

Corpus-level Fine-grained Entity Typing Using Contextual Information

Yadollah Yaghoobzadeh and Hinrich Schütze

Center for Information and Language Processing

University of Munich, Germany

yadollah@cis.lmu.de

Abstract

This paper addresses the problem of corpus-level entity typing, i.e., inferring from a large corpus that an entity is a member of a class such as “food” or “artist”. The application of entity typing we are interested in is knowledge base completion, specifically, to learn which classes an entity is a member of. We propose FIGMENT to tackle this problem. FIGMENT is embedding-based and combines (i) a global model that scores based on aggregated contextual information of an entity and (ii) a context model that first scores the individual occurrences of an entity and then aggregates the scores. In our evaluation, FIGMENT strongly outperforms an approach to entity typing that relies on relations obtained by an open information extraction system.

1 Introduction

Natural language understanding (NLU) is not possible without knowledge about the world – partly so because world knowledge is needed for many NLP tasks that must be addressed as part of NLU; e.g., many coreference ambiguities can only be resolved based on world knowledge. It is also true because most NLU applications combine a variety of information sources that include both text sources and knowledge bases; e.g., question answering systems need access to knowledge bases like gazetteers. Thus, high-quality knowledge bases are critical for successful NLU.

Unfortunately, most knowledge bases are incomplete. The effort required to create knowledge bases is considerable and since the world changes, it will always continue. Knowledge bases are therefore always in need of updates and corrections. To address this problem, we present an information extraction method that can be used for

knowledge base completion. In contrast to most other work on knowledge base completion, we focus on fine-grained *classification of entities* as opposed to *relations between entities*.

The goal of knowledge base completion is to acquire knowledge in general as opposed to detailed analysis of an individual context or sentence. Therefore, our approach is *corpus-level*: We infer the types of an entity by considering the set of all of its mentions in the corpus. In contrast, named entity recognition (NER) is *context-level* or *sentence-level*: NER infers the type of an entity in a particular context. As will be discussed in more detail in the following sections, the problems of corpus-level entity typing vs. context/sentence-level entity typing are quite different. This is partly because the objectives of optimizing accuracy on the context-level vs. optimizing accuracy on the corpus-level are different and partly because evaluation measures for corpus-level and context-level entity typing are different.

We define our problem as follows. Let K be a knowledge base that models a set E of entities, a set T of fine-grained classes or *types* and a membership function $m : E \times T \mapsto \{0, 1\}$ such that $m(e, t) = 1$ iff entity e has type t . Let C be a large corpus of text. Then, the problem we address in this paper is *corpus-level entity typing*: For a given pair of entity e and type t determine – based on the evidence available in C – whether e is a member of type t (i.e., $m(e, t) = 1$) or not (i.e., $m(e, t) = 0$) and update the membership relation m of K with this information.

We investigate two approaches to entity typing: a global model and a context model.

The *global model* aggregates all contextual information about an entity e from the corpus and then based on that, makes a classification decision on a particular type t – i.e., $m(e, t) = 0$ vs. $m(e, t) = 1$.

The *context model* first scores each individual

context of e as expressing type t or not. A final decision on the value of $m(e, t)$ is then made based on the distribution of context scores. One difficulty in knowledge base completion based on text corpora is that it is too expensive to label large amounts of text for supervised approaches. For our context model, we address this problem using *distant supervision*: we treat *all* contexts of an entity that can have type t as contexts of type t even though this assumption will in general be only true for a *subset* of these contexts. Thus, as is typical for distant supervision, the labels are incorrect in some contexts, but we will show that the labeling is good enough to learn a high-quality context model.

The global model is potentially more robust since it looks at all the available information at once. In contrast, the context model has the advantage that it can correctly predict types for which there are only a small number of reliable contexts. For example, in a large corpus we are likely to find a few reliable contexts indicating that “Barack Obama” is a bestselling author even though this evidence may be obscured in the global distribution because the vast majority of mentions of “Obama” do not occur in author contexts.

We implement the global model and the context model as well as a simple combination of the two and call the resulting system FIGMENT: FINE-Grained eMbedding-based Entity Typing. A key feature of FIGMENT is that it makes extensive use of distributed vector representations or *embeddings*. We compute embeddings for words as is standard in a large body of NLP literature, but we also compute embeddings for *entities* and for *types*. The motivation for using embeddings in these cases is (i) better generalization and (ii) more robustness against noise for text types like web pages. We compare the performance of FIGMENT with an approach based on Open Information Extraction (OpenIE).

The main contributions of this paper can be summarized as follows.

- We address the problem of corpus-level entity typing in a knowledge base completion setting. In contrast to other work that has focused on learning *relations* between entities, we learn *types* of entities.
- We show that context and global models for entity typing provide complementary infor-

mation and combining them gives the best results.

- We use embeddings for words, entities and types to improve generalization and deal with noisy input.
- We show that our approach outperforms a system based on OpenIE relations when the input corpus consists of noisy web pages.

In the following, we first discuss related work. Then we motivate our approach and define the problem setting we adopt. We then introduce our models in detail and report and analyze experimental results. Finally, we discuss remaining challenges and possible future work and present our conclusions.

2 Related work

Named entity recognition (NER) is the task of detecting and classifying named entities in text. While most NER systems (e.g., Finkel et al. (2005)) only consider a small number of entity classes, recent work has addressed fine-grained NER (Yosef et al., 2012; Ling and Weld, 2012). These methods use a variety of lexical and syntactic features to segment and classify entity mentions. Some more recent work assumes the segmentation is known and only classifies entity mentions. Dong et al. (2015) use distributed representations of words in a hybrid classifier to classify mentions to 20 types. Yogatama et al. (2015) classify mentions to more fine-grained types by using different features for mentions and embedding labels in the same space. These methods as well as standard NER systems try to maximize correct classification of mentions in individual contexts whereas we aggregate individual contexts and evaluate on accuracy of entity-type assignments inferred from the entire corpus. In other words, their evaluation is *sentence-level* whereas ours is *corpus-level*.

Entity set expansion (ESE) is the problem of finding entities in a class (e.g., medications) given a seed set (e.g., {“Ibuprofen”, “Maalox”, “Prozac”}). The standard solution is pattern-based bootstrapping (Thelen and Riloff, 2002; Gupta and Manning, 2014). ESE is different from the problem we address because ESE starts with a small seed set whereas we assume that a large number of examples from a knowledge base (KB) is available. Initial experiments with the system of Gupta

and Manning (2014) showed that it was not performing well for our task – this is not surprising given that it is designed for a task with properties quite different from entity typing.

More closely related to our work are the OpenIE systems NNPLB (Lin et al., 2012) and PEARL (Nakashole et al., 2013) for *fine-grained typing of unlinkable and emerging entities*. Both systems first extract relation tuples from a corpus and then type entities based on the tuples they occur in (where NNPLB only uses the subject position for typing). To perform typing, NNPLB propagates activation from known members of a class to other entities whereas PEARL assigns types to the argument slots of relations. The main difference to FIGMENT is that we do not rely on relation extraction. In principle, we can make use of any context, not just subject and object positions. FIGMENT also has advantages for noisy text for which relation extraction can be challenging. This will be demonstrated in our evaluation on web text. Finally, our emphasis is on making yes-no decisions about possible types (as opposed to just ranking possibilities) for all entities (as opposed to just emerging or unlinkable entities). Our premise is that even existing entities in KBs are often not completely modeled and have entries that require enhancement. We choose NNPLB as our baseline.

The fine-grained typing of entities performed by FIGMENT can be used for *knowledge base completion (KBC)*. Most KBC systems focus on *relations* between entities, not on *types* as we do. Some generalize the patterns of relationships within the KB (Nickel et al., 2012; Bordes et al., 2013) while others use a combination of within-KB generalization and information extraction from text (Weston et al., 2013; Socher et al., 2013; Jiang et al., 2012; Riedel et al., 2013; Wang et al., 2014). Neelakantan and Chang (2015) address entity typing in a way that is similar to FIGMENT. Their method is based on KB information, more specifically entity descriptions in Wikipedia and Freebase. Thus, in contrast to our approach, their system is not able to type entities that are not covered by existing KBs. We infer classes for entities from a large corpus and do not assume that these entities occur in the KB.

Learning embeddings for words is standard in a large body of NLP literature (see Baroni et al. (2014) for an overview). In addition to words, we

also learn *embeddings for entities and types*. Most prior work on entity embeddings (e.g., Weston et al. (2013), Bordes et al. (2013)) and entity and type embeddings (Zhao et al., 2015) has mainly used KB information as opposed to text corpora. Wang et al. (2014) learn embeddings of words and entities in the same space by replacing Wikipedia anchors with their corresponding entities. For our global model, we learn entity embedding in a similar way, but on a corpus with automatically annotated entities. For our context model, we learn and use type embeddings jointly with corpus words to improve generalization, a novel contribution of this paper to the best of our knowledge. We learn all our embeddings using `word2vec` (Mikolov et al., 2013).

Our problem can be formulated as *multi-instance multi-label (MIML)* learning (Zhou and Zhang, 2006), similar to the formulation for relation extraction by Surdeanu et al. (2012). In our problem, each example (entity) can have several instances (contexts) and each instance can have several labels (types). Similar to Zhou and Zhang (2006)’s work on scene classification, we also transform MIML into easier tasks. The global model transforms MIML into a multi-label problem by merging all instances of an example. The context model solves the problem by combining the instance-label scores to example-label scores.

3 Motivation and problem definition

3.1 Freebase

Large scale KBs like Freebase (Bollacker et al., 2008), YAGO (Suchanek et al., 2007) and Google knowledge graph are important NLP resources. Their structure is roughly equivalent to a graph in which entities are nodes and edges are relations between entities. Each node is also associated with one or more semantic classes, called types. These types are the focus of this paper.

We use Freebase, the largest available KB, in this paper. In Freebase, an entity can belong to several classes, e.g., “Barack Obama” is a member of 37 types including “US president” and “author”. One *notable type* is also defined for each entity, e.g., “US-president” for “Obama” since it is regarded as his most prominent characteristic and the one that would be used to disambiguate references to him, e.g., to distinguish him from somebody else with the same name.

There are about 1500 types in Freebase, or-

ganized by domain; e.g., the domain “food” has types like “food”, “ingredient” and “restaurant”. Some types like “location” are very general, some are very fine-grained, e.g., “Vietnamese urban district”. There are types that have a large number of instances like “citytown” and types that have very few like “camera_sensor”. Entities are defined as instances of types. They can have several types based on the semantic classes that the entity they are referring to is a member of – as in the above example of Barack Obama.

The types are not organized in a strict taxonomy even though there exists an *included type* relationship between types in Freebase. The reason is that for a user-generated KB it is difficult to maintain taxonomic consistency. For example, almost all instances of “author” are also instances of “person”, but sometimes organizations author and publish documents. We follow the philosophy of Freebase and assume that the types do not have a hierarchical organization.

3.2 Incompleteness of knowledge base

Even though Freebase is the largest publicly available KB of its kind, it still has significant coverage problems; e.g., 78.5% of persons in Freebase do not have *nationality* (Min et al., 2013).

This is unavoidable, partly because Freebase is user-generated, partly because the world changes and Freebase has to be updated to reflect those changes. All existing KBs that attempt to model a large part of the world suffer from this incompleteness problem. Incompleteness is likely to become an even bigger problem in the future as the number of types covered by KBs like Freebase increases. As more and more fine-grained types are added, achieving good coverage for these new types using only human editors will become impossible.

The approach we adopt in this paper to address incompleteness of KBs is extraction of information from large text corpora. Text can be argued to be the main repository of the type of knowledge represented in KBs, so it is reasonable to attempt completing them based on text. There is in fact a significant body of work on corpus-based methods for extracting knowledge from text; however, most of it has addressed relation extraction, not the acquisition of type information – roughly corresponding to unary relations (see Section 2). In this paper, we focus on typing entities.

3.3 Entity linking

The first step in extracting information about entities from text is to reliably identify mentions of these entities. This problem of *entity linking* has some mutual dependencies with entity typing. Indeed, some recent work shows large improvements when entity typing and linking are jointly modeled (Ling et al., 2015; Durrett and Klein, 2014). However, there are constraints that are important for high-performance entity linking, but that are of little relevance to entity typing. For example, there is a large literature on entity linking that deals with coreference resolution and inter-entity constraints – e.g., “Naples” is more likely to refer to a US (resp. an Italian) city in a context mentioning “Fort Myers” (resp. “Sicily”).

Therefore, we will only address entity typing in this paper and consider entity linking as an independent module that provides contexts of entities for FIGMENT. More specifically, we build FIGMENT on top of the output of an existing entity linking system and use FACC1,¹ an automatic Freebase annotation of ClueWeb (Gabrilovich et al., 2013). According to the FACC1 distributors, precision of annotated entities is around 80-85% and recall is around 70-85%.

3.4 FIGER types

Our goal is fine-grained typing of entities, but types like “Vietnamese urban district” are too fine-grained. To create a reliable setup for evaluation and to make sure that all types have a reasonable number of instances, we adopt the FIGER type set (Ling and Weld, 2012) that was created with the same goals in mind. FIGER consists of 112 tags and was created in an attempt to preserve the diversity of Freebase types while consolidating infrequent and unusual types through filtering and merging. For example, the Freebase types “dish”, “ingredient”, “food” and “cheese” are mapped to one type “food”. See (Ling and Weld, 2012) for a complete list of FIGER types. We use “type” to refer to FIGER types in the rest of the paper.

4 Global, context and joint models

We address a problem setting in which the followings are given: a KB with a set of entities E , a set of types T and a membership function $m : E \times T \mapsto \{0, 1\}$ such that $m(e, t) = 1$ iff entity e has type t ; and a large annotated corpus C

¹lemurproject.org/clueweb12/FACC1

in which mentions of E are linked. As mentioned before, we use FACC1 as our corpus.

In this problem setting, we address the task of *corpus-level fine-grained entity typing*: we want to infer from the corpus for each pair of entity e and type t whether $m(e, t) = 1$ holds, i.e., whether entity e is a member of type t .

We use three scoring models in FIGMENT: global model, context model and joint model. The models return a score $S(e, t)$ for an entity-type pair (e, t) . $S(e, t)$ is an assessment of the extent to which it is true that the semantic class t contains e and we learn it by training on a subset of E . The trained models can be applied to large corpora and the resulting scores can be used for learning new types of entities covered in the KB as well as for typing new or unknown entities – i.e., entities not covered by the KB. To work for new or unknown entities, we would need an entity linking system such as the ones participating in TAC KBP (McNamee and Dang, 2009) that identifies and clusters mentions of them.

4.1 Global model

The global model (GM) scores possible types of entity e based on a *distributed vector representation* or *embedding* $\vec{v}(e) \in \mathbb{R}^d$ of e . $\vec{v}(e)$ can be learned from the entity-annotated corpus C .

Embeddings of words have been widely used in different NLP applications. The embedding of a word is usually derived from the distribution of its context words. The hypothesis is that words with similar meanings tend to occur in similar contexts (Harris, 1954) and therefore cooccur with similar context words. By extension, the assumption of our model is that entities with similar types tend to cooccur with similar context words.

To learn a score function $S_{GM}(e, t)$, we use a multilayer perceptron (MLP) with one shared hidden layer and an output layer that contains, for each type t in T , a logistic regression classifier that predicts the probability of t :

$$S_{GM}(e, t) = G_t \left(\tanh \left(\mathbf{W}_{\text{input}} \vec{v}(e) \right) \right)$$

where $\mathbf{W}_{\text{input}} \in \mathbb{R}^{h \times d}$ is the weight matrix from $\vec{v}(e) \in \mathbb{R}^d$ to the hidden layer with size h . G_t is the logistic regression classifier for type t that is applied on the hidden layer. The shared hidden layer is designed to exploit the dependencies among labels. Stochastic gradient descent

(SGD) with AdaGrad (Duchi et al., 2011) and minibatches are used to learn the parameters.

4.2 Context model

For the context model (CM), we first learn a scoring function $S_{c2t}(c, t)$ for individual contexts c in the corpus. $S_{c2t}(c, t)$ is an assessment of how likely it is that an entity occurring in context c has type t . For example, consider the contexts c_1 = “he served SLOT cooked in wine” and c_2 = “she loves SLOT more than anything”. SLOT marks the occurrence of an entity and it also shows that we do not care about the entity mention itself but only its context. For the type t = “food”, $S_{c2t}(c_1, t)$ is high whereas $S_{c2t}(c_2, t)$ is low. This example demonstrates that some contexts of an entity like “beef” allow specific inferences about its type whereas others do not. We aim to learn a scoring function S_{c2t} that can distinguish these cases.

Based on the context scoring function S_{c2t} , we then compute the corpus-level CM scoring function S_{CM} that takes the scores $S_{c2t}(c_i, t)$ for all contexts of entity e in the corpus as input and returns a score $S_{CM}(e, t)$ that assesses the appropriateness of t for e . In other words, S_{CM} is:

$$S_{CM}(e, t) = g(U_{e,t}) \quad (1)$$

where $U_{e,t} = \{S_{c2t}(c_1, t), \dots, S_{c2t}(c_n, t)\}$ is the set of scores for t based on the n contexts $c_1 \dots c_n$ of e in the corpus. The function g is a summary function of the distribution of scores, e.g., the mean, median or maximum. We use the mean in this paper.

We now describe how we learn S_{c2t} . For training, we need contexts that are labeled with types. We do not have such a dataset in our problem setting, but we can use the contexts of linked entities as distantly supervised data. Specifically, assume that entity e has n types. For each mention of e in the corpus, we generate a training example with n labels, one for each of the n types of e .

For training S_{c2t} , a context c of a mention is represented as the concatenation of two vectors. One vector is the *average* of the embeddings of the $2l$ words to the left and right of the mention. The other vector is the *concatenation* of the embeddings of the $2k$ words to the left and right of the mention. E.g., for $k = 2$ and $l = 1$ the context c is represented as the vector: $\Phi(c) = [x_{-2}, x_{-1}, x_{+1}, x_{+2}, \text{avg}(x_{-1}, x_{+1})]$ where $x_i \in \mathbb{R}^d$ is the embedding of the context word at position i relative to the entity in position 0.

We train S_{c2t} on context representations that consist of embeddings because our goal is a robust model that works well on a wide variety of genres, including noisy web pages. If there are other entities in the contexts, we first replace them with their notable type to improve generalization. We learn word and type embeddings from the corpus C by replacing train entities with their notable type.

The next step is to score these examples. We use an MLP similar to the global model to learn S_{c2t} , which predicts the probability of type t occurring in context c :

$$S_{c2t}(c, t) = G_t \left(\tanh \left(\mathbf{W}_{\text{input}} \Phi(c) \right) \right)$$

where $\Phi(c) \in \mathbb{R}^n$ is the feature vector of the context c as described above, $n = (2k + 1) * d$ and $\mathbf{W}_{\text{input}} \in \mathbb{R}^{h \times n}$ is the weight matrix from input to hidden layer with h units. Again, we use SGD with AdaGrad and minibatch training.

4.3 Joint model

Global model and context model have complementary strengths and weaknesses.

The strength of CM is that it is a direct model of the only source of reliable evidence we have: the context in which the entity occurs. This is also the way a human would ordinarily do entity typing: she would determine if a specific context in which the entity occurs implies that the entity is, say, an author or a musician and type it accordingly. The order of words is of critical importance for the accurate assessment of a context and CM takes it into account. A well-trained CM will also work for cases for which GM is not applicable. In particular, if the KB contains only a small number of entities of a particular type, but the corpus contains a large number of contexts of these entities, then CM is more likely to generalize well.

The main weakness of CM is that a large proportion of contexts does not contain sufficient information to infer all types of the entity; e.g., based on our distant supervised training data, we label every context of “Obama” with “author”, “politician” and Obama’s other types in the KB. Thus, CM is trained on a noisy training set that contains only a relatively small number of informative contexts.

The main strength of GM is that it bases its decisions on the entire evidence available in the corpus. This makes it more robust. It is also more efficient to train since its training set is by a factor

of $|M|$ smaller than the training set of CM where $|M|$ is the average number of contexts per entity.

The disadvantage of GM is that it does not work well for rare entities since the aggregated representation of an entity may not be reliable if it is based on few contexts. It is also less likely to work well for non-dominant types of an entity which might be swamped by dominant types; e.g., the author contexts of “Obama” may be swamped by the politician contexts and the overall context signature of the entity “Obama” may not contain enough signal to infer that he is an author. Finally, methods for learning embeddings like `word2vec` are bag-of-word approaches. Therefore, word order information – critical for many typing decisions – is lost.

Since GM and CM models are complementary, a combination model should work better. We test this hypothesis for the simplest possible joint model (JM), which adds the scores of the two individual models:

$$S_{\text{JM}}(e, t) = S_{\text{GM}}(e, t) + S_{\text{CM}}(e, t)$$

5 Experimental setup and results

5.1 Setup

Baseline: Our baseline system is the OpenIE system no-noun-phrase-left-behind (NNPLB) by Lin et al. (2012) (see Section 2). Our reimplementation performs on a par with published results.² We use NNPLB as an alternative way of computing scores $S(e, t)$. Scores of the four systems we compare – NNPLB, GM, CM, JM – are processed the same way to perform entity typing (see below).

Corpus: We select a subset of about 7.5 million web pages, taken from the first segment of ClueWeb12,³ from different crawl types: 1 million Twitter links, 120,000 WikiTravel pages and 6.5 million web pages. This corpus is preprocessed by eliminating HTML tags, replacing all numbers with “7” and all web links and email addresses with “HTTP”, filtering out sentences with length less than 40 characters, and finally doing a simple tokenization. We merge the text with the FACC1 annotations. The resulting corpus has 4 billion tokens and 950,000 distinct entities. We use the 2014-03-09 Freebase data dump as our KB.

²The precision of our implementation on the dataset of three million relation triples distributed by (Lin et al., 2012) is 60.7% compared to 59.8% and 61% for tail and head entities reported by Lin et al. (2012).

³<http://lemurproject.org/clueweb12>

Entity datasets: We consider all entities in the corpus whose notable types can be mapped to one of the 112 FIGER types, based on the mapping provided by FIGER. 750,000 such entities form our set of entities. 10 out of 112 FIGER types have no entities in this set.⁴

We run the OpenIE system Reverb (Fader et al., 2011) to extract relation triples of the form $\langle \text{subject}, \text{relation}, \text{object} \rangle$. Since NNPLB only considers entities in the subject position, we filter out triples whose subject is not an entity. The size of the remaining set of triples is 4,000,000. For a direct comparison with NNPLB, we divide the 750,000 entities into those that occur in subject position in one of the extracted triples (about 250,000 *subject entities* or SE) and those that do not (about 500,000 *non-subject entities* or NSE). We split SE 50:20:30 into train, dev and test sets. The average and median number of FIGER types of the training entities are 1.8 and 2, respectively. We use NSE to evaluate performance of FIGMENT on entities that do not occur in subject position.⁵

Context sampling: For S_{c2t} , we create train', dev' and test' sets of *contexts* that correspond to train, dev and test sets of *entities*. Because the number of contexts is unbalanced for both entities and types and because we want to accelerate training and testing, we downsample contexts. For the set train', we use the notable type feature of Freebase: For each type t , we take contexts from the mentions of those entities whose notable type is t . Recall, however, that each context is labeled with all types of its entity – see Section 4.2.

Then if the number of contexts for t is larger than a minimum, we sample the contexts based on the number of training entities of t . We set the minimum to 10,000 and constrain the number of samples for each t to 20,000. Also, to reduce the effect of distant supervision, entities with fewer distinct types are preferred in sampling to provide discriminative contexts for their notable types. For test' and dev' sets, we sample 300 and 200 random contexts, respectively, for each entity.

System setup: As the baseline, we apply NNPLB to the 4 million extracted triples. To learn entity embeddings for GM, we run `word2vec` (skipgram, 200 dimensions, window size 5) on

a version of the corpus in which entities have been replaced by their Freebase IDs, based on the FACC1 annotation. We then train MLP with number of hidden units $h = 200$ on the embeddings of training entities until the error on dev entities stops decreasing.

Our reasoning for the unsupervised training setup is that we do not use any information about the types of entities (e.g., no entities annotated by humans with types) when we run an unsupervised algorithm like `word2vec`. In a real-world application of FIGMENT to a new corpus, we would first run `word2vec` on the merger of our corpus and the new corpus, retrain GM on training entities and finally apply it to entities in the new corpus. This scenario is simulated by our setup.

Recall that the input to CM consists of $2k$ unit embeddings and the average of $2l$ unit embeddings where we use the term *unit* to refer to both words and types. We set k to 4 and l to 5. To learn embeddings for units, we first exclude lines containing test entities, and then replace each entity with its notable type. Then, we run `word2vec` (skipgram, 100 dimensions, window size 5) on this new corpus and learn embeddings for words and types.

Using the embeddings as input representations, we train S_{c2t} on train' until error on dev' stops decreasing. We set the number of hidden units to 300. We then apply the trained scoring function S_{c2t} to test' and get the scores $S_{c2t}(c, t)$ for test' contexts. As explained in Section 4.2, we compute the corpus-level scores $S_{CM}(e, t)$ for each entity by averaging its context-level scores (see Equation 1).

Ranking evaluation: This evaluation shows how well the models rank types for entities. The ranking is based on the scores $S(e, t)$ produced by the different models and baselines. Similar to the evaluation performed by Lin et al. (2012), we use precision at 1 (P@1) and breakeven point (BEP, Boldrin and Levine (2008)). BEP is F_1 at the point in the ranked list at which precision and recall have the same value.

Classification evaluation: This evaluation demonstrates the quality of the thresholded assignment decisions produced by the models. These measures more directly express how well FIGMENT would succeed in enhancing the KB with new information since for each pair (e, t) , we have to make a binary decision about whether to put it in the KB or not. We compare our decisions with the gold KB information.

⁴The reason is that the FIGER mapping uses Freebase user-created classes. The 10 missing types are not the notable type of any entity in Freebase.

⁵The entity datasets are available at <http://cistern.cis.lmu.de/figment>

	all types	head types	tail types
NNPLB	.092	.246	.066
CM	.406	.662	.268
GM	.533	.725	.387
JM	.545	.734	.407

Table 2: Type macro average F_1 for all, head and tail types

Our evaluation measures are (i) accuracy: an entity is correct if all its types and no incorrect types are assigned to it; (ii) micro average: F_1 of all type-entity assignment decisions; (iii) entity macro average F_1 : F_1 of types assigned to an entity, averaged over entities; (iv) type macro average F_1 : F_1 of entities assigned to a type, averaged over types.

The assignment decision is made based on thresholds, one per type, for each $S(e, t)$. We select the threshold that maximizes F_1 of entities assigned to the type on dev.

5.2 Results

Table 1 presents results for the ranking evaluation as well as for the first three measures of the classification evaluation. MFT is the most frequent type baseline that ranks types according to their frequency in train. We also show the results for head entities (frequency higher than 100) and tail entities (frequency less than 5). The performance of the systems is in this order: JM > GM > CM > NNPLB > MFT.

Table 2 shows the results of the fourth classification measure, type macro average F_1 , for all, head (more than 3000 train entities, 11 types), and tail (less than 200 train entities, 36 types) types. The ordering of models for Table 2 is in line with Table 1: JM > GM > CM > NNPLB > MFT.

We can easily run FIGMENT for **non-subject entities** (NSE) exactly the same way we have run it for subject entities. We test our JM on the 67,000 NSE entities with a frequency of more than 10. The top ranked type returned for 73.5% of entities was correct. Thus, due to our ability to deal with NSE, we can type an additional 50,000 entities correctly.

6 Analysis

Effect of window size in CM: Table 3 explores the effect of using different context sizes. Recall that CM was trained with $2k = 8$ for the concatena-

2k	0	2	4	6	8	10	12	14
h	50	100	200	250	300	400	450	450
micro	.576	.613	.672	.673	.668	.674	.680	.674
P@1	.663	.685	.687	.718	.694	.744	.722	.742

Table 3: Effect of the context size $2k$ in CM ($2k$: context size, h: number of hidden units in MLP)

tion and $2l = 10$ for the average window size. We change $2k$ from 0 to 14 while keeping $2l = 10$. The number of hidden units used in each model is also reported. The table shows that CM can leverage larger context sizes well.

Poor results of NNPLB: NNPLB is mostly hampered by Reverb, which did not work well on the noisy web corpus. As a result, the quality of the extracted relations – which NNPLB entity typing is based on – is too low for reliable typing decisions. The good results of NNPLB on their non-noisy published relation triples confirm that. On the three million relation triples, when mapping Freebase types to FIGER, P@1 of NNPLB is .684; when limiting entities to those with more than 10 relations, the results improve to .776.

GM performs better than CM and JM performs best: The fact that GM outperforms CM shows that decisions based on one global vector of an entity work better than aggregating multiple weak decisions on their contexts. That is clearest for tail entities – where one bad context can highly influence the final decision – and for tail types, which CM was not able to distinguish from other similar types. However, the good results of the simple JM confirm that the score distributions in CM do help. As an example, consider one of the test entities that is an “author”. GM and CM wrongly predict “written_work” and “artist”, respectively, but JM correctly outputs “author”.

Errors of CM: Many CM errors are caused by its simple input representation: it has to learn all linguistic abstractions that it wants to rely on from the training set. One manifestation of this problem is that CM confuses the types “food” and “restaurant”. There are only few linguistic contexts in which entities of these types can be exchanged for each other. On the other hand, the context words they cooccur with in a bag-of-words (BOW) sense are very similar. Thus, this indicates that CM pays too much attention to BOW information and that its representation of contexts is limited in terms of generalization.

	all entities					head entities					tail entities				
	P@1	BEP	acc	mic	mac	P@1	BEP	acc	mic	mac	P@1	BEP	acc	mic	mac
MFT	.101	.406	-	-	-	.111	.410	-	-	-	.097	.394	-	-	-
NNPLB	.365	.480	.000	.099	.096	.378	.503	.000	.114	.109	.368	.474	.000	.086	.084
CM	.694	.734	.299	.668	.635	.713	.751	.385	.738	.702	.608	.661	.118	.487	.452
GM	.805	.856	.426	.733	.688	.869	.899	.489	.796	.769	.665	.757	.299	.578	.510
JM	.816	.860	.435	.743	.699	.874	.900	.500	.803	.776	.688	.764	.306	.601	.532

Table 1: Ranking and classification results for SE entities. P@1 and BEP are ranking measures. Accuracy (acc), micro (mic) and macro (mac) are classification measures.

Assumptions that result in errors: The performance of all models suffers from a number of assumptions we made in our training / evaluation setup that are only approximately true.

The first assumption is that FACC1 is correct. But it has a precision of only 80-85% and this caused many errors. An example is the lunar crater “Buffon” in Freebase, a “location”. Its predicted type is “athlete” because some FACC1 annotations of the crater link it to the Italian goalkeeper.

The second assumption of our evaluation setup is the completeness of Freebase. There are about 2,600 entities with the single type “person” in SE test. For 62% of the errors on this subset, the top predicted type is a subtype of person: “author”, “artist” etc. We manually typed a random subset of 50 and found that the predicted type is actually correct for 44 of these entities.

The last assumption is the mapping from Freebase to FIGER. Some common Freebase types like “award-winner” are not mapped. This negatively affects evaluation measures for many entities. On the other hand, the resulting types do not have a balanced number of instances. Based on our training entities, 11 types (e.g., “law”) have less than 50 instances while 26 types (e.g., “software”) have more than 1000 instances. Even sampling the contexts could not resolve this problem and this led to low performance on tail types.

7 Future work

The performance of FIGMENT is poor for tail types and entities. We plan to address this in the future (i) by running FIGMENT on larger corpora, (ii) by refining the FIGER type set to cover more Freebase entities, (iii) by exploiting a hierarchy over types and (iv) by exploring more complex input representations of the context for the CM.

FIGMENT’s context model can in principle be based on any system that provides entity-type as-

essment scores for individual contexts. Thus, as an alternative to our scoring model $S_{c2t}(c, t)$, we could use sentence-level entity classification systems such as FIGER (Ling and Weld, 2012) and (Yogatama et al., 2015)’s system. These systems are based on linguistic features different from the input representation we use, so a comparison with our embedding-based approach is interesting. Our assumption is that FIGMENT is more robust against noise, but investigation is needed.

The components of the version of FIGMENT we presented, in particular, context model and global model, do not use features derived from the mention of an entity. Our assumption was that such features are less useful for fine-grained entity typing. However, there are clearly some types for which mention-based features are useful (e.g., medications or organizations referred to by abbreviations), so we will investigate the usefulness of such features in the future.

8 Conclusion

We presented FIGMENT, a corpus-level system that uses contextual information for entity typing. We designed two scoring models for pairs of entities and types: a global model that scores based on aggregated context information and a context model that aggregates the scores of individual contexts. We used embeddings of words, entities and types to represent contextual information. Our experimental results show that global model and context model provide complementary information for entity typing. We demonstrated that, comparing with an OpenIE-based system, FIGMENT performs well on noisy web pages.

Acknowledgements. Thanks to the anonymous reviewers for their valuable comments. This work was supported by Deutsche Forschungsgemeinschaft (grant DFG SCHU 2246/8-2, SPP 1335).

References

- Marco Baroni, Georgiana Dinu, and Germán Kruszewski. 2014. Don't count, predict! A systematic comparison of context-counting vs. context-predicting semantic vectors. In *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics, ACL 2014*, pages 238–247.
- Michele Boldrin and David K. Levine. 2008. *Against intellectual monopoly*. Cambridge University Press Cambridge.
- Kurt D. Bollacker, Colin Evans, Praveen Paritosh, Tim Sturge, and Jamie Taylor. 2008. Freebase: a collaboratively created graph database for structuring human knowledge. In *Proceedings of the ACM SIGMOD International Conference on Management of Data, SIGMOD 2008, Vancouver, BC, Canada, June 10-12, 2008*, pages 1247–1250.
- Antoine Bordes, Nicolas Usunier, Alberto García-Durán, Jason Weston, and Oksana Yakhnenko. 2013. Irreflexive and hierarchical relations as translations. *CoRR*, abs/1304.7158.
- Li Dong, Furu Wei, Hong Sun, Ming Zhou, and Ke Xu. 2015. A hybrid neural model for type classification of entity mentions. In *Proceedings of the Twenty-Fourth International Joint Conference on Artificial Intelligence, IJCAI 2015, Buenos Aires, Argentina, July 25-31, 2015*, pages 1243–1249.
- John C. Duchi, Elad Hazan, and Yoram Singer. 2011. Adaptive subgradient methods for online learning and stochastic optimization. *Journal of Machine Learning Research*, 12:2121–2159.
- Greg Durrett and Dan Klein. 2014. A joint model for entity analysis: Coreference, typing, and linking. *TACL*, 2:477–490.
- Anthony Fader, Stephen Soderland, and Oren Etzioni. 2011. Identifying relations for open information extraction. In *Proceedings of the 2011 Conference on Empirical Methods in Natural Language Processing, EMNLP 2011, 27-31 July 2011, John McIntyre Conference Centre, Edinburgh, UK, A meeting of SIGDAT, a Special Interest Group of the ACL*, pages 1535–1545.
- Jenny Rose Finkel, Trond Grenager, and Christopher D. Manning. 2005. Incorporating non-local information into information extraction systems by gibbs sampling. In *ACL 2005, 43rd Annual Meeting of the Association for Computational Linguistics, Proceedings of the Conference, 25-30 June 2005, University of Michigan, USA*.
- Evgeniy Gabrilovich, Michael Ringgaard, and Amar-nag Subramanya. 2013. Facc1: Freebase annotation of cluweb corpora.
- Sonal Gupta and Christopher D. Manning. 2014. Improved pattern learning for bootstrapped entity extraction. In *Proceedings of the Eighteenth Conference on Computational Natural Language Learning, CoNLL 2014, Baltimore, Maryland, USA, June 26-27, 2014*, pages 98–108.
- Zellig S. Harris. 1954. Distributional structure. *Word*, 10:146–162.
- Xueyan Jiang, Volker Tresp, Yi Huang, and Maximilian Nickel. 2012. Link prediction in multi-relational graphs using additive models. In *Proceedings of the International Workshop on Semantic Technologies meet Recommender Systems & Big Data, Boston, USA, November 11, 2012*, pages 1–12.
- Thomas Lin, Mausam, and Oren Etzioni. 2012. No noun phrase left behind: Detecting and typing un-linkable entities. In *Proceedings of the 2012 Joint Conference on Empirical Methods in Natural Language Processing and Computational Natural Language Learning, EMNLP-CoNLL 2012, July 12-14, 2012, Jeju Island, Korea*, pages 893–903.
- Xiao Ling and Daniel S. Weld. 2012. Fine-grained entity recognition. In *Proceedings of the Twenty-Sixth AAAI Conference on Artificial Intelligence, July 22-26, 2012, Toronto, Ontario, Canada*.
- Xiao Ling, Sameer Singh, and Daniel S. Weld. 2015. Design challenges for entity linking. *TACL*, 3:315–328.
- Paul McNamee and Hoa Trang Dang. 2009. Overview of the tac 2009 knowledge base population track. In *Text Analysis Conference (TAC)*, volume 17, pages 111–113.
- Tomas Mikolov, Kai Chen, Greg Corrado, and Jeffrey Dean. 2013. Efficient estimation of word representations in vector space. *CoRR*, abs/1301.3781.
- Bonan Min, Ralph Grishman, Li Wan, Chang Wang, and David Gondek. 2013. Distant supervision for relation extraction with an incomplete knowledge base. In *Human Language Technologies: Conference of the North American Chapter of the Association of Computational Linguistics, Proceedings, June 9-14, 2013, Westin Peachtree Plaza Hotel, Atlanta, Georgia, USA*, pages 777–782.
- Ndapandula Nakashole, Tomasz Tylenda, and Gerhard Weikum. 2013. Fine-grained semantic typing of emerging entities. In *Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics, ACL 2013, 4-9 August 2013, Sofia, Bulgaria, Volume 1: Long Papers*, pages 1488–1497.
- Arvind Neelakantan and Ming-Wei Chang. 2015. Inferring missing entity type instances for knowledge base completion: New dataset and methods. In *NAACL HLT 2015, The 2015 Conference of the North American Chapter of the Association for*

- Computational Linguistics: Human Language Technologies, Denver, Colorado, USA, May 31 - June 5, 2015*, pages 515–525.
- Maximilian Nickel, Volker Tresp, and Hans-Peter Kriegel. 2012. Factorizing YAGO: scalable machine learning for linked data. In *World Wide Web Conference*, pages 271–280.
- Sebastian Riedel, Limin Yao, Andrew McCallum, and Benjamin M. Marlin. 2013. Relation extraction with matrix factorization and universal schemas. In *Human Language Technologies: Conference of the North American Chapter of the Association of Computational Linguistics, Proceedings, June 9-14, 2013, Westin Peachtree Plaza Hotel, Atlanta, Georgia, USA*, pages 74–84.
- Richard Socher, Danqi Chen, Christopher D. Manning, and Andrew Y. Ng. 2013. Reasoning with neural tensor networks for knowledge base completion. In *Advances in Neural Information Processing Systems 26: 27th Annual Conference on Neural Information Processing Systems 2013. Proceedings of a meeting held December 5-8, 2013, Lake Tahoe, Nevada, United States.*, pages 926–934.
- Fabian M. Suchanek, Gjergji Kasneci, and Gerhard Weikum. 2007. Yago: a core of semantic knowledge. In *Proceedings of the 16th International Conference on World Wide Web, WWW 2007, Banff, Alberta, Canada, May 8-12, 2007*, pages 697–706.
- Mihai Surdeanu, Julie Tibshirani, Ramesh Nallapati, and Christopher D. Manning. 2012. Multi-instance multi-label learning for relation extraction. In *Proceedings of the 2012 Joint Conference on Empirical Methods in Natural Language Processing and Computational Natural Language Learning, EMNLP-CoNLL 2012, July 12-14, 2012, Jeju Island, Korea*, pages 455–465.
- Michael Thelen and Ellen Riloff. 2002. A bootstrapping method for learning semantic lexicons using extraction pattern contexts. In *Proceedings of the ACL-02 Conference on Empirical Methods in Natural Language Processing, EMNLP 2002, Stroudsburg, PA, USA*, pages 214–221.
- Zhen Wang, Jianwen Zhang, Jianlin Feng, and Zheng Chen. 2014. Knowledge graph and text jointly embedding. In *Proceedings of the 2014 Conference on Empirical Methods in Natural Language Processing, EMNLP 2014, October 25-29, 2014, Doha, Qatar, A meeting of SIGDAT, a Special Interest Group of the ACL*, pages 1591–1601.
- Jason Weston, Antoine Bordes, Oksana Yakhnenko, and Nicolas Usunier. 2013. Connecting language and knowledge bases with embedding models for relation extraction. In *Proceedings of the 2013 Conference on Empirical Methods in Natural Language Processing, EMNLP 2013, 18-21 October 2013, Grand Hyatt Seattle, Seattle, Washington, USA, A meeting of SIGDAT, a Special Interest Group of the ACL*, pages 1366–1371.
- Dani Yogatama, Daniel Gillick, and Nevena Lazic. 2015. Embedding methods for fine grained entity type classification. In *Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing of the Asian Federation of Natural Language Processing, ACL 2015, July 26-31, 2015, Beijing, China, Volume 2: Short Papers*, pages 291–296.
- Mohamed Amir Yosef, Sandro Bauer, Johannes Hoffart, Marc Spaniol, and Gerhard Weikum. 2012. HYENA: hierarchical type classification for entity names. In *COLING 2012, 24th International Conference on Computational Linguistics, Proceedings of the Conference: Posters, 8-15 December 2012, Mumbai, India*, pages 1361–1370.
- Yu Zhao, Zhiyuan Liu, and Maosong Sun. 2015. Representation learning for measuring entity relatedness with rich information. In *Proceedings of the Twenty-Fourth International Joint Conference on Artificial Intelligence, IJCAI 2015, Buenos Aires, Argentina, July 25-31, 2015*, pages 1412–1418.
- Zhi-Hua Zhou and Min-Ling Zhang. 2006. Multi-instance multi-label learning with application to scene classification. In *Advances in Neural Information Processing Systems 19, Proceedings of the Twentieth Annual Conference on Neural Information Processing Systems, Vancouver, British Columbia, Canada, December 4-7, 2006*, pages 1609–1616.