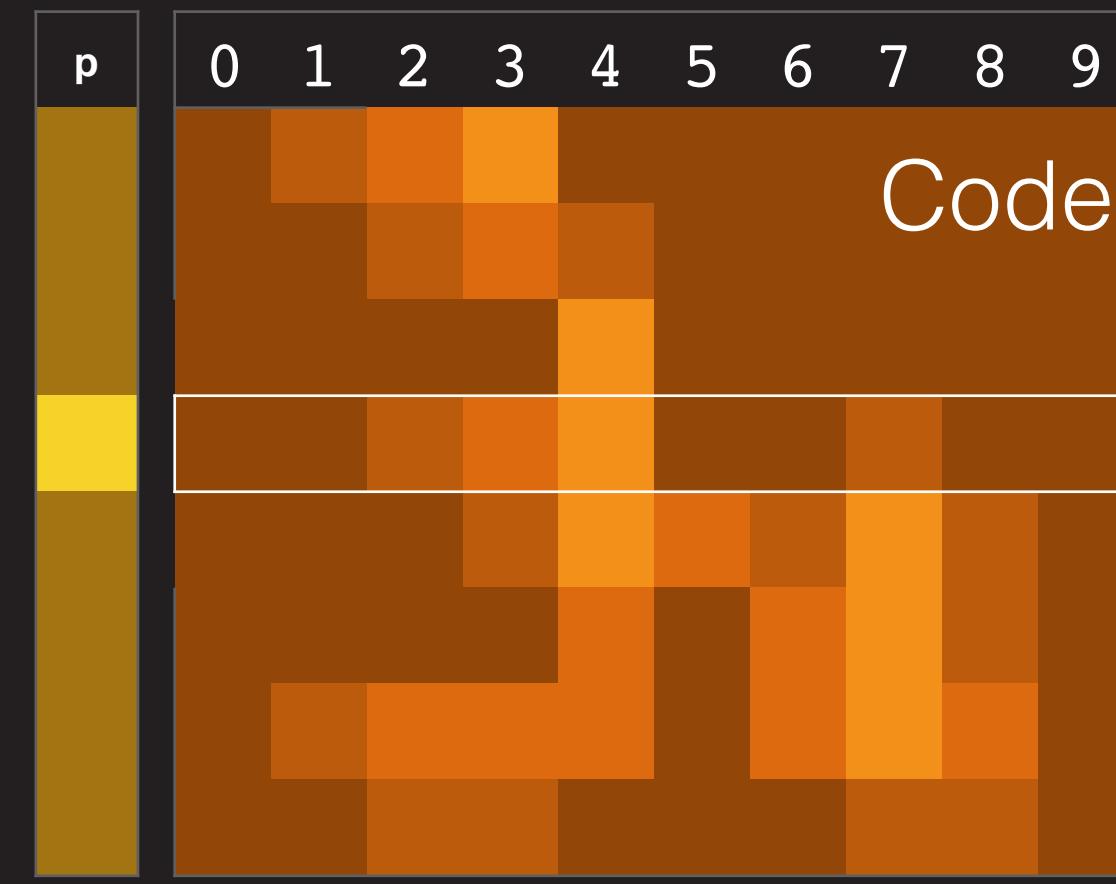
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**Pituitary ACTH hypersecretion** ... is a form of hyperpituitarism characterized by an abnormally high level of ACTH produced by the **anterior pituitary** ...

Agent

Program Interpreter



Question

Which specialty deals with pituitary ACTH hypersecretion?

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

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Reader

# Neural Theorem Provers



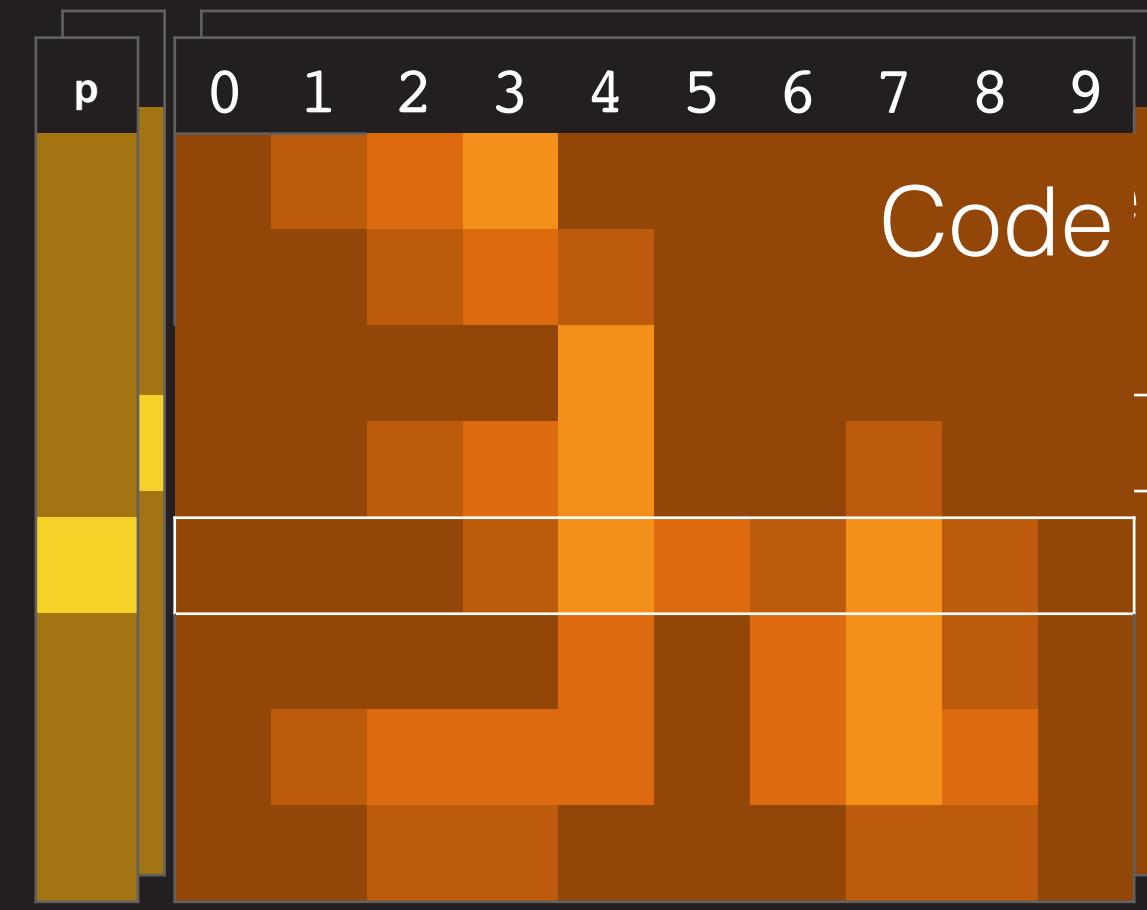
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**Pituitary ACTH hypersecretion** ... is a form of hyperpituitarism characterized by an abnormally high level of ACTH produced by the **anterior pituitary** ...

Agent

Program Interpreter



Code



What is ACTH hypersecretion created by?

Question

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

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Reader

# Neural Theorem Provers



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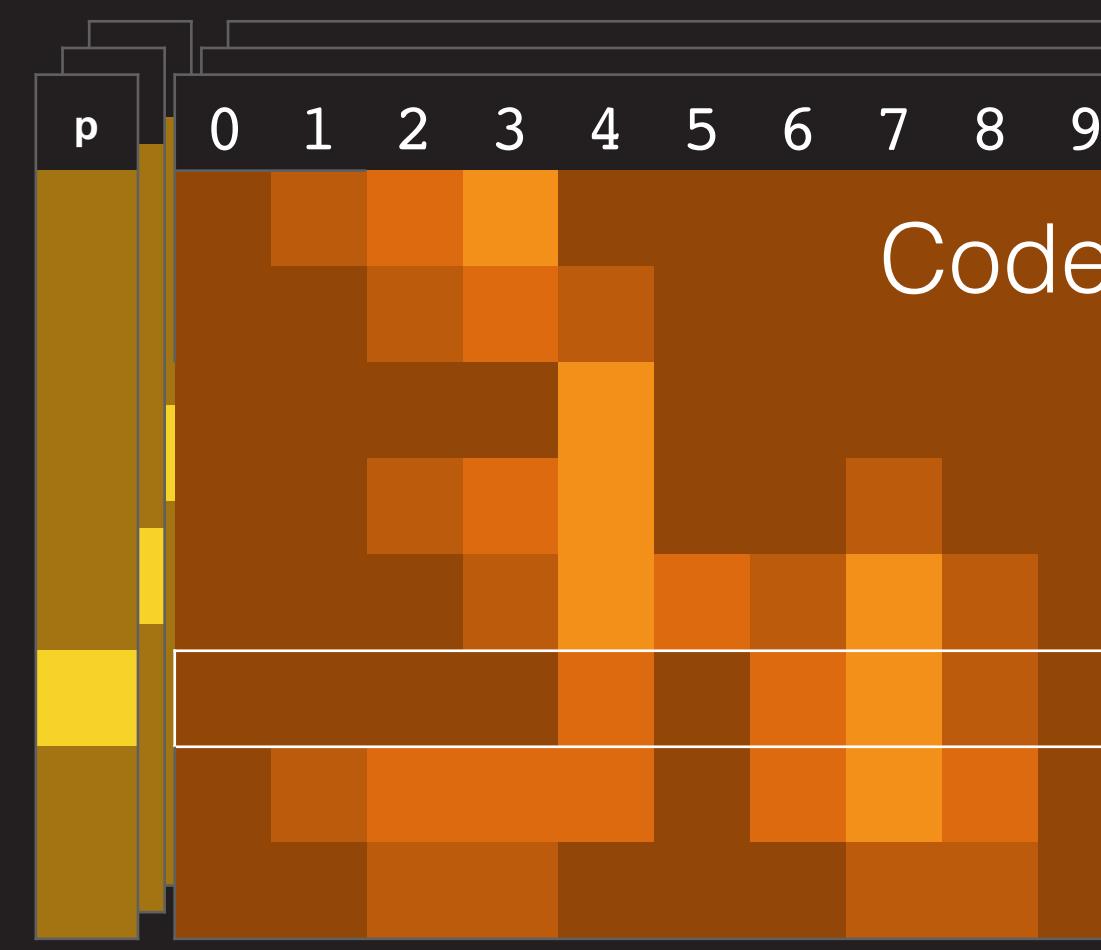


**Pituitary ACTH hypersecretion** ... is a form of hyperpituitarism characterized by an abnormally high level of ACTH produced by the **anterior pituitary** ...

Agent



Program Interpreter



Question

What is the pituitary a part of?

Code

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.

Reader

# Neural Theorem Provers



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Program Interpreter



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Question

Code

What topic covers the endocrine system?

Reader



# Vectors Correspond to Interpretable Rules



Which medical specialty deals with pituitary ACTH hypersecretion?



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

Agent



Program Interpreter



Code

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

Question

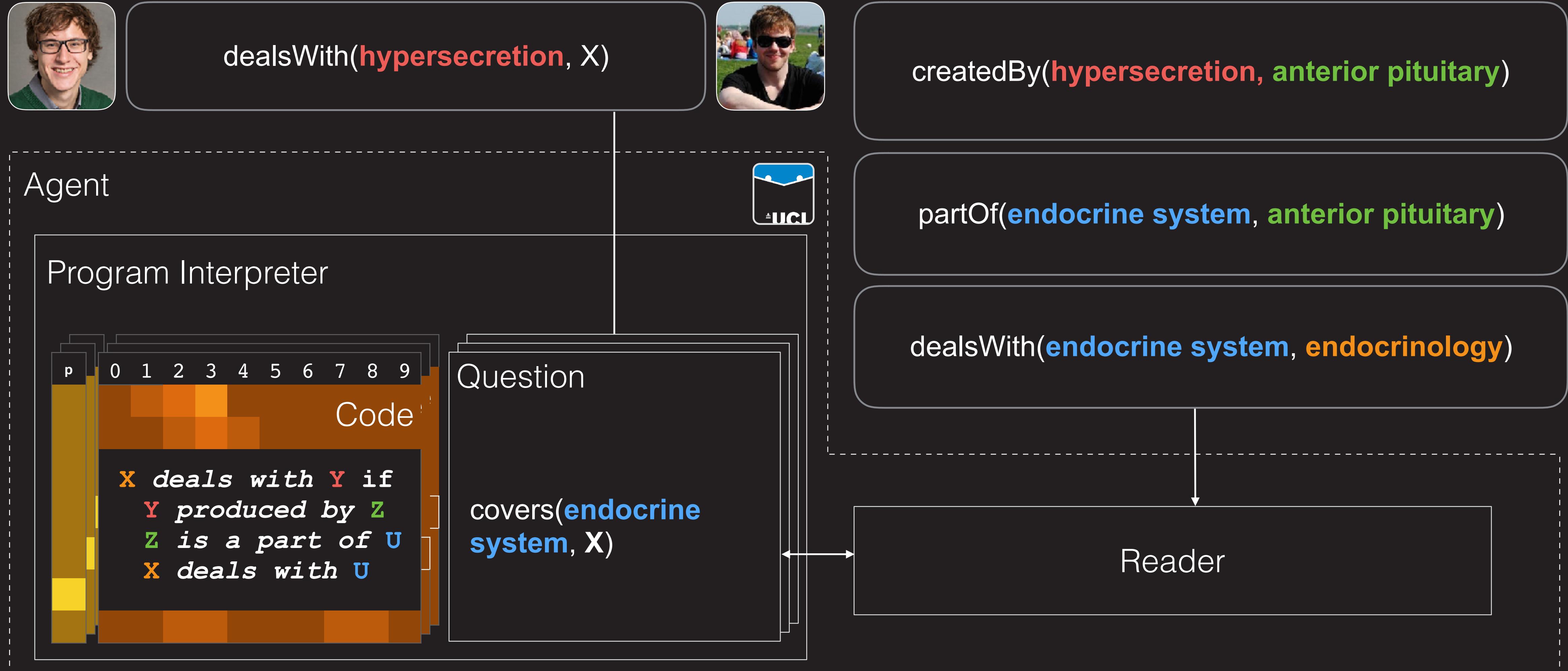
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Reader

# Catch: Currently only Works on Relational Data



# Catch: Currently only Works on Relational Data



dealsWith(**hypersecretion**, X)

Agent



createdBy(**hypersecretion**, **anterior pituitary**)

*Amounts to Differentiable  
Version of the **Backward  
Chaining** algorithm used  
in **Prolog***

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

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

# Supports Soft Unification



dealsWith(hypersecretion, X)



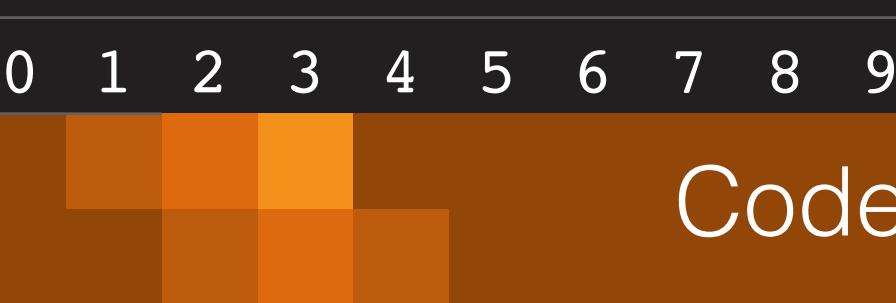
createdBy(hypersecretion, anterior pituitary)

Agent

Program Interpreter



partOf(endocrine system, anterior pituitary)



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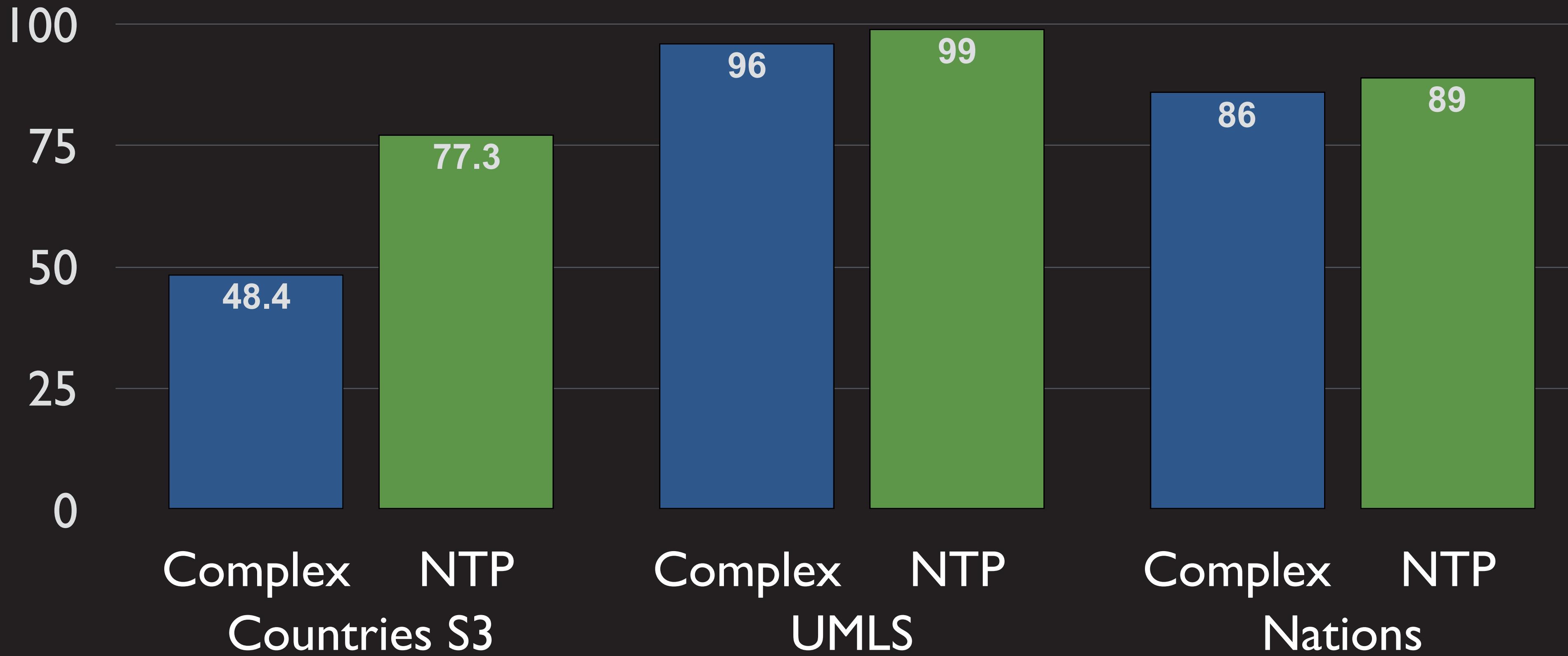
Question

covers(endocrine  
system, X)

dealsWith(endocrine system, endocrinology)

Reader

# Results on Benchmark (Rank of Correct Answer)



*Comparable or Better than Baselines, and interpretable*

# Interpretability: Learnt Rules

- ▶ if **X** is located in **Y** and **Y** is located in **Z** then **X** is located in **Z**
- ▶ if **X** expels diplomats of **Y** then **X** shows negative behaviour towards **Y**
- ▶ if **X** interacts with **Y** and **Y** interacts with **Z** then **X** interacts with **Z**

# Limitations

- ▶ Scalability
  - ▶ Currently only works for KBs with < 10k facts
  - ▶ Small proof depth
- ▶ Still requires relational representation

# Conclusion

- ▶ Great Progress in End-to-End Reading Comprehension
- ▶ **Reasoning** (aggregation, calculation etc.) end-to-end is still very challenging
- ▶ Our Approaches
  - ▶ create datasets
  - ▶ cast reasoning as **program learning** and **execution**
  - ▶ are **end-to-end differentiable** (can be trained on downstream loss)
  - ▶ are inspired and tied to **traditional symbolic formalisms** (Forth, Prolog/Datalog)
  - ▶ are learnt models are **interpretable**
  - ▶ allow injection of **prior knowledge**