Natural Language Processing for tasks with specialized domain language – Project Report

data.camp097@audi.de

October 23, 2019

Contents

1 Definition

1.1 Overview

Natural Language Processing as a sub-discipline of machine learning has had major success in recent years on a broad range of problems. Many natural language related task in the industry are however not yet automated. As an example, in the automotive industry these tasks comprise automated scanners for the monitoring of (social) media with respect to potential quality or safety

problems (a legal requirement for manufacturers), automated analysis of warranty and repair documents, systems for customer support, monitoring and analysis of patent applications to identify trends and many more. One of the main hurdles for automation of these spezialized tasks has been performance: When confronted with highly specialized sub-domain languages like automotive engineering, commercial off the shelf (COTS) products decline in performance, often up to a point of being useless [2].

1.2 Problem Statement

One key element of many NLP pipelines are word embeddings, dense vecor representations of the vocabulary. Examples of these methods are word2vec [3], GloVe [4] or FastText [5]. These word embeddings are able to represent (surprisingly) much semantic and syntactic meaning, which makes downstream NLP tasks in general much easier. However, to learn this, the embeddings have to be trained extensively, state of the art are data corpora with tens of billions of tokens. When it comes to specialized sub-domain language, data is in general not easily available, often proprietary, confidential or copyright protected and never as abundant as general text. The basic hypothesis for this capstone project is the assumption that the dominant problem of NLP algorithms operating on specialized domain languages is the fact that during training the algorithm hasn't seen any or enough domain specific text. For this reason I trained two different vector representations, the classic word2vec and the more recent FastText on a self-aquired domain specific data corpus and compared it with different metrics to a generic model, the Facebook German Fasttext Model.

1.3 Metrics

The evaluation of word embeddings is no easy task. To the best of my knowledge, there does not exist a single commonly used or agreed upon method on how to evaluate these models [9–11]. Instead a range of methods is used. These methods fall in two categories, extrinsic and intrinsic. Intrinsic evaluation takes into consideration only the embedding itself whereas extrinsic methods measure the embedding performance indirectly by a downstream NLP task with its own metric. For this project, I implemented the following metrics to compare the different embedings:

- M_1**: Extrinsic measure.** A real world multiclass classification task of software change requests (CRQ) for embedded control software. The classification separates the CRQs by topic to forward it directly to the right experts and change control boards.[1]

  For the classification task, I built an LSTM with the word embedding as a first (untrainable layer). The architecture itself is pretty basic using an attention layer. [2] The motivation for the attention layer is the fact, that the engineers are encouraged to use a certain structure to describe the CRQ. Therefore it might be possible, to focus the attention to certain areas of the CRQ for classification.

[1] The CRQs themselfes are confidential and cannot be published or submitted.
[2] Adopted from `https://github.com/philipperemy/keras-attention-mechanism`

The model itself can be found in the notebook "LSTM.ipynb".

- M_2**: Clustering by subsystem.** A vehicle is built from subsystems like engine, transmission, exhaust system, etc.. For 5 subsystems we will pick representative 10 representative words that will represent this subsystem.

  The basic idea of this metric is then to leverage clustering or classification in the vector space of the embedding itself. As the metric for word embeddings is the consine distance,

  $$d(\mathbf{a}, \mathbf{b}) = \cos(\theta) = \frac{\mathbf{a} \cdot \mathbf{b}}{|\mathbf{a}| \cdot |\mathbf{b}|} \tag{1}$$

  the clustering or classifcation algorithms will have to use this as a measure of distance.

  To generate a metric out of this idea, I chose KNN classification with cosine distance and use the train(!) error as the metric. This is motivated by the intuition, that KNN classification only works if the subsystems are tightly grouped and have distance to other clusters.

- M_3**: Word analogy.** Another intrinsic metric for word embddings is to assess semantic meaning. We look for relations of the form

  $$a : b :: c : d$$

  In particular, we will assess the semantic representation of technical concepts. Two examples are

  $$\text{engine} : \text{engine control unit} :: \text{transmission} : \text{transmission control unit}$$

  $$\text{camshaft} : \text{camshaft bearing} :: \text{crankshaft} : \text{crankshaft bearing}$$

  We can extract the word d from words a,b and c from the embedding simply with

  $$d = \underset{i}{\text{argmax}} \frac{(x_b - x_a + x_c)^T \cdot x_i}{|x_b - x_a + x_c|} \tag{2}$$

  For this to become a metric, I simply count the number of word analogies the embeddings get right in their Top-n list.

- M_4**: Word similarity**. A well known metric is the correlation with human similarity scores (like wordsim353...) pairs of words from technical jargon and ask colleagues to rate their similarity. This measure of similarity will then be compared to the cosine distance the embeddings produce for these word pairs. This metric can also be adopted to include relatedness instead of similarity.

- M_5**: Visualizytions** As a qualitative measure I visualized the embeddings using t-SNE [12] to get a comparative qualitative measure.

2 Analysis

2.1 The Dataset

For a domain specific data corpus I scraped the text from the following sources:

- technical / specialist books: 60 titles, 28507 pages, 5950125 words in total
- internal technical documentation: 17763 change requests for embedded control software with a total of 960921 words[3]
- patents: 500 patents from the domain vehicle powertrain, containing a total of 9871 pages with a total of 3929993 words.

A sample change request after preprocessing looks like this:

```
['zustart', 'verbrenners', 'riemenstartergenerator', 'rsg', 'verfügung',
'steht', 'maschine', 'reduzierte', 'momentenreserve', 'vorgehalten',
'problem', 'fällt', 'zustart', 'verfügbarkeit', 'rsgs', 'erhöhte',
'drehmomentreserve', 'sprunghaft', 'fahrerwunschmoment', 'einkoordiniert',
'fahrer', 'spürt', 'ruck', 'fahrerwunschmoment', 'fahren', 'zustart',
'größe', 'disttqlimelm', 'tqmaxeldrv', 'begrenzt', 'disttqlimelm',
'tqmaxeldrv', 'enthält', 'aktuell', 'momentenreserve', 'covom', 'tqresvstat',
'covom', 'tqresvstat', 'zeigt', 'wegfall', 'verfügbarkeit', 'rsgs',
'erhöhten', 'bedarf', 'momentenreserve', 'sprunghaft', 'fällt', 'zustart',
'verfügbarkeit', 'rsgs', 'darf', 'erhöhte', 'drehmomentenreserve',
'fahrerwunsch', 'begrenzen', 'ablaufsteuerung', 'signal', 'covom',
'tqresvstrt', 'berücksichtigt', 'begrenzung', 'fahrerwunsches', 'maximal',
'verfügbare', 'fahrmoment', 'signal', 'verwendet', 'aktuell', 'gültige',
'momentenreserve', 'covom', 'tqresvstrt', 'enthält']
```

The preprocessed data corpus contains 27801 texts with a total of 7177448 words. The maximum length of a text is 312768, the minimum length is 0, the mean length is 258.2 words. A histogram of the text length ist plotted in figure 1. It shows that rather short texts dominate the dataset, the longest text being an abnormality. This distribution reflects the design of the data corpus from a large number of (short) change request texts mixed with a few hundred (medium length) patents and 60 (long) books.

This data corpus would in principle be easy to scale up by at least two orders of magnitede. As a company, we have access to electronic versions of books from almost all major publishers in the field. Furthermore we have electronic access to the major journals in the field. The patent database is public and with a paid account we can access an unlimited number of documents. The internally available data is of course limited, however only a fraction of the available data was used in this project.

2.2 Algorithms and Techniques

Embedding Algorithms The main idea of word embeddings is the representation of the vocabulary by a dense vector representation in a relatively low-dimensional vector space as opposed to the sparse alternatives Bag-of-Words or

[3] proprietary, cannot be submitted

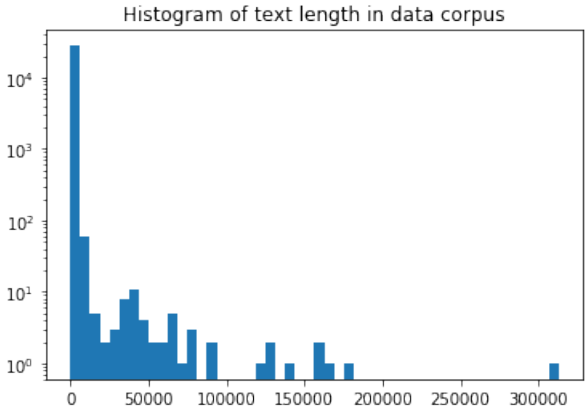


Figure 1: Histogram of the text length after preprocessing

one-hot encoding. The idea behind this is to capture semantic and syntactic meaning that cannot be represented by the sparse representations.

word2vec word2vec learns the word embeddings with one of two methods (see figure 2[4]):

- CBOW Model: This method takes the context of each word as the input and tries to predict the word corresponding to the context.
- Skip-Gram: This method takes a target word and tries to predict the words in the context.

Both methods use neural nets to learn, the basic structure for CBOW is depicted in figure 3[5]

FastText FastText extends word2vec. It is built on character n-grams, whereas word2vec takes whole words as the smallest units. This property should give FastText an advantage with rare words and especially with German compound nouns.

Evaluation Techniques The techniques used to evaluate the are described in section 1.3.

2.3 Benchmark Models

As a benchmark I chose the pretrained German Facebook FastText embedding. [6] This model is trained on German Common Crawl and Wikipedia Data (in the range 10-100 billion tokens).

[4]https://towardsdatascience.com/an-implementation-guide-to-word2vec-using-numpy-and-google-sheets-13445eebd281

[5]`https://towardsdatascience.com/introduction-to-word-embedding-and-word2vec-652d0c2060fa`

[6]`https://fasttext.cc/docs/en/crawl-vectors.html`

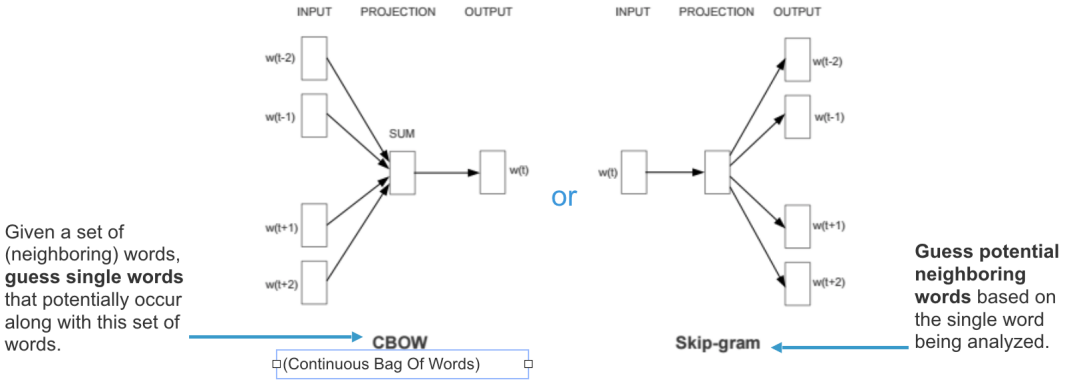


Figure 2: The basic idea of word2vec

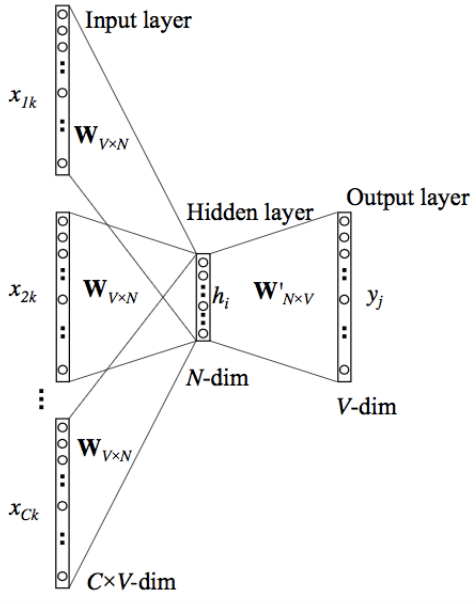


Figure 3: The basic network architecture from word2vec CBOW

3 Methodology

During the implementation I tried to use existing packages as much as possible. For NLP related tasks these were gensim [7], NLTK [8] and spacy [6]. For machine learning related tasks, these were Keras, TensorFlow and scikit-learn.

3.1 Data Preprocessing

For the preprocessing, the following steps were taken:

- Scraping raw text from pdf. This is done with the Python packages "textract" and "PyPDF2". Used on the patents and the books, the CRQs were scraped directly to raw text via SQL from a database.
- The structure of the data is a list of lists, the inner lists being the scope over which the windows run while training.
- The raw text is serialzied to disk using pickle.
- The raw text is stripped of punctuation, numerics, multiple whitespace, words shorter than 3 letters, and German stop words. It is lower-cased and split. A lemmatizer was integrated but not used due to runtime considerations. The list of German stop words was imported from the python package "get_stop_words", the preporcessing was mainly done with the package "gensim" preprocessing functions.
- The preprocessed text is serialized to disk using pickle,

The scraping and preprocessing is implemented in the notebook "Data Collection.ipynb".

3.2 Embedding Training

Training the embeddings was done using the package "gensim".

```
model_w2v = Word2Vec(training_data, size=300, window=5, min_count=5)
model_ft = FastText(training_data, size=300, window=5, min_count=5)
```

The main parameters of the embedding are the size of the embedding vector space, which I set to 300, and the window size, which defines the number of words in the context, to 5. Both pretty much default values. The training of the embeddings is implemented in the notebook "Embeddings.ipynb"

3.3 Evaluating the Embeddings

The metrics are described in section 1.3 Implementation relied as much as possible on existing packages like keras, scikit-learn and gensim. The results are discussed in section 4.

The evaluation metrics are implemented in the notebooks "LSTM.ipynb" and "Metrics.ipynb"

3.4 Optimization

Optimizing the embeddings To optimize the embeddings, a few options are available.

- Embedding parameters. I used "default" emedding parameters, vector space dimensions of 300 and context window size of 5. It might be worthwhile to experiment with these parameters.
- More training data: As the training data is unlabelled, it is feasible to massively increase the amount of domain specific training data. I would assume that at least a factor of 100 would be possible.
- Using different embedding algorithms. So far, I used only 2 widely used algorithms, word2vec and FastText, but there are many more established algorithms with will documented strengths and weaknesses. It might be worthwhile to see if improvements could be made by choosing more wisely.
- Retraining a pretrained network. For some embedding algorithms it is possible to retrain them on additional data. It would be interesting to measure the performance of a retrained embedding and compare the results to the exclusively trained embeddings used in this project. In theory it might be possible to somehow bring the good general performance and the domain specific training together.

Optimizing the classifier Even though the classifier is mainly used as a metric to evaluate the different embeddings, some very basic optimization was done before using it. The overall goal is to prevent overfitting and increase test accuracy.

The networt currently still seems to overfit, see figures 4 and 5. This is not surprising considering the very small number of available labelled samples and the relatively large capacity of the network.

To prevent overfitting, the following steps were taken:

- Early termination was implemented in the learning.
- Dropout was applied extensively through the network (between layers and recurrently inside the LSTM layer). Dropout rate used is 0.4 everywhere.
- Model Capacity was reduced by decreasing the size of the LSTM internal state to 80)

Other options that were not thoroughly explored in this project include

- Regularization. Not yet included.
- Data augmentation. Cropping might be an option, but was not explored.
- Acquisistion of more data. Always an option :-)

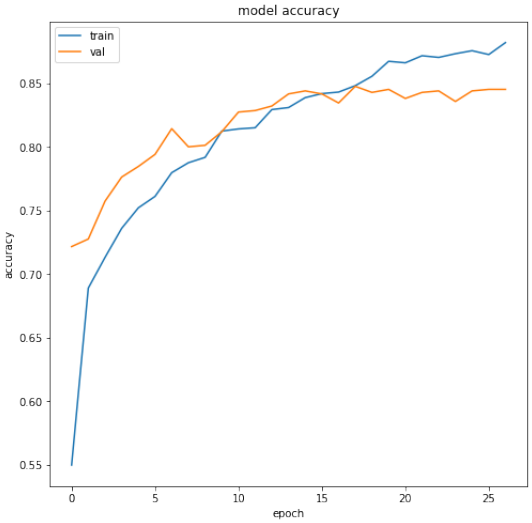


Figure 4: Model accuravy while learning with domain specific FastText Embedding

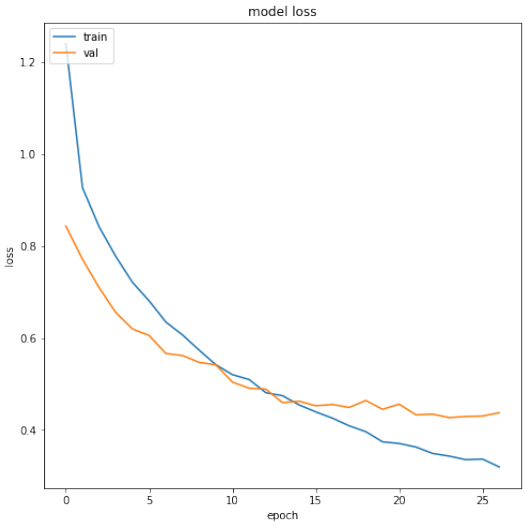


Figure 5: Loss while learning with domain specific FastText Embedding

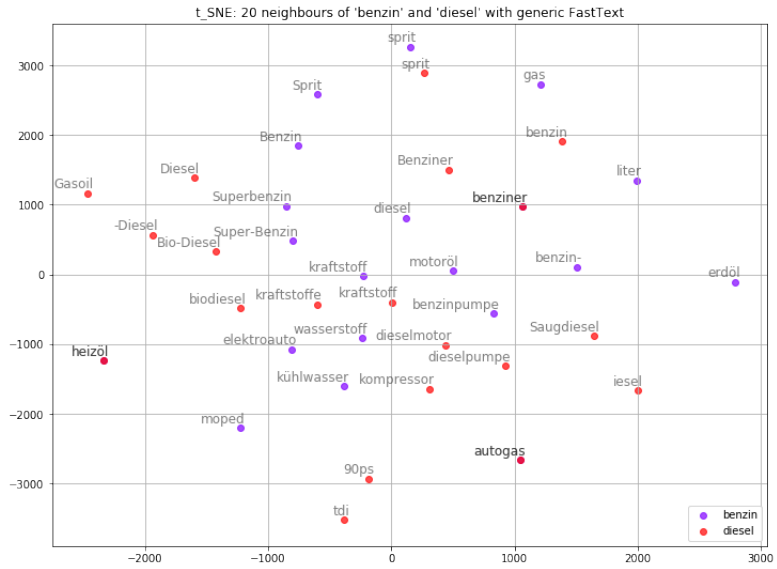


Figure 6: t-SNE for generic FastText on word pair ('Benzin', 'Diesel')

4 Results

4.1 Visualizations

To get a qualitative impression of what the embeddings learned to represent I produced t-SNE plots for the 20 nearest neighbours of two different word pairs: ('Motor', 'Getriebe') (meaning engine and transmission, respectively) and ('Benzin', 'Diesel') (meaning gasoline and diesel, respectively).

From an automotive engineer's point of view, these groups of words should be clearly separated as they refer to different subsystems or different classes of internal combustion engines.

The following plots show the degree of separation the embeddings assigned to these groups of words. The specifically trained FastText stands out here as it seems to be able to distinguish between these clusters of words, see figure 7 and 10.

4.2 Quantitative Results

The metrics M_1–M_4 produce qunatitavie results that are summarized in the following table

	M_1	M_2	M_3	M_4
Word Embedding	Test Acc [%]	Train Acc [%]	Top-10	Pearson Corr
Generic German FastText	80.0	67.4	0	-0.28
domain specific word2vec	83,6	88.4	1-Top1,2	0.42
domain specific FastText	84.5	90.7	1-Top5	0.41

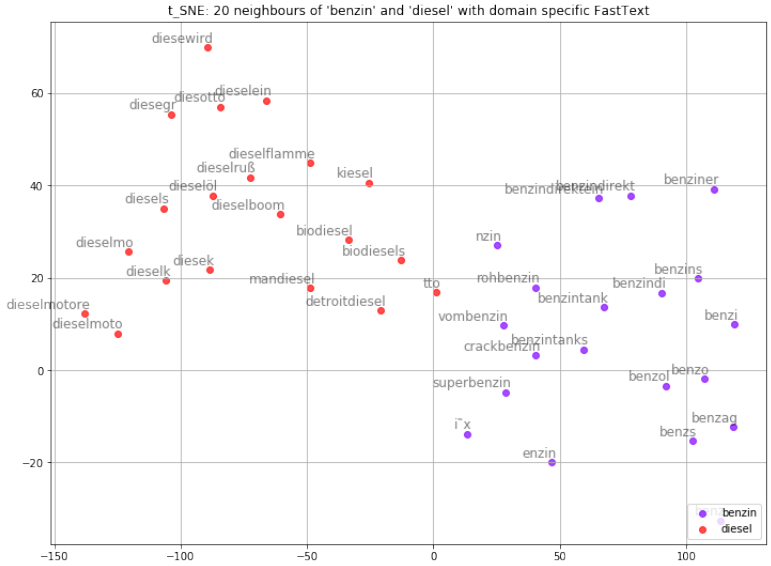


Figure 7: t-SNE for domain specific FastText on word pair ('Benzin', 'Diesel')

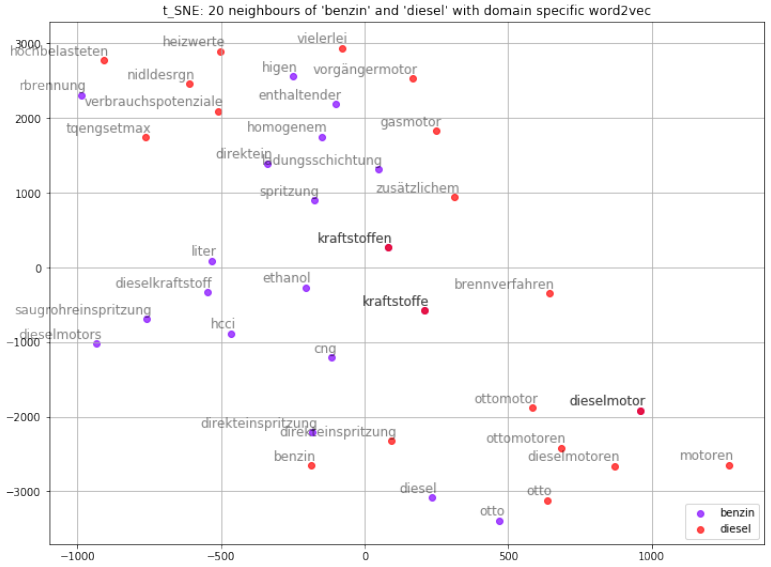


Figure 8: t-SNE for domain specific wor2vec on word pair ('Benzin', 'Diesel')

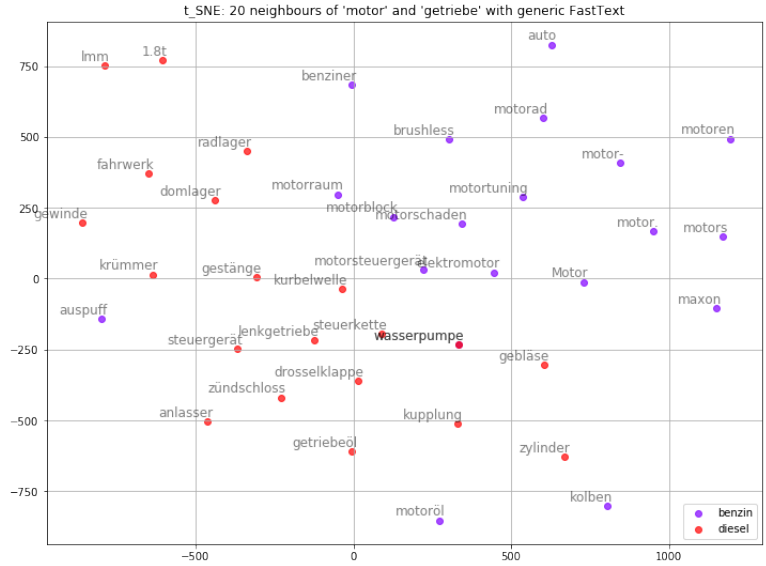


Figure 9: t-SNE for generic FastText on word pair ('Motor', 'Getriebe')

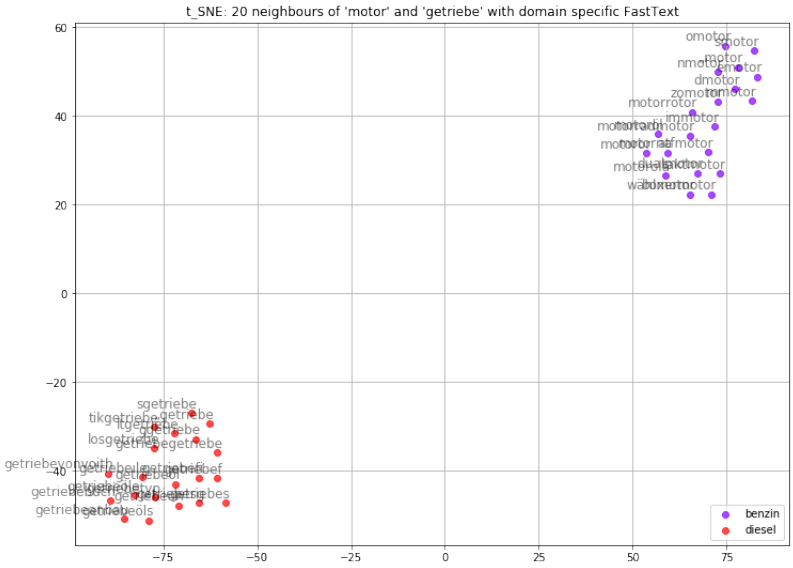


Figure 10: t-SNE for domain specific FastText on word pair ('Motor', 'Getriebe')

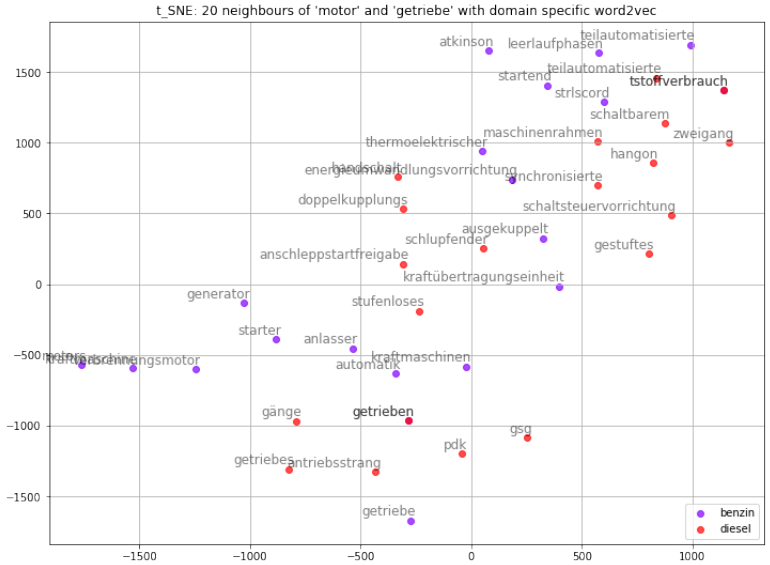
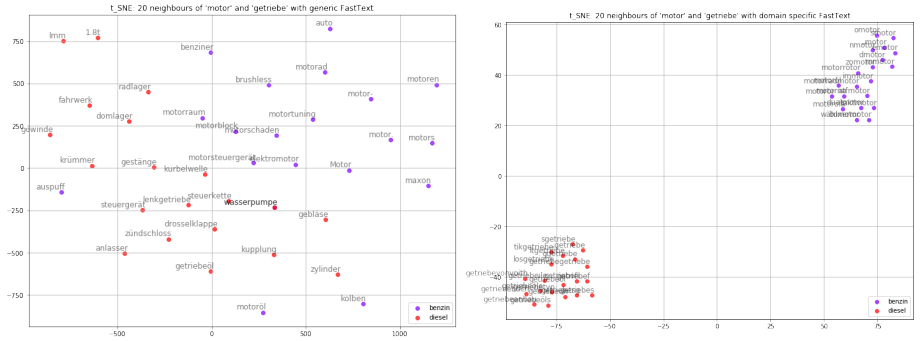


Figure 11: t-SNE for domain specific wor2vec on word pair ('Motor', 'Getriebe')

Before we discuss the results of the metrics, a caveat is in order: The choice of subsystems and subsystem representatives in M_2, the choice of word analogies in M_3 and the design and assessment of the word similarity list in M_4 would not hold up to any scientific standards. In particular the sample size of all metrics is to small to deliver robust results. Hence the interpretation and discussion of the results is highly speculative.

M_1 Downstream Classification The results show that the specifically trained word embeddings perform better in this downstream application. This might seem surprinsing, because the generic model is trained on a data corpus 3-4 orders of magnitude larger than the domain specific data corpus used to train the domain specific models. On the other hand, the task needs domain specific knowledge, so a specifically trained model might have an advantage. I would like to point out that I did not put much effort in optimizing the architecture, loss function or learning of the classifier. The overall performance for all embeddings could probably be improved significantly (see also section 3.4). However, all that is relevant in this context are the relative performances of the different embeddings.

M_2 Subsystem Classification in Embedding Space The results suggest that the embeddings trained on domain specific data can separate the subsystems of the vehicle quite well, whereas the generic model performs significantly worse in this regard. FastText might have an edge over word2vec due to it's property of using character n-grams as the smallest entity, whereas word2vec has complete words as entity. This might help to correctly classify compund nouns.



(a) Generic FastText

(b) Domain Specific FastText

Figure 12: Side-by-side comparison of t-SNE of nearest neighbors of "motor" and "getriebe" ("engine" and "transmission")

***M_3* Word Analogy** 6 analogies with automotive specific meaning were randomly picked. A point is given for every correctly found analogy in the top-10. Both specifically trained embeddings get one analogy right, whereas the generic embedding does not reproduce any analogy. The word2vec produces the analogy with Top-1 and Top-2 whereas the fasttext embedding gets it with Top-5 only.

***M_4* Word Similarity** The similarity measure used is a PEARSON-coefficient between the human similarity score and the cosine similarity of the embedding. The results would suggest, that only the domain specific embeddings capture the similarities, whereas the generic model does not represent any domain specific semantics. This result is to be expected, but would have to be proven in a more rigorous manner.

5 Conclusion

By all metrics employed, the generic Facebook FastText model performed worse than the domain specific models. This is remarkable, because the data corpus used to train the generic embedding is of the size 10s to 100s of billion words, whereas we trained the domain specific embeddings on a corpus of a little more than 10 million words, three to four orders of magnitude smaller.

This is maybe visualized best by comparing the t-SNE embeddings for two groups of words belonging to the subsystem "motor" and "getriebe" respectively, see figure 12. The domain specific FastText clearly and cleanly separates these two groups of words, whereas the Generic FastText does not. This is an indication that the domain specific model captures domain specific meaning better than the generic model, even though the data corpus it is trained on is tiny compared to the generic model.

5.1 Reflection

In this project I trained word embeddings and compared them to available pretrained embeddings with 5 different metrics. To achive this, I went through the following steps:

1. Data Collection: I collected technical text data for the subdomain of automotive engineering and converted it to raw text.
2. Data Preprocessing: The raw text data was preprocessed by removing punctuation, nunmerics, redundant whitespace, short words and stop words. It is lowercased and split in single words.
3. Embedding Training: I trained two different word embeddings on this data corpus, word2vec and FastText
4. Evaluation: I evaluated these two embeddings against the current FastText German pretrained model with 5 different metrics, including multiclass text classification, visualization with t-SNE and 3 other intrinsic metrics based on word similarity, analogy and subsystem clustering.

One somewhat surprising difficulty was the support for the German language: Even though it is currently the third most used language for internet content, the suport for German in NLP toolkits and embeddings is not nearly as good as for English: Lists of Stopwords have to be imported from additional sources, lemmatizers are hard to find, pretrained models are not readily and abundantly available.

5.2 Improvement/Future Work

There is much work to be done. From the 9 embeddings I set out to cover, I have implemented 3 (colored in the following table)

Word Embedding	pretrained	trained	retrained
word2vec	gensim Standard	gensim Implementation	done w/ gensim implementation
GloVe	gensim Standard	w/ gensim implementation	n.a., needs global cooccurence matrix
FastText	from Facebook	gensim implementation	done w/ undocumented feature in Facebook implementation ???

The metrics implemented should in general be valid, however all 5 would need refinement as already mentionend in the caveat in section 4.2 to deliver statistically significant results.

5.3 Additional Research Questions

Due to time contraints, I didn't touch the additional research questions I raised in the proposal. I still think it would be interesting to follow up on them.

Extra Dimesions. If we retrain a word embedding for a specialized subdomain, do we need to add a few dimensions to the vector space "to make room" for additional semantic concepts? Intuitition would suggest that all existing dimensions are already somehow occupied and new technical concepts would require "new space". So an additional question would be: Do extra dimesions improce the embedding quality? And if so, what semantic meaning can we assign the new dimensions?

Compund Nouns. A distinctive feature of the German language are compound nouns. This holds especially true for technical terms like Nockenwellenlagerungskonzept (cam shaft bearing method). I expect this to be of particular importance to be reflected in the embedding.

Web Resources

- `https://github.com/kudkudak/word-embeddings-benchmarks/blob/master/web/datasets/similarity.py`
- `https://github.com/Hironsan/awesome-embedding-models`
- `https://github.com/philipperemy/keras-attention-mechanism`

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