

Knowledge Augmentation for Reasoning in Language

ACL 2023 Tutorial
“Complex Reasoning in Natural Language”

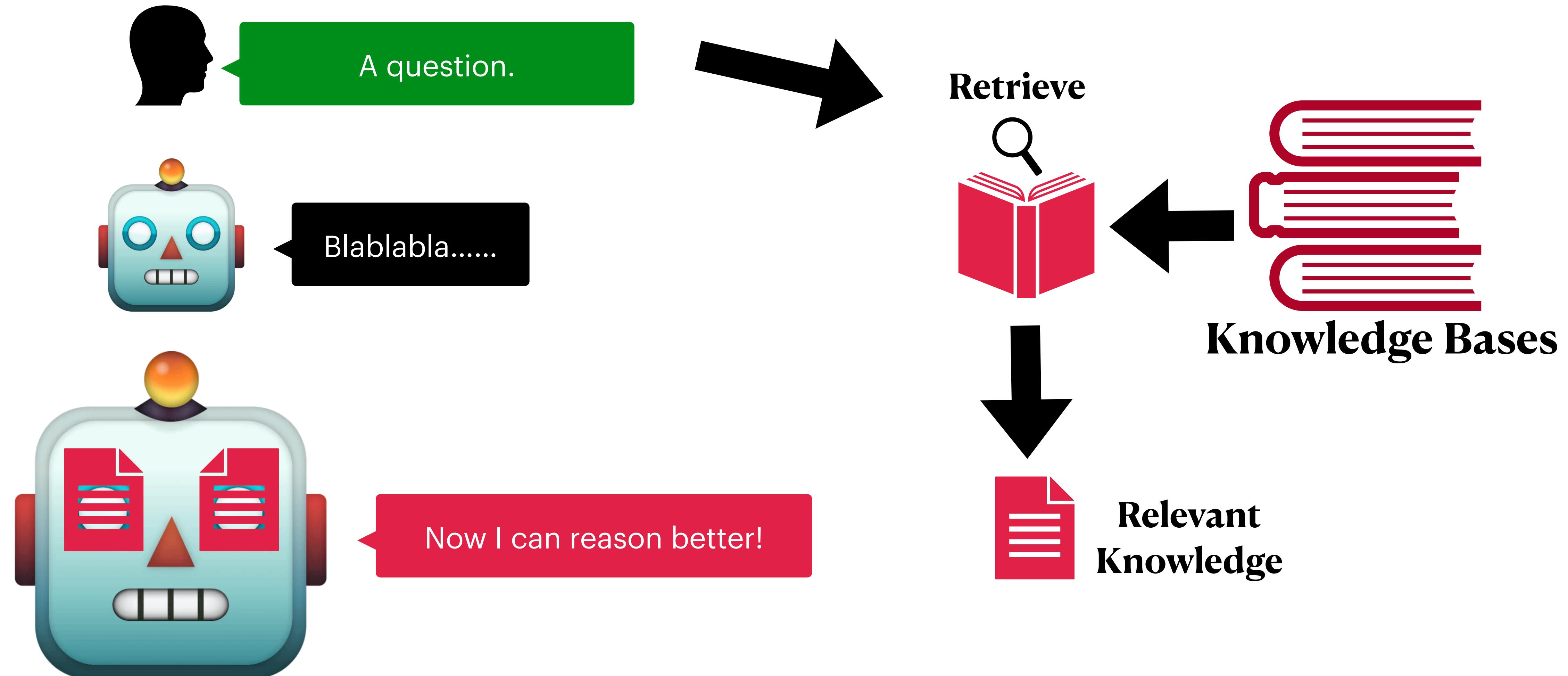
Bill Yuchen Lin

<https://yuchenlin.xyz>



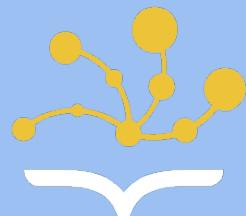
MOSAIC
COMMONSENSE

Knowledge Augmentation for Reasoning



Knowledge Sources

Structured Knowledge



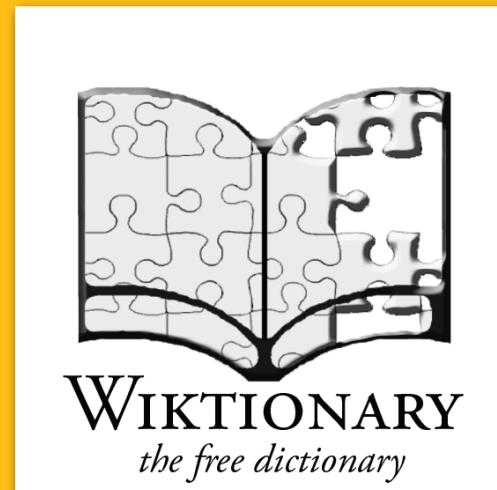
Dbpedia



Un/Semi-structured Knowledge



WIKIPEDIA
The Free Encyclopedia



wikiHow
to do anything

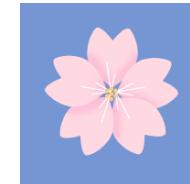


AI2 GenericsKB [4]

Instance-based Knowledge



Datasets

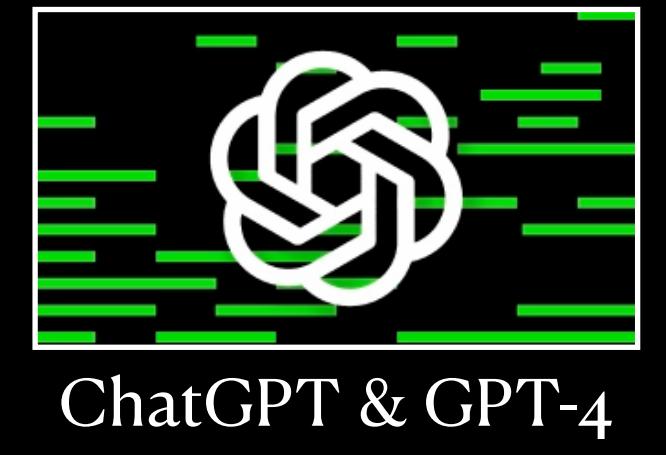


PromptSource

G FLAN Collection [6]

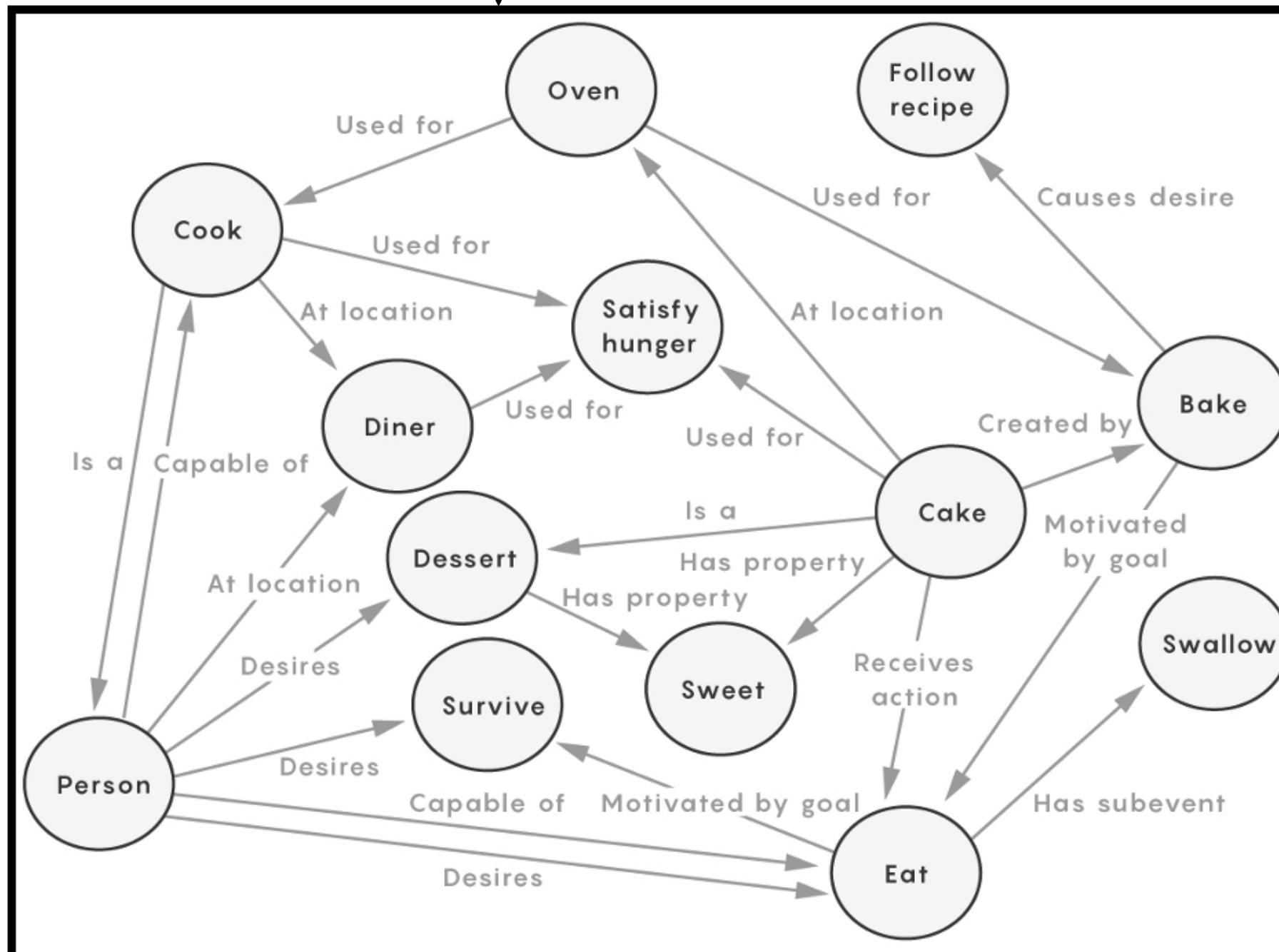


AI2 COMET [8]

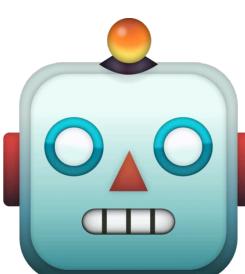




Structured Knowledge



Symbolic Structures of Knowledge



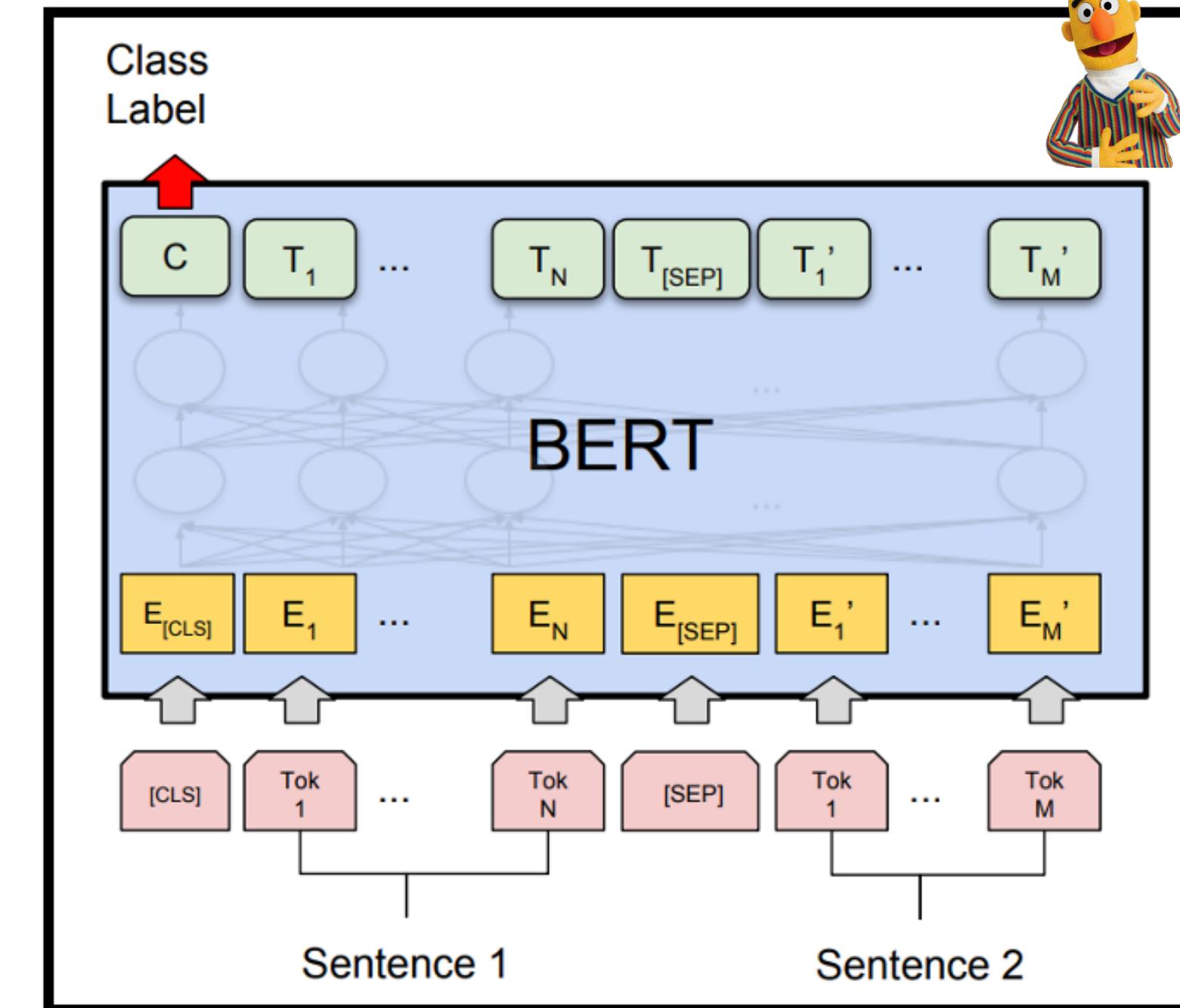
How can we incorporate structured knowledge into neural language models?

Task: Multiple-Choice QA

Question: xxxxx?

Options: A) a_1, B) a_2, C) a_3

Am I too old?

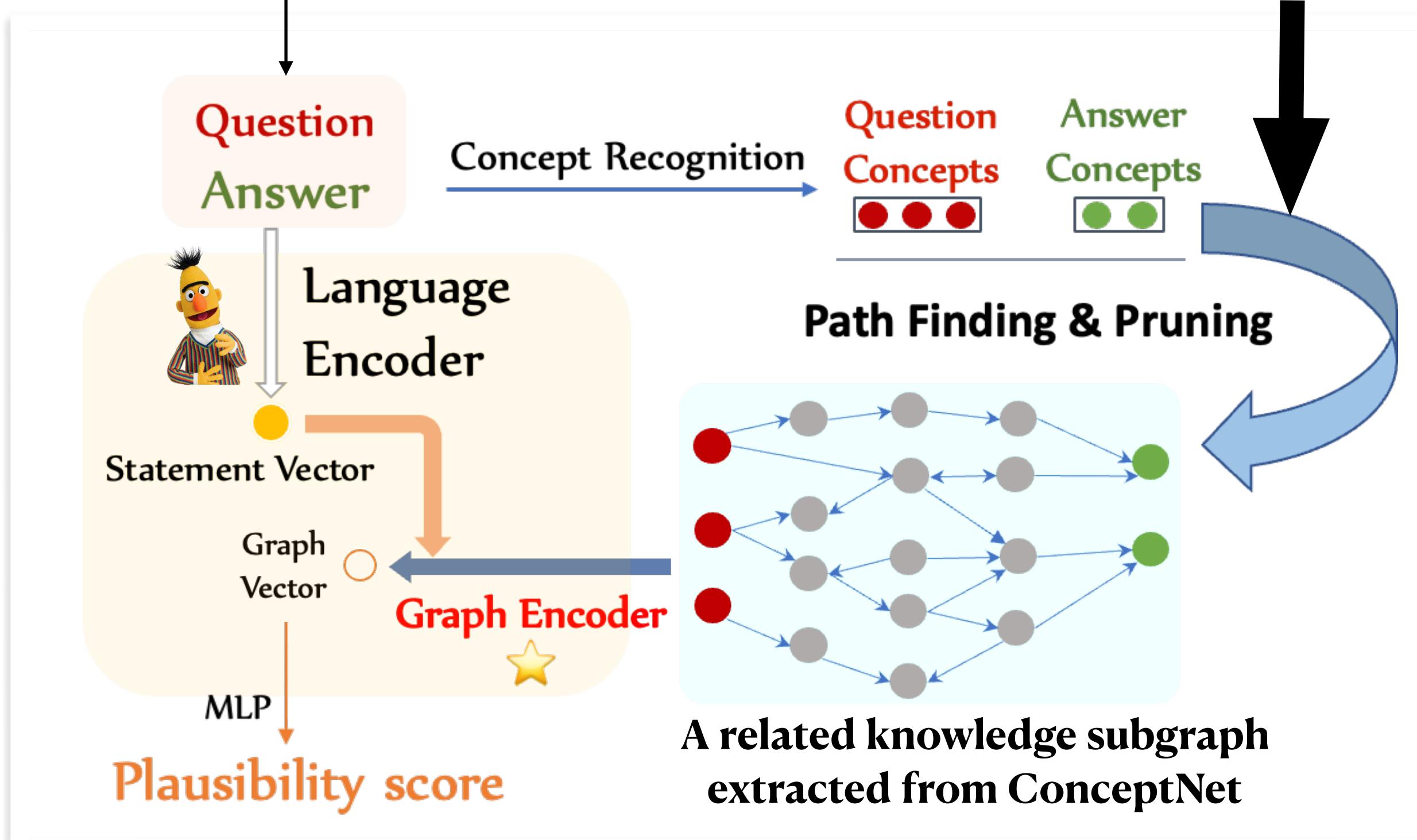


Neural Language Models (e.g., BERT [9])

Multiple-Choice QA

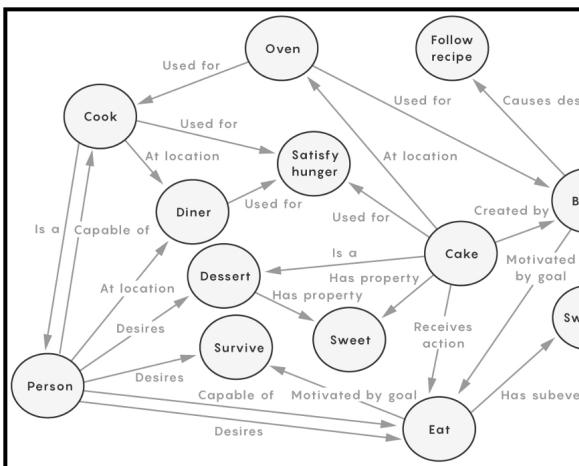
Question: xxxxx?

Candidates: A) a_1, B) a_2, C) a_3



KagNet: Knowledge-Aware Graph Networks for Commonsense Reasoning

Knowledge Graph

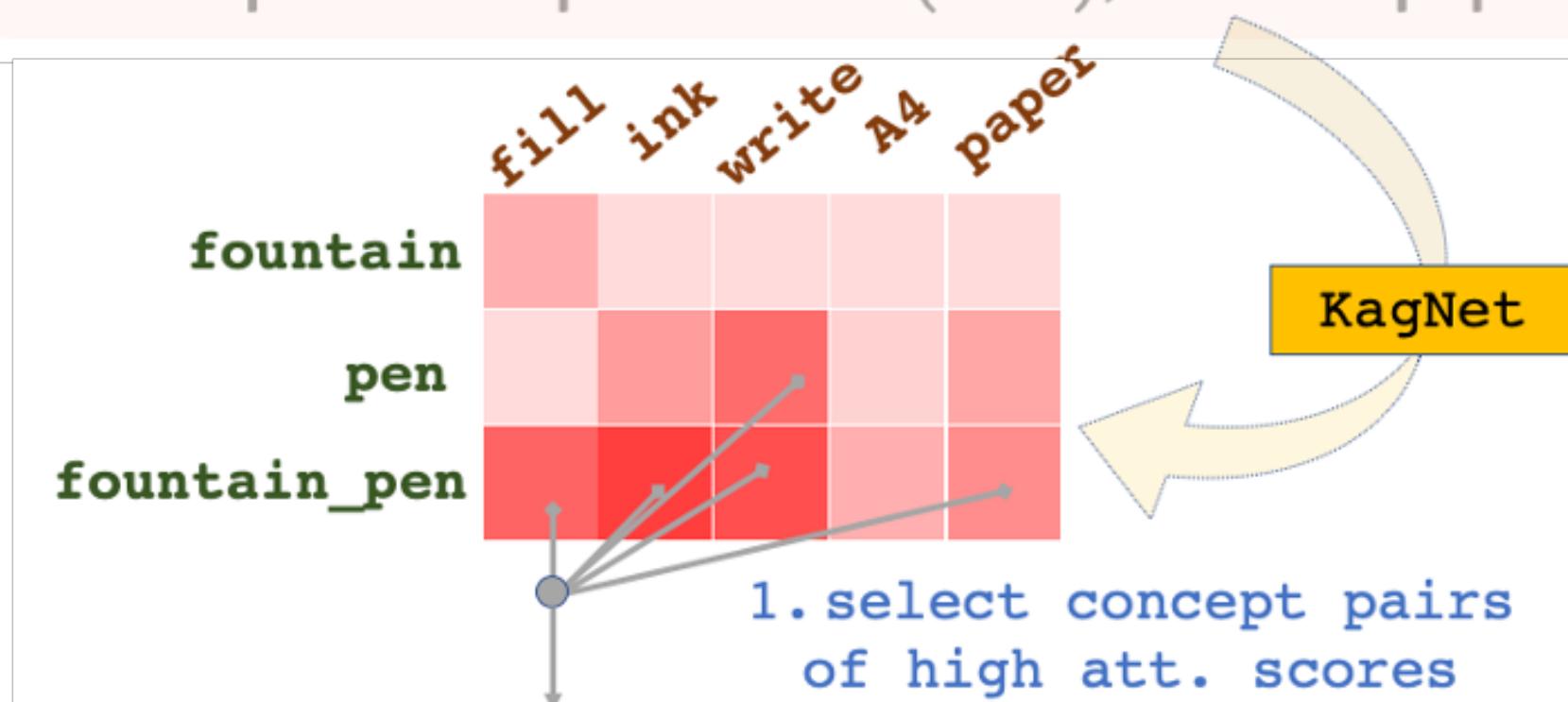


Features

- LM encoder to encode the text of question + candidate
- Graph encoder to encode knowledge subgraphs
- Late fusion of Text Embeddings + Graph Embeddings
- Interpretable

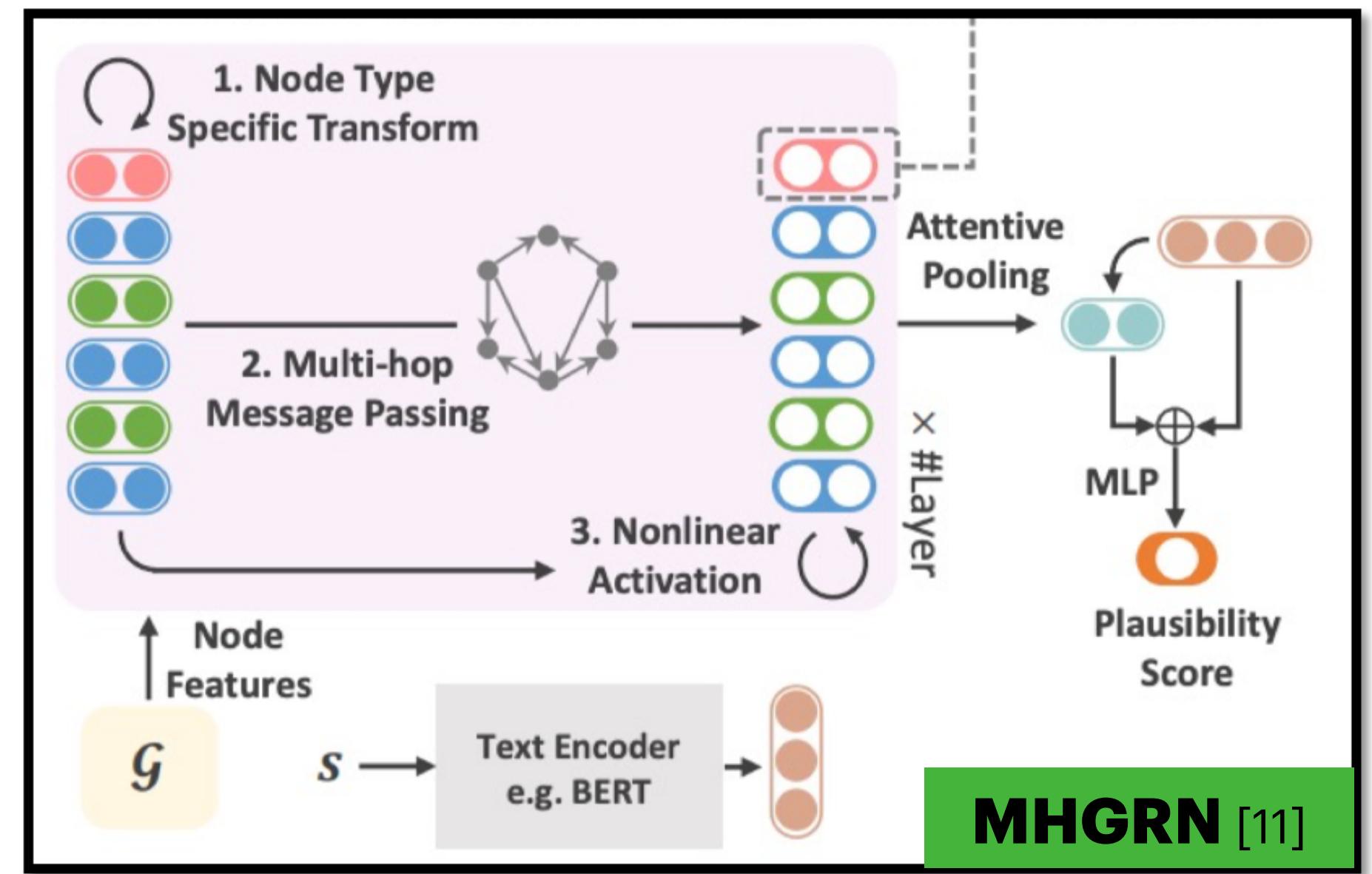
What do you **fill** with **ink** to **write** on an **A4 paper**?

A: fountain pen ✓ (KagNet); B: printer (BERT);
C: squid D: pencil case (GPT); E: newspaper

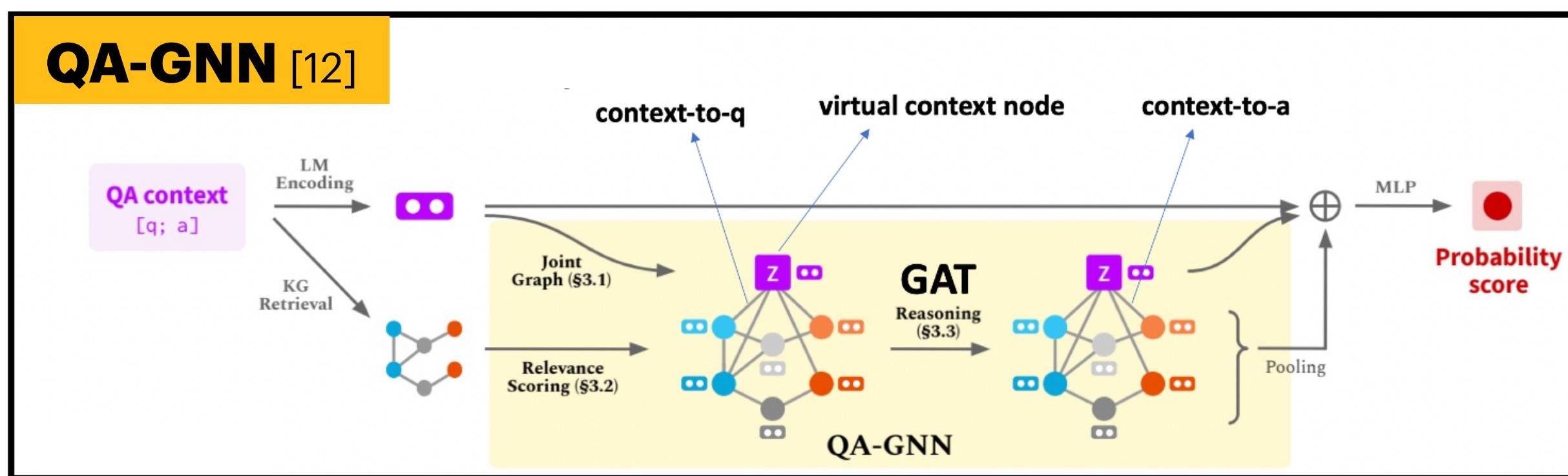


```

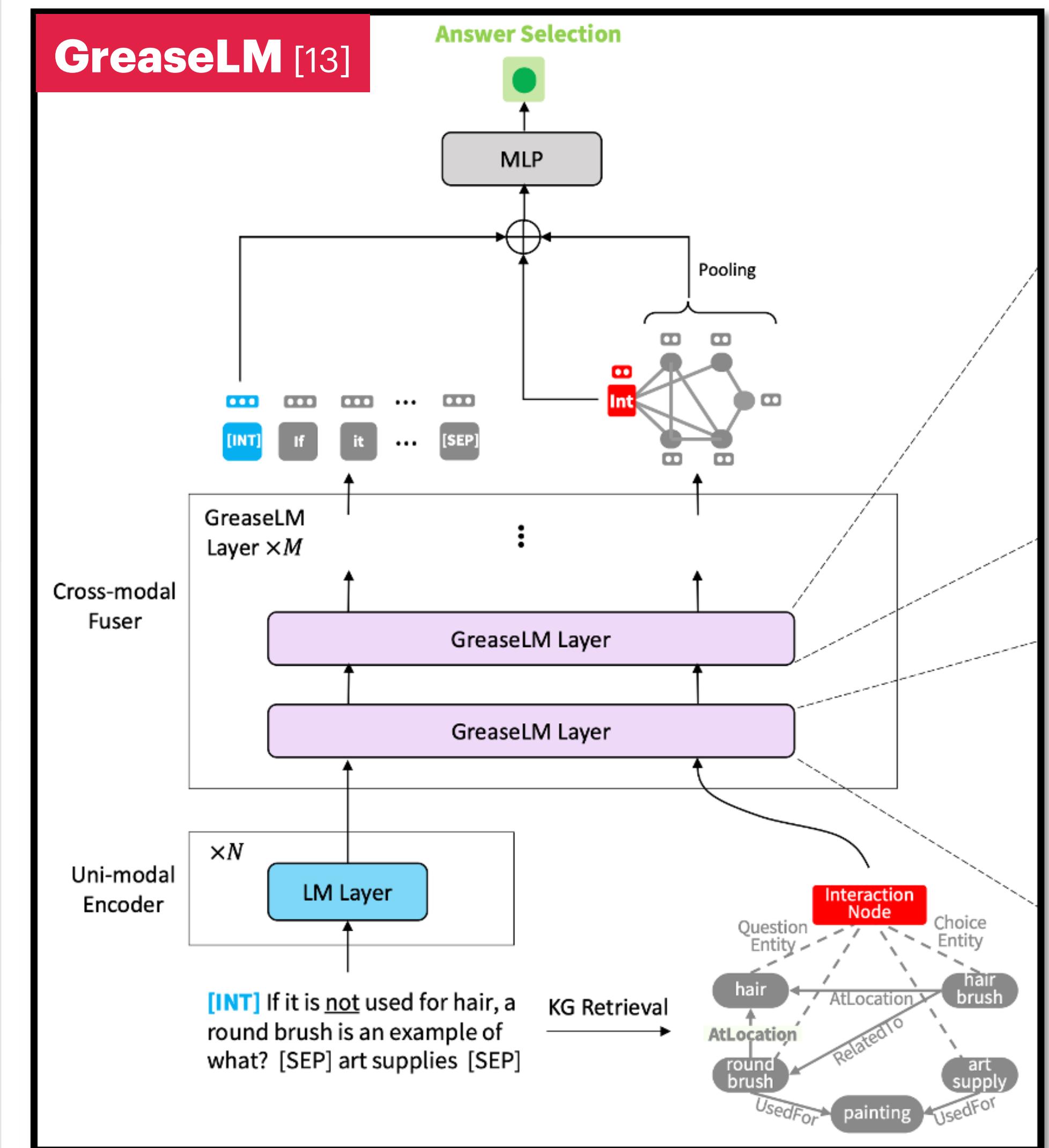
ink --PartOf-- fountain_pen
ink --RelatedTo-- container <-IsA- fountain_pen
fill <-HasSubEvent- ink <-AtLocation- fountain_pen
fill --RelatedTo-- container <-IsA- fountain_pen
write <-UsedFor- pen
write <-UsedFor- pen <-IsA- fountain_pen
paper <-RelatedTo- write <-UsedFor- fountain_pen
..... 2. Ranking via path-level attn.
  
```



- Multi-hop graph encoder → Scalable



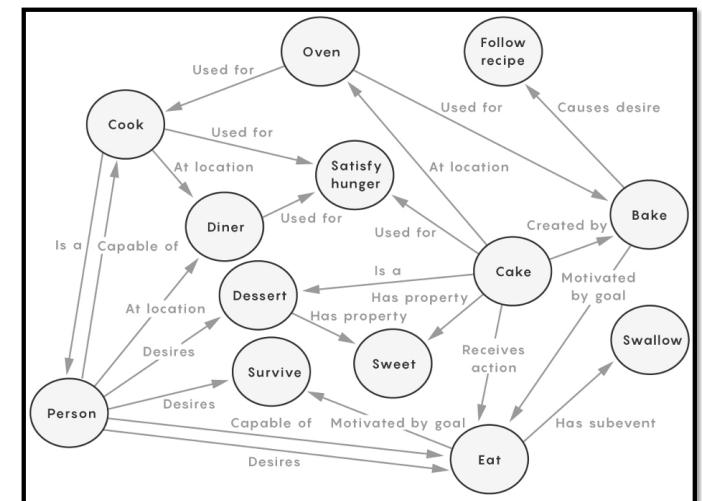
- Text embeddings as virtual nodes in graph encoding



- Early fusion of graphs and text encoders



Un/Semi-structured Knowledge



KGs can be limited:

1. Incompleteness
2. Only for binary relations

AI2 GenericsKB

Software system

From Wikipedia, the free encyclopedia

Not to be confused with System software.

A **software system** is a **system** of intercommunicating **components** based on **software** forming part of a **computer system** (a combination of **hardware** and software). It "consists of a number of separate **programs** **configuration files** which are used to set up these programs, **system documentation**, which describes the structure of the system, and **user documentation** which explains how to use the system".^[1]

The term "software system" should be distinguished from the terms "**computer program**" and "**software**". The term computer program generally refers to a set of instructions (**source**, or **object code**) that perform a specific task. However, a software system generally refers to a more encompassing concept with many more components such as specification, **test** **results**, end-user documentation, maintenance records, etc.^[2]

Tree

- o Trees are perennial plants that have long woody trunks.
- o Most trees add one new ring for each year of growth.
- o Trees grow using photosynthesis, absorbing carbon dioxide and releasing oxygen.



Task: Open-Ended QA

Question: xxxxx?

(A target knowledge corpus.)

Complex questions need multiple reasoning steps.

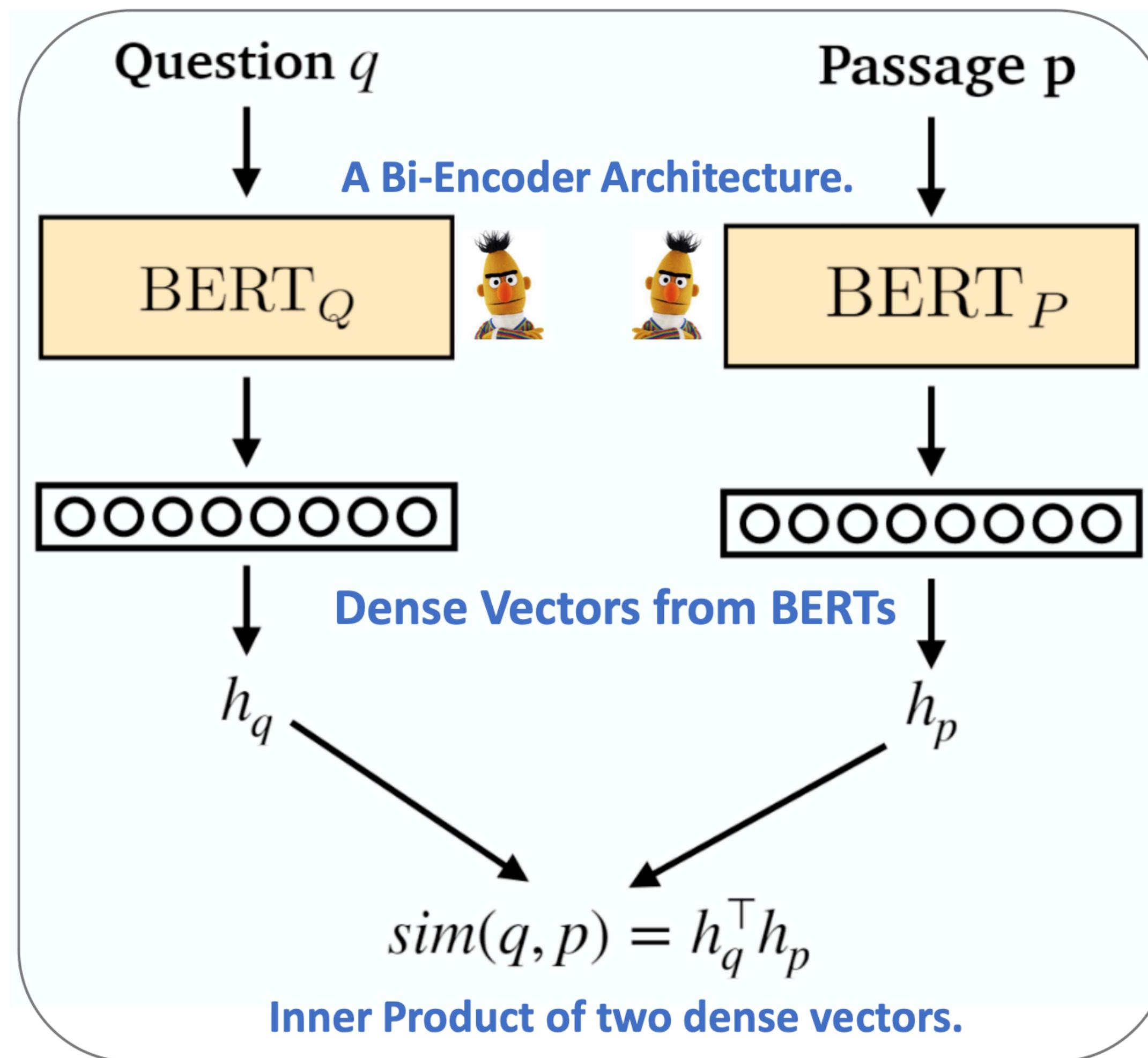
Who voices the dog in the TV show Family Guy ?

What can help alleviate global warming?

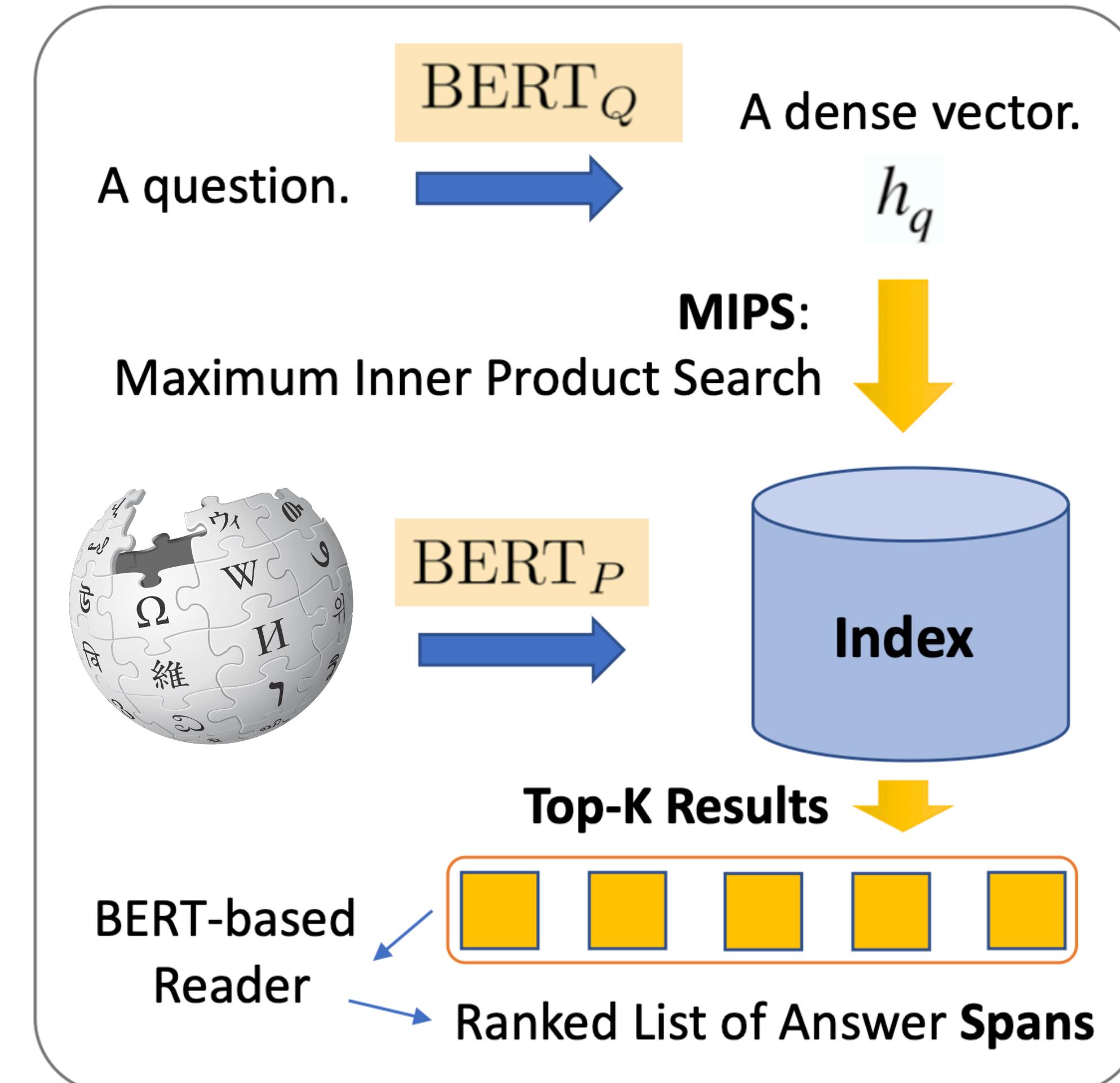
What will separate iron filings from sand?

Dense Passage Retrieval (DPR) [14]

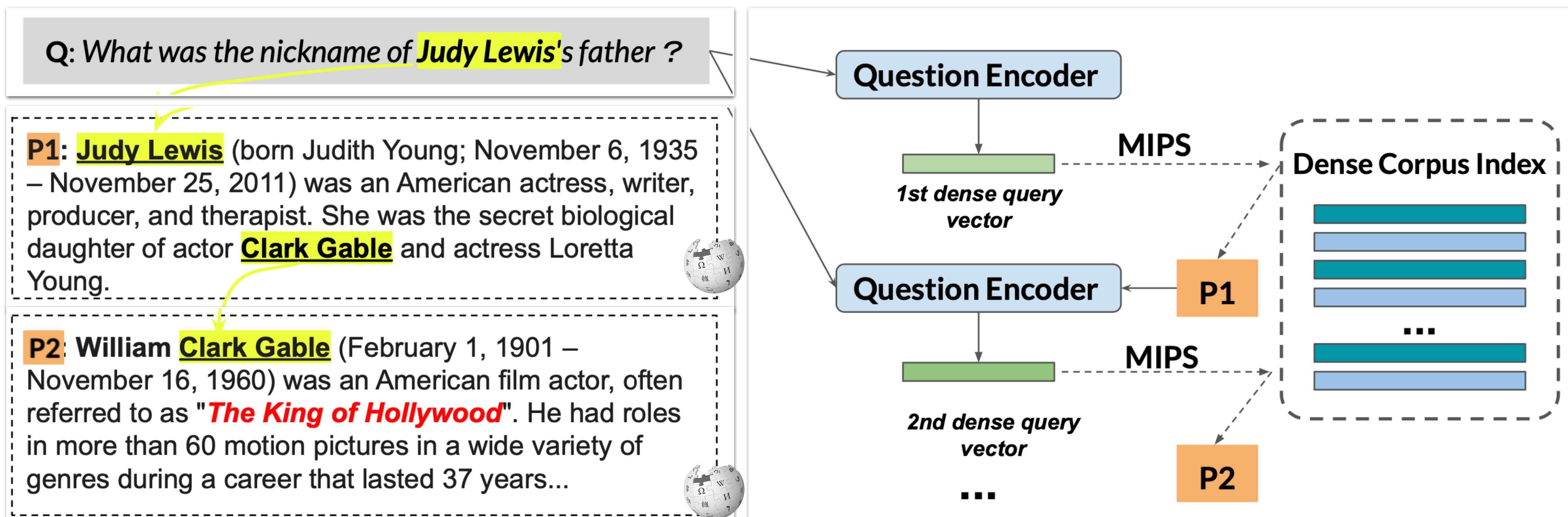
A Trainable Method for Passage Retrieval



MIPS-based Inference Pipeline



Multi-hop Dense Retrieval (MDR) [15]



Differentiable Fact-Following Operations (DrFact) [17]



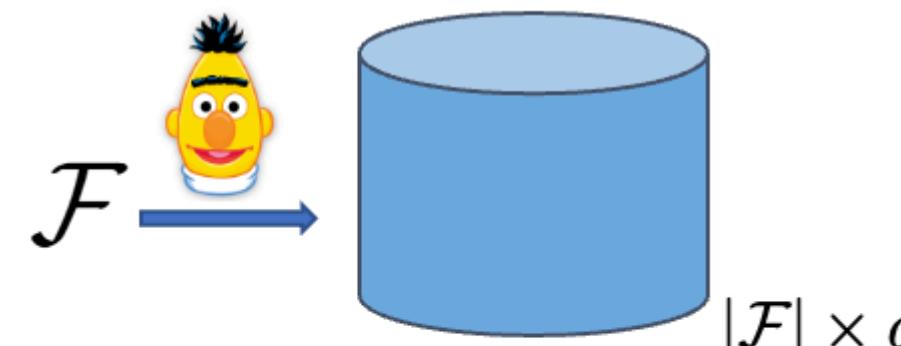
a **corpus** of common-sense facts, e.g., **GenericsKB**. \mathcal{F}

$$f_i \in \mathcal{F}$$

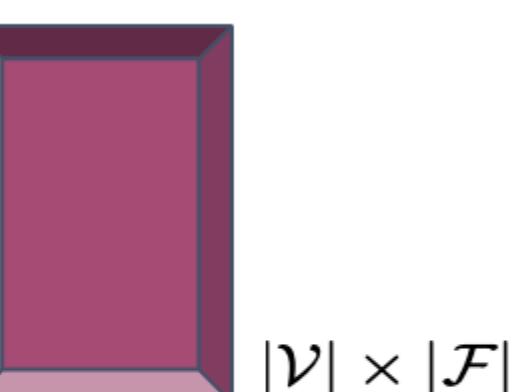
A **fact** is a sentence of generic commonsense knowledge

$$c_j \in \mathcal{V}$$

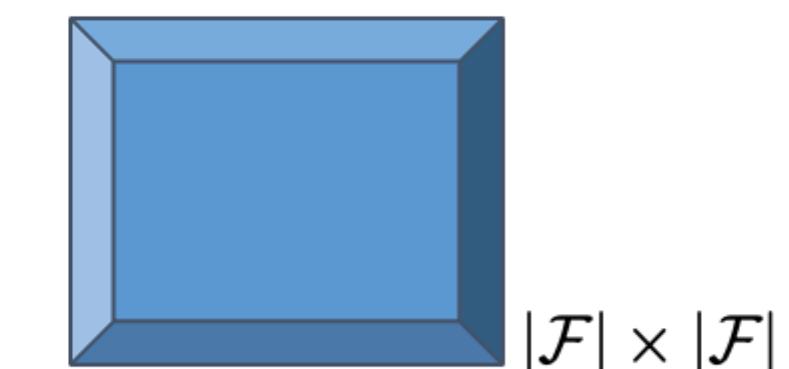
A **concept** is a noun or noun-chunk that are mentioned in \mathcal{F}



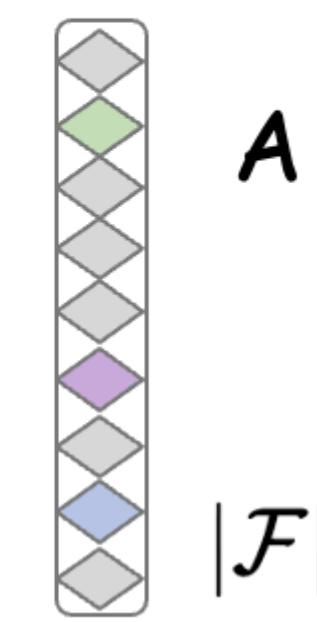
Dense Matrix
of Fact Embeddings



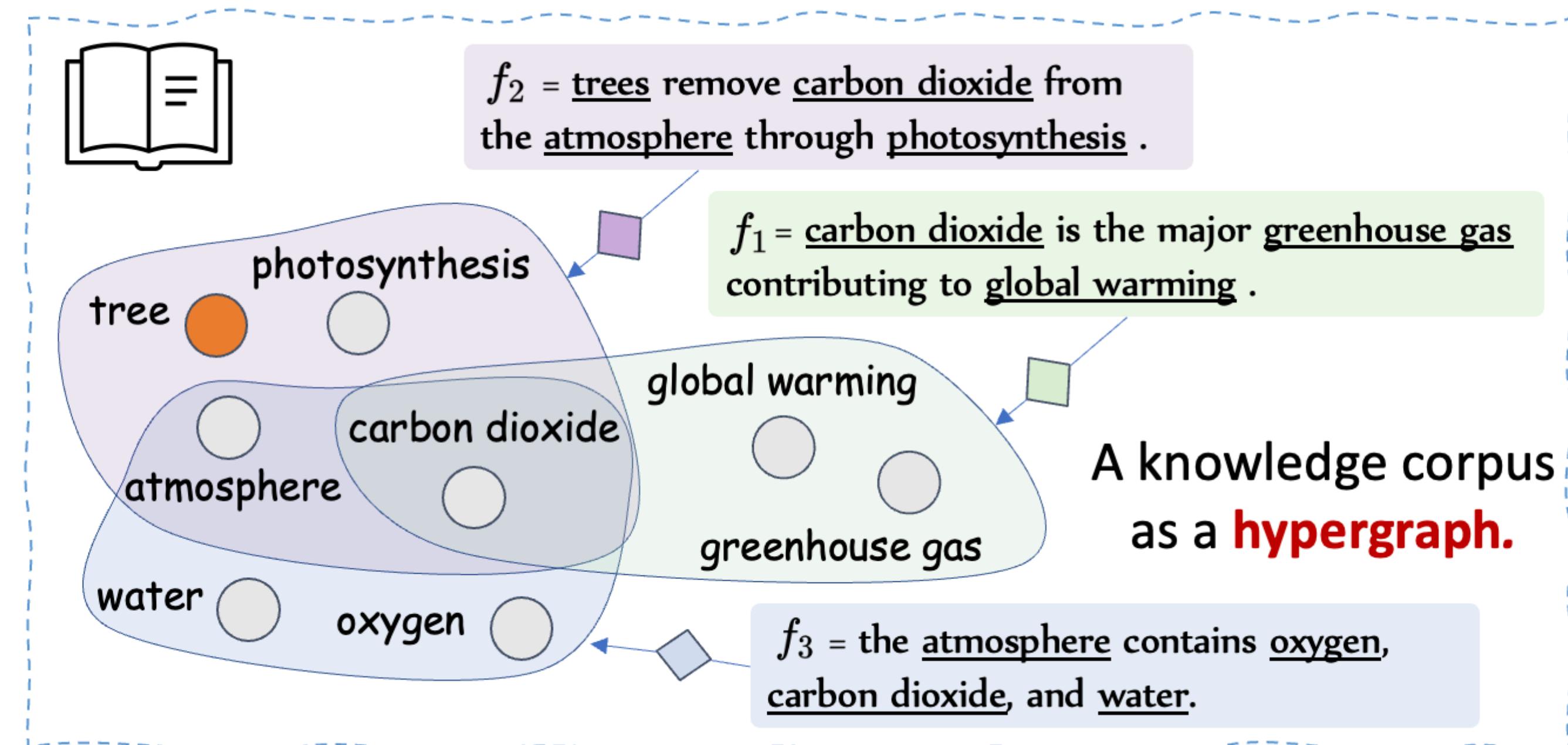
Sparse Matrix
of Concept-to-Fact Links



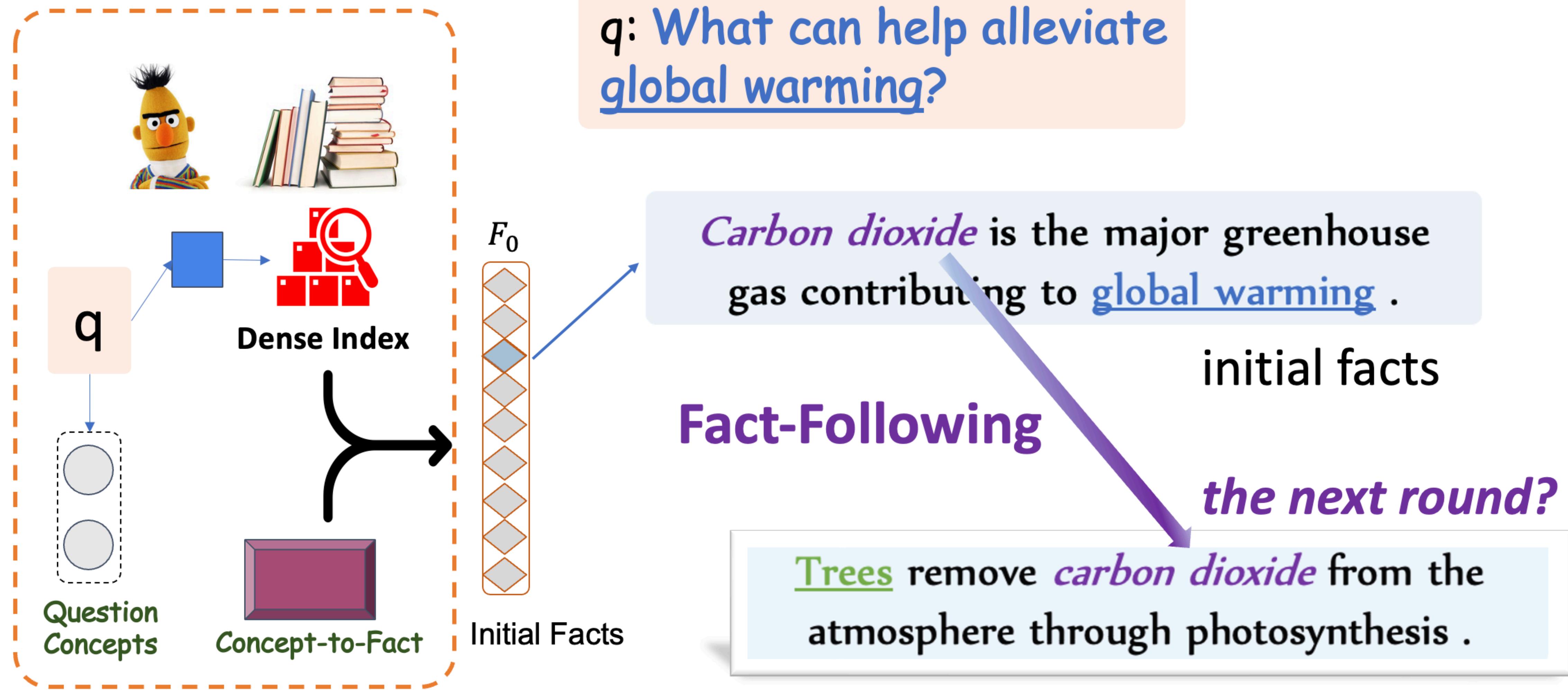
Sparse Matrix
of Fact-to-Fact Links



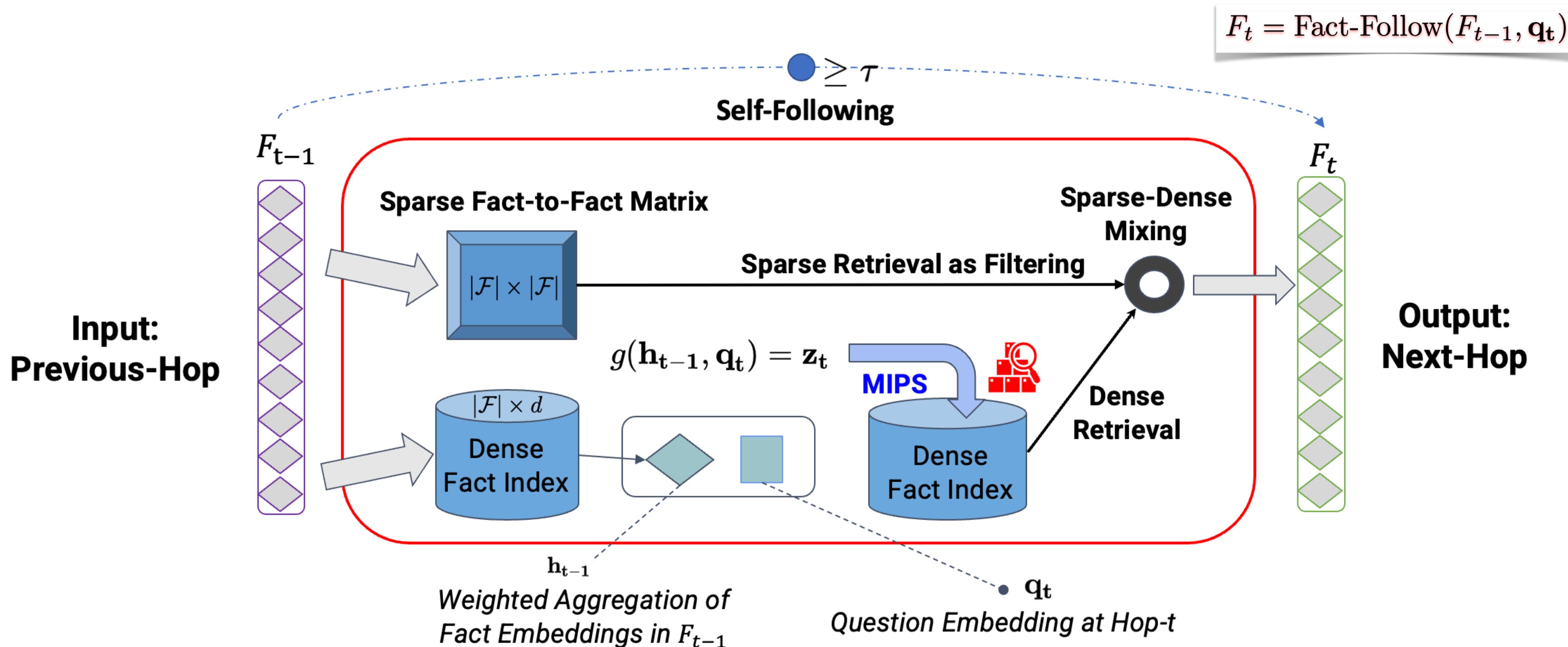
A weighted set of facts
→
A sparse vector.



Differentiable Fact-Following Operations (DrFact) [17]



Differentiable Fact-Following Operations (DrFact) [17]



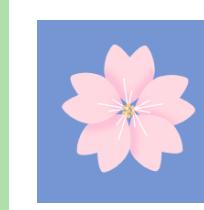
A quick comparison

Methods	BM25	DPR [14] / MDP [15]	DrKIT [16]	DrFact [17]
Knowledge Structure	A set of documents	A set of documents	Mention-Entity Bipartite Graph	Concept-Fact Hypergraph
Multi-hop Reasoning Formulation	-	- / Multiple-Round	Entity-Following	Fact-Following
Index for Dense Retrieval	-	Passage Embeddings	Mention Embedding	Fact Embeddings
Sparse Retrieval Method	TF-IDF based Index+ BM25 Ranking Func.	-	Entity-Mention Cooccurrence	Fact-to-Fact Matrix
Multi-Hop Questions	-	- / Single model	Aggregating Multiple Models	A single model w/ Self-Following
Intermediate Supervision	-	-	N/A	Distant Supervision

Instance-based Knowledge



Datasets



PromptSource

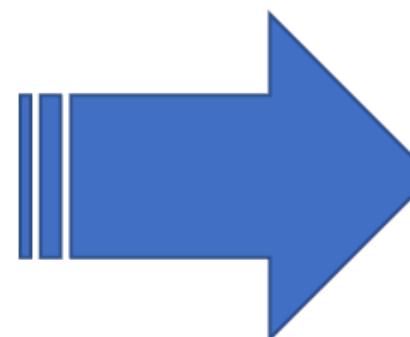
Can we use NLP datasets as (virtual) knowledge for learning to reason?

diverse NLP tasks



SST: sentiment analysis

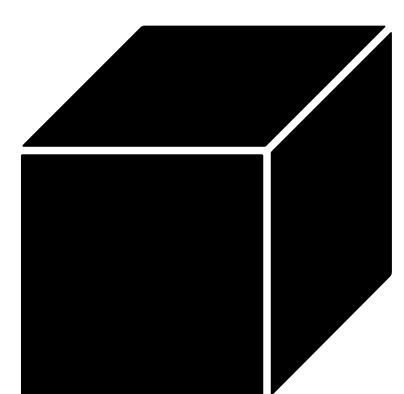
Data Instances



Implicit
Knowledge



an
unseen
task

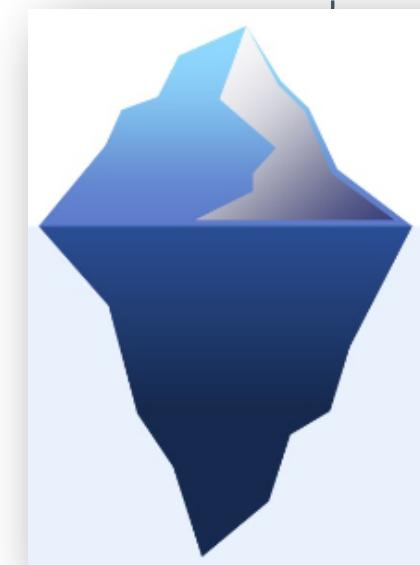


It's hard to explicitly get unique knowledge are used in solving these tasks.

ReCross: Retrieval-Augmentation for Cross-Task Generalization [18]

A unseen task.

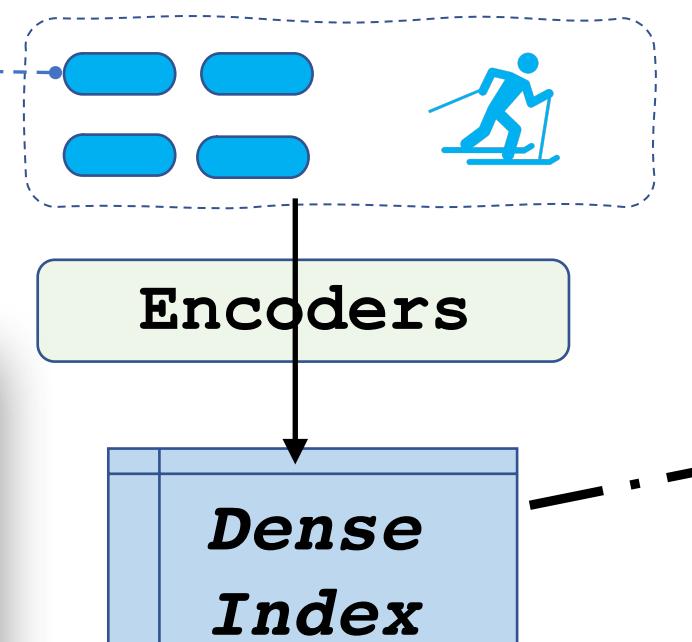
Does "her" refer to Alice or Mary in this sentence: Alice ... Mary... and her ...



Input: Is this review positive or negative? Review: Best cast ...
Output: Positive

Many seen instances.

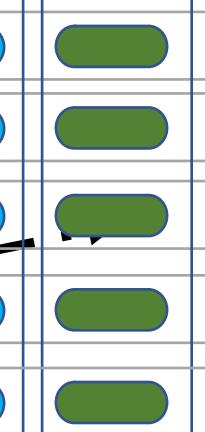
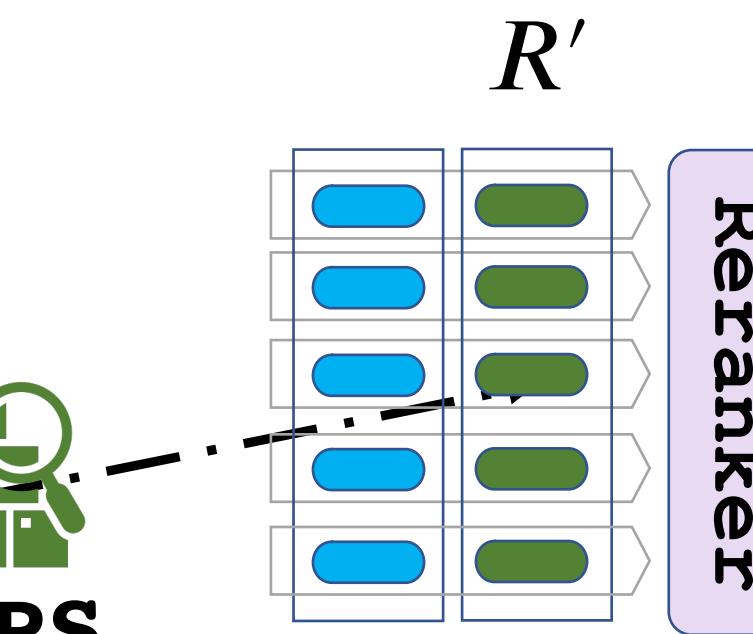
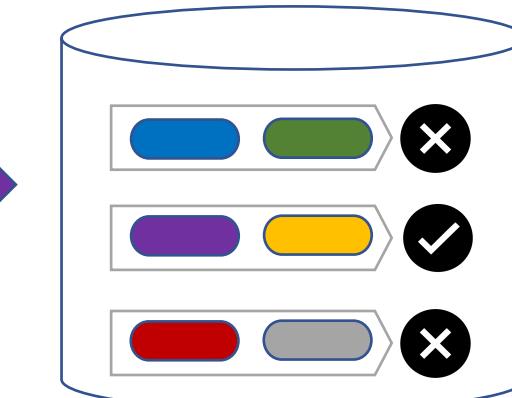
Query examples



Instances



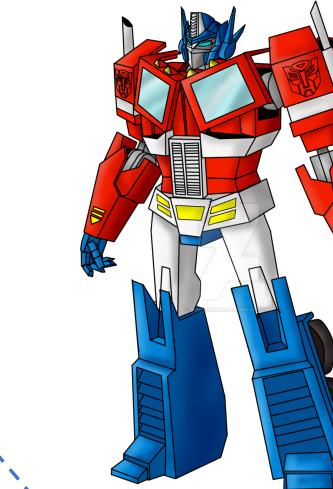
Distant Supervision



Reranker

topK

R



FT/ICL

a small set of retrieved skills (input-output pairs)

Multi-task LM

Iterative boosting alg. to train reranker for better alignment.



Datasets +



PromptSource

Textual Knowledge

🕸️ Structured Knowledge

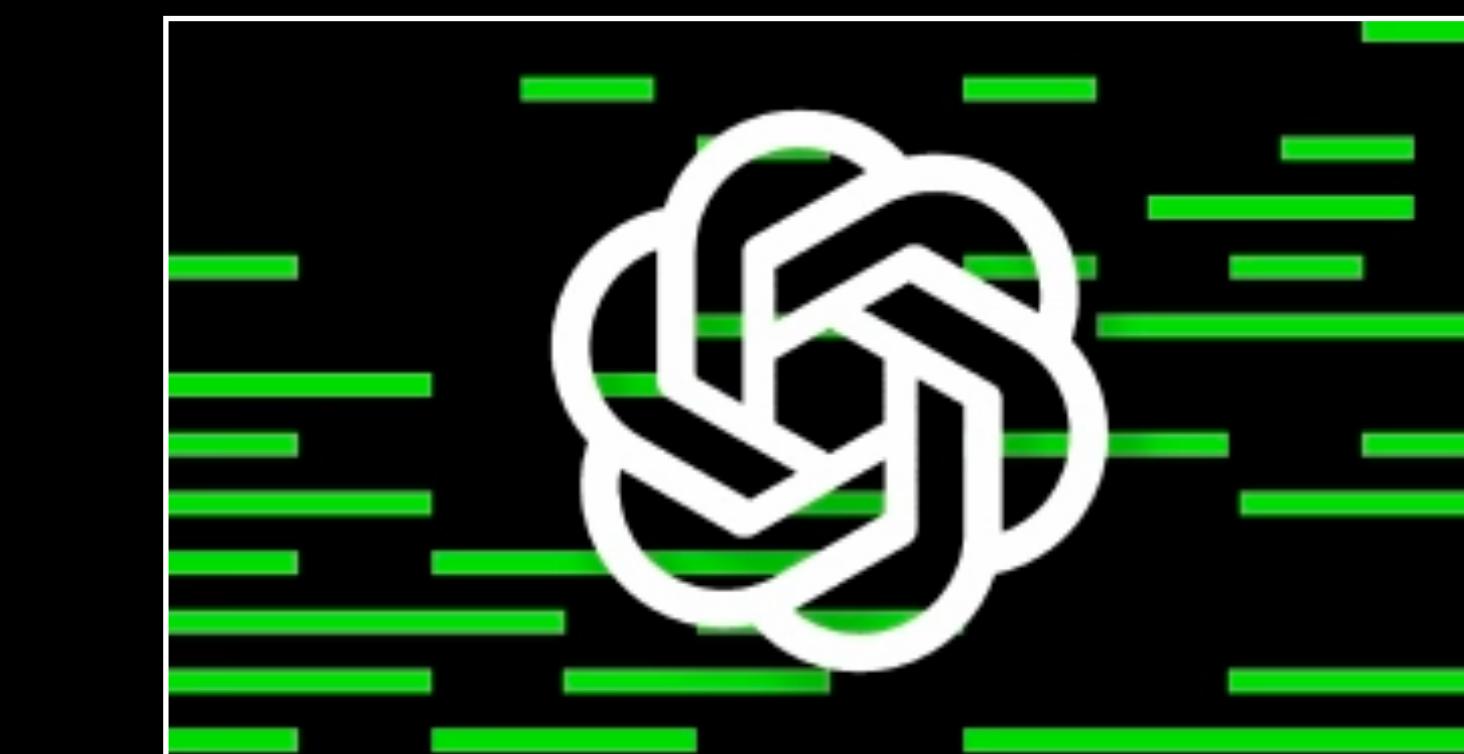
📚 Un/Semi-structured Knowledge

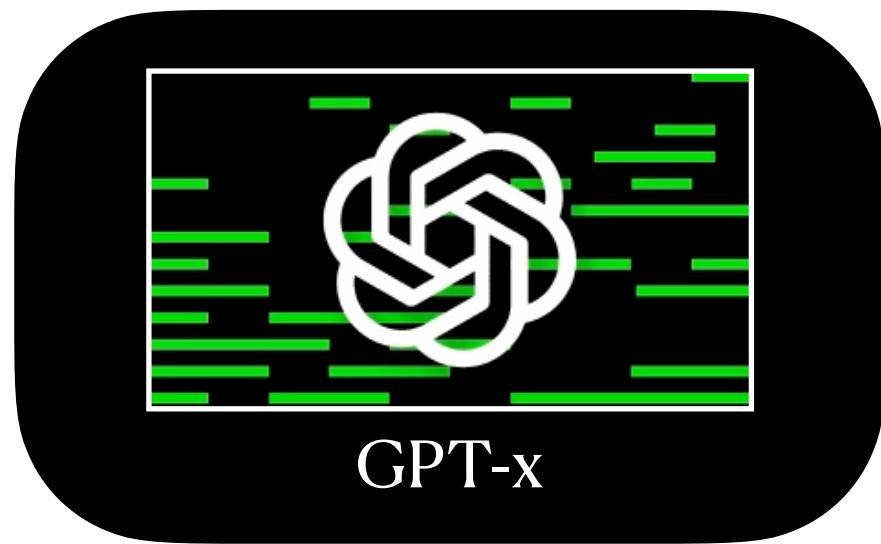
⟳ Instance-based Knowledge

We are super **generalizable** and **easy to query**!
But, we often **hallucinate** and make mistakes.

We are very **accurate, easy to modify, trustworthy**, and **verifiable**;
However, we are **incomplete & hard to query!**

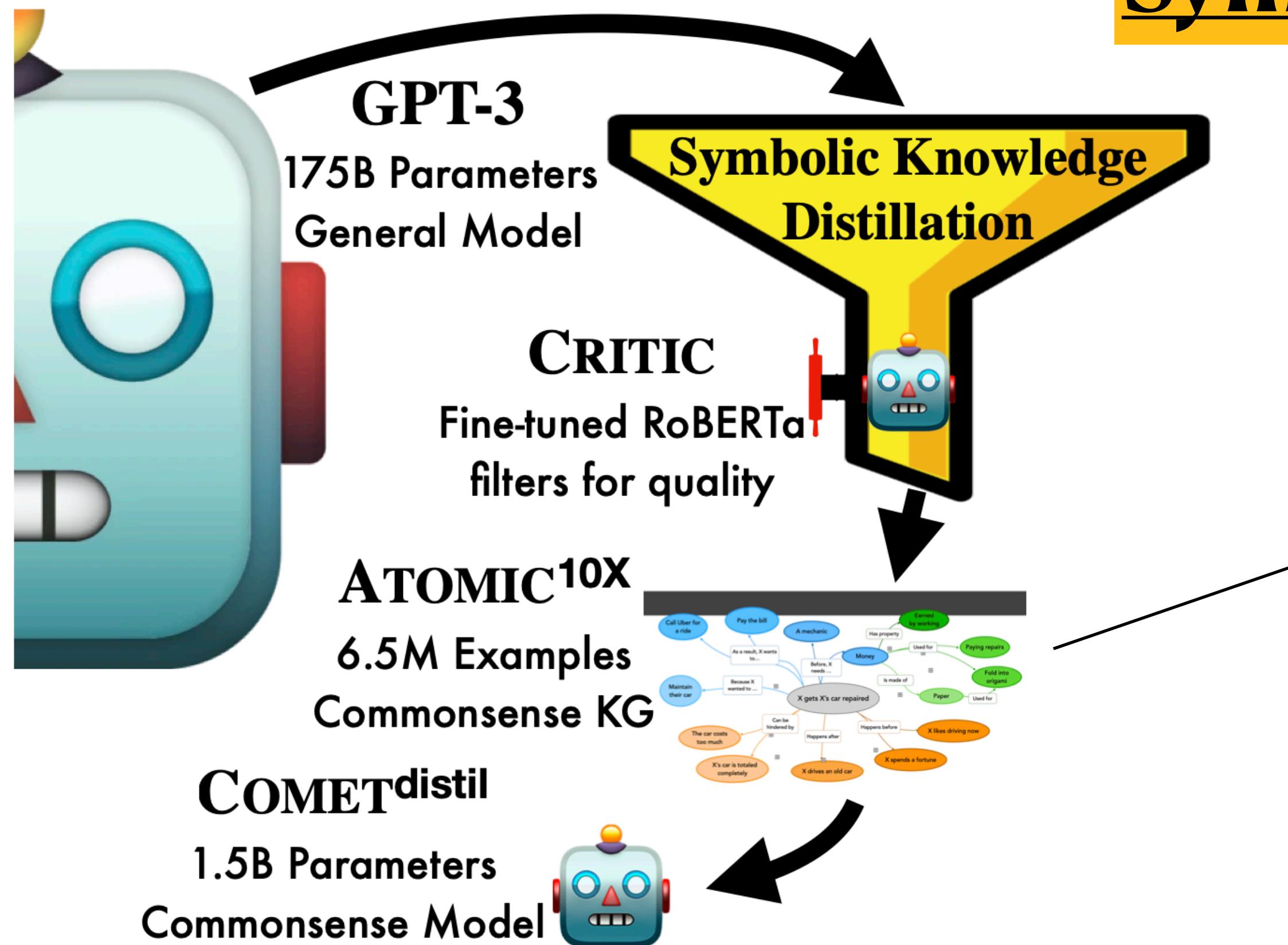
🤖 Parametric Knowledge





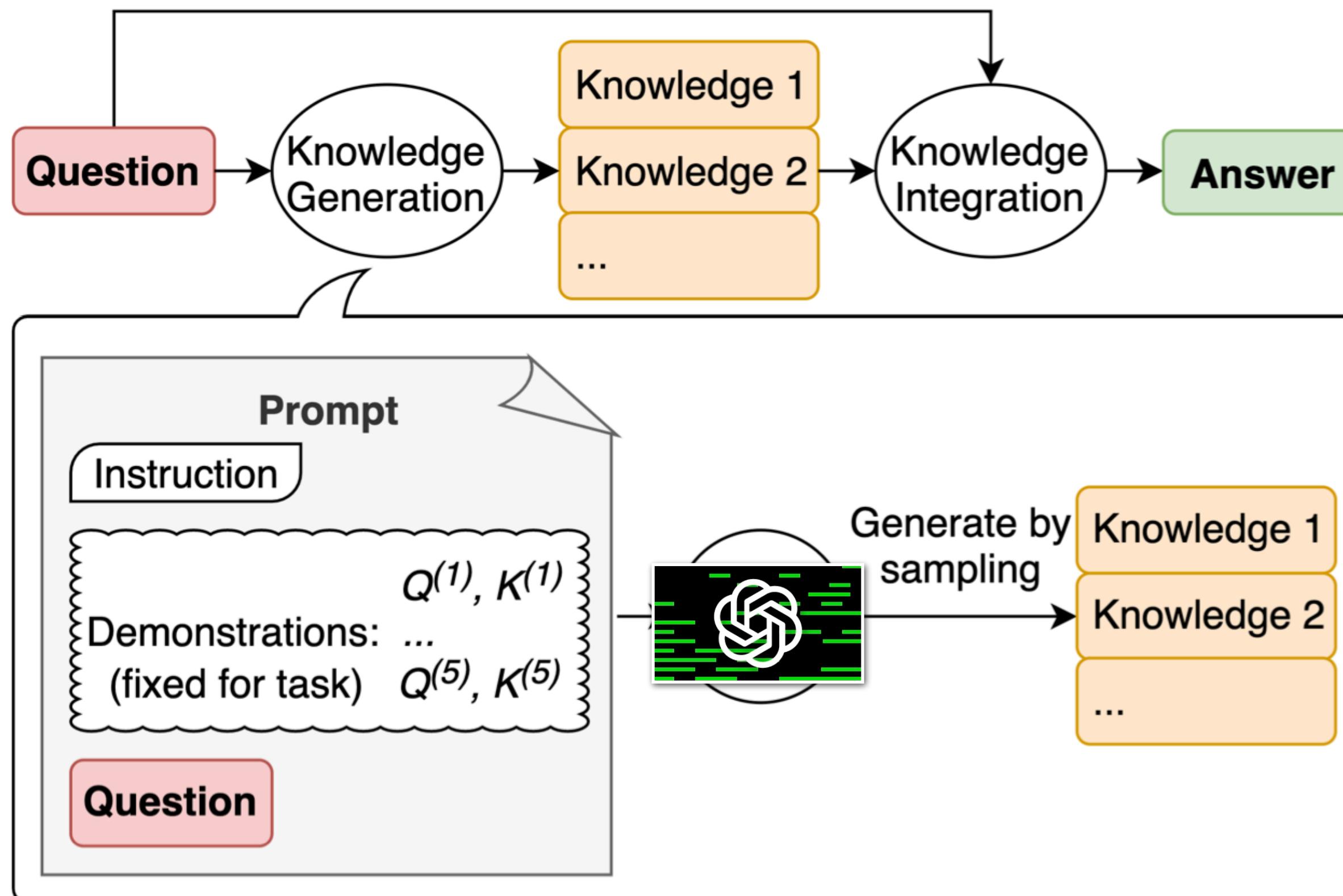
- We can be very expensive.
- You have no idea about our data/weights.

Symbolic Knowledge Distillation [19]



	ATOMIC^{10X}	
xEffect <i>so, X</i>	gets in shape	
xWant <i>so, X wants</i>	to avoid Y	
xNeed <i>X needed</i>	to have taken typing lessons	
xEffect <i>so, X</i>	is punished by his grandfather	
xIntent <i>because X wants</i>	to be self sufficient	
xStarts <i>X starts running</i>		
xEngage <i>X and Y engage in an argument</i>		
xLearn <i>X learns to type fast</i>		
xSteal <i>X steals his grandfather's sword</i>		
xTakeUp <i>X takes up new employment</i>		

Generated Knowledge Prompting (GKP) [20]



Task	NumerSense [22]
Prompt	<p>Generate some numerical facts about objects. Examples: Input: penguins have <mask> wings. Knowledge: Birds have two wings. Penguin is a kind of bird.</p> <p>...</p>
	<p>Input: a typical human being has <mask> limbs. Knowledge: Human has two arms and two legs.</p>
	<p>Input: {question} Knowledge:</p>
	<p>Input: The word children means <mask> or more kids. Knowledge: The word child means one kid. The word children is the plural form of the word child. Prediction: two</p>

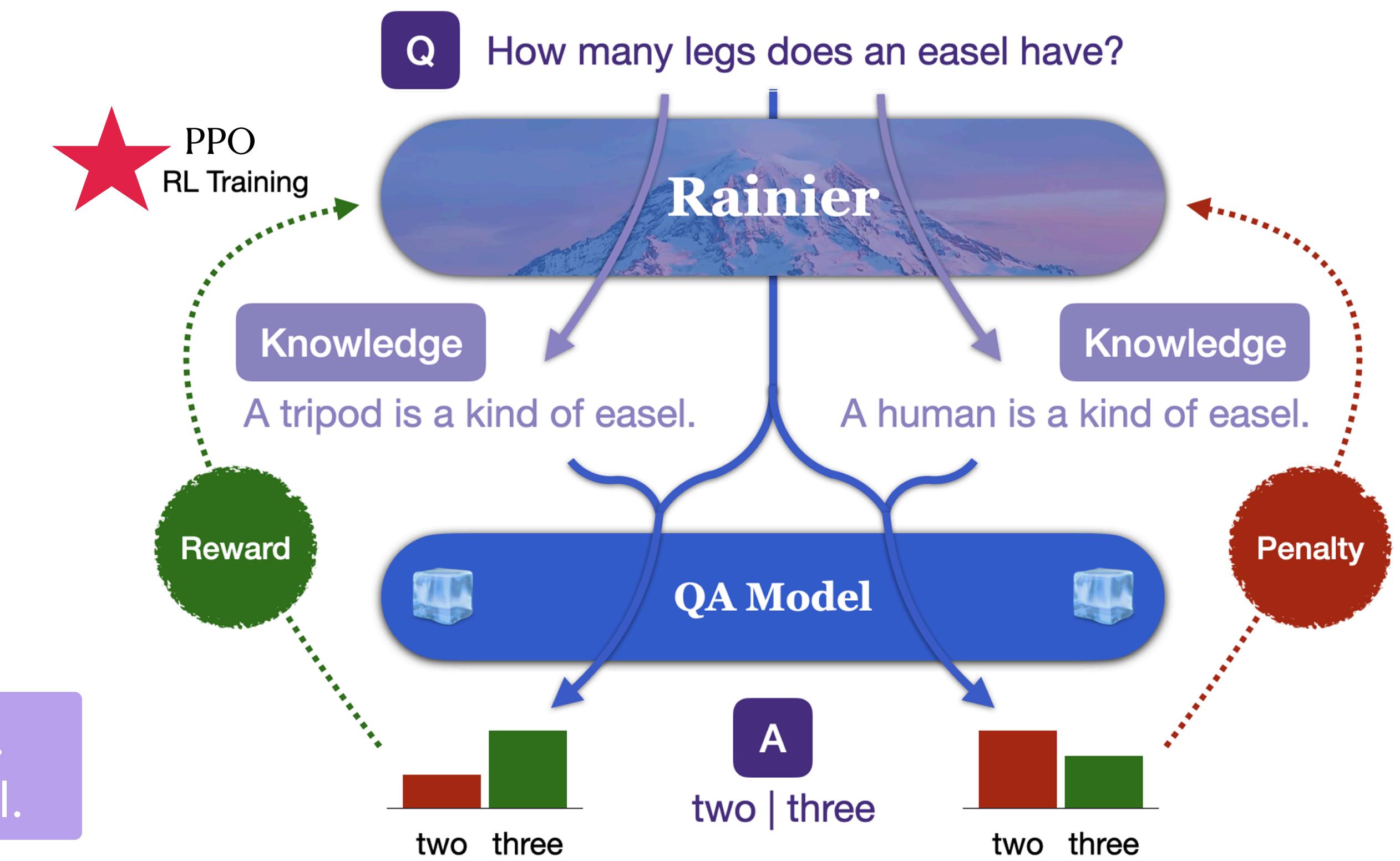
Reinforced Knowledge Introspector (Rainer) [21]

Task	NumerSense
Prompt	Generate some numerical facts about objects. Examples: Input: penguins have <mask> wings. Knowledge: <i>Birds have two wings. Penguin is a kind of bird.</i> ... Input: a typical human being has <mask> limbs. Knowledge: <i>Human has two arms and two legs.</i> Input: How many legs does an easel have? Knowledge:

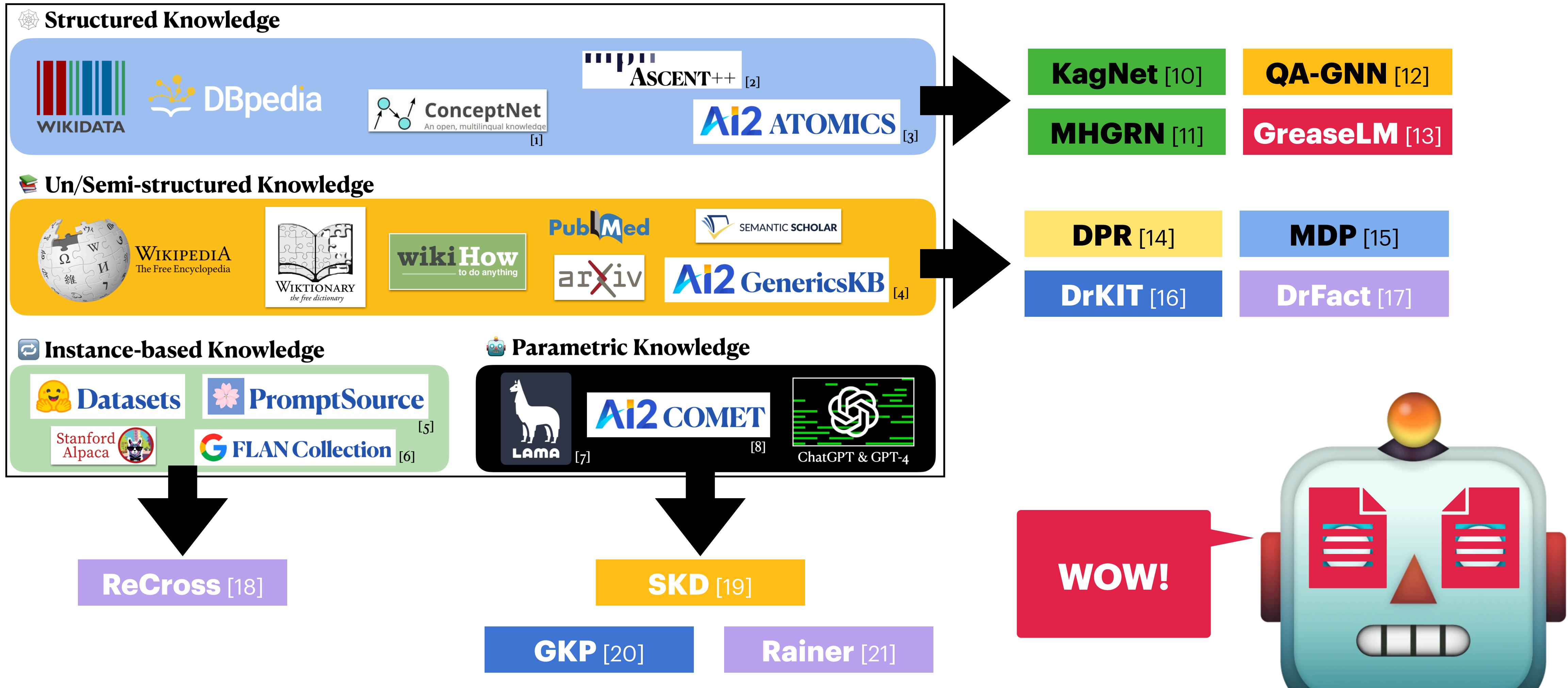
Generated Knowledge Prompting (GKP)



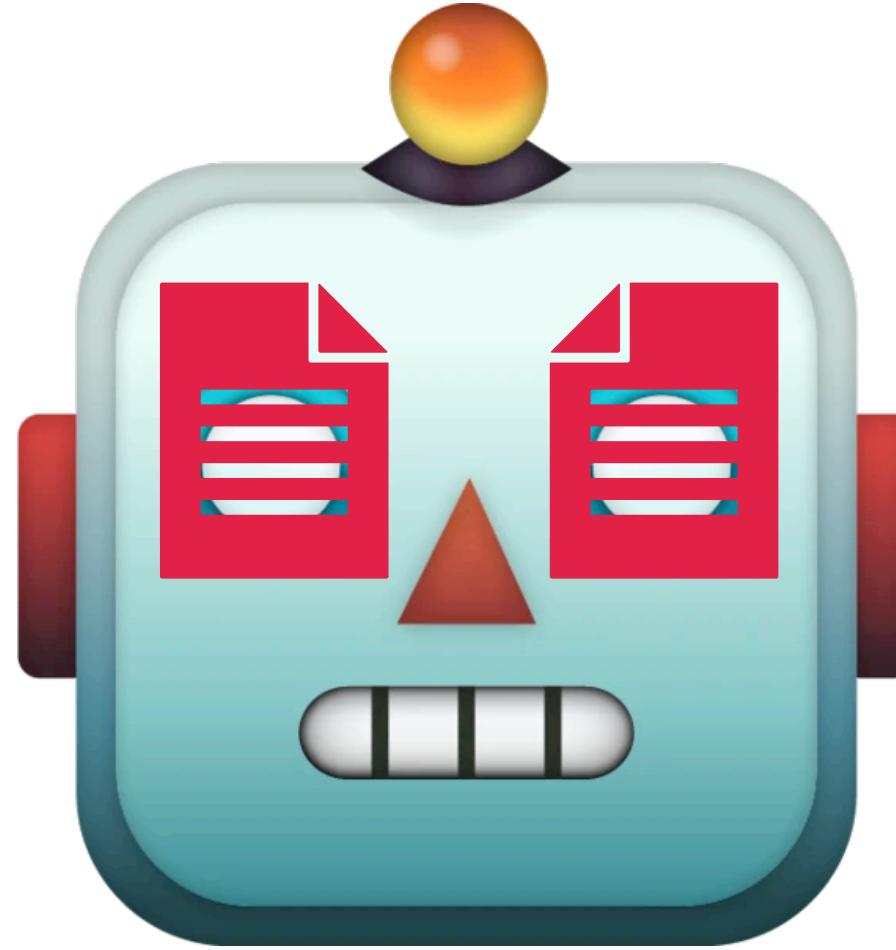
- A tripod is a kind of easel.
- A human is a kind of easel.



Conclusion



Future Directions



How can we merge all these different sources of knowledge into a
unified knowledge model?

How can we deliver a more **faithful** and **interpretable** reasoning
models with **low cost**?

How do we **collect** and **ground** knowledge of
real world and **social interactions** between humans?