

Appendix

A The Formal Definition and Derivation of EFO-1 Query Family

A.1 First Order Queries, A Self-Contained Guide

The First-Order (FO) query is a very expressive family of logical queries given by the following definitions.

The first-order logic handles the set of variables $Vars = \{x_1, \dots, x_n\}$ and set of functions $\{f_1, \dots, f_m\}$. We say f is a function of arity $k \geq 0$ if f has k inputs. Functions of arity 0 are called constants. Then we give the formal definition of terms.

Definition 1 (*Terms*). *The set of **terms** is defined inductively as follows:*

- $Vars \subset Terms$.
- If $t_1, \dots, t_k \in Terms$ and f is a k -ary function, then $f(t_1, \dots, t_k) \in Terms$.
- Nothing else in $Terms$.

In first-order logic we also have the predicates $\{P_1, \dots, P_l\}$. The predicate P is of arity k when it takes k terms as the input. Each predicate indicates whether the specific type of relation exists amongst its inputs by returning True or False. We note that a predicate of arity 0 is a proposition of the propositional logic. Then we give the formal definition of the first-order formula.

Definition 2 (*First-Order Formula*). *The set of **Formulas** can be defined inductively as follows:*

- If $t_1, \dots, t_k \in Terms$ and P is a k -ary predicate, then $P(t_1, \dots, t_k) \in Formulas$. (*Atomic formulas*).
- If $\phi \in Formulas$ and $\psi \in Formulas$, then
 - $\neg\phi \in Formulas$,
 - $\phi \wedge \psi \in Formulas$,
 - $\phi \vee \psi \in Formulas$,

where \wedge, \vee , and \neg are connectives. We note that in some definition, one may consider the logical implication connective \implies . However, our definition is complete since implication can be represented by \wedge, \vee , and \neg .

- If $\phi \in Formulas$ and $x \in Vars$, then
 - $\exists x.\phi \in Formulas$,
 - $\forall x.\phi \in Formulas$,

where \forall and \exists are the universal and the existential quantifiers, respectively.

A first order formula can be converted to various normal forms. The key idea of normal form is that the derived formula is logically equivalent to the original formula. In formally, the prenex normal form is to move all the quantifiers before in the front. Here we give the formal definition of the prenex normal form.

Definition 3 (*Prenex Normal Form*). *The prenex normal form of a formula is derived by executing the following six conversions until there is nothing to do.*

- Convert $\neg(\forall x.\phi)$ to $\exists x.(\neg\phi)$;
- Convert $\neg(\exists x.\phi)$ to $\forall x.(\neg\phi)$;
- Convert $(\forall x.\phi) \wedge \psi$ to $\forall x.(\phi \wedge \psi)$;

- *Convert* $(\forall x.\phi) \vee \psi$ to $\forall x.(\phi \vee \psi)$;
- *Convert* $(\exists x.\phi) \wedge \psi$ to $\exists x.(\phi \wedge \psi)$;
- *Convert* $(\exists x.\phi) \vee \psi$ to $\exists x.(\phi \vee \psi)$;

where $\phi, \psi \in \text{Formula}$.

Then we can give rise to the formal definition of the first-order query over the knowledge graph by considering the following first-order formula in the prenex normal form [17]:

$$F = \square y_1, \dots, \square y_m. f(x_1, \dots, x_n, y_1, \dots, y_m; P, O), \quad (1)$$

where \square is either the existential quantifier \exists or the universal quantifier \forall , f is the first-order formula with logical connectives (\wedge, \vee, \neg) , predicates $p \in P$, and constant object $o \in O$. $\{x_1, \dots, x_n\}$ are $n > 0$ free logical variables and $\{y_1, \dots, y_m\}$ are m quantified logical variables. In the knowledge graph, the predicate $p \in P$ is related to the specific relation r . $p(a, b)$ is True if and only if the entity a, b has the relation r .

The answer set \mathcal{A}_F of F contains n -tuples of objects $A = (a_1, \dots, a_n) \in \mathcal{A}_F$, such that, any instantiation of F by considering the assignment of free variables $x_i = a_i, 1 \leq i \leq n$ is true if and only if $(a_1, \dots, a_n) \in \mathcal{A}_F$.

A.2 EFO-1 Queries on KG

We consider a knowledge graph $\mathcal{G} = (\mathcal{E}, \mathcal{R})$, where \mathcal{E} is the set of entities and \mathcal{R} is the set of relation triples. Then we formally list the conditions that narrow FO queries down to Existential First Order Query with the single free variable (EFO-1 queries). Our conditions follow what have been considered in [15, 13, 12, 10],⁸ including:

- (1) only existential quantifiers $\square = \exists$,
- (2) predicates induced by relations: $p_{\text{rel}}(a_{\text{head}}, a_{\text{tail}}) = \text{True} \iff (\text{head}, \text{rel}, \text{tail}) \in \mathcal{R}$, and
- (3) single free logical variable in each query.
- (4) Exists a feasible topological ordering determined by predicate is $O < y_1 < \dots < y_m < x$, ($p(a, b) \in F$ gives a partial ordering of $a < b$), and we require that for $\forall y_i, i = 1 \dots m$, at least one of the followings is true:
 - $\exists p \in P, \exists t, 1 \leq t < i$, s.t. $p(y_t, y_i) \in F$
 - $\exists p \in P, o \in O$, s.t. $p(o, y_i) \in F$

Similarly, at least one of the following must be true:

- $\exists p \in P, \exists j, i < j \leq m$, s.t. $p(y_i, y_j) \in F$
- $\exists p \in P$, s.t. $p(y_i, x) \in F$

Based on (1), one can conduct Skolemization [17] by replacing all existentially quantified logical variables by corresponding Skolem functions. The intuition of Skolemization is to replacement of $\exists y$ by a concrete choice function computing y from all the arguments y depends on. The chosen function is also known as the Skolem function. Specifically, in the context of knowledge graph a Skolem function is induced from the predicate p by producing all entities that satisfy p given the known entity. In this paper, we also use the term “projection” to indicate the Skolem function following [16, 15].

By (2), all Skolem functions are equivalent to the forward and backward relations in \mathcal{G} . According to (3), there will be only one target node. Then by (4), guaranteed by the topological ordering and following requirements, we will obtain a tree of operators (OpsTree), whose root represents the target variable and leaves are the known entities, i.e., anchor nodes. An example of EFO-1 query is shown in Figure 1.

Though some work [15] claimed to consider the “first-order query” and represent them in the OpsTree, they actually considers the EFO-1 queries that formally derived in this paper. Our formal derivation of EFO-1 queries from the first-order queries shows that there are still gaps towards the truly first order queries. Thus, we still have a long way to achieve the logical completeness.

⁸This family is also called by Skolem set logic in [13].

B The LISP-like Grammar for EFO-1 Query Types

Here we present the LISP-like grammar for the EFO-1 query types. The string generated by our grammar is called an EFO-1 formula. Each EFO-1 formula is a set of nested arguments segmented by parentheses. The first argument indicates the specific operator and the other arguments (if any) are the operands of the specific operator. Our grammar is context free and the preliminary version considers the [e,p,i,u,n] operators.

Grammar 1: EFO-1

```
Formula      := Intersection|Union|Projection|Negation
Intersection := (i,Formula,Formula)
Union        := (u,Formula,Formula)
Negation     := (n,Formula)
Projection   := (p,Formula|Entity)
Entity       := (e)
```

where | is the pipe symbol to indicate multiple available replacement.

In our implementation, we follow the assumption of *bounded negation*, where the Negation only appears in one of the operands of intersection. Then, the grammar is modified into

Grammar 2: EFO-1 with the bounded negation

```
Formula      := Intersection|Union|Projection
Intersection := (i,Formula,Formula|Negation)
Union        := (u,Formula,Formula)
Negation     := (n,Formula)
Projection   := (p,Formula|Entity)
Entity       := (e)
```

Moreover, the LISP-like grammar is flexible enough and can be extended by other operators. For example, the following grammar supports multiIUD and bounded negation.

Grammar 3: Extended EFO-1 with the bounded negation

```
Formula      := Intersection|Union|Projection|Difference
               |Multi-Intersection|Multi-Union|Multi-Difference

Difference    := (d,Formula,Formula)
Intersection  := (i,Formula,Formula)
Union        := (u,Formula,Formula)
Negation     := (n,Formula)
Projection   := (p,Formula|Entity)
Entity       := (e)

Multi-Intersection := (I,Multi-I-Operands)
Multi-Union       := (U,Multi-U-Operands)
Multi-Difference  := (D,Multi-D-Operands)
Multi-I-Operands  := (Formula|Negation),Multi-I-Operands
                  | (Formula|Negation),Formula
Multi-U-Operands  := Formula,Multi-U-Operands
                  | Formula,Formula
Multi-D-Operands  := Formula,Multi-D-Operands
                  | Formula,Formula
```

Based on the formal description above, we are able to discuss the combinatorial space of EFO-1 queries as well as various normal forms with different choice of operators.

Table 11: The operators that are considered in the grammar of EFO-1 formula.

Operator	Input	Output	Explanation
e	Entity id e_i	Set $S = \{e_i\}$	Create a singleton set from one entity
p	Entity set S and projection function $Proj$	Set $T = \{Proj(e) : e \in S\}$	Project a set of entities to another set of entities
i	Entity sets S_1 and S_2	Set $T = S_1 \cap S_2$	Take the intersection of two sets
u	Entity sets S_1 and S_2	Set $T = S_1 \cup S_2$	Take the union of two sets
n	Entity set S	Set $T = \bar{S}$	Take the complement of one set against all entities
d	Entity sets S_1 and S_2	Set $T = S_1 - S_2$	Take the set difference of S_1 and S_2
I	Entity sets S_1, S_2, \dots, S_n	Set $T = \cap_{k=1}^n S_k$	Take the intersection of n sets. $n > 2$
U	Entity sets S_1, S_2, \dots, S_n	Set $T = \cup_{k=1}^n S_k$	Take the union of n sets. $n > 2$
D	Entity sets S_1, S_2, \dots, S_n	Set $T = S_1 - S_2 - \dots - S_n$	Take the difference of multiple sets

B.1 Justification of Operators

Here we present the precise definitions of the operators that are considered in our grammars in the Table 11. The operators can be directly used in the sampling process in Section 3.3. The operator **e** is also known as the anchor node in this paper.

B.2 Generate EFO-1 Formulas

We employ the depth-first search based algorithm to iterate through the Grammar 2. The generated formula can be considered as a binary tree. The generation process terminates when the number of Projection **p** and Negation **n** reaches the threshold. The termination threshold is not consistent to the grouping criteria in the Table 2 which only considers the Projection operator. For the generation, we consider the negation additionally in order to avoid the endless generation of negations.

C Transformation to Disjunctive Normal Form

Transforming the EFO-1 queries to DNF is more complicated than EPFO queries considered in [16], even with the straight forward $[\mathbf{e}, \mathbf{p}, \mathbf{i}, \mathbf{u}, \mathbf{n}]$ operators. Notably, the order of some operators must not be changed for EFO-1 queries, such as $\mathbf{i} \ \& \ \mathbf{p}^9$ or $\mathbf{n} \ \& \ \mathbf{p}^{10}$. Here we list the procedures to transform general EFO-1 queries with $[\mathbf{e}, \mathbf{p}, \mathbf{i}, \mathbf{u}, \mathbf{n}]$ to a DNF.

1. **De Morgan's Law** If the operand of a negation operator is intersection or union, switch the positions of negation and intersection/union with De Morgan's law.
2. **Negation cancellation** If the operand of a negation operator is another negation, remove those two negation operators.
3. **p-u switch** If the operand of a projection operator is an union, switch the position of union and projection. The projection operator should be duplicated while switching.
4. **i-u switch** If one of the operands of an intersection operator is an union, We apply $A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$ to switch the union operator and the intersection operator.

⁹ $f(A \cap B) \subset f(A) \cap f(B)$, where f is the projection function and A and B are sets.

¹⁰ $f(\bar{A}) \subset \bar{f(A)}$ where f is the projection function, $\bar{\cdot}$ is the negation operator and A is a set.

The first two procedures make the negation operator lower than union and intersection operator and the last two procedures make the union higher than the intersection operator. We follow those 4 procedures until no more changes happens. In this way, we get a DNF of the original formula. Since some operators cannot be switched, the DNF of EFO-1 query types may not ensure all intersection operators right below the unions. But for the DNF of first order logical formulas, all conjunctions are right below the disjunctions, see Example 1. We note that this type of queries has not been discussed so far in the current literature.

Example 1. *Considering the DNF of EFO-1 queries*

$$f_1(f_2(A) \cap f_3(B)) \cup f_4(C) \quad (2)$$

where f_i is the projection functions and ABC are sets. The query type can be presented by $(u, (p, (i, (p, (e)), (p, (e)))), (p, (e)))$. We note that This EFO-1 query can be re-written as the first order formula with the single free variable α and the existential quantified variable β .

$$?\alpha\exists\beta[p_1(\beta, \alpha) \wedge p_2(A, \beta) \wedge p_3(B, \beta)] \vee p_4(C, \alpha), \quad (3)$$

where p_i are the corresponding predicates from projection function f_i , $i = 1, \dots, 5$. Though the EFO-1 query has intersection as the input of f_1 , we still call this query a DNF.

We note that the DNF transformation will exponentially increase the complexity of the queries because of the step 4 [15].

D Example of Different Normal Forms

An example is also presented to show the difference of different normal forms in the Table 12. We note that the example contains 5 anchor nodes to reveal all the features though in EFO-1-QA dataset, sampled data only contains no more than 3 anchor nodes.

F Grounding Query Types with Meaningful Negation

When grounding the query types, we can barely require the query to be valid: for example, a query like 'Find one that has won the Oscar but not the Turing award.' is valid while the 'but not the Turing award' part is meaningless since there's actually no one who wins both the Oscar and the Turing award. Therefore, a better alternative should be 'Find one who wins the Oscar but not the Golden Globe.' in consideration of this reason. With the *bounded negation* assumption, and for the sake of simplicity, we may only consider the case of (i, (subquery1), (n, subquery2)) to illustrate our sampling method: we need to finish the sampling in the subquery1 first, then we randomly select an entity in the answer set of subquery1 and require the subquery2 to exclude it if possible.

This sampling method creates more realistic grounded queries and those grounded queries are apparently harder in our experiments since those negation queries must be understood by the model to get the correct answer set.

G Dataset Format

We organize our dataset conceptually into two tables. The first table stores the information about query types, the columns of which include different normal forms of the formula in LISP-language, the formula ID, and other statistics. The second table is to store the information of the grounded queries with columns for easy and hard answer set, JSON string for different normal forms and the formula ID that indicating the query type. Those two tables can be joined by the formula ID. In our practice, we split the second table by the formula ID and store each sub-table in a file named by the formula ID. The data sample is also provided with the supplementary materials.

H The Choice of Normal Forms

Here we explain the reasons why we choose those normal forms and in Table 3. The key difference is the way we model the union operator: DM form replace union with intersection and negation while DNF form requires union operator only appear at the root of the OpsTree, which create two basic types of forms. The original form is also kept for the purpose of comparison. Then we face the choice of IU/iu and the choice of d/D/n, which can make six combinations in total.

In DNF forms, the combination [e, p, i, u, D] are filtered out for it lacks practical meaning. More importantly, it is either the same as [e, p, I, U, D] or the same as [e, p, i, u, d] when the number of anchor node is restricted to be no more than three.

In DM forms, the difference is not allowed as it violates the hypothesis of *bounded negation*. The choice of I/i offers us two variants: DM and DM+I.

In original forms, we only offer the choice of d/n to avoid complex transformation and keep the queries as 'original' as possible.

In total: five DNF forms, two DM forms, and two original forms makes nine forms we listed in Table 3.

I Implementation Details of NewLook

Some details of NewLook is not fully covered in the original paper [12] while the released version¹¹ is not suitable to justify the combinatorial generalizability. Here we list several details of our implementation of NewLook.

Group Division In the released version, the connectivity tensor τ is generated by entire graph. Accessing the entire graph contradicts the Open Word Assumption. In our reproduction, we

¹¹<https://github.com/lihuiliu11h/NewLook>

Table 13: Review of existing CQA models, where * means the DNF is required and † means the bounded negation must be assumed. For EmQL, the difference operator is claimed to be available, however, it does not indicate how to train this operator as intersection and union.

CQA Model	Support Operators									Support EPFO	Support EFO-1
	e	p	i	I	u	U	n	d	D		
GQE [10]	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓*	✗
Q2B [16]	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓*	✗
EmQL [19]	✓	✓	✓	✗	✓	✗	✗	□	✗	✓	□†
BiQE [11]	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓*	✗
HypE [6]	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓*	✗
BetaE [15]	✓	✓	✓	✓	✗	✗	✓	✗	✗	✓*	✓*
CQD [1]	✓	✓	✓	✗	✓	✗	✗	✗	✗	✓	✗
LogicE [13]	✓	✓	✓	✓	✗	✗	✓	✗	✗	✓*	✓*
NewLook [12]	✓	✓	✓	✓	✗	✗	✗	✓	✓	✓*	✓*†

Table 14: Number of different query types of [e, p, i, u, n] system.

	Original	DM	DM+I	DNF	DNF+IU
Original	0	57	132	15	90
DM	57	0	75	148	256
DM+I	132	75	0	223	181
DNF	15	148	223	0	84
DNF+IU	90	256	181	84	0

only use the training edges to avoid leaking the information of unseen edges and the number of group is set to 200.

Intersection The origin mathematical formulas have been proven to be impractical since z_i will be infinity when $x_{u_i} = x_{u_t}$, and we fix this problem by adding a small value $\epsilon = 0.01$ in the denominator.

Difference The update method of x has not been shown, so we implement this by intuition: $(x_{u_t})_j = 1 \iff (x_{u_1})_j = 1, (x_{u_i})_j = 0, \forall i = 2, \dots, k$.

Loss function The value of hyper-parameter λ is not provided, so we set it to 0.02.

MLP The hyperparameter of MLP is not given, so we let all MLP be a two-layer network with hidden dimension as 1,600 and ReLU activation.

J Short Review of Existing CQA Models

We compared the details of different CQA models in Table 13. We can see that most of the CQA models support the EPFO queries but only three CQA models support EFO-1 query.

K The Normal Forms in [e, p, i, u, n] System

To justify the impact of normal forms, we select the query types that has different EFO-1 formula representation when two normal forms are fixed. The number of the query types that are picked given two normal forms are shown in the Table 14.

L Additional Experimental Results

Here we list detailed experiment results and add some discussions on them. Due to the large number of the query types, we group and report the queries by the maximum projection length and number of anchor nodes in Table 7, ??, and ??. These three tables are the results on FB15k-237, FB15k, NELL, correspondingly .

Our analysis mainly focus on FB15k-237 shown in Table7, but FB15k and NELL also shows similar phenomena.

Impact of the Max Projection Length. It shows a clear descending trend of performance as the query depth increases in all models. NewLook [12] call this phenomenon “cascading error” as error propagates in each projection operation. In fact, projection plays a pivotal role in all CQA models. For example, CQD [1] only trains queries of type $(p, (e))$ and uses logical t-norms to represent union and intersection. Beta [15] doubles training steps for query types only containing projection. Moreover, the operator of anchor entity is always projection: as queries like $(u, (e), (e))$ or $(i, (e), (e))$ are not allowed, which makes projection be indispensable. For all reasons above, we believe the modeling of projection operation is the fundamental factor to final results.

Impact of the Number of Anchor Nodes. A query type with more anchor nodes is not necessarily harder. For example, in depth 2 and 3, queries with 3 anchor nodes have higher scores than those with 2 anchor nodes. This is partially because of the feature of the intersection: we find that $(I, (p, (e)), (p, (e)), (p, (e)))$ has much higher score than $(I, (p, (e)), (p, (e)))$, and all of the three models also report similar results in their own experiments. On the contrary, $(U, (p, (e)), (p, (e)), (p, (e)))$ is harder than $(U, (p, (e)), (p, (e)))$, and other queries with U show similar results. This different behaviour is reasonable, as intersection shrinks answer size while union enlarges it. The averaged answer size of each group is listed in Table17.

The Choice of Operators. The NewLook model [12] uses difference to replace negation in its query representation, which leads to the fact that DNF+IUd and DNF+IUD are the only two forms that NewLook can fully support. In Table 7, since all possible query types with one anchor node are $1p, 2p, 3p$, the leading performance of NewLook on those queries illustrates that NewLook model projection operation better. However, in more complex query types, LogicE outperforms NewLook, indicating that difference operator D/d might not be a better alternative to negation operator n. Additionally, the multi operator D performs slightly better than the binary d.

In additional, we also report the detailed performances of EPFO and Negation queries on each knowledge graph as categorized by Beta [15], see Table 16-21. We can see from the results that our benchmark is generally harder and fairer than existing datasets [15].

Table 15: Benchmark results(%) on FB15k. The mark \dagger indicates the query groups that previous datasets have not fully covered. The boldface indicates the best scores. The best scores of the same model are underlined.

CQA Model	Normal Form	Metric	Query type groups (# anchor nodes, max length of Projection chains)									AVG.
			(1,1)	(1,2)	(1,3)	(2,1)	(2,2) \dagger	(2,3) \dagger	(3,1) \dagger	(3,2) \dagger	(3,3) \dagger	
BetaE	DM	MRR	51.86	25.48	23.55	30.24	19.14	17.46	26.69	17.73	15.54	17.18
		HIT@1	39.09	17.06	15.63	19.75	11.44	10.76	16.66	10.67	9.43	10.46
		HIT@3	59.20	27.40	25.60	35.09	21.01	18.79	31.13	19.45	16.74	18.76
		HIT@10	76.20	42.36	38.82	50.50	34.32	30.53	46.44	31.65	27.42	30.30
		RA-Oracle	47.46	33.05	32.94	33.02	24.65	24.36	29.03	21.55	20.63	21.83
	DM +I	MRR	51.86	25.48	23.55	30.24	19.14	17.46	26.78	17.78	15.60	17.22
		HIT@1	39.09	17.06	15.63	19.75	11.44	10.76	16.77	10.71	9.48	10.51
		HIT@3	59.20	27.40	25.60	35.09	21.01	18.79	31.20	19.51	16.81	18.81
		HIT@10	76.20	42.36	38.82	50.50	34.32	30.53	46.51	31.70	27.48	30.35
		RA-Oracle	47.46	33.05	32.94	33.02	24.65	24.36	29.14	21.59	20.69	21.89
	DNF +IU	MRR	51.86	25.48	23.55	38.81	21.24	19.47	33.96	20.92	18.45	20.31
		HIT@1	39.09	17.06	15.63	25.37	12.50	11.78	20.88	12.25	10.87	12.05
		HIT@3	59.20	27.40	25.60	45.48	23.30	20.89	39.69	22.89	19.76	22.10
		HIT@10	76.20	42.36	38.82	65.55	38.67	34.65	60.68	38.33	33.44	36.74
		RA-Oracle	47.46	33.05	32.94	44.67	28.46	28.37	39.64	27.08	26.26	27.51
LogicE	DM	MRR	61.56	29.76	25.41	38.00	22.89	20.22	32.90	21.31	18.47	20.53
		HIT@1	49.63	20.51	17.24	25.16	14.05	12.80	20.48	12.92	11.39	12.68
		HIT@3	69.51	32.56	27.71	44.89	25.56	21.99	39.10	23.74	20.12	22.71
		HIT@10	82.40	47.94	41.17	62.15	40.27	34.76	56.90	37.89	32.39	35.93
		RA-Oracle	58.57	37.90	35.18	43.69	29.73	28.38	37.87	26.84	25.31	26.92
	DM +I	MRR	61.56	29.76	25.41	38.00	22.89	20.22	32.98	21.33	18.49	20.55
		HIT@1	49.63	20.51	17.24	25.16	14.05	12.80	20.56	12.95	11.40	12.70
		HIT@3	69.51	32.56	27.71	44.89	25.56	21.99	39.19	23.77	20.14	22.73
		HIT@10	82.40	47.94	41.17	62.15	40.27	34.76	56.98	37.91	32.41	35.96
		RA-Oracle	58.57	37.90	35.18	43.69	29.73	28.38	37.96	26.88	25.33	26.95
	DNF +IU	MRR	61.56	29.76	25.41	40.83	23.91	21.22	34.92	22.66	19.85	21.89
		HIT@1	49.63	20.51	17.24	26.88	14.40	13.15	21.16	13.34	11.86	13.14
		HIT@3	69.51	32.56	27.71	48.51	26.74	23.10	41.63	25.20	21.54	24.17
		HIT@10	82.40	47.94	41.17	67.44	42.82	37.19	62.16	41.37	35.75	39.33
		RA-Oracle	58.57	37.90	35.18	47.36	31.56	30.37	40.79	29.16	27.91	29.38
NewLook	DNF +IUd	MRR	58.82	30.93	26.12	40.49	22.07	20.69	30.15	19.22	18.48	19.80
		HIT@1	46.87	22.02	17.88	28.02	13.55	13.09	17.64	11.16	11.22	11.96
		HIT@3	66.32	33.76	28.59	46.29	24.24	22.37	35.06	20.97	19.92	21.58
		HIT@10	80.51	48.54	42.01	65.33	38.99	35.60	55.62	35.23	32.70	35.28
		RA-Oracle	55.31	39.14	36.06	45.99	29.05	29.39	35.25	24.82	25.88	26.57
	DNF +IUD	MRR	58.82	30.93	26.12	40.49	22.07	20.69	30.42	19.35	18.51	19.87
		HIT@1	46.87	22.02	17.88	28.02	13.55	13.09	17.73	11.21	11.23	<u>11.99</u>
		HIT@3	66.32	33.76	28.59	46.29	24.24	22.37	35.48	21.14	19.94	<u>21.66</u>
		HIT@10	80.51	48.54	42.01	65.33	38.99	35.60	56.27	35.56	32.76	<u>35.44</u>
		RA-Oracle	55.31	39.14	36.06	45.99	29.05	29.39	35.54	24.99	25.92	<u>26.66</u>

Table 16: Benchmark results(%) on NELL. The mark † indicates the query groups that previous datasets have not fully covered. The boldface indicates the best scores. The best scores of the same model are underlined.

CQA Model	Normal Form	Metric	Query type groups (# anchor nodes, max length of Projection chains)									AVG.
			(1,1)	(1,2)	(1,3)	(2,1)	(2,2) [†]	(2,3) [†]	(3,1) [†]	(3,2) [†]	(3,3) [†]	
BetaE	DM	MRR	28.75	10.01	9.96	13.06	8.95	8.85	8.94	8.71	8.85	8.93
		HIT@1	20.41	5.87	6.15	8.25	5.35	5.47	5.23	5.39	5.60	5.58
		HIT@3	31.79	10.53	10.28	14.29	9.38	9.22	9.47	9.11	9.31	9.38
		HIT@10	45.28	17.71	17.16	22.41	15.90	15.25	16.07	14.98	15.00	15.27
		RA-Oracle	24.59	14.63	15.42	14.27	12.71	12.87	10.98	11.63	12.16	12.08
	DM +I	MRR	28.75	10.01	9.96	13.06	8.95	8.85	8.97	8.73	8.86	8.94
		HIT@1	20.41	5.87	6.15	8.25	5.35	5.47	5.25	5.40	5.60	5.59
		HIT@3	31.79	10.53	10.28	14.29	9.38	9.22	9.53	9.12	9.31	9.39
		HIT@10	45.28	17.71	17.16	22.41	15.90	15.25	16.10	15.01	15.03	15.29
		RA-Oracle	24.59	14.63	15.42	14.27	12.71	12.87	11.00	11.65	12.16	12.09
	DNF +IU	MRR	28.75	10.01	9.96	14.84	10.06	10.02	10.55	10.27	10.64	<u>10.58</u>
		HIT@1	20.41	5.87	6.15	9.22	5.96	6.13	5.99	6.25	6.63	<u>6.52</u>
		HIT@3	31.79	10.53	10.28	16.21	10.51	10.46	11.27	10.76	11.19	<u>11.12</u>
		HIT@10	45.28	17.71	17.16	25.84	18.02	17.45	19.34	17.90	18.27	<u>18.32</u>
		RA-Oracle	24.59	14.63	15.42	17.47	14.69	14.89	13.78	14.39	15.30	<u>14.98</u>
LogicE	DM	MRR	35.23	13.53	13.75	16.16	11.40	11.35	11.06	10.75	11.05	11.13
		HIT@1	25.74	8.62	8.92	10.32	7.20	7.52	6.44	6.82	7.36	7.26
		HIT@3	40.27	14.28	14.73	17.85	12.16	12.02	11.97	11.45	11.79	11.89
		HIT@10	53.28	23.05	22.80	27.52	19.24	18.52	19.97	18.09	17.94	18.38
		RA-Oracle	30.69	19.62	20.32	18.94	16.33	16.16	14.41	14.77	15.23	15.25
	DM +I	MRR	35.23	13.53	13.75	16.16	11.40	11.35	11.07	10.75	11.06	11.14
		HIT@1	25.74	8.62	8.92	10.32	7.20	7.52	6.49	6.84	7.37	7.27
		HIT@3	40.27	14.28	14.73	17.85	12.16	12.02	11.95	11.44	11.80	11.89
		HIT@10	53.28	23.05	22.80	27.52	19.24	18.52	19.96	18.10	17.95	18.39
		RA-Oracle	30.69	19.62	20.32	18.94	16.33	16.16	14.40	14.77	15.23	15.26
	DNF +IU	MRR	35.23	13.53	13.75	18.19	12.94	13.00	12.40	12.48	13.22	13.07
		HIT@1	25.74	8.62	8.92	11.45	8.05	8.42	6.98	7.71	8.57	8.31
		HIT@3	40.27	14.28	14.73	20.13	13.90	13.86	13.41	13.33	14.16	14.01
		HIT@10	53.28	23.05	22.80	31.35	22.15	21.61	23.01	21.49	21.94	22.04
		RA-Oracle	30.69	19.62	20.32	22.08	18.84	18.87	16.62	17.55	18.75	18.39
NewLook	DNF +IUd	MRR	33.59	12.06	11.42	16.55	10.30	10.52	9.50	8.91	10.08	9.88
		HIT@1	24.78	7.12	6.79	10.59	6.22	6.47	5.33	5.28	6.25	6.04
		HIT@3	37.19	12.73	12.00	18.00	10.82	10.99	10.00	9.31	10.53	10.35
		HIT@10	51.89	21.72	20.31	28.47	17.98	18.12	17.63	15.70	17.24	17.10
		RA-Oracle	29.50	18.03	17.76	19.27	15.07	15.85	12.21	12.50	14.76	14.15
	DNF +IUD	MRR	33.59	12.06	11.42	16.55	10.30	10.52	9.53	8.94	10.09	9.90
		HIT@1	24.78	7.12	6.79	10.59	6.22	6.47	5.34	5.29	6.26	6.04
		HIT@3	37.19	12.73	12.00	18.00	10.82	10.99	10.05	9.34	10.54	<u>10.36</u>
		HIT@10	51.89	21.72	20.31	28.47	17.98	18.12	17.68	15.75	17.25	<u>17.13</u>
		RA-Oracle	29.50	18.03	17.76	19.27	15.07	15.85	12.24	12.53	14.76	<u>14.16</u>

Table 17: Average number of answers of queries.

Knowledge Graph	Query type groups (# anchor nodes, max length of Projection chains)								
	(1,1)	(1,2)	(1,3)	(2,1)	(2,2)	(2,3)	(3,1)	(3,2)	(3,3)
FB15k-237	3.22	17.56	23.44	12.37	18.49	22.61	13.16	17.60	21.22
FB15k	4.09	20.07	24.26	15.34	20.42	24.02	15.38	19.37	23.02
NELL	3.13	20.54	22.23	16.66	22.08	22.87	19.22	21.18	22.84

Table 18: Benchmark results(%) on EPFO queries of FB15k-237.

CQA Model	Normal Form	Metric	(# anchor nodes, max length of projection chains)									AVG.
			(1,1)	(1,2)	(1,3)	(2,1)	(2,2)	(2,3)	(3,1)	(3,2)	(3,3)	
BetaE	DM	MRR	18.79	9.72	9.64	15.51	10.00	8.78	15.05	11.09	9.33	9.98
		HIT@1	10.63	4.63	4.68	9.53	5.39	4.44	9.71	6.60	5.16	5.63
		HIT@3	20.37	9.61	9.44	16.97	10.35	8.88	16.52	11.67	9.58	10.35
		HIT@10	36.19	19.80	19.38	27.44	18.96	16.96	25.45	19.72	17.23	18.30
		RA-Oracle	14.38	14.40	16.99	16.00	13.47	13.66	15.11	12.99	12.57	12.93
	DM +I	MRR	18.79	9.72	9.64	15.51	10.00	8.78	15.19	11.12	9.37	10.02
		HIT@1	10.63	4.63	4.68	9.53	5.39	4.44	9.92	6.62	5.20	5.66
		HIT@3	20.37	9.61	9.44	16.97	10.35	8.88	16.58	11.72	9.64	10.40
		HIT@10	36.19	19.80	19.38	27.44	18.96	16.96	25.52	19.77	17.29	18.35
		RA-Oracle	14.38	14.40	16.99	16.00	13.47	13.66	15.32	13.03	12.63	12.98
	DNF +IU	MRR	18.79	9.72	9.64	17.97	11.35	9.77	19.11	13.41	11.05	11.81
		HIT@1	10.63	4.63	4.68	10.59	5.96	4.85	11.85	7.72	5.99	6.50
		HIT@3	20.37	9.61	9.44	19.43	11.59	9.82	20.86	14.01	11.29	12.17
		HIT@10	36.19	19.80	19.38	33.10	21.84	19.08	33.62	24.46	20.70	22.01
		RA-Oracle	14.38	14.40	16.99	20.17	15.98	15.81	21.34	16.90	15.79	16.23
LogicE	DM	MRR	20.71	10.70	10.18	19.49	12.16	10.35	19.07	13.50	11.16	12.00
		HIT@1	11.66	5.20	5.25	12.07	6.68	5.56	12.38	8.03	6.34	6.91
		HIT@3	23.02	10.66	9.96	21.36	12.62	10.55	20.65	14.32	11.55	12.53
		HIT@10	39.81	21.25	19.48	34.59	22.86	19.51	32.51	24.13	20.43	21.86
		RA-Oracle	15.64	15.27	17.28	21.13	16.49	15.82	20.77	16.62	15.37	15.94
	DM +I	MRR	20.71	10.70	10.18	19.49	12.16	10.35	19.13	13.52	11.17	12.02
		HIT@1	11.66	5.20	5.25	12.07	6.68	5.56	12.42	8.04	6.34	6.91
		HIT@3	23.02	10.66	9.96	21.36	12.62	10.55	20.81	14.34	11.58	12.56
		HIT@10	39.81	21.25	19.48	34.59	22.86	19.51	32.62	24.16	20.45	21.89
		RA-Oracle	15.64	15.27	17.28	21.13	16.49	15.82	20.79	16.66	15.39	15.95
	DNF +IU	MRR	20.71	10.70	10.18	19.79	12.59	10.68	20.21	14.50	11.95	12.78
		HIT@1	11.66	5.20	5.25	11.90	6.79	5.62	12.67	8.44	6.68	7.22
		HIT@3	23.02	10.66	9.96	21.56	13.03	10.86	21.97	15.31	12.34	13.31
		HIT@10	39.81	21.25	19.48	36.03	23.85	20.27	35.48	26.30	21.99	23.48
		RA-Oracle	15.64	15.27	17.28	21.81	17.31	16.55	22.04	18.08	16.64	17.16
NewLook	DNF +IUD	MRR	22.31	11.19	10.39	21.66	12.76	10.77	21.76	14.74	11.95	12.92
		HIT@1	13.55	5.62	5.18	13.74	7.09	5.85	14.24	8.88	6.84	7.52
		HIT@3	24.62	11.40	10.38	23.85	13.22	10.83	23.66	15.49	12.27	13.40
		HIT@10	40.53	22.18	20.47	37.48	23.66	20.04	36.82	26.06	21.66	23.28
		RA-Oracle	17.66	16.32	17.79	24.11	17.73	16.85	24.15	18.63	16.92	17.59

Table 19: Benchmark results(%) on queries with negation of FB15k-237.

CQA Model	Normal Form	Metric	(# anchor nodes, max length of projection chains)						AVG.
			(2,1)	(2,2)	(2,3)	(3,1)	(3,2)	(3,3)	
BetaE	DM	MRR	7.24	6.19	5.84	9.49	7.22	6.47	6.92
		HIT@1	2.15	2.25	2.03	4.14	3.24	2.85	3.04
		HIT@3	6.47	5.41	5.14	9.72	7.02	6.17	6.66
		HIT@10	17.92	13.61	12.96	20.26	14.61	13.07	14.12
		RA-Oracle	10.26	9.99	10.95	11.21	9.70	10.04	9.99
	DM +I	MRR	7.24	6.19	5.84	9.48	7.22	6.47	6.92
		HIT@1	2.15	2.25	2.03	4.12	3.24	2.85	3.04
		HIT@3	6.47	5.41	5.14	9.73	7.03	6.17	6.67
		HIT@10	17.92	13.61	12.96	20.26	14.62	13.08	14.12
		RA-Oracle	10.26	9.99	10.95	11.20	9.71	10.05	9.99
	DNF +IU	MRR	7.24	6.19	5.84	10.16	7.78	7.04	7.46
		HIT@1	2.15	2.25	2.03	4.32	3.42	3.04	3.21
		HIT@3	6.47	5.41	5.14	10.36	7.50	6.64	7.12
		HIT@10	17.92	13.61	12.96	21.92	15.88	14.32	15.33
		RA-Oracle	10.26	9.99	10.95	12.41	10.78	11.25	11.08
LogicE	DM +I	MRR	8.01	6.80	6.28	11.03	8.29	7.42	7.93
		HIT@1	2.28	2.48	2.39	4.88	3.77	3.38	3.57
		HIT@3	7.44	6.23	5.67	11.54	8.17	7.19	7.76
		HIT@10	19.80	14.87	13.48	23.24	16.81	14.89	16.11
		RA-Oracle	10.21	10.18	11.19	13.04	11.02	11.30	11.24
	DM+I	MRR	8.01	6.80	6.28	11.07	8.31	7.44	7.94
		HIT@1	2.28	2.48	2.39	4.90	3.79	3.39	3.58
		HIT@3	7.44	6.23	5.67	11.59	8.19	7.22	7.79
		HIT@10	19.80	14.87	13.48	23.31	16.85	14.92	16.14
		RA-Oracle	10.21	10.18	11.19	13.06	11.04	11.32	11.26
	DNF +IU	MRR	8.01	6.80	6.28	10.99	8.42	7.58	8.05
		HIT@1	2.28	2.48	2.39	4.70	3.77	3.41	3.57
		HIT@3	7.44	6.23	5.67	11.37	8.22	7.30	7.82
		HIT@10	19.80	14.87	13.48	23.48	17.18	15.20	16.42
		RA-Oracle	10.21	10.18	11.19	12.96	11.23	11.63	11.49
NewLook	DNF +IUd	MRR	4.73	4.50	4.38	6.43	5.30	5.00	5.17
		HIT@1	0.80	1.48	1.50	2.14	2.08	1.97	1.99
		HIT@3	4.25	3.77	3.71	6.21	4.90	4.54	4.74
		HIT@10	12.34	10.01	9.35	14.91	11.06	10.32	10.85
		RA-Oracle	4.37	5.90	7.36	6.52	6.63	7.65	7.10
	DNF +IUD	MRR	4.73	4.50	4.38	6.50	5.35	5.02	5.20
		HIT@1	0.80	1.48	1.50	2.16	2.10	1.97	2.00
		HIT@3	4.25	3.77	3.71	6.26	4.95	4.56	4.76
		HIT@10	12.34	10.01	9.35	15.08	11.18	10.35	10.92
		RA-Oracle	4.37	5.90	7.36	6.57	6.67	7.67	7.14

Table 20: Benchmark results(%) on EPFO queries of FB15k.

CQA Model	Normal Form	Metric	(# anchor nodes, max length of projection chains)									AVG.
			(1,1)	(1,2)	(1,3)	(2,1)	(2,2)	(2,3)	(3,1)	(3,2)	(3,3)	
BetaE	DM	MRR	51.86	25.48	23.55	32.07	20.42	18.66	28.51	20.26	17.36	18.97
		HIT@1	39.09	17.06	15.63	23.82	13.37	12.02	21.38	13.74	11.22	12.56
		HIT@3	59.20	27.40	25.60	35.86	22.30	20.17	31.63	22.24	18.88	20.72
		HIT@10	76.20	42.36	38.82	47.78	34.22	31.56	42.08	32.91	29.27	31.41
		RA-Oracle	47.46	33.05	32.94	33.80	25.61	25.21	29.44	23.42	22.08	23.36
	DM +I	MRR	51.86	25.48	23.55	32.07	20.42	18.66	28.76	20.38	17.46	19.07
		HIT@1	39.09	17.06	15.63	23.82	13.37	12.02	21.69	13.85	11.31	12.65
		HIT@3	59.20	27.40	25.60	35.86	22.30	20.17	31.84	22.39	18.99	20.83
		HIT@10	76.20	42.36	38.82	47.78	34.22	31.56	42.24	33.04	29.38	31.51
		RA-Oracle	47.46	33.05	32.94	33.80	25.61	25.21	29.74	23.55	22.19	23.46
	DNF +IU	MRR	51.86	25.48	23.55	44.93	23.92	21.26	44.04	26.31	21.48	23.71
		HIT@1	39.09	17.06	15.63	32.24	15.14	13.34	31.69	17.14	13.40	15.18
		HIT@3	59.20	27.40	25.60	51.44	26.11	22.91	49.79	28.88	23.22	25.84
		HIT@10	76.20	42.36	38.82	70.36	41.48	36.92	69.08	44.66	37.49	40.66
		RA-Oracle	47.46	33.05	32.94	51.28	31.96	30.44	51.04	33.54	29.74	31.67
LogicE	DM	MRR	61.56	29.76	25.41	42.92	25.26	21.77	39.51	25.46	21.04	23.30
		HIT@1	49.63	20.51	17.24	31.77	16.89	14.30	29.03	17.30	13.79	15.61
		HIT@3	69.51	32.56	27.71	48.83	27.88	23.75	44.87	28.24	23.06	25.68
		HIT@10	82.40	47.94	41.17	63.89	41.68	36.38	59.37	41.32	35.19	38.24
		RA-Oracle	58.57	37.90	35.18	48.91	32.53	29.93	44.83	31.38	27.97	30.02
	DM +I	MRR	61.56	29.76	25.41	42.92	25.26	21.77	39.63	25.47	21.05	23.31
		HIT@1	49.63	20.51	17.24	31.77	16.89	14.30	29.16	17.32	13.80	15.63
		HIT@3	69.51	32.56	27.71	48.83	27.88	23.75	44.94	28.24	23.07	25.69
		HIT@10	82.40	47.94	41.17	63.89	41.68	36.38	59.50	41.35	35.21	38.27
		RA-Oracle	58.57	37.90	35.18	48.91	32.53	29.93	44.98	31.42	27.99	30.04
	DNF +IU	MRR	61.56	29.76	25.41	47.17	26.96	23.08	44.33	28.13	23.01	25.42
		HIT@1	49.63	20.51	17.24	34.35	17.47	14.76	31.62	18.42	14.55	16.48
		HIT@3	69.51	32.56	27.71	54.27	29.86	25.19	50.68	31.22	25.15	28.01
		HIT@10	82.40	47.94	41.17	71.83	45.92	39.54	69.46	47.54	39.82	43.19
		RA-Oracle	58.57	37.90	35.18	54.42	35.59	32.52	51.76	35.88	31.59	33.77
NewLook	DNF +IUD	MRR	58.82	30.93	26.12	52.60	28.84	24.06	50.64	30.87	24.51	27.31
		HIT@1	46.87	22.02	17.88	40.51	19.61	15.92	38.06	21.24	16.22	18.52
		HIT@3	66.32	33.76	28.59	59.44	31.81	26.21	57.66	34.30	26.81	30.08
		HIT@10	80.51	48.54	42.01	75.89	47.17	40.03	75.04	49.94	40.86	44.62
		RA-Oracle	55.31	39.14	36.06	58.44	37.32	33.49	57.14	38.70	33.14	35.65

Table 21: Benchmark results(%) on queries with negation of FB15k.

CQA Model	Normal Form	Metric	(# anchor nodes, max length of projection chains)						AVG.
			(2,1)	(2,2)	(2,3)	(3,1)	(3,2)	(3,3)	
BetaE	DM	MRR	26.59	17.23	13.48	25.77	16.36	13.14	15.31
		HIT@1	11.62	8.54	6.58	14.29	9.00	7.07	8.29
		HIT@3	33.56	19.08	14.17	30.88	17.94	13.93	16.73
		HIT@10	55.93	34.46	27.09	48.63	30.97	24.98	29.15
	RA-Oracle	MRR	31.46	23.21	21.50	28.83	20.53	18.73	20.26
		HIT@1	11.62	8.54	6.58	14.31	9.00	7.07	8.29
		HIT@3	33.56	19.08	14.17	30.88	17.94	13.93	16.72
		HIT@10	55.93	34.46	27.09	48.64	30.97	24.98	29.15
	RA-Oracle	MRR	31.46	23.21	21.50	28.83	20.53	18.72	20.26
		HIT@1	11.62	8.54	6.58	15.48	9.60	7.53	8.82
		HIT@3	33.56	19.08	14.17	34.64	19.65	15.20	18.23
		HIT@10	55.93	34.46	27.09	56.48	34.90	28.11	32.69
LogicE	DM	MRR	28.17	19.34	15.04	29.59	19.06	15.10	17.66
		HIT@1	11.94	9.80	7.80	16.20	10.54	8.25	9.65
		HIT@3	37.01	22.08	16.13	36.21	21.30	16.26	19.64
		HIT@10	58.66	38.16	29.35	55.66	36.02	28.70	33.55
	RA-Oracle	MRR	33.25	25.52	23.21	34.38	24.38	21.81	23.72
		HIT@1	11.94	9.80	7.80	16.25	10.57	8.26	9.67
		HIT@3	37.01	22.08	16.13	36.31	21.34	16.29	19.68
		HIT@10	58.66	38.16	29.35	55.71	36.04	28.73	33.57
	RA-Oracle	MRR	33.25	25.52	23.21	34.45	24.42	21.82	23.74
		HIT@1	11.94	9.80	7.80	15.92	10.59	8.33	9.70
		HIT@3	37.01	22.08	16.13	37.10	21.94	16.80	20.21
		HIT@10	58.66	38.16	29.35	58.51	38.03	30.39	35.33
NewLook	DM	MRR	28.17	19.34	15.04	29.65	19.09	15.12	17.69
		HIT@1	11.94	9.80	7.80	16.25	10.57	8.26	9.67
		HIT@3	37.01	22.08	16.13	36.31	21.34	16.29	19.68
		HIT@10	58.66	38.16	29.35	55.71	36.04	28.73	33.57
	RA-Oracle	MRR	33.25	25.52	23.21	34.45	24.42	21.82	23.74
		HIT@1	11.94	9.80	7.80	15.92	10.59	8.33	9.70
		HIT@3	37.01	22.08	16.13	37.10	21.94	16.80	20.21
		HIT@10	58.66	38.16	29.35	58.51	38.03	30.39	35.33
	RA-Oracle	MRR	33.25	25.52	23.21	35.30	25.51	23.07	24.84
		HIT@1	11.94	9.80	7.80	15.92	10.59	8.33	9.70
		HIT@3	37.01	22.08	16.13	37.10	21.94	16.80	20.21
		HIT@10	58.66	38.16	29.35	58.51	38.03	30.39	35.33
NewLook	DNF +IUd	MRR	16.28	11.92	9.46	19.90	12.89	10.55	12.05
		HIT@1	3.04	4.45	3.67	7.42	5.69	4.66	5.18
		HIT@3	20.00	12.89	9.59	23.76	13.74	10.85	12.79
		HIT@10	44.20	26.73	20.83	45.90	27.26	21.98	25.63
	RA-Oracle	MRR	21.08	16.65	15.73	24.30	17.30	16.34	17.18
		HIT@1	3.04	4.45	3.67	7.56	5.77	4.68	5.23
		HIT@3	20.00	12.89	9.59	24.38	14.00	10.91	12.96
		HIT@10	44.20	26.73	20.83	46.89	27.76	22.12	25.96
	RA-Oracle	MRR	21.08	16.65	15.73	24.74	17.56	16.43	17.35
		HIT@1	3.04	4.45	3.67	7.56	5.77	4.68	5.23
		HIT@3	20.00	12.89	9.59	24.38	14.00	10.91	12.96
		HIT@10	44.20	26.73	20.83	46.89	27.76	22.12	25.96

Table 22: Benchmark results(%) on EPFO queries of NELL.

CQA Model	Normal Form	Metric	(# anchor nodes, max length of projection chains)									AVG.
			(1,1)	(1,2)	(1,3)	(2,1)	(2,2)	(2,3)	(3,1)	(3,2)	(3,3)	
BetaE	DM	MRR	28.75	10.01	9.96	15.81	10.06	9.54	11.85	10.63	9.90	10.29
		HIT@1	20.41	5.87	6.15	10.57	6.34	6.08	7.65	7.14	6.51	6.77
		HIT@3	31.79	10.53	10.28	17.44	10.69	9.98	12.98	11.28	10.50	10.93
		HIT@10	45.28	17.71	17.16	26.27	17.33	16.14	19.99	17.38	16.39	17.05
		RA-Oracle	24.59	14.63	15.42	16.46	14.04	13.66	13.70	13.80	13.36	13.64
	DM +I	MRR	28.75	10.01	9.96	15.81	10.06	9.54	11.95	10.64	9.90	10.29
		HIT@1	20.41	5.87	6.15	10.57	6.34	6.08	7.76	7.16	6.51	6.78
		HIT@3	31.79	10.53	10.28	17.44	10.69	9.98	13.15	11.29	10.50	10.94
		HIT@10	45.28	17.71	17.16	26.27	17.33	16.14	20.05	17.40	16.41	17.06
		RA-Oracle	24.59	14.63	15.42	16.46	14.04	13.66	13.82	13.82	13.36	13.65
	DNF +IU	MRR	28.75	10.01	9.96	18.48	11.90	11.06	15.41	13.54	12.35	12.73
		HIT@1	20.41	5.87	6.15	12.02	7.37	6.94	9.66	8.89	7.99	8.24
		HIT@3	31.79	10.53	10.28	20.33	12.57	11.59	16.96	14.41	13.10	13.53
		HIT@10	45.28	17.71	17.16	31.41	20.85	19.00	26.67	22.59	20.77	21.45
		RA-Oracle	24.59	14.63	15.42	21.26	17.33	16.29	19.83	18.88	17.61	17.90
LogicE	DM	MRR	35.23	13.53	13.75	19.42	12.66	12.04	14.99	13.08	12.24	12.75
		HIT@1	25.74	8.62	8.92	13.21	8.47	8.13	9.85	9.00	8.41	8.74
		HIT@3	40.27	14.28	14.73	21.61	13.61	12.83	16.59	14.09	13.12	13.72
		HIT@10	53.28	23.05	22.80	31.69	20.64	19.40	24.98	20.83	19.46	20.36
		RA-Oracle	30.69	19.62	20.32	21.75	17.89	16.97	18.71	17.66	16.72	17.23
	DM +I	MRR	35.23	13.53	13.75	19.42	12.66	12.04	15.03	13.09	12.25	12.76
		HIT@1	25.74	8.62	8.92	13.21	8.47	8.13	9.94	9.02	8.42	8.75
		HIT@3	40.27	14.28	14.73	21.61	13.61	12.83	16.58	14.10	13.14	13.74
		HIT@10	53.28	23.05	22.80	31.69	20.64	19.40	24.97	20.83	19.47	20.36
		RA-Oracle	30.69	19.62	20.32	21.75	17.89	16.97	18.74	17.68	16.73	17.24
	DNF +IU	MRR	35.23	13.53	13.75	22.48	15.23	14.18	17.91	16.28	15.19	15.63
		HIT@1	25.74	8.62	8.92	14.90	9.88	9.30	11.26	10.81	10.13	10.38
		HIT@3	40.27	14.28	14.73	25.02	16.51	15.23	19.84	17.61	16.37	16.90
		HIT@10	53.28	23.05	22.80	37.42	25.50	23.42	30.98	26.78	24.78	25.62
		RA-Oracle	30.69	19.62	20.32	26.45	22.08	20.48	23.47	22.83	21.50	21.89
NewLook	DNF +IUD	MRR	33.59	12.06	11.42	22.09	13.59	12.16	17.73	14.70	13.21	13.81
		HIT@1	24.78	7.12	6.79	14.66	8.62	7.69	11.33	9.61	8.65	9.02
		HIT@3	37.19	12.73	12.00	24.27	14.47	12.79	19.23	15.71	13.95	14.67
		HIT@10	51.89	21.72	20.31	37.14	23.13	20.64	30.46	24.53	21.92	23.03
		RA-Oracle	29.50	18.03	17.76	26.10	20.28	18.24	23.87	21.10	19.28	19.89

Table 23: Benchmark results(%) on queries with negation of NELL.

CQA Model	Normal Form	Metric	(# anchor nodes, max length of projection chains)						AVG.
			(2,1)	(2,2)	(2,3)	(3,1)	(3,2)	(3,3)	
BetaE	DM	MRR	7.56	7.30	6.57	7.49	7.67	7.47	7.53
		HIT@1	3.62	3.86	3.42	4.02	4.43	4.41	4.36
		HIT@3	7.98	7.42	6.68	7.72	7.93	7.74	7.79
		HIT@10	14.68	13.77	12.30	14.12	13.69	13.18	13.44
		RA-Oracle	9.89	10.73	10.23	9.62	10.46	10.58	10.47
	DM +I	MRR	7.56	7.30	6.57	7.48	7.69	7.49	7.54
		HIT@1	3.62	3.86	3.42	3.99	4.45	4.42	4.37
		HIT@3	7.98	7.42	6.68	7.72	7.95	7.75	7.80
		HIT@10	14.68	13.77	12.30	14.13	13.72	13.20	13.46
		RA-Oracle	9.89	10.73	10.23	9.60	10.48	10.60	10.49
	DNF +IU	MRR	7.56	7.30	6.57	8.12	8.49	8.39	8.34
		HIT@1	3.62	3.86	3.42	4.16	4.82	4.85	4.74
		HIT@3	7.98	7.42	6.68	8.42	8.78	8.68	8.62
		HIT@10	14.68	13.77	12.30	15.68	15.36	15.00	15.09
		RA-Oracle	9.89	10.73	10.23	10.75	11.96	12.26	11.96
LogicE	DM	MRR	9.62	9.51	9.05	9.09	9.48	9.50	9.46
		HIT@1	4.56	5.30	5.47	4.74	5.64	5.99	5.74
		HIT@3	10.34	9.98	9.31	9.66	10.01	10.03	9.99
		HIT@10	19.20	17.13	15.59	17.47	16.61	15.94	16.33
		RA-Oracle	13.32	13.98	13.48	12.26	13.20	13.26	13.21
	DM +I	MRR	9.62	9.51	9.05	9.09	9.48	9.50	9.47
		HIT@1	4.56	5.30	5.47	4.76	5.65	5.99	5.75
		HIT@3	10.34	9.98	9.31	9.64	10.00	10.04	9.99
		HIT@10	19.20	17.13	15.59	17.46	16.61	15.95	16.34
		RA-Oracle	13.32	13.98	13.48	12.23	13.19	13.26	13.20
	DNF +IU	MRR	9.62	9.51	9.05	9.65	10.42	10.63	10.43
		HIT@1	4.56	5.30	5.47	4.83	6.03	6.51	6.16
		HIT@3	10.34	9.98	9.31	10.19	11.01	11.25	11.02
		HIT@10	19.20	17.13	15.59	19.02	18.63	18.20	18.34
		RA-Oracle	13.32	13.98	13.48	13.20	14.68	15.13	14.77
NewLook	DNF +IUd	MRR	5.46	5.35	5.08	5.39	5.77	5.98	5.82
		HIT@1	2.45	2.62	2.40	2.33	2.93	3.10	2.96
		HIT@3	5.46	5.33	5.01	5.38	5.84	6.04	5.88
		HIT@10	11.14	10.25	9.71	11.21	10.91	11.09	10.97
		RA-Oracle	5.60	7.25	7.87	6.39	7.84	8.81	8.21
	DNF +IUD	MRR	5.46	5.35	5.08	5.44	5.81	5.99	5.85
		HIT@1	2.45	2.62	2.40	2.35	2.94	3.11	2.97
		HIT@3	5.46	5.33	5.01	5.45	5.88	6.05	5.91
		HIT@10	11.14	10.25	9.71	11.28	11.00	11.12	11.03
		RA-Oracle	5.60	7.25	7.87	6.43	7.89	8.83	8.24