ReSCORE: Label-free Iterative Retriever Training for Multi-hop Question Answering with Relevance-Consistency Supervision

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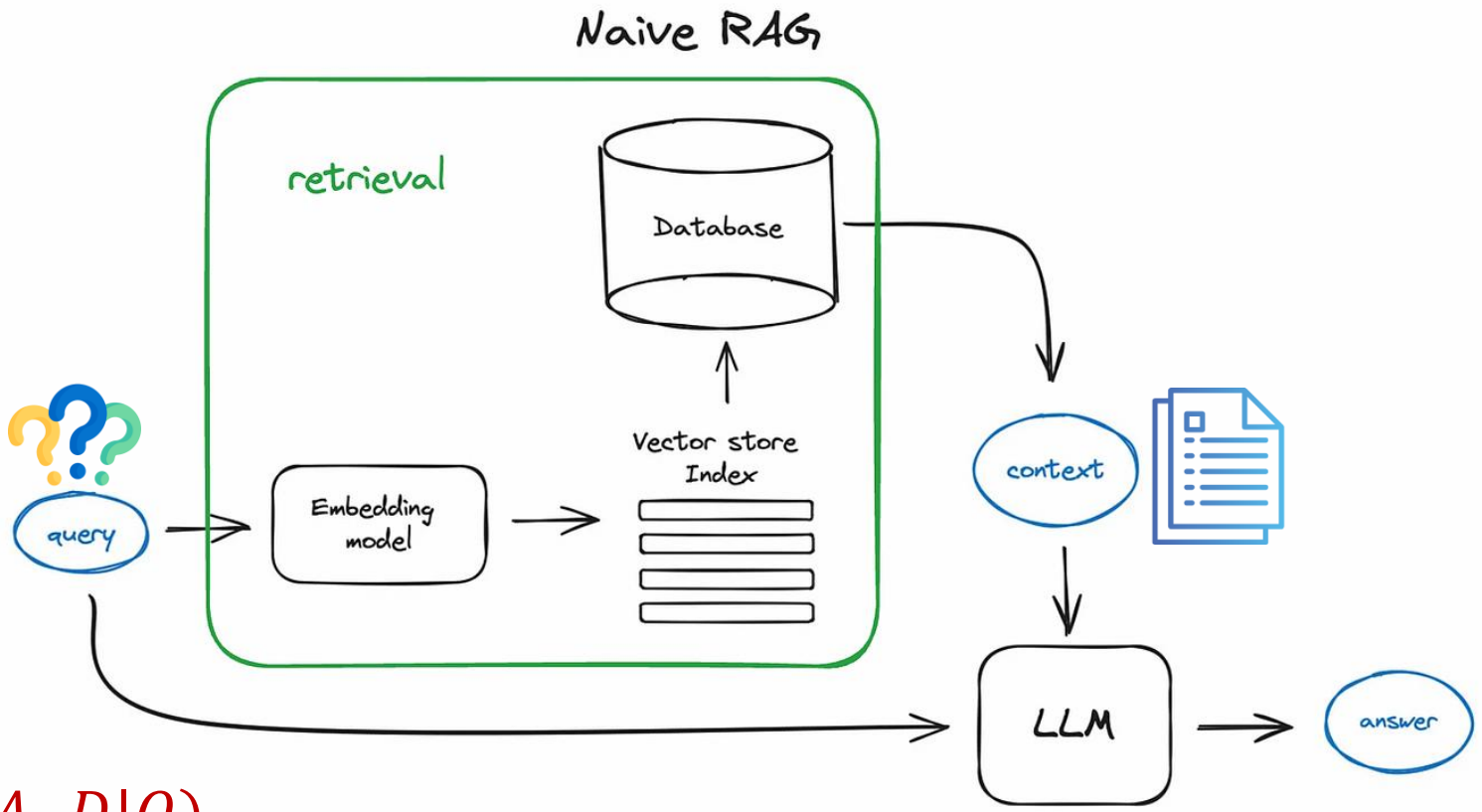
KOREA UNIVERSITY

MIIL Multimodal Interactive Intelligence Laboratory

Retrieval Augmented Generation



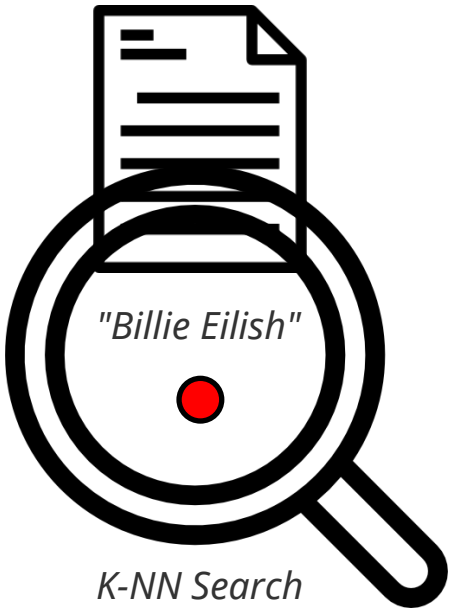
$$P_{QA}(A|Q) = \sum_{D} P(A, D|Q)$$

$$P_{RAG}(A, D|Q) = P_{generate}(A|D, Q)\, P_{retrieve}(D|Q)$$

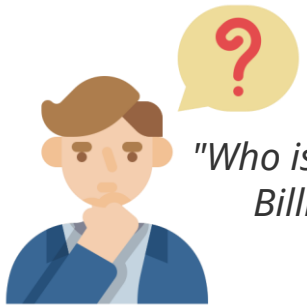
Multi-hop Question Answering & Challenges

Single-hop

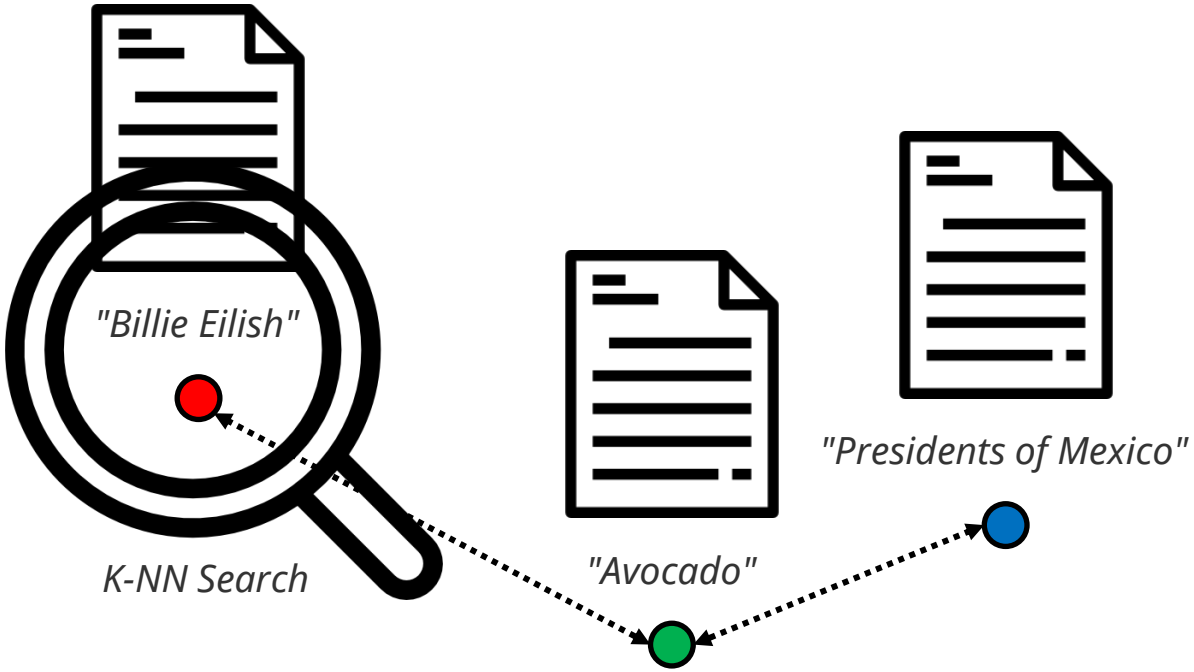
“What is Billie Eilish’s favorite food?”



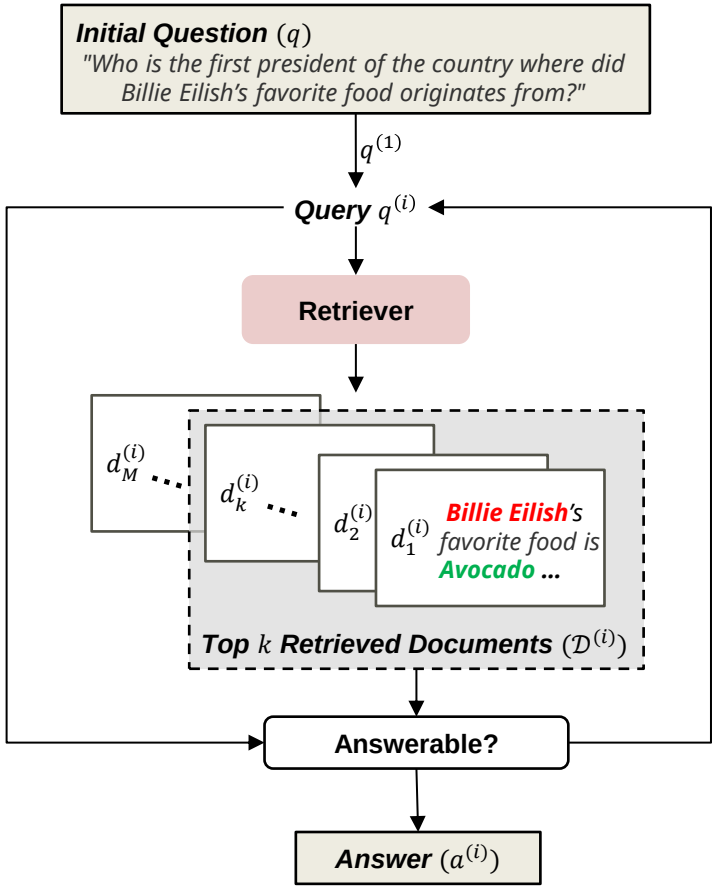
Multi-hop

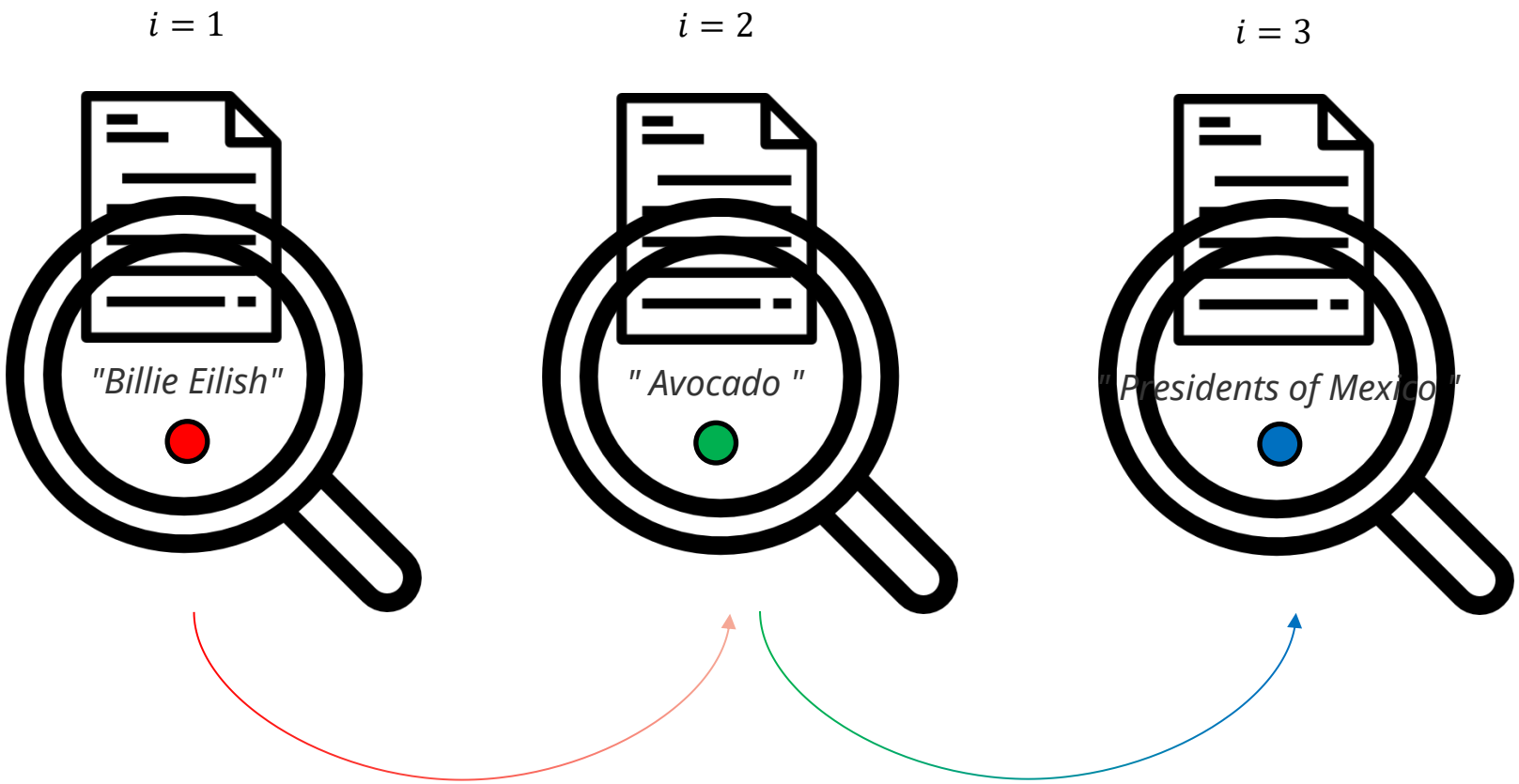


"Who is the first president of the country where did Billie Eilish’s favorite food originates from?"



Iterative RAG Inference Framework



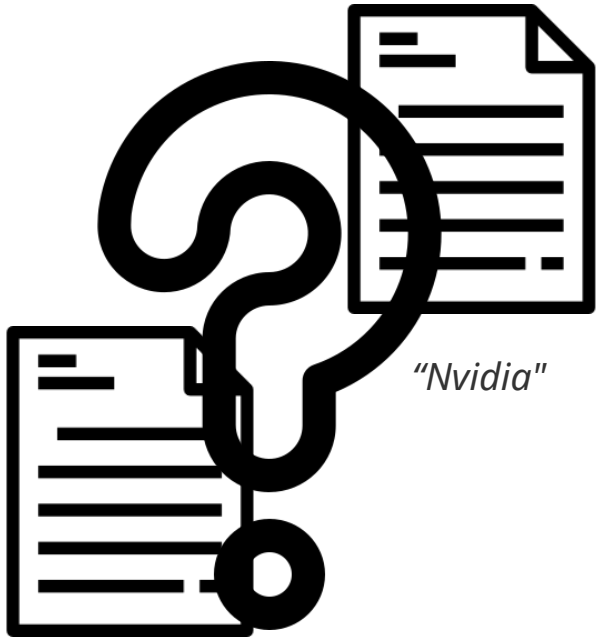


Challenges of Labeling MHQA & Label-free Training

"Who is the first president of the country where did Billie Eilish's favorite food originates from?"

"Billie Eilish"

"Elon Musk"



"Nvidia"

"South Korea"

" Presidents of Mexico "

" Avocado"

"Paris"

Relevance-Consistency Supervision

$$P_{QA}(A|Q) = \sum_{D} P(A, D|Q)$$

$$P_{RAG}(A, D|Q) = P_{generate}(A|D, Q)\, P_{retrieve}(D|Q)$$

$$P_{Retriever}(D|Q) \propto P_{LLM}(A, Q|D)$$

$$P_{LLM}(A, Q|D) = P_{Consistency}(A|D, Q)\, P_{Relevance}(Q|D)$$

"Who is the first president of the country where did Billie Eilish's favorite food originates from?"

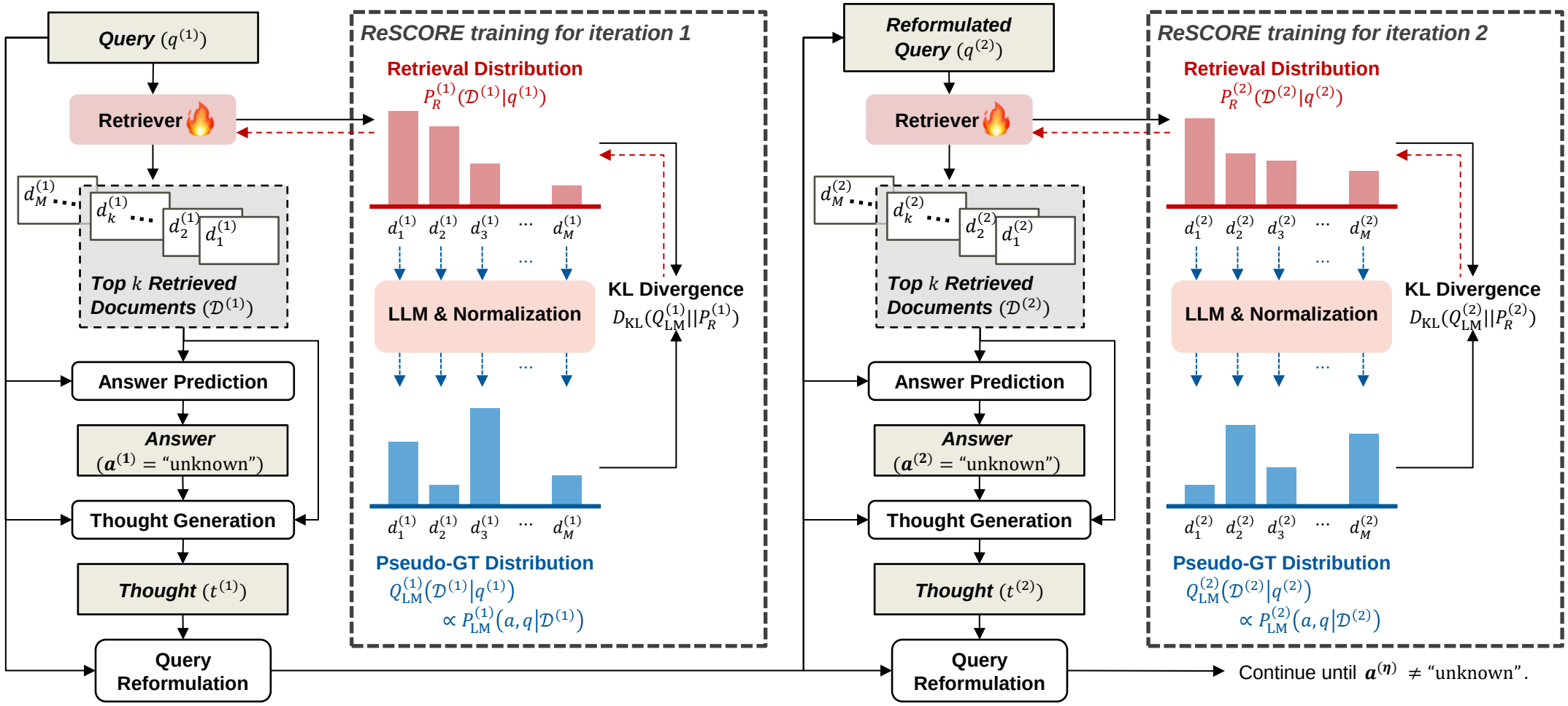
"Presidents of Mexico"

$P_{Consistency}(A|D, Q)$

"Billie Eilish"

$P_{Relevance}(Q|D)$

ReSCORE Training



Comparison to SOTA MHQA Baselines

Model	MuSiQue EM	MuSiQue F1	HotpotQA EM	HotpotQA F1	2WikiMHQA EM	2WikiMHQA F1
ReAcT (GPT-3.5+BM25)†	10.2	19.7	36.0	46.9	28.0	37.3
FLARE (GPT-3.5+BM25)†	11.2	18.7	36.4	47.8	31.8	42.8
Self-RAG (GPT-3.5+BM25)†	10.6	19.2	33.8	44.4	24.4	30.8
Adaptive-Note (GPT-3.5+BM25)†	13.2	24.2	45.6	58.4	43.2	54.2
IRCoT (Flan-T5-XL+BM25)‡	22.0	31.8	44.42	56.2	49.7	54.9
Adaptive-RAG (Flan-T5-XL+BM25)‡‡	**23.6**	31.8	42.0	53.8	40.6	49.8
Our Baseline (Llama-3.1-8B+BM25)	15.2	23.6	42.2	55.7	44.6	52.2
Our Baseline (Llama-3.1-8B+Contriever)	15.2	23.8	39.4	52.3	32.8	41.6
IQATR (Llama-3.1-8B+Contriever trained w/ ReSCORE)	23.4	**32.7**	**47.2**	**59.3**	**50.0**	**59.7**

	MuSiQue			HotpotQA			2WikiMHQA		
	cEM	EM	F1	cEM	EM	F1	cEM	EM	F1
Self-Ask	-	13.8	27.0	-	-	-	-	30.0	36.1
Self-Ask + SE	-	15.2	27.2	-	-	-	-	40.1	52.6
SearChain + ColBERT	17.1	-	-	56.9	-	-	46.3	-	-
IQATR (Ours)	30.4	23.4	32.7	59.6	47.2	59.3	57.0	50.0	59.7

Model	QA EM	QA F1	MHR$_i$@8 $i=1$	MHR$_i$@8 $i=2$	MHR$_i$@8 $i=\eta_n$
MuSiQue					
Self-RAG*	1.2	8.2	25.8	25.8	25.8
+ReSCORE	2.8	10.8	24.9	31.6	31.6
FLARE	7.3	13.3	31.0	37.1	37.1
+ReSCORE	8.2	15.3	30.9	40.1	43.3
Adaptive-Note	9.6	17.7	44.9	50.2	50.2
+ReSCORE	11.2	20.5	45.1	49.8	55.3
Our Baseline	15.2	23.8	44.9	51.6	51.6
+ReSCORE	23.4	32.7	46.8	63.0	65.2
HotpotQA					
Self-RAG*	5.6	17.9	36.1	36.5	36.5
+ReSCORE	8.7	19.2	33.8	37.2	37.2
FLARE	27.5	38.9	37.2	48.4	48.4
+ReSCORE	31.4	42.5	39.2	48.5	51.7
Adaptive-Note	42.0	55.3	44.8	49.8	50.1
+ReSCORE	43.8	58.0	47.3	63.3	77.2
Our Baseline	39.4	52.3	44.8	47.5	47.5
+ReSCORE	47.2	59.3	46.6	69.3	72.4
2WikiMHQA					
Self-RAG*	3.0	19.1	26.3	27.1	27.1
+ReSCORE	5.6	21.2	25.9	28.4	32.8
FLARE	23.2	35.0	32.5	42.9	42.9
+ReSCORE	26.5	38.0	33.2	45.6	45.6
Adaptive-Note	35.7	46.1	45.7	59.2	59.2
+ReSCORE	37.4	49.3	49.8	63.2	67.5
Our Baseline	32.8	41.6	45.7	56.9	56.9
+ReSCORE	50.0	59.7	51.2	81.2	88.0

Pseudo-GT Supervision Ablation

Method	MuSiQue			HotpotQA			2WikiMHQA		
	R@8	EM	F1	R@8	EM	F1	R@8	EM	F1
None	47.1	15.2	23.8	61.7	39.4	52.3	58.9	32.8	41.6
$P_{LM}(a\|d,q)$	41.4	5.8	12.3	42.8	19.2	26.4	41.9	18.8	26.5
$P_{LM}(q\|d)$	47.9	15.9	25.9	65.9	42.0	53.9	63.2	39.2	47.9
$P_{LM}(q,a\|d)$	55.7	16.4	26.3	68.3	43.6	56.4	67.1	41.4	51.7

$$P_{QA}(A|Q) = \sum_{D} P(A, D|Q)$$

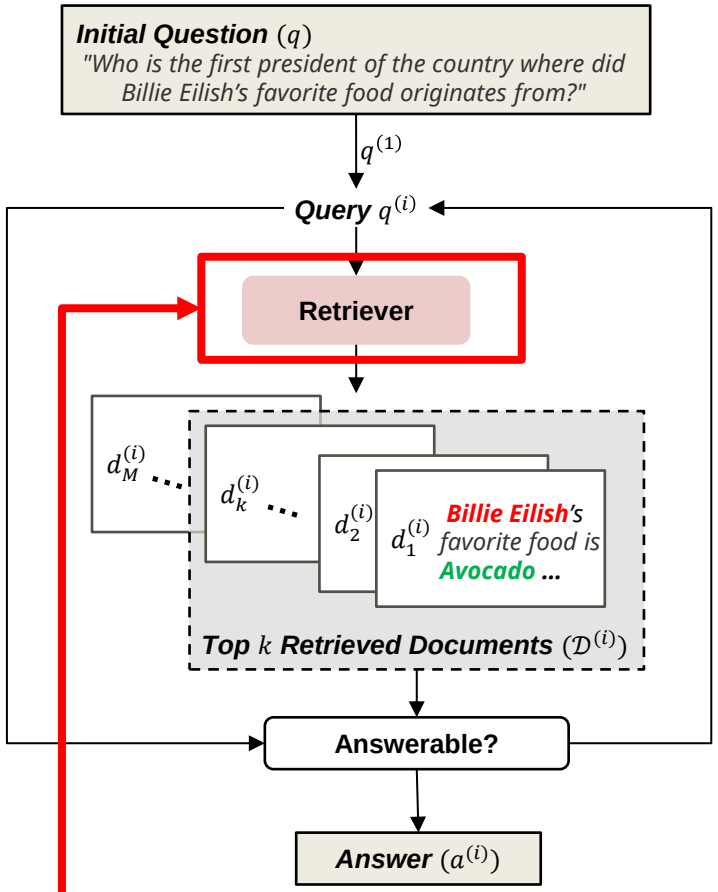
$$P_{RAG}(A, D|Q) = P_{generate}(A|D, Q)\, P_{retrieve}(D|Q)$$

$$P_{Retriever}(D|Q) \propto P_{LLM}(A, Q|D)$$

$$P_{LLM}(A, Q|D) = P_{Consistency}(A|D, Q)\, P_{Relevance}(Q|D)$$

Pseudo-GT Label	R@2	R@4	R@8	R@16
MuSiQue				
None	32.7	40.1	47.1	53.6
$P_{LM}(q \mid d)$	34.6	41.1	47.9	54.2
$P_{LM}(a \mid q, d)$	28.9	35.1	41.4	47.8
$P_{LM}(q, a \mid d)$	**42.7**	**50.3**	**55.7**	**60.4**
HotpotQA				
None	49.4	56.5	61.7	66.3
$P_{LM}(q \mid d)$	55.2	62.4	65.9	69.1
$P_{LM}(a \mid q, d)$	27.5	34.4	42.8	52.5
$P_{LM}(q, a \mid d)$	**58.1**	**64.6**	**68.3**	**70.7**
2WikiMHQA				
None	46.4	54.3	58.9	63.4
$P_{LM}(q \mid d)$	50.8	59.1	63.2	66.1
$P_{LM}(a \mid q, d)$	26.1	33.3	41.9	51.2
$P_{LM}(q, a \mid d)$	**53.7**	**63.0**	**67.1**	**68.7**

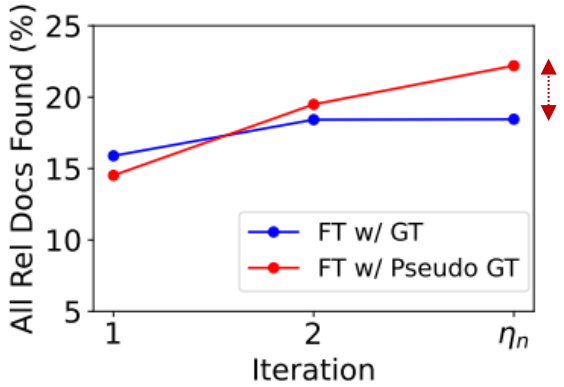
Comparison with GT



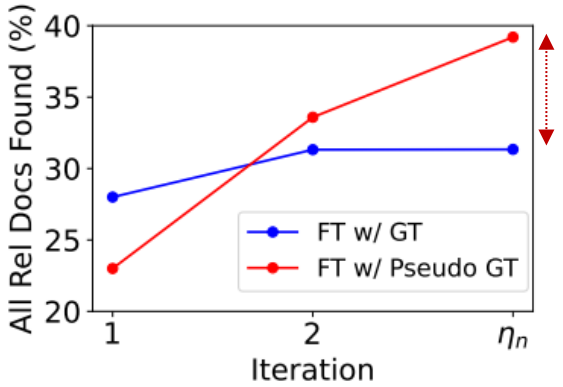
Replaced the Retriever with GT-trained

Label	QA EM	QA F1	MHR$_i$@8 $i=1$	MHR$_i$@8 $i=2$	MHR$_i$@8 $i=\eta_n$
MuSiQue					
None	15.2	23.8	44.9	51.6	51.6
GT	15.8	24.9	46.7	54.8	54.8
Pseudo-GT	23.4	32.7	46.8	63.0	65.2
HotpotQA					
None	39.4	52.3	44.8	47.5	47.5
GT	45.2	55.8	48.7	52.7	52.7
Pseudo-GT	47.2	59.3	46.6	69.3	72.4
2WikiMHQA					
None	32.8	41.6	45.7	56.9	56.9
GT	37.1	46.2	48.5	61.7	61.7
Pseudo-GT	50.0	59.7	51.2	81.2	88.0

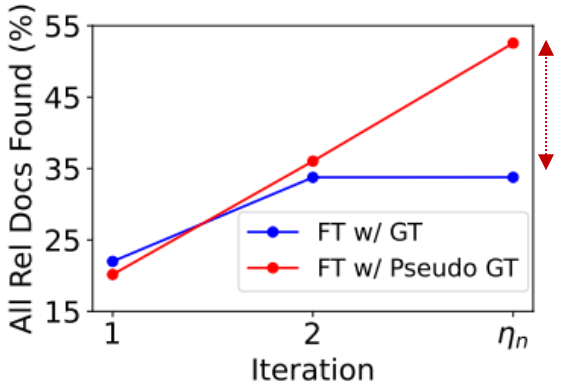
Comparison of GT and Pseudo-GT Labels



(a) MuSiQue Dataset

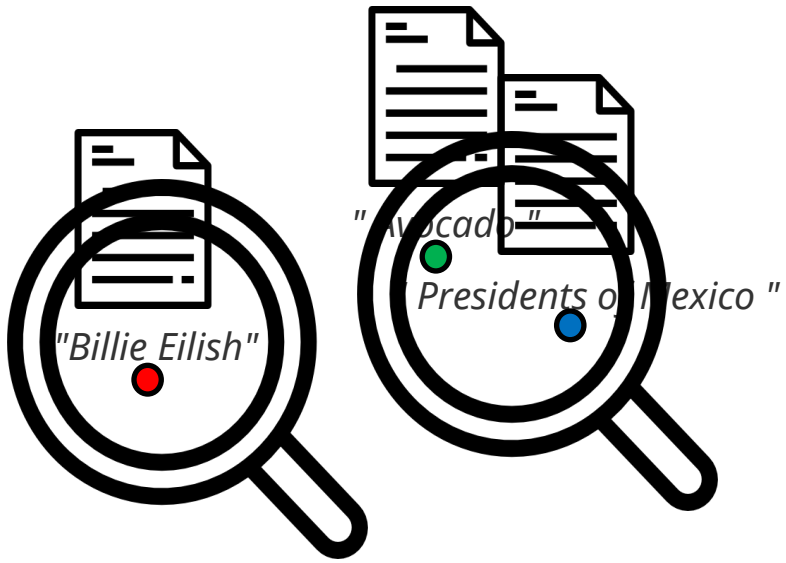


(b) HotpotQA Dataset



(c) 2WikiMHQA Dataset

All Rel Docs Found



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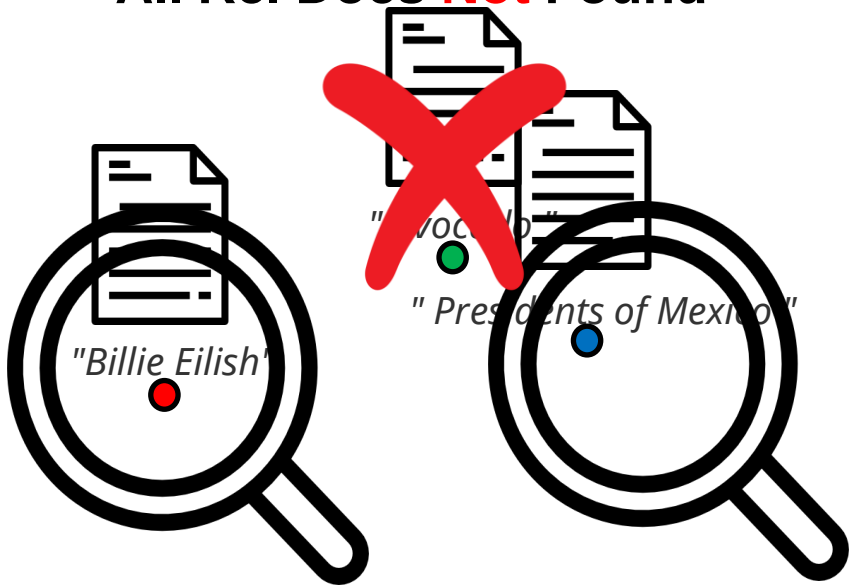
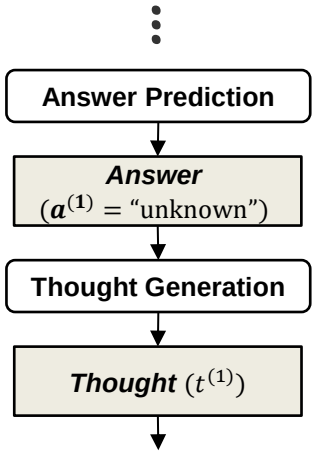


Query Reformulation Ablation



"Who is the first president of the country where did Billie Eilish's favorite food originates from?"

*"**Billie Eilish**'s favorite food is **Avocado**"*

Query Reformulation

None

" Who is the first president of the country where did Billie Eilish's favorite food originates from?"

OR

LLM-rewrite

*"Who is the first president of the country where did **Avocado** originates from?"*

OR

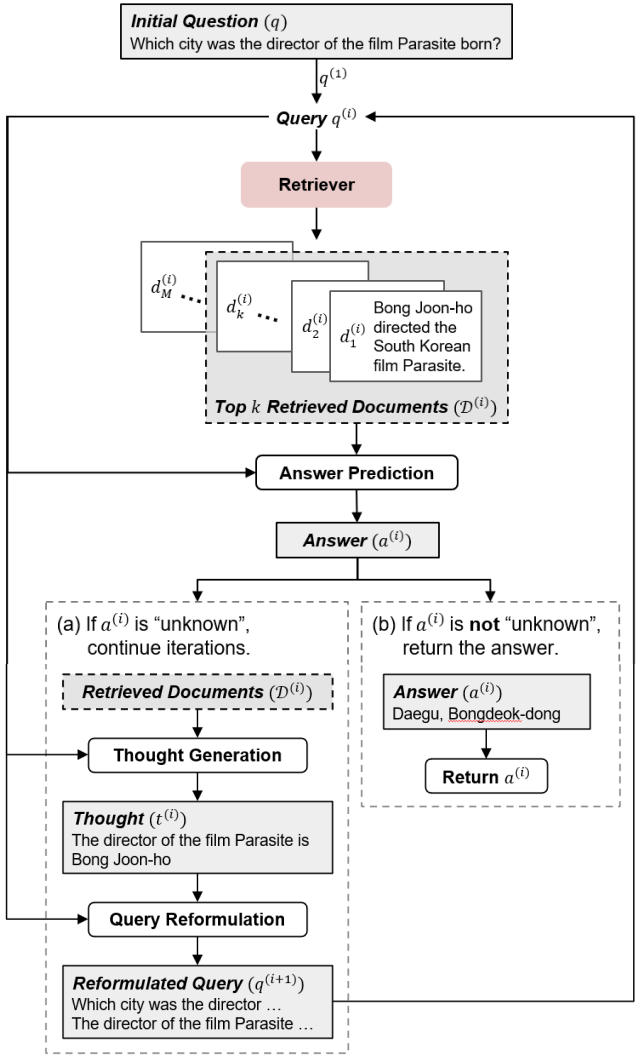
Thought-concat

*"Who is the first president of the country where did Billie Eilish's favorite food originates from? **Billie Eilish**'s favorite food is **Avocado.**"*

Reformulation Method	QA EM	QA F1	MHR$_i$@8 $i=1$	MHR$_i$@8 $i=2$	MHR$_i$@8 $i=\eta_n$
MuSiQue					
None	10.8	17.8	44.7	45.4	47.4
LLM-rewrite	21.2	30.5	45.1	56.7	63.7
Thought-concat	23.4	32.7	46.8	63.0	65.2
HotpotQA					
None	29.4	41.1	42.8	43.6	43.8
LLM-rewrite	44.2	57.4	41.9	54.8	64.7
Thought-concat	47.2	59.3	46.6	69.3	72.4
2WikiMHQA					
None	35.6	44.7	48.6	49.7	49.8
LLM-rewrite	51.7	60.1	50.0	86.0	89.5
Thought-concat	50.0	59.7	51.2	81.2	88.0

Summary: Label-free Iterative Retriever Training for Multi-hop QA

Research Objective



Task

- **Complex questions** that need to be answered by logically-connecting relevant information from multiple documents.

Prior Works

- **Rely on BM25**, as it is cost- and labor-intensive to prepare documents labeled with their relevance to respective queries across iterations.

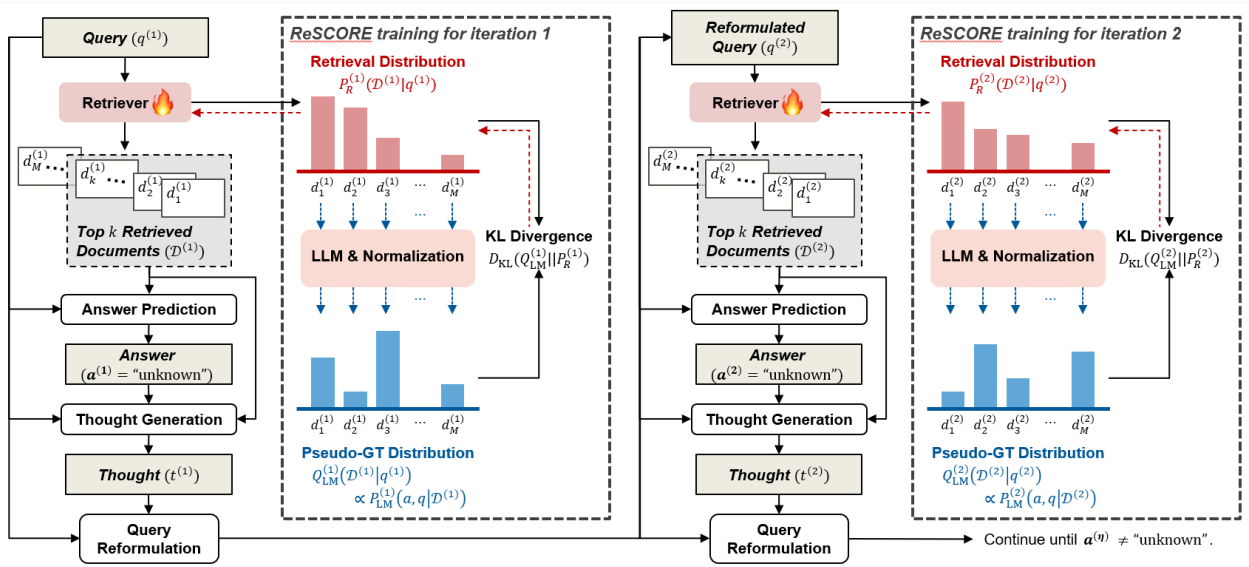
$$Q_{\mathrm{LM}}^{(i)}(d_j^{(i)} \mid q) \propto P_{\mathrm{LM}}^{(i)}(a, q \mid d_j^{(i)}) \quad (1)$$

$$= P_{\mathrm{LM}}^{(i)}(q \mid d_j^{(i)}) \cdot P_{\mathrm{LM}}^{(i)}(a \mid q, d_j^{(i)}) \quad (2)$$

Goal

- ReSCORE leverages **LLM** probability as **pseudo-ground truth label** to train the retriever

Our Method



Results

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E.O.D.