

## LLM with KGs

- LLM의 능력을 더 발전시키기 위해 KG를 사용해서 knowledge injection 방법을 찾아보자.
- Reasoning on Graphs : Faithful and interpretable large language model reasoning
  - 위 논문은 LLM과 KG를 결합하여 신뢰성있고 해석이 가능한 추론을 가능하게 하는 Reasoning on Graphs(RoG)라는 새로운 방법을 제안함. (planning-retrieval-reasoning framework)
  - Planning module : Generate **relation paths** grounded by KGs as faithful **plans**. (planning optimization)
  - Retrieval-reasoning module : Above plans are used to retrieve valid reasoning paths from KGs to conduct faithful reasoning (retrieval-reasoning optimization)
- 논문에서 얻어갈 정보를 알아보자.

## Reasoning on Graphs : Faithful and interpretable large language model reasoning

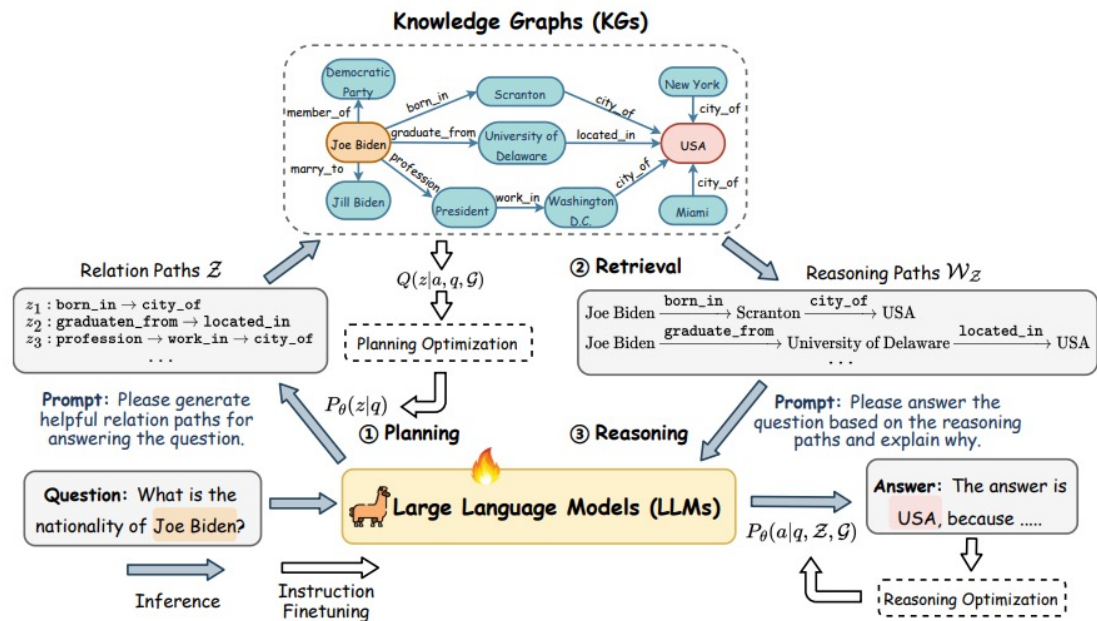
**Knowledge Graphs (KGs)** contain abundant factual knowledge in the form of a set of triples:  $\mathcal{G} = \{(e, r, e') | e, e' \in \mathcal{E}, r \in \mathcal{R}\}$ , where  $\mathcal{E}$  and  $\mathcal{R}$  denote the set of entities and relations, respectively.

**Relation Paths** are a sequence of relations:  $z = \{r_1, r_2, \dots, r_l\}$ , where  $r_i \in \mathcal{R}$  denotes the  $i$ -th relation in the path and  $l$  denotes the length of the path.

**Reasoning Paths** are the instances of a relation path  $z$  in KGs:  $w_z = e_0 \xrightarrow{r_1} e_1 \xrightarrow{r_2} \dots \xrightarrow{r_l} e_l$ , where  $e_i \in \mathcal{E}$  denotes the  $i$ -th entity and  $r_i$  denotes the  $i$ -th relation in the relation path  $z$ .

**Example 1.** Given a relation path:  $z = \text{marry\_to} \rightarrow \text{father\_of}$ , a reasoning path instance could be:  $w_z = \text{Alice} \xrightarrow{\text{marry\_to}} \text{Bob} \xrightarrow{\text{father\_of}} \text{Charlie}$ , which denotes “Alice” is married to “Bob” and “Bob” is the father of “Charlie”.

# Reasoning on Graphs : Faithful and interpretable large language model reasoning



GOAL

$$P_\theta(a|q, \mathcal{G}) = \sum_{z \in \mathcal{Z}} P_\theta(a|q, z, \mathcal{G}) P_\theta(z|q), \quad (1)$$

$$\log P(a|q, \mathcal{G}) \geq \underbrace{\mathbb{E}_{z \sim Q(z)} [\log P_\theta(a|q, z, \mathcal{G})]}_{\text{Retrieval-reasoning optimization}} - \underbrace{D_{\text{KL}}(Q(z) \| P_\theta(z|q))}_{\text{Planning optimization}}, \quad (2)$$

Retrieval-reasoning optimization      Planning optimization

## Planning Optimization

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

$$\begin{aligned} \mathcal{L}_{\text{plan}} &= D_{\text{KL}}(Q(z) \| P_\theta(z|q)) = D_{\text{KL}}(Q(z|a, q, \mathcal{G}) \| P_\theta(z|q)) \\ &= \mathbb{E}_{z \sim Q(z|a, q, \mathcal{G})} Q(z|a, q, \mathcal{G}) [\log Q(z|a, q, \mathcal{G}) - \log P_\theta(z|q)] \\ &= -\mathbb{E}_{z \sim Q(z|a, q, \mathcal{G})} Q(z|a, q, \mathcal{G}) \log P_\theta(z|q) + \text{CONST} \\ &= -\sum_{z \in Q(z|a, q, \mathcal{G})} \log P_\theta(z|q). \end{aligned} \quad (4)$$

## Retrieval-reasoning Optimization

$$\mathcal{L}_{\text{reason}} = \mathbb{E}_{z \sim Q(z|a, q, \mathcal{G})} [\log P_\theta(a|q, z, \mathcal{G})] = \log P_\theta(a|q, \mathcal{Z}_K, \mathcal{G}).$$

$$\mathcal{L} = \underbrace{\log P_\theta(a|q, \mathcal{Z}_K, \mathcal{G})}_{\text{Retrieval-reasoning}} + \underbrace{\sum_{z \in Q(z|a, q, \mathcal{G})} \log P_\theta(z|q)}_{\text{Planning}}.$$

## Reasoning on Graphs : Faithful and interpretable large language model reasoning

- KG(Freebase)를 사용하며, QA 데이터셋은 Freebase기반의 데이터셋(WebQSP, CWQ)를 사용한다.
- Planning optimization 수식에서 지식 그래프가 어떻게 사용되나면 Question entity와 Answer entity를 연결하는 shortest path relation을 미리 수집하고, prompt로 생성한 것과 비교해서 shortest path relation에 속하지 않은 relation path가 생성되면 제외하고 진행하는 것. 즉 애초에 데이터 생성시 미리 QA 문제당 relation path를 함께 저장해놓음.
- Freebase 지식 그래프는 업데이트 되지 않는 그래프(static KG)이므로 ConceptNet(Dynamic KG) 사용이 더 적합해보임.
  - ✓ <https://arxiv.org/pdf/2310.04835.pdf>
- 이 논문의 contribution은 지식 그래프의 장점인 structured knowledge를 LLM에 주입하기 위해 concept(entity)가 아닌 **relation path**를 사용했다는 점과 prompt를 사용하는 것에 대한 정당성을 수식으로 증명.
- LLM with KGs 관련 논문들의 task는 QA-task가 많다. 아무래도 KG entity linking하기에 쉽기 때문,,
  - ✓ QA dataset으로 만들어야 하나?
  - ✓ Prompting을 어떻게 활용하고, 정당성 증명? (더 찾아봐야 할 듯 하다)
  - ✓ 소개한 논문과 관련된 paper를 찾는지, ConceptNet을 사용한 paper를 찾을지,,,