Current Status and Emerging Trends of Generative Artificial Intelligence Technology: A Bibliometric Analysis

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Abstract

With the widespread application of ChatGPT (Chat Generative Pre-trained Transformer), its superordinate concept, generative artificial intelligence (Gen AI), has received increasing attention from researchers. The current study attempted to explore the current status and emerging trends of Gen AI technology research by visualizing the relevant published articles using the *Biblioshiny* tool. A total of 1,902 academic articles in the Web of Science (WOS) database published between 2014-2022 were analyzed. Annual publications, most productive journals and countries, co-authors, co-occurring keywords, document co-citations, and emerging trends of Gen AI research were analyzed. The following are the main findings of the study: the current status of Gen AI research is reflected in the following aspects: (1) the volume of documents produced is increasing year on year; (2) the publication of practical applications such as ChatGPT has brought a high level of interest to related research exploring the application of Gen AI in various research fields, such as education, medicine, drug discovery, and so on; and (3) two influential co-citation clusters have been formed. The emerging trends of the application of Gen AI research are also summarized as follows: (1) Gen AI has powerful technical advantages; (2) the application of Gen AI has great potential in the field of medicine, education and so on for the future; and (3) the updating and development of relevant technologies will always be the focus of Gen AI research.

Keywords: Generative artificial intelligence, ChatGPT, Generative adversarial network, Biblioshiny, Web of Science

1 Introduction

Generative Artificial Intelligence (Gen AI), as a branch of artificial intelligence (first defined in 1956) [1], refers to a technology leveraging a deep learning model to be trained to generate human-like content (e.g., images, words, audio) based on complex and diverse cues (e.g., languages, instructions, questions) by humans [2]. The product of Gen AI is seemingly intelligent output, according to human-provided hints and training [3]. Compared to traditional rule-based and data-based AI techniques (e.g., Conversational AI, Generic AI) [4], Gen AI is more creative and flexible, allowing for the creation of entirely new content, rather than simply reasoning and predicting based on existing rules or data. Due to technical features such as its excellent data mega-quantification, cross-modal integration, cognitive interaction power, and so on [5-6], Gen AI is being applied in various fields (e.g., medicine, business, engineering, education, etc.) [7-9]. In education, it can be used as a virtual teaching assistant to assist in monitoring classrooms, assessing students' performance, and conducting personalized education [10]. For example, *Magic Write* (embedded in Canva docs) can generate a draft and spark inspiration in response to learner-provided words; *Channel* analyzes your data and provides visual information based on tips provided by some humans. ChatGPT (Chat Generative Pre-Trained Transformer), a practical application product concerning Gen AI, has attracted worldwide attention since being published in November 2022 by the company, OpenAI [11]. It can autonomously learn from big data based on large language models (LLMs), to respond logically to questions in a human-like way [12].

Although Gen AI has become popular worldwide, some problems remain, such as lower response accuracy rate, no guarantee of the quality of the generated content, no transparency of the generation process, and so on [13-14]. To gain a comprehensive picture of Gen AI and to predict future trends, it makes sense to visualize the knowledge domain of articles concerning Gen AI technology research.

The aim of this study was to visually analyze the data retrieved from the Web of Science database (WOS) in terms of annual publications, cooperating countries, co-authors, co-occurrence keywords, co-citations, and popular topics, using the *Biblioshiny* tool. The visual knowledge maps it forms can help us to understand the knowledge areas, quantitative research patterns and trends about a field of study, which can help to acquire comprehensive knowledge about Gen AI research.

2 Method and Data

A bibliometric analysis, also referred to as scientometrics, was conducted in this study, and graphs and figures were used to numerically and visually illuminate the current state of research in the field and to learn more about future research directions [15].

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2.1 Data Collection

The relevant data were retrieved from the Web of Science (WOS), an English database with comprehensive papers covering a wide range of categories from around the world. Due to the incompatibility of data formats exported from different databases, to ensure the validity of the data analysis, only one database was included. Literature in the Core Collection was retrieved on April 29, 2023. Generative adversarial network, as the underlying model of Gen AI realization, was first proposed by Goodfellow et al. in 2014 [16]. Thus, the timespan for the search was from January 1, 2014, to December 31, 2022. Data were retrieved according to the following search formula: "TS = (generative artificial intelligence)."

A total of 4,329 papers were initially identified. After excluding documents that were not of the article type, 2,028 records of articles were uploaded to *Biblioshiny*; then the timespan was set to 2014-2022, and 126 articles were excluded. Finally, a total of 1,902 articles were retained for further analysis. The specific searching strategy is shown in Figure 1.

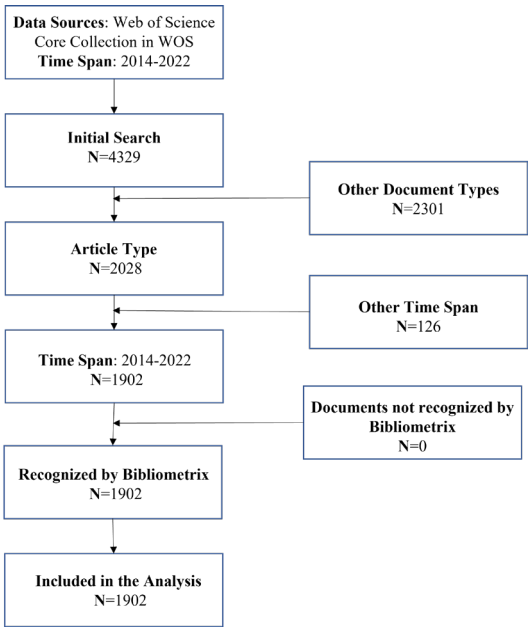

Figure 1. Flowchart of the bibliometric methodology used in this study

2.2 Analysis Tool and Data Processing

In the current study, *Biblioshiny*, based on the RStudio cloud, was used to organize and analyze the document data to generate visual information concerning Gen AI research, for example, the data annual production in WOS, most productive journals and countries, most collaborative authors, keywords, as well as the potential relationships between keywords, authors, references, countries, and journals.

As for the data processing, firstly, the data exported from the database needed to be uploaded to *Biblioshiny*. In "Filters," the timespan was set to "2014-2022" and only "article" was selected as the type of document for the analysis. Then, we selected the appropriate option to carry out different analyses, for example, in "Overview," by selecting "Annual Scientific Production," the number of publications on Gen AI research each year could be determined.

3 Results

3.1 Analysis of The Number of Annual Publications, Journals, and Countries

In this section, some basic information about Gen AI research in the period of 2014-2022 in the WOS database is presented by charts or tables.

As shown in Figure 2, the overall annual number of publications in the WOS database has shown a year-on-year increase. Although the generative adversarial network, as the underlying model of Gen AI realization, was first proposed by Goodfellow et al. in 2014 [16], from 2014 to 2016, there were relatively few articles on Gen AI. In 2018, there was a sudden increase in the annual number of articles in WOS, and this growth trend continued unabated until the end of 2022.

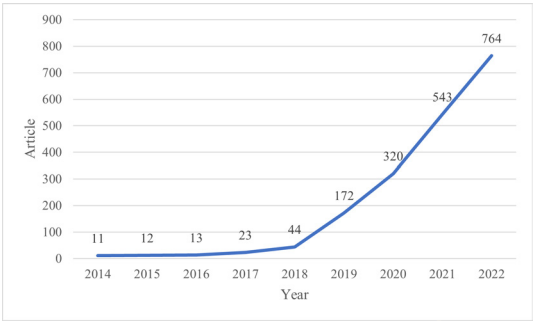

Figure 2. The number of annual publications on Gen AI research in WOS (2014-2022)

Figure 3 represents the average citations per year of articles on Gen AI research in WOS. In the last nine years, the average citation value reached its highest point in 2020 (MeanTCperYear = 17.9). Table 1 and Figure 4 show the information about the productive journals. *IEEE Access* has had the highest number of articles with 105. Figure 4 represents the trends in the annual production of the top five journals. For *IEEE Access*, 2018 was a turning point, as there was a rapid increase in its annual production year on year after this; for the other five journals, 2019 was a turning point, with a relatively slow increase in annual production year on year after this.

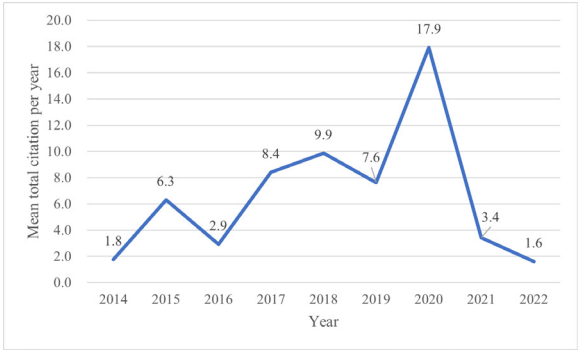

Figure 3. Average citations per year of articles on Gen AI research in WOS (2014-2022)

Table 1. The top 10 most productive journals

Journal name	Number of published papers
IEEE Access	105
IEEE Transactions on Image Processing	41
Neurocomputing	39
Applied Sciences-Basel	29
Engineering Applications of Artificial Intelligence	28
Frontiers in Artificial Intelligence	28
Electronics	26
Sensors	26
IEEE Transactions on Geoscience and Remote Sensing	24
IEEE Transactions on Geoscience and Remote Sensing	23

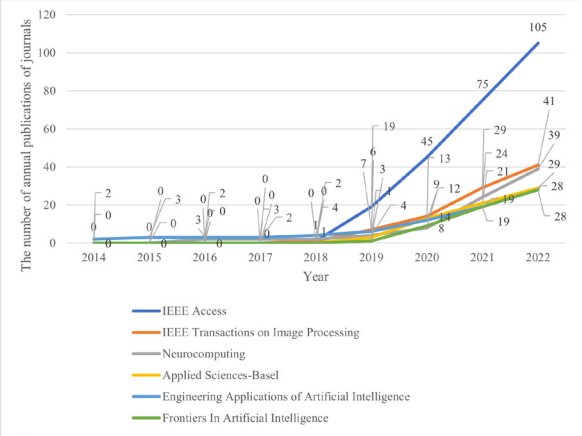

Figure 4. The trends in the annual production of the top five journals (2014-2022)

Table 2, Figure 5, and Figure 6 show the information of productive countries. China, the USA, and Korea were the top three most contributive countries in 2014-2022. However, the most total citations of articles were produced by the USA, followed by China and then Canada. Figure 5 and Figure 6 graphically illustrates the collaboration between the different countries; as can be seen, the collaboration relationship between China and the USA is relatively strong.

Table 2. The top 10 most productive countries

Country	The number of published papers	Total citations
China	789	7,799
USA	239	22,240
Korea	171	1,317
Germany	69	803
United Kingdom	62	882
Japan	62	398
India	50	726
Canada	49	1,531
Australia	45	1,251
Span	37	502

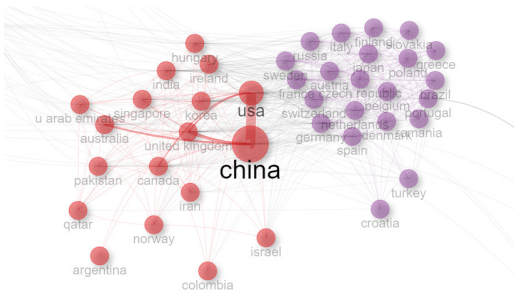

Figure 5. The collaboration of countries on Gen AI research in WOS (2014-2022)

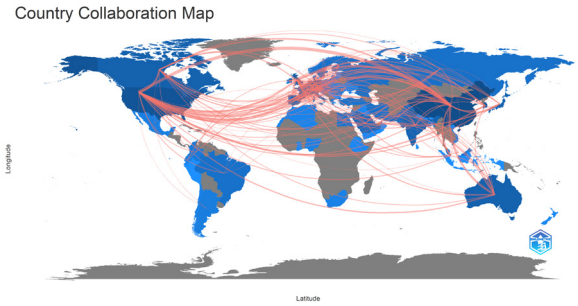

Figure 6. Countries' collaboration world map

3.2 Co-authorship Analysis

In terms of the volume of published articles, the most productive authors in the field of Gen AI in the last nine years were Li, J. with 47 articles, followed by Wang, Y., Zhang, Y., Li, Y., and Li, X (see Table 3). Table 4 represents the top 10 most cited authors in Gen AI research. Li, J.'s articles have the highest impact and are the most cited. Figure 7 shows the top 10 authors' production in the period of 2014-2022. Larger nodes indicate more publications, and darker nodes indicate more influential articles. Figure 8 shows the collaborative relationship between productive authors. The size of nodes reflects the impact of authors; the different colored nodes indicate different research directions, and lines between nodes indicate a collaborative relationship between authors, with thicker lines indicating a closer relationship. Some relatively stable collaboration clusters were formed, as shown in Figure 8. Meanwhile, the clusters with core authors also indicate the most influential research groups in the research area of Gen AI, which can provide individualized or meaningful scientific research information or results to other researchers, for example, the co-author clusters with Wang, Y. and with Zhang, J.

Table 3. Top 10 authors with the highest number of articles in the period of 2014-2022

Rank	Count	Authors
1	47	Li, J.
2	41	Wang, Y.
3	41	Zhang, Y.
4	40	Li, Y.
5	34	Li, X.
6	32	Wang, J.
7	31	Liu, Y.
8	31	Zhang, J.
9	31	Zhang, X.
10	30	Zhang, L.

Table 4. Top 10 most cited authors in Gen AI research

Rank	Authors	h-index	TC	Count
1	Li, J.	14	564	47
2	Li, H.	12	498	25
3	Li, Y.	12	455	40
4	Wang, J.	12	454	32
5	Wang, Y.	12	541	41
6	Aspuru-guzik, A.	11	1762	15
7	Zhang, J.	11	378	8
8	Li, L.	10	319	26
9	Li, X.	10	239	34
10	Tao, D.	10	748	16

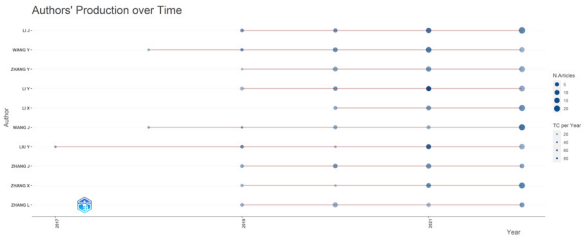

Figure 7. A diagram showing the top 10 authors' production over time (2014-2022)

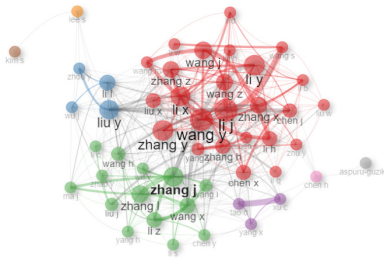

Figure 8. The collaboration of authors on Gen AI research in WOS (2014-2022)

3.3 Co-occurring Keywords Analysis

The co-occurring keywords with high frequency and centrality reflect the hot topics of research. As shown in Figure 9, the higher the values of centrality and frequency of a node, the more important the keyword represented by the node is in the research field. The top 10 research co-occurring keywords are shown in Table 5. The top one is "classification," with 100 occurrences. The second and third most frequent keywords are "model" and "network." Meanwhile, the word-cloud visualization of articles allowed us to identify the most relevant keywords (see Figure 9, Figure 10). These results highlight that the key co-occurring terms for Gen AI research were classification, model, network, neural-networks, design, and artificial-intelligence.

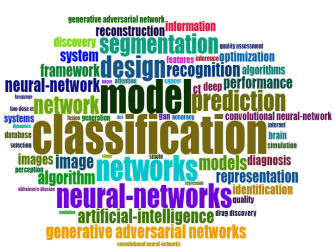

Figure 9. Word cloud of keywords in Gen AI research from 2014 to 2022 in WOS

Table 5. Top 10 co-occurring keywords in Gen AI research in the period of 2014-2022

Rank	Keywords	Occurrences
1	classification	100
2	model	86
3	networks	64
4	neural-networks	62
5	design	56
6	prediction	53
7	segmentation	50
8	Artificial-intelligence	47
9	recognition	38
10	Generative adversarial networks	36

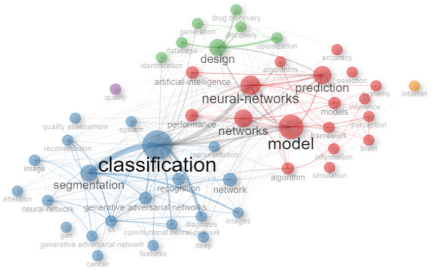

Figure 10. The collaboration of keywords on Gen AI research in WOS (2014-2022)

3.4 Document Co-citation Analysis

A document co-citation network, calculated using the Walktrap clustering algorithm, is shown in Figure 11. The nodes represent the cited references, and the links between nodes reflect the co-citation relationships. Obviously, two cluster networks were formed, and the core authors of the two networks are respectively Goodfellow et al., and Zhu, Y. There are also relationships between the two cluster networks, and four clustering labels have also been presented in Table 6.

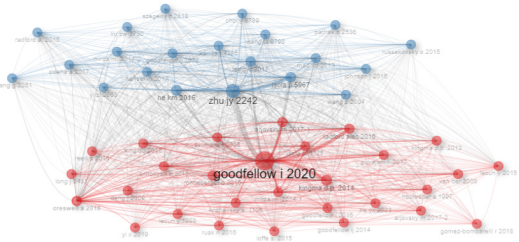

Figure 11. Co-citation network of 2014–2022

Table 6. Cluster keywords in the Gen AI field from 2014-2022

Rank centrality	Clustering label	Cluster frequency
1	internet	13
2	design	206
3	classification	577
4	model	755

Table 7 shows the top 10 most globally cited articles in Gen AI research. The article of *Generative Adversarial Networks* by Goodfellow et al. (2020) [17] was the most globally cited article, with total citations of 16,712. The second was *An overview of deep learning in medical imaging focusing on MRI* by Lundervold, A. S. (2018) [18], with

total citations of 753. As for the other core author in another cluster network, Zhu, Y.'s (2019) article with 304 total citations ranks 7th [19]. Figure 12 shows the relationship of research development trajectories between authors with collaborative relationships.

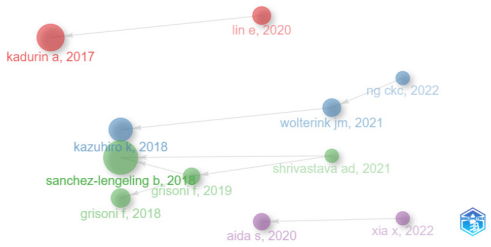

Figure 12. The development trajectories between authors with collaborative relationships

3.5 Emerging Trends

The trend topics of keywords, thematic map, and thematic evolution map could be used to explore the emerging trends of Gen AI research.

Firstly, Figure 13 shows the trend topics of co-occurring keywords in recent years. The larger the node, the more frequently the keywords appear. It can be seen that "classification," "artificial-intelligence," "neural-network," "model," and "networks" are the top five research hotspots. There are also terms that received less attention from researchers after 2020, for example, "representations," "computer-aided detection," and "Bayesian-inference."

Figure 14 shows a thematic map of Gen AI research. Themes in the first quadrant are generally the motor-themes, which are important and well-developed research themes; the second quadrant includes very special-interest themes that are well developed but not important for current research; the emerging or disappearing themes are included in the third quadrant; the fourth quadrant refers to the fundamental themes that are important to the field, but are not yet well developed, generally representing foundational concepts. It can be seen that "classification," "segmentation," and "generative adversarial networks" were all included in the first quadrant, making it the most important and well-developed research area. The accuracy of classification strategy is important for the application of Gen AI in various areas (e.g., in healthcare, drug discovery, education) [20-21]. Generative adversarial networks are the underlying model of Gen AI realization, so related research has been well established. Research concerning "behavior," "face," and "memory" situated in the second quadrant has been well explored but is not meaningful for current research. Researchers have proposed a generative adversarial method to improve face identification accuracy [22], and the research methods have been well established. The terms "accuracy" and "registration" are included in the third quadrant, which represents the emerging or disappearing themes of Gen AI. Ensuring and upgrading the algorithms' accuracy is an important issue for the effectiveness of Gen AI applications [23]. Finally, the terms "models," "neural-networks," "design," and "identification" are included in the fourth quadrant, meaning that they are important and fundamental issues for the current research.

Table 7. Top 10 most globally cited articles in Gen AI research (2014-2022)

Author, year	Article title	Journal name	Total citations
Goodfellow I, 2020	Generative Adversarial Networks	Commun ACM	16,712
Lundervold AS, 2018	An overview of deep learning in medical imaging focusing on MRI	Z. FUR Med. Phys.	753
Sanchez-Lengeling B, 2018	Inverse molecular design using machine learning: Generative models for matter engineering	Science	733
Zhavoronkov A, 2019	Deep learning enables rapid identification of potent DDR1 kinase inhibitors	Nat. Biotechnol.	399
Nweke HF, 2018	Deep Learning Algorithms for Human Activity Recognition using Mobile and Wearable Sensor Networks: State of the Art and Research Challenges	Expert Syst. Appl.	375
Vinyals O, 2017	Show and Tell: Lessons learned from the 2015 MSCOCO Image Captioning Challenge	IEEE Trans. Pattern Anal. Mach. Intell.	345
Zhu Y, 2019	Physics-Constrained Deep Learning for High-dimensional Surrogate Modeling and Uncertainty Quantification without Labeled Data	J. Comput. Phys.	304
Rives A, 2021	Biological Structure and Function Emerge from Scaling Unsupervised Learning to 250 Million Protein Sequences	Proc. Natl. Acad. Sci. U. S. A.	295
Waheed A, 2020	CovidGAN: Data Augmentation using Auxiliary Classifier GAN for Improved Covid-19 Detection	IEEE Access	292
Ahmed R, 2020	A review and evaluation of the state-of-the-art in PV solar power forecasting: Techniques and optimization	Renew Sust Energ Rev	284

Figure 15 represents the thematic evolution map of Gen AI research. In this study, five time periods of hot research on Gen AI have been identified. As shown in Figure 15, since 2014, "model" has been the research hotspot and the knowledge foundation for the last 10 years. In 2017-2018, research on "information," "neural-networks," "algorithms," "frameworks," and "chemical space" began to increase; however, "model" was still the most important focus. In 2021, research on "classification" received the most attention. In recent years, relevant research on "models," "internet," "inference," "simulation," "network," "brain," and "classification" has received much attention from researchers.

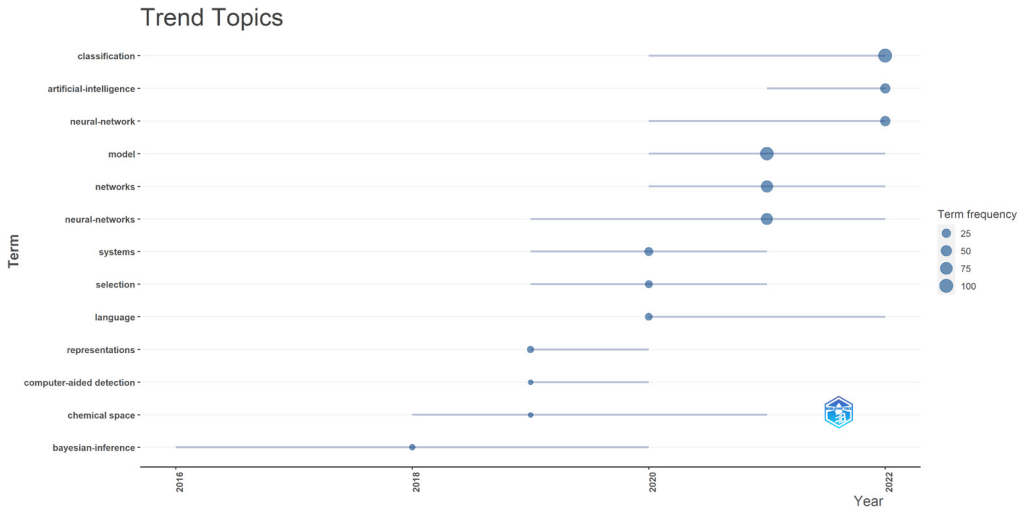

Figure 13. The trend topics of keywords on Gen AI research in 2014-2022

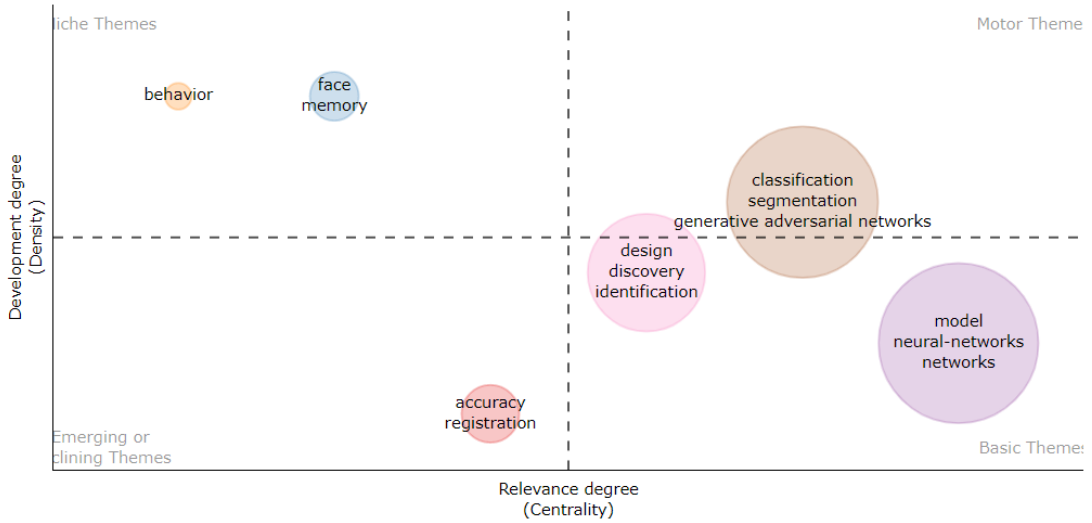

Figure 14. Thematic map of Gen AI research in 2014-2022

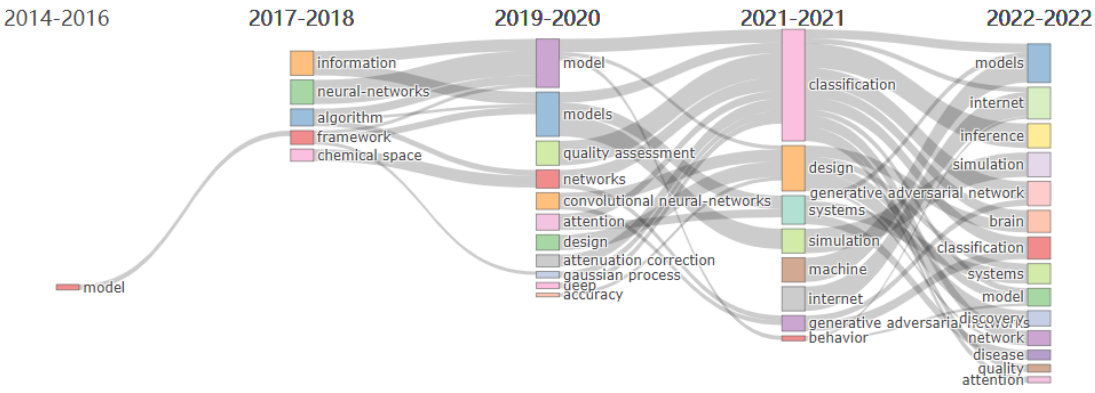

Figure 15. Thematic evolution of Gen AI research in 2014-2022

4 Discussion and Conclusion

This study aimed to explore the current status and emerging trends of Gen AI research by visualizing and analyzing the annual publications, co-authors, co-citations, and co-occurrence keywords of data retrieved from the WOS database in the period from 2014-2022 using the *Biblioshiny* tool. The results are summarized as follows.

4.1 Current Status of Generative Artificial Intelligence Research

As a relatively cutting-edge technology, there has been an increasing production volume associated with Gen AI research in the WOS database. According to the results of analysis of the number of production years, from 2014-2016, the total number of publications in international journals was less than 100, and there was a break of a few years during this period. According to the results of the keyword analysis, the keywords of "classification," "network" and "generative adversarial network" have received some attention from researchers. As a generative model based on adversarial learning, it can generate realistic data, such as images, audio, and so on. Since the generative adversarial network was first proposed by Goodfellow in 2014 [16], various types of research on GAN have sprung up; however, the focus of these studies has been on updating and optimizing the technology, and no physical applications have been developed and applied. Therefore, the results of this study show that there were few articles concerning the application of Gen AI between 2014 and 2018, which is reasonable. Interestingly, the continued low volume of publication started to increase year on year since 2018. In June 2018, the US company, OpenAI, presented the Transformer-based pre-trained language model (Generative Pre-trained Transformer GPT-1) [24], which was subsequently progressively refined over the next four years. Therefore, as physical applications are generated, the number of related application studies increases. For example, Cooper (2023) attempted to apply ChatGPT in science education, and found that it can be an effective research tool for assistance with editing [25]. Victor et al. (2023) conducted an experiment to verify how Gen AI makes examinations fairer [26]. What's more, some influential co-citation clusters about Gen AI have been formed based on the above conclusions; the first one is the cluster with the core author Goodfellow et al. (2014) [18], who first presented the generative adversarial network, the technological foundation of Gen AI. Another co-citation cluster was linked by Zhu, Y. (2019) [19], who provided a methodology to refine the deep learning model. Zhu's paper provided its individual research information on deep learning, which has played an important role in the technology development of Gen AI research. In addition, according to the results, it is also interesting to note that although Chinese authors have published the most articles, their articles are the second most cited, following those by US authors.

4.2 Emerging Trends of Generative Artificial Intelligence Research

Although it is only in the last four years that the number of relevant studies published on Gen AI has increased, its potential for the future cannot be underestimated.

Firstly, Gen AI has powerful technical advantages. According to the results, keywords such as classification, deep learning, machine learning, training, and task analysis appear frequently in international papers, suggesting that a research hotspot is the exploration of the implementation of Gen AI techniques. This phenomenon can be inferred from published studies. The basic building framework of the ChatGPT uses the transformer model developed by Google in 2017 [27]. These techniques and ideas have directly helped the GPT family of systems to develop excellent text generation capabilities.

Secondly, Gen AI technology has great potential for practical applications. Based on the results, the topics of "classification," "model," "artificial intelligence," "recognition," and "prediction" have received widespread attention. Many researchers have made numerous efforts to optimize classification algorithms and to refine models to ensure more accurate and efficient recognition. Huang et al. (2019) proposed a generative adversarial method to improve face identification accuracy [22], while Xue (2020) proposed a generative adversarial network to improve classification performance [28]. Meanwhile, the technological evolution further facilitates Gen AI practical application in various fields. For example, Shang et al. (2022) constructed how students' online learning progress can be monitored and tracked based on the principle of human-machine collaboration, and its application has been effective [29]. Gen AI technology relies on language, images, and a multimodal foundation model to achieve better content generation [2].

Finally, the development of relevant technologies will always be the focus of Gen AI. According to the results, relevant research such as models, generative adversarial networks, classification, artificial intelligence, neural-networks, deep learning, machine learning and so on still deserves researchers' attention. The generative adversarial network, as a deep learning model, is the underpinning construction of Gen AI technology. It cannot be updated and optimized without optimization of the generative adversarial network algorithm. The generative adversarial network has been used and updated in a variety of scenarios. For example, Wang et al. developed a novel fault diagnosis method to overcome the weakness of generating one category fault signals in one time of traditional generative adversarial networks [30]. Overall, it is the continuous innovation of technologies that provides the conditions for the iteration of Gen AI.

4.3 Limitations and Future Work

There are some shortcomings in the current study. First, data were retrieved only from one database, which may have an impact on the comprehensiveness of the results. More databases could be selected in the future research. Second, extensive surveys of certain research fields can be provided by *Biblioshiny*; however, it is not capable of performing deep analysis of individual articles. Therefore, future research could combine CiteSpace with other tools to provide in-depth analysis of the application of Gen AI research.

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