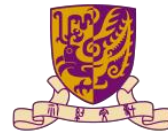


CSC6203/CIE6021: Large Language Model



香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

Lecture 7: Knowledge, Reasoning, and Prompt engineering

Winter 2023
Benyou Wang
School of Data Science

Recap

Last lecture

- **Philosophy** of the final project
- **Research in our team**
 - **Past**: What we have done
 - **Present and Future** : What we are doing and will do
- More on **LLM tendency**

- Insights from **Assignments**
- **Possible topics** for final projects
- **Tips** of report (paper) writing

Final project (Dates might be changed)

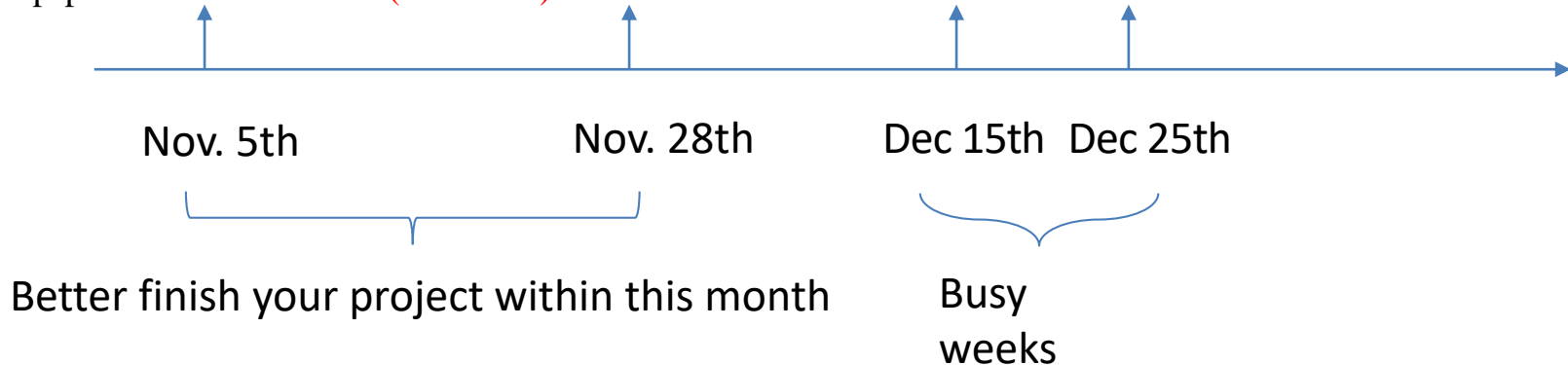
Students complete a research project in teams of 1-3

Do not need a draft proposal, directly submit your final version. (Reduce your workload)

Final proposal deadline: **Nov. 28th** 11:59pm (Simply explain your idea in one page. You are encouraged to ask TA or instructor for suggestions and revision!)

In-class presentation: **Dec 15th**. (We will survey all of you guys to decide whether to have in-class presentation)

Final paper deadline: **Dec 25th (final date)**



Please consider your proposal for final projects

People you could contact to have suggestions:

- Juhao Liang: LLM training, modulization, Human-computer interaction, tools&plugins
- Xidong Wang: RLHF, benchmark, and Data engineering
- Junyin Chen: Medical LLMs and multi-modal LLMs
- Fei Yu: Reasoning and RLHF
- Zhengyang Tang: Reasoning, Retrieval, and prompting engineering

Today's lecture

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- **Knowledge** in LLMs
 - LLMs as knowledge bases
 - Facts updating for LLMs
- **Reasoning** in LLMs
 - Why reasoning is special in LLMs
 - Techniques for better reasoning

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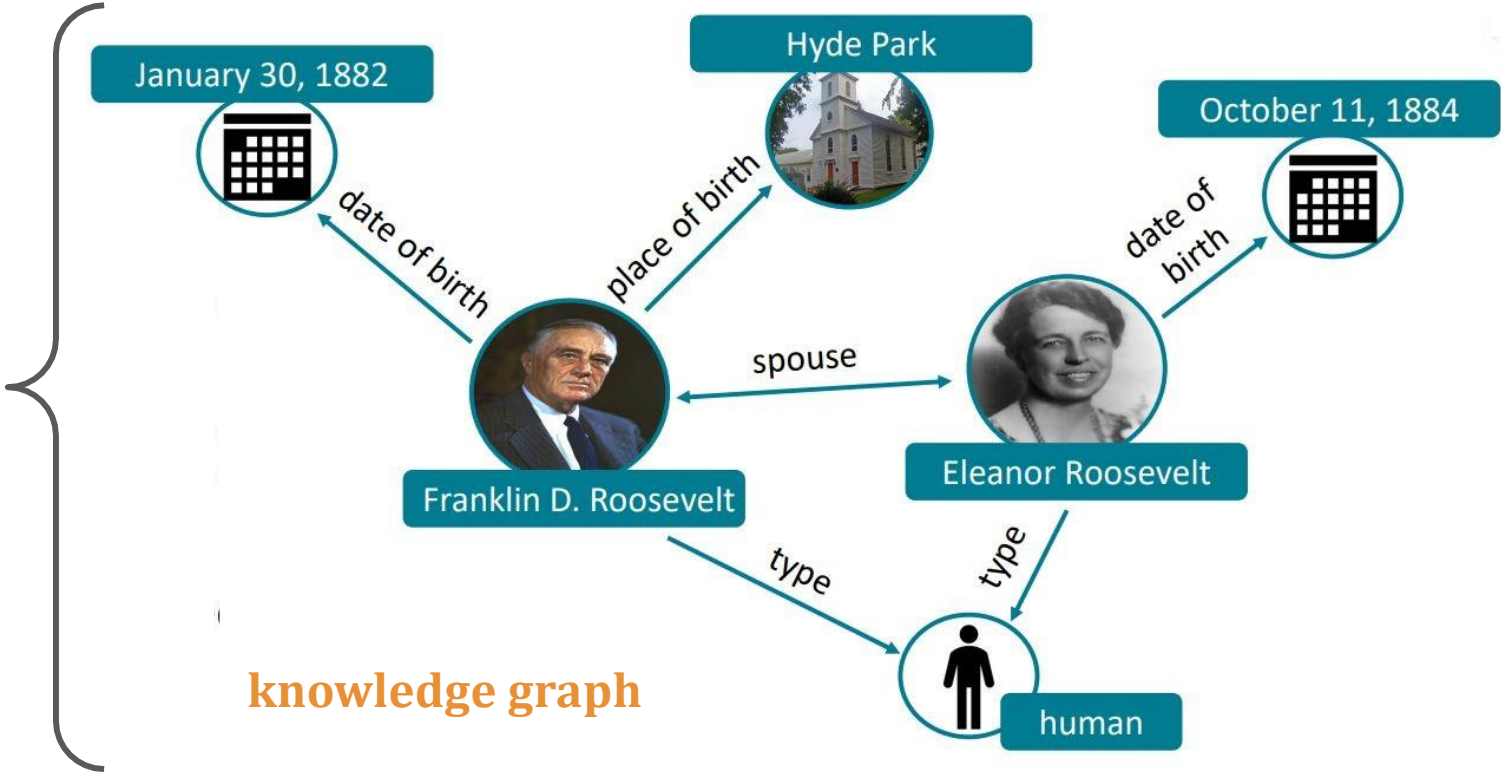
What is a knowledge base?

What is a knowledge base?

knowledge base



Example

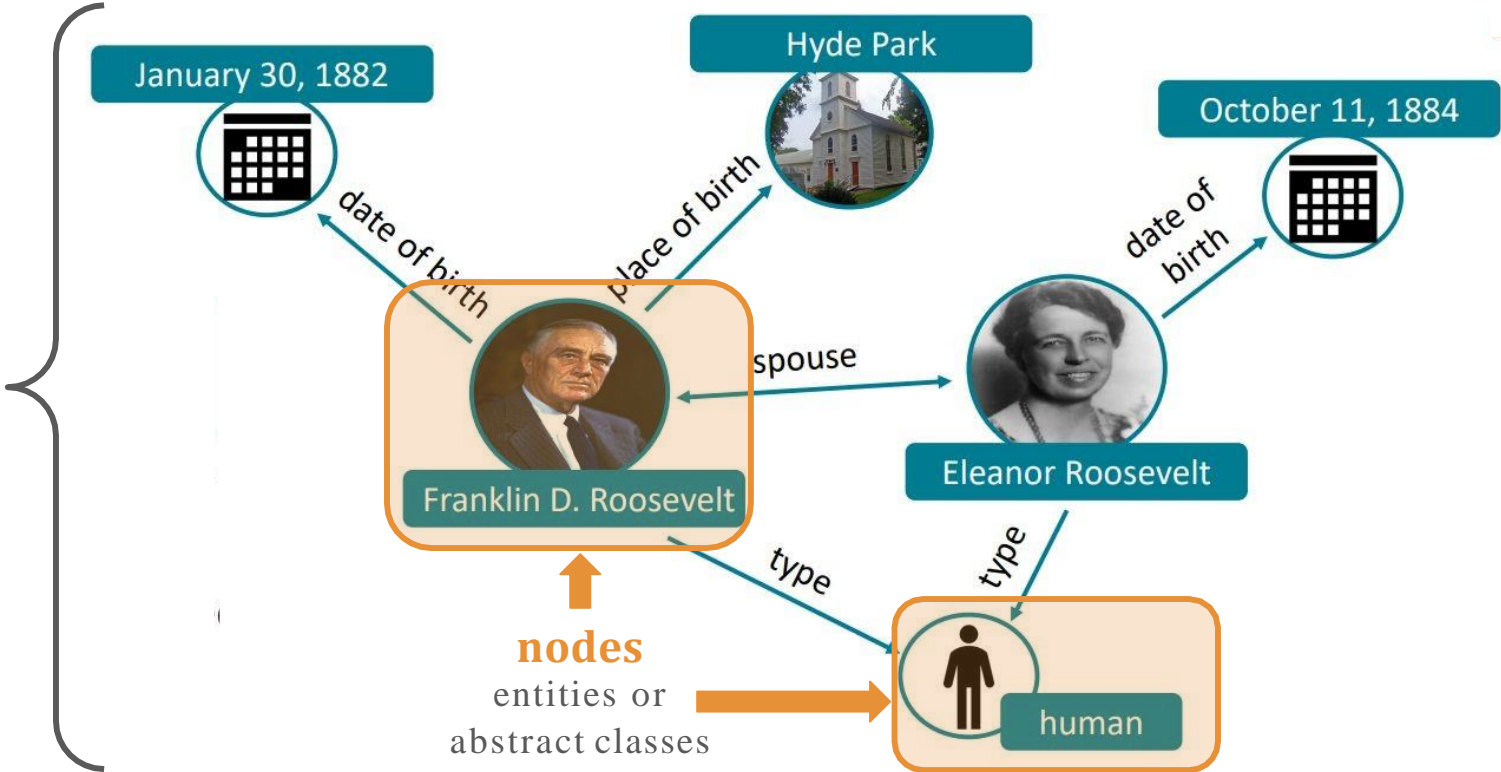


What is a knowledge base?

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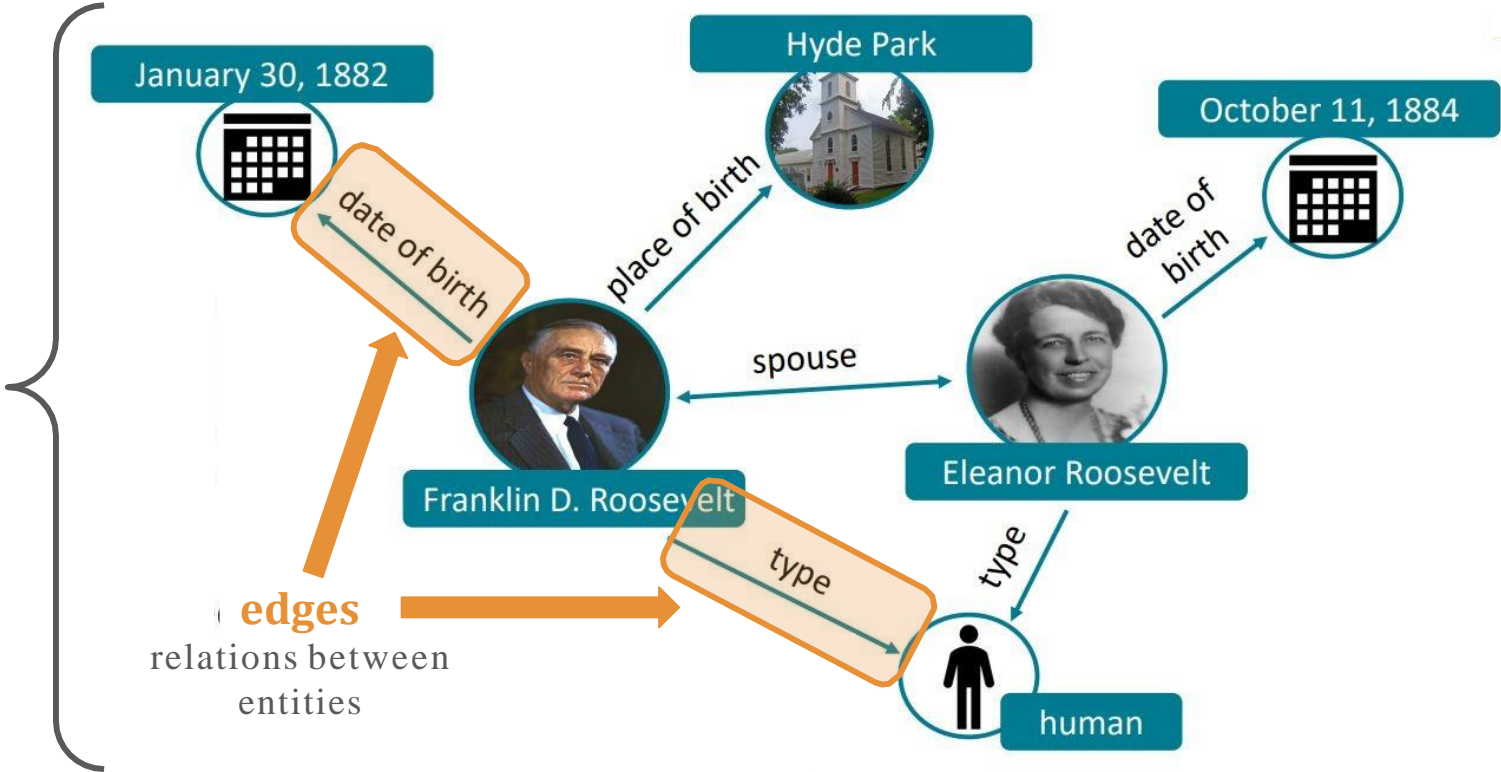


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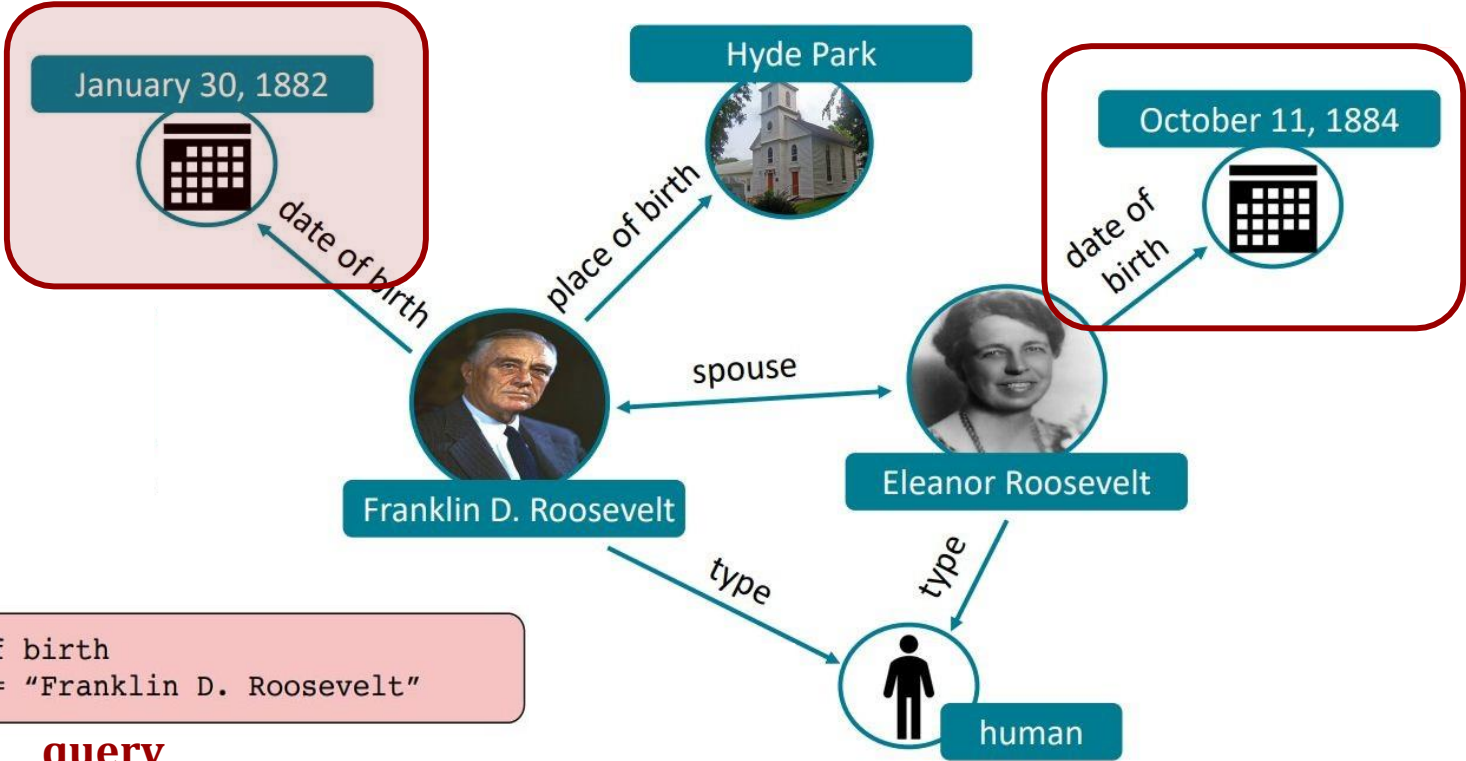
knowledge base



Example



How to query?



query

How were knowledge bases formed?

The image shows three overlapping screenshots of Wikipedia pages, illustrating unstructured text. The top-most screenshot is for 'Valorant', the middle one for 'Brie', and the bottom one for 'T. S. Eliot'. Each page contains a mix of text, lists, and structured data, but the overall layout is not uniform or machine-readable.

Valorant
From Wikipedia, the free encyclopedia

Brie
From Wikipedia, the free encyclopedia
(Redirected from Brie (cheese))

T. S. Eliot
From Wikipedia, the free encyclopedia
(Redirected from Ts eliot)

Thomas Stearns Eliot OM (26 September 1888 – 4 January 1965) was a poet, essayist, publisher, playwright, literary critic and editor.^[R] Considered one of the 20th century's major poets, he is a central figure in English-language Modernist poetry. Born in St. Louis, Missouri, to a prominent Boston Brahmin family, he moved to England in 1914 at the age of 25 and went on to settle, work, and marry there.^[R] He became a British citizen in 1927 at the age of 39, subsequently renouncing his American citizenship.^[R]

Eliot first attracted widespread attention for his poem "The Love Song of J. Alfred Prufrock" in 1915, which, at the time of its publication, was considered outlandish.^[R] It was followed by "The Waste Land" (1922), "The Hollow Men" (1925), "Ash Wednesday" (1930), and *Four Quartets* (1943).^[R] He was also known for seven plays, particularly *Murder in the Cathedral* (1935) and *The Cocktail Party* (1949). He was awarded the 1948 Nobel Prize in Literature, "for his outstanding, pioneer contribution to present-day poetry"^[R]

T. S. Eliot
OM

Eliot in 1934 by Lady Ottoline Morrell

Born	Thomas Stearns Eliot 26 September 1888 St. Louis, Missouri, US
Died	4 January 1965 (aged 76) London, England
Occupation	Poet · essayist · playwright · publisher · critic
Citizenship	American (1888–1927) British (1927–1965)

unstructured text

Structured knowledge base

How were knowledge bases formed?

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Valorant (stylized as **VALORANT**) is a free-to-play first-person shooter video game developed by Riot Games under the Call of Duty brand. The game began on April 7, 2020, and was released on June 2, 2020. It is the first game in the Valorant Strike series. The game's mechanics and inaccuracy are considered to be a departure from the Call of Duty franchise.

Cont

- Gameplay
 - Unlocks
 - Skills
 - Character
 - Gameplay
 - Gameplay
 - Gameplay
 - Gameplay
 - Gameplay
- Agents
 - Demolition
 - Support
 - Initiator
 - Controller
 - Flank
 - Defender

Brie
From Wikipedia, the free encyclopedia
(Redirected from Brie cheese)


T. S. Eliot
From Wikipedia, the free encyclopedia
(Redirected from T. S. Eliot)

Brie (/briː/) is a soft cheese named after the town of Brie in France. It is made from cow's milk and is a member of the Camembert family. Brie is a soft cheese with a slight mould. The texture is soft and creamy, depending on the ripeness. It is often served with bread and butter. Brie is a popular cheese in France and is also popular in other countries. Brie is a soft cheese with a slight mould. The texture is soft and creamy, depending on the ripeness. It is often served with bread and butter. Brie is a popular cheese in France and is also popular in other countries.

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**Knowledge Extraction
Pipeline**

unstructured text

Structured knowledge base

How were knowledge bases formed?

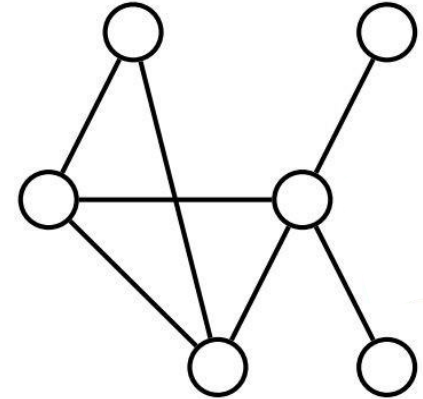
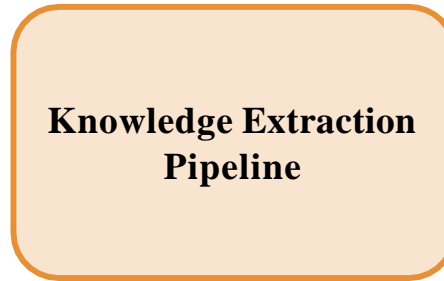
Stacked screenshots of Wikipedia articles illustrating unstructured text:

- Valorant**: From Wikipedia, the free encyclopedia
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The T. S. Eliot article includes a biographical summary and a table of personal details:

T. S. Eliot	OM
Eliot in 1934 by Lady Ottoline Morrell	
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unstructured text

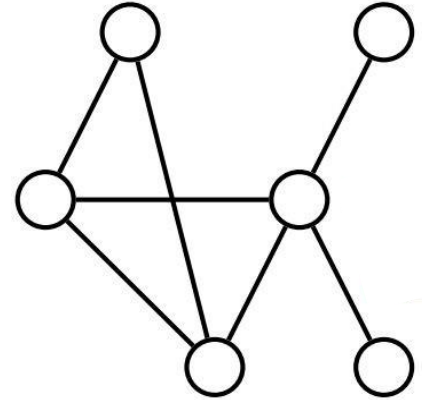
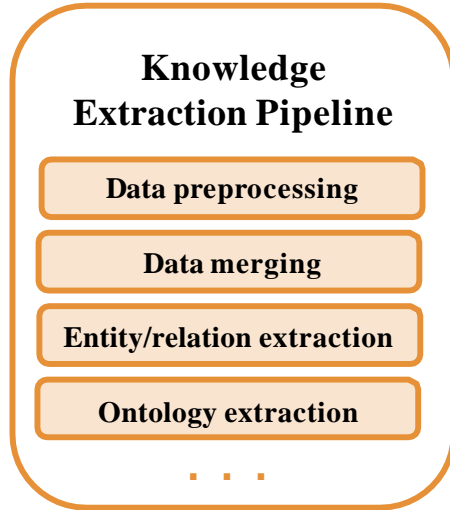


Structured knowledge base

Downsides of using knowledge bases

Downsides of using knowledge bases

The image shows three overlapping screenshots of Wikipedia pages. The top page is for 'Valorant', the middle for 'Brie', and the bottom for 'T. S. Eliot'. The 'T. S. Eliot' page is the most prominent, showing a detailed biography, a photograph, and a table of his works and awards. This illustrates the complexity of extracting structured information from unstructured text.



Populating the knowledge base often involves **complicated, multi-step NLP pipelines**

Downsides of using knowledge bases

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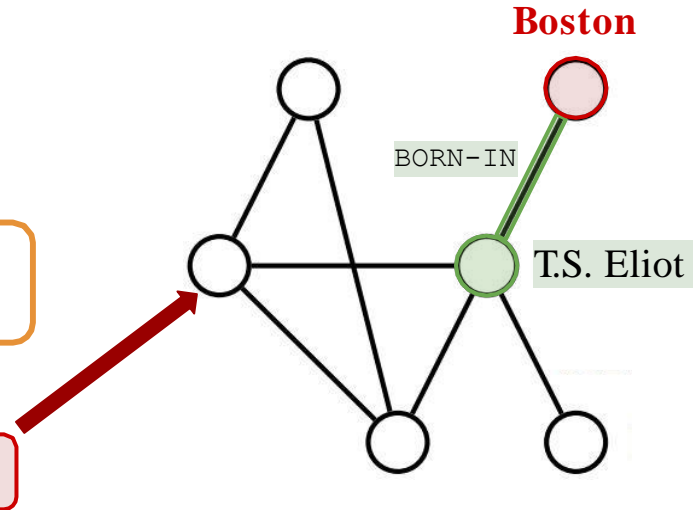
unstructured text

“Born in St. Louis, Missouri, to a prominent Boston Brahmin family...”

Knowledge Extraction Pipeline

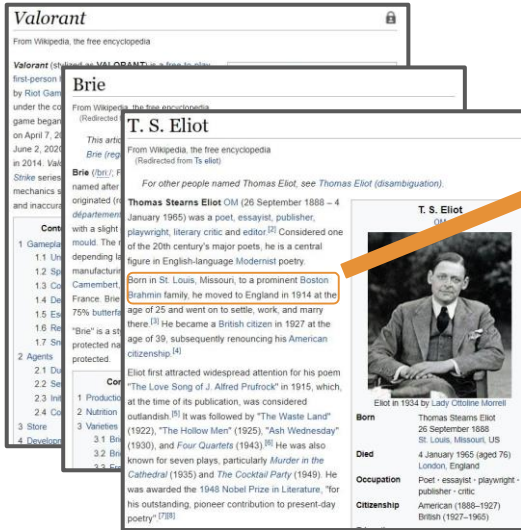
(T.S. Eliot, BORN-IN, Boston)

incorrect extraction



Prone to **error propagation** (from human annotations or knowledge extraction)

Downsides of using knowledge bases



unstructured text

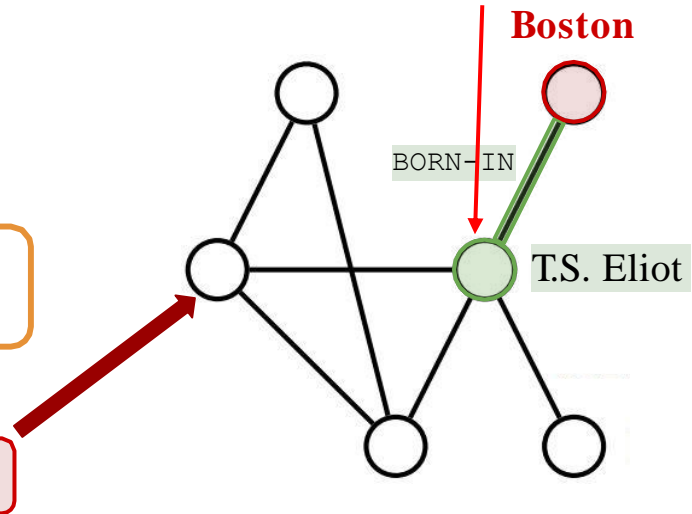
“Born in St. Louis, Missouri, to a prominent Boston Brahmin family...”

Knowledge Extraction Pipeline

(T.S. Eliot, BORN-IN, Boston)

incorrect extraction

Q: Describe Eliot’s family’s related information.



Triples lead to **information loss**: hard to include all possible information we may be interested in.

Are there better alternatives?

Traditional knowledge bases are **inflexible**
and require **significant manual effort**.

Language Models as Knowledge Bases? (Petroni et al., 2019)

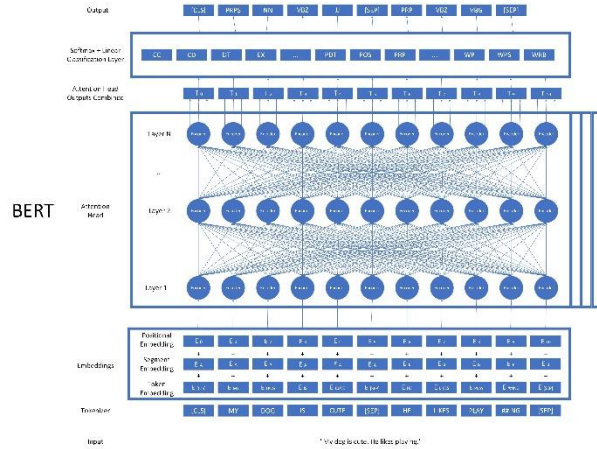
Language models as knowledge bases?

Why language models?

- Scalability: pre-trained on a huge corpus of data
- Time/Labor efficiency: does not require annotations/supervision
- Flexibility: more flexible with natural language queries
- Accessibility: can be used off-the-shelf

Do language models really store knowledge?

LAMA probe



probe(探针, 探测)



LAMA Probe



- Goal: evaluate **factual + commonsense knowledge** in language models



LAMA Probe



- **Goal: evaluate factual + commonsense knowledge in language models**
- Collect set of **knowledge sources** (i.e. set of facts) and test to see how well the model's knowledge captures these facts



LAMA Probe



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- *How do we know how “knowledgeable” a LM is about a particular fact?*



LAMA Probe



- **Goal: evaluate factual + commonsense knowledge** in language models
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Given a cloze statement that queries the model for a missing token, **knowledgeable LMs rank ground truth tokens high** and other tokens lower

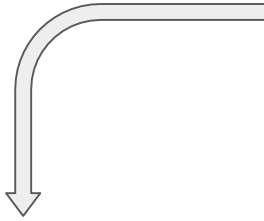
Evaluation of LM via LAMA

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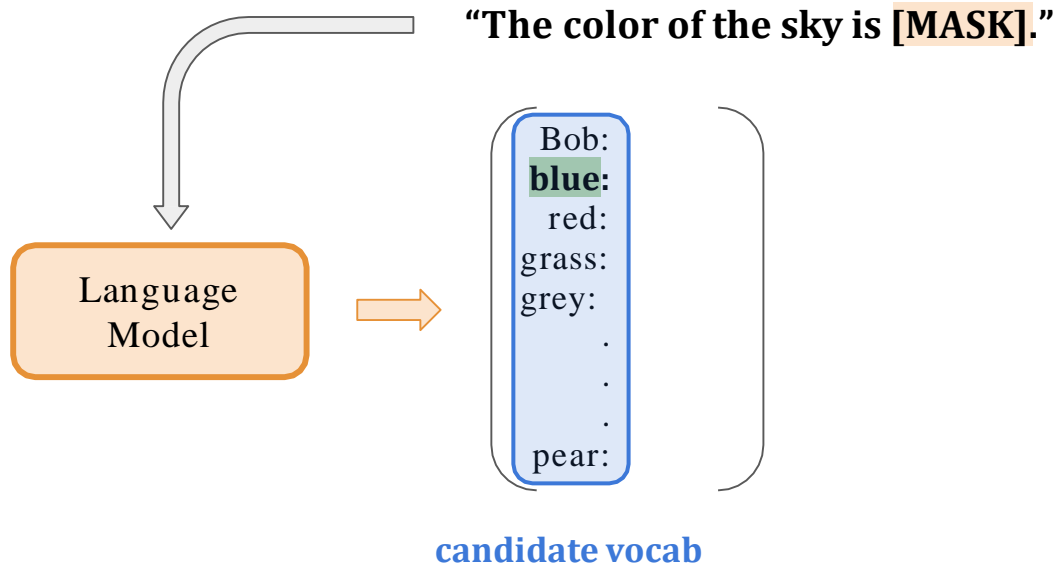
“The color of the sky is [MASK].”



Language
Model

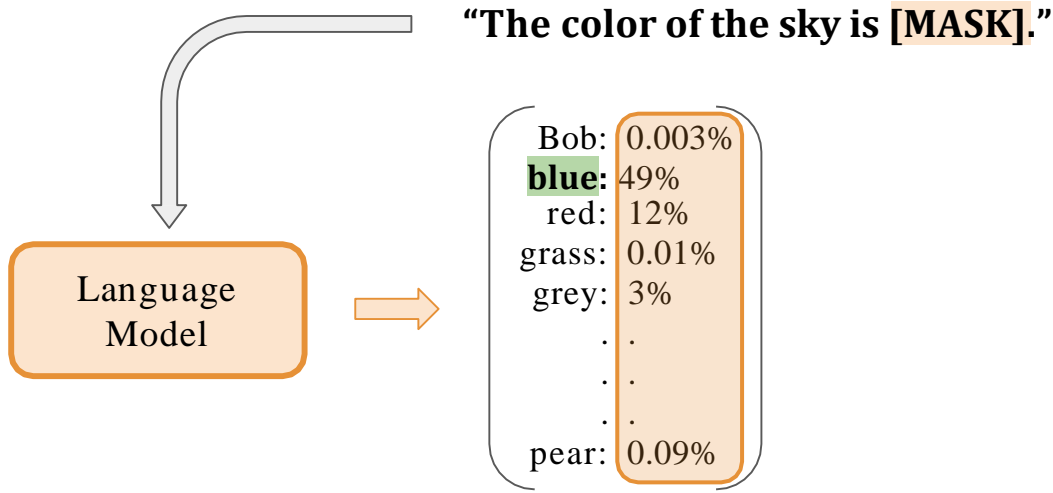
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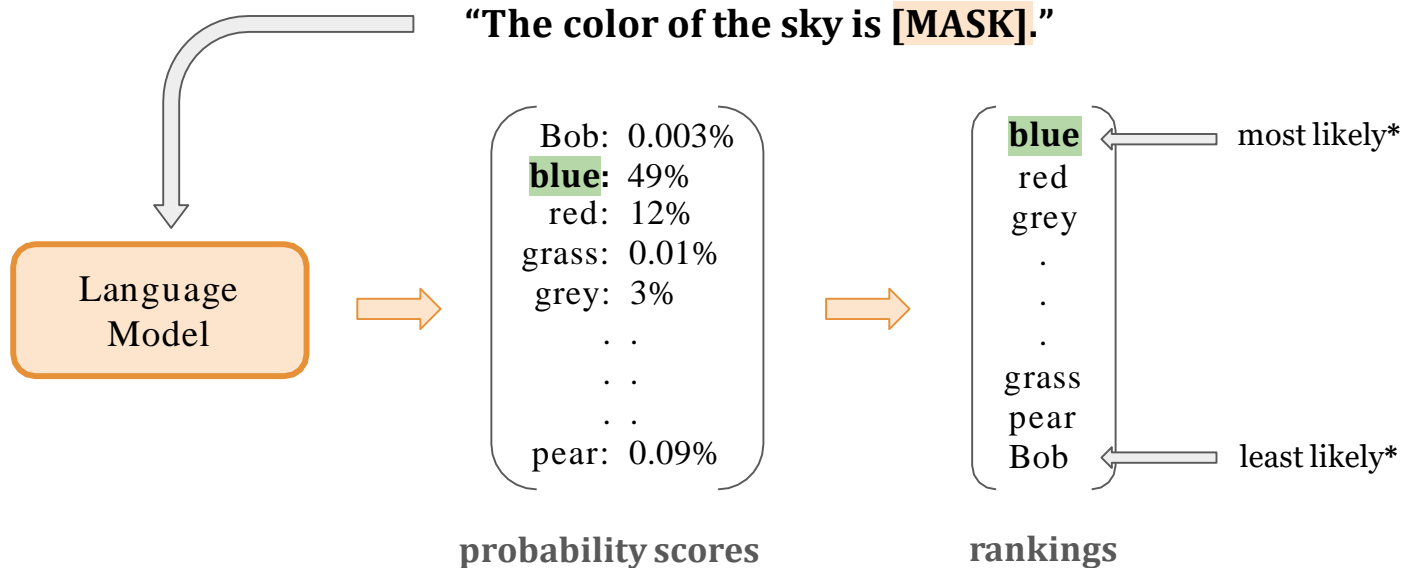
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probability scores

Evaluation of LM via LAMA

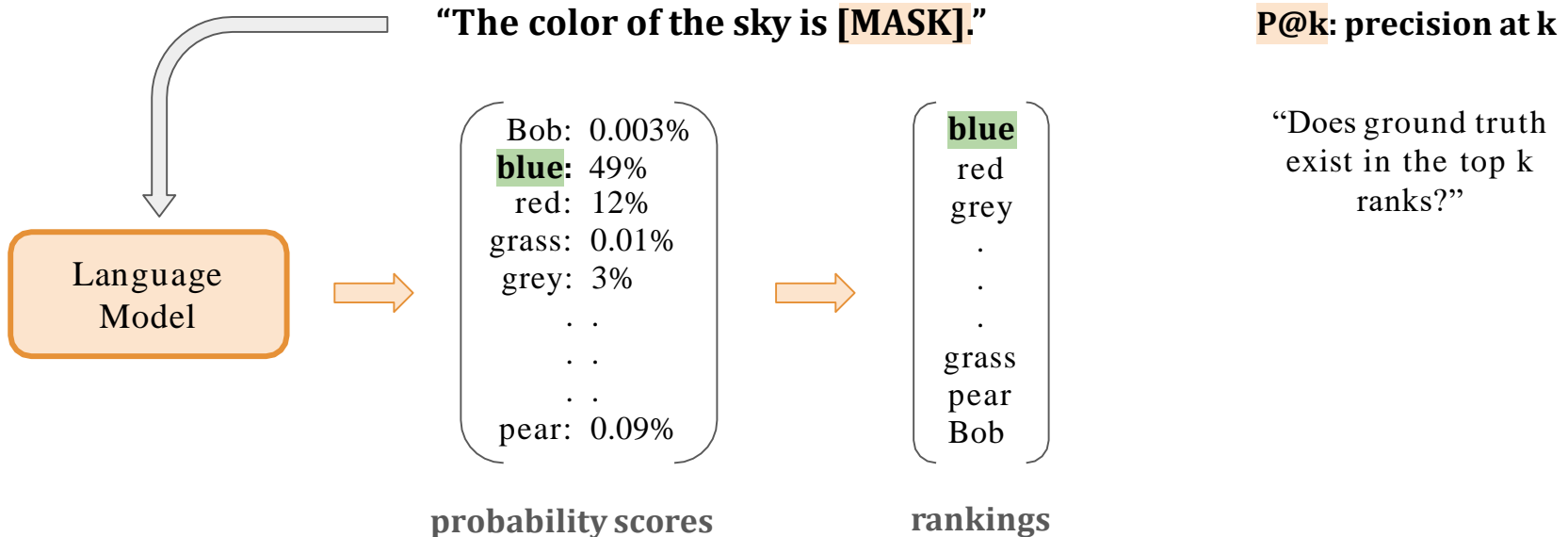
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*according to the LM

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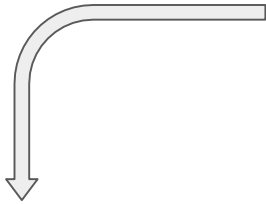
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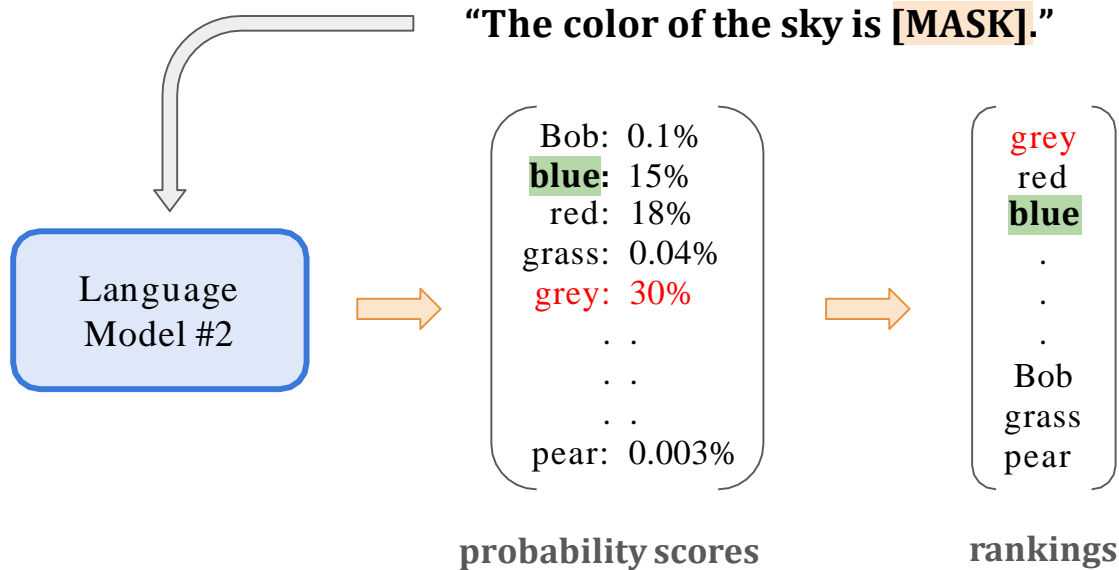
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Language
Model #2

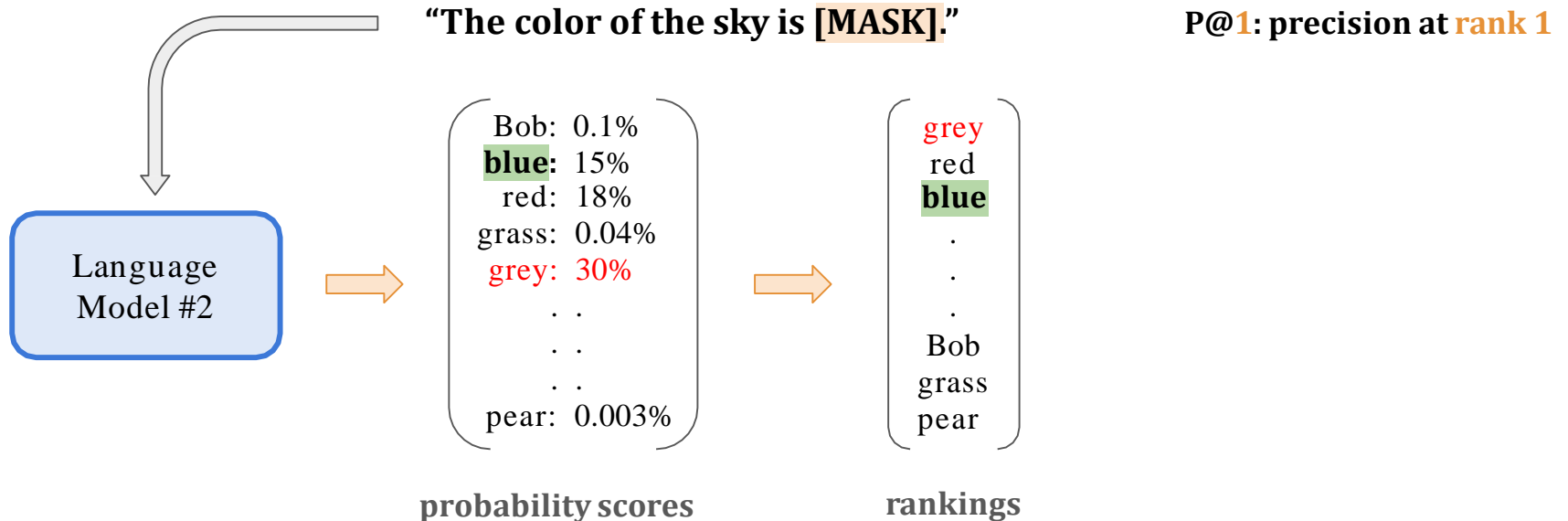
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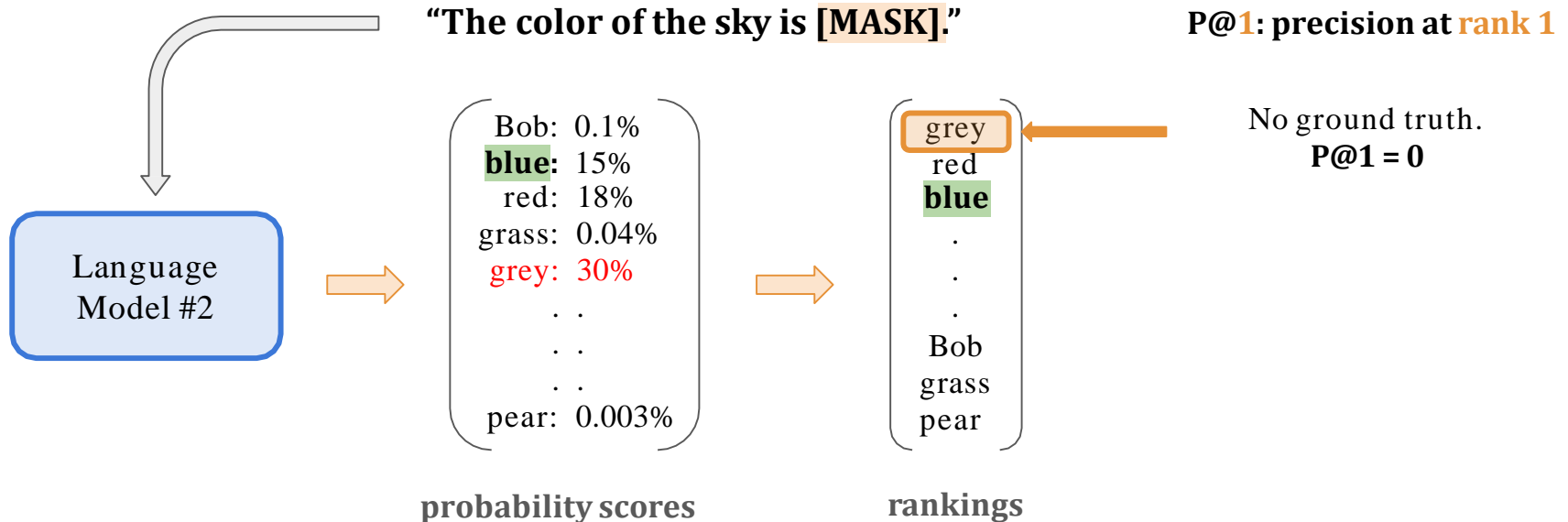
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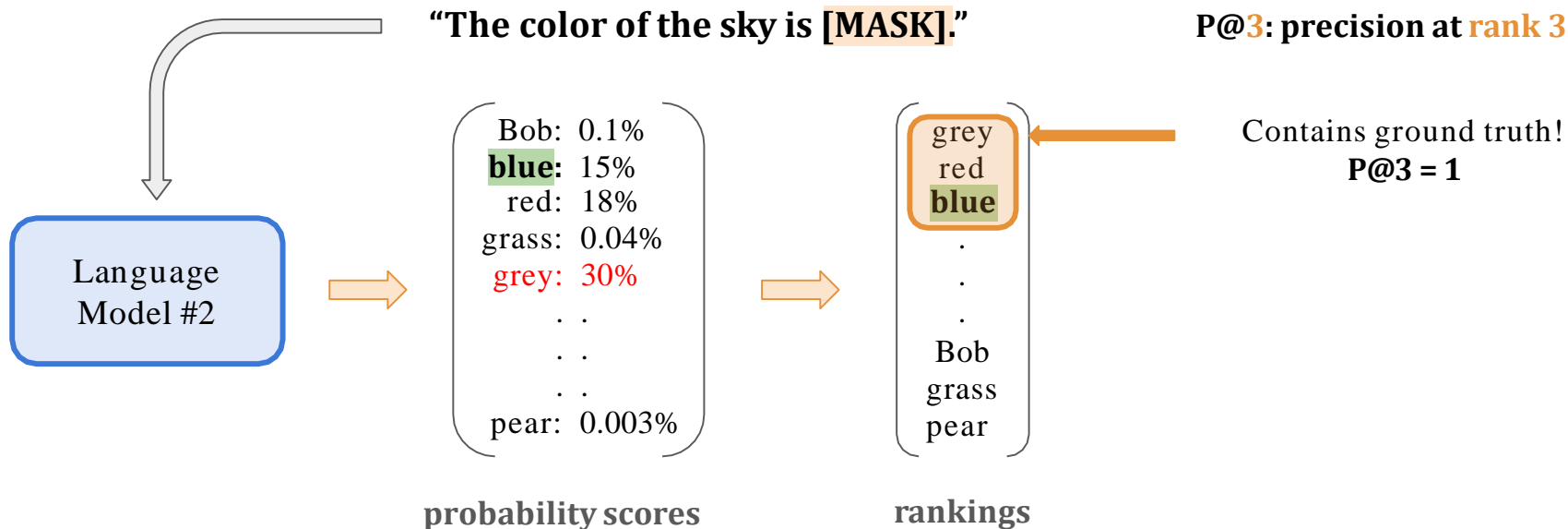
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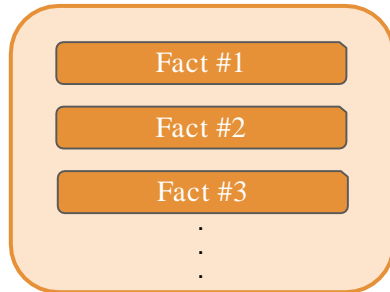
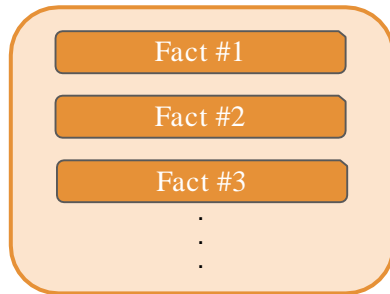
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Architecture of the LAMA probe

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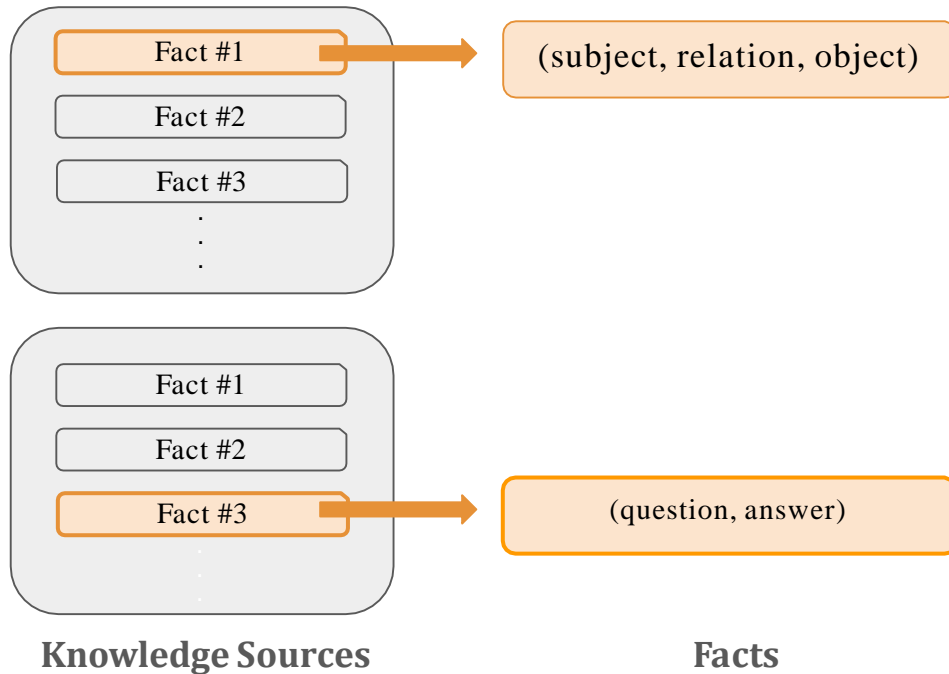
Step 1: Compile knowledge sources



Knowledge Sources

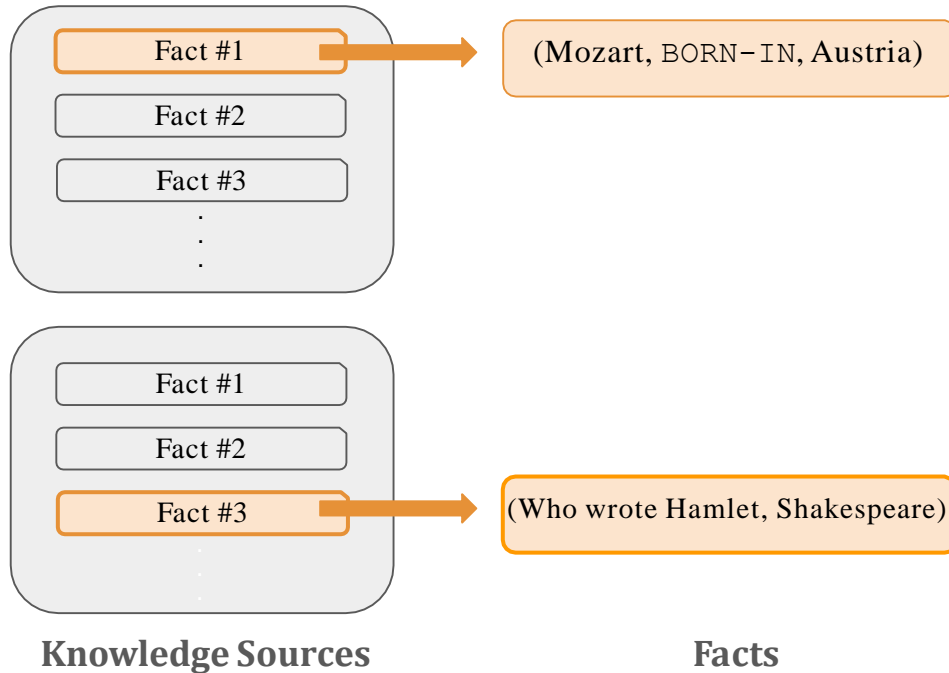
Architecture of the LAMA probe

Step 2: Formulate facts into triplets or question-answer pairs



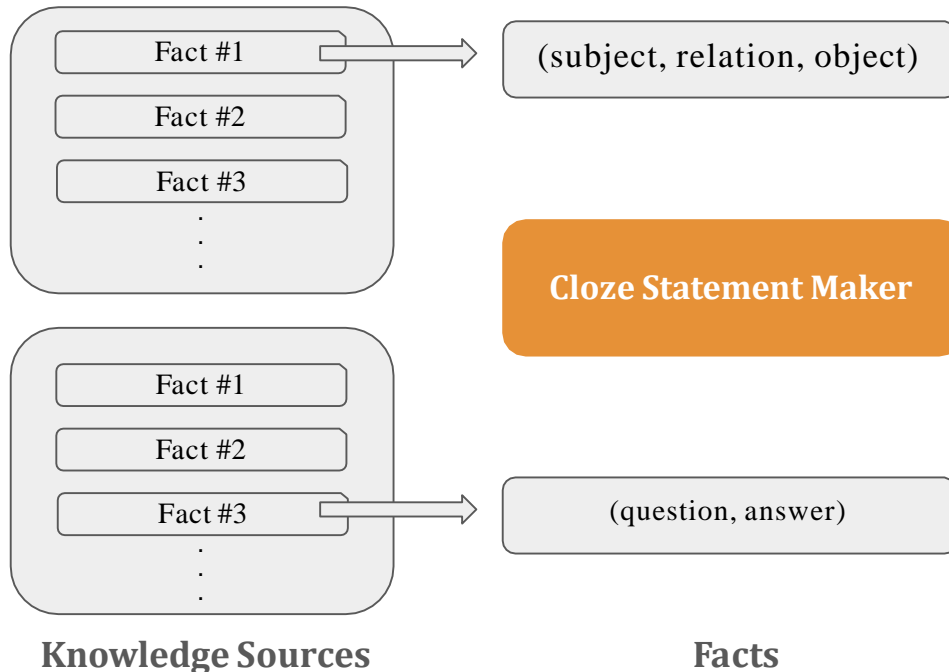
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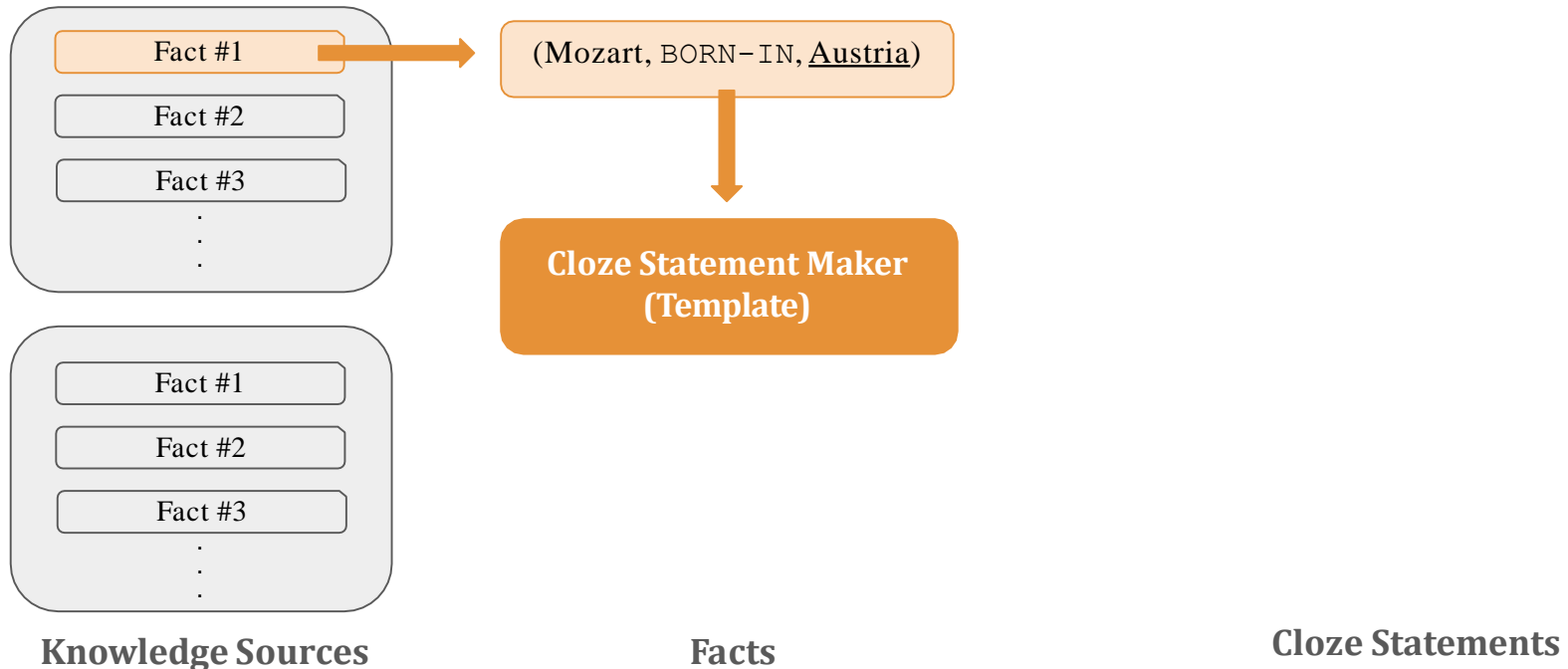
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Step 3: Create cloze statements, either manually or via templates



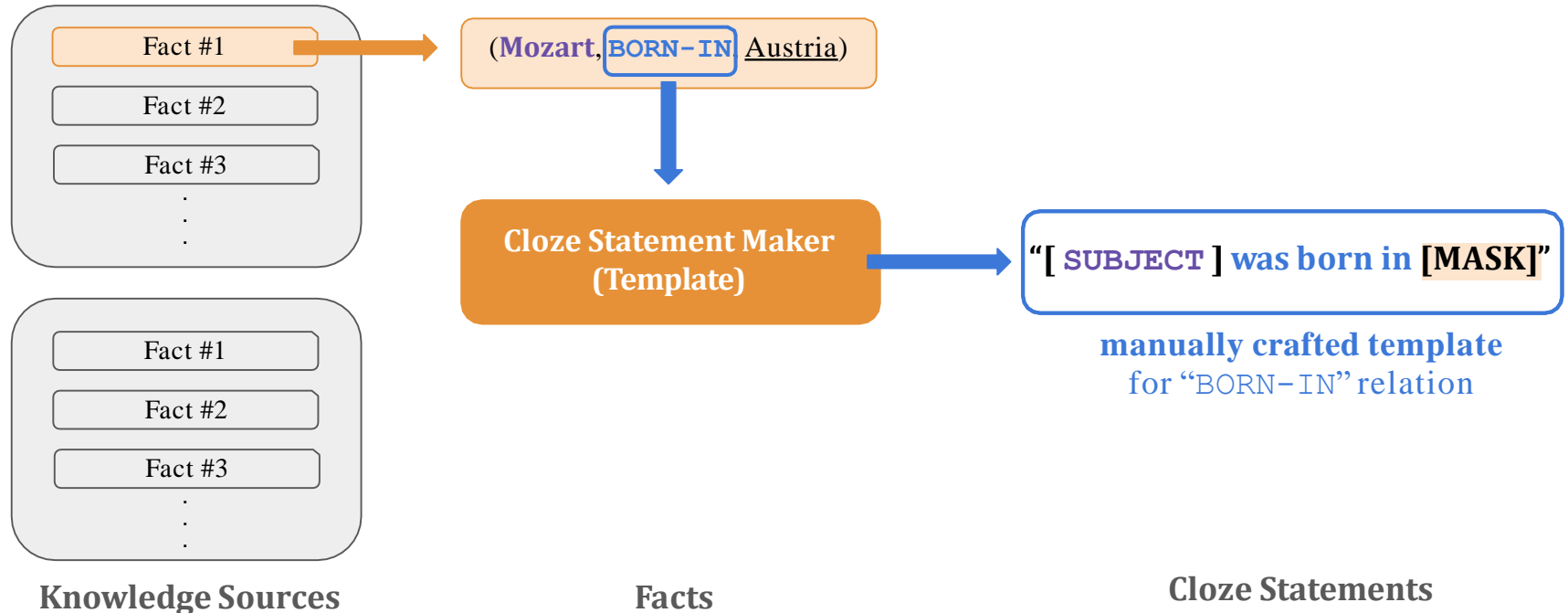
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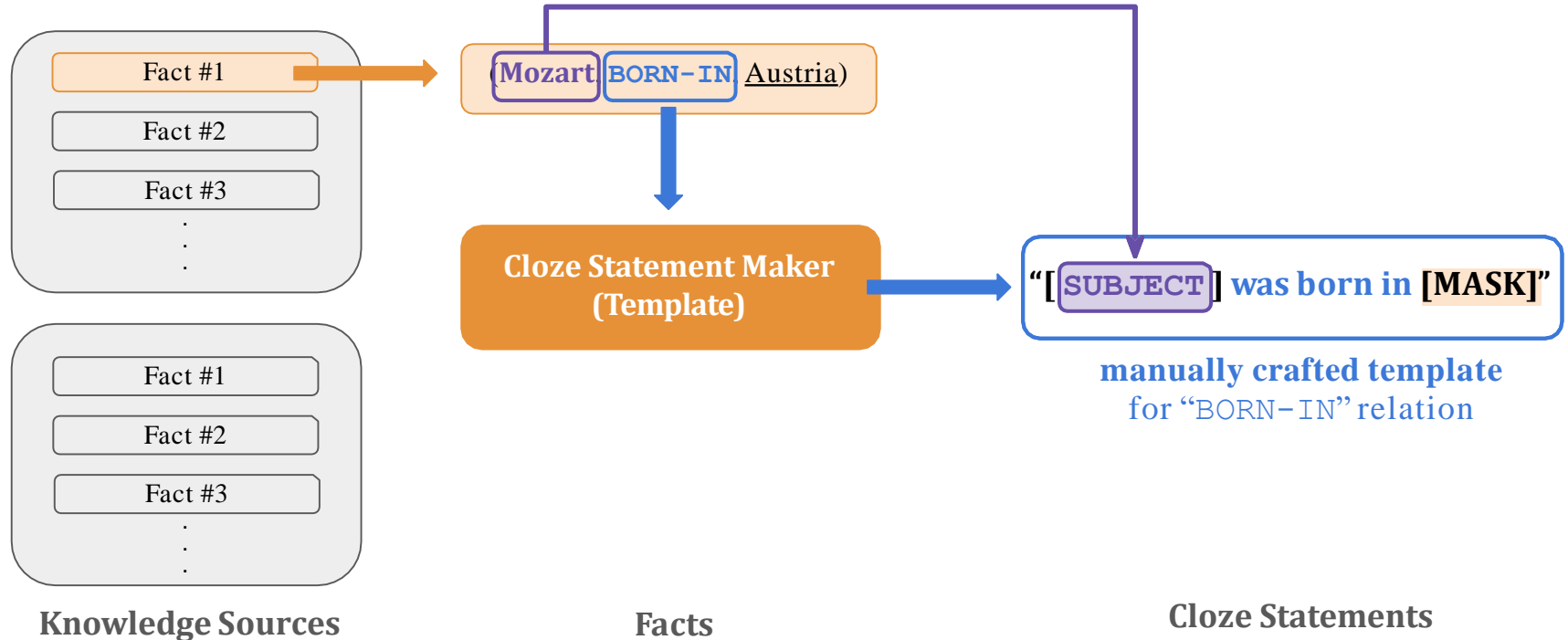
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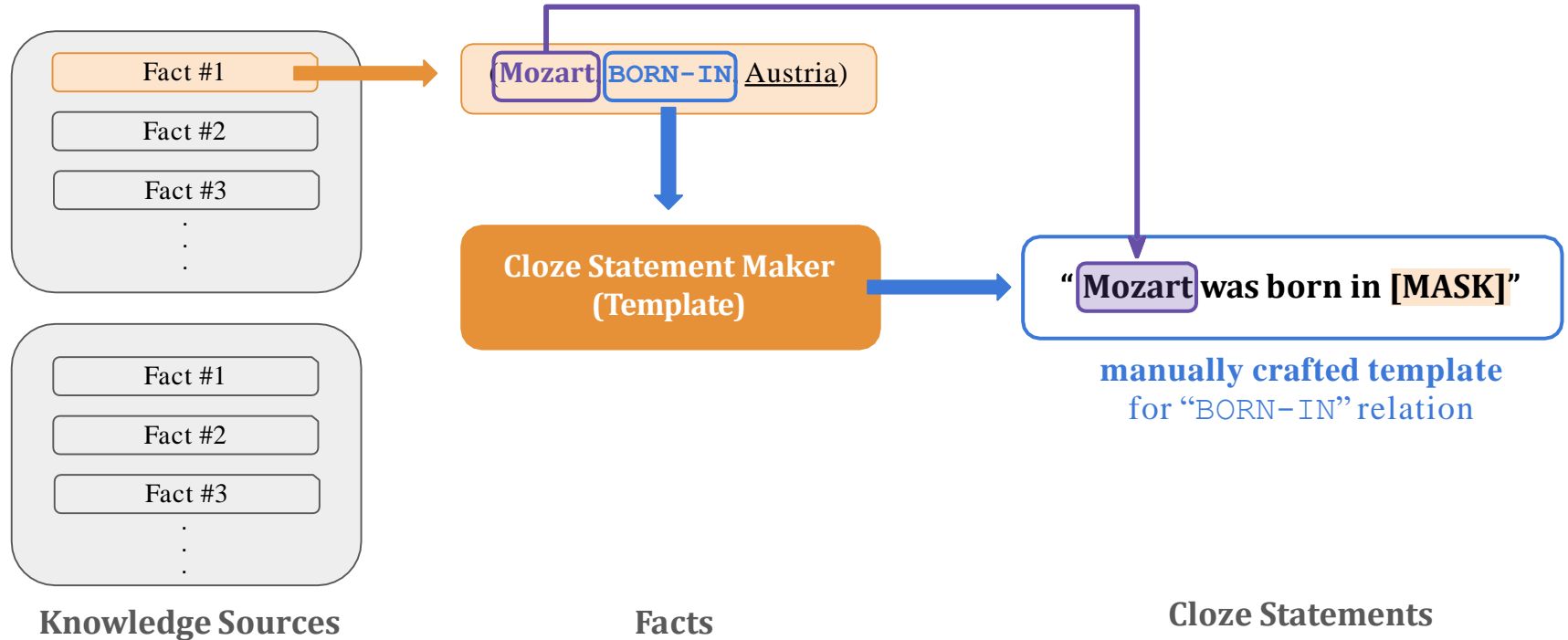
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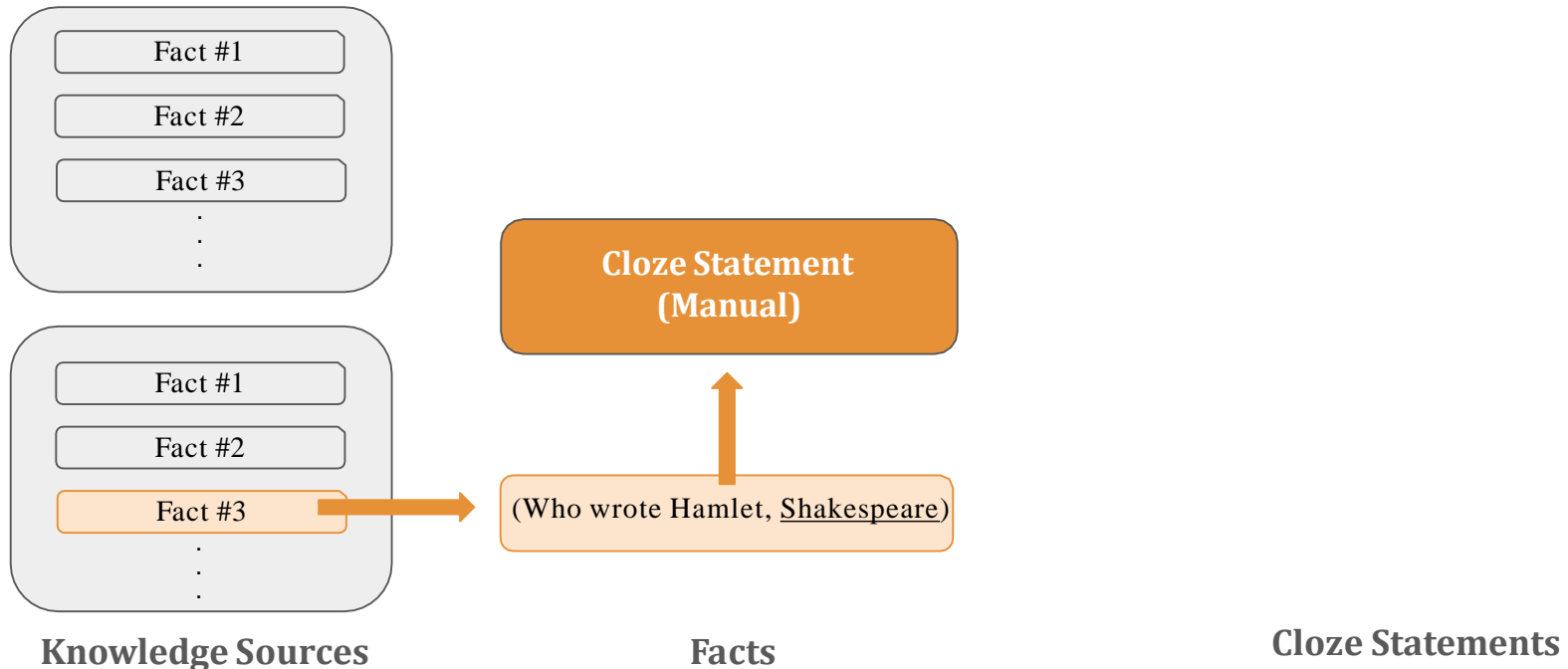
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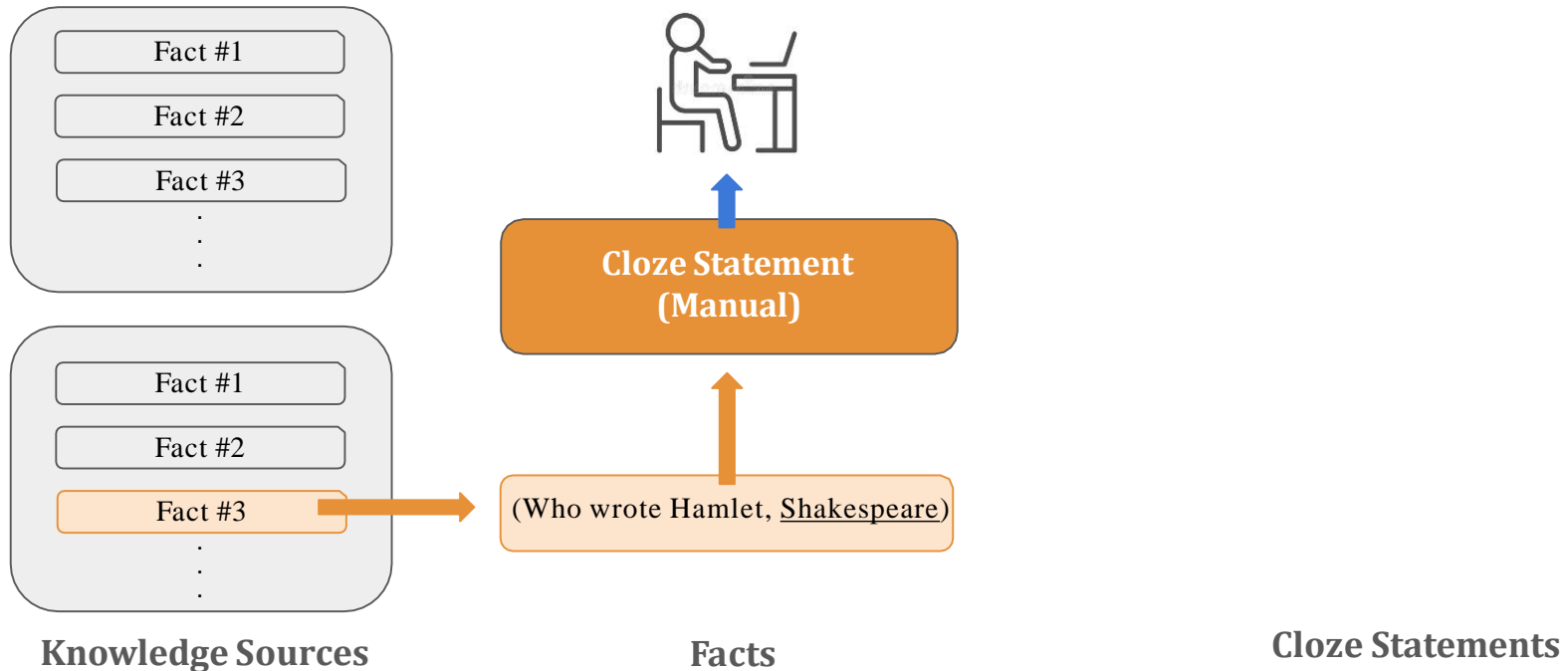
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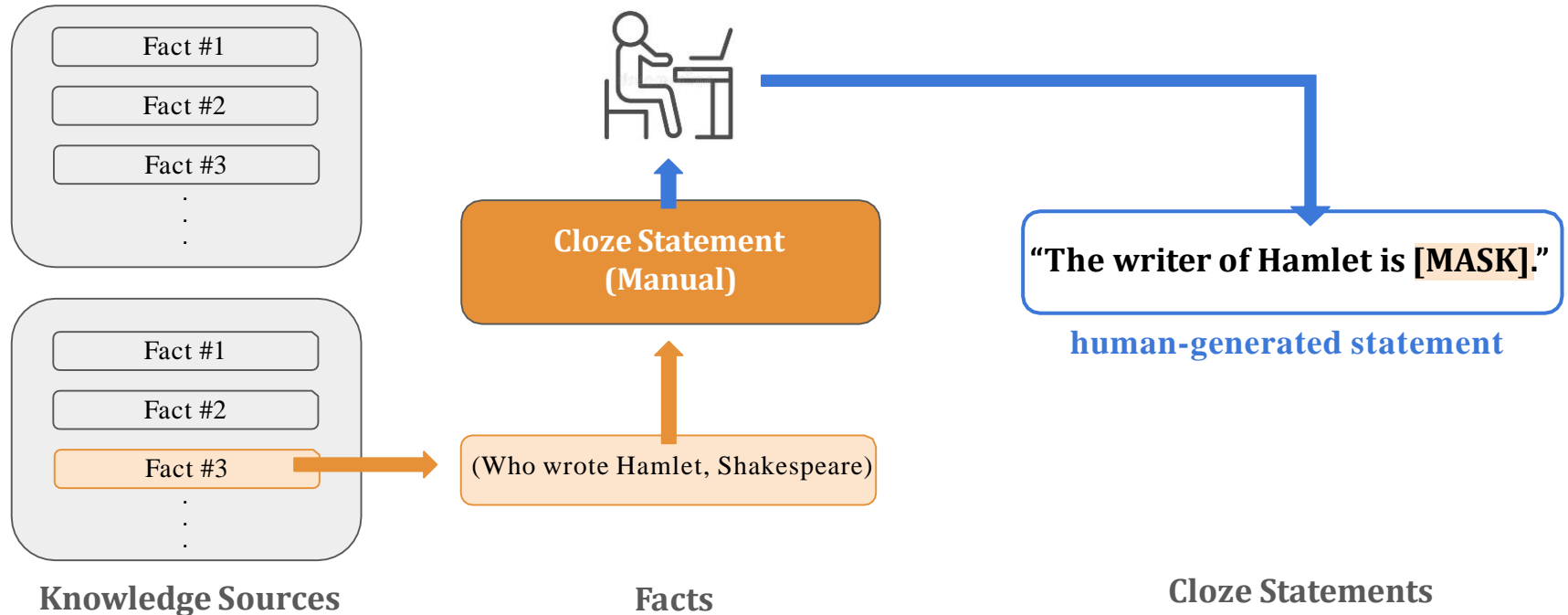
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More discussions on LAMA

Question 1

Describe what the LAMA Probe is in (Petroni et al., 2019)

- Convert facts to cloze statements (either manually or using templates)
- Ask LM to rank candidate vocabulary and see if ground truth is in top k rank

Can you think of any drawbacks of the probes?

- Answers must be single-token
- Relies on manual templates
- Questions are constrained to very specific and simple types of questions

Data leakage: **train-test overlap**

- **[Testing]** Many of the knowledge sources were extracted from **Wikipedia**
- **[Training]** However, pre-training corpora for language models almost always contain data from **Wikipedia**...
- How much of the amazing knowledge retrieval is due to **train-test overlap** in the knowledge probing benchmarks?

Train-test overlap is responsible for LM's ability to do knowledge retrieval! ([Lewis et al., 2020](#))

Model		Open Natural Questions				TriviaQA				WebQuestions			
		Total	Question Overlap	Answer Overlap Only	No Overlap	Total	Question Overlap	Answer Overlap Only	No Overlap	Total	Question Overlap	Answer Overlap Only	No Overlap
Open book	RAG	44.5	70.7	34.9	24.8	56.8	82.7	54.7	29.2	45.5	81.0	45.8	21.1
	DPR	41.3	69.4	34.6	19.3	57.9	80.4	59.6	31.6	42.4	74.1	39.8	22.2
	FID	51.4	71.3	48.3	34.5	67.6	87.5	66.9	42.8	-	-	-	-
Closed book	T5-11B+SSM	36.6	77.2	22.2	9.4	-	-	-	-	44.7	82.1	44.5	22.0
	BART	26.5	67.6	10.2	0.8	26.7	67.3	16.3	0.8	27.4	71.5	20.7	1.6
Nearest Neighbor	Dense	26.7	69.4	7.0	0.0	28.9	81.5	11.2	0.0	26.4	78.8	17.1	0.0
	TF-IDF	22.2	56.8	4.1	0.0	23.5	68.8	5.1	0.0	19.4	63.9	8.7	0.0

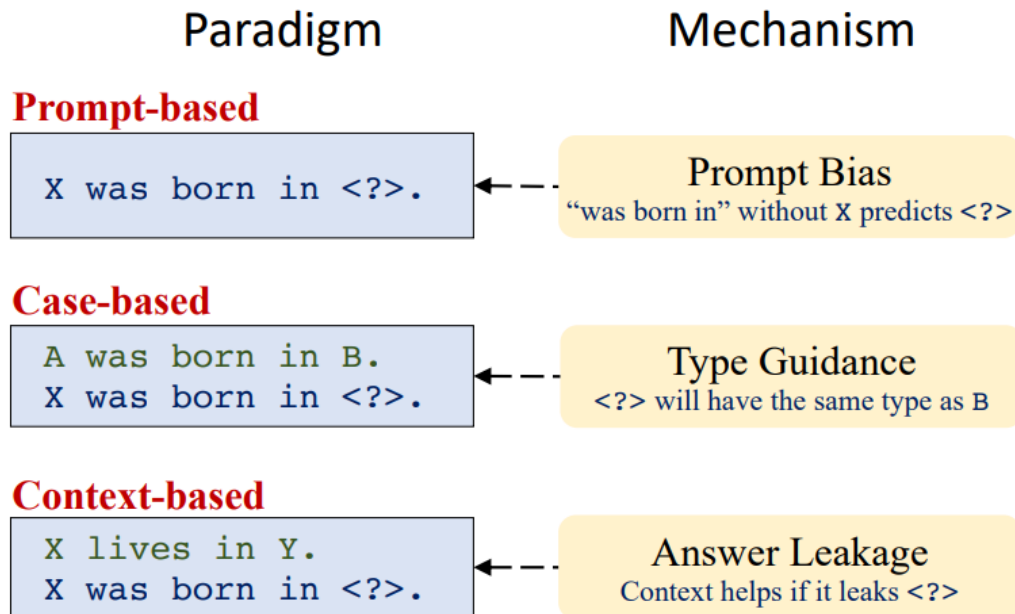
When there is **question overlap**, both open and closed-book LMs perform well

Train-test overlap is responsible for LM's ability to do knowledge retrieval! ([Lewis et al., 2020](#))

Model		Open Natural Questions				TriviaQA				WebQuestions			
		Total	Question Overlap	Answer Overlap Only	No Overlap	Total	Question Overlap	Answer Overlap Only	No Overlap	Total	Question Overlap	Answer Overlap Only	No Overlap
Open book	RAG	44.5	70.7	34.9	24.8	56.8	82.7	54.7	29.2	45.5	81.0	45.8	21.1
	DPR	41.3	69.4	20.6	19.3	57.9	80.4	50.6	31.6	42.4	74.1	20.8	22.2
	FID	51.4	71.3		34.5	67.6	87.5		42.8	-	-		-
Closed book	T5-11B+SSM	36.6	77.2	21.2	9.4	-	-		-	44.7	82.1	41.5	22.0
	BART	26.5	67.6	10.2	0.8	26.7	67.3	16.3	0.8	27.4	71.5	20.7	1.6
Nearest Neighbor	Dense	26.7	69.4	7.0	0.0	28.9	81.5	11.2	0.0	26.4	78.8	17.1	0.0
	TF-IDF	22.2	56.8	4.1	0.0	23.5	68.8	5.1	0.0	19.4	63.9	8.7	0.0

But with **no question or answer overlap**, performance drops sharply!

Revising LAMA – underlying mechanisms



Revising LAMA – Reporting Bias

It is uninteresting to say one is **thinking** or **breathing**.
But something related to **murders** seems interesting to share

Action	Actual Frequency for Lifetime (Source)
thinking	1,433,355,000 (50,000 per day)
breathing	660,489,984 (23,040 per day)
blinking	344,005,200 (12,000 per day)
eating	86001.3: 3 times per day
sleeping	28667.1: 1 time per day
working	20420.4: 5 times a week
exercising	8168.16: 2-3 times a week
getting married	1.66: 0-3 times per life
getting divorced	1: 0-2 times per life
being born	1
being named	1
dying	1
being abused	0.5 (source)
being injured	0.1263 (Episodes per 1,000 population: 126.3)
being raped	0.01 (18.3% of women (50.8% of population) and 1.4% of men (49.2% of population))
being killed	4.01×10^{-2} (murder + 1 out 28 in accident)
being arrested	0.031526 (3,152.6 arrests per 100,000)
being adopted	0.021 (7 million out of 328.2)
being murdered	4.37×10^{-3} (1 in 229 deaths)
being abandoned	0.000175 (7000 each year, out of 4M births)

Revising LAMA – Reporting Bias

	BERT	RoBERTa	GPT-2		BERT	RoBERTa	GPT-2
The person ____.	wins (11.4)	said (5.8)	let (4.3)	The person is ____.	killed (7.5)	gone (6.3)	let (4.3)
	died (11.4)	responds (4.0)	see (3.9)		married (6.6)	deceased (3.8)	see (3.9)
	dies (10.6)	replied (3.4)	make (2.4)		dying (4.2)	arrested (2.9)	make (2.4)
	won (7.8)	dies (3.3)	get (2.1)		deceased (3.8)	missing (2.5)	get (2.1)
	lost (3.5)	died (2.9)	look (2.1)		eliminated (2.6)	responding (1.9)	look (2.1)
	said (2.4)	responded (2.5)	take (1.2)		retired (2.2)	involved (1.9)	take (1.2)
	speaks (1.9)	says (2.4)	set (1.2)		lost (2.0)	reading (1.9)	set (1.2)
	answered (1.6)	replies (2.2)	give (1.1)		arrested (2.0)	dying (1.9)	give (1.1)
	replied (1.3)	asked (2.1)	using (1.1)		elected (1.5)	confused (1.5)	using (1.1)
	loses (1.3)	commented (2.1)	go (1.1)		disabled (1.5)	reporting (1.5)	go (1.1)

Table 1: Top LM predictions for actions performed by people along with their scores (percents).

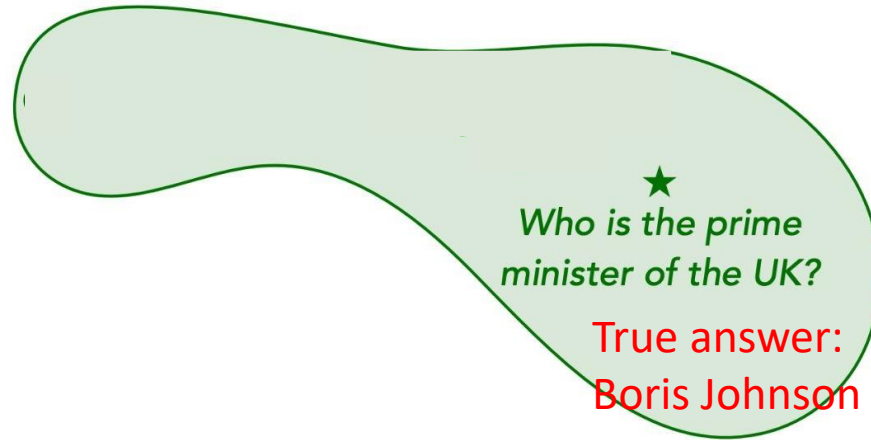
Reporting bias: due to Grice’ s conversational maxim of quantity (Grice et al., 1975), people rarely state the obvious, thus many trivial facts (“people breathe”) are rarely mentioned in text, while uncommon events (“people murder”) are reported disproportionately (Gordon and Van Durme, 2013; Sorower et al., 2011).

- **Knowledge in LLMs**
 - LLMs as knowledge bases
 - Facts updating for LLMs
- **Reasoning in LLMs**
 - Why reasoning is special in LLMs
 - Techniques for better reasoning

How to update knowledge in
pre-trained models?

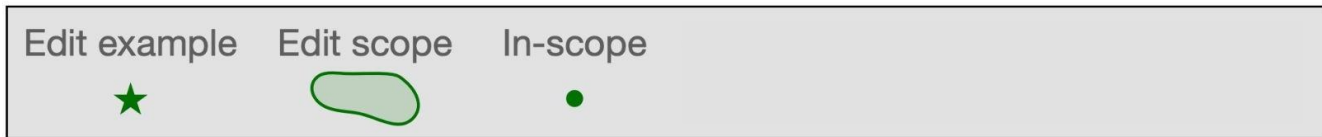
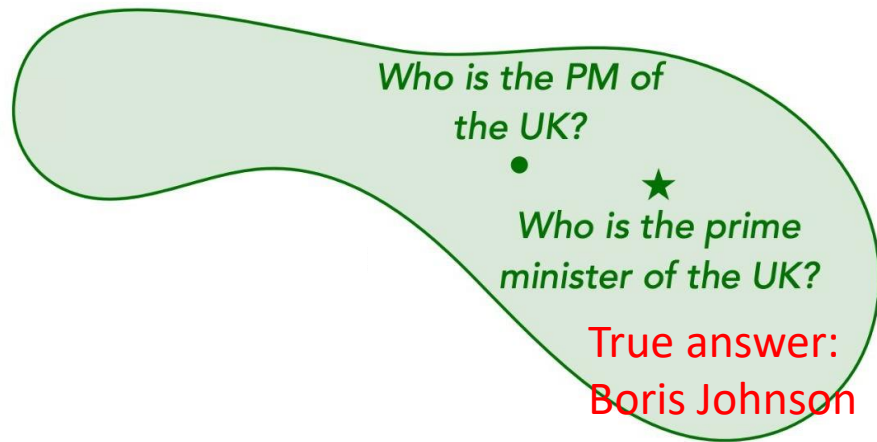
Edit What, Exactly?

Defining the problem



Edit What, Exactly?

Defining the problem

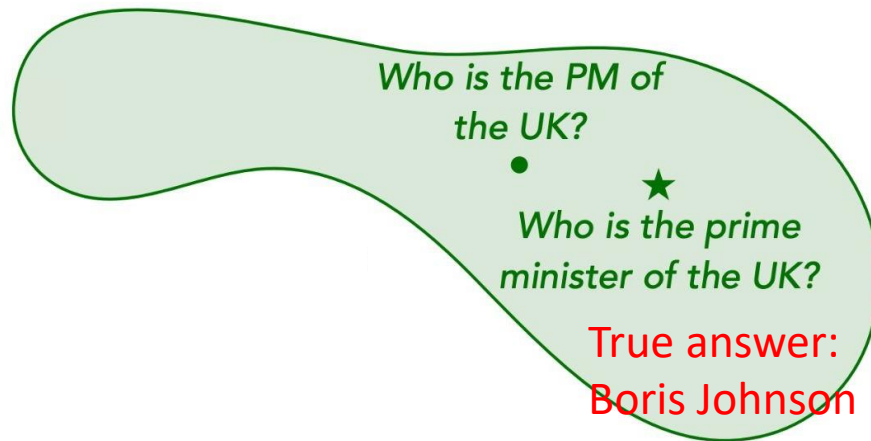


Edit What, Exactly?

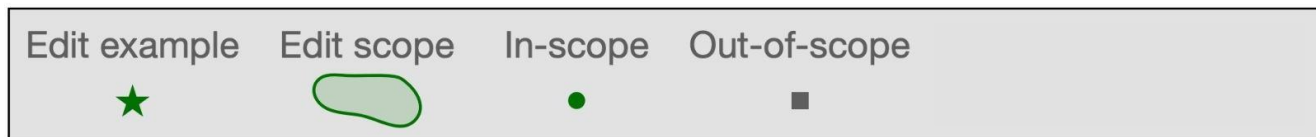
Defining the problem

■
Why is the sky blue?

■
*What club does
Messi play for?*

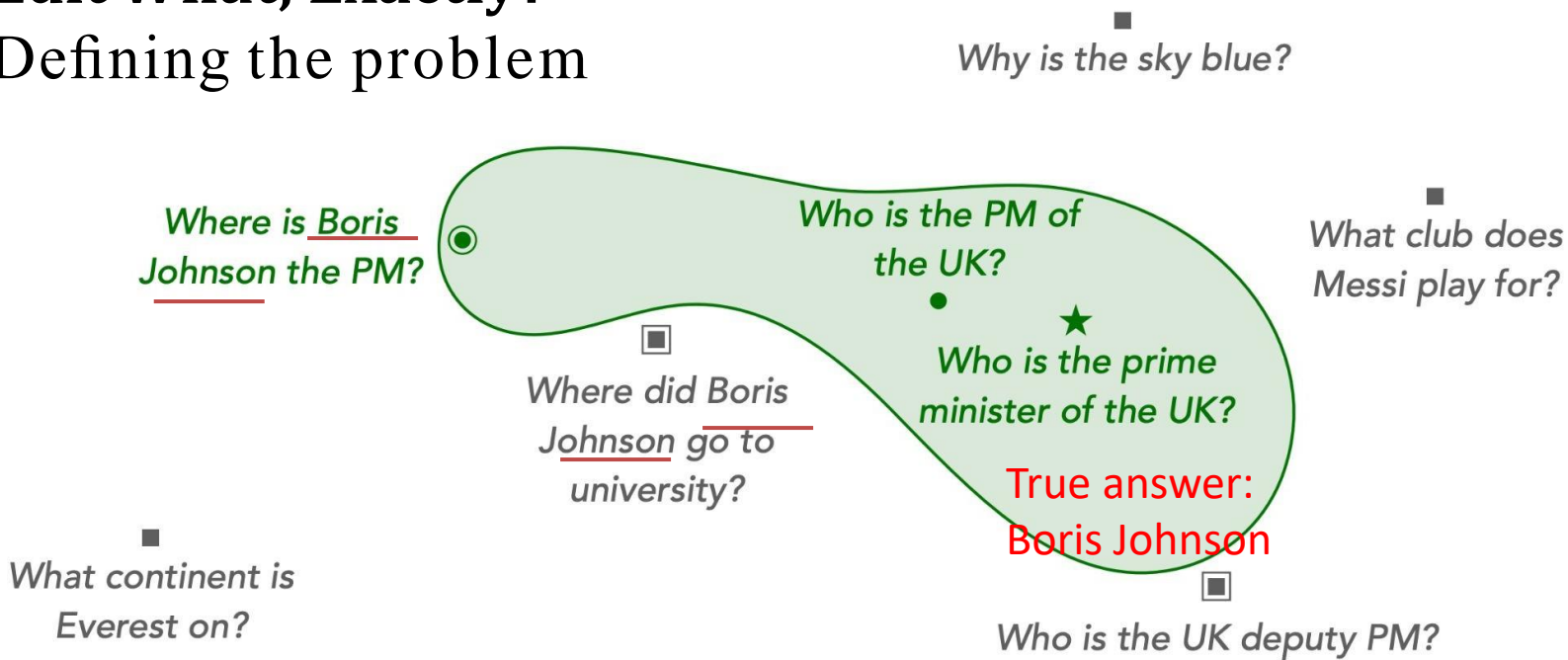


■
*What continent is
Everest on?*



Edit What, Exactly?

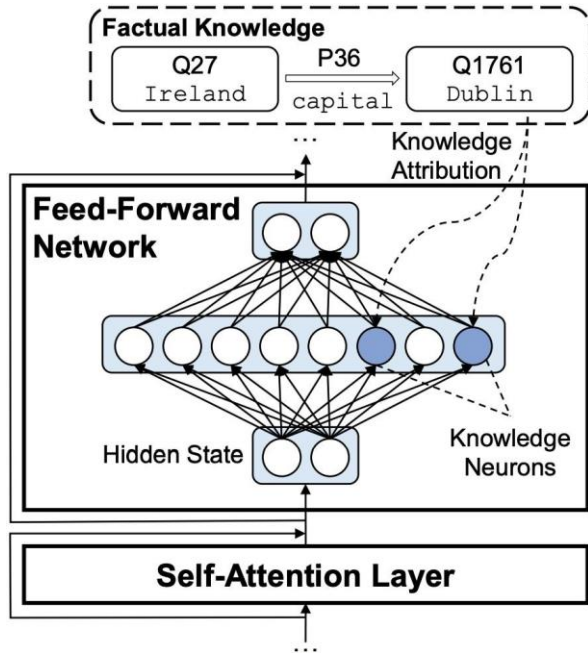
Defining the problem



Edit example	Edit scope	In-scope	Out-of-scope	Hard in/out-of-scope
★		●	■	● □

How to edit knowledge in pre-trained models?

Knowledge Neurons



- What is a knowledge neuron
 - **Activations** after the first feed-forward layer
- Assumption
 - Knowledge neurons are associated with factual knowledge
- Implications
 - If we can identify these neurons, we can alter them to edit (update/erase) knowledge.
 - No additional training is involved.

Identify knowledge neurons

Given a relational fact e.g. (Mozart, BORN-IN, Austria)

1. produce N diverse prompts;
2. for each prompt, calculate the knowledge attribution scores of neurons;
3. for each prompt, retain the neurons with attribution scores greater than the attribution threshold T , obtaining the coarse set of knowledge neurons;
4. considering all the coarse sets together, retain the knowledge neurons shared by more than $p\%$ prompts.

Knowledge neuron editing

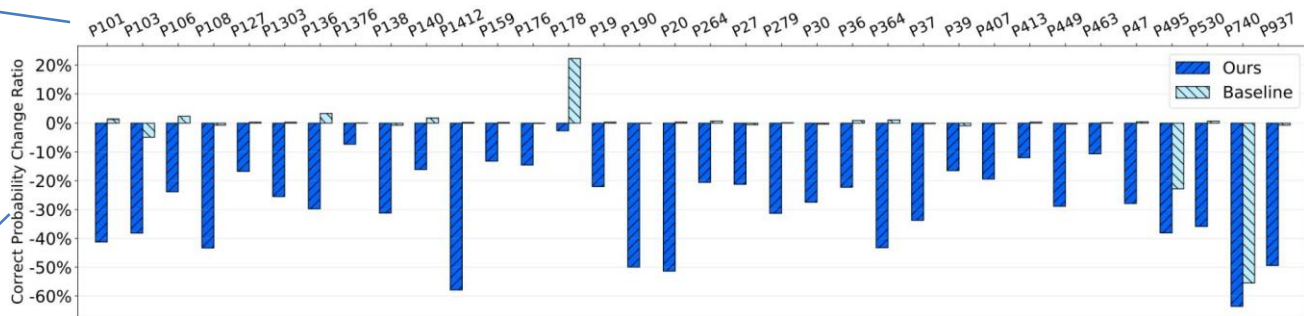
Knowledge neuron: activations after the first feed-forward layer

Suppressing the neuron: activation = 0

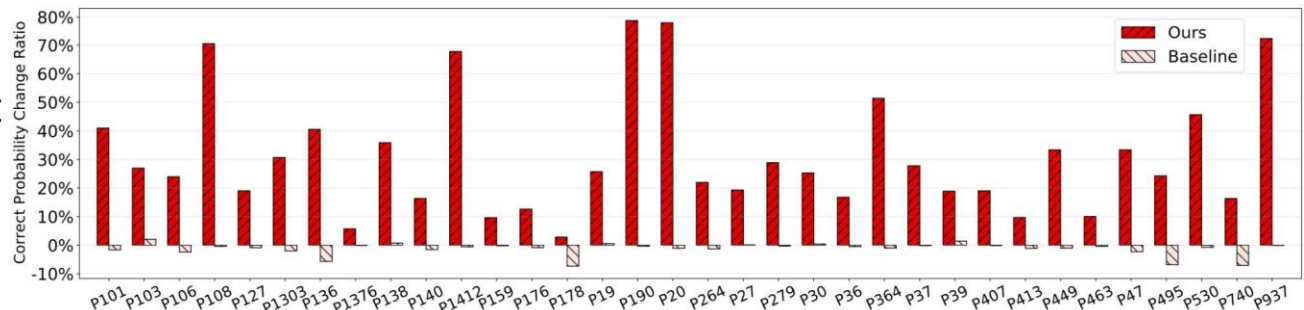
Amplifying the neuron: activation = 2*activation

Suppressing or Amplifying Knowledge Neurons

Topic: ←
P176:
manufacture



Probability
change ratio
for the correct
answer



Suppressing the neurons **hurt** performance and **amplifying** neurons **increase** performance by up to 30% on average.

Drawback

Sensitive to the format of the prompt collected by human

Relations	Template #1	Template #2	Template #3
P176 (manufacturer)	[X] is produced by [Y]	[X] is a product of [Y]	[Y] and its product [X]
P463 (member_of)	[X] is a member of [Y]	[X] belongs to the organization of [Y]	[X] is affiliated with [Y]
P407 (language_of_work)	[X] was written in [Y]	The language of [X] is [Y]	[X] was a [Y]-language work

Table 1: Example prompt templates of three relations in PARAREL. [X] and [Y] are the placeholders for the head and tail entities, respectively. Owing to the page width, we show only three templates for each relation. Prompt templates in PARAREL produce 253,448 knowledge-expressing prompts in total for 27,738 relational facts.

- Knowledge in LLMs
 - LLMs as knowledge bases
 - Facts updating for LLMs
- Reasoning in LLMs
 - Why reasoning is special in LLMs
 - Techniques for better reasoning

Human Intelligence vs. Traditional machine learning? (Hint: reasoning)

Humans	Traditional machine learning
Learn from only a few examples	Large amounts of labeled data
Can explain rationale for decisions	Black box
Out-of-distribution generalization	No

Attempts to fill the gap in the past decades

- Bayesian machine learning, kernel machines, nonparametric, sparsity, large-margin, semi-supervised learning, manifold learning, graph-based learning, transductive learning, meta learning, transfer learning, active learning, domain adaptation, structural learning, low-rank, ...

FAILED

Teaching language models to reason (Denny Zhou), 2023.

Multi-step reasoning is hard for language models

“type 1”

This movie sucks!

Novak Djokovic wins
the 2021 French
Open.

Thank you!

Language
Model

Sentiment = negative

Topic = Tennis

Translation: 谢谢!

Take the last letters of
the words in “Elon Musk”
and concatenate them.

“uk” ❌ (“nk”)

“type 2”

The cafeteria had 23 apples. If
they used 20 to make lunch and
bought 6 more, how many apples
do they have?

27 ❌ (9)

What do language models learn from next-word prediction?

<i>Grammar</i>	In my free time, I like to { <u>run</u> , banana}
<i>Lexical semantics</i>	I went to the zoo to see giraffes, lions, and {zebras, <u>spoon</u> }
<i>World knowledge</i>	The capital of Denmark is {Copenhagen, London}
<i>Sentiment analysis</i>	Movie review: I was engaged and on the edge of my seat the whole time. The movie was {good, bad}
<i>Harder sentiment analysis</i>	Movie review: Overall, the value I got from the two hours watching it was the sum total of the popcorn and the drink. The movie was {bad, good}
<i>Translation</i>	The word for “pretty” in Spanish is {bonita, hola}
<i>Spatial reasoning</i>	[...] Iroh went into the kitchen to make some tea. Standing next to Iroh, Zuko pondered his destiny. Zuko left the {kitchen, store}
<i>Math question</i>	First grade arithmetic exam: $3 + 8 + 4 =$ {15, 11}

[thousands (millions?) more]

Extreme multi-task learning!

What can't language models learn from next-word prediction?

<i>Current world knowledge</i>	The stock price of APPL on March 1st, 2023 is {???
<i>Arbitrarily long arithmetic</i>	$36382894730 + 238302849204 = \{???\}$
<i>Many-step reasoning</i>	Take the nineteenth digit of Pi and multiply it by the e to the fourth power. The resulting ones-digit of the resulting number is {???
<i>Predict the future</i>	The winner of the FIFA world cup in 2026 is {???
<i>Information not in the training data</i>	Jason Wei's favorite color is {???
<i>Extremely long inputs</i>	[2,000 page Harry Potter fan-fiction] What happened after Harry opened the chest for the second time? {???

Jason Wei' s rule of thumb (经验法则)

language models can do (with decent accuracy)
most text tasks that **an average human can do in 1 minute.**



2018

Today (2023)

Future ...?

...
Protein discovery
Clinical diagnosis
Play chess well
High-level planning
Abstract reasoning
Simple math
Commonsense reasoning
Know world knowledge
Translation
Sentiment analysis
Generate coherent text
Be grammatically correct

...
Protein discovery
Clinical diagnosis
Play chess well
High-level planning
Abstract reasoning
Simple math
Commonsense reasoning
Know world knowledge
Translation
Sentiment analysis
Generate coherent text
Be grammatically correct

...
(?) Protein discovery
(?) Clinical diagnosis
(?) Play chess well
(?) High-level planning
(?) Abstract reasoning
Simple math
Commonsense reasoning
Know world knowledge
Translation
Sentiment analysis
Generate coherent text
Be grammatically correct

Hard Language Tasks: Reasoning

Reasoning Problems

Q: If there are 3 cars in the parking lot and 2 more cars arrive, how many cars are in the parking lot?

A: The answer is **5**

Mathematical Reasoning

Q: Take the last letters of the words in "Elon Musk" and concatenate them

A: The answer is **nk**.

Symbolic Reasoning

Q: What home entertainment equipment requires cable?

Answer Choices: (a) radio shack (b) substation
(c) television (d) cabinet

A: The answer is **television**.

Commonsense Reasoning

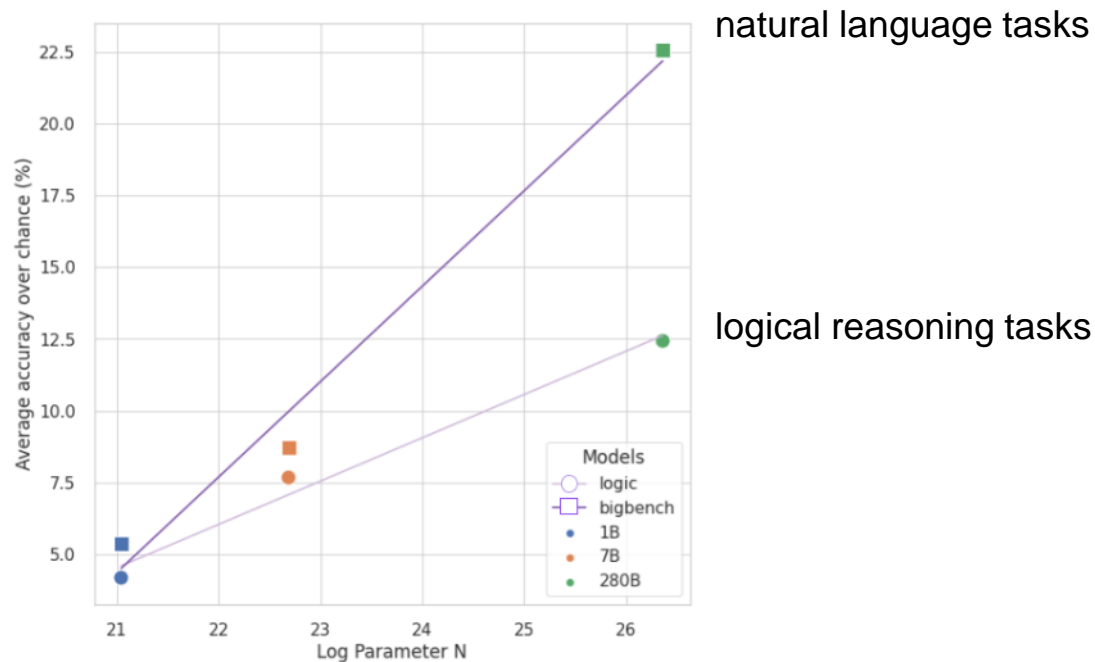
Q: Wolves are afraid of mice. Sheep are afraid of wolves. Emily is a wolf. What is Emily afraid of?

A: The answer is **mice**.

Logical Reasoning

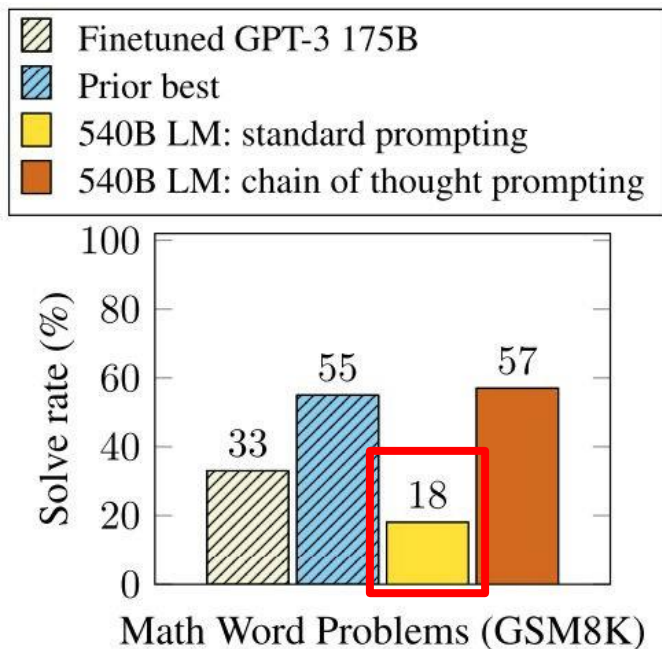
Scaling laws are worse for logical reasoning

(Creswell et al. 2022)



LLM fails in challenging mathematical reasoning

GSM8K (mathematical reasoning):



It is not trivial for even a 540B model to deal with the problem

- Knowledge in LLMs
 - LLMs as knowledge bases
 - Facts updating for LLMs
- Reasoning in LLMs
 - Why reasoning is special in LLMs
 - Techniques for better reasoning

What is In-Context Learning?

Circulation revenue has increased by 5% in Finland. // Positive

Panostaja did not disclose the purchase price. // Neutral

Paying off the national debt will be extremely painful. // Negative

The company anticipated its operating profit to improve. // _____

LM

Circulation revenue has increased by 5% in Finland. // Finance

They defeated ... in the NFC Championship Game. // Sports

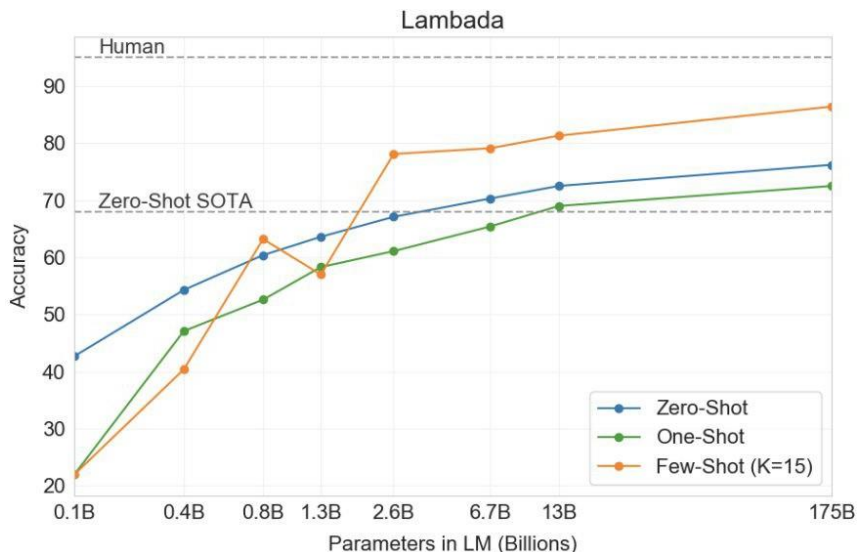
Apple ... development of in-house chips. // Tech

The company anticipated its operating profit to improve. // _____

LM

What Can In-Context Learning Do?

- No parameter tuning need
- Only need few examples for downstream tasks
- GPT-3 improved SOTA on LAMBADA (last word prediction task) by 18%!



Works like magic!

A simple way to improve the performance – Chain of Thought prompting (CoT)

Standard Prompting

Input

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

A: The answer is 11.

Q: The cafeteria had 23 apples. If they used 20 to make lunch and bought 6 more, how many apples do they have?

Model Output

A: The answer is 27. ❌

Chain of Thought Prompting

Input

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

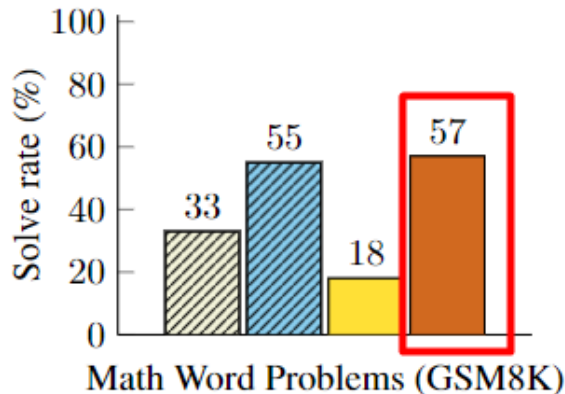
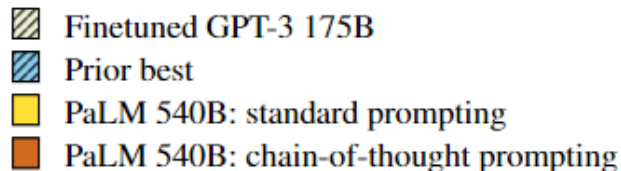
A: Roger started with 5 balls. 2 cans of 3 tennis balls each is 6 tennis balls. $5 + 6 = 11$. The answer is 11.

Q: The cafeteria had 23 apples. If they used 20 to make lunch and bought 6 more, how many apples do they have?

Model Output

A: The cafeteria had 23 apples originally. They used 20 to make lunch. So they had $23 - 20 = 3$. They bought 6 more apples, so they have $3 + 6 = 9$. The answer is 9. ✅

<input, intermediate results, output>



- decompose into easier intermediate steps
- interpretable

Zero-Shot CoT – Let's think step by step

(a) Few-shot

Examples

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

A: The answer is 11.

Q: A juggler can juggle 16 balls. Half of the balls are golf balls, and half of the golf balls are blue. How many blue golf balls are there?

A:

(Output) The answer is 8. ❌

(c) Zero-shot

Q: A juggler can juggle 16 balls. Half of the balls are golf balls, and half of the golf balls are blue. How many blue golf balls are there?

A: The answer (arabic numerals) is

(Output) 8 ❌

(b) Few-shot-CoT (Wei et al., 2022)

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

A: Roger started with 5 balls. 2 cans of 3 tennis balls each is 6 tennis balls. $5 + 6 = 11$. The answer is 11.

Q: A juggler can juggle 16 balls. Half of the balls are golf balls, and half of the golf balls are blue. How many blue golf balls are there?

A:

(Output) The juggler can juggle 16 balls. Half of the balls are golf balls. So there are $16 / 2 = 8$ golf balls. Half of the golf balls are blue. So there are $8 / 2 = 4$ blue golf balls. The answer is 4. ✓

CoT Examples

Step-by-step Answer

(d) Zero-shot-CoT (KoJima et al., 2022)

Q: A juggler can juggle 16 balls. Half of the balls are golf balls, and half of the golf balls are blue. How many blue golf balls are there?

A: **Let's think step by step.**

(Output) There are 16 balls in total. Half of the balls are golf balls. That means that there are 8 golf balls. Half of the golf balls are blue. That means that there are 4 blue golf balls. ✓

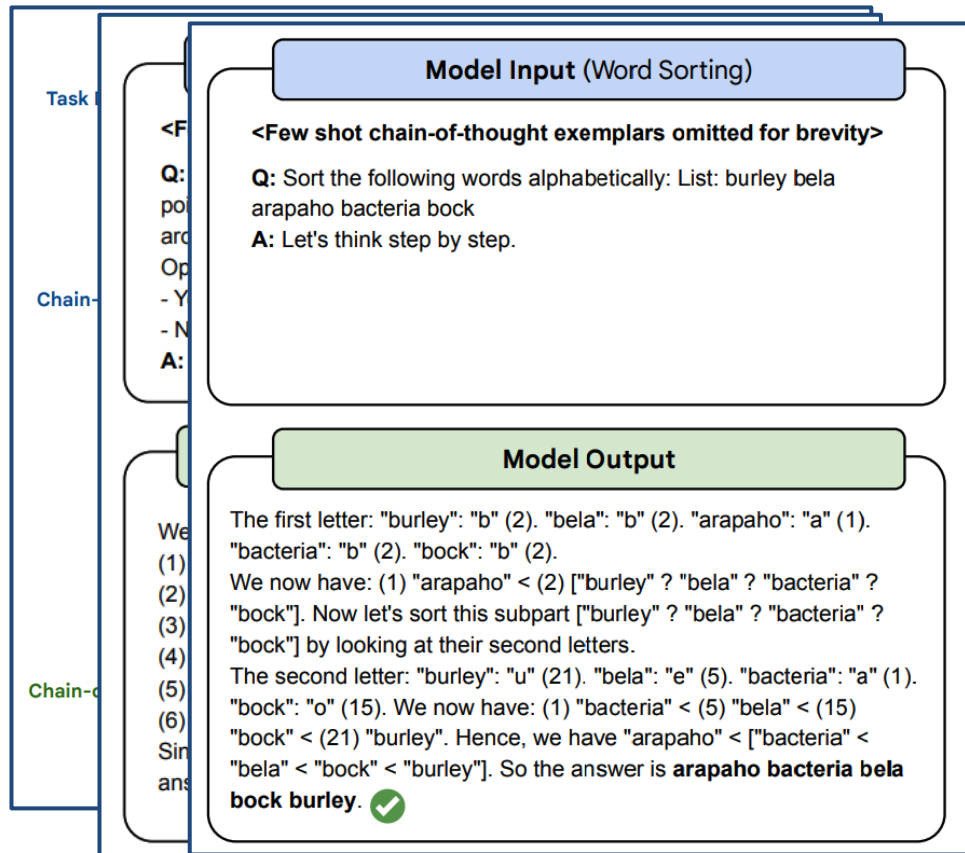
Step-by-step Answer

CoT on BIG-Bench: Benchmark

BIG-Bench Hard (BBH):

- 23 challenging tasks from BIG-Bench benchmark where no model beats avg. human rater

[Challenging BIG-Bench tasks and whether chain-of-thought can solve them \(2022\).](#)



CoT on BIG-Bench: Result summary

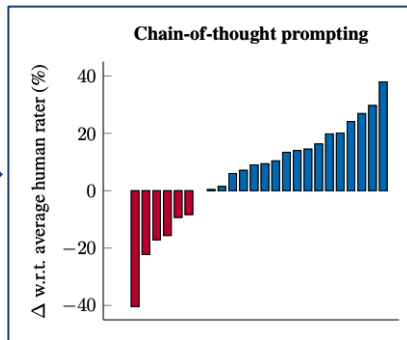
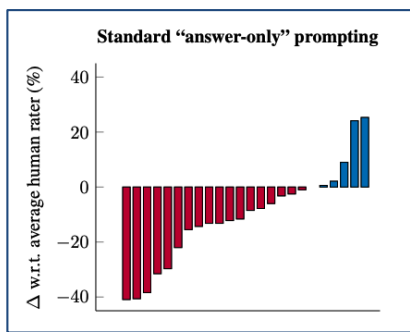
	BBH all (23 tasks)	# tasks above avg. human-rater
Average human-rater	67.7	N/A
Max human-rater	94.4	23 / 23
Best prior BIG-Bench result	50.9	0 / 23
Codex (code-davinci-002)		
- Answer-only prompting	56.6	5 / 23
- CoT prompting	73.9 (+16.7)	17 / 23

Model much lower than average human rater

Detail: better formatting (options, task description) already beats prior best

[Challenging BIG-Bench tasks and whether chain-of-thought can solve them \(2023\).](#)

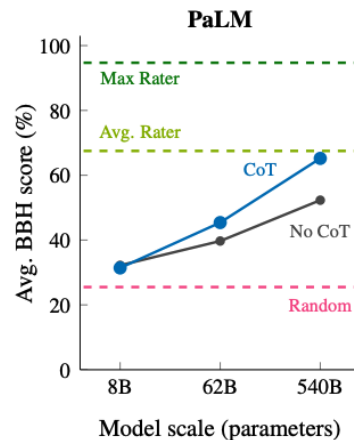
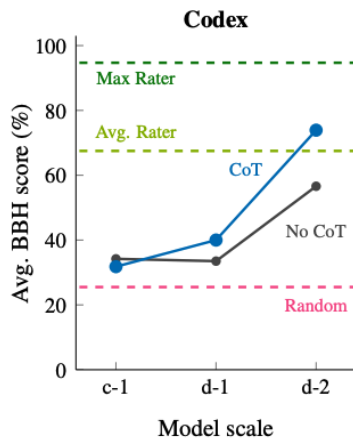
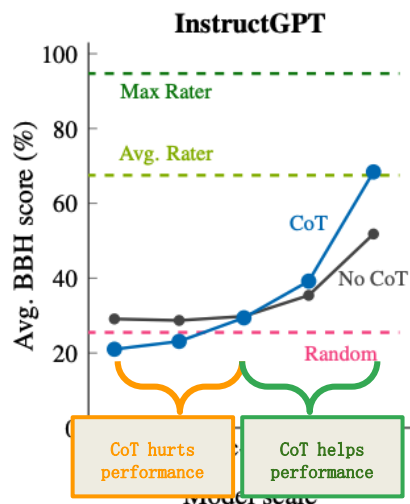
CoT prompting improves by performance by +16.7%, passes avg. human on majority of tasks



CoT on BIG-Bench: Scaling

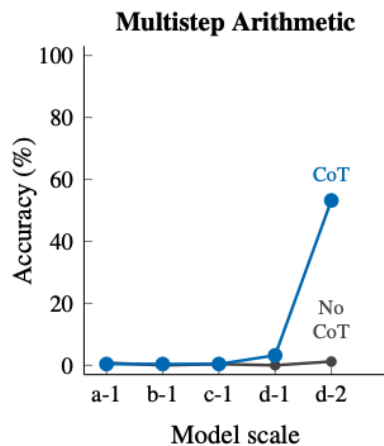
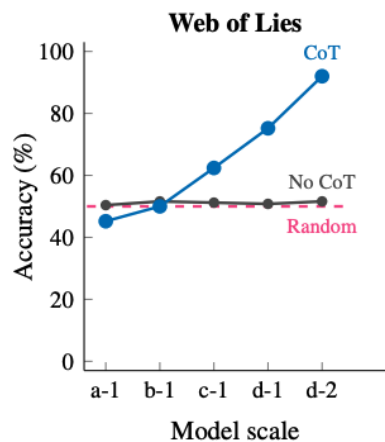
- CoT requires sufficient model scale for positive delta

[Challenging BIG-Bench tasks and whether chain-of-thought can solve them \(2023\).](#)



CoT on BIG-Bench: Emergence

- No-CoT performance is flat, i.e., hasn't unlocked emergence (yet :))
- CoT unlocks emergent performance



[Challenging BIG-Bench tasks and whether chain-of-thought can solve them \(2023\).](#)

Model Input (Multistep Arithmetic)

<Few shot chain-of-thought exemplars omitted for brevity>

Q: $((4 + 7 * 4 - -5) - (-4 - 1 - -4 - 4)) =$
A: Let's think step by step.

Model Output

Let's recall that the order of operations in mathematics is as follows: (1) Parentheses, (2) exponents, (3) multiplication and division (from left to right), (4) addition and subtraction (from left to right). So, remember to always compute the expressions inside parentheses or brackets first.

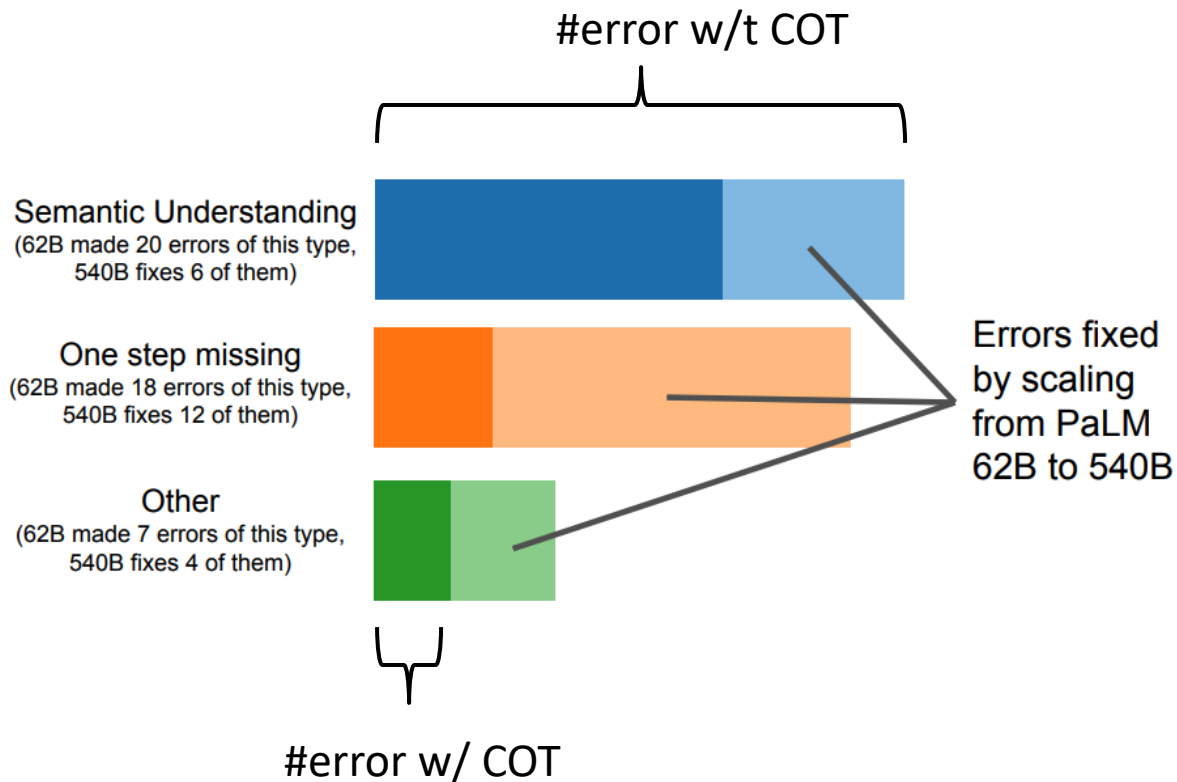
This equation can be written as "A - B", where A = $(4 + 7 * 4 - -5)$ and B = $(-4 - 1 - -4 - 4)$.

Let's calculate A = $(4 + 7 * 4 - -5) = (4 + (7 * 4) - -5) = (4 + (28) - -5) = (4 + 28 - -5) = (4 + 28 + 5) = 37$.

Let's calculate B = $(-4 - 1 - -4 - 4) = ((-4 - 1) - -4 - 4) = ((-5) - -4 - 4) = ((-5 - -4) - 4) = ((-5 + 4) - 4) = (-1 - 4) = -5$.

Then, the final equation is A - B = $37 - -5 = 37 + 5 = 42$. So the answer is **42**. ✓

Why does scaling up improve chain-of-thought?



Multilingual chain-of-thought prompting

Prompt the model with Bengali math problems and Bengali reasoning

Input is highly improbable (Bengali is 0.01% of pre-training data)

Model Input

প্রশ্ন: রজারের 5টি টেনিস বল আছে। সে আরও 2 ক্যান টেনিস বল কিনেছে। প্রতিটি ক্যান 3টি করে টেনিস বল আছে। তার কাছে এখন কতগুলি টেনিস বল আছে?

ধাপে ধাপে উত্তর: রজারের প্রথমে 5টি বল ছিল। 2টি ক্যানের প্রতিটিতে 3টে টেনিস বল মানে 6টি টেনিস বল। $5 + 6 = 11$ । উত্তর হল 11।

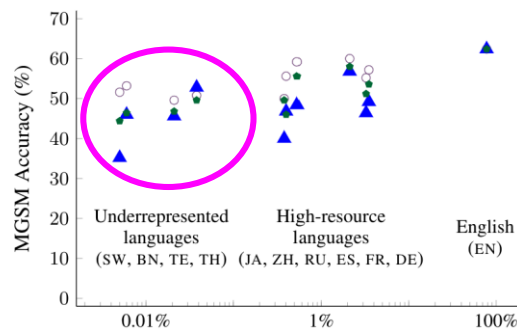
প্রশ্ন: জেনেটের হাঁসগুলি প্রতিদিন 16টি ডিম পাড়ে। তিনি প্রতিদিন প্রাতরাশে তিনটি করে ডিম খান এবং বন্ধুদের জন্য প্রতিদিন চারটি ডিম দিয়ে মাফিন তৈরি করেন। অবশিষ্ট হাঁসের ডিমগুলি তিনি প্রতিদিন কৃষকদের বাজারে প্রতি ডিম \$2 দরে বিক্রয় করেন। তিনি কৃষকদের বাজারে প্রতিদিন কত ডলার উপার্জন করেন?

Model Output

ধাপে ধাপে উত্তর: প্রতিদিন 16টি ডিম পাড়ে। প্রতিদিন তিনটি ডিম খান এবং চারটি ডিম দিয়ে মাফিন তৈরি করেন। তাই প্রতিদিন $16 - 3 - 4 = 9$ টি ডিম অবশিষ্ট থাকে। প্রতিটি ডিমের মূল্য \$2 হলে প্রতিদিন $9 * 2 = 18$ ডলার উপার্জন করেন। উত্তর হল 18। ✓

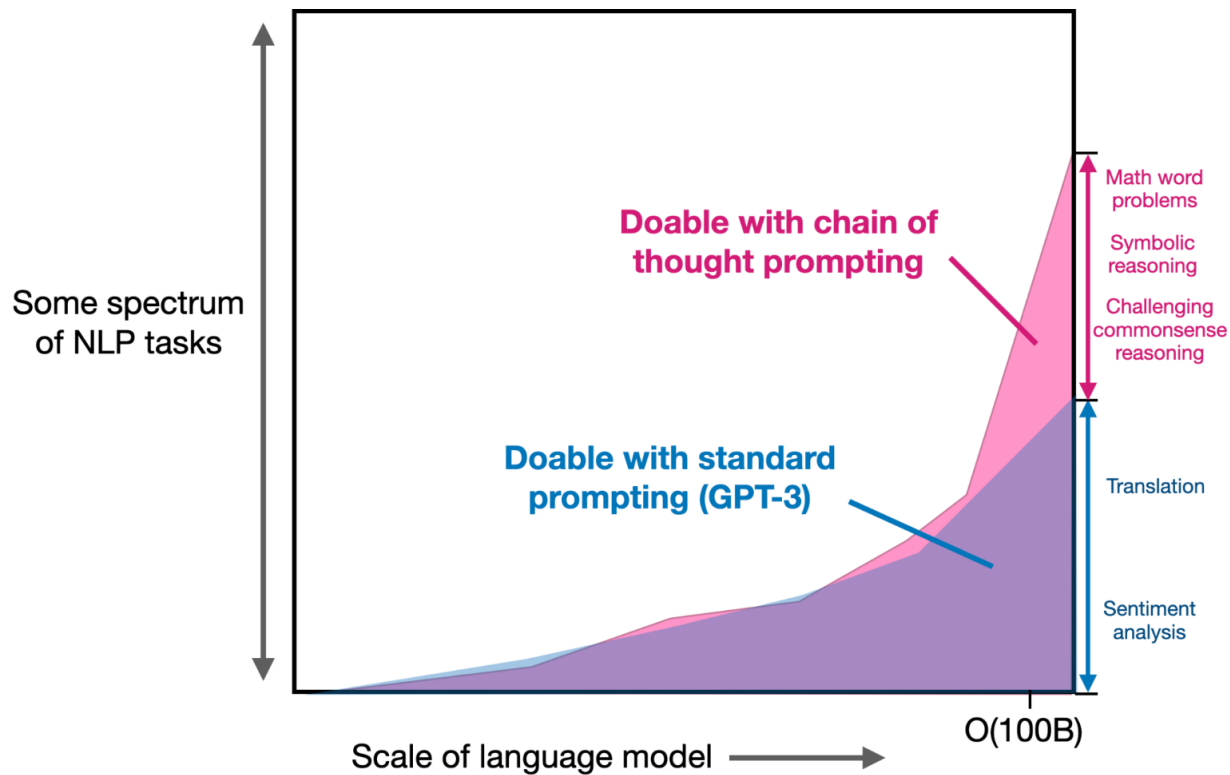
Language models are multilingual chain-of-thought reasoners

- Translate to English with Google Translate and solve with English intermediate steps
- ▲ Intermediate reasoning steps in the language of the question
- Intermediate reasoning steps in English

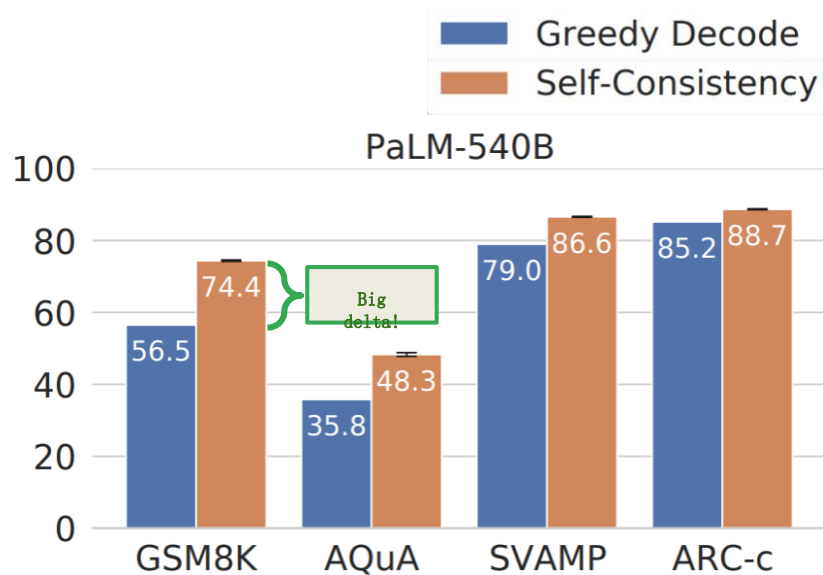


Frequency of language in pre-training dataset (token percentage)

Underrepresented languages did surprisingly well, demonstrating the compositionality of the model (model is neither multilingual nor trained to do reasoning)



Self-consistency works really well



A surprising result on math word problems

Question: A particle moves so that it is at $(3 \sin \frac{t}{4}, 3 \cos \frac{t}{4})$ at time t . Find the speed of the particle, measured in unit of distance per unit of time.

Model output: The speed is the magnitude of the velocity vector. Therefore, we must first find the velocity vector, which is the derivative of the position vector. We have

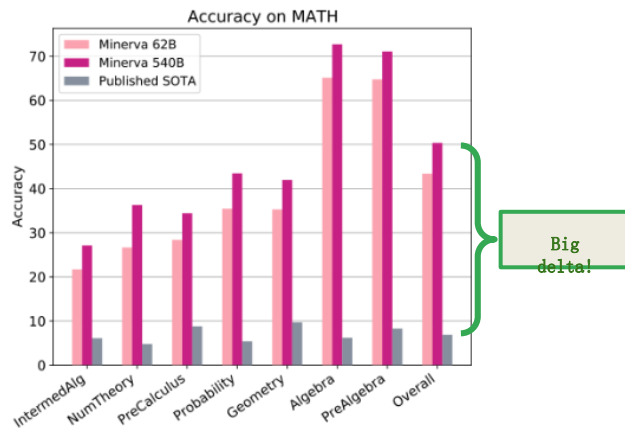
$$\mathbf{v} = \frac{d}{dt} \left(3 \sin \frac{t}{4}, 3 \cos \frac{t}{4} \right) = 3 \left(\cos \frac{t}{4}, -\sin \frac{t}{4} \right) \frac{1}{4} = \left(\frac{3}{4} \cos \frac{t}{4}, -\frac{3}{4} \sin \frac{t}{4} \right).$$

Therefore, the magnitude of the velocity vector is

$$\begin{aligned} |\mathbf{v}| &= \sqrt{\left(\frac{3}{4} \cos \frac{t}{4} \right)^2 + \left(-\frac{3}{4} \sin \frac{t}{4} \right)^2} = \sqrt{\frac{9}{16} \cos^2 \frac{t}{4} + \frac{9}{16} \sin^2 \frac{t}{4}} \\ &= \frac{3}{4} \sqrt{\cos^2 \frac{t}{4} + \sin^2 \frac{t}{4}} = \frac{3}{4}. \end{aligned}$$

Therefore, the speed of the particle is $\frac{3}{4}$.

[Solving quantitative reasoning problems with language models \(2022\).](#)



Chain-of-thought analysis

Benefits

Expands the range of abilities for language models

Multi-step reasoning can now be solved!

Works for any text (and image?) task

Every task has a chain-of-thought.

No fine-tuning needed.

Single model, many tasks

Some interpretability (can read chain-of-thought)

Though it's not necessarily how the model reasons

Drawbacks

Requires a large language model

Emergent ability

Higher inference cost than directly answering

CoT can be hundreds of tokens

Requires manually writing chains-of-thought in the prompts via exemplars

(Some zero-shot that works for common multi-step reasoning problems)

Suggested further reading:

[Large language models are zero-shot reasoners.](#)

CoT is not enough

- Error propagation: one incorrect step leads to cumulative errors
- Chain structure limitation: the scope of exploration is limited
- Uncertainty: greedy decoding may not lead to a great reasoning path

Q: Calculate $(2+3)*5$

A:

Calculate $2+3$, we get 6

$$6*5 = 30$$

The final answer is 30

Cumulative error

Q: Can 1, 2, 3, 4 get 24 in game 24?

A:

$$1+2 = 3$$

$$3*3 = 9$$

$$9+4 = 13$$

$$13 \neq 24$$

So 1,2,3,4 cannot get 24 in game 24.

Limited exploration

Q: What is $1+2+3+\dots+6$?

A:

$$1+2 = 3$$

$$3+3 = 6$$

$$6+4 = 10$$

$$10+5 = 15$$

$$15+6 = 21$$

So $1+2+3+4+5+6=21$.

Correct yet not good

Improve CoT in different phases of reasoning

- Pre-process of the reasoning task:
 - Decomposition: e.g. Least-to-most prompting
- Improvement in the reasoning phase:
 - Tool using: e.g. PoT
 - Planning: e.g. ToT
- Utilization of the reasoning result:
 - Major voting: e.g. Self-consistency
 - Verify: e.g. Verifier
 - Refine: e.g. Self-refine

Least-to-most prompting

Explicitly decompose into subquestions

Stage 1: Decompose Question into Subquestions

Q: It takes Amy 4 minutes to climb to the top of a slide. It takes her 1 minute to slide down. The water slide closes in 15 minutes. How many times can she slide before it closes?

Language Model

A: To solve "How many times can she slide before it closes?", we need to first solve: "How long does each trip take?"

Stage 2: Sequentially Solve Subquestions

Subquestion 1

It takes Amy 4 minutes to climb to the top of a slide. It takes her 1 minute to slide down. The slide closes in 15 minutes.

Q: How long does each trip take?

Language Model

A: It takes Amy 4 minutes to climb and 1 minute to slide down. $4 + 1 = 5$. So each trip takes 5 minutes.

Append model answer to Subquestion 1

It takes Amy 4 minutes to climb to the top of a slide. It takes her 1 minute to slide down. The slide closes in 15 minutes.

Q: How long does each trip take?

A: It takes Amy 4 minutes to climb and 1 minute to slide down. $4 + 1 = 5$. So each trip takes 5 minutes.

Language Model

A: The water slide closes in 15 minutes. Each trip takes 5 minutes. So Amy can slide $15 \div 5 = 3$ times before it closes.

Subquestion 2

Q: How many times can she slide before it closes?

Figure 1: Least-to-most prompting solving a math word problem in two stages: (1) query the language model to decompose the problem into subproblems; (2) query the language model to sequentially solve the subproblems. The answer to the second subproblem is built on the answer to the first subproblem. The demonstration examples for each stage's prompt are omitted in this illustration.

Program of Thoughts(PoT)

Output Python programs and call Python interpreter to calculate the answers

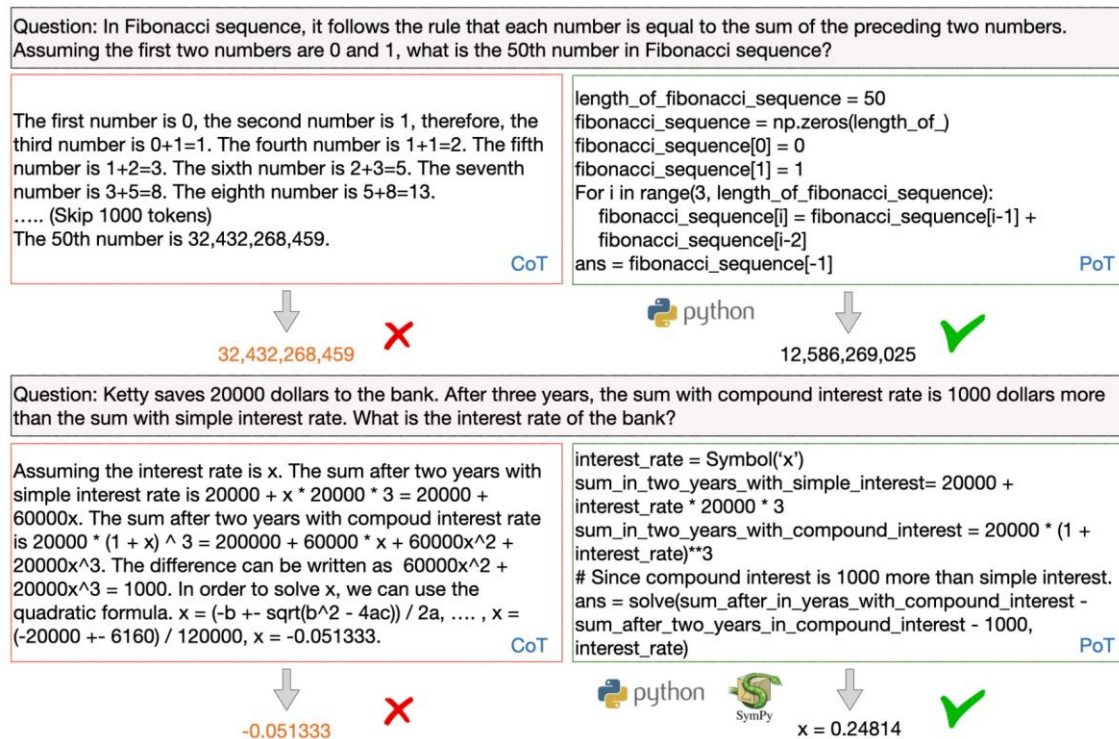
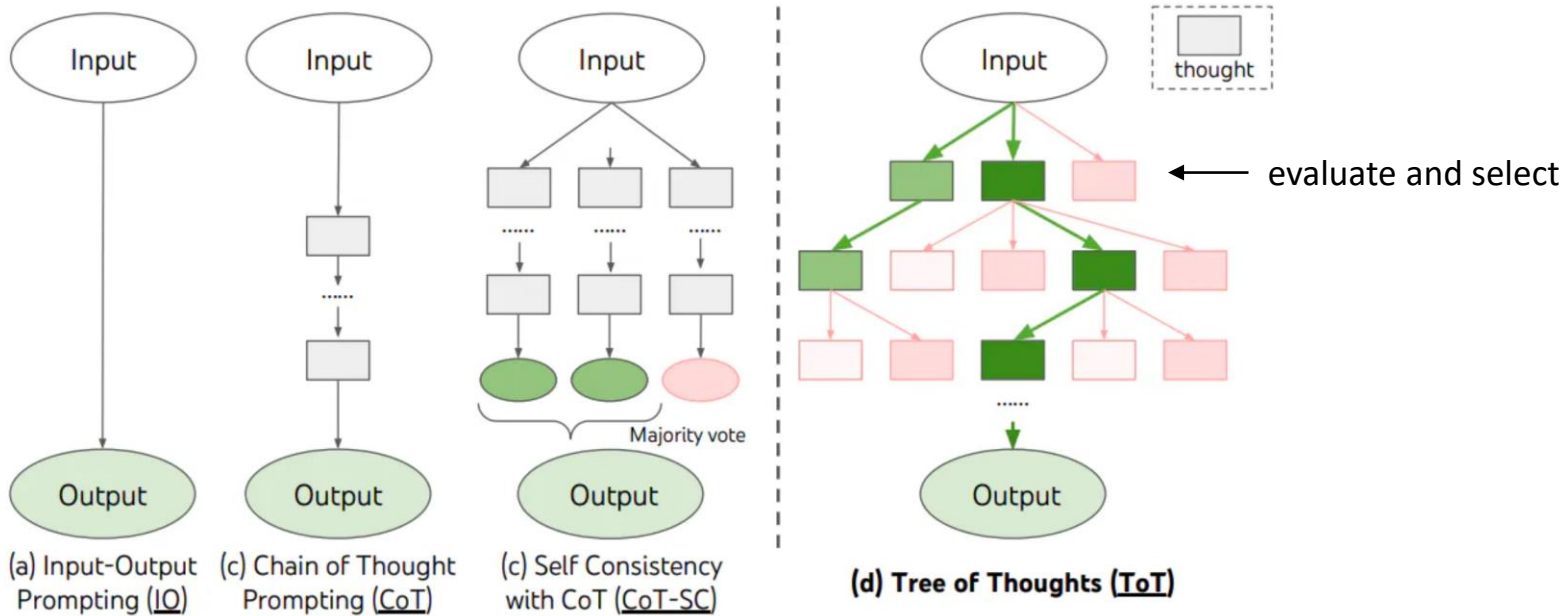


Figure 1: Comparison between Chain of Thoughts and Program of Thoughts.

Tree of Thoughts(ToT)

Explore over units of text that serve as intermediate steps

The ToT framework is illustrated below:



A trick for CoT: Self-consistency

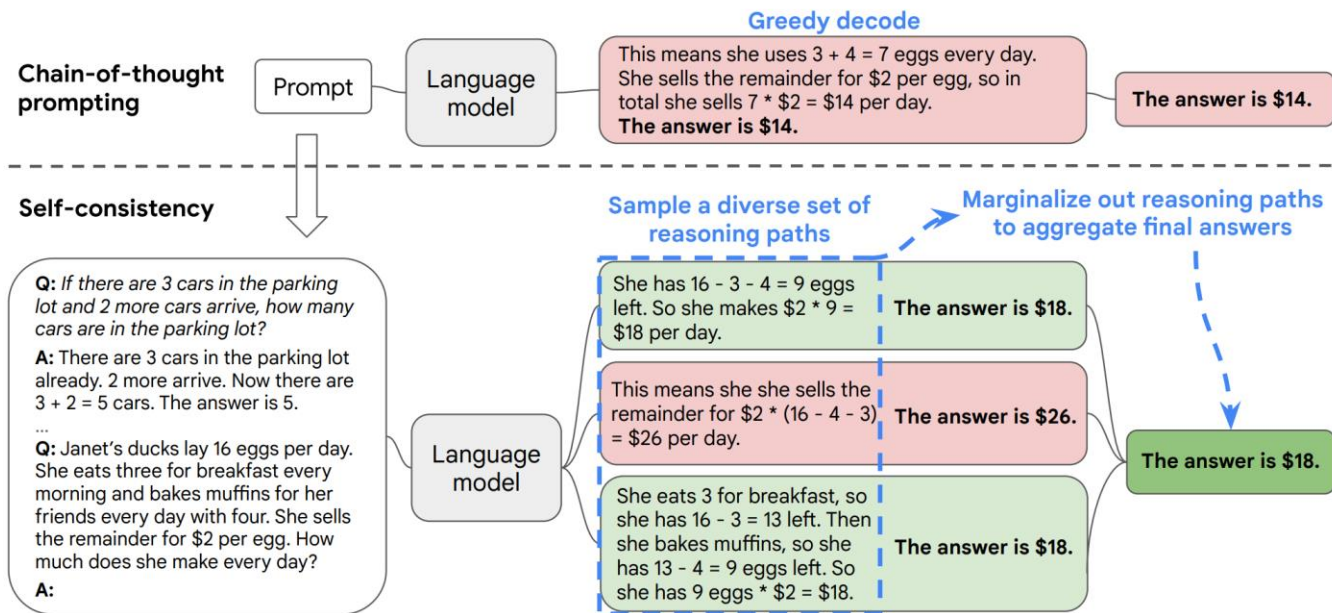
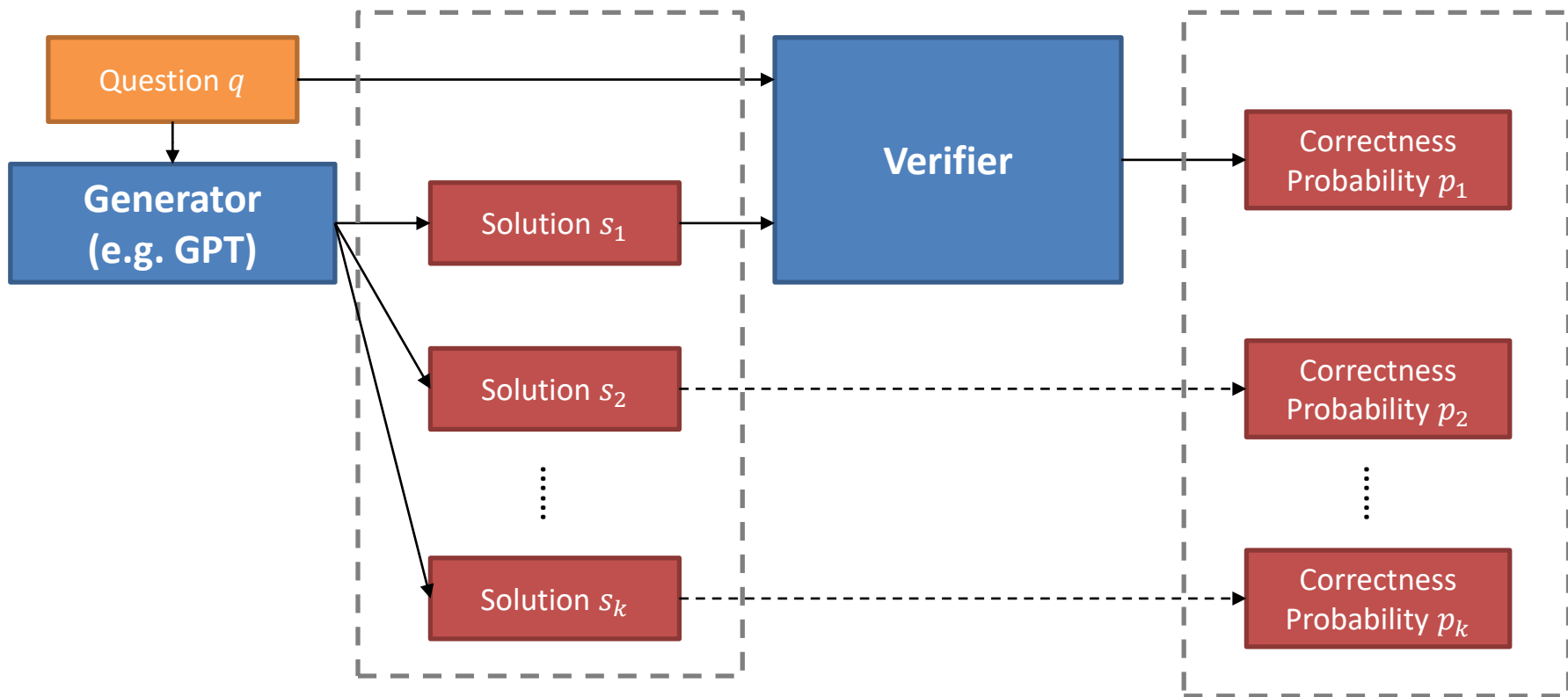


Figure 1: The self-consistency method contains three steps: (1) prompt a language model using chain-of-thought (CoT) prompting; (2) replace the “greedy decode” in CoT prompting by sampling from the language model’s decoder to generate a diverse set of reasoning paths; and (3) marginalize out the reasoning paths and aggregate by choosing the most consistent answer in the final answer set.

Verifier in COT



Self-refine

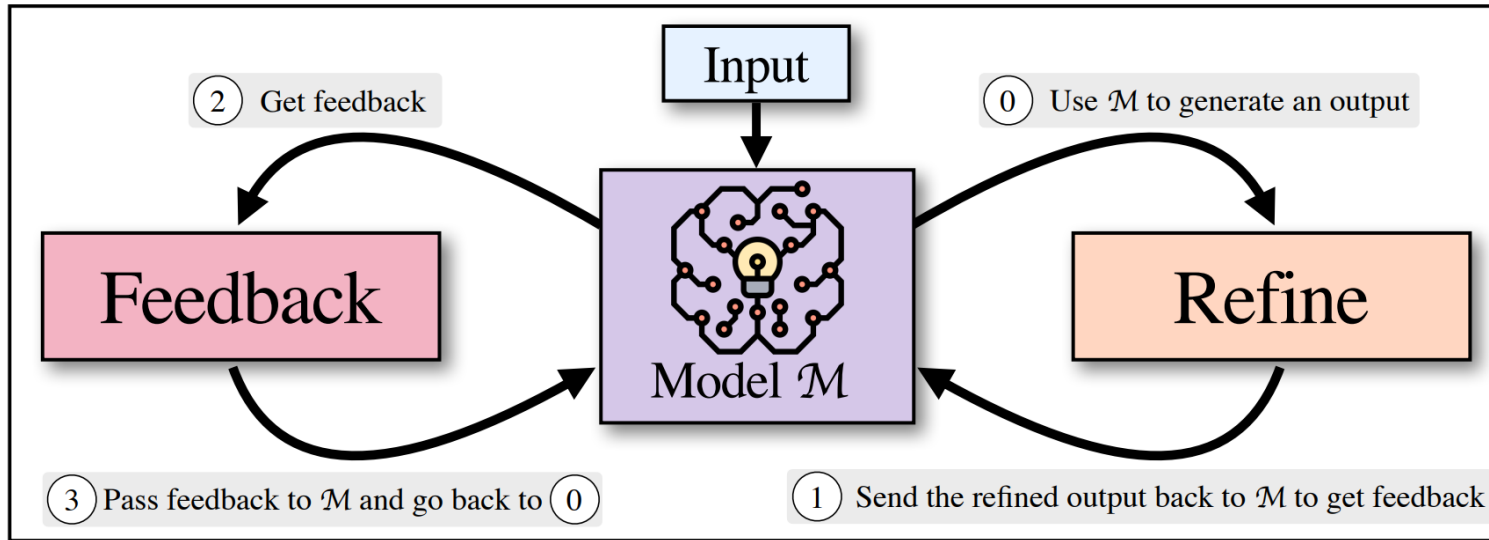


Figure 1: SELF-REFINE starts by taking an initially generated output (0), and passing it back to the same model \mathcal{M} (1) to get feedback (2); feedback on the initial output is passed back to the model (3), to iteratively refine (0) the previously generated output. SELF-REFINE is instantiated with a powerful language model such as GPT-3.5 and does not involve human assistance.

Should we employ all the techniques above?

- Usually CoT can perform well under many situations
- Accuracy vs **Cost**:
 - Additional techniques need more computational sources (self-consistency) or additional data processing(PoT) although these techniques can usually improve the performance.
 - the trade off depends on the real application.

COT in Medical LLMs

ChatGPT 4 ▾



You

糖尿病患者可以吃牛油果吗？先给出详细的理由再给答案。



ChatGPT

牛油果是一种营养丰富的水果，含有高比例的单不饱和脂肪，这种脂肪对心脏健康有益，可以帮助降低胆固醇。对于糖尿病患者来说，牛油果中的单不饱和脂肪有助于调节血糖水平，因为它们可以减缓消化过程，从而减少血糖水平的波动。此外，牛油果还含有丰富的纤维，对维持血糖水平稳定也很有帮助。

牛油果中的钾含量高，有助于预防糖尿病相关的并发症，如高血压。不过，牛油果的热量相对较高，所以糖尿病人在食用时应注意分量控制。

总的来说，糖尿病患者是可以吃牛油果的，但应该将其作为平衡饮食的一部分，并注意总的热量摄入，避免过量食用。在任何饮食调整之前，最好先咨询医生或营养师的建议。



COT in Multi-modal LLMS



Please describe the image as detail as possible and then answer the following questions:
what is the logo in the image?

The answer should be as detailed as possible and provide some relevant information

The description and the detailed is separated by one line of "-----"



The image features a brightly colored juice carton placed on a table with a blurred background that suggests a domestic setting. The carton is predominantly orange, with blue and green accents and features graphic elements and text.

The front of the carton has a large central graphic of an anthropomorphic lion character dressed in sporty attire, including a white tank top and blue shorts. The lion is playing tennis, as indicated by the tennis racket in one hand and a ball in the other. Surrounding the lion character are images of fruits, which indicate the flavors of the juice inside the carton. There are depictions of an apple, a peach, and oranges. These fruit illustrations are quite vibrant and realistic in appearance, in contrast to the cartoonish lion character.

Above the lion, the product name "LEON" is written in large, bold, blue letters with a white outline, which makes it stand out against the orange background. Below the name, there are smaller white letters that read "jabłka, brzoskwinie, pomarańcze," which are the Polish words for "apples, peaches, oranges," describing the juice flavors.

At the bottom of the carton, there is a circular blue logo with a checkmark symbol and the text "ŹRÓDŁO WITAMIN" which translates to "SOURCE OF VITAMINS" in Polish. This suggests that the juice is being marketed as a healthy option, rich in vitamins.

The background contains other items that are out of focus, including a wicker basket with a pink ribbon, green grapes, and what appears to be a decorative white miniature bicycle. To the right, there's a glimpse of a red rose and a bowl that contains some sort of food, possibly pastries or bread.

The logo on the carton is the "Hortex" logo, which is placed at the top of the carton. The Hortex logo is relatively small compared to the rest of the graphics and is characterized by bold, white capital letters spelling "Hortex" on a red rectangular background. The text has a shadow effect that gives a sense of depth, and there appears to be a green leaf graphic element to the left of the text, which is likely a part of the logo's design, emphasizing the company's association with natural and plant-based products.

Hortex is a well-known brand in Poland, recognized for its wide range of food products, including frozen fruits and vegetables, as well as various types of juices and beverages. The company has a history dating back several decades and is reputed for providing products made from natural ingredients without the addition of artificial preservatives and colorants.

Send a message

Acknowledgement

- Princeton COS 597G:
<https://www.cs.princeton.edu/courses/archive/fall22/cos597G/>
- Scaling, emergence, and reasoning (Jason Wei, NYU):
https://docs.google.com/presentation/d/1EUV7W7X_w0BDrscDhPg71MGz_JCkeaPkGCJ3bN8dluXc/edit?resourcekey=0-7Nz5A7y8JozyVrnDtceEKJA#slide=id.g16197112905_0_0
- Prompting engineering lectures (DAIR-AI):
<https://github.com/dair-ai/Prompt-Engineering-Guide/blob/main/lecture/Prompt-Engineering-Lecture-Elvis.pdf>
- Prompt engineering guide: <https://www.promptingguide.ai/>

Optional reading material

In-context learning:

- An Explanation of In-context Learning as Implicit Bayesian Inference(<https://arxiv.org/abs/2111.02080>)
- Rethinking the Role of Demonstrations: What Makes In-Context Learning Work?(<https://arxiv.org/abs/2202.12837>)

Knowledge probing:

- How Much Knowledge Can You Pack Into the Parameters of a Language Model?(<https://arxiv.org/abs/2002.08910>)

Knowledge editing

- Fast model editing at scale(<https://arxiv.org/abs/2110.11309>)