Mapping the Knowledge Structure and Research Evolution of Deep Learning

Ke Yuan, Chenmeng Zhao, Yayun Chen, Lin Shen, Qian Tang*, and Chunfu Jia

Abstract—**Deep learning is a significant research field in today's society, especially in the field of artificial intelligence. To gain a more comprehensive understanding of the current state of research in the field of deep learning and to identify areas of intense interest, this paper uses Citespace for research and learning, samples 1863 articles from the Web of Science (WoS) core dataset, which spans the years 2017 to 2023, and adopts the methods of co-occurrence analysis, keyword burst analysis, and co-citation analysis. Information visualization is used to conduct bibliometric analysis, examining keywords, research institutions, authors, and countries. The analysis demonstrates a significant increase in the literature record from 2017 to 2022, followed by a decline from 2022 to 2023. The research on deep learning spans various fields, including computer science, engineering, and telecommunications, which are considered crucial areas of study. China, the USA, and England are leading the way in the field of deep learning research. These countries have established extensive cooperative relationships with many countries, with research institutions and authors playing a vital role in the cooperative network. The current theoretical research hotspots of deep learning mainly include "convolutional neural networks", "neural networks", "models", "classification", etc. The focus of research in deep learning has shifted from theoretical research to practical applications. It is now being applied in various areas, such as deep reinforcement learning, bearing fault, and semi-supervised learning. In the future, deep learning technology will be applied to more cutting-edge technologies.**

Index Terms—**Deep Learning, Neural Network, Citespace, Bibliometric Analysis.**

I. Introduction

THE present era is the information age. The vast amount of information, the proliferation of knowledge, and the extremely fast transmission speed consistently challenge people's ways of thinking and learning. When confronted with a substantial volume of information and data, relying solely on manual methods becomes insufficient for analysis. People must employ specific algorithms to analyze all kinds of data. Deep learning is a crucial technology in data analysis. Deep learning [1] involves analyzing the value of data using machine learning, data mining techniques, and neural network theory. The principle of deep learning involves constructing a model that mimics the neural structure of the human brain. It mainly focuses on the development and application of neural networks, which is an emerging research area in machine learning. Some commonly used models or algorithms of deep learning are Autoencoder [2], Restricted Boltzmann Machines [3], Deep Belief Networks [4], Convolutional Neural Networks [5], etc. As theoretical research progresses, the use of deep learning continues to expand. In 2017, AlphaGo defeated world-class professional go players, which sparked a heated discussion on artificial intelligence and deep learning. Currently, deep learning has been widely used in various fields, such as face recognition, speech recognition, and image processing, resulting in significant practical benefits.

Bibliometrics [6] describes the interdisciplinary science of quantitative analysis of all knowledge carriers through mathematics and statistics. This tool is useful and effective for evaluating academic achievements and research progress in a specific field. It provides a visual representation of the field's development and constituent relationships. Through statistical analysis of the extracted literature information, the spatial and temporal distribution characteristics of publication output can be obtained from relevant countries/regions, disciplines, research institutes, and journals. Research progress and trends are often determined by analyzing the most commonly used keywords in various research fields, such as convolutional neural network, classification, computational modeling, and multimodal. In addition, co-citation analysis is an effective method for revealing the knowledge structure and knowledge base of the research field through the examination of highly cited literature. In recent studies, researchers have found that utilizing co-occurrence analysis, cluster analysis, and entities in titles can provide a more effective and comprehensive bibliometric method. This approach has been successfully applied to explore research hotspots and frontiers in various fields, including medical imaging, image processing, earth sciences, remote sensing, and neural computing.

This paper mainly utilizes Citespace visualization software for bibliometrics to visually analyze the literature on deep learning research in the WoS core data set over the past seven years (2017–2023). The aim is to identify the research direction and current trends in deep learning in recent years. In order for relevant researchers to gain a better understanding of the current state of development and research in deep

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learning, and to have a firm grasp on its future direction.

II. Methods and Data

A. Methods and Tools

Cluster analysis, co-occurrence analysis, co-citation analysis, and cooperative network analysis were conducted using Citespace [7], a document visualization analysis software developed by Professor Chaomei Chen of the School of Computing and Information at Drexel University. The construction of a co-occurrence matrix forms the foundation of cluster analysis. By counting the number of occurrences of any two keywords in the same article, an n×n similarity matrix is constructed. Co-occurrence analysis and co-citation analysis assess the correlation strength of network nodes by considering the frequency of their occurrences or citations. There are two most commonly used methods for calculating the connection strength in the network in Citespace. These methods are known as *Cosine* and *Jaccard*, and they are represented by equations (1) and (2), respectively.

$$Cosine(c_{ij}, s_i, s_j) = \frac{c_{ij}}{\sqrt{s_i, s_j}} \tag{1}$$

$$Jaccard(X, Y) = \frac{X \bigcap Y}{X \bigcup Y} \tag{2}$$

Cluster analysis is used to group objects that share some of the same characteristics into a group. Unsupervised learning models analyze document data by using distance Settings and similarity formulas. In document clustering analysis, the construction of two text vectors is the key to comparison. There are several commonly used algorithms in this area, such as the term Frequency inverse Document Frequency (TF-IDF) and its various refinements and weighting algorithms. These algorithms use TF to measure the frequency of a particular word or phrase in a document, as shown in formula (3). On the other hand, IDF is used to filter out some common words, as shown in formula (4)..

$$tf_{i,j} = \frac{n_{i,j}}{\sum_{k=1}^{j} n_{k,j}}. \tag{3}$$

$$idf_j = \log \frac{n_{i,j}}{1 + |j : t_i \subseteq d_j|} \tag{4}$$

B. Data Sources

Web of Science (WoS) is the world's largest comprehensive academic information resource that encompasses a wide range of disciplines, including the most influential 8850 (SCI) +3200 (SSCI) +1700 (AHCI) core academic journals in various research fields such as natural science, engineering technology, and biomedical science. In this paper, the core database of Web of Science is selected as the target database for retrieving source files, and the retrieval formula is TS=(Deep Learning) AND DT=(Article) AND LA=(English). The retrieval period spanned from 2017 to 2023, specifically until December 31, 2023. A substantial collection of 186341 literatures was acquired during this time. The top 1% of highly cited literatures were selected, and 1863 literatures were finally obtained.

III. Results and Discussion

A. Literature Distribution

1) Time Distribution of the Literature: Based on the WoS core dataset, a total of 1863 papers on deep learning from 2017 to 2023 (to December 31) were obtained through high citations. The distribution of these papers is shown in Fig.1. As can be seen from the figure, the literature record increased exponentially from 2017 to 2022 and plummeted from 2022 to 2023. According to relevant information, in the May 2017 match, Ke Jie lost 0-3 to AlphaGo. The competition officially started a wave of research in the fields of artificial intelligence, deep learning, and machine learning, resulting in a renewed interest in related research papers. In November 2022, OpenAI publicly launched its Large Language Model (LLM) ChatGPT, reaching a significant milestone of over 100 million users in just two months [8]. This also brings artificial intelligence to another peak.

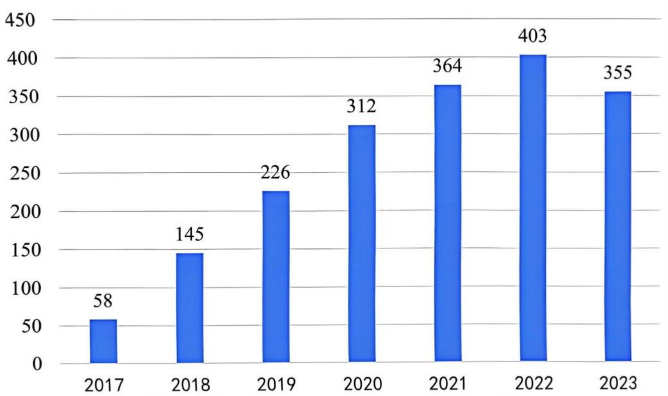

Fig. 1. Trends in the growth of the literature

2) Disciplinary Distribution of the Literature: The disciplinary distribution of research literature is helpful in understanding the disciplinary structure of the research field. The top 5 areas of deep learning research are shown in Fig.2. These categories included Computer Science (933), Engineering (677), Telecommunications (212), Physics (98), and Mathematics (89). The research on deep learning encompasses various fields, with Computer Science and Engineering being prominent areas of study in recent years. At the same time, there is a significant amount of research being conducted on deep learning in the fields of Chemistry and Physics. This demonstrates the widespread application of deep learning across various research domains and its growing significance in human life.

3) Distribution of Publications in the Literature: Academic journals play a crucial role in facilitating the exchange and dissemination of research results. According to Citespace's analysis of primary source publications in the research field, the top 5 publications in terms of the number of journals can be seen in Fig.3. The journals listed include IEEE Access (108), Applied Sciences Basel (42), Neurocomputing (34), Sensors (30), and Multimedia Tools And Applications (22). All five publications cover a range of topics, including computing, medical imaging, image processing, earth sciences, remote sensing, and neural computing. It also highlights the extensive scope of research in deep learning.

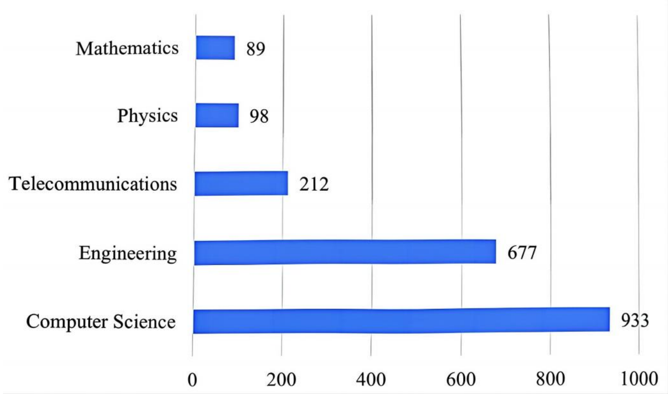

Fig. 2. Top 5 disciplinary categories in deep learning research

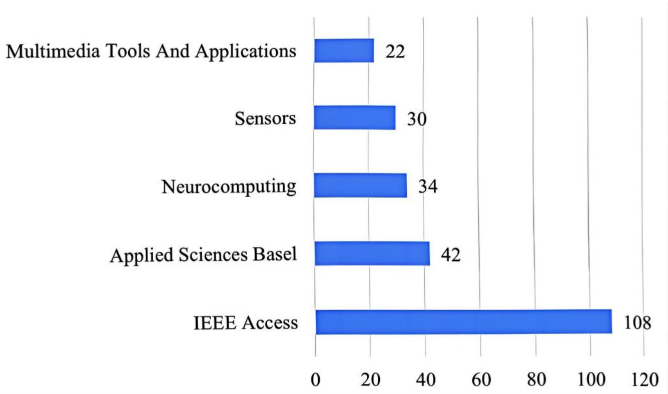

Fig. 3. Top 5 publications distribution of deep learning research

B. Cooperation Network Analysis

1) Institutions Cooperation Analysis: A collaborative network analysis was conducted on 184 research institutions using Citespace. The nodes represent research institutions, and the size of the nodes corresponds to the number of publications. The connecting lines represent the collaboration between institutions (as shown in Fig.4). For instance, Chinese Acad Sci [9], Univ Chinese Acad Sci [10], and Tsinghua Univ [11] often collaborate, focusing on utilizing deep learning for fault diagnosis. Stanford University [12] and Sun Yat Sen University [13] have a strong collaboration and focus on studying machine learning. Nanyang Technological University [14] and Northwestern Polytechnical University [15] both focus on the theoretical level of super-resolution. The main focus of the research is convection, led by MIT [16] and Harvard Medical School [17]. Wuhan University [18] mainly studied transfer diagnosis.

2) Analysis of National Cooperation Networks: A collaborative network with 93 nodes and 105 links is shown in Fig.5. The size of the nodes represents the number of articles published in different countries, while the color of the nodes reflects the centrality of each country. The larger the node, the more articles are published, and a high centricity of nodes implies their significance. China, the USA, and India have the largest nodes, suggesting that these three countries lead in terms of the number of publications in deep learning research. The purple circle of nodes in Canada stands out with its wide range, suggesting that Canada has significant centrality and extensive cooperation with other countries.

TABLE I
LITERATURE PRODUCTION AND CENTRALITY OF THE TOP 17 RESEARCH INSTITUTIONS

Institution	Count	Centrality
Chinese Academy of Sciences	50	0.47
University of Electronic Science	30	0.26
University of California System	28	0.22
Tsinghua University	23	0.24
University of Chinese Academy of Sciences	21	0.55
Shenzhen University	21	0.37
State University System of Florida	20	0.24
Egyptian Knowledge Bank (EKB)	20	0.02
Nanyang Technological University	19	0.04
National Institute of Education (NIE) Singapore	19	0.04
Shanghai Jiao Tong University	17	0.08
Huazhong University of Science	17	0.02
Zhejiang University	17	0.02
Stanford University	16	0.21
Xi'an Jiaotong University	16	0.27
Harvard University	15	0.06
Beijing Institute of Technology	15	0.02

TABLE II
THE NUMBER OF PUBLICATIONS AND CENTRALITY OF THE TOP 9 COUNTRIES

Countries	Count	Centrality
China	747	0.31
USA	397	0.12
India	144	0.04
South Korea	142	0.24
England	98	0.00
Australia	97	0.20
Canada	83	0.41
Japan	74	0.08
Saudi Arabia	61	0.00

Table II shows the publication volume and centrality of the leading nine countries, with China, the USA, India, and South Korea being the top four. The maximum value of centrality for Canada is 0.41. This indicates that many countries, including France, England, the USA, and Germany, maintained extensive academic collaboration. However, China had the highest number of publications but had less collaboration with other countries in the fields of remote sensing and neural computing. It further indicates the wide research range of deep learning.

C. Co-Citation Analysis and High-Citation Literature Analysis

1) Co-citation Analysis of the Literature: Two or more papers are considered co-cited if they are both referenced by a subsequent paper. The co-citation analysis of the literature was conducted using Citespace. Fig.6 illustrates that the citation network consists of 273 nodes and 311 edges. Nodes represent cited papers, and the line between nodes indicates that two papers are cited in the same paper, indicating a co-cited relationship between them. The higher the co-citation frequency of the two authors, the closer their scholarly relationship is. Therefore, most literature had established citation relationships, which were then analyzed by clustering, resulting in six clusters, namely, six color blocks. For instance, Kingma [19] and Krizhevsky [20] analyzed the application. Abadi [21] and Rusk [22] supervised deep feature extraction. Silver [23] and Mnih studied multi-task learning. Vedaldi [24] and Dong [25] utilized deep convolutional framelet techniques to achieve image super-resolution, demonstrating

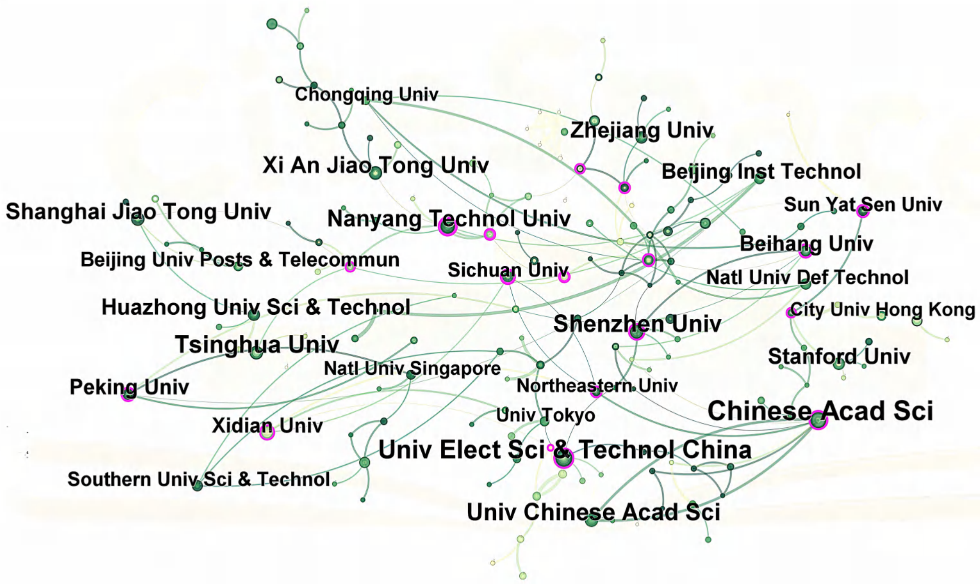

Fig. 4. Institutional cooperation network analysis

Fig. 5. Analysis of country cooperation networks

the potential of deep learning in the medical field. Farabet [26] and Schmidhuber [27] conducted research on breast mass classification. Zeiler and Girshick [28] described the color camera data.

2) Total Co-Citation Analysis of Publications: Co-citation analysis is a quantitative research method in bibliometrics and scientometrics, which has been widely used in multidisciplinary research fields. Journal co-citation analysis allows for the positioning and classification of journals, determining their core or peripheral position in the discipline, and facilitating academic evaluation. As shown in Fig.7, the nodes represent publications and the lines between the nodes represent the relationships between publications. There were a total of 269 publications that had co-citation relationships, and the cluster analysis resulted in the identification of six distinct clusters. The red section focuses on Deep learning methods and primarily includes publications like LECTURE NOTES IN COMPUTER SCIENCE [29–31] and PROC CVPR IEEE [32]. The yellow section focuses on periocular representatives and includes publications like MED IMAGE ANAL [33] and IEEE T MED IMAGING [34]. The green section focuses on the attention mechanism and includes publications like SCIENCE [35, 36] and NATURE [37]. The orange section focuses on deep dictionary learning and includes publications such as NEUROCOMPUTING [38] and EXPERT SYST APPL [39]. The cyan section focuses on rolling bearing and includes publications such as IEEE ACCESS [40, 41] and IEEE T INTELLL TRANSP.

3) Analysis of High-Citation Literature: Generally, literature with a high number of citations reflects its academic influence and the classic degree of the literature to a certain extent. It often serves as a knowledge base for further research by related researchers. Thus, it is essential to utilize Citespace software for analyzing highly cited literature. Table III presents a list of the top ten references that have received a high number of citations. It includes information on the citation frequency for each reference. LeCu et al. [42] are the fathers of deep learning research and have made significant contributions in the fields of convolutional neural networks and image recognition. Alex Krizhevsky proposed the deep network model AlexNet in 2012. Long et al. [43] conducted extensive research on convolutional neural networks, focusing on their ability to enhance the accuracy of image segmentation and improve target recognition performance.

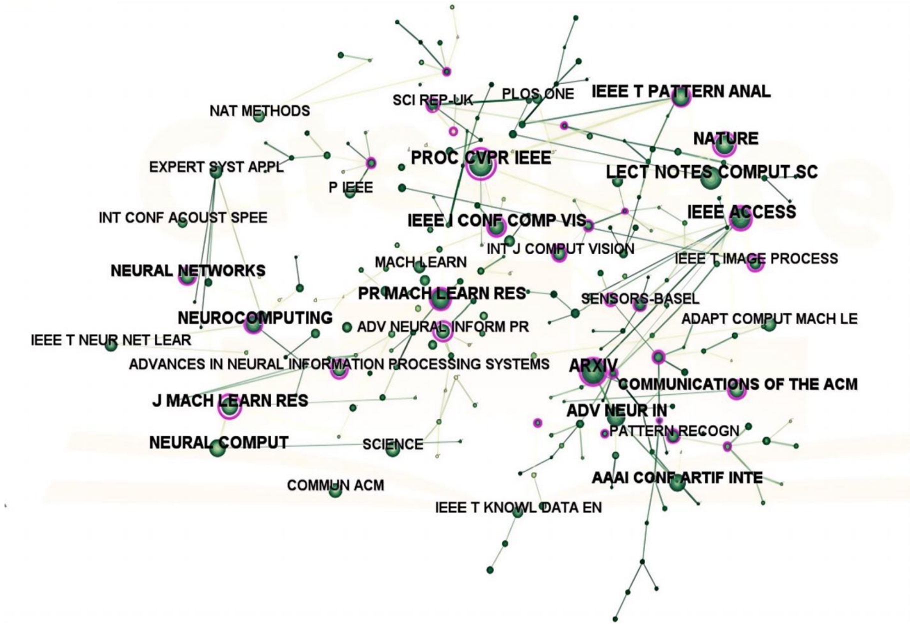

Fig. 6. Co-citation analysis of literature

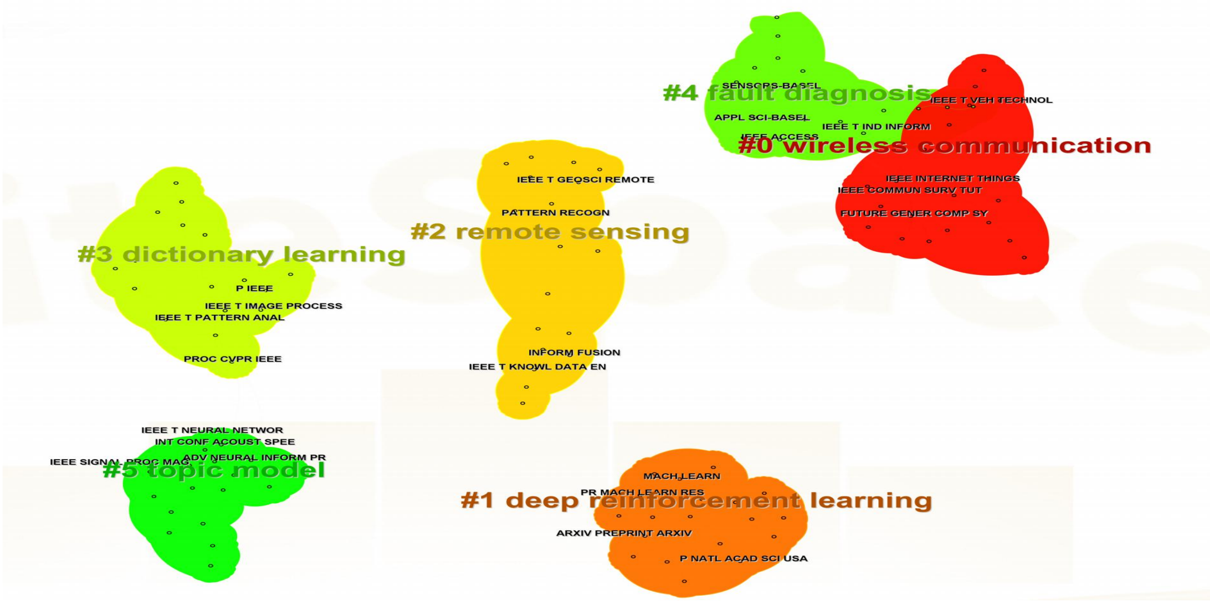

Fig. 7. Total co-citation analysis of publications

TABLE III
TOP 10 HIGH-CITATION REFERENCES

Title	Author	Year	Journal	Count
ImageNet classification with deep convolutional neural networks	Krizhevsky A.	2017	ADV NEURAL INFORM PR	638
Deep learning	LeCun Y	2015	NATURE	454
ImageNet Classification with Deep Convolutional Neural Networks	Andrew Zisserman	2015	ARXIV	337
Deep Residual Learning for Image Recognition	He KM	2016	PROC CVPR IEEE	295
Adam: A Method for Stochastic Optimization	Kingma D P	2014	INT C LEARNING	269
Dropout: A Simple Way to Prevent Neural Networks from Overfitting	Zheng et al	2014	J MACH LEARN RES	252
Going deeper with convolutions	Szegedy C.	2015	P IEEE C COMP VIS PA	188
Batch Normalization: Accelerating Deep Network Training by Reducing Internal Covariate Shift	Goodfellow I	2016	ADAPT COMPUT MACH LE	184
Fully convolutional networks for semantic segmentation	Long J	2015	PROC CVPR IEEE	175
ImageNet Large Scale Visual Recognition Challenge	Russakovsky O	2015	INT J COMPUT VISION	173

It is evident that most of the highly cited papers focus on research related to convolutional neural networks. This indicates that convolutional neural networks are currently a popular area of study in the field of deep learning.

IV. Research Hotspots and Frontier Analysis

A. *Research Hotspots Analysis*

Keywords represent the theme of the literature research field and reflect the important information that the article wants to express. Citespace was used to perform cluster

TABLE IV
THE FREQUENCY AND CENTRALITY OF THE TOP 17 KEYWORDS

Rank	Keywords	Occurrences	Centrality
1	deep learning	942	0.00
2	convolutional neural network	365	0.04
3	neural network	327	0.03
4	model	214	0.04
5	classification	212	0.03
6	machine learning	203	0.04
7	algorithm	163	0.04
8	network	124	0.08
9	system	111	0.03
10	prediction	99	0.05
11	feature extraction	89	0.09
12	deep neural network	84	0.04
13	feature	81	0.04
14	transfer learning	80	0.03
15	recognition	78	0.03
16	image	77	0.04
17	artificial intelligence	74	0.07

analysis on keywords, and after removing irrelevant and repetitive cluster information, a total of 6 cluster information were obtained, as shown in Figure 8. This paper divides the current hot topics in deep learning into five categories.

Deep reinforcement learning: Deep learning is a new research area in the field of machine learning and serves as a crucial link between machine learning and artificial intelligence. This is a complex machine learning algorithm designed to train machines using vast amounts of data, enabling them to analyze and learn in a way similar to humans. Yann et al. proposed that deep learning is a representational learning method that has multi-level representation. It is obtained by combining simple nonlinear modules, and it has made significant advances in various fields such as identification, drug activity prediction, particle accelerator analysis, natural language processing, and medical field.

Bearing fault: Bearing fault are the key issues concerned by the current industrial development. As industrial equipment becomes increasingly complex, large-scale, and intelligent, traditional diagnosis technology has been difficult to meet the needs of fault diagnosis in modern industry. The research on deep learning in the related fields of model building, feature extraction, and classification provides a fresh perspective and method for fault diagnosis. Jia et al. [44] proposed an intelligent diagnosis method based on deep learning, utilizing models such as deep learning automatic encoders, deep belief networks, and convolutional neural networks. This method utilizes a neural network to achieve fault feature extraction and intelligent diagnosis. Firstly, the neural network is pretrained through unsupervised layer-by-layer learning, and then fine-tuned through supervised algorithms. Among them, the unsupervised process is helpful in mining fault features, while the supervised process is helpful in constructing identification fault features for classification.

Semi-Supervised Learning: Semi-supervised learning is an important module in the field of machine learning in recent years, which combines supervised learning and unsupervised learning. It works by using large amounts of unlabeled data and combining labeled data together. Since semi-supervised learning has become an important module, there have been many applications using unlabeled examples to improve the accuracy and speed of learning algorithms.

5G network: It has higher data transmission speed, lower latency, and larger network capacity, providing users with a faster, more stable, and more reliable communication experience. It will be widely used in fields such as smartphones, the Internet of Things, smart cities, and industrial automation, promoting the development of digitization, intelligence, and interconnection. For instance, the 5G network supports edge computing, which means that computing nodes deployed at the edge of the network can execute the deep learning model, enabling intelligent devices to make intelligent decisions locally without relying on remote servers. In this way, smart devices can become more intelligent, respond more quickly, and continue to work without network connectivity.

Big data: The interdependence and mutual promotion between big data and deep learning have jointly built the foundation of modern data science and artificial intelligence, providing strong support for data analysis, prediction, and decision-making in various fields. Big data contains rich information and value, and through deep learning techniques, it can be effectively mined and analyzed to extract useful knowledge and insights. Deep learning models can achieve intelligent analysis of data by learning its features and patterns, thereby providing support for decision-making and prediction. For instance, Han et al. [45] used SVR to propose speech emotion recognition based on a dimensional emotion description model;that is, a regression prediction algorithm was used to estimate emotion attribute values. Sang et al. [46] proposed a deep convolutional neural network (CNN) that can interpret semantic information in the face without the need for manual feature design. This network aims to automatically recognize human emotions based on facial information with high accuracy.

A total of 298 keywords were chosen through the utilization of Citespace. Table IV shows the top 17 keywords, frequency, and centrality. Among them, deep learning is in an absolute position. The algorithm, machine learning, neural network, and feature extraction are all crucial components of deep learning research. Current research hotspots in deep learning can be identified by key terms such as model and classification. Deep learning is a branch of machine learning that utilizes neural network algorithms to perform various tasks, such as feature extraction, optimization, and classification.

B. Frontier Analysis

The timeline chart shows the historical span of literature in each cluster, with a particular emphasis on outlining the relationship between each cluster. The timeline obtained by keyword clustering is shown in Fig. 9. The figure provides an overview of six research topics in deep learning from 2017 to 2023. On the horizontal axis, we have the time slice from 2017 to 2023, with each year represented by a unit length. The nodes on the graph represent keywords, while the connections between nodes indicate the relationship between these keywords. The larger the node, the higher the frequency of keywords, and the larger the red range of nodes, the higher the centrality of keywords.

From 2017 to 2018, deep learning has gradually become mature in deep reinforcement learning and semi-supervised learning, and there are more studies related to it than other

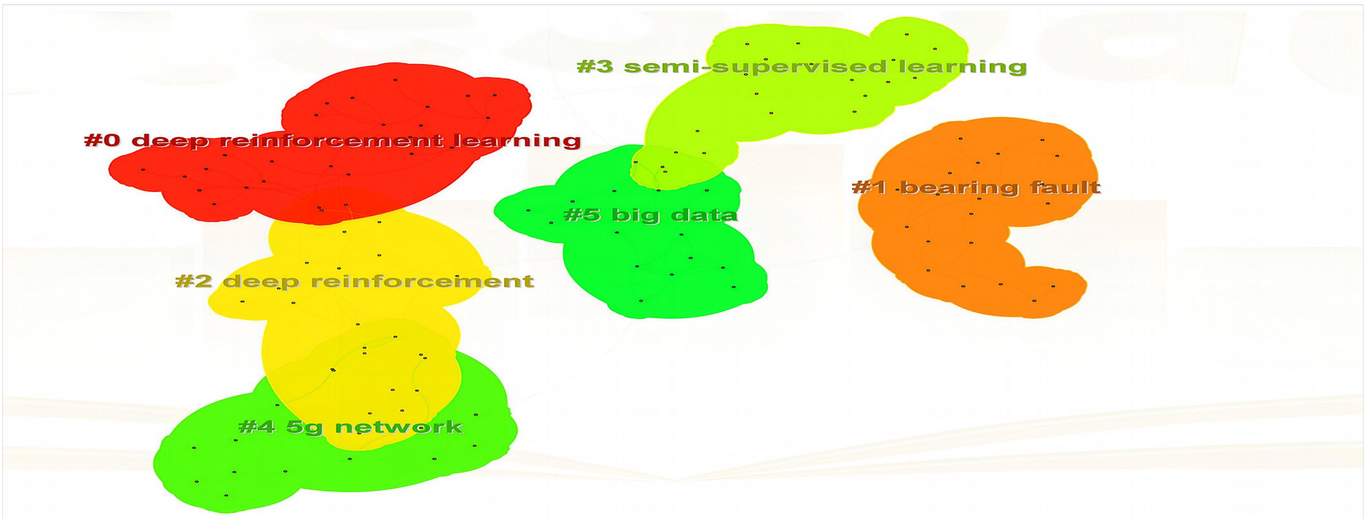

Fig. 8. Keywords cluster analysis

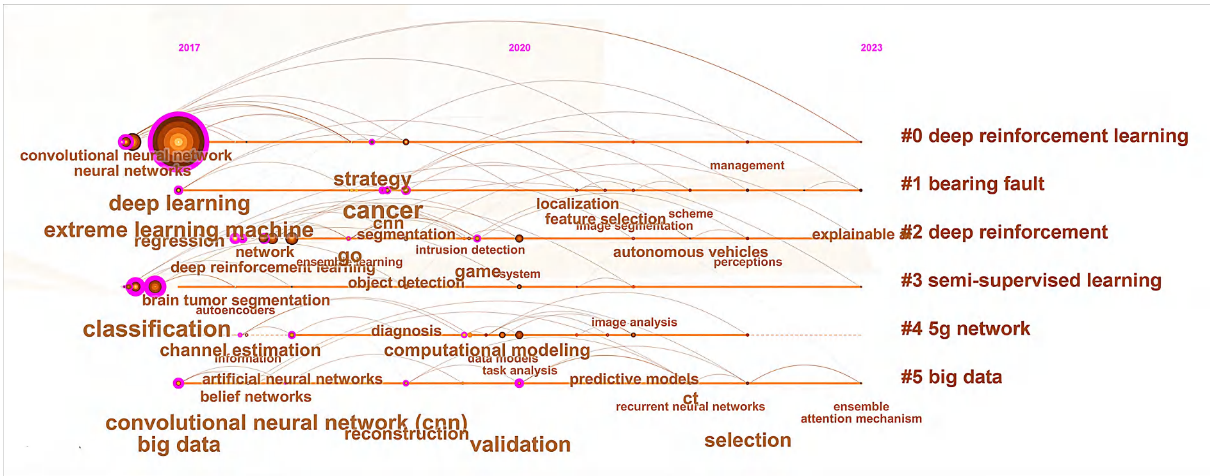

Fig. 9. Timeline view of deep learning keywords

aspects. The convolutional neural network has reached a level of maturity, with many related research studies available. Research hotspots in 2017 mainly focused on image segmentation, computers, and classification. Since 2019, there has been a noticeable increase in research on computational modeling. On the other hand, the focus on multimodal and segmentation studies has gradually declined. The research on deep reinforcement learning, semi-supervised learning, and other areas has reached a stable state over time. This indicates that the research focus of deep learning will continue to be distributed to deep reinforcement learning, emotion recognition, and semi-supervised learning. Computational modeling will be studied for a short or long time.

The frequency growth rate in some years is more likely to reflect local hot spot changes in the field and represent the research frontier in the field. This paper utilizes the mutation algorithm in Citespace software to identify the changes in keywords within the realm of deep learning from 2017 to 2023. The resulting list of 15 mutation keywords is organized based on the distribution of their appearance over time, as shown in Table V. Among them, the strength column represents the mutation intensity of the keyword. The greater the intensity, the higher the occurrence frequency of the keyword in the mutation time period. The "Begin" and "End" columns indicate the start and end times of the keyword mutation, while the formation time period refers to the time when the keyword becomes popular. As shown in Table V, the burst intensity of "Big data" (5.99) is the most robust, followed by "Representations" (5.63). The explosion of "Localization" and "Metric learning" is due to the fact that characteristics and patterns can be learned because of the data aggregation effect. The decrease in the proportion of sparse data eliminates the data aggregation effect, making feature learning more challenging. Feature engineering is a very important link in the successful application of machine learning. ScottLocklin states that "machine learning algorithms succeed by building an engineered feature that the learner can understand".

V. Conclusion

This paper utilizes Citespace visualization software to conduct a quantitative analysis of the relevant literature in the

TABLE V
TOP 15 KEYWORDS WITH THE STRONGEST CITATION BURSTS

Keywords	Year	Strength	Begin	End	2017 - 2023
Big data	2017	5.99	2017	2020	■■■■□□□
Representations	2018	5.63	2018	2020	□■■■□□□
Features	2017	5.25	2017	2019	■■■□□□□
Learning (artificial intelligence)	2018	4.3	2018	2020	□■■■□□□
Extreme learning machine	2017	4.28	2017	2020	■■■■□□□
Dna	2018	4.05	2018	2019	□■■□□□□
Algorithm	2017	3.41	2017	2018	■■□□□□□
Feature learning	2017	2.88	2017	2019	■■■□□□□
Image segmentation	2021	2.57	2021	2023	□□□□■■■
Deep belief network	2017	2.4	2017	2019	■■■□□□□
Semi-supervised learning	2019	2.4	2019	2020	□□■■□□□
Remote sensing	2020	2.21	2020	2021	□□□■■□□
Representation	2018	2.15	2018	2020	□■■■□□□
Localization	2021	2.06	2021	2023	□□□□■■■
Metric learning	2021	2.06	2021	2021	□□□□■■■

field of deep learning within the WoS core data set from 2017 to 2023, resulting in the generation of relevant maps. The main contents consist of literature distribution, cooperative network analysis, co-citation analysis, research hotspots, and research frontiers. By conducting various analyses such as institutional cooperation network analysis, national cooperation network analysis, reference co-citation analysis, journal co-citation analysis, keyword co-occurrence map, timeline map, and emergent word map, the knowledge structure, research progress, and research hot spots in the field of deep learning during this period can be determined. The conclusions are as follows:

From the perspective of literature distribution, the number of documents showed an increasing trend from 2017 to 2022, indicating that this period is the development stage of deep learning. Deep learning research is spread across various fields, including computer science, engineering, telecommunications, and more. From the perspective of cooperative networks, China has the largest number of documents in the field of deep learning research, followed by the USA. There is a significant amount of research in the field of deep learning in China. Currently, countries have established a relatively mature collaboration network in the field of deep learning research, with Chinese universities, research institutes, and other research institutions leading the way in research. The cooperation directions between research institutions are mainly distributed in fault diagnosis, machine learning, convection, super-resolution, etc.

Through the keyword clustering analysis, six research hotspots of deep learning are obtained: deep reinforcement learning, bearing fault, deep reinforcement, semi-supervised learning, 5G network, and big data. The map of emergent words reveals the extensive usage of convolutional neural networks in the field of deep learning. It continues to be a prominent area of research in this field.

Overall, the theoretical research in the field of deep learning continues to advance, and its application in various related fields is also progressing. Focusing on the research direction and research hotspot of deep learning, this paper puts forward the method of system analysis and evolution path based on the Citespace visual knowledge map, and analyzes the current research status in the field of deep learning. However, there are still some limitations in this paper. For instance, all the data sources used in this paper are derived from the WoS core data set, and the data sources are not wide enough. This paper focuses exclusively on the relevant literature in the field of deep learning from 2017 to 2023, with a limited time frame. Additionally, this paper solely utilizes Citespace software for analysis. Despite its widespread use in many bibliometric studies, the analysis results are still constrained by the software's functionality. In conclusion, the analysis results of this paper are obviously objective and reliable, and they are hardly affected by subjective factors.

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