

Comparison of Keyword Extraction and Word Vector Generation Methods for Use in Identifying Related Genomic Datasets

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Abstract

Data-sharing requirements have led to wide availability of genomic datasets in public repositories. Researchers can reuse and combine these datasets to address novel hypotheses. However, after identifying one or more datasets that are relevant to a particular research question, a researcher may have difficulty identifying other datasets that are also relevant, due to the large quantity of available datasets and lack of structure with which they are described. In this study, we focus specifically on Gene Expression Omnibus, a repository that contains genomic data from hundreds of thousands of experiments that is commonly used in biomedical analyses. Notable efforts have been made to manually annotate these data but not been able to keep pace as new datasets are submitted. To address this problem, we use natural language processing (NLP). Under the assumption that a researcher has manually identified a subset of available datasets related to a particular research topic, we use NLP algorithms to extract keywords from the abstract associated with each dataset. Next we summarize the keywords using diverse embedding algorithms and compare the vectors generated to available datasets to identify potential related datasets.

In terms of word vector generation we test six different models. These models vary in training method, domain, and architecture. The six models are the following: BioWordVec - a FastText model trained on biomedical text, FastTextWiki - A FastText model trained on Wikipedia data, FastTextCBOW - a custom FastText model trained on only StarGEO data using the CBOW (continuous-bag-of-words) method, FastTextSkipGram - A custom FastText model trained on only StarGEO data using the SKIPGRAM technique, SciSpaCy - A SpaCy model trained on scientific literature, and SpaCy - A SpaCy model trained with the readily available large web corpus.

We also test nine keyword extraction methods. Three of the methods are statistical models while the other six are graphical methods. The statistical methods are TF-IDF, KP-Miner, and YAKE. TF-IDF works by comparing the frequency of each word found in the passage to its frequency in other passages that exist in the corpus. KP-Miner evaluates each word based on the context surrounding the words to identify keywords. YAKE combines elements of both TF-IDF and KP-Miner by using the context while also taking into account the frequency at which the word appears in the document. The first graphical approach we test is TextRank which is based off of a web technique called PageRank which is used for identifying related webpages through hyperlinks. TextRank performs a similar analysis with text by creating a graph where each word is represented as a node. Relationships between words are drawn as connected nodes. These relationships are used to identify keywords. TopicRank is a process similar to TextRank but the text is preprocessed to create n-grams of nouns and adjectives as keyphrase candidates before creating a graph with them to identify keywords. SingleRank is another extension of TextRank with each node having a weight value assigned to it. PositionRank is a more complicated extension of TextRank where the position of the word within the sentence is assigned a weight along with actual context as in TextRank. TopicalPageRank is another extension of TextRank that seeks to improve experience by weighting those words that appear more in the document. The last graphical approach is MultipartiteRank which uses a multipartite graph to construct the initial graph and calculate weights between nodes.

We found that different combinations of keyword extraction methods and word vector generation yield very different results. This variety was also reflected across the query domains. These results show that natural language processing is a powerful tool that can be harnessed for data collection and more research needs to be done in this area.

Introduction

Natural Language Processing is computational technique that allows computers to process human language [1]. In the past, Natural Language Processing has been used in several biomedical applications such as concept extraction, electronic health record analysis, and text mining. [2,3,4]. However there is a lack of research detailing natural language approaches to data collection, specifically the collection of relevant datasets for analysis. Recently an article was published that details an approach to dataset recommendation using a researchers interests and CV to identify datasets [5]. This paper also detailed some difficulties in dataset recommendation. Some of these challenges are a lack of widely-accepted metadata format, lack of available tools, and an exponential rise in available datasets [5]. In this paper we detail an alternative approach to address this problem using readily available natural language processing tools to identify related datasets from an initial set of related articles.

The major obstacle to data collection for a researcher is a lack of available tools. The aforementioned paper details an approach to help address this issue, but is not capable of using a user-generated query to identify related datasets. Another related tool is BioCaddie [6] which is an ongoing tool to index current datasets to make them easily searchable. However the advantage to our approach is that it requires no indexing and can be applied to any text-based data. Our methodology utilises two techniques widely used in natural language processing, namely keyword extraction and word vector generation [7,8]. Using these two tools, our approach can take several pre-identified datasets and identify other related datasets, no matter how niche the subject area. We test a variety of these different techniques to identify those that are most promising for future use.

Methods

Data Collection

To measure the accuracy of our method, we only used data that had already been manually identified as related. To achieve this we used the Search Tag Analyze Resource for GEO application (StarGEO). StarGEO is a collection of datasets from the Gene Expression Omnibus that have manually annotated by biomedical graduate students to facilitate the task of collecting related datasets [9]. For each entry in StarGEO the dataset has an abstract, title, and Gene Expression Omnibus accession number. Each dataset in StarGEO has been hand curated and attached to several tags that seek to categorize on a broad level the type of data available [9]. To ensure a mixture of broad and narrow queries, as well as different domains, we selected six queries to test. While StarGEO has a variety of species to choose from, all queries were filtered to only return human genomic data. Two of which are broad with ~100 articles returned, two are medium with ~20 articles returned and two are small with ~10 articles returned. These queries cover a wide range of domains. It is important to note that since StarGEO is an ongoing project, it is likely that these queries currently have more articles than at the time of writing.

Keywords	Number of Articles Returned by StarGeo
Family History + Breast Cancer	6
Liver Damage + Hepatitis	9
Monozygotic Twins	25
Kidney + Tumor + Cell Line	16
Diabetes + Type 1	97
Osteosarcoma	112

The purpose of widely varying the amount of articles returned is to ensure that our method works for narrowly defined topics as well as broad topics. All data accession was performed using the StarGEO API [10]. The API was accessed and results were stored in a dictionary keyed by accession number to combined abstract and title.

Model Collection

Once the data was collected the next step was identifying the techniques to be tested. Research has already shown that a variety of natural language processing models are effective on biomedical literature [11,12]. However we felt it was necessary to test a variety of techniques for both keyword extraction and word vector generation to identify the combination most suited to the task of collecting related genomic data.

Keyword Identification is the first step that our data in the dictionary goes through. To accomplish consistent querying in a standardized framework we used the PKE package available in Python. All documentation is available on GitHub [13]. The PKE packages allowed us to use one single package to access all the keyword embedding techniques, instead of individually querying each technique. The keyword extraction techniques that were tested are the following: TFIDF, KP-Miner, YAKE, TextRank, SingleRank, TopicRank, TopicalPageRank, PositionRank and MultipartiteRank [13]. Each of these techniques uses a different algorithm to identify keywords, an example of the diversity of returned keywords is available in the appendix.

After the keywords have been identified from the target text, word vectors are generated from each keyword using a word vector model. These models use large amounts of unlabeled text to identify the meanings of words and express those as a numeric vector. For our project we selected 6 different models that encompass a variety of techniques and training data. The two major frameworks used in this project were SpaCy and FastText. These models are the two most widely used frameworks in natural language processing and both have been used in biomedical applications [11,14,15]. However there are differences in how these models train on sample text and generate word vectors. For these reason we chose to test both platforms.

The source of training data is an important aspect of generating word vectors. Recent literature supports matching the training data to the testing data [11]. However the benefit of keeping the training and testing data in the same domain is not supported in all the literature [12]. To test this effect we have models trained on both biomedical literature and other sources such as web blogs, news, and Wikipedia [16]. This training data has several possible algorithms for processing and generating word vectors. The two majors options are Continuous-Bag-Of-Words (CBOW) and SKIPGRAM, a complete explanation of these algorithms is outside the scope of this paper. Both of these algorithms have been shown effective on biomedical natural language processing, but small differences have been shown between the word vectors generated from either algorithm [17]. Due to this, both algorithms are tested. There are a total of 6 models tested in this paper. FastText and Spacy are compared head to head, as well as different algorithms and training data. A summary of each model and brief details are shown below.

Model	Summary
BioWordVec	FastText Model trained on generic biomedical data with SKIPGRAM
FastTextWiki	FastText model trained on Wikipedia data with CBOW
FastTextCBOW	FastText model trained on GEO data using CBOW
FastTextSKIPGRAM	FastText model trained on GEO data using SKIPGRAM
SciSpacy	A Spacy model designed for usage in biomedical applications
SpacyWebLG	A Spacy model desined for generic usage

Vector Generation

The initial step of vector generation is the identification of the top ten keywords from the text source. Each one of these keywords is turned into a word vector. This word vector is stored as a list of numeric values. The models vary in the length of this numeric vectors from 100 - 300. Once each vector has been generated from each keyword these vectors are added element-wise and then divided by the number of keywords. This technique has been shown to be the simplest and most accurate way to generate a singular word vector from various word embeddings and is usually used to generate document-wide word embeddings [18].

Model Evaluation

All model evaluation is performed in a Docker container to allow other researchers to perform the same analysis described in this section [19].The Docker image used to build the container is the python:3.8.5 image available on the Docker website [20]. Running the docker container as pulled from github will run a bash script that performs the following steps. 1. StarGEO is queried to prepare the six queries. The prepareQueryData.py script takes two arguments. The first is a list of GEO identifiers and the second is the query number that these identifiers should belong to. PrepareQueryData.py creates a file system that contains all the abstract and titles of the series that correspond to each identifier.

The file system will put each text file into the directory for the corresponding query. This script also randomly selects half of the data to be used as the training data. 2. GetGeoQueries.py is run. This script uses text files generated by GEO to evaluate the performance of GEO. A detailed explanation of this is found below in the manual comparison section. 3. A do loop iterates over the numbers 10,20, and 30. These numbers are the number of keywords that each model should try to identify from the text. Each iteration performs the following analysis. i. Six scripts that correspond to SciSpaCy, BioWordVec, FastTextWiki, SpaCy, FastTextSkipGram, and FastTextCBOW are run. Each of these scripts takes the following three arguments : number of keywords, vector size, and number of StarGEO articles. Each script performs the following steps: a. All candidate articles from StarGEO are queried b. The specific word vector model is loaded (SciSpaCy, BioWordVec, ...) c. For each query and keyword combination findSimilarity() is run in Helper.py and added to a multiprocessing thread. This script prints to an output file the calculated similarity of each article using each combination d. The top 1,10 and 100 articles are returned to compare against the articles that StarGEO previously identified as related.

Reduced Set Testing

The results contained within this paper are from a reduced set of all StarGEO articles (266) plus an additional 1000 randomly queried articles from GEO. The purpose for performing the reduced set was the full 41,823 article corpus from StarGEO ran for over one month and we were not able to complete the full testing. A reduced corpus of 1000 articles allowed us to compare the various methods head to head without the need for extensively long wait times. However the analysis is set up in such a way as to allow the researcher to easily change the amount of articles used in the analysis.

Manual Gene Expression Omnibus Evaluation

Gene Expression Omnibus (GEO) is the parent corpus from which StarGEO is derived [21]. To compare our technique directly to GEO we use a manual evaluation. We first use the advanced search option on GEO to input the exact queries we used from StarGEO. To maintain consistency with StarGEO, the results are limited to series and human genomic data. A summary file of all the results is downloaded and analyzed. To ensure equal comparison the results are filtered to only include those datasets that exist in StarGEO's corpus while excluding SuperSeries. Using the same technique for the StarGEO evaluation the top 1,10, and 100 articles are identified and compared against the relevant articles from StarGEO.

Results

The two main techniques in this paper are keyword identification and word vector generation. Both of these methods are described below.

Keyword Identification

Keyword extraction is a vital part of the analysis. There are a variety of techniques to achieve this, and we test the most common 9 techniques in this paper. Each technique performs the analysis slightly differently and this leads to variation in the keywords identified. An example of the variation is shown below.

Sample Abstract -> "BRCA1 and BRCA2 are the genes related with breast and ovarian cancer. They have function in DNA repair processes and thus they are tumor suppressor genes. There are hundreds of mutations identified in these genes. Functional deficiencies due to these mutations impair DNA repair and cause irregularities in the DNA synthesis. The standard method for the laboratory assessment of these BRCA genes includes comprehensive sequencing and testing of broad genomic rearrangements. Members of the families with BRCA mutations have an increased risk for early onset of breast cancer and ovarian cancer occurring at any age."

Keyword Extraction Technique	Top 3 Keywords returned
TopicRank	'mutations', 'breast', 'dna repair processes'
TextRank	'dna repair processes', 'tumor suppressor genes', 'serum ca-125 levels'
SingleRank	'brca mutations', 'brca genes', 'breast cancer'
TopicalPageRank	'brca genes', 'brca mutations', 'tumor suppressor genes'
MultipartiteRank	'mutations', 'genes', 'dna repair processes'

Word Vector Generation

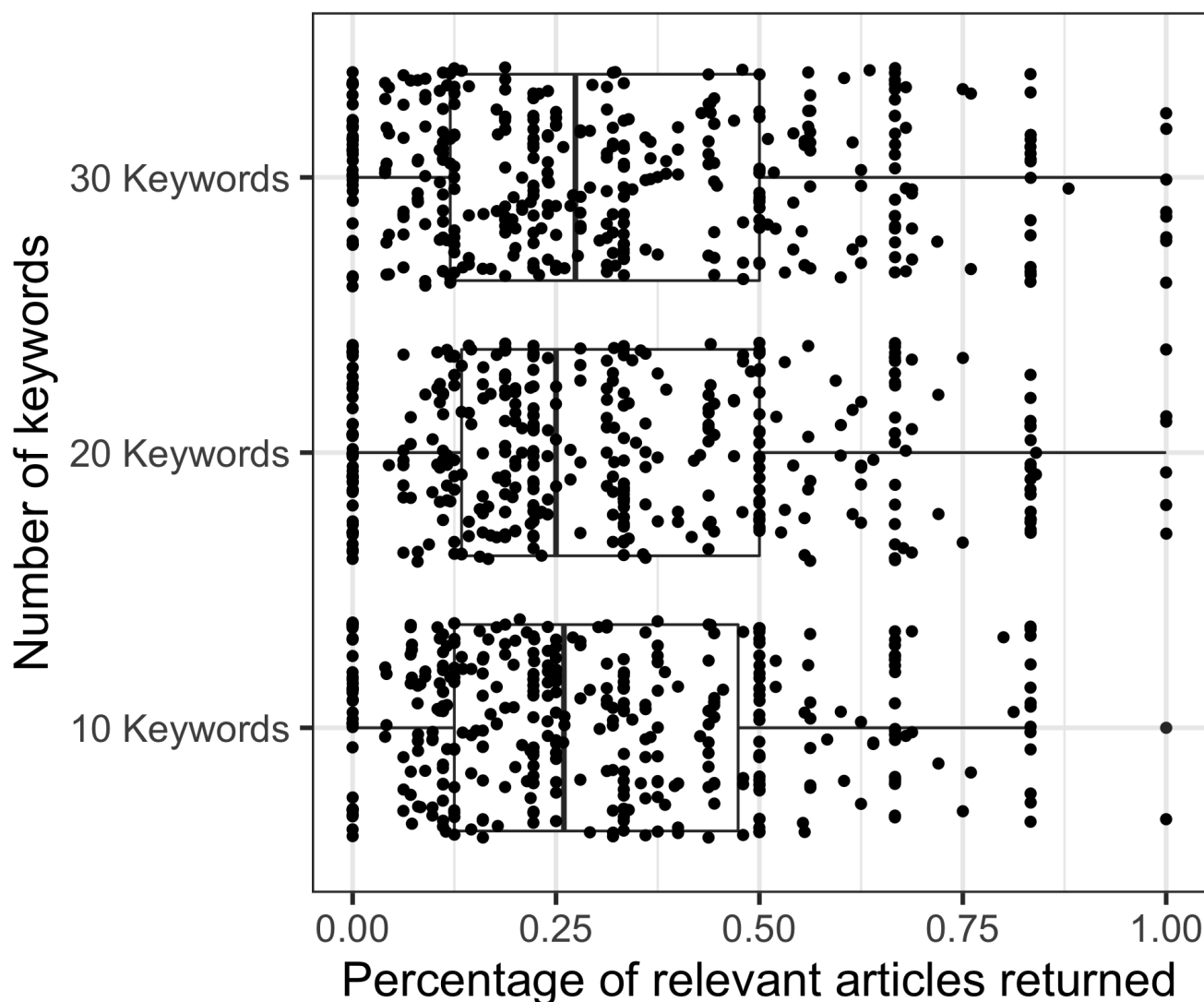
Vector generation is how similarities between articles are calculated. This allows us to give a numerical percentage to quantify the relationship between two datasets. In our analysis we test 6 models that can generate vectors. Each model is trained on unique text and will yield slightly different word vectors. This in turn will generate slightly different cosine similarities. An example of vector generation is shown below:

Word	Vector
Database	[1.3863622 1.0939984 -2.1352 -1.9841313 -0.31141075 1.3959851 ...]
Gene	[1.4969006 2.7855976 -4.313326 -2.5572329 -0.9275282 0.43499815 ...]
Mutation	[2.7130241e+00 2.5561374e-01 -2.1098554e+00 -2.1719341e+00 ...]
Disease	[1.9606729e+00 3.5872436e-01 -2.9315462e+00 -2.3048987e+00 ...]

Evaluation Results


Effect of Number of Keywords Returned on the Percentage of Relevant Articles Returned at 100 Articles

Number of Keywords Extracted vs Percentage of Relevant Articles Returned



This summary graph shows the relationship between the number of keywords queried and percentage of relevant articles returned at 100 articles. Between the three groups a wilcoxon test found no significant difference.

30 keywords

This graph is an example of a graph generated by the AllGraphs script in /images/. All other models are contained in the appendix. This graph is 30 keywords using the SciSpaCy model.  SciSpaCy.

GEO Results

This graph contains the manual Gene Expression Omnibus results.  GEO_Results

Discussion

Overview

The purpose of this project was to illustrate the usage of Natural Language Processing in the data collection phase of any project and to identify techniques to use in future projects. NLP has already been shown to be useful to find related articles of scientific nature [22,23,24]. However to our knowledge no project has been done comparing word vector generation and keyword extraction techniques for usage in data collection. This is addressed in our paper in the head to head comparison of these techniques. We hope this will further our knowledge as to how natural language processing might help researchers in future studies.

Motivation

This project was motivated through our personal experiences attempting to find datasets. Often as researchers a project will began as a big picture idea and the first step is the collection of related datasets to further narrow the project idea. This step can be time-consuming and frustrating due to the lack of tools available and the massive amount of data that exists. Existing tools are limited by user-provided queries that may not be precise. Existing tools such as the search function of Gene Expression Omnibus that take user generated queries are often limited by the exact phrasing of the query. For example the query “mohs” returns 100 results but “moh’s” returns 33 different results. Experiences like this motivated us to look for a technique that could use a dataset to identify related datasets free of human-generated queries.

Observations

The results show a wide variety of accuracy across the queries. This pattern of the same natural language processing technique giving disparate results on intrinsic evaluations is one commonly seen in natural language processing evaluations [8,17,25]. However the results do show a pattern that the best performing results are when the model and data are similar. Another interesting observation is the varying results between queries. The best performing queries are consistently queries one and two which are the smallest queries with six and nine results respectively. This would imply that the more narrowly defined a query, the better this technique can perform.

The amount of keywords does not impact the percentage of relevant articles returned. This is likely due to the fact that 10 keywords is sufficient to capture the meaning of the query. Adding more keywords only adds irrelevant noise to the model.

Practical Utility

Our results show a practical utility for this technique to a researcher who is interested in a very specific knowledge base. If a researcher has previously identified several articles that deal with a narrowly defined subject area, using this technique to query a larger database (not StarGEO) would result in the discovery of potentially all the related datasets that exist in that database. Using this technique, the researcher can bypass the arduous process of collecting datasets and trying to determine which are useful. This technique can also be used to look at multiple datasets within in a broad context. While not useful for potentially finding a niche dataset from a broad query, the ability of this technique to find even distantly related dataset could be used to facilitate a broad understanding of the datasets related to a concept.

It is important to note that this is not a well-polished tool free of bugs. This is a proof of concept that can be applied in various situations to yield useful results. Any customization would require the manual editing of the code to fit the use cause.

Limitations

There are several limitations to our approach. Most obvious is a lack of methods to compare it against. There exists no other tool for gathering related datasets from an initial cohort of datasets. This means that the only external evaluation possible is to compare it to hand curation of datasets by other researchers. We did consider this option but rejected it due to the subjective nature of human curation and the time it would require of the participants. There are also other keyword extraction and word vector generation techniques. Our keyword extraction techniques were limited to those available in the PKR Python package to ensure consistency. Word vectors were limited to the those that were most commonly tested and available in other NLP related papers [[12](#),[26](#)]. Further testing is warranted on less known models and techniques.

All analysis were performed on a Dell PowerEdge R730xd server with two Intel Xeon E5-2640 v4 2.4GHz CPUs that each support 10 cores with two threads apiece with a total of 256gb of RAM. All analyses were run using the Multiprocessing package that allowed each combination of keyword extraction and word vector to each be run as a separate task. This hardware was not capable of running the full analysis even using the multiprocessing package. We hypothesis this is due to the relatively long time it takes to generate a word vector.

Appendix

Comparison of Keywords Techniques

Test Abstract from PubMed. [27] Text = "OBJECTIVE: Novel biomarkers of disease progression after type 1 diabetes onset are needed. RESEARCH DESIGN AND METHODS: We profiled peripheral blood (PB) monocyte gene expression in 6 healthy subjects and 16 children with type 1 diabetes diagnosed ~3 months previously, and analyzed clinical features from diagnosis to 1 year. RESULTS: Monocyte expression profiles clustered into two distinct subgroups, representing mild and severe deviation from healthy controls, along the same continuum. Patients with strongly divergent monocyte gene expression had significantly higher insulin dose-adjusted HbA1c levels during the first year, compared to patients with mild deviation. The diabetes-associated expression signature identified multiple perturbations in pathways controlling cellular metabolism and survival, including endoplasmic reticulum and oxidative stress (e.g. induction of HIF1A, DDIT3, DDIT4 and GRP78). qPCR quantitation of a 9-gene panel correlated with glycaemic control in 12 additional recent-onset patients. The qPCR signature was also detected in PB from healthy first-degree relatives. CONCLUSIONS: A PB gene expression signature correlates with glycaemic control in the first year after diabetes diagnosis, and is present in at-risk subjects. These findings implicate monocyte phenotype as a candidate biomarker for disease progression pre- and post-onset, and systemic stresses as contributors to innate immune function in type 1 diabetes."

Keyword Extraction Technique	Keywords Returned
TopicRank	"monocyte gene expression", "diabetes onset", "year"
TextRank	"divergent monocyte gene expression", "monocyte gene expression", "pb gene expression signature"
SingleRank	"pb gene expression signature", "divergent monocyte gene expression", "monocyte gene expression"
TopicalPageRank	"pb gene expression signature", "divergent monocyte gene expression", "monocyte gene expression"
MultipartiteRank	"monocyte gene expression", "diabetes onset", "type"

30 Keywords

SpaCy_30. FastText CBOW_30. FastText Skipgram_30. FastText Wiki_30. SpaCy_30.

References

1. **Natural language processing: an introduction**
Prakash M Nadkarni, Lucila Ohno-Machado, Wendy W Chapman
Journal of the American Medical Informatics Association (2011-09-01) <https://doi.org/c3r4n3>
DOI: [10.1136/amiajnl-2011-000464](https://doi.org/10.1136/amiajnl-2011-000464) · PMID: [21846786](https://pubmed.ncbi.nlm.nih.gov/21846786/) · PMCID: [PMC3168328](https://pubmed.ncbi.nlm.nih.gov/PMC3168328/)
2. **BioBERT: a pre-trained biomedical language representation model for biomedical text mining**
Jinhyuk Lee, Wonjin Yoon, Sungdong Kim, Donghyeon Kim, Sunkyu Kim, Chan Ho So, Jaewoo Kang
Bioinformatics (2019-09-10) <https://doi.org/ggh5qq>
DOI: [10.1093/bioinformatics/btz682](https://doi.org/10.1093/bioinformatics/btz682) · PMID: [31501885](https://pubmed.ncbi.nlm.nih.gov/31501885/) · PMCID: [PMC7703786](https://pubmed.ncbi.nlm.nih.gov/PMC7703786/)
3. **Natural language processing (NLP) tools in extracting biomedical concepts from research articles: a case study on autism spectrum disorder**
Jacqueline Peng, Mengge Zhao, James Havrilla, Cong Liu, Chunhua Weng, Whitney Guthrie, Robert Schultz, Kai Wang, Yunyun Zhou
BMC Medical Informatics and Decision Making (2020-12-30) <https://doi.org/ghs7xp>
DOI: [10.1186/s12911-020-01352-2](https://doi.org/10.1186/s12911-020-01352-2) · PMID: [33380331](https://pubmed.ncbi.nlm.nih.gov/33380331/) · PMCID: [PMC7772897](https://pubmed.ncbi.nlm.nih.gov/PMC7772897/)
4. **Overview of the First Natural Language Processing Challenge for Extracting Medication, Indication, and Adverse Drug Events from Electronic Health Record Notes (MADE 1.0)**
Abhyuday Jagannatha, Feifan Liu, Weisong Liu, Hong Yu
Drug Safety (2019-01-16) <https://doi.org/ghs53b>
DOI: [10.1007/s40264-018-0762-z](https://doi.org/10.1007/s40264-018-0762-z) · PMID: [30649735](https://pubmed.ncbi.nlm.nih.gov/30649735/) · PMCID: [PMC6860017](https://pubmed.ncbi.nlm.nih.gov/PMC6860017/)
5. **A content-based dataset recommendation system for researchers—a case study on Gene Expression Omnibus (GEO) repository**
Braja Gopal Patra, Kirk Roberts, Hulin Wu
Database (2020) <https://doi.org/ghkftx>
DOI: [10.1093/database/baaa064](https://doi.org/10.1093/database/baaa064) · PMID: [33002137](https://pubmed.ncbi.nlm.nih.gov/33002137/) · PMCID: [PMC7659921](https://pubmed.ncbi.nlm.nih.gov/PMC7659921/)
6. **Finding useful data across multiple biomedical data repositories using DataMed**
Lucila Ohno-Machado, Susanna-Assunta Sansone, George Alter, Ian Fore, Jeffrey Grethe, Hua Xu, Alejandra Gonzalez-Beltran, Philippe Rocca-Serra, Anupama E Gururaj, Elizabeth Bell, ... Hyeon-eui Kim
Nature Genetics (2017-05-26) <https://doi.org/gbhfth>
DOI: [10.1038/ng.3864](https://doi.org/10.1038/ng.3864) · PMID: [28546571](https://pubmed.ncbi.nlm.nih.gov/28546571/) · PMCID: [PMC6460922](https://pubmed.ncbi.nlm.nih.gov/PMC6460922/)
7. **pke: an open source python-based keyphrase extraction toolkit**
Florian Boudin
(2016-12) <https://aclanthology.org/C16-2015>
8. **BioWordVec, improving biomedical word embeddings with subword information and MeSH**
Yijia Zhang, Qingyu Chen, Zhihao Yang, Hongfei Lin, Zhiyong Lu
Scientific Data (2019-05-10) <https://doi.org/gf63th>
DOI: [10.1038/s41597-019-0055-0](https://doi.org/10.1038/s41597-019-0055-0) · PMID: [31076572](https://pubmed.ncbi.nlm.nih.gov/31076572/) · PMCID: [PMC6510737](https://pubmed.ncbi.nlm.nih.gov/PMC6510737/)
9. **Precision annotation of digital samples in NCBI's gene expression omnibus**
Dexter Hadley, James Pan, Osama El-Sayed, Jihad Aljabban, Imad Aljabban, Tej D. Azad, Mohamad O. Hadied, Shuaib Raza, Benjamin Abhishek Rayikanti, Bin Chen, ... Atul J. Butte

Scientific Data (2017-09-19) <https://doi.org/gbv379>
DOI: [10.1038/sdata.2017.125](https://doi.org/10.1038/sdata.2017.125) · PMID: [28925997](https://pubmed.ncbi.nlm.nih.gov/28925997/) · PMCID: [PMC5604135](https://pubmed.ncbi.nlm.nih.gov/PMC5604135/)

10. **STAR | Redefining the meaning of disease... Together!** http://stargeo.org/api_docs/
11. **How to Train good Word Embeddings for Biomedical NLP**
Billy Chiu, Gamal Crichton, Anna Korhonen, Sampo Pyysalo
Association for Computational Linguistics (ACL) (2016) <https://doi.org/gfxvff>
DOI: [10.18653/v1/w16-2922](https://doi.org/10.18653/v1/w16-2922)
12. **A comparison of word embeddings for the biomedical natural language processing**
Yanshan Wang, Sijia Liu, Naveed Afzal, Majid Rastegar-Mojarad, Liwei Wang, Feichen Shen, Paul Kingsbury, Hongfang Liu
Journal of Biomedical Informatics (2018-11) <https://doi.org/ggbx8b>
DOI: [10.1016/j.jbi.2018.09.008](https://doi.org/10.1016/j.jbi.2018.09.008) · PMID: [30217670](https://pubmed.ncbi.nlm.nih.gov/30217670/) · PMCID: [PMC6585427](https://pubmed.ncbi.nlm.nih.gov/PMC6585427/)
13. **boudinfl/pke**
Florian Boudin
(2021-06-30) <https://github.com/boudinfl/pke>
14. **SMAC, a computational system to link literature, biomedical and expression data**
Stefano Pirrò, Emanuela Gadaleta, Andrea Galgani, Vittorio Colizzi, Claude Chelala
Scientific Reports (2019-07-19) <https://doi.org/ghm6ct>
DOI: [10.1038/s41598-019-47046-2](https://doi.org/10.1038/s41598-019-47046-2) · PMID: [31324861](https://pubmed.ncbi.nlm.nih.gov/31324861/) · PMCID: [PMC6642118](https://pubmed.ncbi.nlm.nih.gov/PMC6642118/)
15. **Fast and scalable neural embedding models for biomedical sentence classification**
Asan Agibetov, Kathrin Blagec, Hong Xu, Matthias Samwald
BMC Bioinformatics (2018-12-22) <https://doi.org/ghm6cv>
DOI: [10.1186/s12859-018-2496-4](https://doi.org/10.1186/s12859-018-2496-4) · PMID: [30577747](https://pubmed.ncbi.nlm.nih.gov/30577747/) · PMCID: [PMC6303852](https://pubmed.ncbi.nlm.nih.gov/PMC6303852/)
16. **Enriching Word Vectors with Subword Information**
Piotr Bojanowski, Edouard Grave, Armand Joulin, Tomas Mikolov
arXiv:1607.04606 [cs] (2017-06-19) <http://arxiv.org/abs/1607.04606>
17. **Word2vec convolutional neural networks for classification of news articles and tweets**
Beakcheol Jang, Inhwon Kim, Jong Wook Kim
PLOS ONE (2019-08-22) <https://doi.org/ghg3sp>
DOI: [10.1371/journal.pone.0220976](https://doi.org/10.1371/journal.pone.0220976) · PMID: [31437181](https://pubmed.ncbi.nlm.nih.gov/31437181/) · PMCID: [PMC6705863](https://pubmed.ncbi.nlm.nih.gov/PMC6705863/)
18. **An Empirical Evaluation of doc2vec with Practical Insights into Document Embedding Generation**
Jey Han Lau, Timothy Baldwin
arXiv:1607.05368 [cs] (2016-07-18) <http://arxiv.org/abs/1607.05368>
19. **An introduction to Docker for reproducible research**
Carl Boettiger
ACM SIGOPS Operating Systems Review (2015-01-20) <https://doi.org/gdz6f9>
DOI: [10.1145/2723872.2723882](https://doi.org/10.1145/2723872.2723882)
20. **Docker Hub** https://hub.docker.com/_/python
21. **Gene Expression Omnibus: NCBI gene expression and hybridization array data repository**
R. Edgar

Nucleic Acids Research (2002-01-01) <https://doi.org/fttpkn>
DOI: [10.1093/nar/30.1.207](https://doi.org/10.1093/nar/30.1.207) · PMID: [11752295](https://pubmed.ncbi.nlm.nih.gov/11752295/) · PMCID: [PMC99122](https://pubmed.ncbi.nlm.nih.gov/PMC99122/)

22. Editorial: Mining Scientific Papers: NLP-enhanced Bibliometrics

Iana Atanassova, Marc Bertin, Philipp Mayr

Frontiers in Research Metrics and Analytics (2019-04-30) <https://doi.org/ghcpfz>

DOI: [10.3389/frma.2019.00002](https://doi.org/10.3389/frma.2019.00002) · PMID: [33870034](https://pubmed.ncbi.nlm.nih.gov/33870034/) · PMCID: [PMC8028414](https://pubmed.ncbi.nlm.nih.gov/PMC8028414/)

23. NLP Scholar: An Interactive Visual Explorer for Natural Language Processing Literature

Saif M. Mohammad

arXiv:2006.01131 [cs] (2020-05-31) <http://arxiv.org/abs/2006.01131>

24. tl;dr: this AI sums up research papers in a sentence

Jeffrey M. Perkel, Richard Van Noorden

Nature (2020-11-23) <https://doi.org/ghmnjj>

DOI: [10.1038/d41586-020-03277-2](https://doi.org/10.1038/d41586-020-03277-2) · PMID: [33230274](https://pubmed.ncbi.nlm.nih.gov/33230274/)

25. An Empirical Evaluation of doc2vec with Practical Insights into Document Embedding Generation

Jey Han Lau, Timothy Baldwin

arXiv:1607.05368 [cs] (2016-07-18) <http://arxiv.org/abs/1607.05368>

26. Probabilistic FastText for Multi-Sense Word Embeddings

Ben Athiwaratkun, Andrew Gordon Wilson, Anima Anandkumar

arXiv:1806.02901 [cs, stat] (2018-06-07) <http://arxiv.org/abs/1806.02901>

27. Peripheral Blood Monocyte Gene Expression Profile Clinically Stratifies Patients With Recent-Onset Type 1 Diabetes

Katharine M. Irvine, Patricia Gallego, Xiaoyu An, Shannon E. Best, Gethin Thomas, Christine Wells, Mark Harris, Andrew Cotterill, Ranjeny Thomas

Diabetes (2012-05) <https://doi.org/f3xdx3>

DOI: [10.2337/db11-1549](https://doi.org/10.2337/db11-1549) · PMID: [22403299](https://pubmed.ncbi.nlm.nih.gov/22403299/) · PMCID: [PMC3331753](https://pubmed.ncbi.nlm.nih.gov/PMC3331753/)