

# Relation Extraction

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## Abstract

Recent relation extraction systems predict the relationship between an entity and value given the positions of their mentions in the text. This requires words to be annotated as mentions. The cost of obtaining human annotations for each word scales linearly with the size of the text. Automatic annotation methods allow the annotation process to scale sublinearly in human effort, but may introduce noise due to incorrect annotations. In order to train a probabilistic information extraction model without mention annotations, we specify a model that identifies important words and uses them to explain a triple from a knowledge base.

## 1 Problem Statement

Relation extraction aims to extract facts from a passage of text. Extraction systems convert facts expressed in natural language into a form amenable to computation. Facts consist of three components: Entities, relation types, and values. The challenge is to not only extract facts from text, but also justify the extractions by determining where those facts are mentioned.

A *mention* is a surface realization of an abstract object in text. In relation extraction we justify extractions by identifying fact mentions. As text is noisy, the realization of a fact may be difficult to locate. We focus on locating fact mentions at the word level by identifying individual words as value mentions, rather than entity or type mentions.

The problem description is as follows, focusing on the domain of basketball summaries: Given a written summary of a basketball game  $x = x_1, \dots, x_I$  of length  $I$ , we model the aligned box score  $\{(e_j, t_j, v_j)\}_{j=1}^J$  consisting of entities  $e_j$ , relation types  $t_j$ , and all values  $v_j \in \mathcal{V}$ . The set of facts is our knowledge base (KB), which contains  $J$  facts.

Let  $D = \{(e_j, t_j)\}_{j=1}^J$  and  $v = \{v_j\}_{j=1}^J$ . The KB  $(D, v)$  can be viewed as a data table where  $d$  defines a flattened representation of the rows and columns and  $v$  gives the values of the cells. Our goal is to locate and extract facts from  $x$ .

Modeling only the KB  $(d, v)$  given the text  $x$  is not sufficient, as our goal is to locate fact mentions. We therefore propose a model that first identifies words as value mentions, aligns those mentions to an entity and relation type in order to obtain a fact, and then aggregates word level decisions to resolve conflicts.

## 2 Model

We define a graphical model that performs extraction with justification.

### 2.1 Notation

We first introduce the latent variables of our model. Consider the follow example:  $D = \{(e_1 = \text{John Doe}, t_1 = \text{Points}), (e_2 = \text{John Doe}, t_2 = \text{Rebounds}), (e_3 = \text{John Doe}, t_3 = \text{First name}), (e_3 = \text{John Doe}, t_3 = \text{First name}), (e_3 = \text{John Doe}, t_3 = \text{First name})\}$  with  $v = \{v_1 = 19, v_2 = 12, v_3 = \text{John}, v_4 = \text{Doe}, \dots\}$  aligned to the brief summary  $x = \text{John Doe scored 19 points}$ .

1.  $m = m_1, \dots, m_I$  where each  $m_i \in \{0, 1\}$  indicates whether word  $x_i$  is part of a value mention. In our example, we have  $m_1 = 1$  as  $x_1 = \text{John}$  mentions the value  $v_3$ , the first name of the entity ‘John Doe’.
2.  $a = a_1, \dots, a_I$  where each  $a_i \in \{1, \dots, J\}$  gives the index of the fact whose value word  $x_i$  mentions.
3.  $z = z_1, \dots, z_I$
4.  $v = v_1, \dots, v_J$

The word level extraction process has three steps. For each index  $i \in 1, \dots, I$  we perform

1. Value mention identification: Given a sequence of words  $x$ , we identify whether each word is a value mention with  $p(m \mid x) = \prod_i p(m_i \mid x)$ . Each  $m_i \in \{0, 1\}$ . Not every word in a mention must be identified; it suffices to find at least one word in a value mention.
2. Alignment: Each value mention is then aligned to a record in the knowledge base with  $p(a \mid x, d) = \prod_i p(a_i \mid x, d)$ . We align the word  $x_i$  by choosing who (the entity) and what (the relation type) generate the possible value mention at index  $i$ . In particular,  $a_i = j$  denotes the alignment to the record  $r_j$  with  $a_i \in 1, \dots, J$ . We assume that each value mention aligns to a single record.
3. Translation: All value mentions are translated into a value from the KB schema with  $p(z \mid x) = \prod_i p(z_i \mid x)$ , with  $z_i \in \mathcal{V}$ .

Finally, we aggregate the word level information at the sequence level in order to give a single distribution over the record values for  $x$ .

4. Aggregation  $p(v \mid z, a, m, d) = \prod_j p(v_j \mid z, a, m, d_j)$ : Given the word level values  $z$ , alignments  $a$ , value mention decisions  $m$ , and data table  $d$  we choose the sequence level value  $v_j$ .

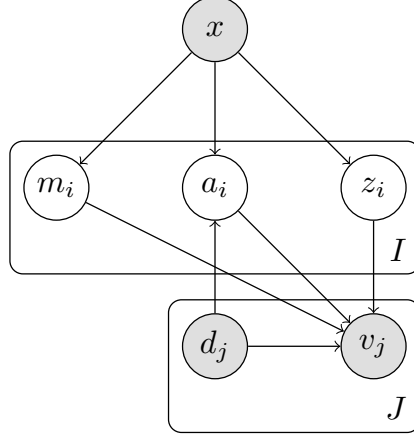


Figure 1: Our model predicts word-level values and alignments then aggregates those choices over all indices  $i$  to make a single decision for each value. Each word has the following latent variables: the mention  $m_i \in \{0, 1\}$  indicates whether word  $x_i$  is a value mention, the alignment  $a_i$  gives what fact  $x_i$  aligns to, and the value  $z_i$  gives the canonical value that  $x_i$  translates to.

This gives us the following factorization of the relation extraction system:

$$\begin{aligned}
 p(v \mid x, d) &= \sum_{z, a, m} p(v, z, a, m \mid x, d) \\
 &= \sum_{z, a, m} p(v \mid z, a, m, x, d) p(z, a, m \mid x, d) \\
 &= \sum_{z, a, m} \left( \prod_j p(v_j \mid z, a, m, x, d) \right) \left( \prod_i p(z_i \mid x) p(a_i \mid x, d) p(m_i \mid x) \right)
 \end{aligned} \tag{1}$$

## 2.2 Parameterization

Our model has four steps: mention identification, mention alignment, mention translation, and aggregation. We parameterize the conditional distributions of each step below.

Let  $\mathbf{h}_i \in \mathbb{R}^d$  be a contextual embedding of the word  $x_i$ , and  $E$  an embedding function that maps entities and types to vectors in  $\mathbb{R}^{d'}$ .

1. Identification: We use the contextual embedding to directly predict whether a word is part of a value mention.

$$p(m_i \mid x) \propto \exp(W_m \mathbf{h}_i), W_m \in \mathbb{R}^{2 \times d}$$

2. Alignment: We decompose the alignment distribution into a distribution over entities  $p(\epsilon_i \mid x, d)$  and types  $p(\tau_i \mid x, d)$ .

$$p(a_i \mid x, d) = p(\epsilon_i = e_{a_i} \mid x, d) p(\tau_i = t_{a_i} \mid x, d)$$

$$p(\epsilon_i \mid x, d) \propto \exp(E(\epsilon_i)^T W_e \mathbf{h}_i)$$

$$p(\tau_i \mid x, d) \propto \exp(E(\tau_i)^T W_t \mathbf{h}_i)$$

with  $W_e \in \mathbb{R}^{d' \times d}$ ,  $W_t \in \mathbb{R}^{d' \times d}$ .

3. Translation: We use the contextual embedding to translate a word into a value.

$$p(z_i | x) \propto \exp(W_z \mathbf{h}_i), W_z \in \mathbb{R}^{|\mathcal{V}| \times d}$$

4. Aggregation: If there exists an index that is a mention and is also aligned to  $r_j$  we allow it to vote on the value  $v_j$ , otherwise we ignore the text and use a prior distribution over values  $p(v_j | d_j) \propto \exp(E(v_j)^T W_v [E(d_j)])$ .

$$p(v_j | z, a, m, d) \propto \begin{cases} \prod \exp(\psi(v_j, z_i, a_i, m_i, d)), & \exists i, m_i = 1 \wedge a_i = j \\ \exp(E(v_j)^T W_v [E(d_j)]), & \text{otherwise} \end{cases}$$

$$\psi(v_j, z_i, a_i, m_i, d) = 1(v_j = z_i, a_i = j, m_i = 1)$$

### 3 Training and Inference

To train a latent variable model, we must marginalize over the unobserved RVs and maximize the likelihood of the observed. Ideally, we would optimize the following objective

$$\log p(v | x, d) = \log \sum_{z, a, m} p(v, z, a, m | x, d) \quad (2)$$

However, maximizing  $\log p(v | x, d)$  directly is very expensive for this model as the summation over  $z, a, m$  is intractable. The summation over  $z, a, m$  has computational complexity  $O((|\mathcal{V}| \cdot J \cdot 2)^I)$ , which is exponential in the length of the text. Additionally, the size of the KB  $J$  may be large as well.

We therefore resort to approximate inference, specifically amortized variational inference.

#### 3.1 Inference network

Our first approach is to introduce an inference network  $q(z, a, m | v, x, d)$  and optimize the following lower bound on the marginal likelihood with respect to the parameters of both  $p$  and  $q$ :

$$\log p(v | x) \geq \mathbb{E}_{q(z, a, m | v, x, d)} \left[ \log \frac{p(v, z, a, m | x, d)}{q(z, a, m | v, x, d)} \right] \quad (3)$$

We propose to parameterize  $q(z, a, m | v, x, d)$  as follows. We decompose

$$\begin{aligned} q(z, a, m | v, x, d) &= q(z | a, v, x) q(a | v, x, d) q(m | v, x) \\ &= \prod_i q(z_i | a, v, x) q(a_i | v, x, d) q(m_i | v, x) \end{aligned} \quad (4)$$

The conditional distributions of our inference network are very similar to the relation extraction model, but they condition on the values  $v$ .

Let  $\mathbf{h}_i \in \mathbb{R}^d$  be a contextual embedding of the word  $x_i$ . We use attention weights over records to get a weighted representation of the records of the KB for each index  $i$ :

$$\begin{aligned}\mathbf{g}_{r_j} &= [E(d_j), E(v_j)] \\ \alpha_j &\propto \exp(\mathbf{g}_{r_j}^T W_\alpha \mathbf{h}_i)\end{aligned}$$

The inference network is given by

1. The value mention model  $q(m_i | v, x)$  has access to the values  $v$  from the KB, which it conditions on when detecting value mentions.

$$p(m_i | v, x) = W'_m \text{MLP}([\sum_j \alpha_j \cdot \mathbf{g}_{r_j}, \mathbf{h}_i]), W'_m \in \mathbb{R}^{2 \times d}$$

2. The alignment model  $q(a_i | v, x, d)$  uses the attention weights to parameterize the alignment  $p(a_i | x) = \alpha_{a_i}$ .
3. The translation model  $q(z_i | a, v, x) = 1(z_i = v_{a_i})$  conditions on the alignments  $a$  and ensures the chosen  $z$  is consistent with the alignments.

We use the score function gradient estimator to perform gradient ascent on the objective in Equation 4 with respect to both  $p$  and  $q$ . We utilize a leave-one-out baseline for variance reduction.

One concern is that the model may learn to never rely on the text for extraction, setting  $m_i = 0$  at every index. We can avoid this by initializing  $q(z)$  to ensure that for words  $x \in \mathcal{V}$  we have  $q(z = x)$  is high, biasing the translation model towards transliteration at the start of training.

## 4 Evaluation

As we assumed that the KB contained a superset of the facts contained in a sequence of text, we are interested in evaluating whether the model can discover and locate the subset of facts that are expressed in the text.

We evaluate by determining whether the model can identify which facts in a KB are expressed in text. Given a ground truth set of facts extracted by a human annotator, we compute the precision and recall of the extractions by the model. We perform extraction by finding  $\arg \max_{z_i, a_i, m_i} q(z_i), q(a_i), q(m_i)$  for each word  $x_i$ .

## References