

CZECH TECHNICAL UNIVERSITY IN PRAGUE  
FACULTY OF ELECTRICAL ENGINEERING  
DEPARTMENT OF CYBERNETICS  
CZECH INSTITUTE OF INFORMATICS, ROBOTICS AND CYBERNETICS



# From FastText to Transformer Models, and their Application in Retrieval-Augmented Generation

Bachelor's Thesis

**Yauheni Zviazdou**

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Supervisor: Ing. Jan Šedivý, CSc.

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## I. Personal and study details

Student's name: **Zviazdou Yauheni** Personal ID number: **507333**  
Faculty / Institute: **Faculty of Electrical Engineering**  
Department / Institute: **Department of Cybernetics**  
Study program: **Open Informatics**  
Specialisation: **Artificial Intelligence and Computer Science**

## II. Bachelor's thesis details

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**Od FastText k Transformer model m a jejich aplikace v Retrieval-Augmented generování**

Guidelines:

Review the representation of words, sentences, and paragraphs, progressing from traditional methods like FastText to advanced transformer-based models such as BERT. The primary focus is to evaluate selected representations using analogy tests and confusion matrix. Use the UPV corpus set for evaluation.

In the second part of the study, emphasis will shift towards selecting optimal representations for Retrieval-Augmented Generation (RAG) algorithms. The investigation will determine the most efficient embeddings and optimal text chunk size for question-answering tasks, particularly in the context of natural language answers generation from technical manuals. Conduct a comprehensive evaluation with a particular focus on suggesting an optimal representation model that balances factuality and CPU requirements.

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- [2] LangChain documentation, <https://js.langchain.com/docs>
- [3] Word2Vec tutorials, <https://www.tensorflow.org/text/tutorials/word2vec>

Name and workplace of bachelor's thesis supervisor:

**Ing. Jan Šedivý, CSc. Big Data and Cloud Computing CIIRC**

Name and workplace of second bachelor's thesis supervisor or consultant:

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Ing. Jan Šedivý, CSc.  
Supervisor's signature

prof. Dr. Ing. Jan Kybic  
Head of department's signature

prof. Mgr. Petr Páta, Ph.D.  
Dean's signature

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.....

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## Abstract

This thesis investigates the application of word and sentence embeddings in Retrieval-Augmented Generation (RAG) for factual Question Answering (QA) tasks using technical manuals. The study explores the effectiveness of traditional FastText embeddings and advanced transformer-based models like Bidirectional Encoder Representations from Transformers (BERT) in capturing semantic relationships within text. We evaluate the quality of these representations using analogy tests and confusion matrix analysis on the UPV corpus set.

Subsequently, we will select optimal representations for RAG algorithms and assess their impact on factual accuracy and computational efficiency during QA. By analyzing the performance with different text chunk sizes, we aim to identify the optimal configuration for factual RAG in technical domains. This research contributes to the field of Natural Language Processing (NLP) by providing insights into selecting effective representations that balance factual accuracy and computational efficiency for QA systems.

**Keywords** NLP, Word Embedding, Transformers, RAG, QA, Semantic Textual Similarity (STS)

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## Abstrakt

Tato práce zkoumá aplikaci embeddingů slov a vět v modelu Retrieval-Augmented Generation (RAG) pro úlohy Question Answering (QA) zaměřené na fakta s využitím technických příruček. Studie se zabývá účinností tradičních embeddingů FastText a pokročilých modelů založených na transformátoru, jako je Bidirectional Encoder Representations from Transformers (BERT), při zachycování sémantických vztahů v textu. Kvalitu těchto reprezentací hodnotíme pomocí analogových testů a analýzy confusion matrix na korpusu UPV. Následně vybereme optimální reprezentace pro algoritmy RAG a posoudíme jejich vliv na faktickou přesnost a výpočetní efektivitu během QA. Analýzou výkonu s různými velikostmi textových fragmentů se snažíme identifikovat optimální konfiguraci pro faktické RAG v technických oborech. Výzkum přispívá k oblasti zpracování přirozeného jazyka (Natural Language Processing (NLP)) tím, že poskytuje poznatky o výběru efektivních reprezentací, které vyvažují faktickou přesnost a výpočetní efektivitu pro systémy QA.

**Klíčová slova** NLP, Word Embedding, Transformátory, RAG, QA, Sémantická podobnost textu

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## Abbreviations

**RAG** Retrieval-Augmented Generation

**NLP** Natural Language Procession

**STS** Semantic Textual Similarity

**QA** Question Answering

**BERT** Bidirectional Encoder Representations from Transformers

**CBOW** Continuous Bag-of-Words

**GloVe** Global vectors

**ML** Machine Learning

**NN** Neural Network

**mBERT** Multilingual Bidirectional Encoder Representations from Transformers

**MTEB** Massive Text Embedding Benchmark

**ALBERT** A Lite BERT

**SimCSE** Simple Contrastive Learning of Sentence Embeddings

**RetroMAE** Retrieval-oriented Language Models Via Masked Auto-Encoder

**mE5** Multilingual E5

**LaBSE** Language-Agnostic BERT Sentence Embedding

**MLM** Masked Language Modeling

**XLM-R** XLM-Roberta

**NSP** Next Sentence Prediction

**BGE** BAAI General Embeddings

**GTE** General Text Embedding

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# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Text representation . . . . .	1
1.2	Evolution of text representation methods . . . . .	1
1.3	Research objective . . . . .	1
<b>2</b>	<b>Literature Review</b>	<b>2</b>
2.1	Traditional word embedding methods . . . . .	2
2.1.1	Word2Vec [23] . . . . .	2
2.1.2	Global vectors (GloVe) [22] . . . . .	2
2.1.3	FastText [20] . . . . .	3
2.2	Transformer-based models . . . . .	3
<b>3</b>	<b>Methodology</b>	<b>4</b>
3.1	Evaluation process . . . . .	4
3.1.1	Text Data Preparation . . . . .	4
3.1.2	Datasets . . . . .	4
3.1.3	Baseline . . . . .	5
3.1.4	Chosen transformer models . . . . .	6
<b>4</b>	<b>Experiments and Results</b>	<b>11</b>
<b>5</b>	<b>Discussion</b>	<b>12</b>
<b>6</b>	<b>Conclusion</b>	<b>13</b>
<b>7</b>	<b>References</b>	<b>14</b>
<b>A</b>	<b>Appendix A</b>	<b>16</b>

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# 1 Introduction

## 1.1 Text representation

The human language, with its nuances and complexities, presents a significant challenge for machines to understand. Natural Language Processing (NLP) bridges this gap, and at its core lies the critical concept of text representation. This process acts as a translator, bridging the gap between the richness of text and the numerical language that machines understand. By effectively capturing the meaning within words and their relationships, text representation empowers NLP models to leverage machine learning's capabilities. From sentiment analysis to machine translation, this ability to represent meaning fuels the advancements in NLP, enabling machines to interact with and decipher human language with ever-increasing accuracy.

## 1.2 Evolution of text representation methods

NLP has undergone a significant transformation in its approach to text representation. Early methods, such as one-hot encoding, while simple to implement, suffered from limitations in efficiency due to dimensionality and sparsity issues.

Word embedding techniques (e.g., Word2Vec, GloVe, FastText) offered a significant improvement by capturing semantic relationships between words through high-dimensional word vectors. However, these techniques primarily focused on local context within a limited window, hindering their ability to capture complex relationships within sentences or documents.

The emergence of deep learning architectures, particularly transformer-based models like Bidirectional Encoder Representations from Transformers (BERT), revolutionized the field of text representation. These models allow to not only understand the meaning of individual words but also consider their interaction and context within a sentence or document.

## 1.3 Research objective

This research aims to evaluate the effectiveness of various word, sentence, and paragraph representations for their subsequent application in Retrieval-Augmented Generation (RAG) algorithms, with a specific focus on the domain of technical Question Answering (QA).

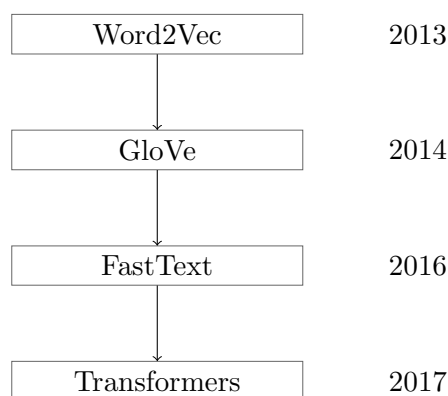


Figure 1.1: Evolution of the text representation methods.

## ■ 2 Literature Review

### ■ 2.1 Traditional word embedding methods

#### ■ Word2Vec [23]

Word2Vec is algorithm that generates word embedding using information about target word (context). Word2Vec uses Neural Network (NN) and Machine Learning (ML) techniques to generate word embedding for every word in vocabulary during training. As NN architecture are used Continuous Bag-of-Words (CBOW) and Skip-gram, Fig. 2.1.

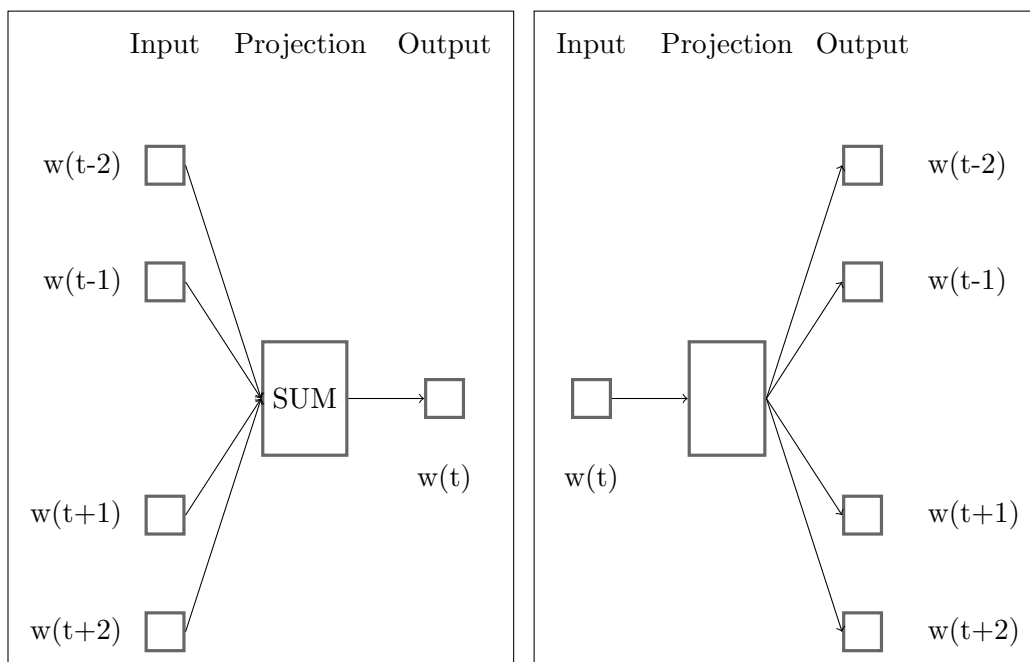


Figure 2.1: CBOW and Skip-gram schemes respectively

Due to its algorithmic simplicity and efficiency, Word2Vec has established itself as a strong baseline for numerous NLP tasks. Compared to more recent and complex models, Word2Vec requires minimal hyperparameter tuning, making it a relatively straightforward approach.

However, it is important to acknowledge that Word2Vec has limitations. These include its inability to capture **global information** within a document, its challenges in effectively handling **morphologically rich languages** (languages with many word variations), and its lack of awareness of the **broader context** beyond a limited window of surrounding words.

#### ■ GloVe [22]

GloVe leverages the co-occurrence statistics of words within a corpus to learn vector representations. This approach involves constructing a co-occurrence matrix, where each entry reflects the frequency of two words appearing together within a predefined window size. This matrix essentially captures the relative importance of various word pairings.

A core principle of GloVe lies in the notion that word vectors should effectively encode the ratios between co-occurrence probabilities of words. By analyzing these ratios, GloVe can identify semantic relationships between words. This is achieved by factorizing the co-occurrence matrix into a lower-dimensional space, allowing for efficient representation and manipulation of word meanings.

To optimize the learned word embeddings, GloVe employs a weighted least squares objective function. This function aims to minimize the discrepancy between the dot product of two word vectors and the logarithm of their co-occurrence probability. Through iterative adjustments of the word vectors, GloVe converges on a solution that yields the desired word embeddings.

### ■ FastText [20]

## ■ 2.2 Transformer-based models

- Discuss traditional word embedding methods like FastText and their limitations.
- Explain the concept of transformer-based models like BERT and their advantages for text representation.
- Review related work on RAG algorithms and their dependence on effective text representations. Discuss existing research on evaluating text representations using analogy tests and confusion matrices.
- Briefly mention the UPV corpus set as the chosen evaluation benchmark.

## ■ 3 Methodology

### ■ 3.1 Evaluation process

This work specifically targets the evaluation of word, sentence, and paragraph representation methods on datasets in the Czech language. This focus on Czech allows for a deeper understanding of how these methods perform in a language with specific characteristics, such as a rich inflectional morphology and the presence of diacritics.

#### ■ Text Data Preparation

In certain foreign languages, a common issue arises when individuals incorrectly write words by omitting diacritics or altering letters, Fig. 3.1. This problem is prevalent in social media, chatbots, and other informal written communications. As a result, embedding models face challenges in comprehending text without diacritics (hereinafter diacriticless). A potential solution involves adapting data representation to accommodate both formal and informal styles of writing.

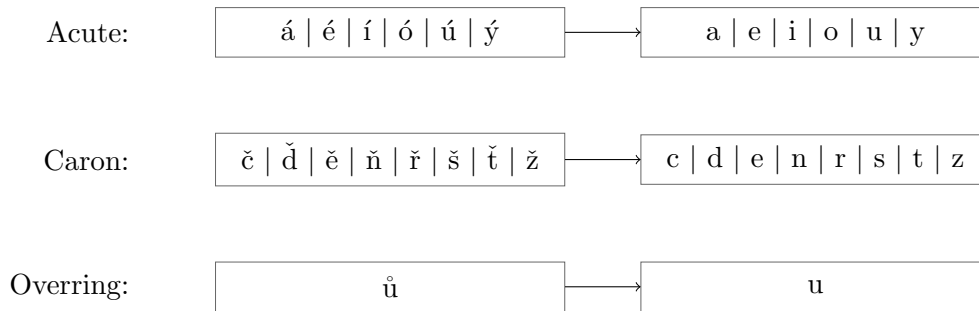


Figure 3.1: Usual changes in informal czech texts.

This study will employ two distinct text representations: text with diacritics and text without diacritics. To ensure optimal evaluation, the diacritic text will be assessed using datasets that preserve these diacritics, while the diacriticless text will be evaluated using datasets that lack diacritics.

As detailed in Lst. 3.1, this script is used for creating diacriticless versions of the datasets.

```
sed 's/./\L&/' "$1" | iconv -f utf-8 -t ascii//TRANSLIT > diacriticless/"$1"
```

Listing 3.1: Script for removing diacritics using Unix utilities

#### ■ Datasets

##### UPV FAQ

Dataset is comprised of frequently asked questions (FAQs) and their answers from the Industrial Property Office of the Czech Republic website, organized into four distinct groups, as detailed in Table 3.1.

This work will evaluate two key metrics using UPV FAQ dataset

- **Question matching accuracy:** This metric involves calculating the cosine similarity between all possible question pairs within a dataset. A question is considered successfully matched if its second-highest cosine similarity score corresponds to another question belonging to the same class (i.e., the question with the highest similarity is likely the same question itself). The overall question matching accuracy is then computed as the ratio of successfully matched questions to the total number of question pairs evaluated.
- **Answer matching accuracy:** This metric assesses the system’s ability to identify the correct answer for a given question. The system accomplishes this by directly comparing the question with pre-generated answer embeddings. By evaluating the similarity between the question and each answer embedding, the system classifies the question as corresponding to the answer with the highest similarity score. The overall answer matching accuracy is then calculated as the proportion of questions for which the system correctly identifies the corresponding answer.

Tests set	Number of tests
FAQv5	2054
FAQ50	561
FAQ76	2025
FAQ76v2	1965
All	6605

Table 3.1: Information about UPV FAQ tests

## ■ Baseline

Due to the inherent morphological richness of the Czech language, this study adopts **FastText** as the baseline word embedding method. This decision is motivated by FastText’s ability to effectively capture morphological variations within words, a characteristic that has been shown to be advantageous for languages like Czech. While other techniques like Word2Vec and GloVe have been explored for word embedding generation, they have demonstrated lower performance in this context. The FastText word embedding model will be trained using the fastText.cc library <sup>1</sup>

## Training parameters

- Architecture: CBOW
- Vector dimensionality: 300
- Loss function: Negative sampling loss
- Dictionary threshold (the frequency of the word to be included in the dictionary): 130

## Training data

FastText model is trained on a segment of a preprocessed Common Crawl repository, which encompasses raw data from web pages, as well as metadata and text extractions. Given the nature of this dataset, it is expected to include misspellings and text lacking diacritics.

<sup>1</sup>fastText.cc library website: <https://fasttext.cc/>

- (i) Eliminating duplicate entries
- (ii) Filtering out lines containing fewer than 9 characters
- (iii) Excluding URLs
- (iv) Breaking lines into individual sentences
- (v) Converting all text to lowercase
- (vi) Removing lines containing words exceeding 30 characters
- (vii) Excluding HTML tags with less than 100 characters
- (viii) Removing lines surpassing 500 characters
- (ix) Omitting words longer than 21 characters

Processed corpus contains 3.87 billion words.

### Model summary

The FastText models trained in this study exhibit differences in vocabulary size. The diacritic model possesses a dictionary of approximately 800,000 words, while the diacriticless model contains roughly 762,000 words. This discrepancy reflects the inherent reduction in word count due to the removal of diacritics in the diacriticless dataset.

These vocabulary sizes directly influence the number of trainable parameters within each model. The number of parameters ( $N$ ) can be calculated using the formula (3.1)

$$N = V_{\text{size}}d + d \quad (3.1)$$

where  $V_{\text{size}}$  is model vocabulary size  
 $d$  is chosen dimensionality of word embeddings

Applying this formula to the vocabulary sizes of our models:

- The diacritics model possesses approximately 240 million parameters.
- The diacriticless model has approximately 229 million parameters.

### ■ Chosen transformer models

To ensure a comprehensive evaluation, a curated selection of embedding models will be utilized. This selection encompasses three distinct categories:

- (i) **Existing Czech Embedding Models:** This category incorporates established Czech embedding models developed within the Czech NLP community. Their inclusion allows for a focused analysis of how these models perform specifically for the Czech language.
- (ii) **Multilingual Models from the Massive Text Embedding Benchmark (MTEB):** The evaluation will leverage highly regarded multilingual models readily available through the MTEB. This inclusion enables an assessment of how these models generalize to the Czech language, providing insights into their adaptability across languages.
- (iii) **Popular Monolingual Models from the MTEB (rank is lower than 100):** In addition to multilingual models, this selection will also include well-regarded monolingual models (models trained on a single language) from the MTEB. This allows for a comparative analysis of how these models, potentially trained on English or other high-resource languages, perform on the Czech dataset.

All models should be open-source. And sentence-bert. 1B. With information about training process. If exist two version of models - monolingual (no czech lang) and multilingual, we evaluate only multilingual

### Czert-B [9]

The Czert model is a set of Czech BERT-like language representation models developed specifically to enhance performance in processing the Czech language. These models leverage the BERT and A Lite BERT (ALBERT) [11] architectures and are designed to outperform multilingual models by training exclusively on Czech data. The training set includes a comprehensive corpus of Czech texts, such as Wikipedia articles, news, and other texts, accumulating to around 36GB of data.

There are 2 variants of the Czert model, Czert-A and Czert-B. Unfortunately Czert-A model is not available, so we will test only Czert-B model. Czert-B model is based on the traditional BERT architecture (110M parameters). Model are pre-trained from scratch using Masked Language Modeling (MLM) and Next Sentence Prediction (NSP) tasks. However, a slight modification is made to the NSP task to adapt it better to the Czech language corpus structure.

### Seznam's models [3]

This study leverages a group of compact word embedding models specifically designed for the Czech language. These models were developed by the Seznam research group with a focus on efficient word representation generation.

- RetroMAE-Small: BERT-small model trained with the Retrieval-oriented Language Models Via Masked Auto-Encoder (RetroMAE) objective [6] on a custom Czech corpus.
- Dist-MPNet-ParaCrawl: BERT-small model distilled from the *sentence-transformers/all-mpnet-base-v2*<sup>2</sup> model, using parallel cs-en dataset [14] for training.
- Dist-MPNet-CzEng: BERT-small model distilled from the *sentence-transformers/all-mpnet-base-v2*<sup>2</sup> model, using parallel cs-en dataset Czeng [10] for training.
- SimCSE-RetroMAE-Small: The RetroMAE-Small model fine-tuned with the Simple Contrastive Learning of Sentence Embeddings (SimCSE) [7].
- SimCSE-Dist-MPNet-ParaCrawl: The Dist-MPNet-ParaCrawl model fine-tuned with the SimCSE.
- SimCSE-Dist-MPNet-CzEng: The Dist-MPNet-CzEng fine-tuned with the SimCSE.
- SimCSE-Small-E-Czech: Czech ELECTRA model [8] fine-tuned with the SimCSE objective to enhance sentence embeddings.

The developed models are about eight times smaller and five times faster than conventional base-sized models, making them suitable for real-time applications where computational efficiency is critical. The models are trained using techniques like pre-training, knowledge distillation, and unsupervised contrastive fine-tuning to adapt to the limited availability of labeled Czech data.

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<sup>2</sup> Model on the huggingface website: <https://huggingface.co/sentence-transformers/all-mpnet-base-v2>



## mBERT

Multilingual Bidirectional Encoder Representations from Transformers (mBERT) [13] leverages the same transformer-based architecture as the original BERT model but boasts an increased number of parameters (178M) to enhance its capabilities. A key distinction of mBERT lies in its ability to understand and process text data across multiple languages. To achieve this multilingual proficiency, mBERT is trained on a massive dataset sourced from Wikipedia entries in 104 different languages. This corpus is meticulously constructed to ensure balanced representation, meaning each language is included regardless of the size or depth of its corresponding Wikipedia. This approach ensures that even languages with limited resources are adequately represented within the training data, fostering better performance for these languages.

## Multilingual E5 (mE5) [1]

mE5 models by Microsoft are advanced text embedding models designed to operate across multiple languages based on English-only E5 models [2]. These models are available in three variants — small, base, and large — catering to different computational efficiency and performance needs. The mE5 models are trained using a two-phase approach. The first phase involves weakly-supervised contrastive pre-training on about 1 billion text pairs sourced from diverse multilingual corpora (Wikipedia, mC4, Multilingual CC News, Reddit, etc.). The second phase is supervised fine-tuning on approximately 1.6 million data points from high-quality labeled datasets (MS MARCO [18], Natural Questions (NQ) [15], TriviaQA [19], SQuAD [21], etc.).

## LaBSE [5]

Language-Agnostic BERT Sentence Embedding (LaBSE) model, developed by Google, is a state-of-the-art model for generating sentence embeddings that are effective across 109 languages. It leverages the transformer architecture and is trained on both monolingual (from sources like CommonCrawl and Wikipedia) and bilingual data (mined from web pages). LaBSE utilizes a dual-encoder structure with BERT-based encoding modules. This setup enables the efficient processing of text pairs in multiple languages.

## XLM-R [12]

The XLM-Roberta (XLM-R) model is a significant advancement in unsupervised cross-lingual representation learning, introduced by Facebook AI. It is specifically designed to improve performance across a wide range of cross-lingual tasks. XLM-R is pre-trained on a dataset dubbed 'CC-100', derived from Common Crawl, covering about 2.5 terabytes of text across 100 languages. This dataset is significantly larger than the ones used by its predecessors, offering a broader and more diverse linguistic foundation.

## SentenceTransformers multilingual models [16]

- `distiluse-base-multilingual-cased-v2`: Multilingual knowledge distilled version of multilingual Universal Sentence Encoder [17]. This version supports 50+ languages including Czech.

- paraphrase-multilingual-MiniLM-L12-v2: Multilingual version of paraphrase-MiniLM-L12-v2, trained on parallel data for 50+ languages including Czech.
- paraphrase-multilingual-mpnet-base-v2: Multilingual version of paraphrase-mpnet-base-v2, trained on parallel data for 50+ languages including Czech.

### UAE-Large-V1 [4]

The UAE-Large-V1 model focuses on enhancing short and long Semantic Textual Similarity (STS) tasks through a novel angle-optimized text embedding approach that works by dividing text embeddings into real and imaginary components in a complex space. This model is designed to address the challenges posed by the saturation zones of the cosine function, which can impede learning by causing vanishing gradients.

The model is trained using a hybrid objective that combines cosine similarity, in-batch negatives, and angle differences in complex space. This approach helps overcome the limitations of traditional cosine similarity measures by ensuring better gradient flow during training. Training dataset includes around 21K samples and is specifically designed to evaluate STS performance on long texts, which are common in real-world applications.

### Nomic Embed V1 and Nomic Embed V1.5

The Nomic model [0], designed for reproducible long-context text embedding, employs a modified BERT architecture optimized for 8192 token sequences. It includes innovations such as rotary positional embeddings and SwiGLU activations, enhancing its ability to process longer texts. The model undergoes a comprehensive training regime starting with unsupervised contrastive pretraining on large-scale datasets, followed by supervised fine-tuning using human-annotated data. This process leverages contrastive learning to improve text embedding capabilities, significantly enhancing performance on both short and long-context tasks.

Nomic Embed V1.5 is an improvement upon Nomic Embed V1 that utilizes Matryoshka Representation Learning [0] which gives developers the flexibility to trade off the embedding size for a negligible reduction in performance.

### snowflake-arctic-embed

This study investigates the use of snowflake-arctic-embed, a suite of text embedding models optimized for retrieval tasks. The suite offers multiple model sizes (xs, s, m, m-long, l) for flexibility.

Snowflake-arctic-embed leverages a two-stage training pipeline

- (i) Pretraining on large batches of query-document pairs with dynamically generated negative examples using dataset with 400M samples combining public data and proprietary web search data.
- (ii) Fine-tuning the model on a smaller dataset (1M samples) consisting of query-positive document-negative document triplets to improve retrieval accuracy.

### GTE and GTE-v1.5

The General Text Embedding (GTE) model is a pivotal development in NLP, utilizing a deep Transformer encoder based on a BERT-like architecture for generating dense text embeddings. Initially, the GTE model is unsupervisedly pre-trained on approximately 800 million text pairs from diverse web sources, enabling broad semantic coverage. It then undergoes supervised fine-tuning with 3 million annotated text triples from varied datasets, including MS MARCO and Natural Questions, applying contrastive learning to enhance text relevance detection and similarity assessments. This dual-stage training strategy equips the GTE model to excel in complex NLP tasks, demonstrating significant versatility and robust performance across multiple applications.

There is also updated version GTE-v1.5.

### BGE-v1.5

BAAI General Embeddings (BGE) Models [0] are built on a BERT-like architecture, available in three sizes: small, base, and large. They are trained using a sophisticated multi-stage process involving pre-training on large unlabeled data, contrastive learning for fine-tuning on text pairs, and multi-task learning with high-quality labeled datasets. This training regimen equips BGE models to handle a wide range of text embedding tasks with high efficiency and accuracy.

### TaylorAI tiny models

This study incorporates two distilled transformer models from TaylorAI for evaluation:

- **TaylorAI/bge-micro-v2** <sup>3</sup>: This model is a 2-step distilled version of the small BGE-v1.5 model
- **TaylorAI/gte-tiny** <sup>4</sup>: This model is a distilled version of the small version of GTE model
- Describe the evaluation process for different text representations.
  - Specify the chosen word, sentence, and paragraph representation models (e.g., Fast-Text, BERT variants).
  - Explain the usage of analogy tests and confusion matrices for evaluation.
  - Detail the selection process for the UPV corpus set and its suitability for technical QA tasks.
- Outline the second part of the study focusing on RAG for technical QA.
  - Explain the RAG algorithm and its reliance on text representations.
  - Describe the evaluation approach for selecting optimal representations for RAG.
  - Mention the factors considered during evaluation, such as embedding efficiency, text chunk size, and factuality of generated answers.

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<sup>3</sup>TaylorAI/bge-micro-v2 model on the huggingface website: <https://huggingface.co/TaylorAI/bge-micro-v2>

<sup>4</sup>TaylorAI/gte-tiny model on the huggingface website: <https://huggingface.co/TaylorAI/gte-tiny>

## ■ 4 Experiments and Results

- Present the results of the evaluation for different text representations using analogy tests and confusion matrices.
- Discuss the findings regarding the effectiveness of each representation model for capturing semantic relationships in technical text.
- Analyze the results from the RAG evaluation, highlighting the impact of different representations and text chunk sizes on answer generation quality and CPU efficiency.
- Identify the representation model that achieves a balance between factuality of answers and computational demands.

## ■ 5 Discussion

- Interpret the overall findings and their implications for choosing suitable text representations for RAG in technical QA tasks.
- Discuss the strengths and limitations of the chosen evaluation methods.
- Address potential challenges encountered during the study and suggest improvements for future research.

## ■ 6 Conclusion

Summarize the achieved results. Can be similar as an abstract or an introduction, however, it should be written in past tense.

- Summarize the key takeaways from the research, emphasizing the most effective text representation model for RAG in technical QA based on the evaluation criteria.
- Briefly mention the trade-offs between factuality, CPU usage, and other factors in selecting representations for RAG.
- Suggest potential future research directions, such as exploring other text representation methods or evaluating RAG performance on different datasets.

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Model	Tokenization	L	$H_m$	$H_{ff}$	A	V	#params
Czert-B	N/A	12	768	NA	12	31K	12M
mBERT	WordPiece	12	768	3072	12	110k	172M
XLM-R <sub>Base</sub>	SPM	12	768	3072	12	250k	270M
XLM-R <sub>Large</sub>	SPM	24	1024	4096	16	250k	550M

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Table A.1: **Details on model sizes.** We show the tokenization used by each Transformer model, the number of layers L, the number of hidden states of the model  $H_m$ , the dimension of the feed-forward layer  $H_{ff}$ , the number of attention heads A, the size of the vocabulary V and the total number of parameters #params. For Transformer encoders, the number of parameters can be approximated by  $4LH_m^2 + 2LH_mH_{ff} + VH_m$ . While this table gives more hindsight on the difference of capacity of each model, note it does not highlight other critical differences between the models.

## ■ A Appendix A