

# 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, the *cells* of the table, 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. In fact, we assume the KB contains many more facts than those mentioned in the text. This fits many scenarios in real world applications: we may have many entity and type pairs in our data table, but a summary may discuss only a small, salient subset of players and statistics. 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

Consider the following example: Let our KB consist of the data table and values

$$D = \left\{ \begin{array}{l} (e_1 = \text{John Doe}, t_1 = \text{Points}), \\ (e_2 = \text{John Doe}, t_2 = \text{Rebounds}), \\ (e_3 = \text{John Doe}, t_3 = \text{First name}), \\ (e_4 = \text{John Doe}, t_4 = \text{Last name}), \\ \vdots \end{array} \right\}, v = \left\{ \begin{array}{l} v_1 = 8, \\ v_2 = 12, \\ v_3 = \text{John}, \\ v_4 = \text{Doe}, \\ \vdots \end{array} \right\}$$

aligned to the summary  $x = \text{John Doe scored eight points}$ . We introduce the following latent variables:

- $m = m_1, \dots, m_I$  where each  $m_i \in \{0, 1\}$  indicates whether word  $x_i$  is part of a value mention. In our example, we have  $m_4 = 1$  as  $x_4 = \text{eight}$  mentions the value  $v_1 = 8$ . Individual words may be part of a multiword value mention. We aim to identify at least one word in a multiword mention.
- $a = a_1, \dots, a_I$  where each  $a_i \in \{1, \dots, J\}$  gives the index of the cell of the data table  $D_{a_i}$  whose value  $v_{a_i}$  is mentioned at index  $i$ . Again examining  $x_4 = \text{eight}$ , we would have  $a_4 = 1$ , as  $x_4$  is aligned to the the cell  $D_1$  whose value  $v_1 = 8$  is mentioned.
- $z = z_1, \dots, z_I$  where each  $z_i \in \mathcal{V}$  translates a value mention into a value. In the case of  $x_4 = \text{eight}$ , the mention must be translated to the value  $z_4 = 8$ . This is the canonical representation of a value as determined by the schema of the KB. For example, the KB may only store numbers in numerical form, as opposed to alphabetical.

### 2.2 Model

We proceed to detail the model in two stages. We first give the word-level process, which makes a series of choices for each word  $x_i$  in the text  $x = x_1, \dots, x_I$ , then the sequence-level process which aggregates all of the word-level decisions.

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

1. Value mention identification: Given a sequence of words  $x$ , we independently choose whether each word is a value mention with

$$p(m \mid x) = \prod_i p(m_i \mid x) \quad (1)$$

2. Alignment: Each word  $x_i$  is independently aligned to a record in the knowledge base with

$$p(a \mid x, D) = \prod_i p(a_i \mid x, D) \quad (2)$$

We align the word  $x_i$  by choosing the cell whose value generates the possible value mention at index  $i$ . In particular,  $a_i = j$  denotes the alignment to the cell  $d_j$ . We assume that each value mention aligns to a single record. Although we align every word to a cell, words that are not chosen to be mentions, i.e.  $x_i$  such that  $m_i = 0$ , will be ignored.

3. Translation: All words are translated into a value from the KB schema with

$$p(z \mid x) = \prod_i p(z_i \mid x) \quad (3)$$

with  $z_i \in \mathcal{V}$ . We would like this to capture synonyms of values not captured by the limited schema of the KB. Although every word is translated to a value, we ignore those that are not chosen as value mentions.

Finally, we aggregate the word-level choices at the sequence level in order to make a single choices for the values  $v$  given the summary  $x$ .

4. Aggregation: Given the word-level values  $z$ , alignments  $a$ , mentions  $m$ , and data table  $D$  we choose the sequence-level values  $v_j$  independently from

$$p(v \mid z, a, m, d) = \prod_j p(v_j \mid z, a, m, D_j) \quad (4)$$

If any of the word-level choices disagree, for example if  $z_1, a_1, m_1$  indicates that John scored 19 points, but  $z_2, a_2, m_2$  indicates John scored 18, we must aggregate these choices into a single distribution over values.

We assume each of the word-level choices in each of  $z, a, m$  are made independently given the text  $x$  and table cells  $D$ . This gives us the following factorization of the relation extraction system:

$$\begin{aligned} p(v, z, a, m \mid x, D) &= p(v \mid z, a, m, x, d) p(z \mid x) p(a \mid x, D) p(m \mid x) \\ &= \left( \prod_{j=1}^J p(v_j \mid z, a, m, x, D) \right) \left( \prod_{i=1}^I p(z_i \mid x) p(a_i \mid x, D) p(m_i \mid x) \right) \end{aligned} \quad (5)$$

## 2.3 Parameterization

We parameterize the conditional distributions for mention identification, alignment, translation, and aggregation 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 the cells of the data table  $D$  to vectors in  $\mathbb{R}^d$ .

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

$$p(m_i \mid x) \propto \exp(W_m \mathbf{h}_i)_{m_i}, W_m \in \mathbb{R}^{2 \times d} \quad (6)$$



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 the cell  $D_{a_i}$  that  $x_i$  aligns to, and the value  $z_i$  gives the canonical value that  $x_i$  translates to.

2. Alignment: We use a bilinear function of the cell embeddings and contextual embeddings to parameterize the alignment distribution.

$$p(a_i | x, d) \propto \exp(E(D_{a_i})^T W_d \mathbf{h}_i) \quad (7)$$

with  $W_d \in \mathbb{R}^{d \times d}$ .

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

$$p(z_i | x) \propto \exp(W_z \mathbf{h}_i)_{z_i}, W_z \in \mathbb{R}^{|\mathcal{V}| \times d} \quad (8)$$

4. Aggregation: We parameterize a distribution over the value  $v_j$  of cell  $D_j$  by counting the votes of relevant word-level values. In order for a word  $x_i$  to vote on a value  $v_j$  the word must be a mention such that  $m_i = 1$ , it must be aligned to the correct cell  $a_i = j$ , and its translation must match  $z_i = v_j$ . Once the votes are collected, they are aggregated then normalized into a distribution.

If no word votes for any values for cell  $D_j$ , i.e. there does not exist a word  $x_i$  such that  $a_i = j$  and  $m_i = 1$ , we choose the value given only the cell  $p(v_j | d_j) \propto \exp(E(v_j)^T W_v [E(D_j)])$ .

Formally, the conditional distribution is given by

$$p(v_j | z, a, m, d) \propto \begin{cases} \prod \exp(\psi(v_j, z_i, a_i, m_i, d)), & \exists i, m_i = 1 \wedge a_i = j \\ \exp(E(v_j)^T W_v [E(D_j)]), & \text{otherwise} \end{cases} \quad (9)$$

$$\psi(v_j, z_i, a_i, m_i, d) = \mathbf{1}(v_j = z_i, a_i = j, m_i = 1) \quad (10)$$

### 3 Training and Inference

To train a latent variable model, we must marginalize over the unobserved RVs and maximize the likelihood of the observed. Although the latent variables  $z, a, m$  are important, as they indicate where and what facts are contained in the text, they are not observed and must be marginalized over. Therefore we would ideally optimize the following objective

$$\log p(v \mid x, D) = \log \sum_{z, a, m} p(v, z, a, m \mid x, D) \quad (11)$$

However, maximizing  $\log p(v \mid x, D)$  directly is very expensive for this model as the summation over variables  $z, a, m$  is intractable; in particular, the summation has computational complexity  $O((|\mathcal{V}| \cdot J \cdot 2)^I)$ .

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

#### 3.1 Inference network

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

$$\log p(v \mid x) \geq \mathbb{E}_{q(z, a, m \mid v, x, D)} \left[ \log \frac{p(v, z, a, m \mid x, D)}{q(z, a, m \mid v, x, D)} \right] \quad (12)$$

Recall that  $\mathbf{h}_i \in \mathbb{R}^d$  is a contextual embedding of the word  $x_i$ . We introduce the following attention weights over records in order to get a weighted representation of the KB for each index  $i$ :

$$\mathbf{g}_j = [E(D_j), E(v_j)] \quad (13)$$

$$\alpha_j \propto \exp(\mathbf{g}_{r_j}^T W_\alpha \mathbf{h}_i) \quad (14)$$

We propose to parameterize the inference network  $q(z, a, m \mid v, x, D)$  as follows:

1. Identification: To predict whether  $x_i$  is a mention, the inference network uses a weighted representation of the KB along with the contextual representation  $\mathbf{h}_i$

$$p(m_i \mid v, x) \propto \exp \left( V_m \text{MLP} \left( \left[ \sum_j \alpha_j \cdot \mathbf{g}_j; \mathbf{h}_i \right] \right) \right)_{m_i}, V_m \in \mathbb{R}^{2 \times d} \quad (15)$$

where MLP is a neural network.

2. Alignment: The alignment model  $q(a_i \mid v, x, D)$  uses the attention weights to parameterize the alignment  $p(a_i \mid x) = \alpha_{a_i}$ .
3. Translation: The translation model  $q(z_i \mid a_i, v, x) = \mathbf{1}(z_i = v_{a_i})$  conditions on the alignment  $a_i$  and ensures the chosen  $z$  is consistent with the alignment.

The joint distribution of  $z, a, m$  in the inference network is given by

$$\begin{aligned} p(z, a, m \mid v, x, d) &= p(z \mid a, v, x)p(a \mid v, x, d)p(m \mid v, x) \\ &= \prod_i p(z_i \mid a, v, x)p(a_i \mid v, x, d)p(m_i \mid v, x) \end{aligned} \quad (16)$$

We use the score function gradient estimator to perform gradient ascent on the objective in Equation 16 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  $x_i$  where there exists a  $z_i \in \mathcal{V}$  such that  $x_i$  and  $z_i$  are a lexical match we assign high probability to the transliteration  $q(z_i = x_i)$  via pretraining.

## 4 Evaluation

We are interested in evaluating whether the model can discover and locate the subset of facts in a KB that are expressed in the text without observing the values of the KB. We compare the extractions of our model with a ground truth set of facts extracted by a human annotator, reporting the micro-averaged precision, recall, and F1 score.

We perform extraction by finding

$$\arg \max_{z_i^*, a_i^*, m_i^*} p(z_i \mid x), p(a_i \mid x, D), p(m_i \mid x)$$

for each word  $x_i$ . We obtain the fact  $(e_j, t_j, v_j)$  at position  $i$  if  $m_i^* = 1$ ,  $a_i^* = j$  and  $z_i^* = v_j$ . The extraction is considered correct if the ground truth contains a fact with the same entity, type, value, and location.