





Reasoning on Graphs: Faithful and Interpretable Large Language Models Reasoning

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Introduction

Large language models (LLMs) lack up-to-date knowledge and experience hallucinations during reasoning. Knowledge graphs (KGs), which contain abundant factual knowledge in a structured format, offer a reliable source of knowledge for reasoning. However, how to effectively utilize the KGs for LLMs reasoning remains a significant challenge in this area?

Background

LLMs Knowledge Lacking and Hallucination

LLMs are limited by the lack of knowledge and prone to hallucinations during reasoning, which can lead to errors in reasoning processes.

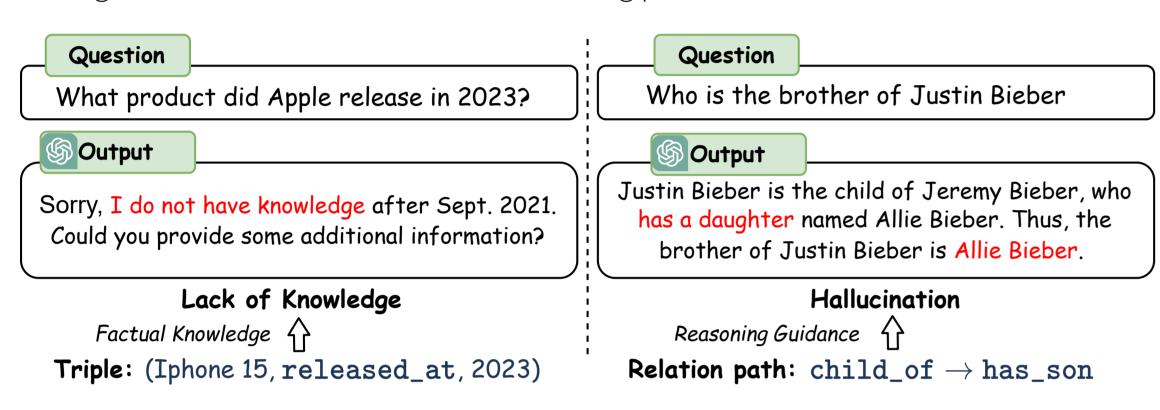


Figure 1. The issues of lack of knowledge and hallucination in LLMs reasoning and how they can be addressed by triples and relation paths from KGs.

KG-enhanced LLM Reasoning

Knowledge graphs (KGs) contain abundant factual knowledge in a structured format offering a reliable source of knowledge for reasoning.

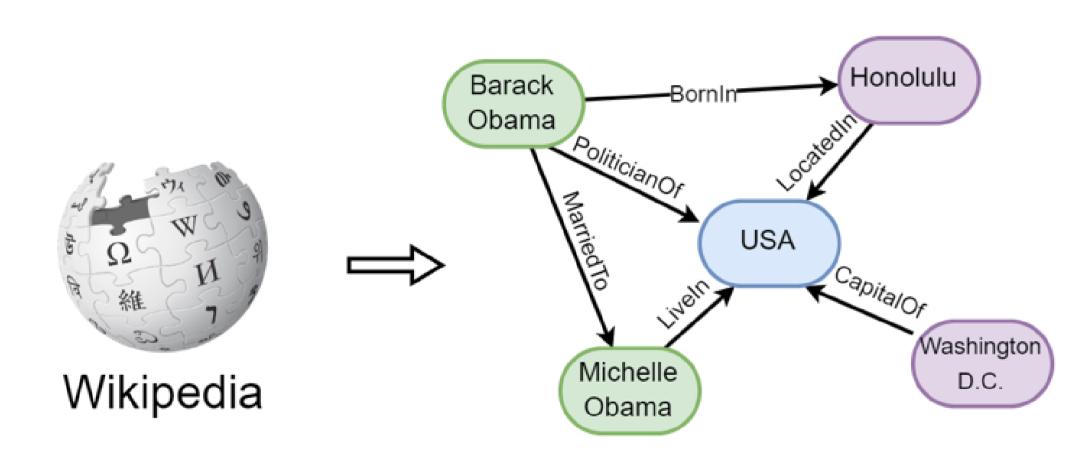


Figure 2. An example of knowledge graphs (KGs).

Existing works adopt the retrieval-augmented generation (RAG) paradigm to enhance LLMs reasoning with KGs.

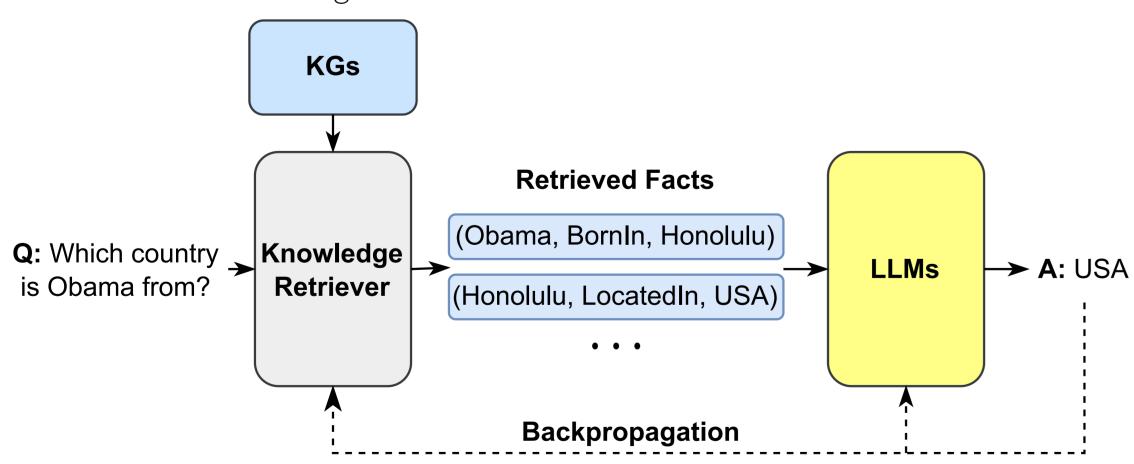


Figure 3. An illustration of the retrieval-augmented generation (RAG) paradigm.

Research Questions

- Efficient Retrieval: How to effectively retrieve relevant knowledge from KGs?
- Effective Reasoning: How to enable LLMs effectively conduct reasoning with
- Faithfulness and Interpretability: How to ensure the faithfulness and interpretability of LLMs reasoning?

Reasoning on Graphs (RoG)

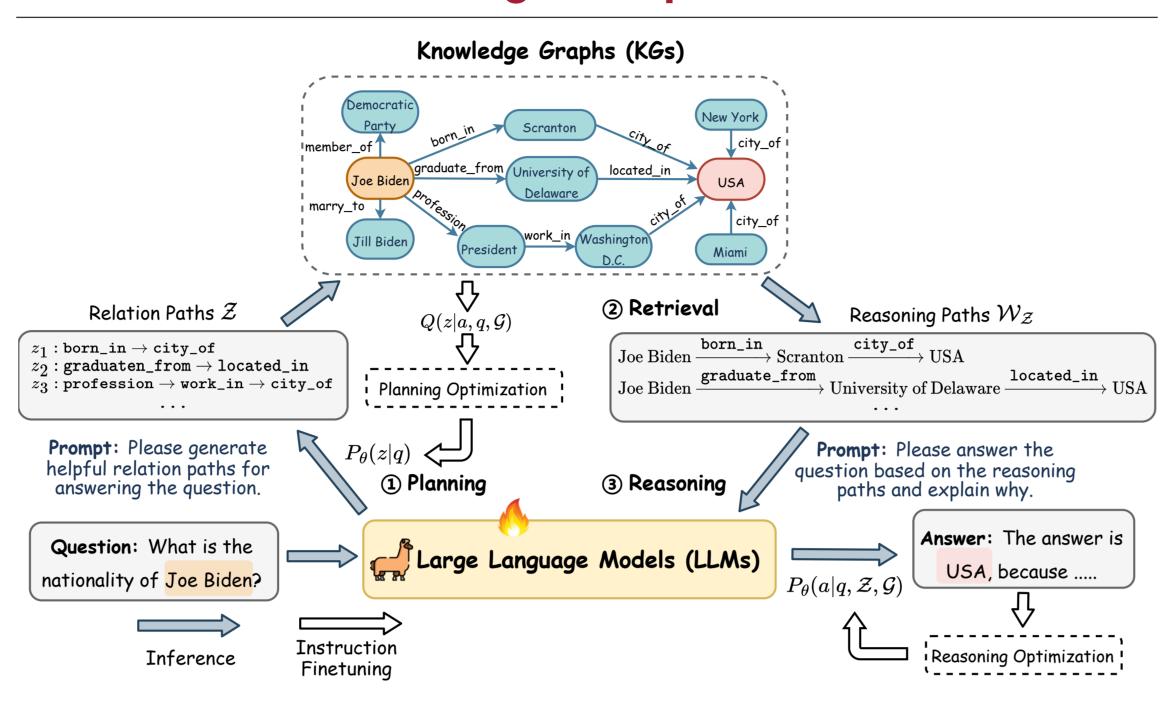


Figure 4. The overall framework of reasoning on graphs (RoG).

Plan-and-solve Reasoning

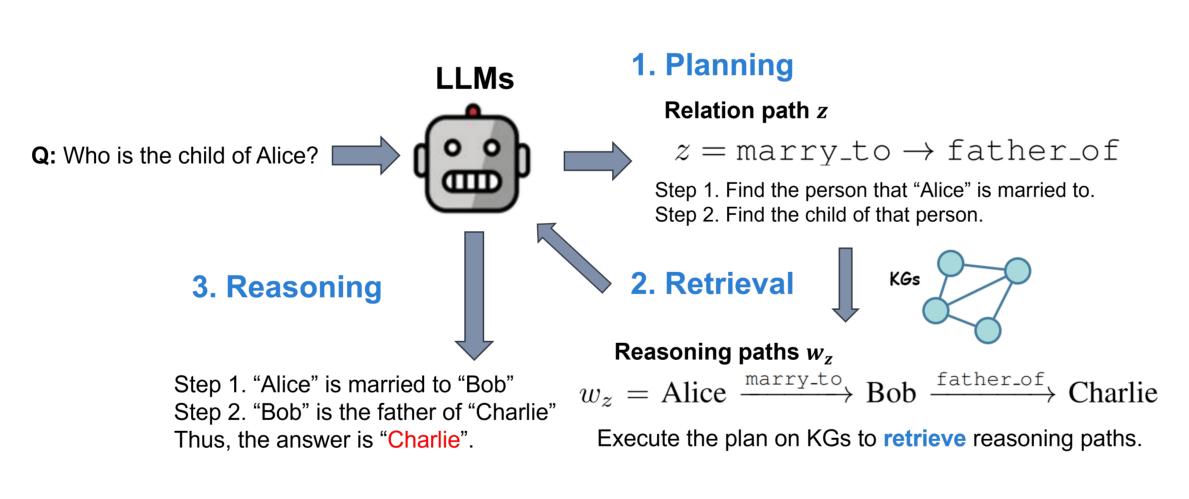
The plan is a hidden logic that can guide the reasoning.

Relation paths as plans

Relation paths are a sequence of relations that can serve as faithful plans for reasoning on graphs.

Planning-retrieval-reasoning

- Planning: generate faithful relation paths as plans.
- Retrieval-Reasoning: reason the answer on graphs with the plans.



Optimization

This function cannot be directly optimized as we do not know the golden plan.

$$P_{\theta}(a|q,\mathcal{G}) = \sum_{z \in \mathcal{Z}} P_{\theta}(a|q,z,\mathcal{G}) P_{\theta}(z|q), \tag{1}$$
 Evidence Lower Bound (ELBO)

 $\log P(a|q,\mathcal{G}) \ge \mathbb{E}_{z \sim Q(z)}[\log P_{\theta}(a|q,z,\mathcal{G})] - D_{\mathrm{KL}}(Q(z)||P_{\theta}(z|q)),$

Estimate the posterior distribution of faithful relation paths with the shortest path Z^* connecting question and answer entities on KGs.

$$Q(z) \simeq Q(z|a, q, \mathcal{G}) = \begin{cases} \frac{1}{|\mathcal{Z}|}, \exists w_z(e_q, e_a) \in \mathcal{G}, \\ 0, else, \end{cases}$$
(3)

Two instruction tunning tasks

$$\mathcal{L} = \log \underbrace{P_{\theta}(a|q, \mathcal{Z}_{K}^{*}, \mathcal{G})}_{\text{Retrieval-reasoning}} + \underbrace{\frac{1}{|\mathcal{Z}^{*}|} \sum_{z \in Z^{*}} \log P_{\theta}(z|q)}_{\text{Planning}}. \tag{4}$$

Prompt

Planning Prompt Template

Please generate a valid relation path that can be helpful for answering the following question: <Question>

Reasoning Prompt Template

Based on the reasoning paths, please answer the given question. Please keep the answer as simple as possible and return all the possible answers as a list.

Reasoning Paths:

<Reasoning Paths>

Question:

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<Question>

Primary Results

Effective Reasoning

Table 1. Performance comparison with different baselines on the two KGQA datasets.

Type	Methods	WebQSP		CWQ	
		Hits@1	F1	Hits@1	F1
Embedding	KV-Mem EmbedKGQA	46.7 66.6	34.5 -	18.4 45.9	15.7 -
	NSM	68.7	62.8	47.6	42.4
	TransferNet KGT5	71.4 56.1	-	48.6 36.5	-
	GraftNet	66.4	60.4	36.8	32.7
Retrieval	PullNet	68.1	-	45.9	- 4 7 4
	SR+NSM SR+NSM+E2E	68.9 69.5	64.1 64.1	50.2 49.3	47.1 46.3
		07.5	O+.1	31.6	
	SPARQL QGG	73.0	73.8	36.9	- 37.4
Semantic Parsing	ArcaneQA	-	75.3	-	-
	RnG-KBQA	_	76.2	-	
	Flan-T5-xl	31.0	-	14.7	-
	Alpaca-7B	51.8	-	27.4	-
LLMs	LLaMA2-Chat-7B	64.4	-	34.6	-
	ChatGPT+CoT	66.8 75.6	-	39.9 48.9	-
LLMs+KGs	KD-CoT	68.6	52.5	55.7	_
	UniKGQA DECAF (DPR+FiD-3B)	77.2 82.1	72.2 78.8	51.2 -	49.1
	RoG	85.7	70.8	62.6	56.2

Efficient Retrieval

Table 2. Effects of integrating the planning module of RoG with different LLMs for reasoning.

Methods	WebQSP		CWQ	
1416111003	Hits@1	Recall	Hits@1	Recall
ChatGPT + RoG Planning	66.77 81.51	. ,	39.90 52.68	35.07 48.51
Alpaca-7B Alpaca-7B + RoG Planning	51.78 56.16		27.44 44.04	23.62 38.46
LLaMA2-Chat-7B LLaMA2-Chat-7B + RoG Planning	64.37 74.20	—	34.60 56.41	29.91 51.99
Flan-T5-xl Flan-T5-xl + RoG Planning	30.95 67.87	17.08 44.93	14.69 37.81	12.25 32.57

Faithfulness and Interpretability

What type of government is used in the country with Northern Dis-

 \rightarrow Israel \rightarrow government.form_of_government.countries \rightarrow Parlia-

Lack of Knowledge

Question

Paths

RoG

	trict?
Answer	Parliamentary system
ChatGPT + CoT	To determine what type of government is used in a country with a Northern District, we need more specific information. The term "Northern District" does not specify the name of any particular country or provide enough context to identify its government type. Could you please provide additional details or clarify the specific country you are referring to?
Reasoning	Northern District → location.administrative division.first level div

The type of government used in the country with the Northern District is a **Parliamentary system**.

Explanations:

Northern District → location.administrative_division.first_level_division.first

So, by following the reasoning paths provided, we can conclude

that the country with the Northern District, which is Israel, uses a Parliamentary system of government.

Hallucination

Reasoning

Paths

Question	Where is the home stadium of the team who won the 1946 World Series championship?		
Answer	Busch Stadium		
	Step 1: Identify the team that won the 1946 World Series championship. The team that won the 1946 World Series championship was the St. Louis Cardinals.		
ChatGPT + CoT	Step 2: Determine the home stadium of the St. Louis Cardinals during that time. The St. Louis Cardinals' home stadium during the 1946 season was Sportsman's Park.		
	Therefore, the possible answer to the question "Where is the home stadium of the team who won the 1946 World Series champi-		

onship?" is: - Sportsman's Park. 1946 World Series → sports.sports_team.championships → St. Louis Cardinals → sports.sports_team.arena_stadium → Busch Stadium

1946 World Series → sports.sports_team.championships → St.

Louis Cardinals → sports.sports_team.arena_stadium → Roger Dean Stadium

Based on the reasoning paths provided, the home stadium of the team who won the 1946 World Series championship is **Busch Sta**-

1. 1946 World Series \rightarrow sports.sports_team.championships \rightarrow St. Louis Cardinals \rightarrow sports.sports_team.arena_stadium \rightarrow RoG Busch Stadium

dium. This conclusion is based on the following path:

The reasoning path leads us to the St. Louis Cardinals as the team that won the 1946 World Series, and Busch Stadium is the stadium associated with the St. Louis Cardinals. Therefore, **Busch Stadium** is the home stadium of the team that won the 1946 World Series championship.