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

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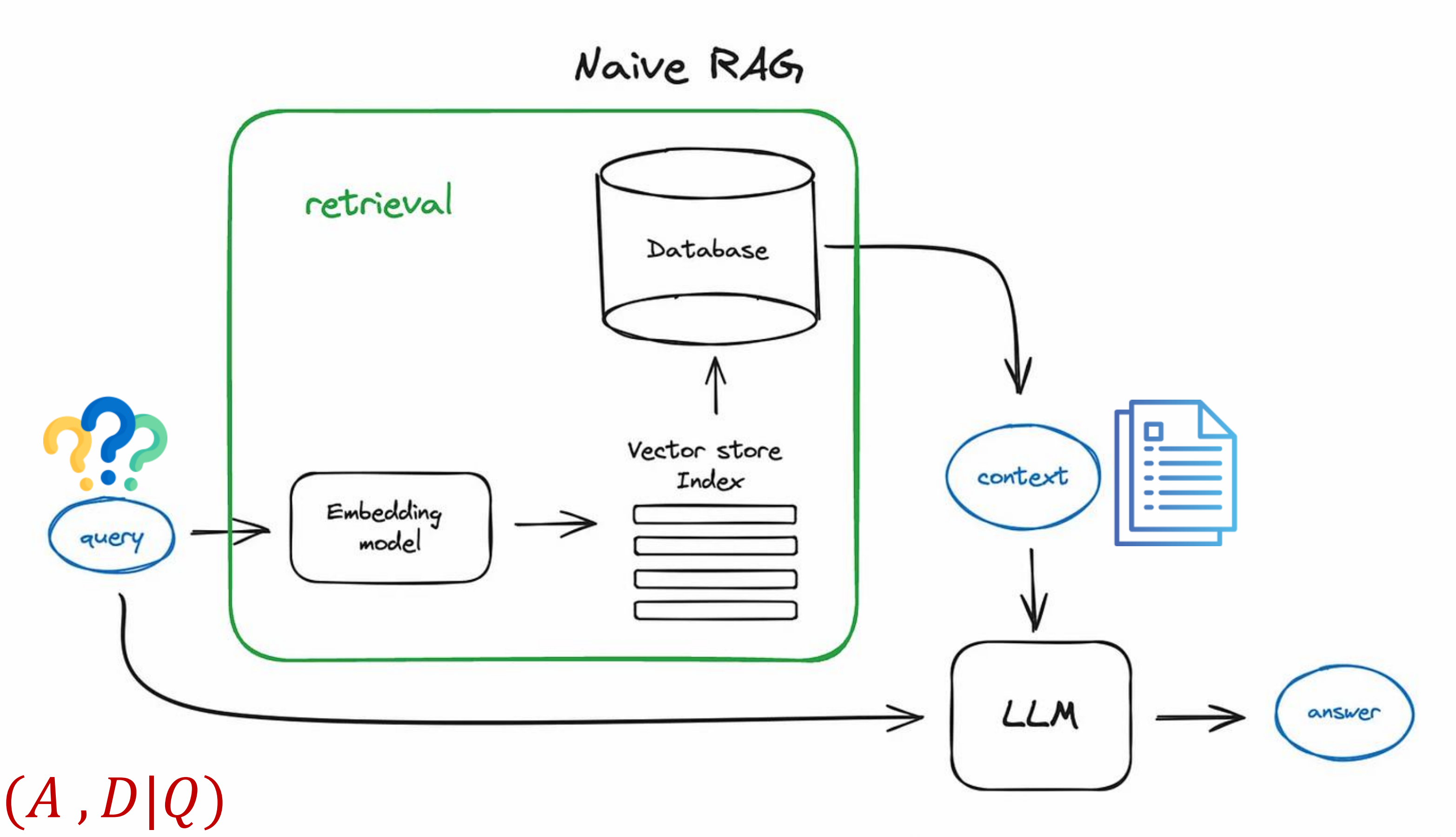
KOREA UNIVERSITY

Multimodal Interactive Intelligence Laboratory

Retrieval Augmented Generation

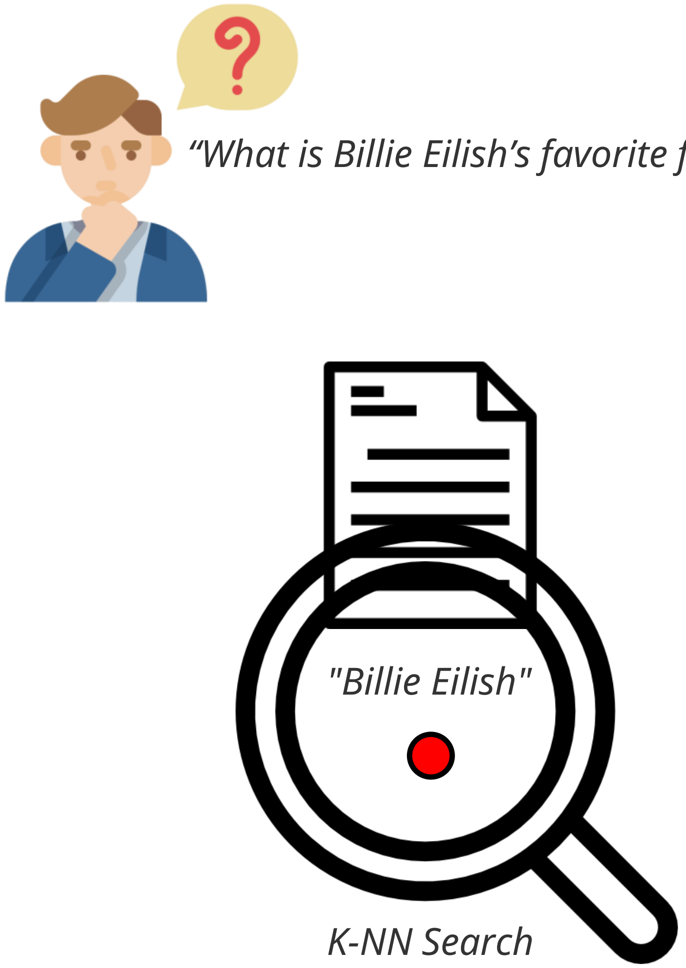


$$P_{QA}(A|Q) = \sum_{D} P(A\,,D|Q)$$

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

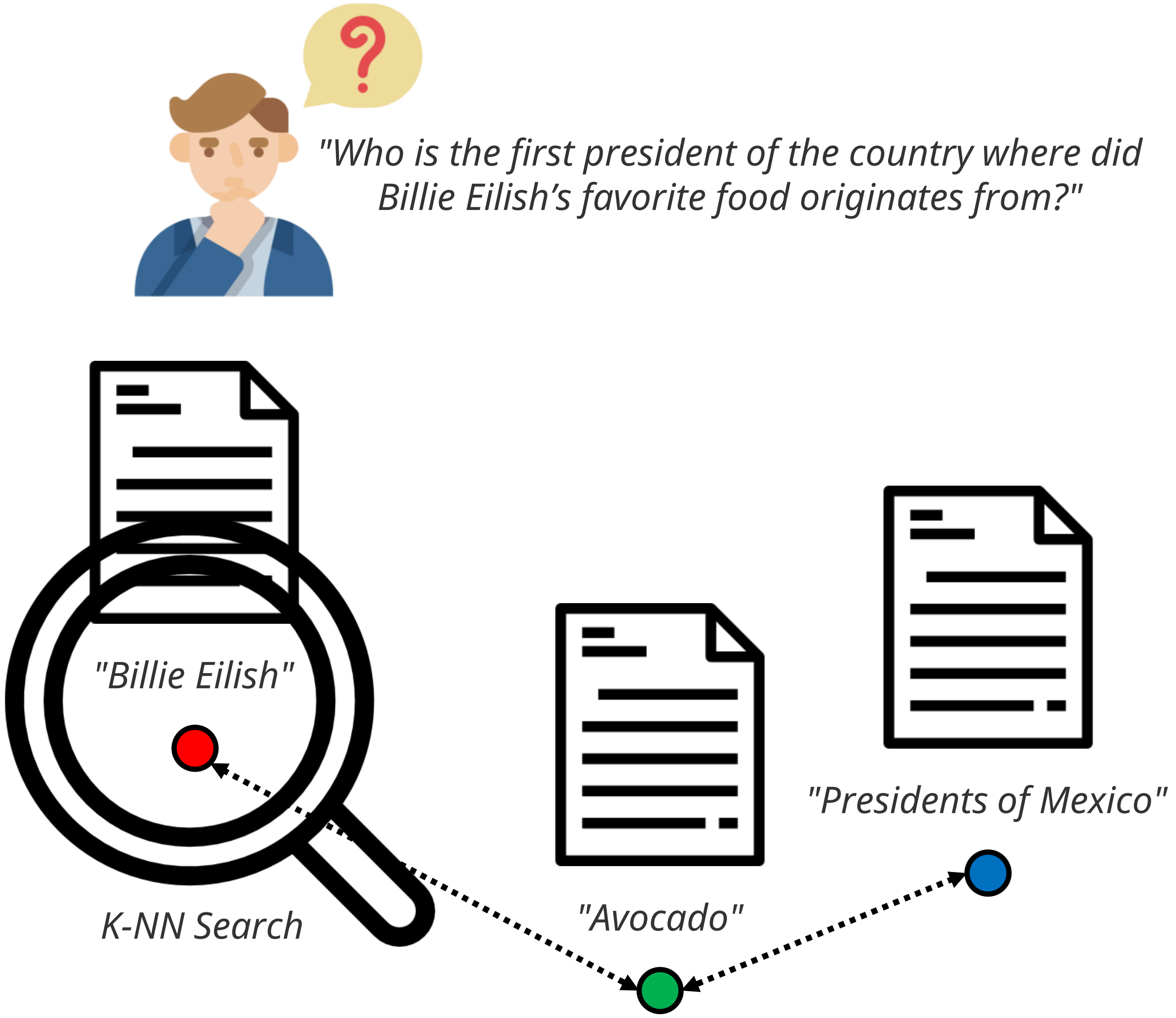
Multi-hop Question Answering & Challenges

Single-hop



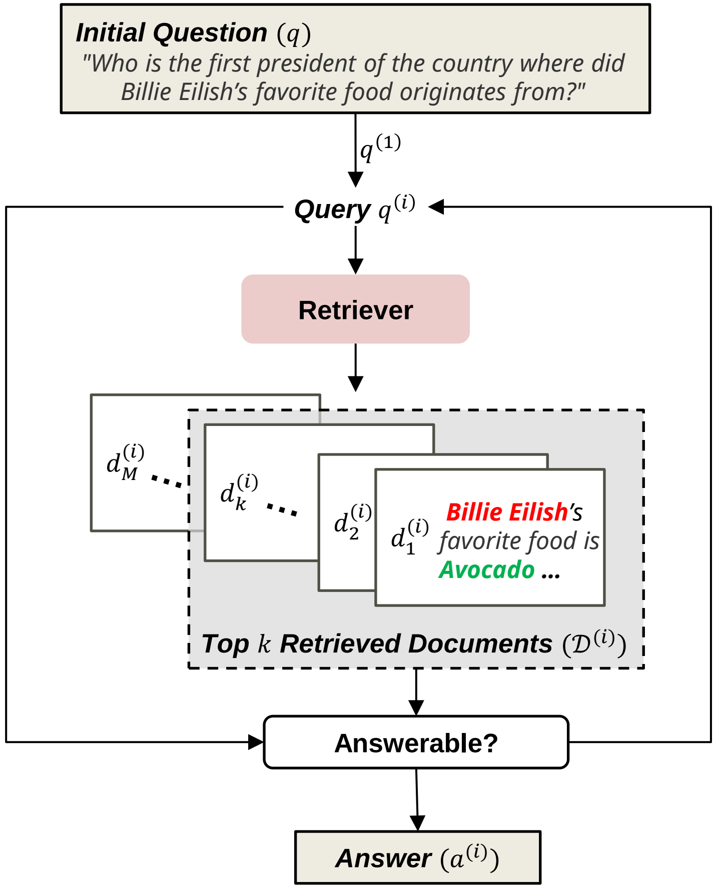
“What is Billie Eilish’s favorite food?”

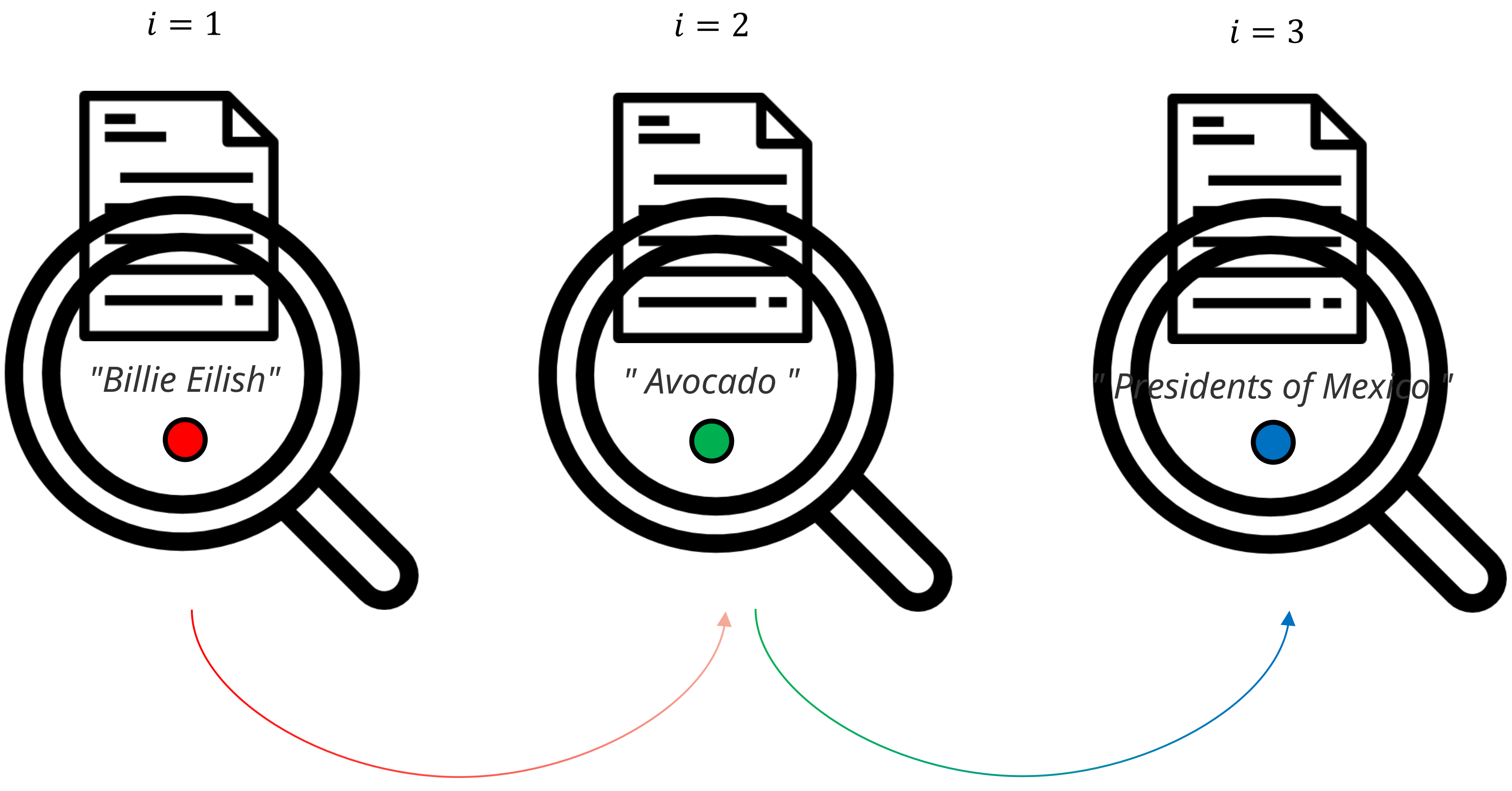
Multi-hop



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

Iterative RAG Inference Framework

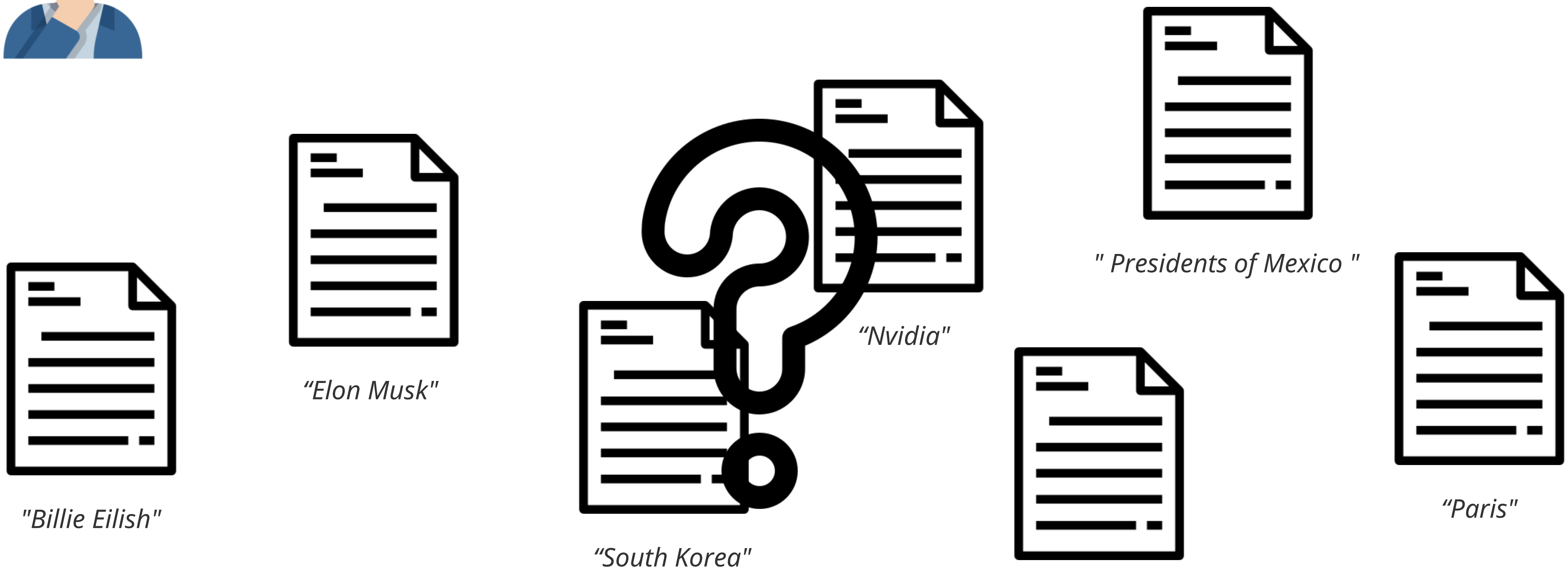

Initial Question (q)
"Who is the first president of the country where did Billie Eilish's favorite food originates from?"
$q^{(1)}$
Query $q^{(i)}$
Retriever
$d_M^{(i)}$
$d_k^{(i)}$
$d_2^{(i)}$
$d_1^{(i)}$
***Billie Eilish**'s favorite food is **Avocado** …*
Top k ***Retrieved Documents*** $(\mathcal{D}^{(i)})$
Answerable?
Answer $(a^{(i)})$



*"**Billie Eilish**'s favorite food is **Avocado**"* *"**Avocado** originated from **Mexico**"*

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"

"South Korea"

"Nvidia"

" Presidents of Mexico "

" Avocado"

"Paris"

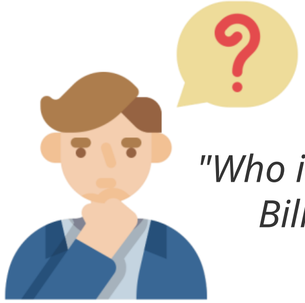
Relevance-Consistency Supervision

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

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

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

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



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

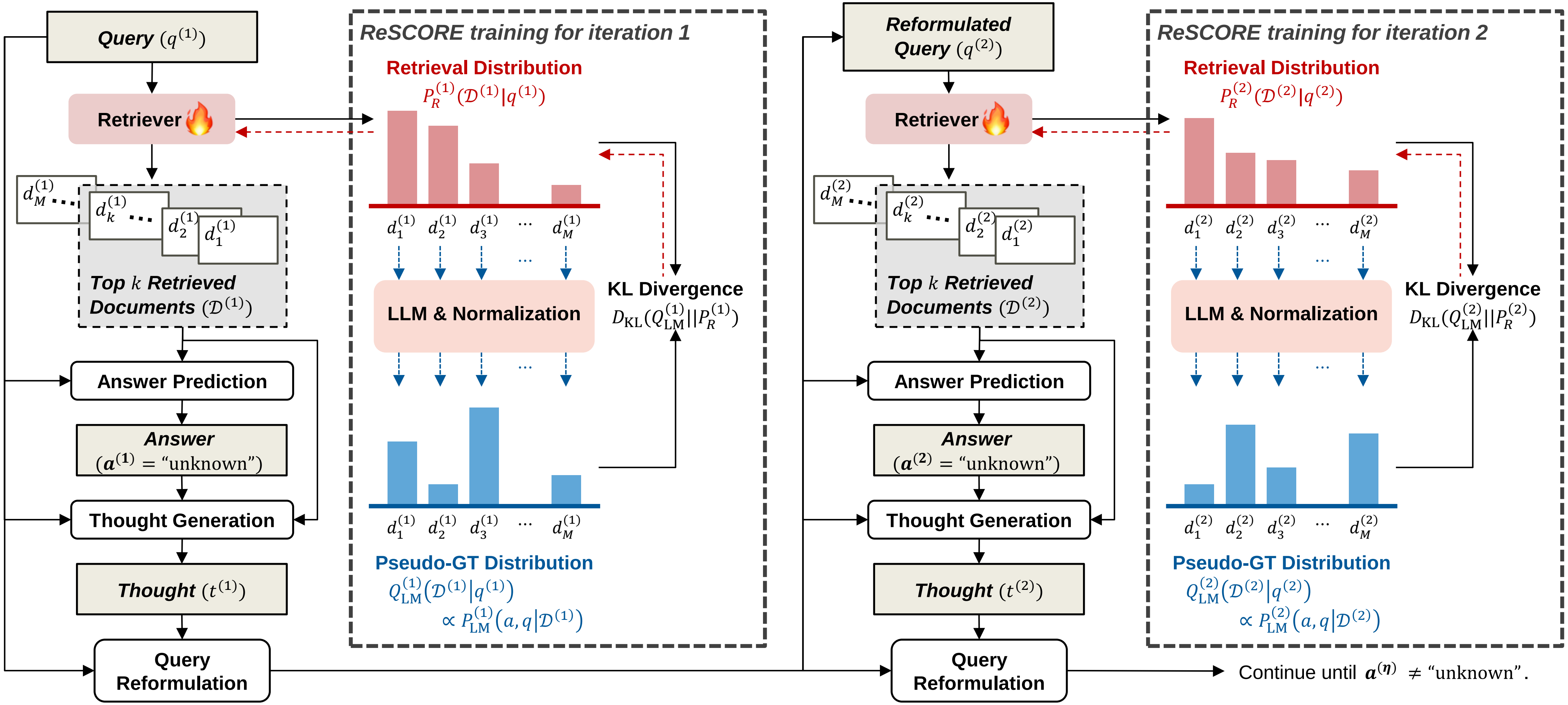
"Presidents of Mexico"

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

"Billie Eilish"

$P_{Relevance}(Q|D)$

ReSCORE Training



Query $(q^{(1)})$

Retriever 🔥

$d_M^{(1)}$ … $d_k^{(1)}$ … $d_2^{(1)}$ $d_1^{(1)}$

Top k Retrieved Documents $(\mathcal{D}^{(1)})$

Answer Prediction

Answer $(\boldsymbol{a}^{(1)} = \text{“unknown”})$

Thought Generation

Thought $(t^{(1)})$

Query Reformulation

ReSCORE training for iteration 1

Retrieval Distribution $P_R^{(1)}(\mathcal{D}^{(1)}|q^{(1)})$

LLM & Normalization

KL Divergence $D_{\text{KL}}(Q_{\text{LM}}^{(1)}||P_R^{(1)})$

Pseudo-GT Distribution $Q_{\text{LM}}^{(1)}(\mathcal{D}^{(1)}|q^{(1)}) \propto P_{\text{LM}}^{(1)}(a,q|\mathcal{D}^{(1)})$

Reformulated Query $(q^{(2)})$

Retriever 🔥

$d_M^{(2)}$ … $d_k^{(2)}$ … $d_2^{(2)}$ $d_1^{(2)}$

Top k Retrieved Documents $(\mathcal{D}^{(2)})$

Answer Prediction

Answer $(\boldsymbol{a}^{(2)} = \text{“unknown”})$

Thought Generation

Thought $(t^{(2)})$

Query Reformulation

ReSCORE training for iteration 2

Retrieval Distribution $P_R^{(2)}(\mathcal{D}^{(2)}|q^{(2)})$

LLM & Normalization

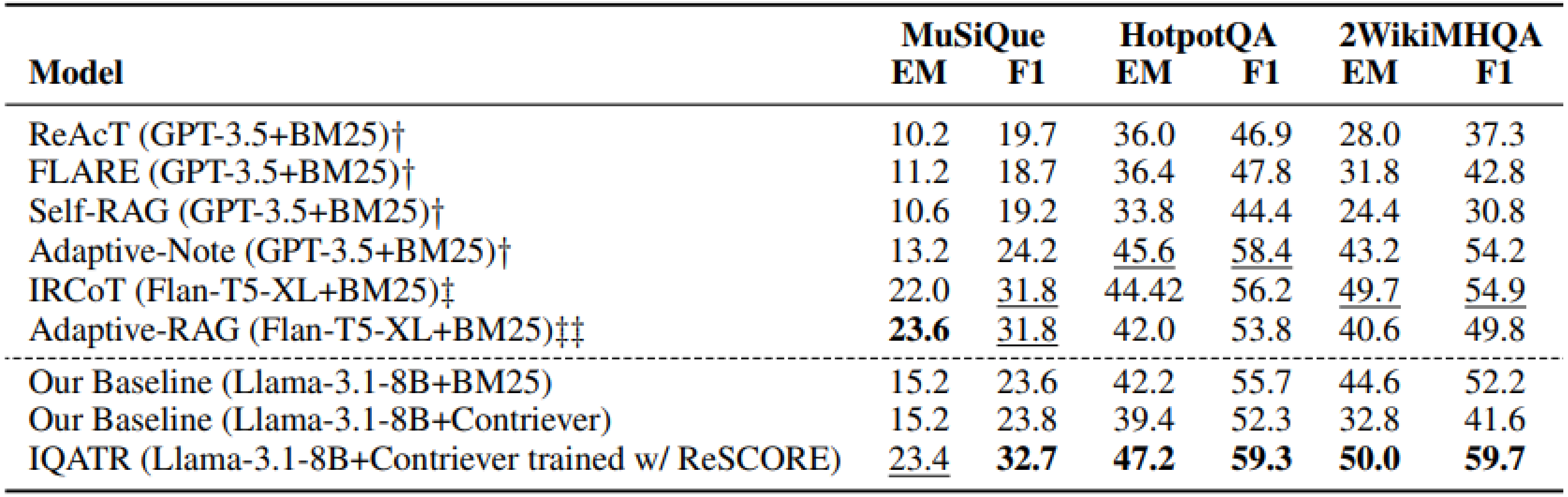
KL Divergence $D_{\text{KL}}(Q_{\text{LM}}^{(2)}||P_R^{(2)})$

Pseudo-GT Distribution $Q_{\text{LM}}^{(2)}(\mathcal{D}^{(2)}|q^{(2)}) \propto P_{\text{LM}}^{(2)}(a,q|\mathcal{D}^{(2)})$

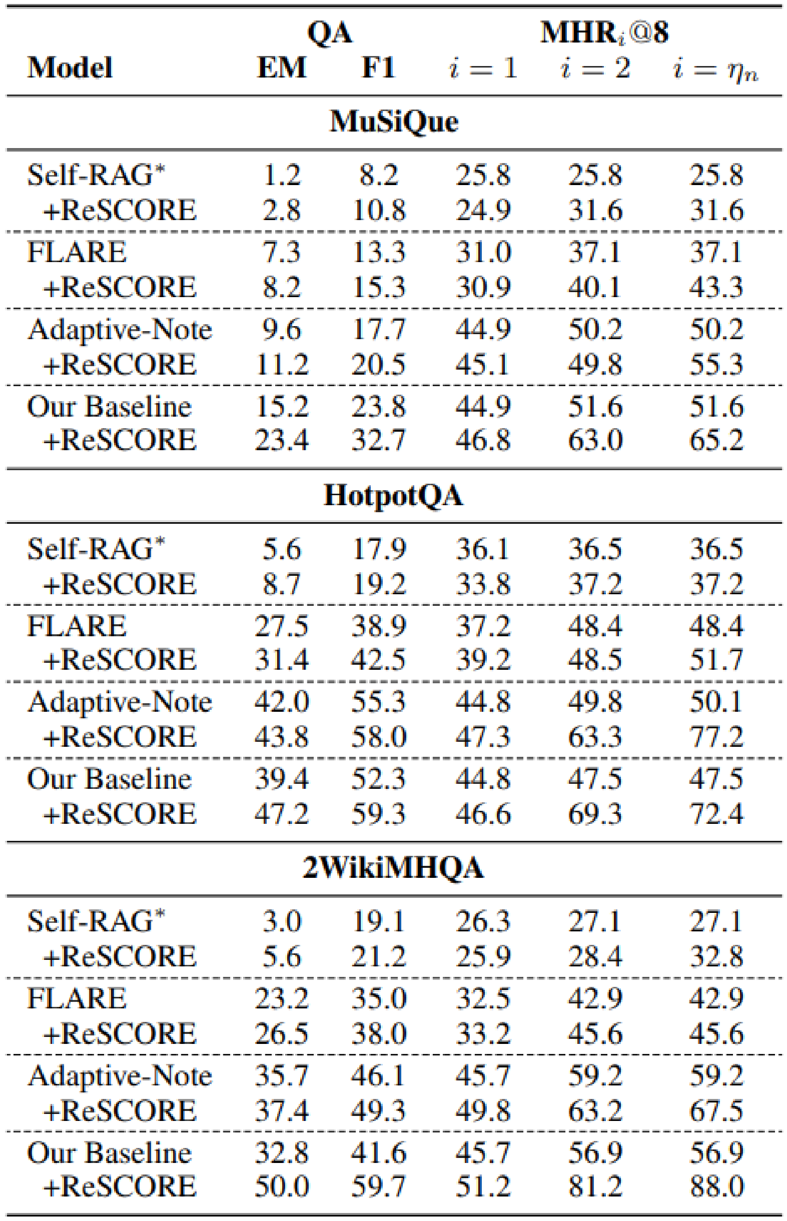
Continue until $\boldsymbol{a}^{(\eta)} \neq \text{“unknown”}$.

$d_1^{(1)}$ $d_2^{(1)}$ $d_3^{(1)}$ ⋯ $d_M^{(1)}$
$d_1^{(1)}$ $d_2^{(1)}$ $d_3^{(1)}$ ⋯ $d_M^{(1)}$
$d_1^{(2)}$ $d_2^{(2)}$ $d_3^{(2)}$ ⋯ $d_M^{(2)}$
$d_1^{(2)}$ $d_2^{(2)}$ $d_3^{(2)}$ ⋯ $d_M^{(2)}$

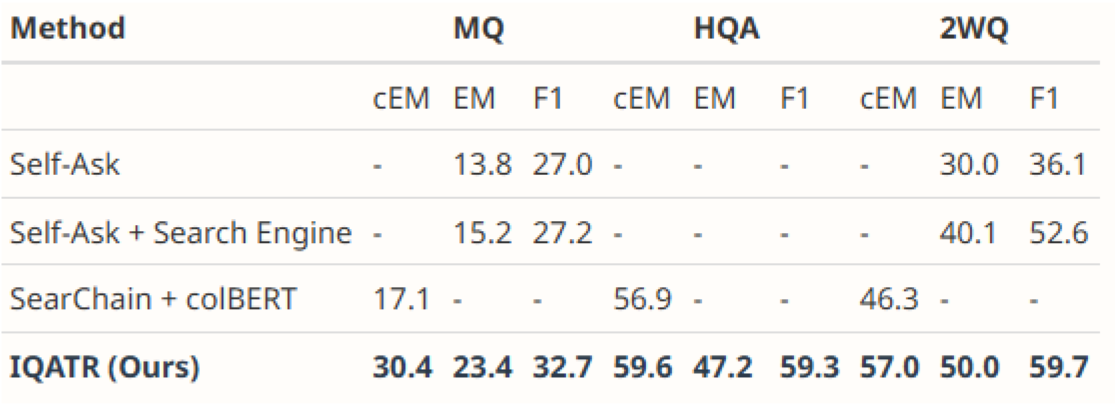
Comparison to SOTA MHQA Baselines



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**

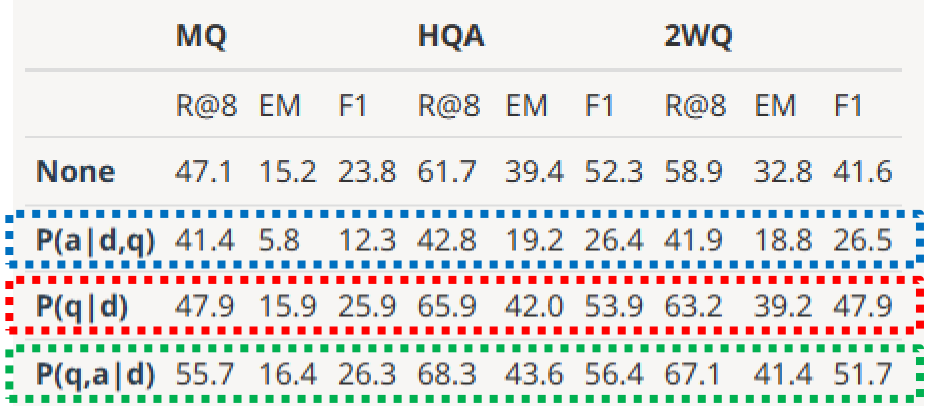


Model	QA EM	QA F1	MHR$_i$@8 $i=1$	MHR$_i$@8 $i=2$	MHR$_i$@8 $i=\eta_n$
MuSiQue					
Self-RAG*	1.2	8.2	25.8	25.8	25.8
+ReSCORE	2.8	10.8	24.9	31.6	31.6
FLARE	7.3	13.3	31.0	37.1	37.1
+ReSCORE	8.2	15.3	30.9	40.1	43.3
Adaptive-Note	9.6	17.7	44.9	50.2	50.2
+ReSCORE	11.2	20.5	45.1	49.8	55.3
Our Baseline	15.2	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



Method	MQ			HQA			2WQ		
	cEM	EM	F1	cEM	EM	F1	cEM	EM	F1
Self-Ask	-	13.8	27.0	-	-	-	-	30.0	36.1
Self-Ask + Search Engine	-	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**

Pseudo-GT Supervision Ablation



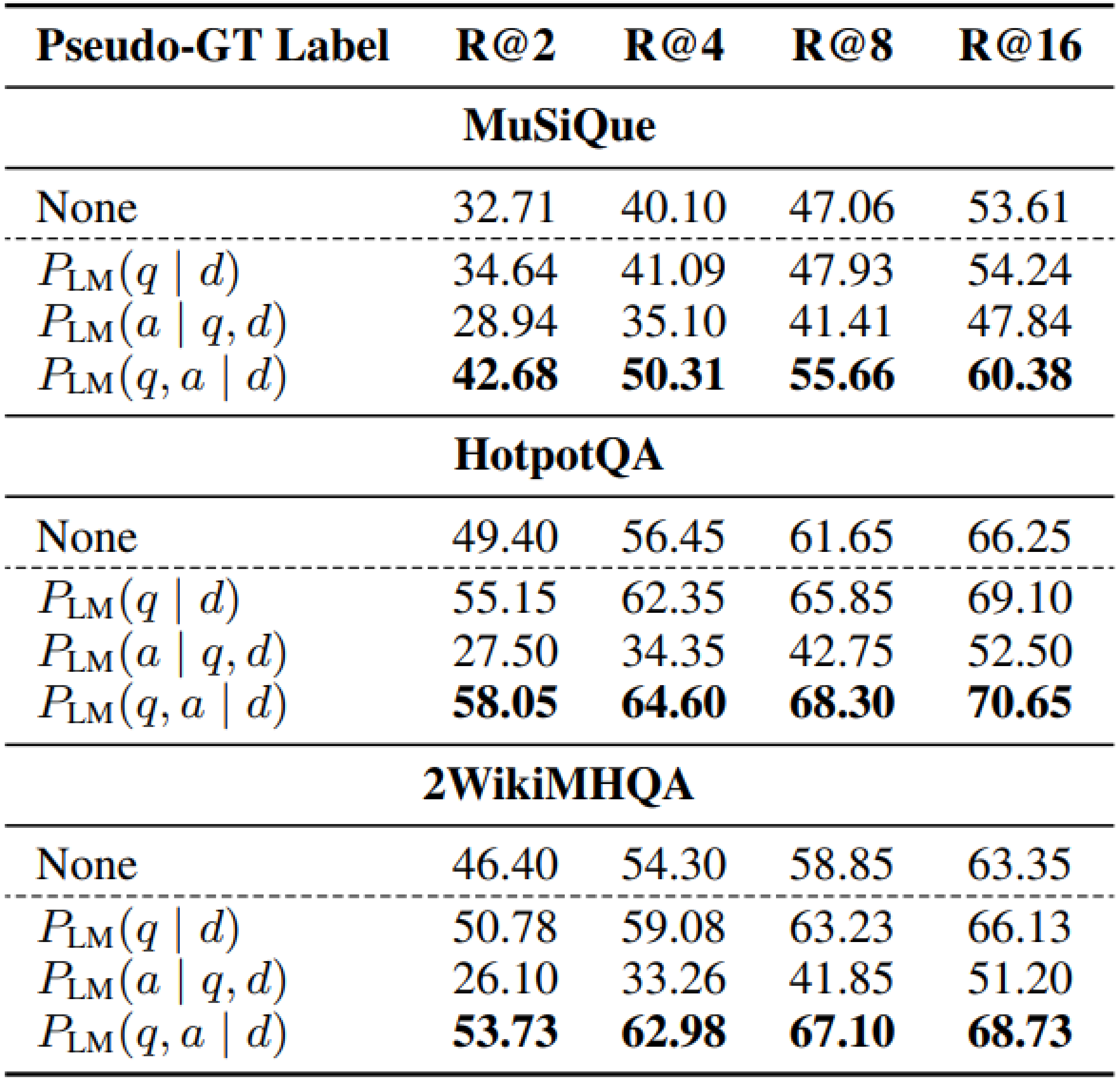
	MQ			HQA			2WQ		
	R@8	EM	F1	R@8	EM	F1	R@8	EM	F1
None	47.1	15.2	23.8	61.7	39.4	52.3	58.9	32.8	41.6
P(a|d,q)	41.4	5.8	12.3	42.8	19.2	26.4	41.9	18.8	26.5
P(q|d)	47.9	15.9	25.9	65.9	42.0	53.9	63.2	39.2	47.9
P(q,a|d)	55.7	16.4	26.3	68.3	43.6	56.4	67.1	41.4	51.7

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

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

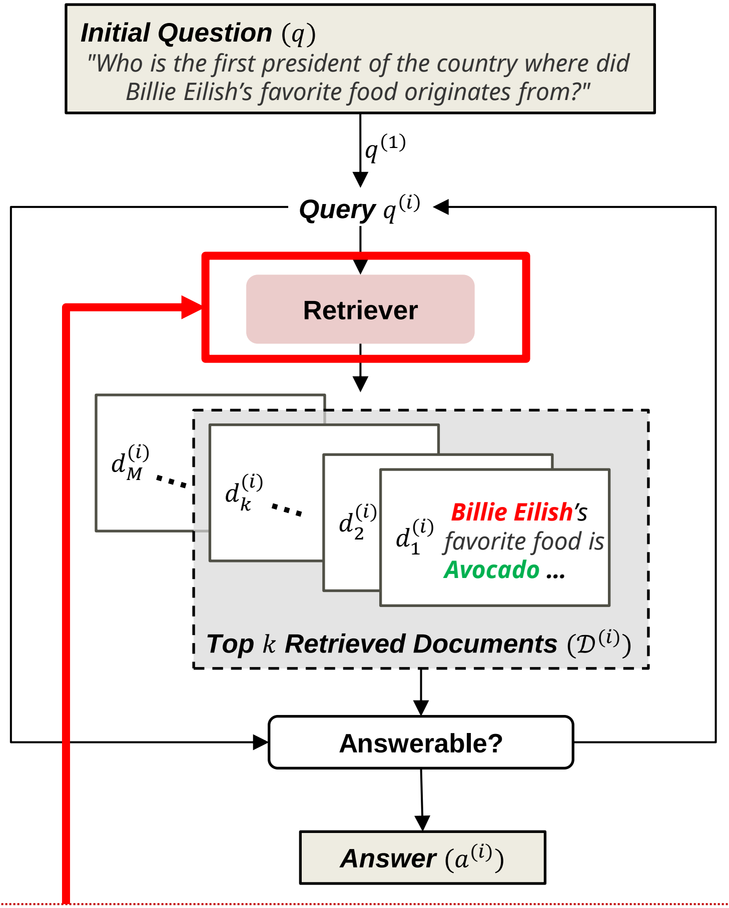
$$P_{Retriever}(D|Q) \propto \boxed{P_{LLM}(A,Q|D)}$$

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



Pseudo-GT Label	**R@2**	**R@4**	**R@8**	**R@16**
MuSiQue				
None	32.71	40.10	47.06	53.61
$P_{\text{LM}}(q \mid d)$	34.64	41.09	47.93	54.24
$P_{\text{LM}}(a \mid q, d)$	28.94	35.10	41.41	47.84
$P_{\text{LM}}(q, a \mid d)$	**42.68**	**50.31**	**55.66**	**60.38**
HotpotQA				
None	49.40	56.45	61.65	66.25
$P_{\text{LM}}(q \mid d)$	55.15	62.35	65.85	69.10
$P_{\text{LM}}(a \mid q, d)$	27.50	34.35	42.75	52.50
$P_{\text{LM}}(q, a \mid d)$	**58.05**	**64.60**	**68.30**	**70.65**
2WikiMHQA				
None	46.40	54.30	58.85	63.35
$P_{\text{LM}}(q \mid d)$	50.78	59.08	63.23	66.13
$P_{\text{LM}}(a \mid q, d)$	26.10	33.26	41.85	51.20
$P_{\text{LM}}(q, a \mid d)$	**53.73**	**62.98**	**67.10**	**68.73**

Comparison with GT

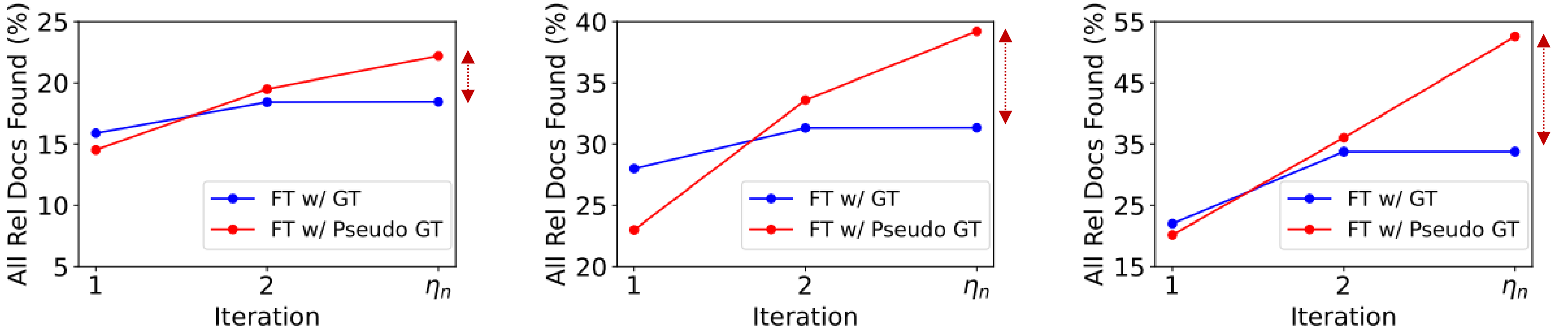


Initial Question (q)
"Who is the first president of the country where did Billie Eilish's favorite food originates from?"
$q^{(1)}$
Query $q^{(i)}$
Retriever
$d_M^{(i)}$
$d_k^{(i)}$
$d_2^{(i)}$
$d_1^{(i)}$
Billie Eilish's favorite food is Avocado ...
Top k Retrieved Documents $(\mathcal{D}^{(i)})$
Answerable?
Answer $(a^{(i)})$

Replaced the Retriever with GT-trained

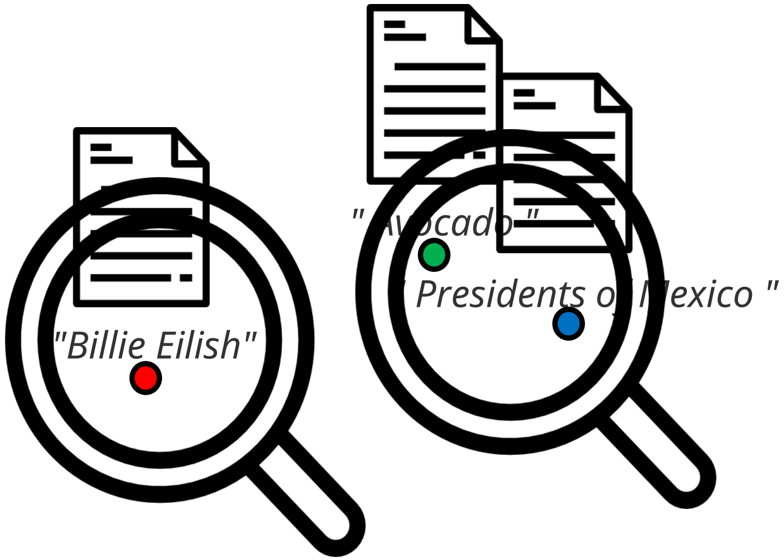
Label	QA EM	QA F1	MHR$_i$@8 $i=1$	MHR$_i$@8 $i=2$	MHR$_i$@8 $i=\eta_n$
MuSiQue					
None	15.2	23.8	44.9	51.6	51.6
GT	15.8	24.9	46.7	54.8	54.8
Pseudo-GT	23.4	32.7	46.8	63.0	65.2
HotpotQA					
None	39.4	52.3	44.8	47.5	47.5
GT	39.2	45.8	48.7	52.7	52.7
Pseudo-GT	47.2	59.3	46.6	69.3	72.4
2WikiMHQA					
None	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

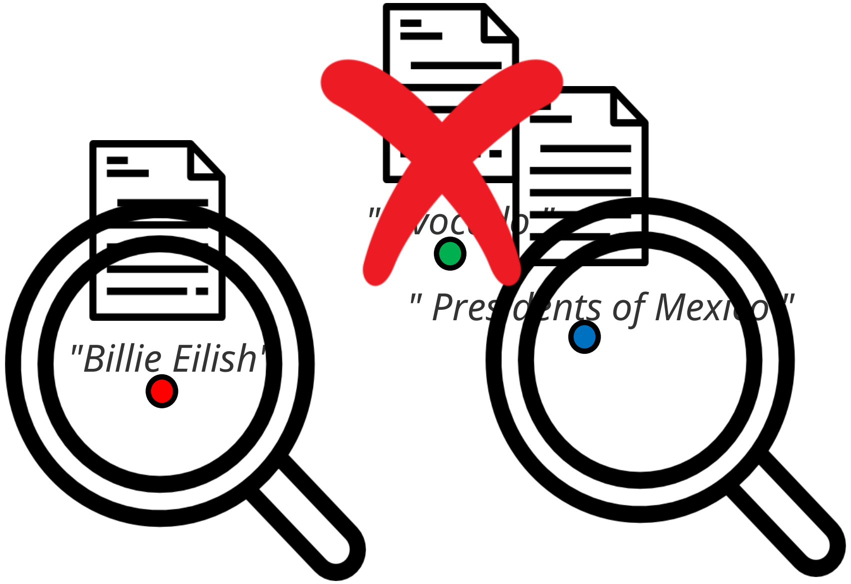


(a) MuSiQue Dataset (b) HotpotQA Dataset (c) 2WikiMHQA Dataset

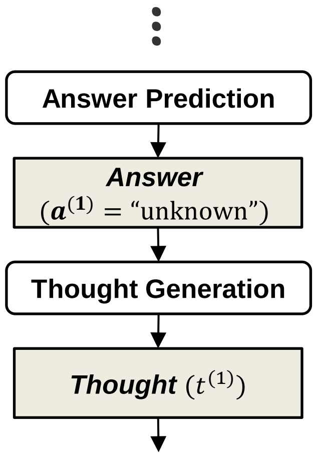
All Rel Docs Found



All Rel Docs Not Found



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

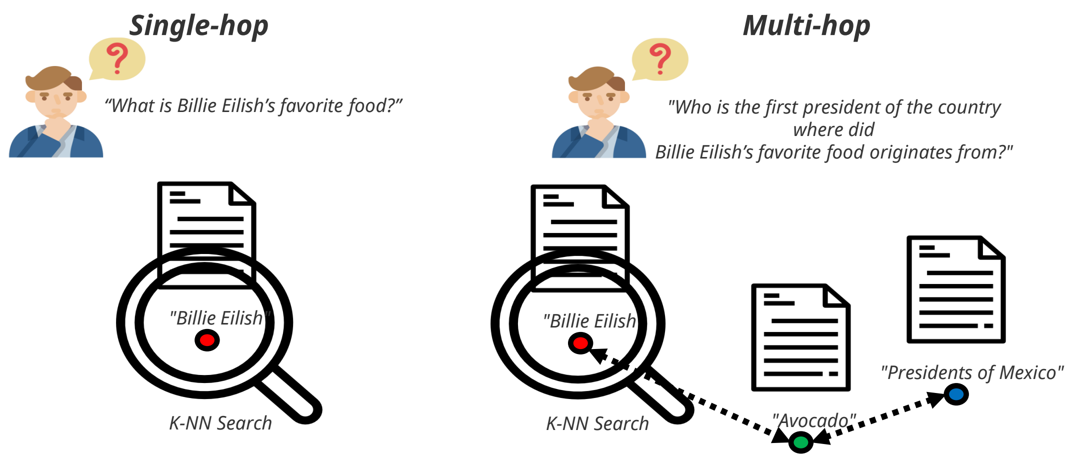
LLM-rewrite *"Who is the first president of the country where did **Avocado** originates from?"*

OR

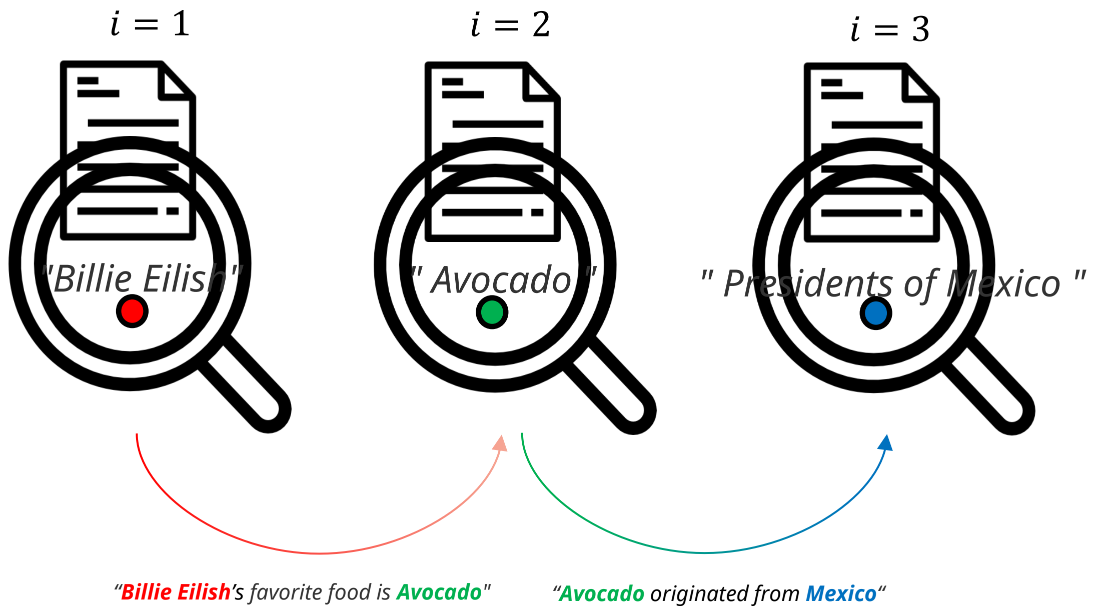
Thought-concat *"Who is the first president of the country where did Billie Eilish's favorite food originates from? **Billie Eilish**'s favorite food is **Avocado.**"*

Reformulation Method	**QA** EM	F1	**MHR$_i$@8** $i=1$	$i=2$	$i=\eta_n$
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

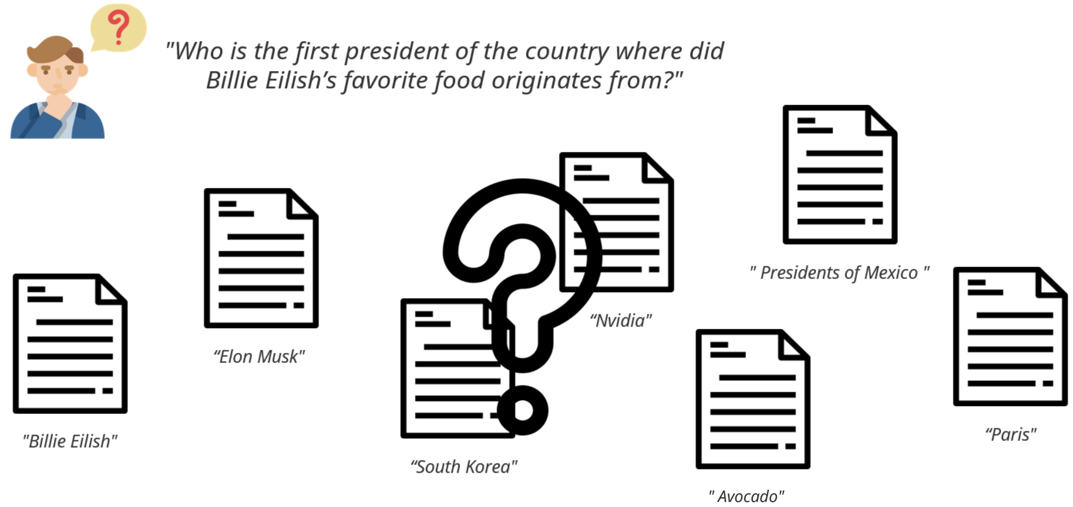
Summary



Single-hop
"What is Billie Eilish's favorite food?"
"Billie Eilish"
K-NN Search
Multi-hop
"Who is the first president of the country where did Billie Eilish's favorite food originates from?"
"Billie Eilish"
K-NN Search
"Avocado"
"Presidents of Mexico"



$i = 1$
$i = 2$
$i = 3$
"Billie Eilish"
" Avocado "
" Presidents of Mexico "
"Billie Eilish's favorite food is Avocado"
"Avocado originated from Mexico"



"Who is the first president of the country where did Billie Eilish's favorite food originates from?"
"Billie Eilish"
"Elon Musk"
"South Korea"
"Nvidia"
" Presidents of Mexico "
" Avocado"
"Paris"

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E.O.D.