CodRED: A Cross-Document Relation Extraction Dataset for Acquiring Knowledge in the Wild

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Abstract

Existing relation extraction (RE) methods typically focus on extracting relational facts between entity pairs within single sentences or documents. However, a large quantity of relational facts in knowledge bases can only be inferred across documents in practice. In this work, we present the problem of cross-document RE, making an initial step towards knowledge acquisition in the wild. To facilitate the research, we construct the first human-annotated cross-document RE dataset CodRED. Compared to existing RE datasets, CodRED presents two key challenges: Given two entities, (1) it requires finding the relevant documents that can provide clues for identifying their relations; (2) it requires reasoning over multiple documents to extract the relational facts. We conduct comprehensive experiments to show that CodRED is challenging to existing RE methods including strong BERT-based models. We make CodRED and the code for our baselines publicly available at https://github.com/thunlp/CodRED.

1 Introduction

Relation extraction (RE), which aims to extract relations between entities from plain text, serves as an essential resource in populating knowledge bases (KBs) from large-scale corpora automatically. Existing RE systems typically focus on either sentence-level RE (Socher et al., 2012; Zeng et al., 2014, 2015; Lin et al., 2016; Qin et al., 2018) or document-level RE (Li et al., 2016; Peng et al., 2017; Quirk and Poon, 2017; Yao et al., 2019), and have achieved promising results on several public benchmarks. However, these works can only extract relational facts from single sentences or documents containing both two target entities, which inevitably limits the coverage of knowledge acquisition. According to our statistics on Wikipedia documents, for over 57.6% of the relational facts in Wikidata (Erxleben et al., 2014; Vrandečić and Krötzsch, 2014), the head and tail entities do not co-occur in a single document. This inspires that it is crucial to break through the limitations of document boundaries to acquire knowledge in the wild.

In this work, we make an initial step in this direction, presenting the problem of cross-document RE (cross-doc RE), which requires a RE system to infer the relation between two entities by retrieving and reasoning over multiple documents. Compared to conventional sentence/document-level RE, cross-doc RE presents new challenges in two levels of granularity: (1) at the coarse-grained level, given an entity pair, RE systems are required to find multiple informative documents for each entity, instead of restricted to the sentence/document containing both entities; (2) on the fine-grained level, RE systems are required to perform both intra- and cross-document reasoning in multiple documents and then predict the relations by aggregating information. The challenges come from not only the non-trivial nature of each phase, but also the intrinsic inter-dependence among the phases.

Fig. 1 shows an example for cross-doc RE, in which Amun-her-khepeshef and Merneptah do not co-appear in a single document. To identify their relation, we need to first retrieve the relevant documents for each entity and then recognize two reasoning text paths in these documents. The first reasoning text path (the documents titled “Nefertari” and “Memephtah”) shows that both target entities are the son of Ramesses II, and the second one indicates that they also share a common sister Meritamen. The information of these two reasoning text paths is complementary to each other and suggests the relation between Amun-her-khepeshef and Merneptah is sibling.

Although several datasets have been proposed for investigating cross-document reasoning (Over and Yen, 2004; Yang et al., 2018), there is still
no dataset designed for cross-doc RE. To facilitate the research, we construct the first human-annotated Cross-document Relation Extraction Dataset named as CodRED, aiming to test the RE systems’ ability of knowledge acquisition in the wild. CodRED has the following features: (1) it requires natural language understanding in different granularity, including coarse-grained document retrieval, as well as fine-grained cross-document multi-hop reasoning; (2) it contains 30, 504 relational facts associated with 210, 812 reasoning text paths, as well as enjoys a broad range of balanced relations, and long documents in diverse topics; (3) it provides strong supervision about the reasoning text paths for predicting the relation, to help guide RE systems to perform meaningful and interpretable reasoning; (4) it contains adversarially-created hard NA instances to avoid RE models to predict relations by inferring from entity names instead of text information (Peng et al., 2020).

To assess CodRED, we propose two representative solutions based on the strong BERT-based RE architecture, including (1) a pipeline model that first extracts a relational graph for each document, and then reasons over these graphs to extract the relation; and (2) an end-to-end model that jointly considers text across different documents in text paths to predict the relation. We conduct comprehensive experiments under both closed and open settings on CodRED. Experimental results show that CodRED is very challenging to the strong BERT-based solutions, indicating ample room for further research.

2 Data Collection

In this section, we introduce the data collection process of the cross-doc RE dataset. Given an entity pair \((h, t)\), cross-doc RE consists of two stages: (1) Document Retrieval, which finds multiple relevant documents of given entity pairs \(h\) and \(t\) from a large-scale corpus \(D\), which could provide clues for identifying their relationship; (2) Cross-Document Reasoning, which reasons over the retrieved documents to predict the relation.

To focus on the problem of cross-doc RE, we only annotate the relational facts where the composing entities do not co-occur in a single document. As illustrated in Fig. 1, a relational fact can be better inferred through multiple complementary reasoning text paths (i.e., two documents that contain the head and tail entity respectively, and are connected by bridging entities) in the wild. Hence, we want to construct a cross-doc RE dataset in which each instance contains a relational fact with multiple reasoning text paths as well as strong supervision about supporting evidence.

However, it is infeasible for human annotators to label multiple reasoning text paths over documents for a relational fact from scratch. We thus carefully design a principled data collection pipeline for cross-doc RE. Specifically, we construct CodRED from the English Wikipedia and Wikidata through three stages: (1) Generating distantly supervised annotations from Wikipedia documents, which serves as relation recommendations for further human annotations; (2) Annotating relations and the corresponding supporting evidence by multiple independent crowdworkers; (3) Generating adversarial hard NA instances (i.e., entity pairs and text paths that do not express positive relations) to alleviate the reasoning shortcuts in RE. Here we introduce main procedure of data collection, and we refer readers to the appendix for more details.
2.1 Distantly Supervised Annotation Generation

To select relational facts and their relevant reasoning text paths for human annotations, we align Wikipedia articles with Wikidata under the distant supervision assumption (Mintz et al., 2009). To ensure the quality and encourage the diversity of the corpus, we select the articles in the Wikipedia popular page list¹ as the document candidates, which cover various topics in open domain. Specially, we first recognize named entity mentions in the documents by a BERT-based (Devlin et al., 2019) named entity recognition system. Then we link these named entity mentions to Wikidata, and merge the entity mentions with same IDs in Wikidata. Finally, we align each named entity pair from two different documents with their relations in Wikidata to form one reasoning text path of this entity pair.

However, different from previous works that adopt sentence-level (Riedel et al., 2010; Han et al., 2018) or document-level (Yao et al., 2019) distant supervision, we find that directly performing distant supervision for entities across documents will lead to substantial noise (i.e., over 95% raw relation labels from distant supervision are not expressed in the given text paths, according to manual verification on distantly supervised samples). To address the problem, we introduce additional requirements that there exists at least one relational reasoning chain between the target entity pair in two documents. Here, the reasoning chain is defined as a relational path between the entity pair \((h, t)\), which is bridged by another entity \(e\) appearing in both documents, such that \(e\) has relation with \(h\) and \(t\) in Wikidata respectively. The reasoning chain can be formally denoted as \(h \xrightarrow{r_1} e \xrightarrow{r_2} t\). For example, in Fig. 1, \textit{Amun-her-khepeshef} and \textit{Merneptah} are linked by a reasoning chain consisting of two relational facts: \textit{Amun-her-khepeshef} \textit{father} \textit{Ramesses II} \textit{child} \textit{Merneptah}. To alleviate the noise in reasoning chains, we ask experts to manually filter out frequent reasoning chains that cannot induce the target relations. We observe that this constraint can substantially alleviate the wrong-labeling problem, with less than 45% noise in the improved distantly supervised annotations.

In addition, we further sub-sample the annotations of frequent relations for two reasons: (1) to balance the relation distribution; (2) to prevent the strong correlation between the relations and documents (i.e., we make sure that the co-occurrence of any relation and document is fewer than 20), inspired by Welbl et al. (2018).

2.2 Human Annotation Generation

After obtaining distantly supervised relation annotations, we ask human annotators to label them to remove the noisy annotations in distant supervision. To ensure the dataset quality, we provide principled guidelines as well as training to the annotators, and utilize a test task to examine if the annotators understand our annotation principle. We also conduct regular quality inspections for each annotator, and update the feedback in the individual reports.

During the annotation, human annotators are asked to label (1) \textit{text paths}, i.e., whether a relational fact can be supported by the given text path without external knowledge, and (2) \textit{evidence sentences}, i.e., selecting a set of evidence sentences (if any) from the reasoning text path that can fully support the relational fact. Each reasoning text path is annotated independently by at least two annotators, and will be further annotated by a third annotator if there are disagreements in whether the relational fact can be supported.

After human annotation, each entity pair is associated with multiple reasoning text paths, which are labeled with either positive relations, or \textit{NA} indicating no relation. The final relations between an entity pair are aggregated from all paths in between, by the union of the positive relations in each path. The final relation will be \textit{NA} if there is no positive path in between. We discard the text paths if the relations can be extracted from one document, i.e., there are evidence annotations in only one document.

2.3 Adversarial NA Instance Generation

We find obvious reasoning shortcuts in our and most existing RE datasets (Peng et al., 2020), i.e., there are obvious correlations between some relations and entity names. This makes RE models could easily infer the relations from the entity names without performing complex reasoning in text, which may over-estimate their performance. To overcome this problem, we employ a novel adversarial \textit{NA} instance generation strategy at entity-level, which requires RE models to pay more attention to understanding text. Moreover, we also add

¹https://en.wikipedia.org/wiki/Wikipedia:Lists_of_popular_pages_by_WikiProject
²\(r_1\) and \(r_2\) can be relations or inverse relations in Wikidata.
We first introduce the data split process, including which is important in real-world applications. (i.e., there are text paths between entity pairs), which is important in real-world applications.

**Entity-Level Adversarial NA Instance.** We select challenging adversarial NA entity pairs, i.e., entity pairs that do not have relations in Wikidata but are assigned with high confidence of positive relations by RE models. Specifically, we first train a series of RE classifiers (i.e., CNN, LSTM and BERT, etc.) that extract the relations based on entity names. Then for each positive entity pair \((h, t)\), we generate an NA entity pair by replacing \(h\) or \(t\) with the top entity ranked by the confidence of the ensemble models. We generate 23,069 adversarial NA entity pairs in total, reducing the percentage of positive instances to 15.6% in the dataset.

**Path-Level Adversarial NA Instance.** To test the model ability of cross-document reasoning in the presence of noise in closed setting (see Sec. 3), we generate NA reasoning text paths for both human-annotated and adversarial NA entity pairs. Given an entity pair, we enumerate all possible reasoning text paths consisting of two documents that contain head and tail entities respectively, and share at least one common entity. To select hard NA paths, we choose the reasoning text paths that have the most shared entities between the composing documents.

### Table 1: Statistics of data split. (#Fact: the number of relational facts; #Path: the number of reasoning text paths; Pos.: Positive.)

| Set  | #Fact | #Path |
|------|-------|-------|
|      | Pos.  | NA    | Pos.  | NA    |
| Train| 2,733 | 16,668 | 8,623 | 120,925 |
| Dev  | 1,010 | 4,558  | 2,558 | 38,182 |
| Test | 1,012 | 4,523  | 2,505 | 38,019 |

Since CodRED requires natural language understanding in different granularity, we design two benchmark settings to fully evaluate each required capability including (1) document retrieval, and (2) cross-document reasoning.

**Closed Setting.** In this setting, we test model capabilities in cross-document reasoning. Given an entity pair, RE models need to extract relations based on the given positive text paths and NA text paths. The first challenge comes from intra- and cross-document multi-hop reasoning in each text path. RE models need to first resolve complex interactions between entities within long documents, which may require logical, coreference and commonsense reasoning (Yao et al., 2019). Then RE models have to overcome the semantic gap between documents, and perform cross-document multi-hop reasoning through multiple potential bridging entities (4.7 on average) to establish the relation in each reasoning text path. The second challenge is that RE models need to synthesize all information in multiple text paths to obtain the final relation.

**Open Setting.** This setting fully tests the ability of RE in the wild. Given a target entity pair, models need to first retrieve relevant documents for the entity pair from full English Wikipedia corpus (5,882,234 documents in total, 3,646 reasoning text path candidates for each entity pair on average), then perform cross-document reasoning with the retrieved documents to predict the relation. Compared with natural language queries in open domain question answering (Chen et al., 2017), the sparse query information in entity pairs presents unique challenges to document retrieval ability. The second challenge comes from both the quadratic number of potential paths (efficiency), and the fine-grained influence of document retrieval on the extraction of relations (effectiveness).

### 3 Post-Processing and Benchmarks

We first introduce the data split process, including the split of positive and NA entity pairs. (1) **Positive entity pair split.** We split the positive entity pairs into training, development and test set, such that there is no overlap in entity names under the same positive relations, to prevent the correlation between relations and entity names. (2) **NA entity pair split.** Adversarially-created NA entity pairs

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1. Here we use entity names to predict the relations, since we find it can effectively eliminate the reasoning shortcuts in our experiments, and also has better computation efficiency.

2. The percentage reflects the sparsity of positive relations in real-world RE scenarios (Zhang et al., 2017).
We refer readers to the appendix for more details. The documents cover a variety of topics, including science (24.6%), work (21.3%) and art (8.7%), etc. Besides, CodRED contains 4,755 positive relational facts and 13,686 positive reasoning text paths, along with 25,749 NA relational facts and 197,126 NA reasoning text paths. CodRED exhibits balanced relation distribution, where the most frequent positive relation accounts for less than 4.5%. (2) Documents. The documents cover a variety of topics, including geography (28.7%), entertainment (19.6%), and society (8.5%), etc. The average length of documents is 2,416 words, presenting challenges for modeling long text in both efficiency and effectiveness. We refer readers to the appendix for more details.

**Required Abilities.** We compare required abilities of CodRED with existing RE datasets in Table 2, including (1) sentence-level RE datasets TACRED (Zhang et al., 2017), FewRel (Han et al., 2018) and KnowledgeNet (Mesquita et al., 2019), and (2) document-level RE datasets BC5CDR (Li et al., 2016), DocRED (Yao et al., 2019) and DialogRE (Yu et al., 2020). Compared with existing RE datasets that mainly focus on extracting relations from local contexts, i.e., single sentences or documents, CodRED presents unique challenges in document retrieval and cross-document reasoning.

**Intra- and Cross-Document Reasoning.** Cross-doc RE requires both intra- and cross-document multi-hop reasoning. For intra-document reasoning, we randomly sample 500 positive reasoning text paths and annotate the number of hops needed within the documents. 1.3 hops are required within documents on average, indicating that there are 2.6 hops in each path on average. For cross-document reasoning, a crucial challenge comes from multiple potential bridging entities between documents (4.7 on average). Each reasoning text path is labeled with 4.8 supporting sentences on average, accounting for 2.7% sentences in each path. This means that models need to select correct and meaningful sentences and bridging entities for cross-document reasoning from rich context and severe distractions.

| Dataset     | DR | CDR | IDR | ISR |
|-------------|----|-----|-----|-----|
| TACRED      | ✓  |     |     |     |
| FewRel      | ✓  |     |     |     |
| KnowledgeNet| ✓  |     |     |     |
| BC5CDR      | ✓  | ✓   | ✓   | ✓   |
| DialogRE    | ✓  | ✓   | ✓   | ✓   |
| DocRED      | ✓  | ✓   | ✓   | ✓   |
| CodRED      | ✓  | ✓   | ✓   | ✓   |

Table 2: Abilities required in different RE datasets. (DR: document retrieval, CDR: cross-document reasoning, IDR: intra-document reasoning, ISR: intra-sentence reasoning.)

In this section, we design baseline models to assess the challenge of CodRED. In the closed setting, we design two representative baselines that perform cross-document reasoning based on strong architectures, including: (1) a pipeline model that first extracts a relational graph (i.e., graph containing entities and their relations) for each document, and then reasons over these graphs to extract the relation; and (2) an end-to-end model that jointly considers text across different documents in text paths to predict the relation. In the open setting, we first retrieve relevant documents and connect them into text paths, and then perform cross-document reasoning to predict the relation. We refer readers to the appendix for implementation details.

### 5.1 Document Retrieval

In the open setting, given an entity pair \((h, t)\) and a document set \(D\) (i.e., full Wikipedia corpus), we first find relevant documents to extract their relation. Due to the large number of possible documents containing \(h\) and \(t\) respectively, we explore several strategies to retrieve the relevant documents and connect them into text paths. Specifically, we enumerate all possible text paths between the target entity pairs (i.e., two documents that contain \(h\) and \(t\) respectively with shared entities) as candidates. We first present a random baseline, where the candidate paths are randomly sampled. We also experiment with several heuristic retrieval strategies, where text paths are ranked by the heuristic scores. Specifically, the score of a text path \((d_h, d_t)\) is given by: (1) entity count: multiplication of the occurrence number of \(h\) in \(d_h\) and the occurrence number of \(t\) in \(d_t\), (2) shared entity: number of shared entities that appears in both \(d_h\) and \(d_t\), or (3) TF-IDF: TF-IDF similarity (Manning et al., 2008) between the two documents. After ranking, we select top \(K\) paths with highest scores \(\{(d_{h_i}, d_{t_i})\}_{i=0}^{K}\).
We build a pipeline model that decomposes cross-document reasoning into three phases as follows:

1. **Intra-Document Relational Graph Extraction.** We predict the relations between the entities within each document containing head or tail entities using a BERT-based document-level RE model, resulting in a relational graph for each document.

2. **Cross-Document Relation Reasoning.** For each possible bridging entity \( e \) (i.e., any entity shared by two relational graphs), we predict the relation between the target entity pair based on the entity types of \( h, t \) and \( e \), and relation \( r_i \) between \((h, e)\), as well as the relation \( r_j \) between \((e, t)\). Note that the prediction is only based on the relational graphs without considering text. Specifically, we feed the concatenation of the embeddings of \( r_i \) and \( r_j \) and embeddings of the types of \( h, t \) and \( e \) (e.g., person, organization and location) into a fully connected layer to obtain the relation distribution.

3. **Relation Aggregation.** We finally obtain the relation between the target entity pair by aggregating relation scores from all bridging entities. For each relation, the aggregated score is obtained by the max relation score from all possible bridging entities in all text paths.

### 5.2.2 End-to-end Model

Despite their simplicity, pipeline models usually suffer from error propagation. We also design an end-to-end model that jointly considers text across documents in text paths to predict the relation.

Specifically, given a text path, we adopt BERT as the text encoder. Since intra- and cross-document text understanding are both important components in cross-doc RE, we introduce two relation prediction tasks, including: (1) **Intra-document relation prediction**, where the model is asked to predict intra-document relations labeled by distant supervision as in Yao et al. (2019). (2) **Cross-document relation prediction**, where the model needs to predict cross-document relations labeled in CodRED.

Specifically, in cross-document relation prediction, documents are first concatenated and then tokenized. Then we add entity markers to mark the positions of head/tail/bridging entity mentions. The tokens are fed into BERT to obtain the text path representation \( p_t \). After that, to select meaningful paths in the presence of noise, following previous works on distantly supervised RE, we synthesize all informative paths by selective attention mechanism (Lin et al., 2016) and obtain the aggregated representation \( x \). The aggregated entity pair representation \( x \) is then fed into a fully connected layer followed by a softmax layer to obtain the distribution of the relation between the entity pair.

Besides the entity-level supervision, we also incorporate path-level supervision using an auxiliary classification task, where models need to predict the relation expressed in each path based on \( p_t \).

## 6 Experiments

In this section, we assess the challenges of CodRED in both closed and open benchmark settings.

### 6.1 Evaluation Metrics

In closed setting, following previous works (Zeng et al., 2015; Lin et al., 2016), we evaluate our model using aggregate precision-recall curves, and report the area under curve (AUC), the maximum F1 on the curve and Precision@K (P@K). In open setting, we first retrieve relevant documents (top 16 paths) from full Wikipedia corpus, and then use the models trained in the closed setting to infer the relation between the entity pair. We report the mean average precision (MAP), Recall@K (R@K) and mean reciprocal rank (MRR) to show the performance of document retrieval.

### 6.2 Overall Results

We report experimental results in both settings in Table 3, where document retrieval in open setting is based on the best performing entity count strategy. From the results we observe that: (1) The overall performance in the two benchmark settings is unsatisfactory for both baseline models, demonstrating the challenge of cross-doc RE. (2) The end-to-end model consistently outperforms the pipeline model by a large margin in both settings. This indicates that the pipeline model, i.e., simple adaptation of existing document-level RE approaches, cannot well handle cross-doc RE. The results show the necessity of developing RE models that jointly model text across different documents tailored for cross-doc RE. (3) The performance of models in open setting is significantly lower than their counterparts in closed setting. Document retrieval results in Table 4 also indicate that simple heuristic retrieval strategies cannot well serve cross-doc RE. In summary, the results show that CodRED is challenging to existing RE models, where retrieving relevant documents in open domain and reasoning over multiple documents present their unique challenges.
### 6.3 Analysis

To provide better understanding of cross-doc RE and CodRED, we conduct comprehensive experiments and analysis. Unless otherwise specified, all the experiments and analysis are conducted in the closed setting on the development set.

**Path-level Supervision.** To investigate the effect of path-level annotations (i.e., annotation indicating whether the path expresses positive or NA relations) for cross-doc RE, we remove path-level supervision and report the results in Table 5, from which we observe that: (1) The model performance degrades in the closed setting when path-level supervision is removed. It indicates path-level supervision could effectively help to filter out the noise within multiple reasoning text paths. (2) In the open setting, the advantage of models supervised by path-level annotations shrinks. We hypothesize the reason is that the retrieved text paths in the open setting exhibit different distributions from the training set, making it difficult for the models to find the positive paths.

To verify the aforementioned hypothesis, we further evaluate the performance of relation classification given golden positive text paths and evidence sentences in the closed setting. Specifically, we remove the NA entity pairs, since they do not have golden positive text paths or evidence. Given an entity pair, we compare the performance of models that during evaluation are provided with (1) all text paths in between, (2) golden positive text paths, (3) golden evidence sentences. Results in Fig. 2 show that: (1) The performance of the end-to-end model improves significantly when golden positive text paths and evidence are given. This shows the importance and challenge of information selection from rich context for cross-doc RE. (2) The performance of the pipeline model degrades, since the number of reasoning chains in golden paths/evidence is very limited, which leads to over-fitting. (3) Extracting relations is challenging in CodRED even if golden evidence sentences are given, since models need to perform reasoning across multiple sentences and also overcome the semantic gap between different documents. In summary, the results indicate ample room for improvement in both selecting relevant information and reasoning over complex context.

**Intra- v.s. Cross-Document Supervision.** To investigate the importance of intra- and cross-document text understanding to cross-doc RE,
we ablate the corresponding supervision (see Sec. 5.2.2) and report the results in Table 6. We observe dramatic drops in performance when removing either intra- or cross-document supervision. This shows that cross-doc RE requires deep text understanding both within and across documents.

**Entity Names v.s. Context.** Previous works have shown that RE systems tend to exploit shallow clues in existing datasets, i.e., predict relations based on entity names, instead of inferring from contexts (Peng et al., 2020). To investigate the contribution of each information source in CodRED, we ablate each information source and report the results in Table 7: (1) **Entity Only.** Models are given only names of the entity pair to predict their relation. (2) **Context Only.** The mentions of head and tail entities in documents are replaced by special mask tokens. Experimental results show that models struggle to predict relations only from entity names, and masking entity names does not dramatically hurt the performance. This indicates that there are no obvious correlations between relations and entity names in CodRED, because of the existence of adversarial NA entity pairs (see Sec. 2.3). In summary, although entity names can provide useful information in many cases, CodRED encourages RE models to infer relations by reasoning in rich context, instead of relying on shallow correlation between relations and entity names. In this sense, CodRED provides a more reasonable benchmark for knowledge acquisition systems.

### 7 Related Work

A variety of RE datasets have been constructed to promote the development of RE systems in recent years, which can be categorized in two main categories: (1) **Sentence-level RE datasets** focus on extracting relations on sentence-level, where the composing entities of a relational fact must co-appear in single sentences, with the relations labeled by human annotators (Doddington et al., 2004; Walker et al., 2006; Hendrickx et al., 2010; Mesquita et al., 2019) or distant supervision (Riedel et al., 2010; Zhang et al., 2017; Elsahar et al., 2018). (2) **Cross-sentence RE datasets** focus on extracting cross-sentence relations from documents (Li et al., 2016; Peng et al., 2017; Quirk and Poon, 2017; Yao et al., 2019) or dialogues (Yu et al., 2020). Notably, NIST TAC SM-KBP 2019 Track aims to extract and link document-level KBs from different languages and modalities. However, these datasets are still limited at sentence-level or document-level without considering cross-document reasoning, which restricts the coverage of knowledge acquisition. Hence, we extend RE to cross-document level, and construct a large-scale human-annotated dataset CodRED to facilitate further research.

Cross-document natural language understanding has received increasing interest in recent years. Several datasets have been constructed including cross-document question answering (Yang et al., 2018; Welbl et al., 2018) and cross-document summarization (Over and Yen, 2004; Owczarzak and Dang, 2011; Fabbri et al., 2019). In comparison with existing datasets, our dataset is tailored for the task of RE with fine-grained path and evidence annotations, and investigates the more open and challenging scenario of knowledge acquisition.

### 8 Conclusion

In this work, we study the problem of cross-doc RE. To facilitate the research for the problem, we present the first human-annotated dataset CodRED, and propose two representative solutions. Experimental results show that CodRED is challenging for strong RE models, indicating ample room for improvement. In this work, we focus on acquiring knowledge from text paths consisting of two documents. In the future, we plan to further explore longer text paths to better facilitate knowledge acquisition in the wild.

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5 The results do not include the pipeline model, since both supervisions are necessary for the model to infer the relation.

6 https://tac.nist.gov/2019/SM-KBP/index.html
9 Ethical Considerations

In this section, we discuss the main ethical considerations of CodRED dataset: (1) Intellectual property protection. CodRED is constructed from Wikipedia and Wikidata, of which permissions are granted to copy, distribute and modify the contents under the terms of the Creative Commons Attribution-ShareAlike 3.0 Unported License and Creative Commons CC0 License respectively. (2) Privacy. The data collection procedure is designed for factual knowledge acquisition, and does not involve privacy issues. (3) Compensation. During relation annotation, the salary for annotating each relation instance is determined by the average time of annotation and local labor compensation standard. (4) Data characteristics. We refer readers to the appendix and data description file for more detailed characteristics of the dataset. (5) Potential problems. While principled measures are taken to ensure the quality of the dataset, there might still be potential problems with the dataset quality, which may lead to incorrect predictions in knowledge acquisition applications. However, moderate noise is common in large-scale modern KBs, even for human contributed contents, which should not cause serious issues.

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A Data Collection Details

Named Entity Annotation. To generate distantly supervised relation annotations, we first annotate named entities in the documents by a named entity recognition system. We fine-tune a BERT\textsubscript{LARGE} (Devlin et al., 2019) model on DocRED (Yao et al., 2019), which achieves 0.91 F1 score on the DocRED validation set. Second, we link each entity mention to Wikidata by matching the mention to the name and aliases of the entities. We link the mention to the most frequent entity in Wikidata with the same name or aliases (if any). After linking the entity mentions to Wikidata, we merge the entity mentions in a document that are linked to the same entities to provide extra coreference information. Finally, each entity is associated with a set of documents that contain the entity.

Noisy Reasoning Chain Filtering. In distantly supervised annotation generation, we introduce requirements that there exists at least one reasoning chain between the labeled entity pair in the text path. To alleviate the noise in reasoning chains, we ask experts to filter out frequent noisy reasoning chains that cannot induce the target relations. Denote \( h, t, b \) as head, tail and bridging entities respectively. Generally, noisy reasoning chains can be categorized into two types as follows:

**Type I.** The relation between \( h \) and \( t \) is different from the relation induced from the reasoning chain. For example, relation \textit{place of death} is different from the relation induced from \( h \text{ employer} \rightarrow b \text{ located in} \rightarrow t \). Type I accounts for 37.8% noisy reasoning chains.

**Type II.** There is large uncertainty in inducing the relation from the reasoning chain. For example, relation \textit{place of birth} cannot be induced from the relation \( h \text{ country of citizenship} \rightarrow b \text{ capital} \rightarrow t \). Type II accounts for 62.2% noisy reasoning chains.

Human Annotation. The annotators mainly consist of undergraduate students, and receive principle training for 4 weeks on average to fully pass the test task and regular inspections. During annotation, in addition to the relational fact, we highlight the mentions of target entities and bridging entities, and provide possible reasoning chains to assist human annotation. The salary for each relation instance is determined by the average time of annotation and local labor compensation standard. We refer readers to data description in data supplement for the user interface of our annotation platform.

Adversarial Negative Instance Generation. To alleviate the obvious correlations between relations and entity names, we employ an adversarial negative instance generation strategy. Specifically, we select entity pairs that do not have relations in Wikidata but are assigned with high confidence of positive relations by RE models.

Given a positive entity pair \((h, t)\), we generate negative entity pairs by replacing one of the entities. We first train several neural models that predicts the relation between an entity pair from entity names, including a BERT-based model, a CNN-based model, an LSTM-based model, a bilinear model, and a bag-of-words model. Specifically, the BERT-based model, CNN-based model, and LSTM-based model take the concatenation of entity names as input to predict the relation score. The bilinear model predicts the relation as follows:

\[
    s_r = \text{sigmoid}(h M_r t + b_r),
\]

where \( s_r \) is the score of relation \( r \), \( M_r \) and \( b_r \) are learnable parameters. \( h \) and \( t \) are entity name embeddings obtained from BERT as follows:

\[
    h = \text{BERT}(h) \quad \text{(2)} \quad t = \text{BERT}(t), \quad \text{(3)}
\]

where \( h \) and \( t \) are the name of the entity pair.

After that, for each positive entity pair \((h, t)\), we generate a negative entity pair by replacing one of the entities. We first select top 100 entities as candidates using the bilinear model due to its efficiency, then select the top entities ranked by the ensemble models as negative entities.

Data Split. In positive entity pair split, we aim to split the positive entity pairs into training, development and test set, such that there is no overlap in entity names under the same positive relations, to prevent the correlation between relations and entity names. Specifically, for each positive relation, the corresponding relational facts are represented as an undirected graph, where nodes correspond to entity pairs, and there is an edge between two nodes if the entity pairs share a common entity. Then we randomly split the connected entity pairs in the graph into training, development and test set, and ensure that relations in development and test set appeared in the training set.
B Data Distribution

We provide distribution of relations and documents. We show relation domain distribution in Fig. 3, and the document domain distribution in Fig. 4. We can see that CodRED enjoys diversity in both relations and documents. We also compare the length of documents in CodRED and existing document-level RE datasets in Table 8. We observe that documents in CodRED are much longer than those in existing document-level RE datasets, presenting new challenges to RE systems. We refer readers to data description in data supplement for relation documentation and reasoning chain distribution.

C Baseline Implementation Details

We provide implementation details of the two proposed baseline methods, including the pipeline model and the end-to-end model. For both baselines, we adopt the BERT\textsubscript{BASE} (110M) implementation by Wolf et al. (2019).

C.1 Pipeline Model.

Intra-document Relational Graph Extraction. This phase aims to predict the relations between the entities within each document containing head or tail entities. Documents are first tokenized into word pieces (Wu et al., 2016). To extract the relation between two entities in a document, we mark the position of entity mentions. Specifically, inspired by Baldini Soares et al. (2019), we adopt special tokens as entity markers and insert them to the start and end of all mentions of an entity. Four special tokens (i.e., \{[UNUSED\(i\)]\}_i=0^3 from BERT vocabulary) are used to mark the start and end of two entities in a document.

After marking the entity mentions, we select relevant text in documents to encode. Since the documents in CodRED are typically very long, and the document length usually exceeds the 512 maximum input length of BERT, we extract text snippets surrounding the two entities in the document. Specifically: (1) if the distance between the nearest mentions of two entities is less than 512, we use the 512 tokens centered on the nearest mentions; (2) otherwise we extract 255 tokens centered on the first mention of each entity, and concatenate them to obtain the input tokens. A snippet will be shifted accordingly if the span encounters the document boundaries. A [CLS] token is put at the beginning, and a [SEP] token is concatenated at the end of the input tokens. Then we feed the tokens into BERT and take the [CLS] embedding in the last layer as the entity pair representation. Finally, the entity pair representation is fed into a fully connected layer followed by a softmax layer to obtain the relation distribution. The target relations are labeled by distant supervision as in Yao et al. (2019). The intra-document relational graph extraction model achieves 53.75 F1 score on the validation set of DocRED (Yao et al., 2019).

Hyperparameters. The hyperparameters are selected by grid search based on AUC metric on the

| Dataset          | Words/Doc. |
|------------------|------------|
| BC5CDR (Li et al., 2016) | 118        |
| DocRED (Yao et al., 2019)   | 198        |
| DialogRE (Yu et al., 2020)  | 226        |
| CodRED            | 2,416      |

Table 8: Comparison of average document length between CodRED and document-level RE datasets.
validation set. The learning rate is 3e-5, selected from {2e-5, 3e-5, 5e-5}. The batch size is 32, selected from {16, 32, 64}. In cross-document relation reasoning phase, the dimension of entity type embedding and relation embedding is 256, selected from {128, 256}. We train our intra-document relational graph extraction model on 4 GeForce RTX 2080Ti GPUs for 2 epochs, which takes about 12 hours. The cross-document relation reasoning model is trained on a GeForce RTX 2080Ti GPUs for 20 epochs, which takes about 0.5 hours.

C.2 End-to-end Model

We provide details about the end-to-end model, including intra-document relation prediction and cross-document relation prediction. For intra-document relation prediction, we adopt the same approach in the pipeline model. Here we introduce details of cross-document relation prediction, including text path encoding and path aggregation.

Text Path Encoding. Given a text path \( p_i \) of an entity pair \((h, t)\), we first encode it into representation. The text path encoding largely follows the implementation of the encoder of intra-document relational graph extraction model in the pipeline method. Documents are first concatenated and tokenized. Then entity markers are inserted to the start and end of all mentions of head, tail and bridging entities. We adopt unused tokens \{[UNUSEDi]\}\(i=0\) from BERT vocabulary as entity markers. \{[UNUSEDi]\}\(i=0\) are used to mark the start and end of head and tail entities. Bridging entities are marked by \{[UNUSEDi]\}\(i=4\) according to their occurrence order in the document containing the head entity. Next we select relevant text snippets around the head/tail entity in the document in a similar approach to pipeline model. Finally we feed the tokens into BERT and take the [CLS] embedding in the last layer as the text path representation \( p_i \).

Path Aggregation. Given the representations of paths \( \{p_i\}^K_{i=0} \) between the entity pair, to select meaningful paths in the presence of noise, we adopt selective attention (Lin et al., 2016) to obtain the aggregated entity pair representation \( x \) as follows:

\[
x = \sum_{i \in K} \alpha_i p_i,
\]

where \( \alpha_i \) is the weight of path \( p_i \), and is defined as:

\[
\alpha_i = \frac{\exp(e_i)}{\sum_{k \in K} \exp(e_k)},
\]

where \( e_i \) is the attention score of the path \( p_i \), which indicates how well the path \( p_i \) and the query relation \( r \) matches. Informative paths are expected to have higher attention scores. The attention score \( e_i \) is given by:

\[
e_i = p_i r,
\]

where \( r \) is the query embedding of relation \( r \).

Hyperparameters. The hyperparameters are selected by grid search according to the AUC metric on the validation set. The learning rate is 3e-5, selected from \{2e-5, 3e-5, 5e-5\}. The batch size is selected 16, selected from \{8, 16, 32\}. We also choose the weight decay value 0.01. We train our model on 4 GeForce RTX 2080Ti GPUs for 10 epochs, which takes about 5 hours.

D Further Analysis

Performance w.r.t. Bridging Entities. Cross-document RE requires cross-document reasoning via bridging entities. To investigate the challenge of cross-document reasoning with respect to possible bridging entity mentions, we report the model performance on text paths with different numbers of shared entity mentions between the two documents. Specifically, each text path (including positive and negative ones) is treated as an independent instance. We train a relation classification model that consists of a text path encoder and a relation predictor. Then we divide 2,558 positive text paths in the development set into subsets according to the number of shared entity mentions in the snippet, and report the accuracy of positive relation classification on each subset in Fig. 5. We observe that with the increase of shared entity mentions, the performance first improves slightly and then drops significantly.
We hypothesize the reason is that (1) when there are few shared entity mentions, increased shared entity mention number indicates smaller semantic gaps and more alternative reasoning chains between the documents; (2) when there is a number of shared entity mentions, further increment in the number will lead to complex context and severe distractions, making the reasoning process more challenging.

E Human Annotation.

During annotation, in addition to the relational fact, we highlight the mentions of target entities and bridging entities, and provide possible reasoning chains to assist human annotation. Fig. 6 shows the user interface of our annotation platform.

F Data Distribution

We provide the list of relations and their descriptions in Wikidata in Table 9, 10, 11, 12, 13 and 14.
| Wikidata ID | Name                           | Description                                                                                                                                     |
|------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| P16        | highway system                 | system (or specific country specific road type) of which the highway is a part                                                                   |
| P17        | country                        | sovereign state of this item; don't use on humans                                                                                               |
| P19        | place of birth                 | most specific known (e.g. city instead of country, or hospital instead of city) birth location of a person, animal or fictional character |
| P20        | place of death                 | most specific known (e.g. city instead of country, or hospital instead of city) death location of a person, animal or fictional character  |
| P22        | father                         | male parent of the subject. For stepfather, use "stepparent" (P3448)                                                                           |
| P25        | mother                         | female parent of the subject. For stepmother, use "stepparent" (P3448)                                                                           |
| P26        | spouse                         | the subject has the object as their spouse (husband, wife, partner, etc.). Use "unmarried partner" (P451) for non-married companions          |
| P30        | continent                      | continent of which the subject is a part                                                                                                       |
| P36        | capital                        | primary city of a country, state or other type of administrative territorial entity                                                               |
| P38        | currency                       | currency used by item                                                                                                                           |
| P39        | position held                  | subject currently or formerly holds the object position or public office                                                                        |
| P40        | child                          | subject has the object in their family as their offspring son or daughter (independently of their age)                                         |
| P50        | family                         | family, including dynasty and nobility houses. Not family name (use P734 for family name).                                                       |
| P53        | author                         | main creator(s) of a written work (use on works, not humans)                                                                                    |
| P54        | member of sports team          | sports teams or clubs that the subject currently represents or formerly represented                                                              |
| P57        | director                       | director(s) of film, TV-series, stageplay, video game or similar                                                                               |
| P58        | screenwriter                   | person(s) who wrote the script for subject item                                                                                                 |
| P59        | constellation                  | the area of the celestial sphere of which the subject is a part (from a scientific standpoint, not an astrological one)                        |
| P61        | discoverer or inventor         | the entity who discovered, first described, invented, or developed this discovery or invention                                              |
| P69        | educated at                    | educational institution attended by subject                                                                                                     |
| P85        | anthem                         | subject’s official anthem                                                                                                                       |
| P86        | composer                       | person(s) who wrote the music [for lyricist, use "lyrics by" (P676)]                                                                         |
| P101       | field of work                  | specialization of a person or organization; see P106 for the occupation                                                                        |
| P102       | member of political party      | the political party of which this politician is or has been a member                                                                             |
| P108       | employer                       | person or organization for which the subject works or worked                                                                                   |
| P112       | founded by                     | founder or co-founder of this organization, religion or place                                                                                |
| P113       | airline hub                    | airport that serves as a hub for an airline                                                                                                     |
| P114       | airline alliance               | alliance the airline belongs to                                                                                                                |
| P115       | home venue                     | home stadium or venue of a sports team or applicable performing arts organization                                                                |
| P118       | league                         | league in which team or player plays or has played in                                                                                           |
| P119       | place of burial                | location of grave, resting place, place of ash-scattering, etc. (e.g. town/city or cemetery) for a person or animal. There may be several places: e.g. re-burials, cenotaphs, parts of body buried separately. |
| P121       | item operated                  | equipment, installation or service operated by the subject                                                                                     |
| P122       | basic form of government       | subject’s government                                                                                                                           |
| P123       | publisher                      | organization or person responsible for publishing books, periodicals, games or software                                                        |
| P126       | maintained by                  | person or organization in charge of keeping the subject (for instance an infrastructure) in functioning order                                   |
| P127       | owned by                       | owner of the subject                                                                                                                          |
| P129       | physically interacts with      | physical entity that the subject interacts with                                                                                                 |
| P131       | located in the administrative territorial entity | the item is located on the territory of the following administrative entity. Use P276 (location) for specifying the location of non-administrative places and for items about events |
| P135       | movement                       | literary, artistic, scientific or philosophical movement associated with this person or work                                                   |
| P136       | genre                          | creative work’s genre or an artist’s field of work (P101). Use main subject (P921) to relate creative works to their topic                         |
| P137       | operator                       | person or organization that operates the equipment, facility, or service; use country for diplomatic missions                                       |
| P138       | named after                    | entity or event that inspired the subject’s name, or namesake (in at least one language)                                                      |
| P140       | religion                       | religion of a person, organization or religious building, or associated with this subject                                                       |
| P144       | based on                       | the work(s) used as the basis for subject item                                                                                                  |
| P149       | architectural style            | architectural style of a structure                                                                                                             |
| P150       | contains administrative territorial entity | (list of) direct subdivisions of an administrative territorial entity                                                                                   |
| P155       | follows                        | immediately prior item in a series of which the subject is a part [if the subject has replaced the preceding item, e.g. political offices, use "replaces" (P1365)] |

Table 9: Relation list of CodRED, including Wikidata IDs, names and descriptions of relations.
| Wikidata ID | Name                      | Description                                                                                                                                 |
|------------|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| P156       | followed by               | immediately following item in a series of which the subject is a part [if the subject has been replaced, e.g. political offices, use "replaced by" (P1366)] |
| P159       | headquarters location     | specific location where an organization’s headquarters is or has been situated. Inverse property of "occupant" (P466).                    |
| P161       | cast member               | actor performing live for a camera or audience [use "character role" (P453) and/or "name of the character role" (P4633) as qualifiers] [use "voice actor" (P725) for voice-only role] |
| P162       | producer                  | person(s) who produced the film, musical work, theatrical production, etc. (for film, this does not include executive producers, associate producers, etc.) [for production company, use P272, video games - use P178] |
| P169       | chief executive officer   | highest-ranking corporate officer appointed as the CEO within an organization                                                                |
| P170       | creator                   | maker of this creative work or other object (where no more specific property exists)                                                         |
| P171       | parent taxon              | closest parent taxon of the taxon in question                                                                                              |
| P175       | performer                 | performer involved in the performance or the recording of a musical work                                                                    |
| P176       | manufacturer              | manufacturer or producer of this product                                                                                                  |
| P177       | crosses                   | obstacle (body of water, road, ...) which this bridge crosses over or this tunnel goes under                                               |
| P178       | developer                 | organisation or person that developed the item                                                                                             |
| P179       | series                    | subject is part of a series, the sum of which constitutes the object                                                                          |
| P180       | depicts                   | depicted entity (see also P921: main subject)                                                                                               |
| P184       | doctoral advisor          | person who supervised the doctorate or PhD thesis of the subject                                                                            |
| P190       | twin towns                | twin towns, sister cities, twinned municipalities and other localities that have a partnership or cooperative agreement, either legally or informally acknowledged by their governments |
| P193       | main building contractor  | the main organization responsible for construction of this structure or building                                                             |
| P197       | adjacent station          | the stations next to this station, sharing the same line(s)                                                                                 |
| P199       | business division         | divisions of this organization                                                                                                             |
| P205       | basin country             | country that have drainage to/from or border the body of water                                                                            |
| P206       | located in or next to body of water |                                                                                                                                          |
| P241       | military branch           | branch to which this military unit, award, office, or person belongs, e.g. Royal Navy                                                       |
| P264       | record label              | brand and trademark associated with the marketing of subject music recordings and music videos                                              |
| P272       | production company        | company that produced this film, audio or performing arts work                                                                              |
| P276       | location                  | location of the item, physical object or event is within. In case of an administrative entity use P131. In case of a distinct terrain feature use P706. |
| P279       | subclass of               | all instances of these items are instances of those items; this item is a class (subset) of that item. Not to be confused with P31 (instance of) |
| P282       | writing system            | alphabet, character set or other system of writing used by a language, supported by a typeface                                               |
| P286       | head coach                | on-field manager or head coach of a sports club (not to be confused with a general manager P505, which is not a coaching position) or person |
| P287       | designed by               | person(s) that designed the item                                                                                                            |
| P291       | place of publication      | geographical place of publication of the edition (use 1st edition when referring to works)                                                |
| P306       | operating system          | operating system (OS) on which a software works or the OS installed on hardware                                                             |
| P335       | subsidiary                | subsidiary of a company or organization, opposite of parent organization (P749)                                                            |
| P355       | is a list of              | common element between all listed items                                                                                                      |
| P360       | part of                   | object of which the subject is a part (it’s not useful to link objects which are themselves parts of other objects already listed as parts of the subject). Inverse property of "has part" (P527, see also "has parts of the class" (P2670)). |
| P366       | use                       | type of rocket or other vehicle for launching subject payload into outer space                                                               |
| P375       | space launch vehicle      | type of rocket or other vehicle for launching subject payload into outer space                                                               |
| P397       | parent astronomical body  | major astronomical body the item belongs to                                                                                                 |
| P398       | child astronomical body   | minor body that belongs to the item                                                                                                         |
| P400       | platform                  | platform for which a work was developed or released, or the specific platform version of a software product                                  |
| P403       | mouth of the watercourse  | the body of water to which the watercourse drains                                                                                          |
| P404       | game mode                 | a video game’s available playing mode(s)                                                                                                    |
| P408       | software engine           | software engine employed by the subject item                                                                                                |
| P411       | canonization status       | stage in the process of attaining sainthood per the subject’s religious organization                                                        |
| P414       | exchange on which this company is traded |                                                                                                                                           |
| P421       | located in time zone      | time zone for this item                                                                                                                     |
| P425       | field of this occupation  | activity corresponding to this occupation (use only for occupations - for people use Property:P101, for companies use P452)                |
| P437       | method or type of distribution for the subject |                                                                                                                                           |
| P449       | network(s) the radio or television show was originally aired on, including |                                                                                                                                           |

Table 10: Relation list of CodRED, including Wikidata IDs, names and descriptions of relations.
| Wikidata ID | Name               | Description                                                                 |
|------------|--------------------|-----------------------------------------------------------------------------|
| P451       | partner industry   | someone in a relationship without being married. Use "spouse" for married couples. |
| P452       | industry           | industry of company or organization                                           |
| P460       | said to be the same as opposite of color of subject | this item is said to be the same as that item, but the statement is disputed |
| P461       | item that is the opposite of this item | item that is the opposite of this item                                       |
| P462       | color               | color of subject                                                             |
| P463       | member of organization or club to which the subject belongs. Do not use for membership in ethnic or social groups, nor for holding a position such as a member of parliament (use P39 for that). | member of organization or club to which the subject belongs. Do not use for membership in ethnic or social groups, nor for holding a position such as a member of parliament (use P39 for that). |
| P479       | input method       | input method or device used to interact with a software product              |
| P483       | input method or device used to interact with a software product | input method or device used to interact with a software product              |
| P485       | archives at the institution holding the subject’s archives | archives at the institution holding the subject’s archives                     |
| P488       | chairperson        | presiding member of an organization, group or body                           |
| P489       | item with description of currency symbol | item with description of currency symbol                                      |
| P495       | country of origin | country of origin of this item (creative work, food, phrase, product, etc.) |
| P504       | home port          | home port of the vessel (if different from "ship registry"); For civilian ships, the primary port from which the ship operates. Port of registry P532 should be listed in "Ship registry". For warships, this will be the ship’s assigned naval base |
| P509       | cause of death     | underlying or immediate cause of death. Underlying cause (e.g. car accident, stomach cancer) preferred. Use ‘manner of death’ (P1196) for broadest category, e.g. natural causes, accident, homicide, suicide |
| P511       | honorific prefix   | word or expression used before a name, in addressing or referring to a person |
| P512       | academic degree    | academic degree that the person holds |
| P516       | powerplant         | equipment or engine used to power the subject                              |
| P520       |armament            | equippable weapon item for the subject                                       |
| P521       | scheduled service destination | airport or station connected by regular direct service to the subject; for the destination of a trip see |
| P523       | temporal range start | the start of a process or appearance of a life form relative to the geologic time scale |
| P527       | has part            | part of this subject. Inverse property of "part of" (P361). See also "has parts of the class" (P2670) |
| P546       | docking port       | intended docking port for a spacecraft                                     |
| P551       | residence           | the place where the person is or has been, resident                          |
| P553       | website account on a website that the person or organization has an account on (use with P554) Note: only used with reliable source or if the person or organization disclosed it. | website account on a website that the person or organization has an account on (use with P554) Note: only used with reliable source or if the person or organization disclosed it. |
| P559       | terminus            | the feature (intersecting road, train station, etc.) at the end of a linear feature |
| P598       | commander of         | for persons who are notable as commanding officers, the units they commanded |
| P607       | conflict            | battles, wars or other military engagements in which the person or item participated |
| P608       | exhibition history exhibitions where the item is or was displayed | exhibitions where the item is or was displayed |
| P610       | highest point       | point with highest elevation in a region, on a path, of a race              |
| P611       | order of monks or nuns to which an individual or religious house belongs | order of monks or nuns to which an individual or religious house belongs |
| P629       | edition or translation of an edition or translation of this entity | edition or translation of this entity                                           |
| P658       | tracklist           | songs contained in this item                                                |
| P664       | organizer           | person or institution organizing an event                                    |
| P674       | characters          | characters which appear in this item (like plays, operas, operettas, books, comics, films, TV series, video games) |
| P676       | author of song lyrics; also use P6 for music composer | author of song lyrics; also use P6 for music composer |
| P703       | found on terrain feature located on the specified landform. Should not be used when the value is only political/administrative (P131) or a mountain range (P4552). | the taxon in which the item can be found |
| P706       | located on terrain feature | located on the specified landform. Should not be used when the value is only political/administrative (P131) or a mountain range (P4552). |
| P707       | satellite bus       | general model on which multiple-production satellite spacecraft is based      |
| P710       | participant         | person, group of people or organization (object) that actively takes/tok part in an event or process (subject). Preferably qualify with "object has role" (P3831). Use P1923 for team participants. |
| P725       | voice actor         | performer of a spoken role in a creative work such as animation, video game, radio drama, or dubbing over [use "character role" (P453) as qualifier] [use "cast member" (P161) for live acting] this person, idea, etc. is informed by that other person, idea, etc., e.g. "Heidegger was influenced by Aristotle". |
| P737       | influenced by       | this person, idea, etc. is informed by that other person, idea, etc., e.g. "Heidegger was influenced by Aristotle". |
| P739       | ammunition          | cartridge or other ammunition used by the subject weapon                    |
| P740       | location of formation | location where a group or organization was formed |
| P747       | has edition         | link to an edition of this item                                             |
| P749       | parent organization | parent organization of an organisation, opposite of subsidiaries (P355)      |
| P750       | distributor         | distributor of a creative work; distributor for a record label              |
| P751       | introduced feature | feature introduced by this version of a product item                         |

Table 11: Relation list of CodRED, including Wikidata IDs, names and descriptions of relations.
| Wikidata ID | Name                                      | Description                                                                 |
|-------------|-------------------------------------------|-----------------------------------------------------------------------------|
| P767        | contributor(s) to the creative work       | person or organization that contributed to a subject: co-creator of a creative work |
| P769        | significant drug interaction              | clinically significant interaction between two pharmacologically active substances (i.e., drugs and/or active metabolites) where concomitant intake can lead to altered effectiveness or adverse drug events. |
| P790        | approved by item(s) [qualifier: statement is approved by other item(s)] | item is approved by other item(s) |
| P800        | notable event                              | significant or notable events associated with the subject |
| P832        | public holiday                             | notable scientific, artistic or literary work, or other work of significance among subject’s works |
| P840        | the narrative location                     | official public holiday that occurs in this place in its honor, usually a non-working day |
| P852        | ESRB rating                               | North American video game content rating - appropriate values are on property’s talk page |
| P859        | sponsor                                    | organization or individual that sponsors this item |
| P915        | filming location                           | actual place where this scene/film was shot. For the setting, use "narrative location" (P840) |
| P921        | main subject                               | primary topic of a work (see also P180: depicts) |
| P924        | medical treatment                          | treatment that might be used to heal the medical condition |
| P931        | place served by transport hub              | territorial entity or entities served by this transport hub (airport, train station, etc.) |
| P937        | work location                              | location where persons were active |
| P941        | inspired by work, human, place or event which inspired this creative work or fictional entity | |
| P944        | Code of nomenclature                       | the Code that governs the scientific name of this taxon |
| P945        | allegiance                                 | the country (or other power) that the person, or organization, served |
| P974        | tributary                                  | stream or river that flows into this main stem (or parent) river |
| P1001       | applies to jurisdiction                    | the item (an institution, law, public office ...) or statement belongs to or has power over or applies to the value (a territorial jurisdiction: a country, state, municipality, ...) |
| P1027       | conferred by person or organization who awards a prize to or bestows an honor upon a recipient | |
| P1037       | relative                                   | family member (qualify with "type of kinship", P1039; for direct family member please use specific property) |
| P1050       | medical condition                          | any state relevant to the health of an organism, including diseases and positive conditions |
| P1056       | material or product produced               | material or product produced by a government agency, business, industry, faculty, or process |
| P1066       | student of person who has taught this person | |
| P1071       | location of final assembly                 | place where the item was made; location of final assembly |
| P1072       | readable file format                       | file format a program can open and read |
| P1073       | writable file format                       | file format a program can create and/or write to |
| P1079       | launch contractor                          | organization contracted to launch the rocket |
| P1080       | from fictional universe                   | subject’s fictional entity is in the object narrative. See also P1441 and P1445 |
| P1142       | political ideology                         | political ideology of this organization or person |
| P1158       | location of landing                        | location where the craft landed |
| P1192       | connecting service                         | service stopping at a station |
| P1303       | musical instrument that a person plays     | |
| P1308       | person who holds an office                 | |
| P1327       | person a professional or athlete works with | |
| P1336       | territory claimed by administrative divisions that claim control of a given area | |
| P1343       | dictionary, encyclopaedia, etc.            | where this item is described |
| P1344       | participant of winner                      | event a person or an organization was/is a participant in, inverse of P710 or P1923 |
| P1346       | winner of an event or award - do not use for wars or battles | |
| P1365       | person or item replaced. Use P1398 (structure replaces) for structures. Use P155 (follows) if the previous item was not replaced or if predecessor and successor are identical. | |
| P1366       | other person or item which continues the item by replacing it in its role. Use P156 (followed by) if the item is not replaced (e.g. books in a series), nor identical, but adds to the series without dropping the role of this item in that series | |
| P1387       | political alignment                        | political position within the political spectrum |
| P1389       | product certification                      | certification for a product, qualify with P1001 ("applies to jurisdiction") if needed |
| P1399       | convicted of crime a person was convicted of | |
| P1408       | place that a radio/TV station is licensed/required to broadcast to | |

Table 12: Relation list of CodRED, including Wikidata IDs, names and descriptions of relations.
| Wikidata ID | Name | Description |
|------------|------|-------------|
| P1411      | nominated for | award nomination received by a person, organisation or creative work (inspired from "award received" (Property:P166)) |
| P1414      | GUI toolkit or framework | framework or toolkit a program uses to display the graphical user interface |
| P1416      | affiliation | organization that a person or organization is affiliated with |
| P1427      | start point | starting place of this journey, flight, voyage, trek, migration etc. |
| P1431      | executive producer | executive producer of a movie or TV show |
| P1433      | published in | larger work that a given work was published in, like a book, journal or music album |
| P1434      | takes place in fictional universe | the subject is a work describing a fictional universe, i.e. whose plot occurs in this universe. |
| P1435      | heritage designation | heritage designation of a cultural or natural site |
| P1441      | present in work | work in which this fictional entity (Q14897293) or historical person is present (use P2860 for works citing other works and P361/P1433 for works being part of / published in other works) |
| P1444      | destination point | intended destination for this route (journey, flight, sailing, exploration, migration, etc.) |
| P1445      | fictional universe described in legal form | to link a fictional universe with a work that describes it: <universe> "described in the work:" <work> |
| P1544      | country for sport | country a person or a team represents when playing a sport |
| P1532      | use by | item or concept that makes use of the subject (use sub-properties when appropriate) |
| P1535      | manifestation of natural product of taxon | links a natural product with its source (animal, plant, fungal, algal, etc.) |
| P1582      | driving side | side of the road that vehicles drive on in a given jurisdiction |
| P1581      | brand | brand of a product |
| P1876      | vessel | vessel involved in this mission, voyage or event |
| P1877      | after a work by artist | artist whose work strongly inspired/ was copied in this item |
| P1891      | signatory | person, country, or organization that has signed an official document (use P50 for author) |
| P1923      | participating team | Like 'Participant' (P110) but for teams. For an event like a cycle race or a football match you can use this property to list the teams and P710 to list the individuals (with 'member of sports team' (P54) as a qualifier for the individuals) |
| P1990      | species kept | taxa, preferably species, present at a zoo, botanical garden, collection, or other institution. NOT specific animals, not for any geographic location |
| P1995      | health specialty | main specialty that diagnoses, prevent human illness, injury and other physical and mental impairments |
| P2079      | fabrication method | method, process or technique used to grow, cook, weave, build, assemble, manufacture the item |
| P2094      | competition class | official classification by a regulating body under which the subject (events, teams, participants, or equipment) qualifies for inclusion |
| P2175      | medical condition treated | disease that this pharmaceutical drug, procedure, or therapy is used to treat |
| P2176      | drug used for treatment | drug, procedure, or therapy that can be used to treat a medical condition |
| P2283      | uses | item or concept used by the subject or in the operation |
| P2321      | general classification of race participants | classification of race participants |
| P2341      | indigenous to | area or ethnic group that a language, folk dance, cooking style, food or other cultural expression is found (or was originally found) |
| P2348      | time period | time period (historic period or era, sports season, theatre season, legislative period etc.) in which the subject occurred |
| P2360      | intended public | this work, product, object or event is intended for, or has been designed to that person or group of people, animals, plants, etc |
| P2389      | organisation directed from the office or person set in period | historical, contemporary or future period the work is set in |
| P2408      | sports discipline competed in | discipline an athlete competed in within a sport |
| P2410      | league level above | the league above this sports league |
| P2500      | league level below | the league below this sports league |
| P2522      | victory | competition or event won by the subject |
| P2541      | operating area sidekick of | area this organisation operates in, serves or has responsibility for close companion of a fictional character |
| P2546      | Koppen climate classification | indicates the characteristic climate of a place |
| P2579      | studied by | subject is studied by this science or domain |
| P2670      | has parts of the class | the subject instance has parts of the object class (the subject is usually not a class) |
| P2743      | this zoological name is coordinate with | links coordinate zoological names |
| P2789      | connects with | item with which the item is physically connected |

Table 13: Relation list of CodRED, including Wikidata IDs, names and descriptions of relations.
| Wikidata ID | Name                                      | Description                                                                 |
|------------|-------------------------------------------|-----------------------------------------------------------------------------|
| P2852      | emergency phone number                    | telephone number to contact the emergency services                          |
| P2853      | electrical plug type                      | standard plug type for mains electricity in a country                        |
| P2860      | cites                                     | citation from one creative work to another                                  |
| P2868      | subject has role                          | role or generic identity of subject (the item that the statement is on) in a certain context. For acting roles, use P453 ("character role"). For roles of the object/value of statements, use P3831 ("object has role"). |
| P2925      | domain of saint or deity                  | domain(s) which this saint or deity controls or protects                     |
| P2935      | connector                                 | connectors which the device has/supports                                     |
| P2962      | title of chess player                     | title awarded by a chess federation to chess players for achievement         |
| P3018      | located in protected area                 | the protected area a place or geographical feature belongs to                |
| P3033      | package management system                 | package management system used to publish the software                       |
| P3075      | official religion                         | official religion in this administrative entity                             |
| P3091      | mount                                     | creature ridden by the subject, for instance a horse                         |
| P3095      | practiced by                              | type of agents that study this subject or work in this profession           |
| P3137      | board member                              | parent peak whose territory this peak resides in, based on the contour of the lowest col |
| P3320      | significant person                        | person linked to the item in any possible way                                |
| P3342      | sibling                                   | the subject has the object as their sibling (brother, sister, etc.). Use "relative" (P1038) for siblings-in-law (brother-in-law, sister-in-law, etc.) and step-siblings (step-brothers, step-sisters, etc.) |
| P3348      | stepparent                                | subject has the object as their stepparent                                   |
| P3373      | points classification                     | programming paradigm in which a programming language is classified           |
| P3996      | programming paradigm                      | morphology of the fruit of this taxon, as defined in botany                 |
| P4000      | therapeutic area                          | disease area in which a medical intervention is applied                      |
| P4132      | linguistic typology                       | classification of languages according to their linguistic trait (as opposed to historical families like romance languages) |
| P4378      | update method                             | method used by an app/OS to receive updates or self-update                  |
| P4446      | reward program                            | reward program associated with the item                                      |
| P4552      | mountain range                            | range or subrange to which the geographically item belongs                  |
| P4614      | drainage basin                            | area where precipitation collects and drains off into a common outlet, such as into a river, bay, or other body of water |
| P4743      | animal breed                               | subject item belongs to a specific group of domestic animals, generally given by association |
| P4791      | commanded by                              | commander of a military unit/army/security service, operation, etc.          |
| P5025      | gens                                      | a group of families from Ancient Rome who shared the same nomen              |
| P5096      | crew                                      | person who has been a member of a crew associated with the vessel or spacecraft. For spacecraft, inverse of crew member (P1029), backup or reserve team or crew (P3015) indicates for a country or a railway line whether rail traffic usually runs on the left or right hand side |
| P5658      | railway traffic side                      | collection that have works of this artist                                    |
| P5826      | majority opinion                          | judicial opinion agreed to by more than half of the members of a court       |
| P5869      | model item                                | defines which item is a best practice example of modelling a subject, which is described by the value of this property, usage instructions at Wikidata:Model item |
| P5995      | kit supplier                              | official supplier of sports goods to a given club or a national sports team |
| P6216      | copyright status                          | copyright status for intellectual creations like works of art, publications, software, etc. |
| P6275      | copyright representative                  | person or organisation who represents the copyright for this person or work of art |
| P6379      | has works in the collection               | geographic area which at some point in time had a cultural, ethnic, linguistic or political basis, regardless of present-day borders |
| P6885      | historical region                         | collection that have works of this artist                                    |
| P6942      | animator                                  | person creating animated sequences out of still images                       |
| P7047      | enemy of                                  | opponent character or group of this character or group                       |
| P7153      | significant place                         | significant or notable places associated with the subject                    |

Table 14: Relation list of CodRED, including Wikidata IDs, names and descriptions of relations.
Figure 6: The annotation platform. Annotators are provided with relational fact and text paths. We also highlight the mentions of target entities and bridging entities, and provide possible reasoning chains to assist annotation.