TransG: A Generative Mixture Model for Knowledge Graph Embedding

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Abstract

Recently, knowledge graph embedding, which projects symbolic entities and relations into continuous vector space, has become a new, hot topic in artificial intelligence. This paper addresses a new issue of multiple relation semantics that a relation may have multiple meanings revealed by the entity pairs associated with the corresponding triples, and proposes a novel generative model for embedding, TransG. The new model can discover latent semantics for a relation and leverage a mixture of relation-specific component vectors to embed a fact triple. To the best of our knowledge, this is the first generative model for knowledge graph embedding, which is able to deal with multiple relation semantics. Extensive experiments show that the proposed model achieves substantial improvements against the state-of-the-art baselines.

1 Introduction

Abstract or real-world knowledge is always a major topic in Artificial Intelligence. Knowledge bases such as Wordnet [Miller, 1995] and Freebase [Bollacker et al., 2008] have been shown very useful to AI tasks including question answering, knowledge inference, and so on. However, traditional knowledge bases are symbolic and logic, thus numerical machine learning methods cannot be leveraged to support the computation over the knowledge bases. To this end, knowledge graph embedding, which projects entities and relations into continuous vector spaces, has been proposed. Among various embedding models, there is a line of translation-based models such as TransE [Bordes et al., 2013], TransH [Wang et al., 2014] and TransR [Lin et al., 2015].

A fact of knowledge base can usually be represented by a triple \((h, r, t)\) where \(h\), \(r\), and \(t\) indicate a head entity, a relation, and a tail entity, respectively. All translation-based models are almost following the same principle \(h_r + r \approx t_r\), where \(h_r\), \(r\), \(t_r\) indicate the embedding vectors of triple \((h, r, t)\), with the head and tail entity vector projected with respect to the relation space.

In spite of the success of these models, none of the previous models can deal with the multiple relation semantics that a relation may have multiple meanings revealed by the entity pairs associated with the corresponding triples. As can be seen from Fig. [1] visualization results on embedding vectors obtained from TransE [Bordes et al., 2013] show that, there are different clusters for a specific relation, and different clusters indicate different latent semantics. For example, the relation HasPart has at least two latent semantics: composition-related as (Table, HasPart, Leg) and location-related as (Atlantics, HasPart, NewYorkBay). This phenomenon is quite common in knowledge bases for two reasons: artificial simplification and nature of knowledge. On one hand, knowledge base curators could not involve too many similar relations, so abstracting multiple similar relations into one specific relation is a common trick. On the other hand, both language and knowledge representations often involve ambiguous information. The ambiguity of knowledge means a semantic mixture. For example, in Freebase, (Jon Snow, birth place, Winter Fall) and (George R.R. Martin, birth place, U.S.) are actually mapped to fictional character and person, respectively. However, this may be done automatically by dealing with multiple relation semantics.

However, since previous translation-based models adopt \(h_r + r \approx t_r\), they assign only one translation vector for one relation, and these models cannot alleviate the issue of multiple relation semantics. To illustrate more clearly, as showed in Fig. [2] there is only one unique representation for relation HasPart in traditional models, thus the models made more errors when embedding the triples of the relation. Instead, in our proposed model, we leverage a Bayesian non-parametric infinite mixture embedding model to handle multiple relation semantics by generating multiple translation components for a relation. Thus, different semantics are characterized by different components in our embedding model. For example, we can distinguish the two clusters HasPart_1 or HasPart_2, where the relation semantics are automatically clustered to represent the meaning of associated entity pairs.

To summarize, our contributions are as follows:

- We address a new issue in knowledge graph embedding, multiple relation semantics that a relation in knowledge graph may have different meanings revealed by the associated entity pairs, which has never been studied previously.
the entities in the original entity space: $h$

TransE

relation-specific space. where $h$ is designed as:

Existing translation-based embedding methods share the same translation principle $h + r \approx t$. Since TransE adopts the principle of $t - h \approx r$, there is supposed to be only one cluster whose centre is the relation vector $r$. However, results show that there exist multiple clusters, which justifies our multiple relation semantics assumption.

- We propose a novel Bayesian non-parametric infinite mixture embedding model, TransG, to address this issue. The model can automatically discover semantic clusters of a relation, and leverage a mixture of multiple relation components for translating an entity pair.
- Extensive experiments show that our proposed model obtains substantial improvements against the state-of-the-art baselines.

2 Related Work

Prior studies are classified into two branches: translation-based embedding methods and the others.

2.1 Translation-Based Embedding Methods

Existing translation-based embedding methods share the same translation principle $h + r \approx t$ and the score function is designed as:

$$f_r(h, t) = |h_r + r - t_r|^2$$

where $h_r, t_r$ are entity embedding vectors projected in the relation-specific space. TransE [Bordes et al., 2013], lays the entities in the original entity space: $h_r = h, t_r = t$.

Figure 1: Visualization of TransE embedding vectors with PCA dimension reduction. Four relations (a ~ d) are chosen from Freebase and Wordnet. A dot denotes a triple and its position is decided by the difference vector between tail and head entity ($t - h$). Since TransE adopts the principle of $t - h \approx r$, there is supposed to be only one cluster whose centre is the relation vector $r$. However, results show that there exist multiple clusters, which justifies our multiple relation semantics assumption.

TransH [Wang et al., 2014], projects entities into a hyperplane for addressing the issue of complex relation embedding: $h_r = h - w_r, t_r = t - w_r$. To address the same issue, TransR [Lin et al., 2015b], transforms the entity embeddings by the same matrix: $h_r = M_r h, t_r = M_r t$. TransR also proposes an ad-hoc clustering-based method, CTransR, where the entity pairs for a relation are clustered into different groups, and the pairs in the same group share the same relation vector. TransM [Fan et al., 2014] leverages the structure of the knowledge graph via pre-calculating the distinct weight for each training triple to enhance embedding.

2.2 Other Embedding Methods

There list other embedding approaches:

- **Structured Embedding (SE).** The SE model [Bordes et al., 2011] transforms the entity space with the head-specific and tail-specific matrices. The score function is defined as $f_r(h, t) = |M_r h_r - M_r t_r|$. According to [Socher et al., 2013], this model cannot capture the relationship between entities.

- **Semantic Matching Energy (SME).** The SME model [Bordes et al., 2012, 2014] can handle the correlations between entities and relations by matrix product and Hadamard product. In some recent work [Bordes et al., 2014], the score function is re-defined with 3-way tensors instead of matrices.

- **Single Layer Model (SLM).** SLM applies neural network to knowledge graph embedding. The score function is defined as $f_r(h, t) = u_1 g(M_{r,1} h + M_{r,2} t)$ where $M_{r,1}, M_{r,2}$ are relation-specific weight matrices. Collobert had applied a similar method into the language model, [Collobert and Weston, 2008].

- **Latent Factor Model (LFM).** The LFM [Jenatton et al., 2012, Sutskever et al., 2009] attempts to capture the second-order correlations between entities by a quadratic form. The score function is as $f_r(h, t) = h^\top W_r t$.

Figure 2: Visualization of multiple relation semantics. The data are selected from Wordnet. The dots are correct triples that belong to HasPart relation, while the circles are incorrect ones. The point coordinate is the difference vector between tail and head entity, which should be near to the centre. (a) The correct triples are hard to be distinguished from the incorrect ones. (b) By applying multiple semantic components, our proposed model could discriminate the correct triples from the wrong ones.
Neural Tensor Network (NTN). The NTN model \cite{Socher et al., 2013} defines a very expressive score function to combine the SLM and LFM: \( f_r(h, t) = u_r \cdot g(h^\top W_r \cdot r + M_r, h + M_r \cdot t + b_r) \), where \( u_r \) is a relation-specific linear layer, \( g(\cdot) \) is the \( \tanh \) function, \( W \in \mathbb{R}^{d \times d \times k} \) is a 3-way tensor.

Unstructured Model (UM). The UM \cite{Bordes et al., 2012} may be a simplified version of TransE without considering any relation-related information. The score function is directly defined as \( f_r(h, t) = \| h - t \|^2_2 \).

RESCAL. This is a collective matrix factorization model which is also a common method in knowledge base embedding \cite{Nickel et al., 2011, Nickel et al., 2012}.

Semantically Smooth Embedding (SSE). \cite{Guo et al., 2015} aims at further discovering the geometric structure of the embedding space to make it semantically smooth.

\cite{Wang et al., 2014} jointly embeds knowledge and texts, we call it Joint Model. \cite{Wang et al., 2015} incorporates the rules, which is called Rule-Based Model. \cite{Lin et al., 2015a} is a path-based embedding model, named PTransE.

3 Methods

In this section, we first introduce TransG, a generative embedding model to capture multiple relation semantics, and then provide a geometric insight.

3.1 TransG: A Generative Mixture Model for Embedding

As stated in “Introduction”, only one single translation vector for a relation may be incompetent to model multiple relation semantics. This means, translation-based principle should be generalized to a mixture model, such as Bayesian Non-Parametric Infinite Mixture Model \cite{Griffiths and Ghahramani, 2011}. Thus, our TransG is proposed as follows:

1. For an entity \( e \in E \):
   (a) Draw each entity embedding vector from a standard normal distribution: \( u_e \sim \mathcal{N}(0, 1) \).

2. For a triple \((h, r, t) \in \Delta:\)
   (a) Draw a semantic component from Chinese Restaurant Process for this relation: \( m_r \sim CRP(\beta) \).
   (b) Draw a head embedding vector from a normal distribution: \( h \sim \mathcal{N}(u_h, \sigma_h^2 E) \).
   (c) Draw a tail embedding vector from a normal distribution: \( t \sim \mathcal{N}(u_t, \sigma_t^2 E) \).
   (d) Draw a relation-specific embedding vector for this semantic component: \( u_{r,m} = t - h \sim \mathcal{N}(u_t - u_h, (\sigma_h^2 + \sigma_t^2)E) \).

where \( \Delta \) is the set of golden triples, \( u_h \) and \( u_t \) indicate the mean embedding vectors for head and tail, \( \sigma_h \) and \( \sigma_t \) indicate the variance of corresponding entity distribution, and \( u_{r,m} \) is the \( m \)-th component translation vector of relation \( r \). Chinese Restaurant Process belongs to Dirichlet Process and it could automatically detect semantic components. Working out the posterior of one triple, we attain the score function as below:

\[
P(h, r, t) \propto \sum_{m=1}^{M_r} \pi_{r,m} \mathcal{P}(u_{r,m}) = \sum_{m=1}^{M_r} \pi_{r,m} e^{-\frac{||u_h + u_{r,m} - u_t||^2_2}{\sigma_h^2 + \sigma_t^2}}
\]

where \( \pi_{r,i} \) is the prior probability for each component indicating the weight of \( i \)-th component, and \( M_r \) is the number of semantic components for the relation \( r \), which is learned from the data automatically by the CRP.

Inspired by Fig1, TransG leverages a mixture of relation component vectors for a specific relation, as formula (1) shows. Each component represents a specific latent semantics. By this way, TransG could distinguish multiple relation semantics. Notably, the CRP could generate multiple semantic components when it is necessary and the relation semantic component number \( M_r \) is learned adaptively from the data.

3.2 Perspective from Geometry

Previous studies always have geometric explanations, and so does TransG. In the previous methods, when the relation \( r \) of triple \((h, r, t) \) is given, the geometric representations are fixed, as \( h + r \approx t \). However, TransG generalizes this geometric principle to:

\[
m^*_r(h, r, t) = \arg\max_{m=1...M_r} \left( \pi_{r,m} e^{-\frac{||u_h + u_{r,m} - u_t||^2_2}{\sigma_h^2 + \sigma_t^2}} \right)
\]

\[
h + u_{r,m^*_r(h, r, t)} \approx t
\]

where \( m^*_r(h, r, t) \) is the index of primary component. Though all the components contribute to the model, the primary one contributes the most due to the exponential effect \( (\cdot \exp(\cdot)) \). When a triple \((h, r, t) \) is given, TransG works out the index of primary component then translates the head entity to the tail one with this worked-out primary translation vector.

For most triples, there should be only one component that have significant non-zero \( (\pi_{r,m} \exp^{-\frac{||u_h + u_{r,m} - u_t||^2_2}{\sigma_h^2 + \sigma_t^2}}) \) value and the others would be small enough, due to the exponential decay. This property reduces the noise from the other semantic components to better characterize multiple relation semantics. In detail, \( (u_t - u_h) \) is almost around only one translation vector \( u_{r,m^*_r(h, r, t)} \) in TransG. Under the condition \( m \neq m^*_r(h, r, t) \), \( ||u_h + u_{r,m} - u_t||^2_2 \) is very large so that the exponential function value is very small. This is why the primary component could represent the primary semantics.

To summarize, previous studies make translation identically for all the triples of the same relation, but TransG automatically selects the best translation vector according to the specific semantics of a triple. Therefore, TransG could focus on the specific semantic embedding to avoid much noise from the other unrelated semantic components and result in promising improvements than existing methods. Note that, all the components in TransG have their own contributions, but the primary one makes the most.

3.3 Training Algorithm

The maximum data likelihood principle is applied for training. As to the non-parametric part, \( \pi_{r,m} \) is generated from the CRP with Gibbs Sampling similar to \cite{He et al., 2013} and \cite{Griffiths and Ghahramani, 2011} and a new component is
Table 1: Statistics of datasets

| Data   | WN18 | FB15K | WN11 | FB13 |
|--------|------|-------|------|------|
| #Rel   | 18   | 1,345 | 11   | 13   |
| #Ent   | 40,943 | 14,951 | 38,696 | 75,043 |
| #Train | 141,442 | 483,142 | 112,581 | 316,232 |
| #Valid | 5,000 | 50,000 | 2,609 | 5,908 |
| #Test  | 5,000 | 59,071 | 10,544 | 23,733 |

Table 2: Evaluation results on link prediction

| Data    | WN18 | FB15K |
|---------|------|-------|
| Mean Rank | Raw | Filter | Raw | Filter |
| Unstructured | 315 | 304 | 35.3 | 38.2 |
| RESCAL [Bordes et al., 2011] | 1,180 | 1,163 | 37.2 | 52.8 |
| SE [Bordes et al., 2011] | 1,011 | 985 | 68.5 | 80.5 |
| SME(bilinear) [Bordes et al., 2011] | 526 | 509 | 54.7 | 61.3 |
| LFM [Jentgen et al., 2012] | 469 | 456 | 71.4 | 81.6 |
| TransE [Bordes et al., 2013] | 263 | 251 | 75.4 | 89.2 |
| TransH [Wang et al., 2014] | 401 | 388 | 73.0 | 82.3 |
| TransR [Lin et al., 2015b] | 238 | 225 | 79.8 | 92.0 |
| CTransR [Lin et al., 2015b] | 231 | 218 | 79.4 | 92.3 |
| PTransE [Lin et al., 2015a] | N/A | N/A | N/A | N/A |
| KGE [He et al., 2015] | 362 | 348 | 80.5 | 93.2 |
| TransG (this paper) | 357 | 345 | 82.5 | 94.7 |

SGD is applied to solve this optimization problem. In addition, we apply a trick to control the parameter update process during training. For those very impossible triples, the update process should be skipped. Hence, we introduce a similar condition as TransE [Bordes et al., 2013] adopts: the training algorithm will update the embedding vectors only if the below condition is satisfied:

\[
P\{h, r, t\} = \sum_{m=1}^{M_r} m_{r,m} e^{-\frac{||u_h^r + u_{r,m} - u_t^r||^2}{\sigma_h^2 + \sigma_t^2}} \leq M e^\gamma \quad (5)
\]

where \(h, r, t\) is the posterior probability as formula 1 shows. To better distinguish the true triples from the false ones, we maximize the ratio of likelihood of the true triples to that of the false ones.

As to the efficiency, in theory, the time complexity of TransG is bounded by a small constant \(M\) compared to TransE, that is \(O(TransG) = O(M * O(TransE))\) where \(M\) is the number of semantic components in the model. Note that TransE is the fastest method among translation-based methods. The experiment of Link Prediction shows that TransG and TransE would converge at around 500 epochs, meaning there is also no significant difference in convergence speed. In experiment, TransG takes 1.4s for one iteration on FB15K while TransR costs 136.8s on the same computer for the same dataset.

4 Experiments

Our experiments are conducted on four public benchmark datasets that are the subsets of Wordnet and Freebase, respectively. The statistics of these datasets are listed in Table 1. Experiments are conducted on two tasks: Link Prediction and Triple Classification. To further demonstrate how the proposed model approaches multiple relation semantics, we present semantic component analysis in the last of this section.

4.1 Link Prediction

In order to testify the performance of knowledge graph completion, link prediction task is conducted. When given an entity and a relation, the embedding models predict the other...
missing entity. More specifically, in this task, we predict \( t \) given \((h, r, *)\), or predict \( h \) given \((*, r, t)\). The WN18 and FB15K are two benchmark datasets for this task. Note that many AI tasks could be enhanced by Link Prediction such as relation extraction [Hoffmann et al., 2011].

**Evaluation Protocol.** We adopt the same protocol used in previous studies. For each testing triple \((h, r, t)\), we corrupt it by replacing the tail \( t \) (or the head \( h \)) with every entity \( e \) in the knowledge graph and calculate a probabilistic score of this corrupted triple \((h, r, e)\) (or \((e, r, t)\)) with the score function \( f_r(h, e)\). By ranking these scores in descending order, we then obtain the rank of the original triple. There are two metrics for evaluation: the averaged rank (Mean Rank) and the proportion of testing triple whose rank is not larger than \( 10 \) (HITS@10). This is called “Raw” setting. When we filter out the corrupted triples that exist in the training, validation, or test datasets, this is the “Filter” setting. If a corrupted triple exists in the knowledge graph, ranking it ahead the original triple is also acceptable. To eliminate this case, the “Filter” setting is more preferred. In both settings, a lower Mean Rank and a higher HITS@10 mean better performance.

**Implementation.** As the datasets are the same, we directly reproduce the experimental results of several baselines from the literature, as in [Bordes et al., 2013], [Wang et al., 2014] and [Lin et al., 2015b]. We have attempted several settings on the validation dataset to get the best configuration. Under the “bern.” sampling strategy, the optimal configurations are: learning rate \( \alpha = 0.001 \), \( k = 100 \), \( \gamma = 2.5 \), \( \beta = 0.05 \) on WN18; \( \alpha = 0.0015 \), \( k = 400 \), \( \gamma = 3.0 \), \( \beta = 0.1 \) on FB15K. Note that all the symbols are introduced in “Methods”. We train the model until it converges.

**Results.** Evaluation results on WN18 and FB15K are reported in Tab.2 and Tab.3. We observe that:

1. TransG outperforms all the baselines obviously. Compared to TransR, TransG makes improvements by 2.6% on WN18 and 25.6% on FB15K, and the averaged semantic component number on WN18 is 5.77 and that on FB15K is 8.77. This result demonstrates capturing multiple relation semantics would benefit embedding.

2. The model has a bad Mean Rank score on the WN18 dataset. Further analysis shows that there are 24 testing triples (0.5% of the testing set) whose ranks are more than 30,000, and these few cases would lead to about 150 mean rank loss. Among these triples, there are 23 triples whose tail or head entities have never been co-occurring with the corresponding relations in the training set. In one word, there is no sufficient training data for those relations and entities.

3. Compared to CTransR, TransG solves the multiple relation semantics problem much better for two reasons. Firstly, CTransR clusters the entity pairs for a specific relation then performs embedding for each cluster, but TransG deals with embedding and multiple relation semantics at the same time, where the two processes can be enhanced by each other. Secondly, CTransR models a triple by only one cluster, but TransG applies an infinite mixture model to refine the embedding. Notably, CTransR never had a purpose to address and solve multiple relation semantic issue, specifically.

### 4.2 Triple Classification

In order to testify the discriminative capability between true and false facts, triples classification task is conducted. This is a classical task in knowledge base embedding, which aims at predicting whether a given triple \((h, r, t)\) is correct or not. WN11 and FB13 are the benchmark datasets for this task. Note that evaluation of classification needs negative samples, and the datasets have already been built with negative triples.

**Evaluation Protocol.** The decision process is very simple as follows: for a triple \((h, r, t)\), if \( f_r(h, t) \) is below a threshold \( \sigma_r \), then positive; otherwise negative. The thresholds \( \{\sigma_r\} \) are determined on the validation dataset.

**Implementation.** As all methods use the same datasets, we directly re-use the results of different methods from the literature. We have attempted several settings on the validation dataset to find the best configuration. The optimal configurations of TransG are as follows: “bern.” sampling, learning rate \( \alpha = 0.001 \), \( k = 50 \), \( \gamma = 6.0 \), \( \beta = 0.1 \) on WN11, and “bern.” sampling, \( \alpha = 0.002 \), \( k = 400 \), \( \gamma = 3.0 \), \( \beta = 0.1 \) on FB13. We limit the maximum number of epochs to 500 but the algorithm usually converges at around 100 epochs.

**Results.** Accuracies are reported in Tab.5 and Fig.3. We observe that:

1. TransG outperforms all the baselines remarkably. Compared to TransR, TransG improves by 1.7% on WN11 and 5.8% on FB13, and the averaged semantic component number on WN11 is 2.63 and that on FB13 is 4.53.

### Table 3: triples classification: accuracy(%) for different embedding methods.

| Methods   | WN11 | FB13 | AVG. |
|-----------|------|------|------|
| NTN       | 70.4 | 87.1 | 78.8 |
| TransE    | 75.9 | 81.5 | 78.7 |
| TransH    | 78.8 | 83.3 | 81.1 |
| TransR    | 85.9 | 82.5 | 84.2 |
| CTransR   | 85.7 | N/A  | N/A  |
| KG2E      | 85.4 | 85.3 | 85.4 |
| TransG    | 87.4 | 87.3 | 87.4 |

![Figure 3: Accuracies of each relations in WN11 for triple classification. The right y-axis is the number of semantic components, corresponding to the lines.](image327x471 to 546x605)
Table 4: Evaluation results on FB15K by mapping properties of relations(%)  

| Relation Category | Predicting Head (HITS@10) | Predicting Tail (HITS@10) |
|-------------------|---------------------------|---------------------------|
|                   | 1-1 | 1-N | N-1 | N-N | 1-1 | 1-N | N-1 | N-N |
| Unstructured       | 34.5 | 2.5 | 6.1 | 6.6 | 34.3 | 4.2 | 1.9 | 6.6 |
| TransE             | 43.7 | 65.7 | 18.2 | 47.2 | 43.7 | 19.7 | 66.7 | 50.0 |
| TransH             | 66.8 | 87.6 | 28.7 | 64.5 | 65.5 | 39.8 | 83.3 | 67.2 |
| TransR             | 78.8 | 89.2 | 34.1 | 69.2 | 79.2 | 37.4 | 90.4 | 72.1 |
| CTransR            | 81.5 | 89.0 | 34.7 | 71.2 | 80.8 | 38.6 | 90.1 | 73.8 |
| PTransE            | 90.1 | 92.0 | 58.7 | 86.1 | 90.1 | 70.7 | 87.5 | 88.7 |
| KG2E               | 92.3 | 93.7 | 66.0 | 69.6 | 92.6 | 67.9 | 94.4 | 73.4 |

Table 5: Different clusters in WN11 and FB13 relations.  

| Relation     | Cluster | Triples (Head, Tail) |    |
|--------------|---------|----------------------|----|
| PartOf       | Location | (Capital of Utah, Beehive State), (Hindustan, Bharat), (Hoover Dam, Battle Born State)... |
|              | Composition | (Monitor, Television), (Bush, Adult Body), (Cell Organ, Cell), (Indian Rice, Wild Rice)... |
| Religion     | Catholicism | (Cimabue, Catholicism), (Bruno Heim, Catholicism), (St.Catald, Catholicism)... |
|              | Others | (Michal Czajkowski, Islam), (Honinbo Sansa, Buddhism), (Asmahan, Druze)... |
| DomainRegion | Abstract | (Computer Science, Security System), (Computer Science, Programming Language)... |
|              | Specific | (Computer Science, Router), (Computer Science, Disk File), (Psychiatry, Isolation)... |
| Profession   | Scientist | (Michael Woodruf, Surgeon), (El Lissitzky, Architect), (Charles Wilson, Physicist)... |
|              | Businessman | (Enoch Pratt, Entrepreneur), (Charles Tennant, Magnate), (Joshua Fisher, Businessman)... |
|              | Writer | (Vlad. Gardin, Screen Writer), (John Huston, Screen Writer), (Martin Fri, Screen Writer)... |

Figure 4: Semantic component number on WN18 (left) and FB13 (right).

This result shows the benefit of capturing multiple relation semantics for a relation.

2. The relations, such as “Synset Domain” and “Type Of”, which hold more semantic components, are improved much more. Conversely, the relation “Similar” holds only one semantic component and is almost not promoted. This further demonstrates that capturing multiple relation semantics can benefit embedding.

4.3 Semantic Component Analysis

In this subsection, we analyse the number of semantic components for different relations and list the component number on the dataset WN18 and FB13 in Fig 4.

Results. As Fig. 4 and Tab. 5 illustrate, we observe that:

1. Multiple semantic components are indeed necessary for most relations. Except for relations such “Similar” and “Nationality”, all other relations have more than one semantic component.

2. Different components indeed correspond to different semantics, justifying the theoretical analysis and effectiveness of TransG. For example, “Profession” has at least three significant semantics: science-related as (El Lissitzky, Architect), business-related as (Enoch Pratt, Entrepreneur) and writer-related as (Vlad.Gardin, Screen Writer).

3. WN11 and WN18 are the different subsets of Wordnet. As we know, the semantic component number is decided on the triples in the dataset. Therefore, It’s reasonable that similar relations, such as “Synset Region” and “Synset Usage” may hold different semantic numbers for WN11 and WN18.

5 Conclusion

In this paper, we address a new issue, multiple relation semantics, and propose TransG, a generative Bayesian non-parametric infinite mixture embedding model for knowledge graph embedding. TransG can discover the latent semantics of a relation automatically and leverage a mixture of relation components for embedding. Extensive experiments show our method achieves substantial improvements against the state-of-the-art baselines.

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