Analysis of the Global Research Status of Graph Theory Based on Bibliometrics

Furui Chen[1,*][a] and Yubin Hu[2][b]
[1]School of Political Science and Public Administration, Soochow University, Suzhou, Jiangsu, China
[2]College of Chemistry, Chemical Engineering and Materials Science, Soochow University, Suzhou, Jiangsu, China

Keywords: Graph Theory, Bibliometrics, Development Trend, Visual Analysis.

Abstract: Graph theory, as a branch of operations research, has an ancient research history. In recent years, it has not only broken new ground in its applications but also optimized its existing models with the help of new tools such as neural networks and machine learning. Based on the Web of Sciences core database, this paper analyses the number of annual papers, core authors, disciplinary layout, countries, and keywords. Using the visual analysis software CiteSpace and VOSviewer, we can comprehensively reveal research trends, research capabilities, and research directions Hotspots in the field of graph theory from 2012 to 2021. The results show an overall upward trend in the development of graph theory research, with two countries, led by China and the United States, dominating most of the research worldwide and collaborating to some extent. The research direction of graph theory has also evolved from expanding applications to optimization models.

1 INTRODUCTION

Many real-world situations can conveniently be described using a diagram consisting of a set of points together with lines joining specific pairs of these points. Notice that in such diagrams, one is mainly interested in whether or not a line joins two given points; how they are joined is immaterial. A mathematical abstraction of situations of this type gives rise to the concept of a graph (Bondy 1976). The graph theory problem can be traced back to Euler's 1736 paper on the Seven Bridges Problem. As an independent branch of mathematics, it is characterized by simple models and strong generalization. It is good at describing the relationship between two things, so it has been widely used in various fields such as management science, computer science, and biology and has achieved fruitful results. With society's development, new methods such as deep learning and neural networks are emerging to innovate and optimize theoretical graph models.

On the other hand, theoretical graph models are being applied to more research areas. With the continuous development of modelling and solving graph theoretical problems, there is an urgent need for systematic analysis and review of the existing research. Therefore, in this paper, we use a bibliometric approach to organize and summarize the research literature in this field in the past ten years from different perspectives, summarize the relevant publications, and show the development paths, research hotspots, and possible future trends of graph theory through data visualization.

2 MATERIALS AND METHODS

To ensure the authority and coverage of the analysed data, the data source was selected as Web of Science (Core Collection), the index was selected as SCI-Expended and SSCI, and the search strategy was selected as (TS= ("graph theory")), the period was January 2012 to December 2021, the search document type was Articles, and the language was English. After screening and de-weighting, a total of 10124 papers were obtained. Please remember that all the papers must be in English without orthographic errors.

[a] https://orcid.org/0000-0002-2689-7747
[b] https://orcid.org/0000-0001-6350-8096

Chen, F. and Hu, Y.
Analysis of the Global Research Status of Graph Theory Based on Bibliometrics.
DOI: 10.5220/0012071300003624
In *Proceedings of the 2nd International Conference on Public Management and Big Data Analysis (PMBDA 2022)*, pages 147-153
ISBN: 978-989-758-658-3

Bibliometrics refers to the application of mathematics and statistical methods to books and other forms of written communication (Pritchard 1969). It is a quantitative research method based on publications, citations, and textual data to describe and analyse the dynamics and progress of a discipline or research field (Van 2019). A bibliometric study's results include descriptive statistics and an analysis of keywords, texts, citations, authors, and their associated networks. It examines the frequency, relevance, centrality, and clustering of the author and textual data. Therefore, scholars often use it to explore the evolutionary patterns, publication trends, author citation networks, and other elements of a topic. In this paper, we use two visualization tools called VOSviewer and CiteSpace to conduct a bibliometric study.

3 DESCRIPTIVE STATISTICS

3.1 Basic Quantitative Information

The 10124 papers used in this study were written by 29669 authors from 6004 organizations in 115 countries, published in 2063 journals, and cited 246046 references from 49818 journals.

3.2 Analysis of Papers' Annual Amount

The number of published papers in a research field can reflect the research results of the field in a specific period. It can be used as an indicator to measure the development trend of a field, visually demonstrating the level of development, the speed of development, and the research activity in that field. Figure 1 shows the annual publication volume and growth rate of graph theory thematic literature from 2012 to 2021. In the past ten years, the overall publication trend of graph theory-related literature has been steadily increasing, especially in the past five years. The annual growth rate of the number of publications is not less than 10%, which reflects the tenacity of graph theory and the attention of more and more scholars.

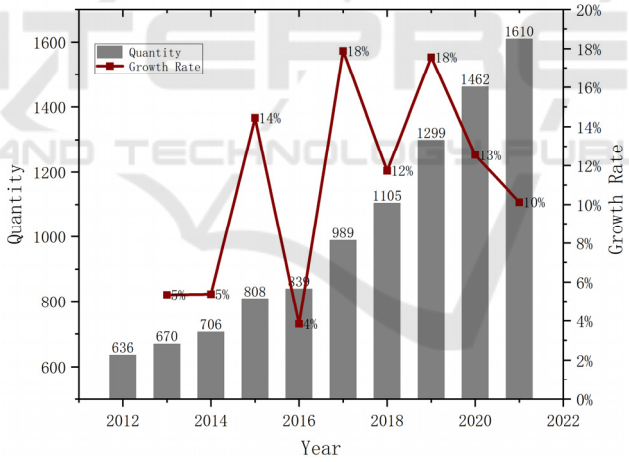


Figure 1: Number and growth rate of papers published from 2012 to 2021.

3.3 Analysis of Journals

The table below shows the top 10 journals regarding the number of articles published, citations, and average citations per page. From this, we can see that the topics of most journals are related to biology and the nervous system. In addition, the top four journals in terms of citations per article are all related to neurology, reflecting that papers on related topics are more likely to be used by other scholars. Meanwhile, only a few journals are general or related to discrete mathematics and other directions.

Table 1: Top 10 Journals.

SN	Source	Quantity	Average Citation
1	JOURNAL OF GRAPH THEORY	203	5.51
2	IEEE ACCESS	184	7.28
3	NEUROIMAGE	167	48.55

4	HUMAN BRAIN MAPPING	135	27.15
5	PLOS ONE	125	45.01
6	SCIENTIFIC REPORTS	106	14.78
7	NEUROCOMPUTING	100	20.15
8	DISCRETE APPLIED MATHEMATICS	99	4.13
9	FRONTIERS IN HUMAN NEUROSCIENCE	80	27.95
10	IET CONTROL THEORY AND APPLICATIONS	80	17.56

3.4 Analysis of Discipline Layout

Based on the classification of Web of Science, a scientific layout analysis of papers on the research topic of "Graph Theory." Table 2 shows the situation of the top 10 disciplines in the classification of global papers in the field of graph theory from 2012 to 2021 in all 200 disciplines. This includes Engineering Electrical Electronics in first place with 16.58% and Neuroimaging in tenth place with 5.03%, which shows that the research application of graph theory has a more balanced distribution and covers a large area.

Table 2: Top 10 Categories.

SN	Categories	Quantity	Proportion
1	Engineering Electrical Electronic	1679	16.58%
2	Neurosciences	1582	15.63%
3	Mathematics	1306	12.90%
4	Mathematics Applied	1137	11.23%
5	Automation Control Systems	800	7.90%
6	Computer Science Information Systems	786	7.76%
7	Computer Science Artificial Intelligence	649	6.41%
8	Telecommunications	592	5.85%
9	Multidisciplinary Sciences	533	5.26%
10	Neuroimaging	509	5.03%

4 VISUAL ANALYSIS AND DISCUSSION

4.1 Core Authors Analysis

Price pointed out that half of the articles on the same topic are written by a group of highly productive authors (Price 1963). Based on this theory, we selected the authors with more than or equal to 5 publications as the core group of authors in this field after trial calculation to understand the cooperative relationship between core authors and provide a reference basis for academic exchange, international cooperation, and talent introduction (White 2003).

Figure 2 shows the network diagram with authors as nodes; the more significant the node, the more frequently the author appears in the research area. Among them, Wenxue Li (80) started the research on Coupled nonlinear systems based on graph theory in 2012 (Li 2012), became the core author with the most posts, and has made several collaborations with YanLiu and others. Qiyong Gong (47) started a graph-theoretic analysis of topological connectivity in the cerebral cortex in 2015 (Lei 2015). Siddiqui and Muhammad Kamran (41) started to analyse the topology of crystalline molecules as well as microbial domains using graph theoretic methods in 2017, obtaining more remarkable results in a short period while collaborating more closely with Sharma (Siddiqui 2017). We can see that the top three core authors have conducted pioneering research using graph theory methods in different fields at different periods. This further reflects the enormous scope of the application of graph theory methods.

In addition to the three authors mentioned above, Table 3 shows the information of the top five core authors in terms of the number of publications, from which we can see that there are many high-quality authors with 76.37 citations per article among the authors with high number of publications.

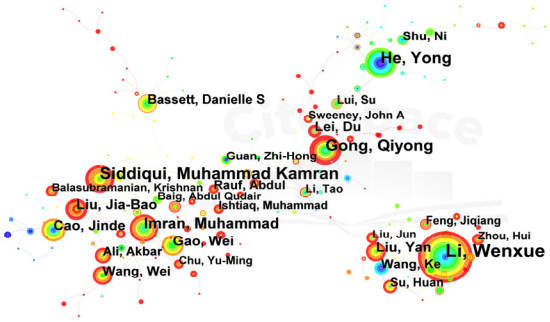


Figure 2: Author Cooperation Network Map.

Table 3: Top 5 Core Author.

SN	Author	Quantity	Average Citation
1	Li, Wenxue	80	14.2
2	Gong, Qiyong	47	23.76
3	He, Yong	43	76.37
4	Siddiqui, Muhammad Kamran	41	12.39
5	Sharma, V. K.	36	6.35

Table 4: Top 10 Countries.

SN	Country	Quantity	Citations	Total link strength	Average Citation	Centrality
1	China	2962	52422	3422734	17.6981	0.10
2	USA	2370	56632	3623603	23.8953	0.26
3	England	647	14602	1367165	22.5687	0.18
4	Canada	521	12582	972406	24.1497	0.12
5	Germany	512	11233	950310	21.9394	0.11
6	France	477	7074	524488	14.8301	0.11
7	India	444	4763	266075	10.7274	0.06
8	Italy	381	7511	855841	19.7139	0.05
9	Spain	379	6105	601484	16.1081	0.13
10	Australia	354	10918	660672	30.8418	0.05

4.2 National Layout Analysis

The top ten countries with the number of publications are listed in the table above.

It can be seen that among all countries, China and the United States have significantly higher publication numbers than other countries, accounting for 29.25% and 23.40% of the total publications, respectively, which reflects that China and the United States are the leading force in graph theory research. In terms of centrality, the U.S. is far ahead, followed by the U.K. and Spain, which indicates that the three have significant influence and play a central role in the national cooperation network. Conversely, China is ranked seventh, reflecting that there is still room for improvement in its posting influence, which needs to be improved further to deepen cooperation.

Using VOSviewer to visualize the state of country cooperation, we find that the papers from both China and the U.S. have an extensive impact range, basically covering all the countries involved, which shows that scholars worldwide in the field of graph theory are expanding their research around these two core countries.

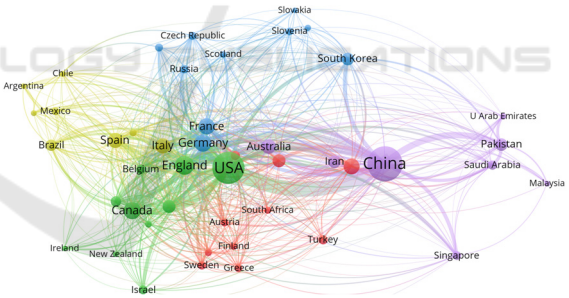


Figure 3: Country Cooperation Network Map.

4.3 Research Institutions Analysis

The table below shows the number of articles published by research institutions, from which we find that 8 of the top 10 search institutions are from China, which again reflects the quantitative leadership of Chinese research. The highest average citation among them is Beijing Normal University (61.50), and the lowest is Harbin Institute Technology at Weihai (14.01), with overall highs and lows and no country-level differences.

Table 5: Top 10 Institutions.

SN	Institutions	Quantity	Average Citation
1	Chinese Academy of Sciences	159	31.67
2	Southeast University	115	31.65
3	Harbin Institute of Technology	115	17.18
4	Beijing Normal University	114	61.50
5	Harbin Institute of Technology at Weihai	96	14.01
6	University of Cambridge	92	44.12
7	University of Electronic Science and Technology of China	88	25.44
8	University of Illinois	84	16.46
9	Peking University	80	35.01
10	Huazhong University of Science and Technology	79	23.10

4.4 Keywords Co-Occurrence Analysis

Keywords summarize an article's gist and essence, and keyword co-occurrence analysis can reveal research priorities in a scholarly field (Wang 2022). Therefore, we used CiteSpace to summarize the keywords of 10124 documents and selected keywords with occurrences greater than 30 for co-occurrence analysis to obtain the following figure.

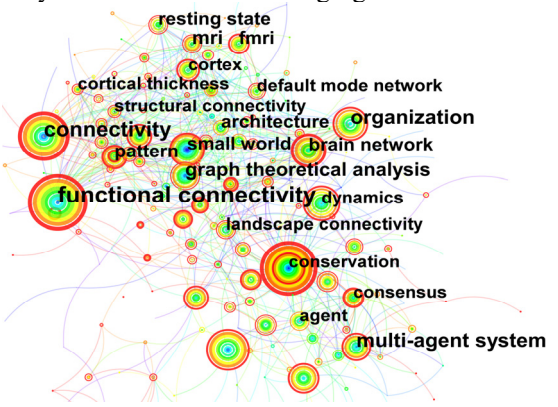


Figure 4: Keywords Clustering Map.

From this, we can see that keywords such as functional connectivity, network, and organization have become the core of the study of graph theory problems. Then we can judge that most of the research on graph theory in the last decade has been conducted around the connectivity of systems. At the same time, we found that the research on graph theory is relatively close to each other in terms of keywords, without any apparent split. To get a clearer picture of the specifics of the keywords, the following table shows the top ten keywords in terms of frequency of occurrence.

Table 6: Top 5 Keyword.

SN	Keyword	Occurrences	Total link strength
1	network	820	1533
2	connectivity	633	1461
3	model	556	827
4	functional connectivity	508	1243
5	system	494	712

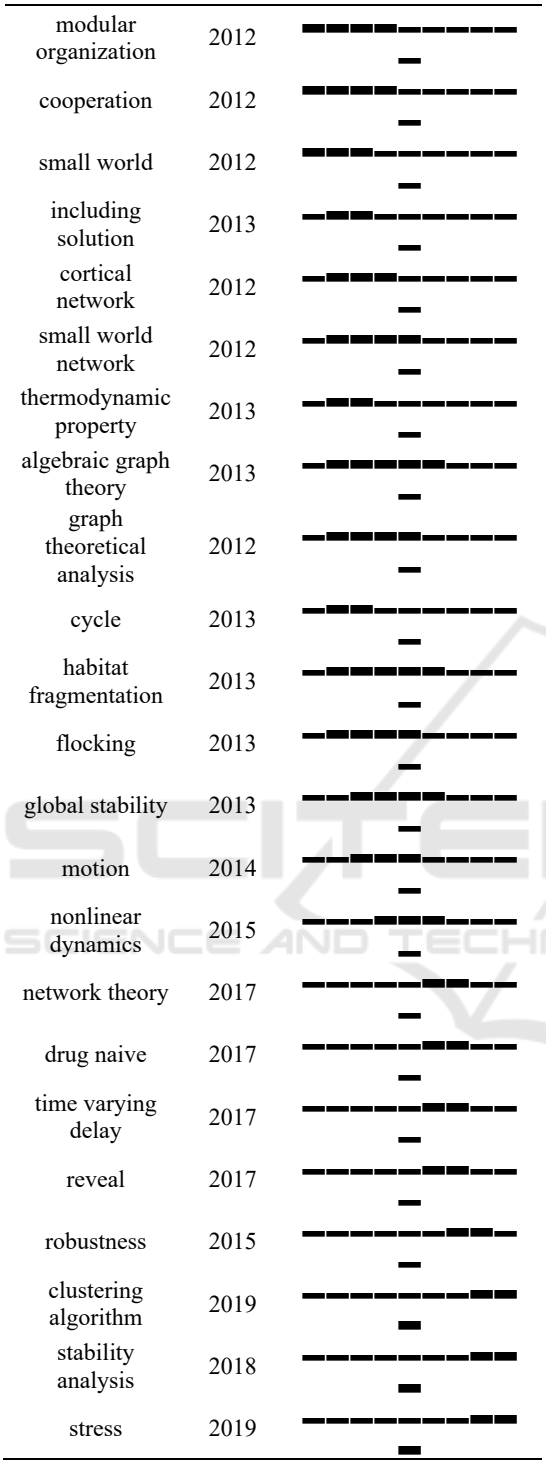
4.5 Keyword Emergence Analysis

Keyword emergence analysis refers to the analysis of words that appear with high or high frequency in the published literature of a research area over a specified period. It is often used to determine the research frontier or to predict the development trend (Yan 2022).

In this work, 25 emergent words with high emergent values are determined using the software CiteSpace. In connection with the further analysis of the emergence intensity and duration, the limit problems and the development trend of graph theory research were investigated in this work. According to the table below, we find that graph theory research in the past decade is divided into two phases, the first being the short two years from 2012 to 2013, in which more than half of the emergent keywords appeared, reflecting the expansion of graph theory research in the application. The second phase is from 2014 to 2021, during which the number of emergent keywords is smaller, but they are often related to algorithmic theory, which reflects the progress of graph theory research in algorithmic optimization of the underlying model in recent years.

Table 7: Distribution of Research Hotspots in Each Stage.

Keywords	Year	2012 - 2021
agent	2012	
anatomical network	2012	



5 CONCLUSIONS

As a classical class of operations research problems, graph theory problems still have sufficient research value and application prospects today. In this paper, we use bibliometric methods and visualization software such as CiteSpace and VOSviewer to conduct descriptive statistics on the number of publications, author information, and publication institutions of graph theory-related literature in the past ten years and conduct keyword emergence analysis to explore the development trend of graph theory problems in recent years.

To summarize, graph theory problems have remained high in popularity in the last decade, used in many fields, such as medicine and chemistry. In the last five years, there has been a wave of underlying optimization designs of algorithmic models. In this process, we find that China, as the main force of research, has a clear lead in both the number of publications and the number of publishing institutions but suffers from two problems: low author centrality and obvious geographical limitations of institutional cooperation, which make it difficult for Chinese scholars' research to have a broader impact often. Therefore, we suggest that China should strengthen the level of cooperation between domestic and foreign research, pay attention to the process of training related talents, and broaden the field of graph theory research applications as much as possible to integrate industry, academia, and research better, and let the benefits of scientific research shade the world.

REFERENCES

Bondy, J. A., & Murty, U. S. R. (1976). *Graph theory with applications* (Vol. 290). London: Macmillan.

Gao, W., Siddiqui, M. K., Naeem, M., & Rehman, N. A. (2017). Topological characterization of carbon graphite and crystal cubic carbon structures. *Molecules*, *22*(9), 1496.

Lei, D., Li, K., Li, L., Chen, F., Huang, X., Lui, S., ... & Gong, Q. (2015). Disrupted functional brain connectome in patients with posttraumatic stress disorder. Radiology, 276(3), 818-827.

Li, W., Su, H., Wei, D., & Wang, K. (2012). Global stability of coupled nonlinear systems with Markovian switching. *Communications in Nonlinear Science and Numerical Simulation*, *17*(6), 2609-2616.

Price, D. J. 1986). *Little science, big science... and beyond* (Vol. 480). New York: Columbia University Press.

Pritchard, A. (1969) 'Statistical Bibliography or Bibliometrics?', Journal of Documentation. 25, 348–349.

Van Raan, A. (2019). Measuring science: Basic principles and application of advanced bibliometrics. In Springer handbook of science and technology indicators. Springer. 237-280.

Wang, C., Dai, J. & Xu, L. (2022). Big Data and Data Mining in Education: A Bibliometrics Study from 2010 to 2022. In *2022 7th International Conference on Cloud Computing and Big Data Analytics*, 507–512.

White, H. D. (2003). Pathfinder networks and author cocitation analysis: A remapping of paradigmatic information scientists. *Journal of the American Society for Information Science and Technology*, *54*(5), 423-434.

Yan, D.; Chen, Y.; Lv, S. & Ma, B. (2022). Research Situation Analysis of Global 3D Printing based on Bibliometrics. In *Proceedings of the 1st International Conference on Public Management and Big Data Analysis*, 269-274.