



A Systematic Literature Review of Natural Language Processing: Current State, Challenges and Risks

Eghbal Ghazizadeh^(✉) and Pengxiang Zhu

Whitireia Polytechnic, 450 Queen Street, Auckland 1010, New Zealand
Eghbal.ghazizadeh@whitireia.ac.nz

Abstract. In this research paper, a comprehensive literature review was undertaken in order to analyze Natural Language Processing (NLP) application based in different domains. Also, by conducting qualitative research, we will try to analyze the development of the current state and the challenge of NLP technology as a key for Artificial Intelligence (AI) technology, pointing out some of the limitations, risks and opportunities. In our research, we rely on primary data from applicable legislation and secondary public domain data sources providing related information from case studies. By studying the structure and content of the published literature, the NLP-based applications have been clearly classified into different fields which include natural language understanding, natural language generation, voice or speech recognition, machine translation, spell correction and grammar check. The development trend, open issues and limitations have also been analyzed.

Keywords: Natural Language Processing · Voice recognition · Artificial intelligence · NLP applications

1 Introduction

NLP technology converts daily oral or written language into binary code that can be recognized by the machine so that the machine can understand the real meaning of human beings [1]. The NLP technology was primarily designed to study how to match the input content on the semantic level, and it also has certain common-sense knowledge and reasoning ability. This is a comprehensive subject across multiple subjects such as mathematics, psychology, computer science, and linguistics. It is divided into Natural Language Understanding (NLU) and Natural Language Generation (NLG). Young [2] indicated that NLP is one of the important branches of computational linguistics and a very active field in AI research. The NLP technology has achieved tremendous results and is rapidly practiced in all industries even though it has been a short time in its development. Industries supported by NLP, such as AI, are also constantly breaking new ground and becoming the focus of the investment market.

The objective demand for NLP in the computer field is language translation. Warren Weaver was the first person who used computers for language translation. Georgetown University and IBM conducted a machine translation experiment of

Russian to English on an IBM-701 computer in 1954 [3]. This is the world's first application of computers in the field of non-numerical computing information processing. The main technique adopted by Noam Chomsky [4] was syntactic matching in pattern recognition but there was a lack of mature syntactic analysis. In 1972, Noam Chomsky developed the famous Augmented Transition Network (ATN) by basing the development from his natural language information retrieval system. In the 1980s, various new grammatical systems emerged, such as generalized phrase structure grammar, lexical functional grammar, and functional unification grammar [3]. In the 1990s, Corpus Linguistic research became popular, and many countries and academic institutions successively launched extensive corpora or knowledge bases in different languages [4]. These linguistic achievements have greatly improved the features of NLP systems, and well-known practical systems such as American METAL and LOGOS, Japanese PIVOT and HICAT, French Ariane and German SUSY have emerged [4]. Cambria & White [1] pointed out that the research and development of NLP in the past 60 years can be divided into NLU, NLG, machine translation, voice recognition, and check for spelling and grammar.

There are many difficulties in NLP, but the key factor of the difficulties is nothing more than the numerous ambiguities or ambiguities that exist in natural language texts and conversations [2]. If the ambiguity of language units at all levels cannot be properly handled, the computer cannot accurately understand the meaning of natural language expressions. Moreover, the problem of acquiring contextual content is also a challenge for machine translation. When understanding a sentence, the exact meaning of the sentence is usually inferred according to the context in which the sentence is located. Taking pronouns as an example, to understand what pronouns refer to, the previous sentence must be inferred. Zhang [5] summarized the drawbacks of this technology, mainly reflected in the limitations of the current system and the necessity of manual operation.

From the literature research, it is found that the current development prospects of NLP are all positive and optimistic, and the research on risks and challenges is relatively lacking. We need to objectively evaluate and study the development of all criteria of NLP. In this research, we will try to address NLP's challenges with considering the below research questions:

RQ1: What are the main fields which uses NLP technology?

RQ2: What have been the limitations of NLP technology in recent years?

RQ3: What are the main risks of developing NLP technology in the future?

Based on document analysis, this article will summarize a brief development history on NLP. Then, it will illustrate the applications of NLP. We also briefly discuss the limitations of NLP and the current and future studying of NLP. The research paper aims to provide underestimated methods for researchers, scholars, and companies who want to keep pace with NLP technology and applications in the past, present, and future.

Our work helps to fully understand the development and application of NLP and hopes to provide a research basis for researchers, scholars and companies who will research and develop NLP technology and its applications in the future. Based on the content analysis method, we emphasized our interest in academia and determined three

main research directions: (i) classification of the application range based on NLP in many fields (ii) limitations to create value in these areas and (iii) by providing promising research paths, challenges and opportunities, conduct further research on the road map to guide researchers. It is worth mentioning that since NLP technology is continuing to grow at a very fast rate, this study cannot be considered exhaustive.

This article will initially introduce the development history and current research results of NLP technology; it will then briefly introduce the framework structure and the current application fields and applications. Then, through a systematic literature review method, a descriptive analysis is performed on the retrieved documents. Next, a conceptual model of this research will be analyzed. After that, it classifies and summarizes the current applications based on NLP technology. Next, it lists the current problems and challenges of NLP technology and presumes the future trend of this technique. Finally, it gives the conclusion of this research.

2 NLP Overview

NLP is the processing of information such as the shape, sound, and context of natural language with a computer [6]. Realizing the exchange of information between humans and machines is an important issue of common concern in AI, computer science and linguistics. Specific forms of NLP cover machine translation, text summarization, text categorization, information extraction, speech synthesis, and voice recognition. Gurbuz [12] pointed out that the NLP mechanism involves two processes, including NLU and NLG. NLU means that real content can be recognized by the computer, while, on the other hand, NLG is focusing on a natural language text.

The methods of NLP can be summarized into the rule method, statistical method and rule statistical method. From a methodological perspective, the rule method is called the rationalist method, and the statistical method is called the empirical method.

The architecture of the whole text processing technology is shown in Fig. 1. First, each word is marked as a separate text, and then the data is pre-trained using learning models such as word2vec and GloVe. After that, the pre-trained results are input into various deep learning applications to use in different NLP applications [7].

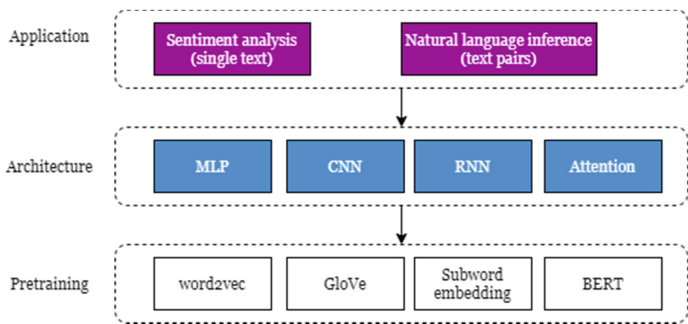


Fig. 1. The technical architecture of NLP

Liu & Zhang [8] proposed that usually a linguist first writes a rule base, such as a dictionary, and then a technical expert builds an algorithm applied to explain and execute the rule library, as shown in Fig. 2. Specifically, the syntactic analyzer analyses the input sentence into a syntactic structure according to the set natural language grammar and then maps the grammatical symbol structure to the semantic symbol structure according to the semantic rules.

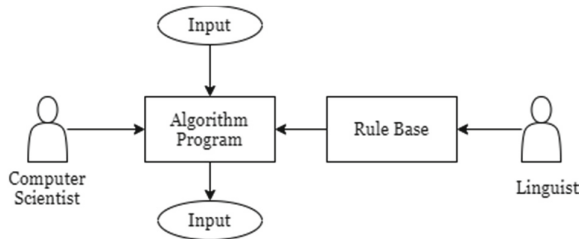


Fig. 2. Process of rule method

The statistical method is used to predict the parameters in the statistical model through the training data in the corpus, to establish a statistical language processing model [8]. The corpus is established by a linguist, and the computer scientist is responsible for establishing statistical models, using the corpus to train model parameters, and writing algorithms to find the solution, as shown in Fig. 3.

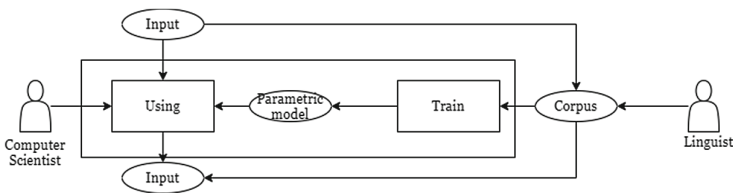


Fig. 3. Process of statistical method

Rule statistics method is the fusion of rule law and statistical law, which fully absorbs the advantages of the two rules. The rule method is easy to express complex language knowledge, and the expression of language knowledge is more intuitive and flexible. However, the coverage of language knowledge is low, and the lack of a unified conflict resolution mechanism for language knowledge. The statistical model of the statistical method provides a unified conflict resolution mechanism. Also, the large-scale number guarantees a broad coverage of language knowledge; at the same time, it is not good at expressing complex and deep language knowledge, therefore, it is not good for languages with scarce data solutions [1].

Statistical methods have been continuously improved in the development process, gradually absorbing the advantages of the rule method to make up for their

shortcomings. Statistical models tend to be more complex, and even some models are directly built based on rule representation, which can express very complex language knowledge. Rule statistics method is the clever integration of the two forms. At present, this method has become the mainstream method of NLP [9].

In our research, we found that the analysis of NLP is extremely extensive, and various classification methods are emerging one after another; each of which has its rationality. From the technology aspect, there are two categories; basic technology and applied technology which we have summerized in Table 1.

Table 1. Technical classification of NLP.

Basic technology	Application technology
Grammar and syntax analysis	Machine translation
Semantic analysis	Information retrieval
Discourse analysis	emotion analysis
Knowledge graph	Automatic question and answer
Language cognitive model	Automatic digest
Language knowledge representation and deep learning	Information extraction
	Information recommendation and filtering
	Text classification and clustering
	Text recognition

3 Research Methodology

In this article, based on the research process mentioned by Briner [10], combined with some of the functions mentioned by Moher [11] in the PRISMA statement, under the principles of transparency, reproducibility and science, the literature of NLP applications is provided. The literature study is carried out through the following steps:

1. Clarify the research purpose and prepare the corresponding research plan.
2. Record and analyze the research results according to the research plan.
3. Summarize the research records and form a research report.

3.1 Locating Studies

In this research paper, most of the well-known library such as AIS library, Google Scholar, Science Direct, ACM digital Library are used as the data sources, and key-words are searched based on the research questions. Irrelevant records such as duplicate records and meeting notices are filtered out, and 22 related papers are finally retrieved. Figure 4 shows the search strategy flow chart.

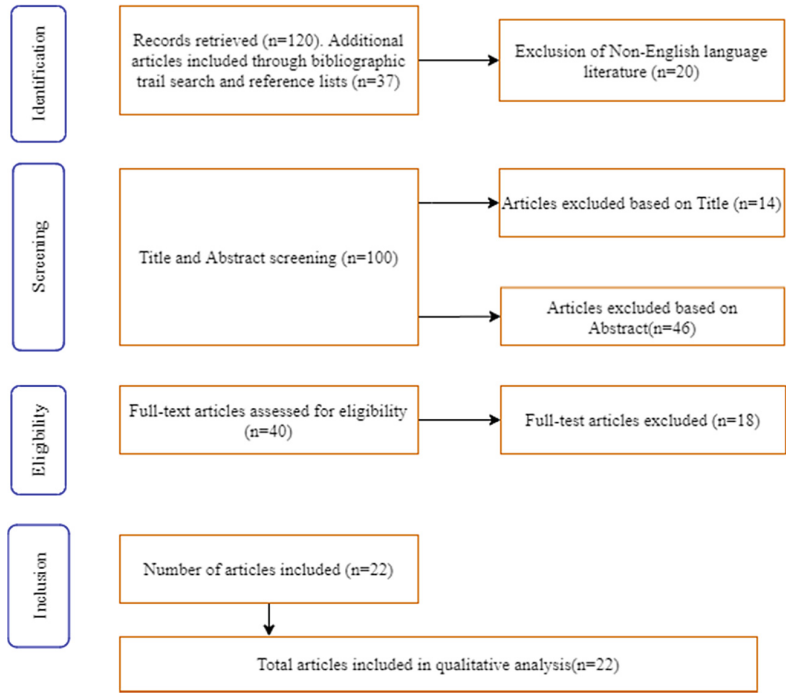


Fig. 4. Flowchart of the search strategy

3.2 Study Selection and Evaluation

By pre-defining the criteria of inclusion and exclusion for the literature review (see Table 2), the author independently evaluated the articles retrieved based on this criterion. Firstly, the assessment is according to the title of the peer review research papers and then by viewing the abstract. Articles that do not meet the standards are removed from the list of candidate articles. However, the reasons are recorded and included in the table. After that, the content of the articles was checked, and more articles that did

Table 2. Inclusion and exclusion criteria

Selection criteria	Scientific database	
Inclusion	Peer-reviewed articles, conference papers Limited to the past ten years	
Exclusion	Filtering by title	Generic articles focus on NLP technology
	Filtering by abstract	Software-oriented articles focus on NLP technology
	Filtering by full text	Technical articles focus on NLP technology

not meet the criteria were ignored. Also, the content which does not focus on the NLP technology was removed.

3.3 Analysis and Synthesis

For all selected articles that meet the chosen criteria, authors have independently reviewed their contents. Moreover, in this research, the selected articles have been summarized.

4 Descriptive Analysis

This article deliberately selected 22 articles published between 2009 and 2019 for research and analysis. The aim of this descriptive analysis is as follows: (i) lists the current research trends and related applications of NLP technology; (ii) summarizes the research methods in the field from the literature; (iii) provides sufficient evidence for the classification of NLP applications in the following sections. The distribution of the subject and type of literature over time will be a key criterion for descriptive analysis.

Figure 5 shows the annual statistical conclusion of the selected papers. It shows that the volume of research literature was the largest, reaching 4, in 2015. This is based on the growth of deep learning technology and the improved maturity of this technology, which results in a highly accurate output, thereby attracting people’s interest in the use of this technology whilst also increasing the developer’s enthusiasm. It should be noted that due to the limited number of articles selected in this article, it may not reflect the real situation.

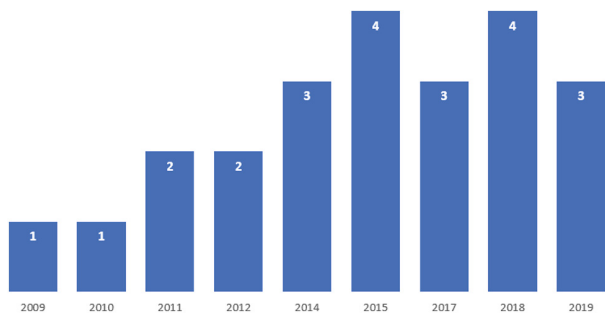


Fig. 5. Year-wise analysis of the chosen public literature per year

5 Taxonomy of NLP-Based Applications

With the continuous deepening and development of NLP research, the fields of NLP applications are getting wider and wider. Especially with the rapid advancement of deep learning technology, the development of NLP applications has also become more

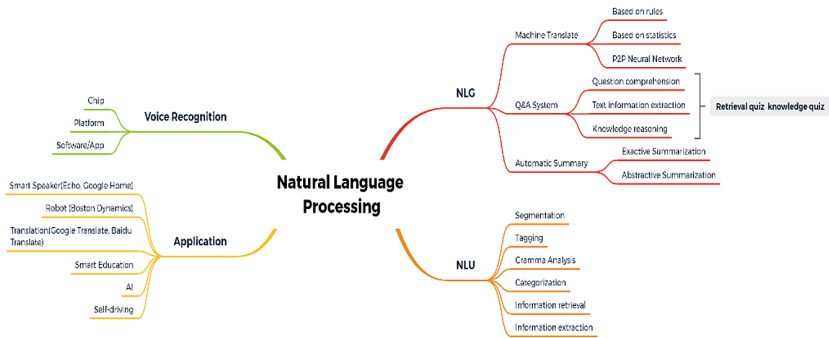


Fig. 6. Mind map of NLP applications

rapid and more accurate. Figure 6 shows the Mind map (the result of our descriptive analysis) of NLP technology and its applications.

Gurbuz [12] found that there are two types of NLP applications; text application and voice application. Text applications include intelligent search engine and intelligent retrieval based on natural language understanding, intelligent machine translation, automatic summarization, text synthesis, text classification, file organization, intelligent automatic composition system, automatic judgment system, information filtering, spam processing, literary research, ancient text research, grammar proofing, text data mining, intelligent decision-making, and computer programming based on natural language. Voice applications include machine simultaneous interpretation, intelligent remote teaching and answering, voice control, intelligent customer service, machine chat, intelligent staff, intelligent transportation information service, intelligent interpretation, real-time interpretation of sports news, voice mining and multimedia mining, multimedia information extraction, text conversion, and intelligent help system for the disabled. Due to limitations, this article only introduces some more frequent applications. Table 3 and Table 4 show the main characteristics and commercial values of these common applications.

Table 3. Main characteristics of frequent NLP applications

Application	Performance	Popularity	Maturity
Knowledge graph	Slow	Low	Low
Machine translation	Middle	High	Middle
Text categorization	Slow	Low	Low
Search engine	Quick	High	High
Recommended system	Quick	Middle	Middle

Table 4. Commercial values of frequent NLP applications

Application	Values	Satisfaction	Provider
Knowledge graph	High	Good	Google, Microsoft, Apple, IBM
Machine translation	High	Good	Google, Baidu
Text categorization	Middle	Bad	Netflix, Facebook, Twitter
Search engine	High	Middle	Google, Baidu, Yahoo
Recommended system	High	Bad	Netflix, Facebook, LinkedIn, Twitter

5.1 Knowledge Graph

The knowledge graph can describe complex associations [9], and the most well-known is to be used in search engines to enrich search results and provide structured results for search results. According to the application model, the application of knowledge graph can be divided into semantic search, knowledge question answering, and knowledge-based big data analysis and decision-making.

Semantic search utilizes the establishment of a large team of knowledge bases to semantically annotate search keywords and document content to improve search results, such as Google and Baidu embedding knowledge graphs in search results. Knowledge question and answer is a question and answer based on the knowledge base, through semantic analysis of the question sentence, and then parse it into a structured query to obtain answers in the existing knowledge base. In the analysis and decision-making of big data, the knowledge graph plays an auxiliary role.

5.2 Machine Translation

Machine translation is the most well-known application of NLP. Generally, machine translation is used as a part of an application, such as cross-language search and drainage [13]. At present, the research institutions and enterprises (such as IBM, Google, and Microsoft) have successively established development teams of machine translation to specialize intelligent translation research. Since 2011, with the rapid development of speech recognition, machine translation technology, and Deep Neural Network (DNN) technology, research on the automatic translation of spoken language has become a new research hotspot in the field of information processing. For example, Google officially launched an upgraded version of its machine translation service on its Android system in January 2011.

5.3 Text Categorization

Text classification refers to the process of classifying a large number of documents into one or more categories based on the content or attributes of the documents [7]. The key problem of this technology is how to construct a classification model and use this model to map unknown documents.

It is possible to classify different journals, news reports, and even multiple documents according to their fields. An important application of text classification is spam email detection. With the significant development of network technology, a lot of

information has been generated by users all over the world. It would be a time-consuming and unrealistic work if relying on manual sorting. Currently, this technology has become extremely important.

5.4 Search Engine

NLP techniques such as word sense disambiguation, syntactic analysis, and referential resolution are often used in search engines [14]. The responsibility of a search engine is not only to help users find answers but also to help users find the services they need to connect people and the physical world. The most basic model of a search engine is to automatically aggregate enough content, parse, process and organize it, and return the corresponding result to the user. Every link requires natural language processing. Users can search for fuzzy requirements such as weather, calendar, ticket, and exchange rate through the search engine, and the results will be presented directly. Users can also search for complex questions, and the search engine can answer them accurately. NLP technology also enables search engines to quickly and accurately return the user's search results.

5.5 Recommended System

The recommendation system relies on the cooperation of data, algorithms, human-computer interaction and other links [15]. It uses data mining technology, information retrieval technology, and computational statistics. The target of using the recommendation system is to analyze the past information generated by users, which can help the user to find value for themselves. While displaying the information in front of interested users, it solves the problems of information overload and supports users without clear requirements through accurate suggestions.

6 Open Issues and Future Trends

6.1 Open Issues

Although the related research on NLP is relatively abstract, the most basic research is still on the study of grammar, syntax, and semantics [16–23]. The core of concern is language and text. There are many difficulties in NLP technology, but the critical factor of the difficulties is nothing more than the various ambiguities or ambiguities that exist in natural language texts and conversations. Ambiguity refers to language misunderstandings generated during language processing, such as semantic analysis and disambiguation requires a lot of knowledge [1]. For example, when performing human language translation, the translator needs to have certain linguistic knowledge and background knowledge.

Natural language is full of ambiguity, human activities and expressions are very complex, and the vocabulary and grammatical rules in the language are limited, which leads to the same language form may represent many different meanings [17]. Taking Chinese as an example, Chinese generally consists of words forming words, sentences

forming words, and sentences forming paragraphs, which contain multiple layers of conversion. Statements of the same form may have different meanings in different contexts. Conversely, the same meaning can also be expressed in different forms of sentences. This is the charm of language, but it also brings difficulties to NLP.

In Chinese, the words segmentation problem is one of the disambiguation tasks. Words are the units with the smallest semantics, so the word segmentation problem in NLP is urgently needed to be solved. Since the Chinese do not have natural word segmentation in languages like English, the processing of Chinese has an additional layer of obstacles. In the process of word segmentation, the computer will add a separator after each word, and sometimes the semantics are ambiguous, and the insertion of the separator becomes difficult. To achieve correct word segmentation, it is necessary to combine the context and fully understand the semantics of the text, which is a challenge for the computer. Language problems at the phrase level still exist. If the ambiguity of language units at all levels cannot be properly handled, the computer cannot accurately understand the meaning of natural language expressions.

Moreover, the problem of acquiring contextual content is also a challenge for machine translation [17]. When understanding a sentence, the exact meaning of the sentence is usually inferred according to the context which the sentence is located. Taking pronouns as an example, to understand what pronouns refer to, we must consider what we said in the previous sentence.

6.2 Future Trends

With the rapid advancement of technology in recent years, people realize that the traditional rationalism method based on syntactic-semantic rules is too complicated, and the empiricism based on statistics can only obtain limited data [4]. The primary development trend of NLP is excessive language data processing in the process of corpus construction. Statistical mathematics methods are getting more and more attention, and the language knowledge generated by machine learning methods is becoming more and more expanded. Besides, NLP technology is also paying more and more attention to the role of vocabulary, and lexicalism has emerged. The establishment of a vocabulary knowledge base has become a hot issue in development. At present, the research of NLP has expanded from text to speech recognition, syntactic analysis, machine translation, machine learning, and information retrieval. While natural language processing is being continuously applied, it is also promoting other emerging disciplines, such as the development of bioinformatics. The spotlight of future research is how to improve the computer's ability to process language.

In the long run, NLP has broad application fields and prospects. As an emerging field that combines the three subjects of computer science, AI, and linguistics, its long-term development has great significance and impact on all subjects. The future development trend of natural language may be from artificial knowledge construction to automatic construction. People can use some explicit knowledge to construct a method to mine the relationship between language components, thus avoiding the tedious and time-consuming process of artificial intelligence.

The future development trend is the in-depth combination of NLP and many fields, thereby creating value for various related industries. The need for NLP in the fields of banking, electrical appliances, and medicine is increasing. The closer the integration of NLP with various industries, the more professional service trends will be.

7 Conceptual Model

Within AI, NLP is an autonomous development; therefore, it is used to analyze, understand, and generate natural language to facilitate communication between people and computer equipment, as well as between people. Its application fields include machine translation, text, voice, image conversion, chatbots, sentimental analysis, text categorization, and information extraction. Figure 7 is our summary of research and brief conceptual model of a knowledge architecture diagram of NLP.

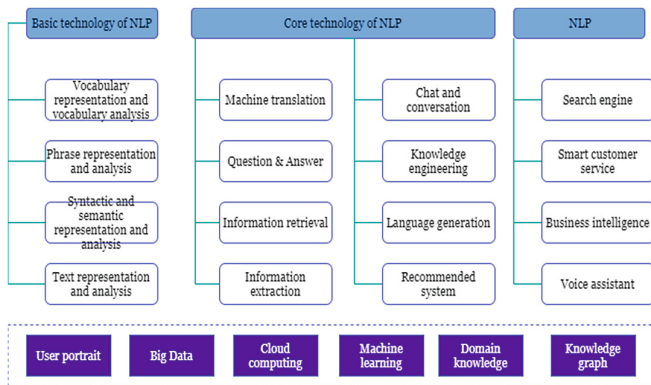


Fig. 7. Conceptual model of knowledge architecture of NLP

8 Conclusion

There are some problems in the process of statistical analysis in this article, which these problems will affect quantity of the statistical results. Firstly, there are inadequacies in the process of the collection of data. The subjective reason is that the keywords retrieved are not comprehensive enough. It is impossible to consider all relevant keywords in NLP research. Moreover, there is a problem with missing data. The primary reason is that the journals included are not completed. There are also certain problems, including missing or undetected data. Furthermore, the data cleansing process also has deficiencies. For example, this article only treats papers with empty authors or institutions as informal papers, and not all authors and institutions such as conference notices and their outputs. Although the statistics of the data mainly rely on automation, the analysis of the statistical results of the data is completely manual and lacks in-depth analysis.

The research results show that NLP is an emerging technology and is growing in discipline. The advancement of NLP technology is full of opportunities and challenges, difficulties and frustrations. The establishment of various models and the proposal of various methods have brought vitality to this technology. Although current systems such as machine translation and speech recognition exist, they are at a very immature stage. The increasingly widespread application of NLP proves that it is in an important position in the computer field and even the entire scientific and technological field. It is believed that in the near future, NLP technology will shine even brighter.

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