Relation-Guided Pre-Training for Open-Domain Question Answering

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Abstract

Answering complex open-domain questions requires understanding the latent relations between involving entities. However, we found that the existing QA datasets are extremely imbalanced in some types of relations, which hurts the generalization performance over questions with long-tail relations. To remedy this problem, in this paper, we propose a Relation-Guided Pre-Training (RGPT-QA) framework[1]. We first generate a relational QA dataset covering a wide range of relations from both the Wikidata triplets and Wikipedia hyperlinks. We then pre-train a QA model to infer the latent relations from the question, and then conduct extractive QA to get the target answer entity. We demonstrate that by pre-training with propoed RGPT-QA techique, the popular open-domain QA model, Dense Passage Retriever (DPR), achieves 2.2%, 2.4%, and 6.3% absolute improvement in Exact Match accuracy on Natural Questions, TriviaQA, and WebQuestions. Particularly, we show that RGPT-QA improves significantly on questions with long-tail relations.

1 Introduction

Open domain question answering is a challenging task that answers factoid questions based on evidence in a large corpus (e.g., Wikipedia). Most open-domain QA systems follow retriever-reader pipeline (Chen et al., 2017), in which a *retriever* selects a subset of candidate entities and associated passages from the corpus that might contain the answer, then a *reader* extracts a text span from the passages as the answer. This process involves multiple entities that are relevant to answer the question. The QA system is required to extract these entities from the question and passages and identify the (latent) semantic relations between these entities in order to answer the question. For example, to answer the following question: "Where did Steph Curry play college basketball at?", the QA model is required to reason the implicit relation triplet ⟨*Steph Curry, Educated At, Davidson College*⟩ to identify the correct answer.

To capture the relation knowledge required to answer questions, most QA systems rely on human-annotated supervised QA datasets. However, it is expensive and tedious to annotate a large set of QA pairs that cover enough relational facts for training a strong QA model. In addition, we showed that even for a large QA dataset like Natural Questions (Kwiatkowski et al., 2019), its training set only covers 16.4% of relations in WikiData (Vrandecic and Krötzsch, 2014) knowledge graph. Moreover, for those covered relations, the frequency distribution is imbalanced, i.e., 30% of relation types appear only once. Consequently, for the questions involving infrequent (a.k.a, long-tail) relations in the training set, the QA exact match accuracy is 22.4% lower than average. Such a biased relation distribution of existing QA datasets severely hurts the generalization of trained QA systems.

To improve the open-domain QA systems for questions with long-tail relations, in this paper, we propose RGPT-QA, a simple yet effective Relation-Guided Pre-training framework for training QA models with augmented relationa facts from knowledge graph. The framework consists of two steps: 1) generate a relational QA dataset that covers a wide range of relations without human labeling; 2) pre-train a QA model to predict latent relations from questions and conduct extractive QA.

The key of our framework is to generate a relational QA dataset that align entities in Wikipedia passages with structured knowledge graph (e.g., WikiData). We call such a dataset Grounded Relational Wiki-Graph. In this graph, each edge indicates the relationship of two connected entities, and the edge is linked to a passage in Wikipedia describing this relationship. As WikiData knowledge

[1]Dataset and code are released at https://github.com/acbull/RGPT-QA.

Findings of the Association for Computational Linguistics: EMNLP 2021, pages 3431–3448
November 7–11, 2021.

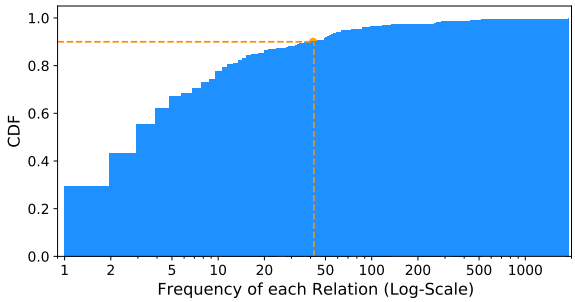


Figure 1: Cumulative distribution function (CDF) of relation frequency in Natural Question Training set.

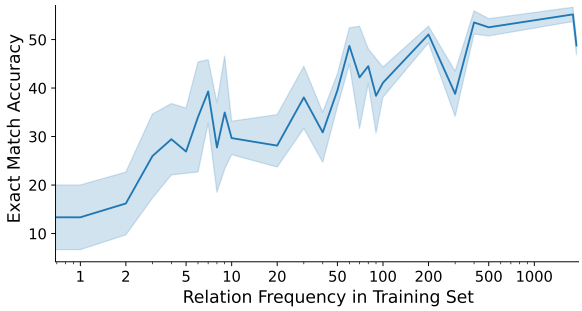


Figure 2: Exact Match accuracy of a trained DPR model in validation set with different relation frequency in training set.

graph also suffers from low coverage of long-tail entities and relations, we further convert hyperlinks in Wikipedia into knowledge triplets without specifying relation labels. Next, we link each relation triplet to a Wikipedia passage to help generate natural questions. We assume that if one passage in the Wiki-page of source entity contains the target entity, then the context in this passage describes the relationship between the two entities. With the constructed graph, we use a template to synthesize question and answer pairs and then pre-train the QA model to capture the relational facts for answering complex open-domain questions.

As a pre-training method, RGPT-QA can be incorporated with any open-domain QA system. In this paper, we utilize the recently developed Dense Passage Retriever (DPR) (Karpukhin et al., 2020) as the base QA system to evaluate the proposed pre-training effectiveness. Experimental results show that RGPT-QA enhances DPR's Exact Match accuracy by 2.2%, 2.4%, and 6.3% on Natural Questions, TriviaQA and WebQuestions respectively. Compared with the existing QA pre-training methods (Lee et al., 2019; Guu et al., 2020a; Lewis et al., 2019), RGPT-QA explicitly captures a wide range of relational facts and thus achieves better performance. Moreover, for the questions containing long-tail relations in Natural Questions, the performance is improved by 10.9%, showing that RGPT-QA alleviates the unbalanced relation distribution problem in the existing QA datasets.

The key contributions of this paper are:

- We propose RGPT-QA, a pre-training method to inject knowledge from relational facts in knowledge graph into QA models.
- RGPT-QA enhances the performance of a popular QA model, i.e., DPR, especially on the questions with long-tail relations.

2 Preliminary and Empirical Analysis

In this section, we firstly introduce the retriever-reader pipeline for open-domain QA, and then we analyze how the relation distribution in existing QA datsets influence generalization performance.

Open-Domain Question Answering. We focus on open-domain question answering that requires to extract answer from a large corpus (e.g. Wikipedia) $\mathbb{C} = \{p_i\}_{i=1}^{N}$ containing N passages. Most open-domain QA systems follow a retriever-reader pipeline proposed by Chen et al. (2017). Given a factoid question q, the QA system first retrieves K relevant passages $\{p_j\}_{j=1}^{K}$ from the corpus $\mathbb{C}$. Then a reading comprehension module extracts a text span $w_{\text{start}}, \ldots, w_{\text{end}}$ from one of these retrieved passages as the answer a to the question. Some QA dataset annotated the passage where the answer a is derived. We called this passage ground truth passage.

For the retriever, earlier systems utilize term-based retrieval methods, such as TF-IDF and BM25, which fails to capture the semantic relationship between question and passage beyond lexical matching. Recent studies (Lee et al., 2019; Karpukhin et al., 2020; Dhingra et al., 2020) use BERT-like pretrained language model to encode the question and passages independently into dense representations, and use maximum inner product search (MIPS) algorithms (Shrivastava and Li, 2014) to efficiently retrieve the most similar passage for each question. In this paper, we utilize Dense Passage Retriever (DPR) (Karpukhin et al., 2020) as the base QA model.

Relation Bias of Existing QA Datasets. We first explore how much relational knowledge between entities is required to answer the questions in the existing open-domain QA dataset. We con-

duct an empirical study to analyze the relation distribution in Natural Questions, one of the largest open-domain QA datasets, and how it influences QA model's performance.

For each question in Natural Question training set, we first select the entity that the ground-truth passage is associated with. We then combine the entity with the answer as an entity pair, and check whether we can find a relation triplet in WikiData describing the relation between these two entities. Out of 58,880 training QA pairs, there are 23,499 pairs that could be aligned. The aligned QA pairs cover 329 relations, which accounts for 16.4% of the total 2,008 relations in WikiData. For most unaligned QA pairs, the answers are not entities and thus cannot be aligned to the graph.

In addition to the low relation coverage issue in Natural Question, we also find that the relation distribution is imbalanced. As showed in Figure 1, 90% of relations have frequency less than 41, and 30% of relations appear only once. On the contrary, the most frequent relation "P161 (cast member)" appears 1,915 times out of 9,238 aligned QA pairs. A complete list of all these relations with aligned QA pairs is shown in Table 6-9 in Appendix.

We then study whether the imbalanced relation distribution influences the performance of QA models trained on these datasets. We use a DPR model trained on training set of Natural Questions and then calculate the Exact Match accuracy in validation set of each aligned QA pairs. We then analyze the correlation of the accuracy with the relation frequency in training set. As illustrated in Figure 2, the validation set accuracy is overall proportional to the relation frequency in training set. For those relations with frequency less than 5, the average accuracy is only 20.3%, much lower than the average accuracy 42.7% over all samples in validation set. This shows that the relation bias in existing QA datasets severely influences the generalization of QA models to questions with long-tail relations.

3 Method

In this section, we will discuss RGPT-QA framework in: 1) how to generate relational QA dataset for the pre-training purpose; and 2) how to construct a self-training task to empower QA model to capture relational facts.

# of linked Entity	5,640,366
# of relation labels	2,008
# of labelled triplet	14,463,728
# of unlabeled triplet (hyperlink)	66,796,110
# of grounded descriptions per triplet	1.25

Table 1: Statistics of Grounded Relational Wiki-Graph.

3.1 Construct QA Pre-Training Dataset

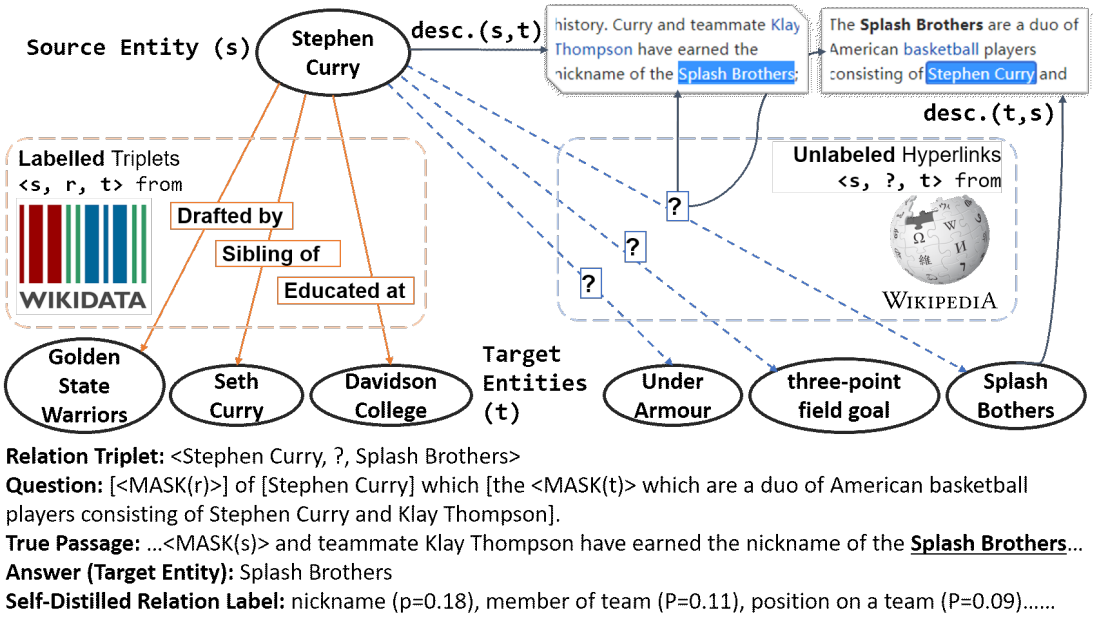
To help QA model capture the knowledge from relation facts required to answer open-domain questions, we first focus on generating QA pre-training dataset, in which there exist relation connections between the source entity in questions to the target answer. Specifically, each QA pair datapoint $d = \left\langle \langle s, r, t \rangle, q, p^+ \right\rangle$ consists of three components: 1) relational triplet $\langle s, r, t \rangle$, in which r denotes the relation between source entity s and target entity t; 2) question q in natural language asking which entity has relation r to source entity s, with target entity t as the correct answer; 3) positive context passage $p^+ \in \mathbb{C}[s]$, a passage from source entity's Wiki-page that contains the target answer t.

Grounded Relational Wiki-Graph. To generate QA pre-training dataset, leveraging the relation triplets in knowledge graph, e.g., WikiData, is a natural choice to define questions that require relation reasoning. We therefore construct Grounded Relational Wiki-Graph, in which each relation triplet $\langle s, r, t \rangle$ is linked to a set of description passages $\{desc.(s, t)\}$ in the Wiki-page of entity s. These descriptions would be later utilized to generate questions q and positive context passages p^+.

To construct such a graph, we use the 2021 Jan. English dump of Wikidata and Wikipedia. For each Wikipedia hyperlink $\langle s, ?, t \rangle$ (? denotes the relation is unlabeled), the passage containing anchored text to t in the Wiki-page of s naturally fits our requirement for $desc.(s, t)$. For each WikiData relation triplet $\langle s, r, t \rangle$, if the two entities are linked by a hyperlink in Wikipedia, we label the relation of the aligned hyperlink as r. For the other triplets $\langle s, r, t \rangle$ without alignment with hyperlinks, we extract all mentioning of target entity t from the Wiki-page of s, and use the context passage as $desc.(s, t)$. The dataset statistics are shown in Table 1.

Relational QA Pair Generation In the following, we introduce the details to generate the relational QA pair from the constructed graph.

Recent unsupervised QA studies (Li et al., 2020; Pan et al., 2020) revealed that if the question q and



Relation Triplet: <Stephen Curry, ?, Splash Brothers>
Question: [<MASK(r)>] of [Stephen Curry] which [the <MASK(t)> which are a duo of American basketball players consisting of Stephen Curry and Klay Thompson].
True Passage: ...<MASK(s)> and teammate Klay Thompson have earned the nickname of the **Splash Brothers**...
Answer (Target Entity): Splash Brothers
Self-Distilled Relation Label: nickname (p=0.18), member of team (P=0.11), position on a team (P=0.09).....

Figure 3: Example of a generated relational QA pair from Grounded Relational Wiki-Graph.

context passage p^+ share a large lexical overlap, then the QA model could utilize low-level lexical patterns as shortcuts to find the answer. These shortcuts hinder the model from learning to comprehend the passages and answer the questions, hurting model's generalizability. To avoid this lexical overlap issue, we aim to generate questions from a passage that is different from the context passage p^+.

We first select all the entity pairs $\langle s, t\rangle$ that have mutual links in the Grounded Relational Wiki-Graph, with $desc.(s,t)$ and $desc(t,s)$ in part of Wikipage of s and t respectively , describing the relationship between the two entities. Without loss of generality, we denote s as source entity and t as the target answer. The passage $desc.(s,t)$ containing target answer t can be used as the positive passage p^+.

Next, we generate a question that is lexically different from p^+ using the following template:

$$q(s,r,t) = [\texttt{MASK}(r)] \text{ of } [s] \text{ which } [desc.(t,s)]?$$

in which $\texttt{MASK}(r)$ is a relation mask token. As $desc.(t,s)$ contains source entity s, it provides information to describe the relationship between s and t, based on which the QA model should learn to infer the latent relation r, and retrieve positive passage $p^+ = desc.(s,t)$ and extract answer entity t. In addition, as $desc.(t,s)$ and $desc.(s,t)$ come from different Wiki-page, our question generation procedure can avoid the lexical overlap issue that often occur in prior Unsupervised QA methods.

Mask Target Answer. As description $desc.(t,s)$ is from target answer t's wiki-page, it often contains the name of entity t. We thus need to mask t from the question. Otherwise, the pre-trained model can simply identify the answer to a question based on the local patterns.

As an example, in Figure 3, we show how to generate question for triplet $\langle$Stephen Curry, ?, Splash Brothers$\rangle$. We firstly retrieve two descriptive passages $desc.(s,t)$ and $desc.(t,s)$ in two entities' wiki pages. Using the template, we generate the question along with the ground-truth passage. We then mask out the target entity in question and source entity in true passage (will discuss later in retrieval pre-training) to avoid shortcut. A list of generated relational QA pairs are shown in Table 10 in Appendix.

3.2 Relation-Guided QA Pre-Training

With the generated relational QA dataset, we introduce how to pre-train both retriever and reader components in the QA model.

3.2.1 Relation Prediction Pre-Training

Our generated QA dataset contains the relation label r between the source entity s and the answer target t. Therefore, we design a self-training task to guide the model to predict the latent relation

in question, which can benefit both retriever and reader. Specifically, we adopt a linear projection layer $\mathrm{L}_R(\cdot)$ over the $\texttt{BERT}_{\texttt{[CLS]}}$ token embedding to predict the relation over the WikiData relation set. The pre-training loss of relation prediction is:

$$\mathcal{L}_{\text{rel}} = \frac{1}{B}\sum_{q} -\log P(r \mid q;\theta),$$

Self-Distillation for Unlabelled Relation The hyperlinks in wikipedia also provide valuable implicit information about the relations between entities. To leverage them, we use the trained relation predictor at each epoch with fixed parameter $\hat{\theta}$ as teacher model to assign soft label and then progressively train the relation predictor as student model based on the assigned labels in the next epoch. This approach is referred to as self-distillation in the literature (Xie et al., 2020; Chen et al., 2020). We minimize this self-distillation loss as:

$$\mathcal{L}_{\text{distill}} = \frac{1}{B}\sum_{q}\sum_{\hat{r}} -\log P(\hat{r}\,|\,q;\theta)\cdot \text{sg}\big(P(\hat{r}\,|\,q;\hat{\theta})\big),$$

where $\text{sg}(\cdot)$ denotes the operation of stop gradient, which avoids back propagation to the teacher network with fixed parameter $\hat{\theta}$. $\hat{r}$ is enumerating all the relation labels.

As the relation predictor at early stages cannot give a reasonable prediction, we put a dynamic weight schedule to $\mathcal{L}_{\text{distill}}$ by a time-dependent weighting term $1 - e^{-\text{epoch}}$, which ramps up from zero to one. Combing the weighted self-distillation loss $\mathcal{L}_{\text{distill}}$ with the supervised relation loss $\mathcal{L}_{\text{rel}}$, we get the final relation loss $\hat{\mathcal{L}}_{\text{rel}}$ to train the model capturing all relational facts covered in the Grounded Relational Wiki-Graph.

3.2.2 Dense Retrieval Pre-Training

The goal of dense retrieval pre-training is to get a question encoder Enc_Q and a passage encoder Enc_P to map questions and all passages in the Wiki Corpus $\mathbb{C}$ into an embedding space, such that each question q is close to its ground-truth positive context passage p^+ in the embedding space. The objective is as follows:

$$P_{\text{retr}}(p^+ \mid q, \mathbb{C}) = \frac{\exp\big(\text{sim}(q,p^+)\big)}{\sum_{p\in\mathbb{C}}\exp\big(\text{sim}(q,p)\big)}, \quad (1)$$

where $\text{sim}(q,p)$ is the cosine similarity between the normalized embeddings of question and passage.

Two-Level Negative Passage Sampling. As we cannot enumerate all other passages in the denominator of Eq(1), we need to sample a set of negative passages for contrastive learning. Previous studies (Karpukhin et al., 2020) have revealed that it is essential that the sampled negative passages should be hard enough to train the retriever. As the question and passage embeddings are encoded independently, DPR can efficiently calculate the similarity of each question to all passages in the batch via dot product. Based on this property, as long as the passages within a batch are similar to each other, they serve the hard cases of negative passages to others. We thus propose a two-level negative passage sampling strategy to construct hard cases for training the retriever in the following.

We first sample at the level of entity. Given a set of randomly sampled b entities, we adopt random walk from these seed entities over the Grounded Relational Wiki-Graph to get B entities. As the connected entities have a relationship, their true passages are also semantically similar, and thus serve as good negative samples. We then conduct sampling at the level of passage. For each source entity s_i with positive passage $p_i^+ \in \mathbb{C}[s_i]$, we randomly pick K other passages from the same Wiki-page to form a negative passage set $\big\{p_{i,j}^- \in \mathbb{C}[s_i], \text{s.t. } p_{i,j}^- \neq p_i^+\big\}_{j=1}^{K}$. These negative passages are similar to p_i^+, as they all describe the same entity s_i.

After we collect both the positive and K negative passages for all the entities, we use the passage encoder Enc_P to get a passage embedding matrix $\mathbf{P}$ with dimension $\big((1+K)\cdot B \times d\big)$. We also use question encoder Enc_Q to get question embedding matrix $\mathbf{Q}$ with dimension $\big(B \times d\big)$. We then get a similarity matrix $\mathbf{S} = \mathbf{Q}\mathbf{P}^T$ with dimension $\big(B \times (1+K)\cdot B\big)$, in which the diagonal entry corresponds to the similarity between question and its positive passage. We thus calculate the retrieval loss with in-batch negative samples via:

$$\mathcal{L}_{\text{retr}} = \frac{1}{B}\Big(\sum_{i\in[1,B]}\big(-\log \text{softmax}(\mathbf{S})\big)_{[i,i]}\Big). \quad (2)$$

Masking Source Entity. As the true passage $p_i^+ = desc.(s,t)$ might contain the name of source entity s. We mask out all the tokens of s from the extracted passages, so that the model is required to understand the passages for correct retrieval instead of exploiting a shortcut.

3.2.3 Reading Comprehension Pre-Training

The goal of reading comprehension pre-training is to get a neural reader that re-ranks the top-k retrieved passages and extracts an answer span from each passage as the answer. The probability of a passage contains the target answer t, and each token in the selected passage being the starting/ending positions of an t are defined as:

$$P_{\text{rank}}(t \in p) = \frac{\exp\left(\text{L}_{\text{rank}}\left(\texttt{BERT}_{\texttt{CLS}}(q,p)\right)\right)}{\sum_{\hat{p}} \exp\left(\text{L}_{\text{rank}}\left(\texttt{BERT}_{\texttt{CLS}}(q,\hat{p})\right)\right)},$$

$$P_{\text{start}}(i \mid p,q) = \frac{\exp\left(\text{L}_{\text{start}}\left(\texttt{BERT}_{\texttt{[i]}}(q,p)\right)\right)}{\sum_{j} \exp\left(\text{L}_{\text{start}}\left(\texttt{BERT}_{\texttt{[j]}}(q,p)\right)\right)},$$

$$P_{\text{end}}(i \mid p,q) = \frac{\exp\left(\text{L}_{\text{end}}\left(\texttt{BERT}_{\texttt{[i]}}(q,p)\right)\right)}{\sum_{j} \exp\left(\text{L}_{\text{end}}\left(\texttt{BERT}_{\texttt{[j]}}(q,p)\right)\right)}.$$

where L_* are linear project layers with different parameters. Note that the re-ranking module adopts cross-attention over questions and passages rather than the dot product of two independently encoded embedding used in retriever. For each QA pair $d = \left\langle \langle s, r, t\rangle, q, p^+ \right\rangle$, we select m other passages in wiki-page of entity s as negative passages, and maximize $P_{\text{rank}}(t \in p^+)$. Then, we calculate $P_{\text{start}}(i \mid p^+, q)$ and $P_{\text{end}}(i \mid p^+, q)$ and maximize the probability for the ground-truth span of target answer t. Combing the passage re-ranking and span extraction objectives, we get reading-comprehension loss $\mathcal{L}_{\text{read}}$.

4 Experiments

In this section, we evaluate RGPT-QA on three open-domain QA datasets: Natural Questions (NQ), Trivia QA and Web Questions (WQ).

4.1 Experiment Settings

We follow the pre-processing procedure described in DPR (Karpukhin et al., 2020) for a fair comparison. We use the English Wikipedia from Dec. 20, 2018 and split each article into passages of 100 disjoint words as the corpus. For each question in all the three datasets, we use a passage from the processed Wikipedia which contains the answer as positive passages. We evaluate the QA system by Exact Match (EM) Accuracy on the correct answer.

Our RGPT-QA could be integrated with any open-domain QA system. In this paper, we incorporate it with the recently developed QA system, Dense Passage Retriever (DPR) (Karpukhin et al., 2020) to evaluate our pre-training framework. The DPR model uses the RoBERTa-base (d=768, l=12) model as the base encoder. We first pre-train the retriever and reader in DPR using RGPT-QA. For retriever, we use the negative passage sampling strategy (c.f. Sec. 3.2.2), with initial entity size set to be 12, batch size of 128 and the hard negative passage number of 2. For reader, we randomly sample 64 source entities per batch to calculate the loss. For each entity, we sample 2 hard negative passages for re-ranking. We pre-train both the retriever and reader for 20 epochs using AdamW optimizer and a learning rate warm-up followed by linear decay. Pre-training is run on 8 Tesla V100 GPUs for two days. After the pre-training, we fine-tune the retriever and reader on each QA dataset following the same procedure and hyper-parameters described in DPR (Karpukhin et al., 2020).

QA Pre-Training Baselines. We compare RGPT-QA with three recently proposed pre-training methods for open-domain QA.

T5 (Raffel et al., 2020) adopts multiple generative tasks to pre-train a generative model. The fine-tuned QA models directly generate answers without needing an additional retrieval step.

ORQA (Lee et al., 2019) adopts a Inverse Cloze Task (ICT) to pre-train retriever, which forces each sentence's embedding close to context sentences.

REALM (Guu et al., 2020a) incorporates a retriever as a module into language model and trains the whole model over masked entity spans.

We directly report the results listed in their papers as they follow the same experiment settings.

We also add two knowledge-guided language models as baselines. Though not targeted at QA problem, these two methods are both designed to capture structured knowledge.

KnowBERT (Peters et al., 2019) adds entity embedding to each entity mention in text, and adopts the entity linking objective to pre-train the model.

KEPLER (Wang et al., 2019) uses Knowledge Embedding objective, i.e., TransE, to guide embedding encoded over entity description.

We initialize DPR base encoders by the released pre-trained models of these two work, and then fine-tune on each QA dataset with the same procedure.

We also add a Unsupervised Question Answering (**Unsup.QA**) (Lewis et al., 2019) as a baseline. For each entity as the answer, Unsup.QA selects a passage containing the entity as context passage and a cloze question. The cloze question is later re-written by a machine translator to natural language. We use the generated QA dataset to pre-train both

	QA System Name	Pre-Training Task for QA	NQ (58.9k/3.6k)	Trivia QA (60.4k/11.3k)	WQ (2.5k/2k)
Supervised	BM25+BERT (Lee et al., 2019)	-	26.5	47.1	17.7
	HardEM (Min et al., 2019a)	-	28.1	50.9	-
	GraphRetriever (Min et al., 2019b)	-	34.5	56.0	36.4
	PathRetriever (Asai et al., 2020)	-	32.6	-	-
	DPR (Karpukhin et al., 2020)	-	41.5	56.8	34.6
Pre-Trained for QA	T5 (large) (Raffel et al., 2020)	T5 (Multitask)	29.8	-	32.2
	ORQA (Lee et al., 2019)	ICT	33.3	45.0	36.4
	$\text{REALM}_{\text{Wiki}}$ (Guu et al., 2020a)	REALM	39.2	-	40.2
	$\text{REALM}_{\text{News}}$ (Guu et al., 2020a)	REALM	40.4	-	40.7
	DPR (KnowBERT (Peters et al., 2019))	Entity Linking	39.1	56.4	34.8
	DPR (KEPLER (Wang et al., 2019))	TransE	40.9	57.1	35.2
	DPR (Unsup.QA (Lewis et al., 2019))	Cloze Translation	41.9	57.3	36.5
	Ours, DPR (RGPT-QA)	RGPT-QA	**43.7**	**59.2**	**40.9**

Table 2: **End-to-end QA** Exact Match Accuracy (%) on test sets of three Open-Domain QA datasets, with the number of train/test examples shown in paretheses below. All the results except the last four rows are copied from the original papers. "–" denotes no results are available. Models in the first block are initialized by BERT/RoBERTa and then directly fine-tuned on the supervised QA datasets. While models in the second block are initialized by RoBERTa and then tuned on some QA pre-training tasks first, and then fine-tuned on the supervised QA datasets.

the retriever and reader of the DPR framework.

4.2 Experimental Results

Pre-Train Model	NQ	Trivia QA	WQ
RoBERTa	78.4 / 63.3	79.4 / 72.6	73.2 / 58.1
KnowBERT	76.7 / 62.6	78.9 / 72.2	73.4 / 58.3
KEPLER	77.9 / 62.8	79.7 / 72.9	74.5 / 58.6
Unsup.QA	78.6 / 63.7	79.9 / 73.0	74.5 / 59.1
RGPT-QA	**80.1 / 64.8**	**81.2 / 73.7**	**76.7 / 61.0**

Table 3: **Retrieval (left)** accuracy over Top-20 results and **Reader (right)** Exact Match over Golden-Passages on validation sets of three Open-Domain QA datasets.

Mask	NPS	$\mathcal{L}_{\text{distill}}$	$\mathcal{L}_{\text{rel}}$	NQ	Trivia QA	WQ
✓	✓	✓	✓	44.3	59.8	41.4
✗	✓	✓	✓	39.7	56.3	34.2
✓	✗	✓	✓	43.5	58.1	39.8
✓	✓	✗	✓	43.8	59.3	40.8
✓	✓	✗	✗	43.1	58.5	40.0

Table 4: **Ablation** of RGPT-QA components on validation sets of three Open-Domain QA datasets. Mask: Mask target entity from question and source entity from passage; NPS: Two-level Negative Passage Sampling.

Table 2 summarizes the overall EM accuracy of the QA systems on the three datasets. The DPR framework pre-trained by RGPT-QA outperforms all other open-domain QA systems. Comparing with DPR without pre-training, RGPT-QA achieves 2.2%, 2.4% and 6.3% enhancement in EM accuracy on the three datasets.

B	K	NQ	Trivia QA	WQ
128	2	80.1	81.2	76.6
128	1	79.7	80.8	76.1
64	2	79.6	80.6	75.8
64	1	79.2	80.1	75.3

Table 5: **Ablation** of batch size and negative sampling for retrieval pre-training. B: Batch Size; K: Number of other passages as negative sample.

Comparing with other pre-training tasks for QA, RGPT-QA outperforms ORQA by 10.4%, 14.2% and 4.5% on the three datasets, and outperforms $\text{REALM}_{\text{News}}$ by 3.3% and 0.2% on NQ and WQ. This demonstrates that the model performance can be enhanced by leveraging relational QA dataset guided by Grounded Relational Wiki-Graph. We provide a detailed analysis in Sec. 4.3.

KnowBERT and KEPER encode structural knowledge into pre-trained language models. Both models focus on generating meaningful entity embedding, and are not designed to infer relations between entities for question answering. From the table, KEPLER trained via TransE performs slightly better than KnowBERT trained via entity linking, and RGPT-QA outperforms KEPLER by 2.8%, 2.1%, 5.7% on the three datasets.

Similar to RGPT-QA, Unsup.QA (Lewis et al., 2019) also generates QA data from Wikipedia. This baseline slightly improves DPR by 0.4%, 0.5%, 1.9% on the three datasets, while our RGPT-QA outperforms it by 1.8%, 1.9%, 4.4%. As discussed in Sec 3.1, one of the main reasons that

our graph-based QA generation strategy performs better is that we adopt grounded description passages $desc.(t, s)$ and $desc.(s, t)$ from different documents as questions and contexts. This avoids the lexical overlap problem in Unsup.QA and help model to capture relational facts.

We also show the retrieval and reader performance separately on validation sets in Table 3. Compared with DPR without pre-training, RGPT-QA improves top-20 accuracy of Retriever by 1.7%, 1.8%, and 3.5%, and improves EM accuracy of Reader by 1.5%, 1.1%, and 2.9%. Also, RGPT-QA outperforms all the other pre-training baselines. This shows that RGPT-QA improves both the retrieval and reader steps of open-domain QA.

Ablation Studies. We then analyze the importance of each model component in RGPT-QA. One key strategy is to mask out the target answer from questions and mask out source entities from passages during retrieval training. This can avoid the model using the entity surface to find the correct passage and answer. Without using masking strategy, the average EM performance drops 5.1%. This shows that it is essential to apply the mask strategy to avoid shortcut in QA pre-training. Next, we replace the hard negative passage sampling during retrieval pre-training with random batch sampling. The average EM performance drops 1.4%, showing the importance of hard negative samples. Finally, we study the unsupervised relation loss $\mathcal{L}_{\text{distill}}$ and the supervised $\mathcal{L}_{\text{rel}}$. Removing them leads to 0.5% and 1.3% performance drop, which shows the benefit of training the model to explicitly infer the relation from questions.

Another key component is the negative passage sampling for dense retrieval pre-training. We study how the batch size and number of negative sample influence the performance of trained retrieval. As is shown in Table 5, increasing batch size and negative sample size can improve the performance of retriever. Even with a small batch size and negative sample, our pre-training framework could still achieves better performance against non-pretrain baseline, showing that our approach is not sensitive to these two hyperparameters.

Few-Shot QA Performance. We analyze the improvement of RGPT-QA when only a few labelled training samples are available. We fine-tune DPR initialized by RGPT-QA on subset of Natural Questions with different percentages. As is shown in Figure 4, RGPT-QA consistently outperforms DPR without pre-training, and the improvement is more significant with small data. Specifically, when only 0.5% (594) labelled QA pairs are provided, the DPR pre-trained by RGPT-QA can still achieve 26.0% Val EM accuracy, significantly higher than 9.4% achieved by the DPR without pre-training. The results show that RGPT-QA provides a good initialization for QA systems and reduce the requirement of large human-annotated QA dataset.

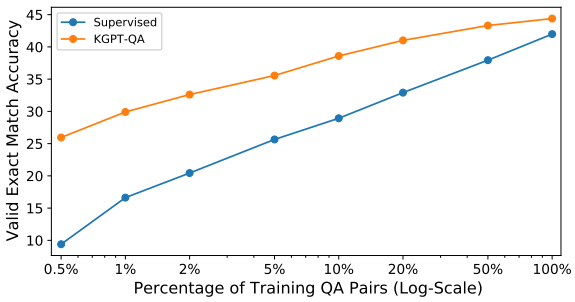


Figure 4: Few-shot QA experiment. Figure shows EM accuracy in validation set of DPR model with and without RGPT-QA pre-training, fine-tuned with different percentage of data on Natural Questions.

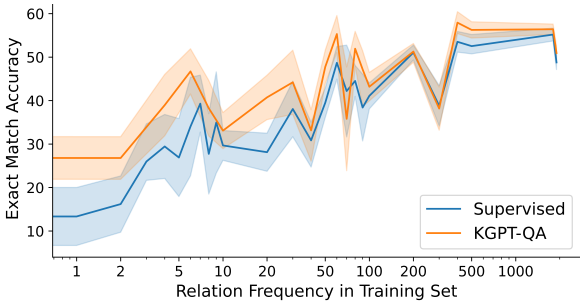


Figure 5: Long-tail relation experiment. EM accuracy of questions in validation set with different relation frequency in training set.

4.3 Generalization for long-tail relations.

As pointed out in Section 2, existing QA datasets suffer high relation bias, and thus a QA model trained on these datasets cannot generalize well to questions with long-tail relations. We thus analyze whether our RGPT-QA can remedy this issue. As is shown in Figure 5, the performance improvement of RGPT-QA against the supervised baseline is much more significant for the questions with infrequent relations. Specifically, for all relations appear less than 5 times in training set, the average EM accuracy of RGPT-QA is 33.3%, significantly higher than 22.4% achieved by DPR without pre-

training. This indicates that our relation QA generation method could indeed improve the performance on QA pairs with long-tail relations. Detailed prediction results are shown in Table 11 in Appendix.

5 Related Works

Unsupervised QA via Question Generation To train a QA system without human annotation of QA pairs, Unsupervised QA has been proposed by Lewis et al. (2019) to generate synthetic $\langle context, question, answer \rangle$ data for training QA models. Lewis et al. (2019) synthesize the QA data by: 1) run NER or noun chunkers over randomly sampled English Wikipedia paragraphs to extract $answers$; 2) Treat the paragraphs surrounding the answer as $context$; 3) Treat the context as clozestyle question and feed into a unsupervised machine translator to generate $natural\ questions$. Some follow-up works also utilize template (Fabbri et al., 2020) and pre-trained language model (Puri et al., 2020) over masked cloze-style questions for more human-readable questions. These cloze-style unsupervised QA methods achieve promising performance than previous heuristic QA baselines but underperform supervised ones. The main limitation is that the question is generated with the masked context as input, resulting in severe overlap of lexicon and word surface with the context. Consequently, the QA model might utilize the lexical pattern as a shortcut to find the answer. To address the problem of context-question lexical overlap, Dhingra et al. (2018) assume each article has an introductory paragraph, and use this paragraph to generate answer. Li et al. (2020) retrieve the Wikipedia cited document as context, Pan et al. (2020) leverage structured tables to extract key information from context, with which to synthesize questions.

To tackle the challenges in previous studies, our framework propose to leverage the Wikipedia hyperlinks and Wikidata relations as the bridge to connect two entities with linked descriptions. With one description as question and the other as context, the question and context are semantically relevant and lexical different, which naturally solve the problem without involving any additional module.

Knowledge-Guided Pre-Training Recently, researchers investigated to inject structured knowledge into pre-trained language models. Zhang et al. (2019) and Peters et al. (2019) propose to add entity embedding to each entity mentions in text, and add entity linking objective to guide model capture structured knowledge. Wang et al. (2019) encode entity text description as entity embeddings and train them via TransE objective. Though these work show improvements over several natural language understanding tasks, they are not dedicated to open-domain question answering tasks.

There are also several pre-training studies for QA. For retrieval, Lee et al. (2019) propose an inverse cloze task, which treats a random sentence as query and the surrounding contexts as ground-truth evidence to train a QA retrieval model. Guu et al. (2020b) propose to explicitly add a retriever module in the language model to train the retriever via language modelling pre-training. For reader, Xiong et al. (2020) propose to a weakly supervised pre-training objective. They construct some fake sentences by replacing the entities in a sentence with the other entities of the same type, and train the model to discriminate original sentence from the fake ones. Verga et al. (2020) incorporate the knowledge graph triplets into language model, so the model could utilize the triplets to predict correct entity. Sun et al. (2021) extend this work by learning a virtual knowledge base by inferring the relation between two co-occurring entity pairs.

Compared with these works, our RGPT-QA mainly differs in: 1) We do not change the base QA model, so the pre-training framework could be applied to any QA systems. 2) We explicitly model the relations between entities, which proves to benefit QA pairs with less frequent relation patterns.

6 Conclusion

In this paper, we propose a simple yet effective pre-training framework RGPT-QA. We leverage both the Wikipedia hyperlinks and Wikidata relation triplets to construct Grounded Relational WikiGraph, based on which we generate relational QA dataset. We then pre-train a QA model to infer the latent relation from the question, and then conduct extractive QA to get the target answer entity. RGPT-QA improves the performance of the state-of-the-art QA frameworks, especially for questions with long-tail relations.

Acknowledgement

This work was partially supported by NSF III-1705169, NSF 1937599, DARPA HR00112090027, Okawa Foundation Grant, and Amazon Research Awards.

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Relation	Frequency	Question	True Answer
P161 (cast member)	1915	what was the geeks name in 16 candles	anthony michael hall
P175 (performer)	1844	who sang the original blinded by the light	bruce springsteen
P676 (lyrics by)	519	who sings the song i can see clearly now the rain is gone	johnny nash
P86 (composer)	442	who made the beavis and butthead theme song	mike judge
P725 (voice actor)	334	who plays the voice of tiana in princess and the frog	anika noni rose
P1346 (winner)	283	who has won the 2017 womens singles wimbledon tennis tournament	garbiñe muguruza
P50 (author)	263	where does the saying standing on the shoulders of giants come from	bernard of chartres
P17 (country)	257	where did the black panther party take place	united states
P527 (has part)	198	the unit of area in mks system is	metre
P162 (producer)	134	who is in the video do n 't worry be happy	bobby mcferrin
P276 (location)	117	where will the summer olympics be held in 2020	tokyo
P840 (narrative location)	103	what state is a christmas story based in	indiana
P915 (filming location)	98	where was the movie the english patient filmed	tunisia
P710 (participant)	88	who died at the gunfight at okay corral	billy clanton
P170 (creator)	87	who came up with britain 's got talent	simon cowell
P1308 (officeholder)	87	who is the first lady of the usa	melania trump
P361 (part of)	74	who sings if you want to destroy my sweater	weezer
$P39_r$ (R: position held)	64	who is the attorney general for new jersey	gurbir grewal
P138 (named after)	64	who proved that mar 's orbit is elliptical not circular	nicolaus copernicus
P112 (founded by)	61	who created a settlement house with the help of other social reformers	ellen gates starr
$P161_r$ (R: cast member)	60	who is miss sue in the blind side	kathy bates
$P31_r$ (R: instance of)	57	the world 's oldest epic tale told in poetry is called the epic of	epic of gilgamesh
P58 (screenwriter)	57	who wrote the story for the shape of water	vanessa taylor
P61 (discoverer or inventor)	55	who developed the analytical engine which had features of present day computers	charles babbage
P26 (spouse)	53	who does young catherine marry in wuthering heights	hareton earnshaw
P1923 (participating team)	52	who did the bengals play in the super bowl	san francisco 49ers
$P166_r$ (R: award received)	51	which indian actor has won the most national awards	amitabh bachchan
P674 (characters)	50	who said better to reign in hell than serve in heaven	satan
P279 (subclass of)	49	when does dna replication occur during the eukaryotic cell cycle	mitosis
$P361_r$ (R: part of)	49	where does the transmission of electrical impulses in the heart begin	sinoatrial node
P131 (is located in)	46	where is saba university school of medicine located	saba
$P279_r$ (R: subclass of)	45	what are the names of the three pedals on a piano	soft pedal
P54 (member of sports team)	41	what team does steph curry brother play for	dallas mavericks
$P1344_r$ (R: participant in)	38	who won rupauls drag race all stars three	trixie mattel
P495 (country of origin)	37	where was the movie snow white and the huntsman filmed	united kingdom
P39 (position held)	34	who is the present speaker of lok sabha 2018	sumitra mahajan
P127 (owned by)	33	who owns the independent newspaper in the uk	alexander lebedev
$P607_r$ (R: conflict)	32	in the civil war who had more soldiers	union army
P31 (instance of)	32	what kind of bridge is the mackinac bridge	suspension bridge
$P1441_r$ (R: present in work)	29	what is the dads name in the adams family	gomez addams
$P175_r$ (R: performer)	28	who does sean astin play in lord of the rings	samwise gamgee
P36 (capital)	28	what is the capital of dadra and nagar haveli	silvassa
P921 (main subject)	24	what disease did susannah have in brain on fire	anti-nmda receptor encephalitis
P186 (material used)	22	what is the liquid in a magic 8 ball	alcohol
$P179_r$ (R: part of the series)	22	what is the second book in the mortal instruments series	city of ashes
$P793_r$ (R: significant event)	21	which territories did the us gain in the spanish-american war	puerto rico
P115 (home venue)	21	where does portland 's nba basketball team the portland trailblazers play	moda center
P371 (presenter)	21	who won beat bobby flay shrimp and grits	bobby flay
P180 (depicts)	19	who r the 4 presidents on mt . rushmore	abraham lincoln
$P800_r$ (R: notable work)	19	the explorer accurately mapped the coasts of europe and north africa	piri reis
P136 (genre)	17	scott joplin is best known as a composer of what kind of music	ragtime
P1431 (executive producer)	16	who hosted the daily show before trevor noah	jon stewart
P47 (shares border with)	16	which indian states share a border with delhi	uttar pradesh
$P54_r$ (R: member of sports team)	16	who scored the first goal in dallas stars history	neal broten
P144 (based on)	16	the tribute money depicts a scene from the	gospel of matthew
P57 (director)	15	who is the director of welcome to new york	chakri toleti
P488 (chairperson)	15	who is the leader of the democratic party now	tom perez
P403 (watercourse outflow)	15	what sea does the nile river flow into	mediterranean sea
P1889 (different from)	14	how to do alt codes on a mac	option key
P1441 (present in work)	14	when does luke skywalker find out leia is his sister	return of the jedi
P734 (family name)	14	who threw the first brick in the stonewall riots	johnson
P1269 (facet of)	14	which supreme court case established the separate but equal doctrine	plessy v. ferguson
P706 (takes place in)	13	what region of the world is greece in	southern europe
P176 (manufacturer)	13	who built the gerald r ford aircraft carrier	newport news shipbuilding
P84 (architect)	12	scottish architect who developed st martins in the field	james gibbs
P150 (contains)	12	what is the name of capital of argentina	buenos aires
P1532 (country for sport)	12	cristiano ronaldo what country does he play for	portugal
P800 (notable work)	12	what was the first book that charles dickens published	the pickwick papers
P641 (sport)	11	what is the number 1 sport in the usa	american football
P1001 (applies to jurisdiction)	11	who won the schenck v. united states case	united states
P206 (on lake)	11	where is ellis island located in new york	upper new york bay
P178 (developer)	11	ms office 2000 was developed by which company	microsoft
P166 (award received)	11	who won best actor in the academy awards this year	gary oldman
$P102_r$ (R: party)	11	who was known as the father of indian national congress	mahatma gandhi
P449 (original broadcaster)	10	what cbs channel is the late late show on	cbs
P2438 (narrator)	10	whos the main character in the great gatsby	nick carraway
P264 (record label)	10	who did the soundtrack for beverly hills cop	mca records
$P674_r$ (R: characters)	10	where is the story of joseph in the bible found	book of genesis
P1891 (signatory)	10	who has started reducing emissions from deforestation and forest degradation	brazil
$P138_r$ (R: named after)	10	roman god of underworld also called orcus and pluto	pluto
P69 (educated at)	10	where did jaren jackson senior play college basketball	georgetown university
P1877 (after a work by)	10	the movie catch me if you can is based on who	frank abagnale

Table 6: Relation with grounded QA pairs of Natural Questions Training Set (Top 1-82 by frequency).

Relation	Frequency	Question	Answer
P155 (follows)	10	what is the latest george rr martin book	a dance with dragons
P1029 (crew member)	10	who was the first to step on moon	neil armstrong
P3342 (significant person)	10	who was picked over kevin durant in the draft	greg oden
P749 (parent organization)	9	what does chi mean in chi st lukes	catholic health initiatives
P735 (given name)	9	who won in the war of alexander and porus	alexander
$P463_r$ (R: member of)	9	countries in the warsaw pact during the cold war	soviet union
P1376 (capital of)	8	cape town is the capital of what country	south africa
P156 (followed by)	8	the things we do for love song artist	10cc
P451 (unmarried partner)	8	who does elena date in the vampire diaries	stefan salvatore
P40 (child)	8	howard stark is the father of what superhero	iron man
P159 (headquarters location)	8	where is the head office of rbi located	mumbai
P287 (designed by)	8	who built the world first binary digit computer z1	konrad zuse
P551 (residence)	8	where did dorothy live in the wizard of oz	kansas
P647 (drafted by)	8	who does dwyane wade play for in the nba	miami heat
P30 (continent)	8	on what continents was the roman empire located at the height of its expansion	asia
P634 (captain)	7	who is the captain of kolkata knight riders	dinesh karthik
P828 (has cause)	7	what is the most common manifestation of portal hypertension – induced splenomegaly	cirrhosis
P123 (publisher)	7	who made all the call of duty games	activision
P2408 (set in period)	7	when did hunchback of notre dame take place	1482
$P27_r$ (R: country of citizenship)	7	who was the last ruler of the tang dynasty	emperor ai of tang
$P135_r$ (R: movement)	7	who wanted the catholic church to reform and address	martin luther
$P101_r$ (R: field of work)	7	who invented the steam engine in the 1800s	james watt
P941 (inspired by)	6	who does squealer in animal farm represent in the russian revolution	vyacheslav molotov
$P136_r$ (R: genre)	6	who are the founding fathers of hip hop	grandmaster flash
$P466_r$ (R: occupant)	6	where did the patriots play before gillette stadium	foxboro stadium
$P119_r$ (R: place of burial)	6	who is buried in the great mausoleum at forest lawn glendale	michael jackson
P88 (commissioned by)	5	who built the castle in just one day	toyotomi hideyoshi
P110 (illustrator)	5	scary stories to tell in the dark artist	stephen gammell
P1366 (replaced by)	5	the old greek city-state of byzantium was rebuilt and became known as	constantinople
P169 (chief executive officer)	5	who become the ceo indian it company wipro in 2016	abidali neemuchwala
P3279 (statistical leader)	5	who is the captain of argentina national team fifa world cup 2018	lionel messi
P2388 (leader's office)	5	who does the us department of justice report to	united states attorney general
$P53_r$ (R: family)	5	who began the first dynasty of egyptian rulers	narmer
$P2522_r$ (R: victory)	5	who won season 2 of food network star	guy fieri
P823 (speaker)	5	who wrote we shall fight on the beaches	winston churchill
P748 (appointed by)	5	who can appoint comptroller and auditor general of india	president of india
P1363 (points/goal scored by)	5	who scored the winning goal for england in the 1966 world cup final	geoff hurst
P22 (father)	5	who was the king after david in the bible	solomon
P1027 (conferred by)	5	who presents national film award traditionally in india	directorate of film festivals
P750 (distributed by)	5	who own the rights to the black panther movie	walt disney studios motion pictures
P825 (dedicated to)	5	who was the song candle in the wind written about	marilyn monroe
P974 (tributary)	5	a tributary flowing into the mississippi from the east is the	ohio river
P8031 (perpetrator)	4	who was the guy who shoot in las vegas	stephen paddock
P885 (river source)	4	what is the starting point of the mississippi river	lake itasca
P631 (structural engineer)	4	who designed the first tunnel under the river thames	marc isambard brunel
$P17_r$ (R: country)	4	what are the countries of the united arab emirates	sharjah
P98 (editor)	4	who was an abolitionist who published and autobiography and anti-slavery newspaper	frederick douglass
P737 (influenced by)	4	qbasic is the extension of which programming language	quickbasic
$P206_r$ (R: on lake)	4	where does the river mekong start and end	mekong delta
P2789 (connects with)	4	a ship traveling through the panama canal could be crossing from the	atlantic ocean
P740 (location of formation)	4	where did the beatles started their career as a band	liverpool
P4743 (animal breed)	4	what kind of dog is bo and sunny	portuguese water dog
P466 (occupant)	4	who used to play in the alamo dome	utsa roadrunners
$P2868_r$ (R: subject has role)	4	who is the commander in chief of military	president of the united states
P5053 (fastest lap)	4	who won the 2018 chinese formula 1 grand prix	daniel ricciardo
$P106_r$ (R: occupation)	4	who is the griot that sings the epic	balla fasséké
$P50_r$ (R: author)	4	what is the title of langston hughes 's first book of poetry	the weary blues
P118 (league)	4	what conference is ohio state in for football	big ten conference
$P2416_r$ (R: sport discipline)	4	who has the world record for the long jump	galina chistyakova
P1552 (has quality)	4	which metal does the word ' ferrous ' refer to answer in words not symbols	iron
P8111 (unit)	4	unit of measure for area of a triangle	square metre
P179 (part of the series)	4	which games are in crash bandicoot n sane trilogy	crash bandicoot
$P131_r$ (R: is located in)	4	what is the name of capital of andhra pradesh	amaravati
P7047 (enemy of)	4	who sent doomsday to the end of time	superman
$P725_r$ (R: voice actor)	3	who does the voice of the cat in the hat	martin short
$P61_r$ (R: discoverer or inventor)	3	who discover the simple microscope first time and when	zacharias janssen
P6 (head of government)	3	who was the founder of the mauryan empire	chandragupta maurya
$P264_r$ (R: record label)	3	this artist was signed in 1952 by atlantic and brought a string of hits	ray charles
P462 (color)	3	what color was the white house when it was built	white
P533 (target)	3	who was killed in the ides of march	julius caesar
P972 (catalog)	3	who is on the top ten most wanted	alexis flores
P1344 (participant in)	3	india 's first olympic medal win as a free nation	1948 summer olympics
P106 (occupation)	3	what did pete best play in the beatles	drummer
$P1366_r$ (R: replaced by)	3	what is the old name for south africa	union of south africa
$P171_r$ (R: parent taxon)	3	what type of organism is made up of prokaryotic cells	archaea
P1411 (nominated for)	3	who won best director at the academy awards	guillermo del toro
P8345 (media franchise)	3	what is the first star wars movie in the series	star wars
P1433 (published in)	3	the story of seven ages by william shakespeare	as you like it
$P20_r$ (R: place of death)	3	who was the explorer that reached the cape of good hope at the southern tip of africa	bartolomeu dias
P87 (librettist)	3	who wrote the libretto for dido and aeneas	nahum tate
P3764 (pole position)	3	who won the abu dhabi grand prix 2017	valtteri bottas
P559 (terminus)	3	what is the southern end of the appalachian trail	springer mountain

Table 7: Relation with grounded QA pairs of Natural Questions Training Set (Top 83-164 by frequency).

Relation	Frequency	Question	Answer
P366 (use)	3	what did the chinese use oracle bones for	pyromancy
P706$_r$ (R: takes place in)	3	what seven countries make up the subcontinent of south asia	sri lanka
P610 (highest point)	3	what is the highest point in the pyrenees mountains in france	aneto
P461 (opposite of)	3	the results of dehydration reactions can be reversed by	hydration reaction
P467 (legislated by)	3	which group is responsible for adopting the declaration of independence	second continental congress
P272 (production company)	3	what is the tv show riverdale based off of	archie comics
P140$_r$ (R: religion)	3	who is the leader of the baptist denomination	thomas helwys
P1419 (shape)	3	what is the shape of the earth 's orbit around the sun	ellipse
P942$_r$ (R: theme music)	3	clubs who sing you 'll never walk alone	liverpool f.c.
P376 (planet)	3	this planet is home to the great red spot	jupiter
P5202 (adapted by)	3	who wrote the lyrics for the song my way	paul anka
P171 (parent taxon)	3	trees of the betel nut genus of palms	areca
P509 (cause of death)	3	what was the cause of the tollund man 's death	hanging
P527$_r$ (R: has part)	3	the bronchi are considered to be part of the	respiratory system
P2849 (produced by)	3	where does red blood cell formation occur in adults	bone marrow
P460 (said to be the same as)	3	the word zion is an ancient biblical term that referred to what city	jerusalem
P1346$_r$ (R: winner)	3	when did the philadelphia eagles last win the super bowl	super bowl lii
P2341 (indigenous to)	3	dogri language is spoken in which state of india	himachal pradesh
P355 (subsidiary)	3	the main agency under the department of homeland security that is responsible for border security is	u.s. customs and border protection
P457 (foundational text)	3	where does one look to find the powers of a corporation	articles of incorporation
P108$_r$ (R: employer)	3	who is the current ceo of mcdonald 's corporation	steve easterbrook
P1923$_r$ (R: participating team)	3	last time houston astros have been to the world series	2017 world series
P8345$_r$ (R: media franchise)	2	what star wars movie came out before the last jedi	the empire strikes back
P112$_r$ (R: founded by)	2	real name of raj chandra in rani rashmoni	babughat
P113$_r$ (R: airline hub)	2	what airline has its hub in charlotte nc	american airlines
P156$_r$ (R: followed by)	2	what is the origin of the coptic language	egyptian language
P137 (operator)	2	who owns the white house in washington dc	national park service
P1552$_r$ (R: has quality)	2	what physical quantity is a measure of the amount of inertia and object has	mass
P2175 (disease treated)	2	topiramate (topamax trokendi) is used to treat which of the following diseases	epilepsy
P25 (mother)	2	who is carries mother on days of our lives	anna dimera
P170$_r$ (R: creator)	2	when was beverly cleary 's first book published	henry huggins
P641$_r$ (R: sport)	2	where do the rocks from curling come from	ailsa craig
P451$_r$ (R: unmarried partner)	2	who does raven end up with in the comics	beast boy
P4584 (first appearance)	2	what was the first game waluigi was in	mario tennis
P2670 (has parts of the class)	2	what do you rest a golf ball on	tee
P1040 (film editor)	2	who is the director of the film avatar	james cameron
P1056$_r$ (R: material produced)	2	who introduced the first micro processor in 1971	intel
P1192$_r$ (R: connecting service)	2	where does the eurostar leave from in paris	gare du nord
P1830 (owner of)	2	where do the carolina panthers play home games	bank of america stadium
P241$_r$ (R: military branch)	2	who served as the general of confederate forces during the civil war	robert e. lee
P111 (measure of)	2	joule is unit of . in mks system	energy
P19$_r$ (R: place of birth)	2	who was the last person to live in versaille	louis xvi
P291 (place of publication)	2	where was the institutes of the christian religion published	basel
P1056 (material produced)	2	by product of saponification of fats and oils	soap
P140 (religion)	2	of which religion is the avesta a sacred book	zoroastrianism
P137$_r$ (R: operator)	2	where do the fisher cats play in nh	northeast delta dental stadium
P162$_r$ (R: producer)	2	producer and director of silence of the lambs	edward saxon
P1582 (fruit of (taxon))	2	a plant that produces a type of bean	fabaceae
P286 (head coach)	2	2) who is the current manager of liverpool fc	jürgen klopp
P118$_r$ (R: league)	2	which nrl teams have never won a premiership	new zealand warriors
P413 (fielding position)	2	what position did ryan tannehill play in college	quarterback
P35 (head of state)	2	the longest serving samma ruler in sindh was	jam nizamuddin ii
P3173 (offers view on)	2	where is the leaning tower of pisa in italy located	pisa
P7959 (historic county)	2	archipelago that includes neolithic settlement of skara brae	orkney
P598$_r$ (R: commands)	2	union generals civil war army of the potomac	ambrose burnside
P306 (operating system)	2	what operating system does the macbook pro have	macos
P101 (field of work)	2	what did robert moog contribute to the music industry in the 1960s	electronic music
P27 (country of citizenship)	2	where is the actress that played wonder woman from	israel
P463 (member of)	2	what band is the girl from the grinch in	the pretty reckless
P4969 (derivative work)	2	what is the first book of pretty little liars	pretty little liars
P19 (place of birth)	2	where did anakin live before he met qui-gon	tatooine
P3938 (named by)	2	who developed the concept of an iron law of wages	ferdinand lassalle
P157$_r$ (R: killed by)	2	who does sansa end up with in game of thrones	ramsay bolton
P607 (conflict)	2	what battle did the tuskegee airmen help win	world war ii
P366$_r$ (R: use)	2	what kind of wax are crayons made from	paraffin wax
P551$_r$ (R: residence)	2	who lived in the land of nod east of eden	cain
P113 (airline hub)	2	where does porter airlines fly from in toronto	billy bishop toronto city airport
P927$_r$ (R: anatomical location)	2	where do the ilium the ischium and the pubis meet	acetabulum
P1000 (record held)	1	who holds the world record for 100 meters	usain bolt
P2541 (operating area)	1	what states does the i pass work in	illinois
P4647 (place of first performan)	1	where does medea go at the end of the play	athens
P483 (studio)	1	where was the dark side of the moon recorded	abbey road studios
P197$_r$ (R: adjacent station)	1	where does the rocky mountaineer leave from in vancouver	pacific central station
P36$_r$ (R: capital)	1	what country is in between poland and lithuania	kaliningrad oblast
P1589$_r$ (R: lowest point)	1	which state is bordered to the north by the artic ocean	alaska
P669 (located on street)	1	what area of paris is the eiffel tower	champ de mars
P1478 (has immediate cause)	1	the united states ' war on terror began in the wake of which of the following events	september 11 attacks
P1269$_r$ (R: facet of)	1	the enlightenment idea of separation of powers included which branches of government	legislature
P2679 (author of foreword)	1	who wrote the current edition of the catechism	pope john paul ii
P669$_r$ (R: located on street)	1	where did the beatles take the abbey road picture	abbey road studios
P837$_r$ (R: day in year)	1	what are three other names for makar sankranti	magh bihu
P3113 (does not have part)	1	which element in group 1 is not an alkaline metal	hydrogen

Table 8: Relation with grounded QA pairs of Natural Questions Training Set (Top 165-246 by frequency).

Relation	Frequency	Question	Answer
P7047$_r$ (R: enemy of)	1	who took out the governor 's eye on walking dead	michonne
P59$_r$ (R: constellation)	1	brightest star in the constellation lyra dan word	vega
P3092 (film crew member)	1	who pioneered animated movies with his short feature steamboat willie in 1928	walt disney
P2348$_r$ (R: time period)	1	the main port of axum was the red sea city of	adulis
P736 (cover art by)	1	who wrote all quite on the western front	erich maria remarque
P469 (lakes on river)	1	where does the water from the nile come from	lake victoria
P205 (basin country)	1	in what country would you find the yellow river	china
P921$_r$ (R: main subject)	1	who began the systematic study of political science	american political science review
P4934 (calculated from)	1	a quantity 15 m / s to the north is a measure of	velocity
P1411$_r$ (R: nominated for)	1	who won the first oscar for best actress	janet gaynor
P4147 (conjugate acid)	1	give the name and formula for the acid derived from the following anion chlorite	chlorous acid
P276$_r$ (R: location)	1	the area between the tigris and euphrates rivers	mesopotamia
P413$_r$ (R: fielding position)	1	who has the most clean sheets in the world	iker casillas
P710$_r$ (R: participant)	1	in the second punic war between carthage and rome carthage formed an alliance with	massylii
P2563$_r$ (R: superpower)	1	who taught defence against the dark arts in book number 5	dolores umbridge
P2596 (culture)	1	which american civilization was located in a rain forest	maya civilization
P1071$_r$ (R: location of creation)	1	where does the young ones develop in humans	uterus
P1535$_r$ (R: used by)	1	what programming language is used in microsoft access	visual basic for applications
P400 (platform)	1	what consoles can you play star wars battlefront on	xbox one
P4913 (dialect of)	1	what type of arabic is spoken in palestine	south levantine arabic
P1066 (student of)	1	who is the minister during the regime of chandragupta	chanakya
P3342$_r$ (R: significant person)	1	who went before michael jordan in the draft	hakeem olajuwon
P86$_r$ (R: composer)	1	who wrote the power of love celine dion	candy derouge
P1427 (start point)	1	where did the tour de france start in 1954	amsterdam
P3373 (sibling)	1	who is the older brother mario or luigi	mario
P2512$_r$ (R: series spin-off)	1	which came first family guy or american dad	family guy
P2505$_r$ (R: carries)	1	where does the appalachian trail cross the hudson river	bear mountain bridge
P5009 (complies with)	1	what type of port is used by flash drives	usb mass storage device class
P2094 (competition class)	1	what weight class did muhammad ali fight in	heavyweight
P1889$_r$ (R: different from)	1	what name is given to fats that are liquid at room temperature	oil
P7937 (form of creative work)	1	wagner 's tristan und isolde is an example of	opera
P522 (type of orbit)	1	what 's the orbit of the international space station	low earth orbit
P1303 (instrument)	1	what kind of bass does john cooper play	bass guitar
P737$_r$ (R: influenced by)	1	who are the members of 3 6 mafia	juicy j
P263 (official residence)	1	where did zeus spend most of his time	mount olympus
P201 (lake outflow)	1	where does the water from lake okeechobee drain	caloosahatchee river
P178$_r$ (R: developer)	1	operating system developed in 1969 at at&t 's bell laboratories	unix
P1312 (has facet polytope)	1	what is the opposite side of a right angle triangle	hypotenuse
P20 (place of death)	1	where did omri build his new political capital	samaria
P2936 (language used)	1	what is the national language of saudi arabia	arabic
P460$_r$ (R: said to be the same as)	1	what color is a school bus yellow or orange	chrome yellow
P682$_r$ (R: biological process)	1	which protein is responsible for the breakdown of a fibrin clot	plasmin
P3300 (musical conductor)	1	who did the music for ready player one	alan silvestri
P547 (commemorates)	1	name of ship that landed at plymouth rock	mayflower
P2079 (fabrication method)	1	the medium of the artwork that decorates the sistine chapel ceiling is	fresco
P1037 (director / manager)	1	who led the red shirts to victory in sicily	giuseppe garibaldi
P972$_r$ (R: catalog)	1	who is number one on america 's most wanted	jason derek brown
P263$_r$ (R: official residence)	1	which greek god ruled over a gloomy kingdom	hades
P2152 (antiparticle)	1	a packet or unit of light energy is called a	photon
P1462 (standards body)	1	who is responsible for creating the standards used on the internet	internet engineering task force
P664$_r$ (R: organizer)	1	when did they start using gloves in ufc	ufc 14
P937 (work location)	1	where did beethoven live most of his life	vienna
P4675$_r$ (R: appears in the form of)	1	what was robin 's name in batman and robin	dick grayson
P2596$_r$ (R: culture)	1	a ruined city on crete centre of the minoan bronze age civilisation	knossos
P2554 (production designer)	1	who made the movie all dogs go to heaven	don bluth
P1038 (relative)	1	what is the first name of huey 's dewey 's and louie 's uncle	donald duck
P3301 (broadcast by)	1	who is broadcasting the super bowl on sunday	nbc
P943 (programmer)	1	who wrote the first computer virus called elk cloner	rich skrenta
P30$_r$ (R: continent)	1	is puerto rico in north or central america	puerto rico
P135 (movement)	1	what kind of art did claude monet paint	impressionism
P5051 (towards)	1	which part of the cerebral hemisphere is supplied by the middle cerebral artery	cerebrum
P676$_r$ (R: lyrics by)	1	what beatles songs does paul play drums on	dear prudence
P364 (original language)	1	what language do they speak in kite runner	dari
P1071 (location of creation)	1	a town in the netherlands known for the production of a tin glazed earthenware	delft
P400$_r$ (R: platform)	1	name of the windows phone 8.1 virtual assistant	cortana
P452 (industry)	1	what did the hudson bay company do for canada	retail
P598 (commands)	1	who controlled or ordered the viet cong in combat	hoàng văn thái
P1303$_r$ (R: instrument)	1	who introduced the bass clarinet as a solo instrument in jazz	herbie mann
P3491 (muscle insertion)	1	what is the origin and insertion of the semimembranosus	medial condyle of tibia
P530 (diplomatic relation)	1	which two countries are on the western border of bolivia	chile
P1542 (has effect)	1	what disease is caused by bacterium treponema pallidum	syphilis
P1336 (territory claimed by)	1	the falkland islands are off the coast of what south american country	argentina
P747 (editions)	1	what is the latest ms office for mac	microsoft office 2016
P7153 (significant place)	1	on which island is the uss arizona memorial	honolulu
P610$_r$ (R: highest point)	1	the highest peak in north america mt . mckinley (or denali) is located in the state of	alaska
P1809 (choreographer)	1	who danced the lead role in appalachian spring	martha graham
P81 (connecting line)	1	what line is parsons green on tube map	district line
P122 (type of government)	1	what type of government did european settlers create in south africa in 1909	constitutional monarchy
P97$_r$ (R: noble title)	1	who was crowned the first holy roman emperor	charlemagne
P4552 (mountain range)	1	what mountain range is the blue mountains part of	great dividing range
P658 (tracklist)	1	what was u2 's lead single from ' the joshua tree '	with or without you
P195 (collection)	1	where is the original star spangled banner located	national museum of american history
P609 (terminus location)	1	where does route 66 start on the east coast	chicago

Table 9: Relation with grounded QA pairs of Natural Questions Training Set (Top 247-329 by frequency).

Triplet	<'edward heath', ?, "admiral's cup">
Question	<mask> of edward heath which 1971 the british prime minister, edward heath, captained one of the winning boats. recent history.
True Passage	...he captained britain's winning team for the **admiral's cup** in 1971 – while prime minister – and also captained the team in the 1979 fastnet race...
Pred. Relation	participant in: 0.33, winner: 0.19, participant: 0.04, victory: 0.03, sport: 0.03
Pred. Answer	admiral's cup (✓)
Triplet	<'scary stories to tell in the dark', 'P110 (illustrated by)', 'stephen gammell'>
Question	<mask> of scary stories to tell in the dark which evocative, nightmarish illustrations for alvin schwartz's "scary stories to tell in the dark" trilogy, he has illustrated nearly seventy
True Passage	scary stories to tell in the dark is a series of three collections of short horror stories for children, written by alvin schwartz and originally illustrated by **stephen gammell**...
Pred. Relation	illustrator: 0.13, creator: 0.11, author: 0.07, editor: 0.02, notable work: 0.02
Pred. Answer	stephen gammell (✓)
Triplet	<'heeley', ?, 'sheffield tramway'>
Question	<mask> of heeley which first routes, to attercliffe and carbrook, brightside, heeley, nether edge and owlerton opened between 1873
True Passage	...**sheffield's old tramway** stretched from sheffield city centre to woodseats and heeley was at a time the terminus...
Pred. Relation	located in the administrative territorial entity: 0.21, located in the administrative territorial entity: 0.14, location: 0.07, shares border with: 0.04, terminus: 0.03
Pred. Answer	old tramway (✗)
Triplet	<'pablo goncálvez', ?, 'patricia miller (tennis)'>
Question	<mask> of pablo goncálvez which luisa, was the first victim of uruguayan serial killer pablo goncálvez, who suffocated the 26-year old to
True Passage	...the victim was 26 years old, had a degree in history and a practicing teacher, and was the sister of the well-known tennis player **patricia miller**...
Pred. Relation	sibling: 0.29, relative: 0.13, spouse: 0.04, relative: 0.04, place of burial: 0.02
Pred. Answer	patricia miller (✓)
Triplet	<'chai prakan district', 'P131$_r$ (R: located in the administrative territorial entity)', 'chai prakan', >
Question	<mask> of chai prakan district which, is home to the district headquarters of<mask><mask><mask><mask> district in the far north of<mask>iang m<mask> province
True Passage	...**chai prakan** is divided into four sub-districts ("tambons"), which are further subdivided into 44 administrative villages ("muban")...
Pred. Relation	located in the administrative territorial entity: 0.43, capital: 0.42, contains administrative territorial entity: 0.04, different from: 0.02, contains settlement: 0.01
Pred. Answer	chai prakarn (✓)
Triplet	<'gothic western', ?, 'lorin morgan-richards'>
Question	<mask> of gothic western which lifestyle and his series "the goodbye family" has been categorized as gothic western. in addition to his work, rich
True Passage	...in the young adult series, "the goodbye family" by **lorin morgan-richards** has been considered gothic western with an element of humor...
Pred. Relation	genre: 0.92, movement: 0.02, field of work: 0.0, genre: 0.0, occupation: 0.0
Pred. Answer	lorin morgan-richards (✓)
Triplet	<'quentin bell', 'P40 (child)', 'virginia nicholson'>
Question	has kid of quentin bell which her father was the writer and art historian quentin bell, nephew of
True Passage	...they had three children: julian bell, an artist and muralist; cressida bell, a notable textile designer; and **virginia nicholson**, the writer of "charleston: a bloomsbury house...
Pred. Relation	child: 0.98, father: 0.0, student: 0.0, sibling: 0.0, relative: 0.0
Pred. Answer	virginia nicholson (✓)
Triplet	<'take me back to london', 'P361 (part of)', 'no.6 collaborations project'>
Question	<mask> of take me back to london which the border" featuring cabello and cardi b, and "take me back to london" featuring stormzy
True Passage	...it was released as the eighth single from sheeran's fourth studio album **"no.6 collaborations project" (2019)**...
Pred. Relation	part of: 0.88, performer: 0.07, lyrics by: 0.01, producer: 0.0, followed by: 0.0
Pred. Answer	"no.6 collaborations project (✓)
Triplet	<'u.s. route 441 in georgia', ? , 'lakemont, georgia'>
Question	<mask> of u.s. route 441 in georgia which area between u.s. route 23/441 and<mask> rabun.<mask><mask> has a post office with zip code
True Passage	...from there it passes through the blue ridge mountain communities of wiley, **lakemont**, and tiger, the latter of which includes...
Pred. Relation	terminus location: 0.15, terminus: 0.11, located in the administrative territorial entity: 0.08, terminus: 0.05, connects with: 0.03
Pred. Answer	wiley (✗)
Triplet	<'anjelica huston', 'P57$_r$ (R: directed by)', 'agnes browne'>
Question	<mask> of anjelica huston which irish romantic comedy-drama film directed, produced by, and starring anjelica huston, based on the book "the mammy" by brendan o
True Passage	...her next directorial effort, the irish dramedy **"agnes browne" (1999)** —in which she also starred as the title character— was released to mixed reviews...
Pred. Relation	terminus location: 0.15, terminus: 0.11, located in the administrative territorial entity: 0.08, terminus: 0.05, connects with: 0.03
Pred. Answer	"agnes browne (✓)
Triplet	<'cadillac eldorado', ?, 'oldsmobile toronado'>
Question	<mask> of cadillac eldorado which 1967, cadillac adopted its own version of the upp for the cadillac eldor<mask>, using the cadillac v8 engine.
True Passage	...by 2000, the eldorado was the last of a dying breed: its buick riviera and **oldsmobile toronado** stablemates had been discontinued, as had its perennial rival the lincoln mark...
Pred. Relation	follows: 0.38, followed by: 0.05, brand: 0.04, based on: 0.02, subclass of: 0.02
Pred. Answer	oldsmobile toronado (✓)
Triplet	<'corsican nuthatch', 'P138 (named after)', 'john whitehead (explorer)'>
Question	eponym of corsican nuthatch which82 where he discovered a bird new to science, the corsican nuthatch. white<mask> travelled in malacca, north borneo,
True Passage	...the corsican nuthatch was discovered by the english collector **john whitehead** in june 1883 when he shot a specimen while on a trip in the corsican mountains...
Pred. Relation	named after: 0.97, discoverer or inventor: 0.01, named after: 0.0, different from: 0.0, place served by transport hub: 0.0
Pred. Answer	john whitehead (✓)
Triplet	<'mutual information', ?, 'information content'>
Question	<mask> of mutual information which formula_13 is also often used for the related quantity of mutual<mask>, many authors use a lowercase formula_14 for
True Passage	...it quantifies the "**amount of information**" (in units such as shannons (bits), nats or hartleys) obtained about one random variable through observing the other random variable...
Pred. Relation	subclass of: 0.48, different from: 0.08, opposite of: 0.06, subclass of: 0.05, said to be the same as: 0.03
Pred. Answer	information theory (✗)
Triplet	<'oculus (film)', 'P272 (production company)', 'intrepid pictures'>
Question	<mask> of oculus (film) which". in may 2012 filmdistrict acquired the film rights to what would become "oculus". soon after, the film released on april 11
True Passage	...eventually, **intrepid pictures** expressed interest in producing the film "as long as you don't do it found footage"....
Pred. Relation	production company: 0.29, producer: 0.19, distributed by: 0.07, screenwriter: 0.04, director: 0.03
Pred. Answer	intrepid pictures (✓)

Table 10: Examples of generated Relational QA datapoints and the predicted relation and answer by DPR pre-trained via RGPT-QA.

Relation Name	Freq	Question	True Answer	RGPT-QA Prediction	Supervised DPR Prediction
R: based on	0	theme song to bridge on the river kwai	the river kwai march	the river kwai march	march
subject has role	0	phenothiazines such as chlorpromazine were the first type of	antipsychotic	psychiatry	medication
practiced by	0	who does the call to prayer in islam	muezzin	muezzin	mosque
industry	1	what product or market does netflix deal with	streaming media	streaming media	netflix
made from	2	mohair is made from the fleece of what animal	angora goat	angora goat	goat
offers view on	2	where is the leaning tower of pisa built	pisa	pisa	pisa the leaning tower of pisa
R: residence	2	who is the founder of ramoji film city	ramoji rao	ramoji rao	telugu film producer ramoji rao
mother	2	who bore abraham first son in the bible	hagar	sarah	yishma'el
R: employer	3	who is the youngest judge currently sitting on the u.s. supreme court	neil gorsuch	neil gorsuch	leonard i. garth
R: has part	3	corpora cavernosa and corpus spongiosum are anatomic structures of	penis	penis	corpus cavernosum
indigenous to	3	urdu is the official language of which state	pakistan	jharkhand	jammu and kashmir
river source	4	what is the source of the colorado river	la poudre pass	la poudre pass	colorado begins at la poudre pass
tributary	5	river that joins the severn near chepstow crossword	river wye	river lugg	lugg
R: family	5	who was the second ruler of the davidic monarchy	solomon	jeroboam	solomon's son, rehoboam
R: genre	6	who is considered by many to be the father of soul	james brown	james brown	sam cooke
R: genre	6	who brought surf music to a national audience	the beach boys	the beach boys	dean
parent organization	8	who owns flying j and pilot truck stops	pilot corporation	pilot corporation	berkshire hathaway
narrator	10	who plays the mom in cheaper by the dozen	bonnie hunt	bonnie hunt	kate
educated at	10	where did the gabbie show go to college	university of pittsburgh	university of pittsburgh	the university of pittsburgh
director	15	who did the movie i can only imagine	erwin brothers	the erwin brothers	bart millard
executive producer	16	who stars in the movie the quiet place	john krasinski	john krasinski	emily blunt
R: player of	16	pitt players in the nfl hall of fame	mike ditka	ruben brown	tony dorsett
R: player of	16	who was the captain when india played its first-ever odi	ajit wadekar	srinivasaraghavan	s
shares border with	16	what state is directly west of north dakota	montana	montana	manitoba
depicts	19	who raised the american flag on iwo jima	michael strank	ira hayes	rene gagnon, ira hayes
depicts	19	faces of the presidents on mt. rushmore	abraham lincoln	thomas jefferson	theodore roosevelt
R: notable work	19	who won the 2015 great british baking show	nadiya hussain	joanne wheatley	edd kimber
presenter	21	who presented gardeners world from 2008 to 2010	toby buckland	joe swift	carol klein and joe swift
presenter	21	who are the new hosts of british bake off	noel fielding	noel fielding	sandi toksvig
material used	22	what kind of meat is on a t-bone	beef	cut from the short loin	tenderloin
main subject	24	new york times co v sullivan held that there must be proof of	actual malice	malice	truth
instance of	29	what kind of money do they use in russia	kopeks	ruble or rouble	the russian ruble or rouble
instance of	29	how does a plane wing create lift which physics concept applies	force	newton's second law	reaction force
country of origin	37	who used the springfield rifle in the civil war	united states	marine corps	army
R: subclass of	44	waste water that contain solid and liquid excreta refers to	sewage	sewage	pathogens
R: subclass of	44	when a blood vessel is injured the first phase in hemostasis to occur is	coagulation	wound healing	endothelial injury
located in	46	what part of new york is coney island	brooklyn	brooklyn	borough of brooklyn
R: part of	49	what regions of south asia have the highest population densities	philippines	philippines	indonesia
R: part of	49	what led to the downfall of the incan empire	battle of cajamarca	captured	victory
characters	50	the settlement of the israelites in canaan is the theme of which book	joshua	the book of joshua	book of joshua
R: award received	51	most number of national awards for best actress	shabana azmi	five	three
participating team	52	who did melbourne beat in the 1964 grand final	collingwood football club	collingwood	melbourne football club
spouse	53	who does jackson end up with in sons of anarchy	tara knowles	tara knowles	opie winston
R: instance of	56	which of the following is the si unit for length	metre	meter	litre
R: instance of	56	what is the most abundant neurotransmitter in the nervous system	serotonin	serotonin	glutamate
R: instance of	56	pricing tactics lower the price of a product below cost	loss leader	loss leader	increase in profits
named after	64	who was saint patrick's day named after	saint patrick	saint patrick	saint patrick
part of	70	arabian sea is the part of which ocean	indian ocean	northern indian ocean	the northern indian ocean
part of	70	who produces the most tires in the world	lego	lego tire: lego tire a lego	lego blocks. lego
officeholder	87	what is the name of the governor of new jersey	phil murphy	phil murphy	democrat phil murphy
participant	88	what two groups were fighting in the chinese civil war	communist party of china	communist party of china	republic of china
participant	88	who played the superbowl halftime show last year	bruno mars	beyoncé	coldplay
participant	88	who came second in the overall ranked of the tour de france last year	rigoberto urán	rigoberto urán	chris froome
filming location	98	what city does the terminator take place in	los angeles	los angeles	hemdale
filming location	98	where was back to the future three filmed	monument valley	monument valley	jamestown, california

Table 11: Comparison of the prediction of DPR initialized by RGPT-QA with DPR without pre-training. These are all samples that two models made different predictions, and the relation frequency in the training set is less than 100.

Question	Predicted Answer	True Answer	Match?	Predicted Relation
Who played mr darling on andy griffith show	Denver Pyle	Denver Pyle	✓	P175 (performer)
Who voices flik in a bug's life	Dave Foley	Dave Foley	✓	P725 (voice actor)
Who's the dad of blair waldorf's baby	Chuck	Chuck	✓	P26 (spouse)
Where do you think glaciers can be found today	rocky mountains	mountain ranges on every continent	✗	$P31_r$ (R: instance of)
When did ginny weasley join the quidditch team	half-blood prince	half-blood prince	✓	$P674_r$ (R: characters)
When does far cry 5 for ps4 come out	2018	march 27, 2018	✗	P400 (game platform)
When do millennials end and gen z start	mid-1990s to mid-2000s	mid-1990s	✗	P155 (preceded by)
Who killed hotchner's wife in criminal minds	George Foyet	George Foyet	✓	P7047 (enemy of)
Who said walk tall and carry a big stick	u.s. president theodore roosevelt	theodore roosevelt	✗	P170 (creator)
Who does the voice of sheen from jimmy neutron	Jeffrey Garcia	Jeffrey Garcia	✓	P734 (family name)
How many seasons of gossip girl are there	6	6	✓	P527 (has part)
What can be used to detect the charge of particles	ionization detectors	particle detector	✗	$P279_r$ (R: subclass of)
Who was robin in the original batman series	Burt Ward	Burt Ward	✓	P161 (cast member)
What is the song funky cold medina about	a love potion	a fictional aphrodisiac	✗	P138 (named after)
What do you call a quarter pounder in france	royal cheese	royal cheese	✓	P1889 (different from)
Who developed the first alternating current electric system	Galileo Ferraris	Nikola Tesla	✗	P61 (inventor)
Who won s5 of rupaul's drag race	Jinkx Monsoon	Jinkx Monsoon	✓	P1346 (winner)
When was the svalbard global seed vault built	2006	2006	✓	P88 (built for)
Who was the mother of dragons married to	Khal Drogo	Dothraki Horselord Khal Drogo	✗	P26 (spouse)
Which organization sets monetary policy for the united states	the federal reserve	the federal reserve	✓	P1001 (jurisdiction)
What season of the voice was miley cyrus on	eleventh	season 11	✗	P179 (part of series)
Upon which document in american history is the language of the declaration of sentiments based	united states declaration of independence	united states declaration of independence	✓	P144 (based on)
What kind of car does dale earnhardt jr drive	chevrolet camaro	chevrolet	✗	P54 (played for)
How many times did brazil win the fifa world cup	five	five	✓	P1344 (participant in)
Second life is an example of a	massively multiplayer online role-playing games	an online virtual world	✗	P31 (instance of)
What percentage of the world's population lives in east asia	22%	22%	✓	$P276_r$ (R: located in)
From which body part shurpnakha drive her name	fingernails	fingernails	✓	P186 (ingredient)
How many chapters does the gospel of john have	four	21	✗	P527 (has part)
Who sang the original always on my mind	b.j. thomas	gwen mccrae	✗	P175 (performer)
Where does the amazon river start and finish	atlantic ocean	atlantic ocean	✓	P403 (watercourse outflow)
Who did dwayne wade play for last year	the miami heat	miami heat	✗	P647 (drafted by)
Who owns the rights to the power rangers	Hasbro	Hasbro	✓	P127 (owned by)

Table 12: Predicted relations for those QA pairs in Natural Questions Valid Set that cannot be aligned to WikiData.