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BIBLIOMETRIC ANALYSIS OF MATH AND ARTIFICIAL INTELLIGENCE RESEARCH

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Abstract: This study conducts a comprehensive bibliometric analysis to explore the landscape of research in mathematics and artificial intelligence (AI). Using Scopus as the primary data source, we identify key publications and trends in these fields. Through VOSviewer, we visualize networks of keywords and collaborations among researchers and institutions. The analysis reveals the prominence of topics such as AI and mathematics in academic discourse, as well as the central role played by countries like the United States, the United Kingdom, and China in research collaboration. Limitations include potential biases in data sources and the reliance on keywords for analysis. Future research could integrate alternative metrics and qualitative analyses to provide a more nuanced understanding of research trends and impact.

Keywords: Bibliometric analysis, Mathematics, Artificial intelligence, Research trends, Collaboration

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1. Introduction

1.1. Overview of Artificial Intelligence

Artificial Intelligence (AI) has emerged as a transformative technology with the potential to revolutionize various aspects of human life. It encompasses a wide array of techniques that enable machines to simulate human intelligence and perform tasks that typically require human cognition. From automating mundane tasks to making complex decisions, AI has become an indispensable tool across numerous industries and fields.

1.2. Significance of AI

The significance of AI lies in its ability to augment human capabilities and streamline processes, leading to enhanced efficiency and innovation. By leveraging AI, organizations can analyze vast amounts of data to gain valuable insights, make data-driven decisions, and predict future trends. Moreover, AI has the potential to revolutionize sectors such as healthcare, finance, manufacturing, and transportation, offering solutions to complex problems and improving overall quality of life.

1.3. Applications of AI

AI finds applications in various domains, including natural language processing, computer vision, robotics, and data analysis. In natural language processing, AI enables machines to understand and respond to human language, facilitating the development of virtual assistants and language translation tools. In computer vision, AI algorithms enable machines to interpret and analyze visual data, leading to advancements in facial recognition, object detection, and autonomous vehicles. Furthermore, AI-driven robotics has revolutionized industries by enabling the development of autonomous machines capable of performing intricate tasks with precision and efficiency.

1.4. Fundamentals of Machine Learning and its Mathematical Basis

Machine Learning (ML), a subset of AI, forms the backbone of many intelligent systems. It involves the development of algorithms that enable machines to learn from data and make data-driven predictions or decisions. At its core, machine learning heavily relies on mathematical concepts such as linear algebra, calculus, and probability theory (Tyagi and Chahal, 2022).

Linear algebra facilitates the representation and manipulation of data in the form of vectors and matrices, allowing ML algorithms to process and transform data efficiently. Calculus plays a crucial role in optimizing ML models by enabling the calculation of gradients and minimizing error functions during the training process. Moreover, probability theory helps in modeling uncertainties and making probabilistic predictions, which is essential in various machine learning applications such as recommendation systems and predictive analytics (Aggarwal, 2020). By harnessing these mathematical foundations, machine learning algorithms can extract patterns and insights from complex data sets, enabling the development of sophisticated AI systems capable of performing intricate tasks with high accuracy and reliability. In the subsequent sections, we delve deeper into the specific mathematical principles that underpin the functioning of AI, exploring their role in various AI applications and the challenges associated with their implementation.

1.5. Role of Linear Algebra in AI

Linear algebra serves as a fundamental pillar for the development and functioning of various artificial intelligence (AI) applications. Its applications range from data representation and transformation to the optimization of AI models. The use of vectors, matrices, and linear transformations enables AI systems to process and manipulate complex data efficiently, facilitating the extraction of meaningful insights and patterns (Dydak, 2023).

1.6. Data Representation and Transformation

In AI, data is often represented and manipulated in the form of vectors and matrices. Vectors serve as a means to represent individual data points, such as features of an input, while matrices provide a structured way to organize and process data sets. Through vector and matrix operations, AI algorithms can perform tasks such as data preprocessing, feature scaling, and dimensionality reduction, which are essential for enhancing the performance and efficiency of machine learning models (Senaratne and Seneviratne, 2023).

1.7. Model Representation and Transformation

Linear algebra plays a pivotal role in the representation and transformation of AI models. Neural networks, a popular class of AI models, heavily rely on linear algebra operations for their architecture and functioning. Matrices of weights and biases are manipulated during the feedforward and backpropagation phases of neural network training, enabling the model to learn complex patterns and relationships within the data. Through matrix multiplications and activations functions, neural networks can make sophisticated decisions and predictions based on the input data (Wylie and Kamel, 1997).

1.8. Optimization of AI Models

Linear algebra techniques are also instrumental in the optimization of AI models. During the training process, AI algorithms aim to minimize a defined cost or error function. Gradient descent, a widely used optimization algorithm, involves calculating gradients using linear algebra operations to iteratively update the model parameters. By adjusting the weights and biases based on the computed gradients, AI models can converge towards optimal solutions, thereby improving their predictive accuracy and generalization capability (Torres Tello, 2022).

1.9. Eigenvalues and Eigenvectors in AI

Eigenvalues and eigenvectors, another key concept in linear algebra, find applications in various AI tasks, such as dimensionality reduction and principal component analysis (PCA). By computing eigenvalues and eigenvectors of covariance matrices, AI systems can identify the most significant patterns and features within high-dimensional data, facilitating the reduction of data complexity without significant information loss. This process aids in enhancing the interpretability and performance of AI models, particularly in tasks involving large and intricate data sets. By leveraging the principles of linear algebra, AI systems can efficiently process, represent, and optimize complex data, thereby facilitating the development of robust and effective AI applications across diverse domains (Nawaz, 2019).

1.10. Significance of Probabilistic and Statistical Approaches in AI

In the realm of Artificial Intelligence (AI), probabilistic and statistical approaches play a critical role in enabling machines to make informed decisions, predictions, and inferences based on data. By leveraging these approaches, AI systems can handle uncertainties, model complex relationships within data, and make rational decisions in various real-world scenarios.

1.11. Bayesian Inference and Decision Making

Bayesian inference forms a cornerstone of probabilistic AI, allowing systems to update their beliefs based on new evidence or data. By incorporating prior knowledge and incorporating observed data, AI models can compute posterior probabilities, enabling the assessment of the likelihood of various outcomes. This process is instrumental in decision-making tasks, as it allows AI systems to make rational decisions by considering both prior knowledge and new information (Golchi and Willard, 2023).

Probability Distributions in Modeling Uncertainties

Probability distributions serve as powerful tools in AI for modeling uncertainties and capturing the variability of data. By fitting probability distributions to observed data, AI models can quantify the likelihood of different outcomes, enabling the assessment of risks and uncertainties associated with decision-making processes. Common distributions such as the Gaussian (normal) distribution, Bernoulli distribution, and Poisson distribution find widespread applications in tasks such as risk assessment, anomaly detection, and predictive modeling (Ismail and Wediawati, 2023).

1.12. Statistical Analysis and Pattern Recognition

Statistical analysis forms the backbone of pattern recognition and data-driven decision-making in AI. By employing statistical techniques such as hypothesis testing, regression analysis, and analysis of variance (ANOVA), AI systems can identify meaningful patterns and relationships within complex data sets. These statistical methods facilitate the extraction of actionable insights from data, enabling AI models to make accurate predictions and classifications in tasks such as image recognition, natural language processing, and predictive analytics (Wang et al., 2018).

1.13. Probabilistic Graphical Models for Complex Inferences

Probabilistic graphical models provide a powerful framework for representing and reasoning under uncertainty in AI systems. By utilizing graphical models such as Bayesian networks and Markov random fields, AI models can capture complex dependencies and relationships among variables, facilitating the representation of causal relationships and making sophisticated inferences about the underlying data. These models enable AI systems to handle complex decision-making tasks and perform probabilistic reasoning in scenarios involving interconnected variables and uncertain relationships (Pitkow and Angelaki, 2017).

1.14. Importance of Statistical Learning Theory

Statistical learning theory forms the theoretical basis for understanding the behavior and performance of AI algorithms. By leveraging concepts such as bias-variance trade-off, model complexity, and generalization error, AI practitioners can develop robust and reliable AI models with optimal predictive performance. This theoretical framework guides the selection of appropriate learning algorithms, model architectures, and regularization techniques, ensuring the development of AI systems that can generalize well to unseen data and adapt to changing environments. By integrating probabilistic and statistical approaches into AI systems, researchers and practitioners can build robust, adaptive, and reliable AI models capable of handling uncertainties and making informed decisions in dynamic and complex environments (Tsiamis et al., 2023).

1.15. Unraveling the Calculus of AI: The Subtle Dynamics at Play

Amid the burgeoning realm of artificial intelligence (AI), the intricate application of calculus stands as the bedrock of numerous cutting-edge algorithms and models. From optimization techniques to gradient-based learning, calculus serves as the fundamental framework that empowers AI systems to adapt, learn, and evolve within complex and dynamic environments (Zhenpeng, 2024).

1.16. The Power of Derivatives in Gradient Descent

At the heart of AI lies the omnipotent concept of derivatives, enabling the optimization of various AI models through gradient descent algorithms. By calculating derivatives with respect to model parameters, AI systems can iteratively adjust their internal configurations to minimize errors and enhance predictive accuracy. This iterative process, guided by the principles of calculus, enables AI models to traverse the multidimensional landscape of loss functions, steering them towards the global or local optima that signify the convergence of optimal solutions (Lin et al., 2024).

1.17. Chain Rule and Backpropagation in Neural Networks

The intricate dynamics of neural networks are governed by the calculus-based technique of backpropagation, which relies on the fundamental principle of the chain rule. Through the systematic propagation of errors backward across the network, the chain rule facilitates the computation of gradients with respect to each layer's parameters, enabling the network to refine its weights and biases based on the calculated error gradients. This recursive application of the chain rule empowers neural networks to learn complex representations and discern intricate patterns within vast and multidimensional datasets (Liu, 2024).

1.18. Integral Calculus for Probability Distributions

In the realm of probabilistic modeling and inference, the integration of calculus through probability density functions enables AI systems to effectively quantify uncertainties and make informed decisions. By leveraging integral calculus to compute the cumulative distribution functions and probabilities associated with various events, AI models can assess the likelihood of specific outcomes and make probabilistic inferences that drive robust decision-making processes (Pap, 2021).

1.19. Partial Derivatives and Multivariable Optimization

The seamless integration of partial derivatives in the optimization of multivariable functions facilitates the fine-tuning of AI models to perform efficiently in high-dimensional spaces. By computing partial derivatives with respect to multiple variables, AI systems can navigate complex landscapes of objective functions, allowing for the identification of optimal parameter configurations that maximize performance and minimize error rates. This multidimensional approach to optimization, rooted in the principles of calculus, empowers AI models to exhibit adaptability and resilience in addressing diverse and dynamic real-world challenges.

In essence, the profound influence of calculus on the evolution and advancement of AI underscores the indispensability of mathematical rigor in shaping the trajectory of intelligent systems. By delving deeper into the intricate interplay between calculus and AI, researchers and practitioners can unlock transformative insights that transcend conventional boundaries, propelling the landscape of AI-driven innovations into uncharted realms of possibility (Pal and Kaushik, 2023).

2. Materials and Methods

2.1. Data Analysis

This article employs bibliometric analysis to examine publications related to mathematics and artificial intelligence (AI). Bibliometrics refers to the mathematical and statistical analysis of specific data in scientific communication, focusing on the examination of data such as authors, topics, cited authors, and cited sources in a statistical manner. This approach enables us to understand the general structure of a particular discipline through the statistical outcomes of such data.

In this context, our study investigates bibliometric variables including the total number of publications concerning mathematics and AI, the languages of these publications, types of documents, author affiliations, institutions of authors, journals cited, active countries, citation counts, types of sources cited in articles, and keyword analysis. A keyword network map was created using the Vosviewer software, a computer program designed for generating and visualizing bibliometric maps. Through this process, the study examines the literature in the fields of mathematics and AI, identifying significant topics and trends within these areas, and supports these findings with bibliometric analyses.

2.1. Methodology

This research aimed to explore the topic of "Mathematics and artificial intelligence" by utilizing the Scopus Index. To conduct the study, the keywords "mathematics, artificial intelligence" were searched across the database within the fields “Abstract title, Abstract, Keywords”,. The research was conducted in a chronological order, ranging from the most recent to the oldest studies.

No modifications were made during the research, and the current situation was examined as is. Therefore, a Scanning Model was employed due to its ability to handle large datasets, and the research was carried out using the General Scanning Model. Bibliometric methods were utilized to perform the analyses. Within the scope of the research, the keywords "mathematics, artificial intelligence" were employed in the SCOPUS Index. These keywords generated a dataset of 6,298 records in Scopus, which constituted the universe of this scientific study.

All the studies from Scopus were examined based on bibliometric data such as authors, publications, citations, keywords, and publication dates. These 6298 studies were downloaded in CSV file format and network maps were created using the Vosviewer software for further analysis.

2.1. Collecting Data

This research initially focused on mathematics but then shifted its focus upon finding 78,607 publications under the 'math' keyword in Scopus. To refine the investigation, a detailed query was conducted using keywords such as "mathematics and artificial intelligence." This resulted in the selection of 6286 publications from Scopus, which were subsequently exported in CSV format for analysis. The exported data was prepared for analysis using the Vosviewer software and was stored in both Excel and RIS formats for further examination.

3. Results and Discussion

3.1. Scopus Database and Analysis of Obtained Values

Scopus is a multidisciplinary database provided by Elsevier, offering access to a wide range of scientific literature; it equips researchers with intelligent tools for analyzing journals, monitoring research outcomes, and visualization. This platform boasts a rich content base that includes peer-reviewed journals, books, and conference publications, continuously updated and expanded to meet the extensive information needs of researchers.

3.2. Scopus Data

A search was conducted in Scopus using the keywords "mathematics, artificial intelligence" within the fields “Abstract title, Abstract, Keywords”, resulting in a total of 6298 documents. The research was carried out on November 21, 2024, and the findings from these search results were analyzed accordingly. Table of documents per year is presented in Table 1.

Table 1. Table of documents per year

Year	Documents
2025	2
2024	266
2023	241
2022	218
2021	284
2020	307
2019	328
2018	435
2017	370

For the year 2025, a total of 2 documents have been cataloged, indicating the data may be partial as the year is ongoing. In 2024, there were 266 documents, which show a substantial increase and possibly reflect a growing interest or advancements in the fields of mathematics and artificial intelligence.

The year 2023 had 241 documents, a solid number that could signify sustained research activity within the respective areas. In 2022, the count was at 218 documents, which may suggest a steady engagement with the topics, albeit with a slight decrease from the previous year. The year 2021 saw 284 documents published, which might indicate a dip in research output, possibly due to global events affecting academic productivity. For 2020, the document count was 307, representing what may be a normal fluctuation in research publications year over year.

The year 2019 had 328 documents, a figure that aligns with the general output trends of the previous years. In 2018, there were 435 documents, showing an increase that might point to changes in research focus or funding landscapes. The year 2017 had 370 documents, which was lower compared to the subsequent years, suggesting a period of less activity or emerging interest in the topics. Finally, in 2016, there were 450 documents, which might reflect the early stages of growing academic attention in the fields of math and artificial intelligence for that decade. Table of documents per year by source is presented in Table 2. The table provides a breakdown of the number of documents per source in a given dataset.

•Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): This source, which includes various subseries, is the most prolific, contributing 920 documents. It suggests a strong emphasis on computer science and its subfields, especially artificial intelligence and bioinformatics, indicating an interdisciplinary approach within the realm of computational research.

•Lecture Notes In Artificial Intelligence Subseries of Lecture Notes In Computer Science: With 117 documents, this source is a significant contributor to the field of artificial intelligence, showcasing a specialized focus on AI research.

•Advances in Intelligent Systems and Computing: The presence of 103 documents from this prestigious interdisciplinary journal indicates the high relevance and impact of research at the intersection of computing and intelligent systems.

•International Joint Conferences on Artificial Intelligence (IJCAI): The inclusion of 96 documents from IJCAI highlights its critical role in the academic and professional development of Artificial Intelligence (AI). These conferences serve as essential platforms for researchers and practitioners to engage in networking, foster collaboration, and disseminate knowledge. The outcomes of these events are widely shared through high-quality proceedings, books, and other educational materials.

•Proceedings of The National Conference on Artificial Intelligence: This outlet has 91 documents, are one of the most prestigious venues in the field. These proceedings document significant advancements in AI research, spanning diverse topics such as machine learning, robotics, natural language processing, and reasoning.

Serving as an essential resource for academics, professionals, and students, the proceedings enable the dissemination of innovative methodologies, theoretical breakthroughs, and practical applications. They not only reflect the state-of-the-art in artificial intelligence but also foster dialogue and collaboration within the global AI research community

•ACM International Conference Proceeding Series: The 74 documents from this series reflect the contribution of conference proceedings, which typically include cutting-edge research presented at ACM conferences, emphasizing innovation and current trends in computer science and related areas.

•CEUR Workshop Proceedings: This outlet has 73 documents, pointing towards a significant number of research works being disseminated through workshops, which are often more focused on recent developments and community engagement in research.

•Communications in Computer and Information Science: This source, with 68 documents, indicates its role in providing a platform for disseminating research related to computer science and the processing of information, which likely includes intersections with mathematical algorithms and AI methodologies.

Table 2. Table of documents per year by source

Source	Documents
Lecture Notes in Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics	920
Lecture Notes In Artificial Intelligence Subseries Of Lecture Notes In Computer Science	117
Advances In Intelligent Systems And Computing	103
Ijcai International Joint Conference On Artificial Intelligence	96
Proceedings Of The National Conference On Artificial Intelligence	91
ACM International Conference	74

The data implies a vibrant and diverse landscape of research outputs across various platforms, ranging from academic journals to conference proceedings, indicating a robust and interdisciplinary research community. Table of documents by subject area is presented in Table 3.

The table categorizes documents by their respective subject areas, illustrating the interdisciplinary reach of the research fields of computer science, mathematics, and related domains:

•Computer Science: With 4,771 documents, this subject area tops the list, underscoring computer science as a central field of study, possibly due to its broad applicability and integration with artificial intelligence.

•Mathematics: The 1,927 documents in this area highlight mathematics as a foundational discipline that supports and intersects significantly with fields like AI and engineering.

•Engineering: Featuring 1,592 documents, engineering showcases the practical applications and design aspects that often incorporate mathematical and computational methods.

•Environmental Science: The 387 documents reflect the use of computational and mathematical tools in addressing environmental challenges and studying ecological phenomena.

•Social Sciences: With 387 documents, this field illustrates the impact and relevance of computational methods and mathematical modeling in areas like psychology, sociology, and economics.

•Decision Sciences: This area, with 301 documents, emphasizes the role of quantitative methods and AI in making informed decisions within various sectors, such as business and policy-making.

•Medicine: The 257 documents suggest an intersection of computational methods with medical research, such as in biostatistics or health informatics.

•Energy: With 217 documents, this category highlights the application of computational methods and artificial intelligence in addressing challenges in energy

production, distribution, and sustainability.
•Physics and Astronomy: Accounting for 217 documents, these sciences employ mathematical models and computational simulations to understand the physical universe.
• Earth and Planetary Sciences: This category contains 193 documents demonstrating the use of computer tools and artificial intelligence to investigate complex geological and planetary phenomena. This field's research includes advances in climate modeling, remote sensing, seismic analysis, and planetary exploration. These contributions improve our ability to investigate Earth's systems, predict natural disasters, and explore other celestial bodies, encouraging a more in-depth understanding of both our planet and the larger cosmos through data-driven insights and novel approaches.
•Biochemistry, Genetics and Molecular: This field, with 162 documents, indicates the use of computational biology and bioinformatics in studying complex biological systems and genetic materials.
This distribution showcases the pervasive nature of mathematical and computational techniques across various disciplines, indicating their essential role in advancing research and contributing to diverse fields of knowledge.

Table 3. Table of documents by subject area

Subject Area	Documents
Computer Science	4771
Mathematics	1927
Engineering	1592
Environmental Science	387
Social Sciences	387
Decision Sciences	301
Medicine	257
Energy	217
Physics and Astronomy	217

Table of documents by type is presented in Table 4. The table categorizes documents by type, which reflects the various formats of scholarly communication in the dataset:
•Conference Paper: There are 4,000 conference papers, this is the most common type, signifying a significant contribution from conference proceedings. These papers often present preliminary findings, innovative ideas, or work-in-progress research and are essential for scholarly exchange in academic conferences.
•Article: With 2,039 documents, indicating that full-fledged, peer-reviewed articles constitute the bulk of the research output. Articles are typically detailed studies reporting original research, comprehensive studies, or theoretical discussions.
•Review: There are 94 review documents, which are likely comprehensive analyses of literature in a particular field. Reviews synthesize existing research, identify trends, and often highlight areas for future exploration.
•Note: With 39 documents, notes are generally short descriptions or announcements of preliminary research findings, corrections, or updates to previous work.
•Book Chapter: The presence of 31 book chapters suggests that compilations of research works in the form of book sections also form a substantial part of the academic discourse. Book chapters allow authors to delve into specific topics in detail within a broader thematic collection.
•Conference Review: There are 26 conference reviews, which may provide overviews or critiques of conference themes, organization, or individual presentations, offering insights into the conference's contribution to the field.
•Editorial: The table shows 22 editorials, which are typically written by the editors of journals or books and may discuss the direction of the research field, comment on current trends, or provide context for the collection of works.
•Book: With 15 documents, books are authored or edited volumes that cover extensive research topics or present comprehensive knowledge in a field. They are valuable for in-depth understanding and often serve as key resources for academics and practitioners.
•Short Survey: With 7 documents, short surveys provide concise overviews of specific research areas, highlighting key developments, challenges, and future directions. These documents are instrumental for readers seeking a quick yet insightful understanding of a topic, serving as valuable references for both newcomers and experienced researchers aiming to stay updated in their fields.
•Letter: Also with 6 documents, letters are brief written communications that may discuss recent research, comment on previously published works, or present small-scale studies.
The distribution of these document types highlights the diversity of research outputs and the various means through which scholars communicate their findings and contribute to their respective fields.

Table 4. Table of documents by type

Document Type	Documents
Conference Paper	4000
Article	2039
Review	94
Note	39
Book Chapter	31
Conference Review	26
Editorial	22
Book	15
Short Survey	7

3.3. Bibliometric Analysis and Visualization of Results Obtained from VOSviewer

Bibliometric analysis is a methodological approach that applies quantitative analysis and statistics to written communication such as publications. It is used to map and evaluate academic literature, tracking the influence and spread of research through citations and revealing patterns of collaboration among authors and institutions. This analysis can identify key trends, prolific authors, and geographic distributions within a field. The technique has evolved to include complex network analyses, exploring relationships between various academic outputs, and has spread beyond library science to multiple disciplines. It is instrumental in understanding the landscape of scholarly communication and the impact of research within and across fields (Mejia et al., 2021).

3.4. VOSViewer

VOSviewer is a tool developed specifically for constructing and visualizing bibliometric networks, which include citation, co-citation, bibliographic coupling, keyword co-occurrence, and co-authorship networks. This software is particularly noted for its graphical representation capabilities, which are essential for displaying large bibliometric maps in an easy-to-understand manner. Its use in exploratory research is quite significant, as it enables researchers to identify and display the relationships between various scientific outputs like publications, researchers, or concepts within a particular field.

The significance of VOSviewer in academia stems from its ability to facilitate preliminary studies that can guide subsequent, more formal research. By visualizing data from sources such as Scopus, researchers can examine co-occurrence data among publications and uncover patterns that may not be immediately apparent through traditional analysis. This not only opens new avenues of inquiry but also enhances the understanding of a field's landscape, showcasing the main actors, networks, and thematic concentrations.

Moreover, VOSviewer has been integrated into various research methodologies and has found a place in research evaluation and management contexts, helping to map out the scholarly activities and collaborations within and across disciplines. Its application extends to various academic domains, making it a versatile tool for those interested in exploring scientific data visually. The developers of VOSviewer, affiliated with Leiden University's Centre for Science and Technology Studies (CWTS), offer courses that provide in-depth training in science mapping techniques, highlighting the tool's importance and application in the broader research management and evaluation sphere (Kirby, 2023).

3.5. VOS Viewer- co-occurrence of keywords

In the intricate world of research, bibliometric analysis stands as a powerful tool, providing insights through the quantitative evaluation of academic literature. The visual representations of such analyses can uncover the depth and spread of knowledge across various fields, making complex data more comprehensible. The upcoming images and their subsequent explanations aim to delve into this process, showcasing the capabilities of VOSviewer, software instrumental in mapping and visualizing scientific landscapes through its analysis of keyword occurrences and co-occurrences. This process is described below (Figure 1).

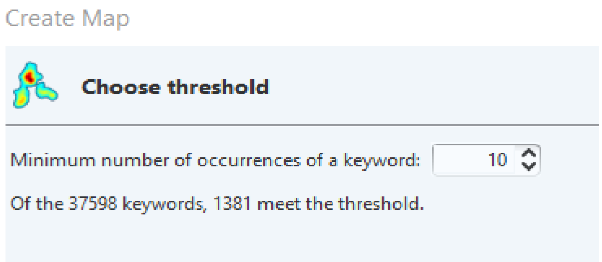

Figure 1. Choose threshold screen.

This image from VOSviewer is displaying the interface where a threshold is set for keyword occurrences in a bibliometric analysis. The user has selected a minimum number of 10 occurrences for a keyword to be included in the analysis. Out of 37,598 keywords, 1,381 meet this threshold, indicating that they appear at least 10 times in the dataset under examination. This thresholding step is crucial in bibliometric analysis as it helps to focus on the most relevant and frequently occurring terms, ensuring that the resulting visualization represents the most significant data points.

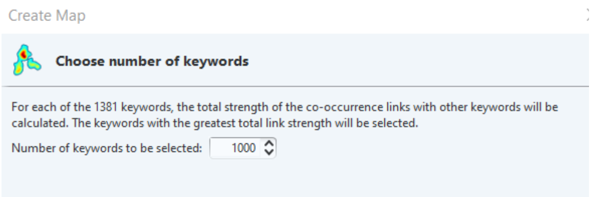

Figure 2. Choose number of keywords screen.

Choose number of keywords screen is presented in Figure 2. In this image from VOSviewer, it's explained that for the set of keywords that passed the previously determined threshold, the software will calculate the total strength of the co-occurrence links between them. Keywords with the highest total link strength will be selected for further analysis. The number to be selected has been set to 270, which is presumably the total number of keywords that met the initial threshold. This selection process is key in identifying the most significant and interconnected terms within a dataset, which are crucial for in-depth bibliometric analysis and visualization.

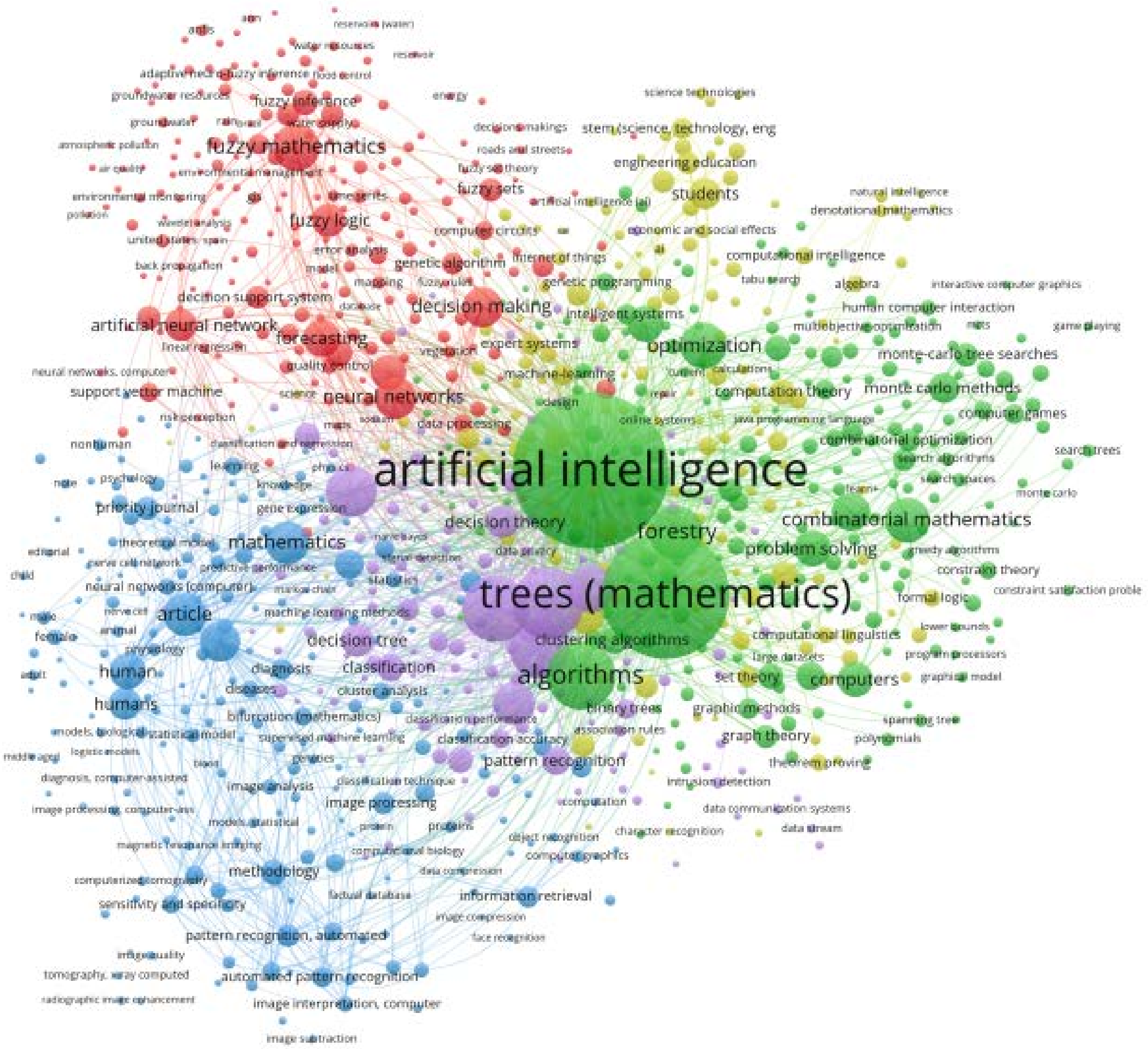

Figure 3. Network visualization.

This is a network visualization map (Figure 3) from VOSviewer, showing the relationships between different keywords in a bibliometric dataset. The largest, most central nodes, such as "artificial intelligence" and "mathematics," represent the most frequently occurring and therefore most significant keywords within the research field being analyzed. The lines connecting the nodes are indicative of the keywords' co-occurrence within the same papers, suggesting thematic linkages. The closer the nodes are to each other, the stronger their relatedness in the literature, suggesting sub-fields or areas of concentrated study within the broader topics.

Overlay visualization is presented in Figure 4. The image depicts a bibliometric network visualization, specifically an overlay visualization, where each node represents a keyword. The size of a node indicates the frequency of the keyword in the dataset, while the lines between nodes represent co-occurrence relationships. Colors likely correspond to different years or time intervals, showing the evolution of topics over time. For instance, larger nodes like "artificial intelligence," "mathematics," and "learning systems" suggest these are central themes within the field, and their connections to other keywords reveal interrelated research areas. The overlay of colors across the network could indicate the historical progression of research emphasis from one year to another.

Density visualization is presented in Figure 5. This image appears to be a density visualization map from bibliometric analysis software such as VOSviewer. It represents a density distribution of keywords within a specific academic field, where areas of higher keyword concentration are depicted with a brighter or more intense color. Such visualizations help identify the most researched areas or hot topics within a field. Keywords like "artificial intelligence," "learning systems," and "trees (mathematics)" are prominently placed and likely represent key research focuses due to their size and central location in the visualization.

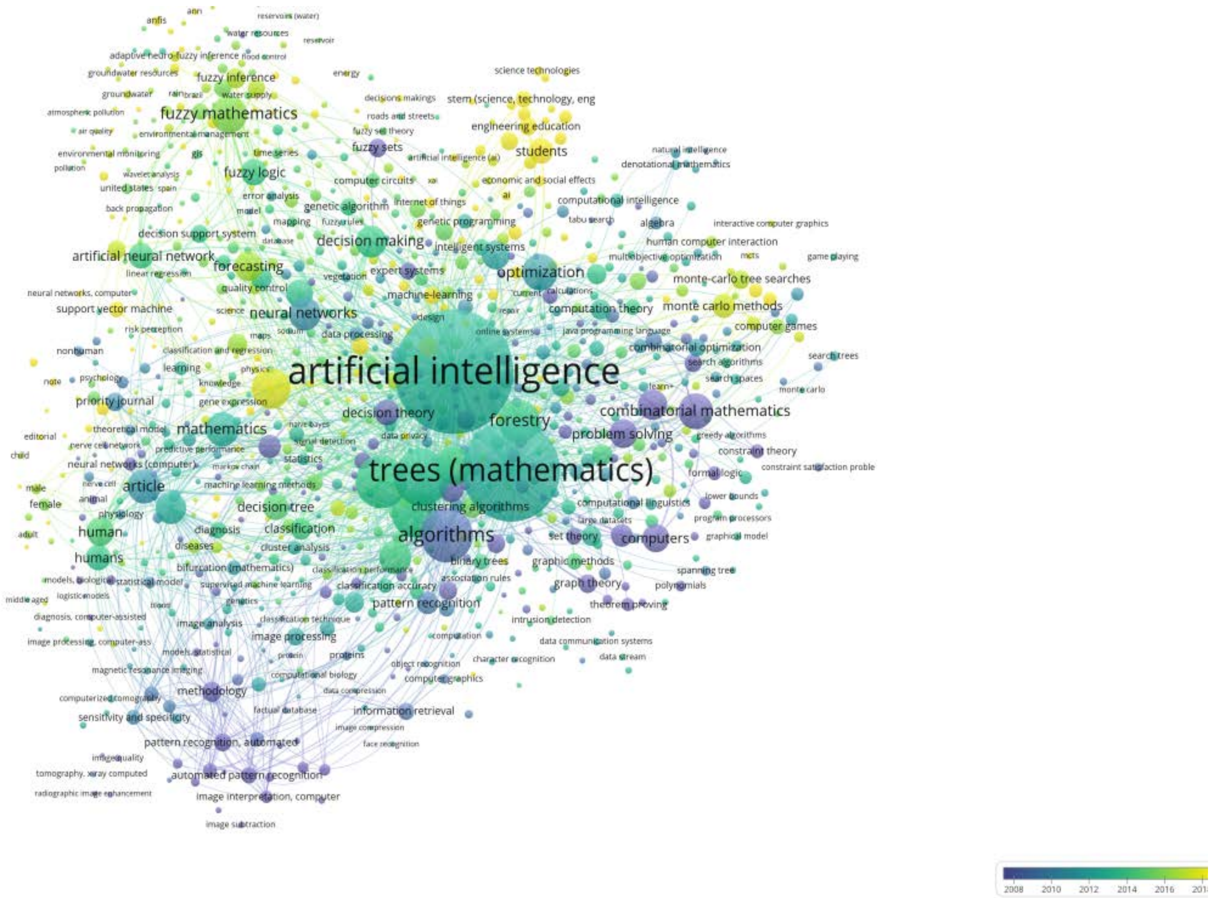

Figure 4. Overlay visualization.

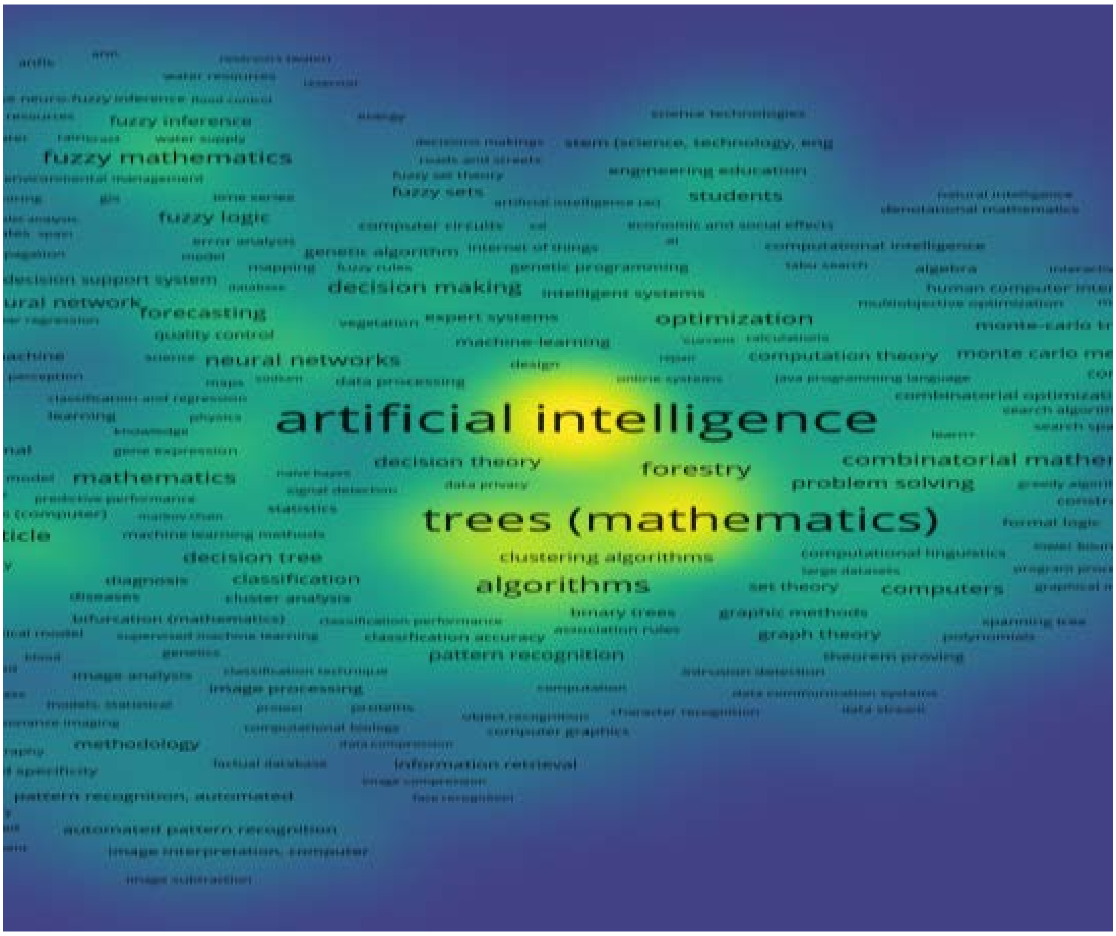

Figure 5. Density visualization.

Each node represents a country, with the node size likely corresponding to the volume of publications or level of activity. The lines indicate collaboration or relationship strength; the thicker and more numerous the lines, the stronger the connections. Central nodes like the United States, China, India, and United Kingdom suggest these countries are major hubs in the network, indicating they may have higher levels of international collaboration or output.

The image shows a network visualization typically used to illustrate international collaboration based on academic publications or similar data. The various nodes represent different countries, and the size of each node may signify the volume of research output or the level of collaborative activity of that country. The lines connecting the nodes denote collaborations between countries, with thicker lines indicating stronger or more numerous collaborations. The colors along the lines and nodes may represent different years, illustrating the evolution of collaboration over time, with newer years possibly represented by cooler colors and older years by warmer colors. Countries with a central position and larger nodes, like the United States, China, India, Germany and United Kingdom are often key players with extensive international collaborations.

Figure 6 and 7 are network visualizations that depict connections, but they differ in their focus and perhaps in the data they represent. The first image seems to be a keyword co-occurrence visualization, showing the relationships between different research topics. The second image looks like it visualizes the collaboration between countries, possibly in research or academic publishing. The color coding could also indicate changes over time or the intensity of activity in both images, but the specific application of the color gradient may vary between them.

Figure 6. Distribution of connections between countries- network visualization.

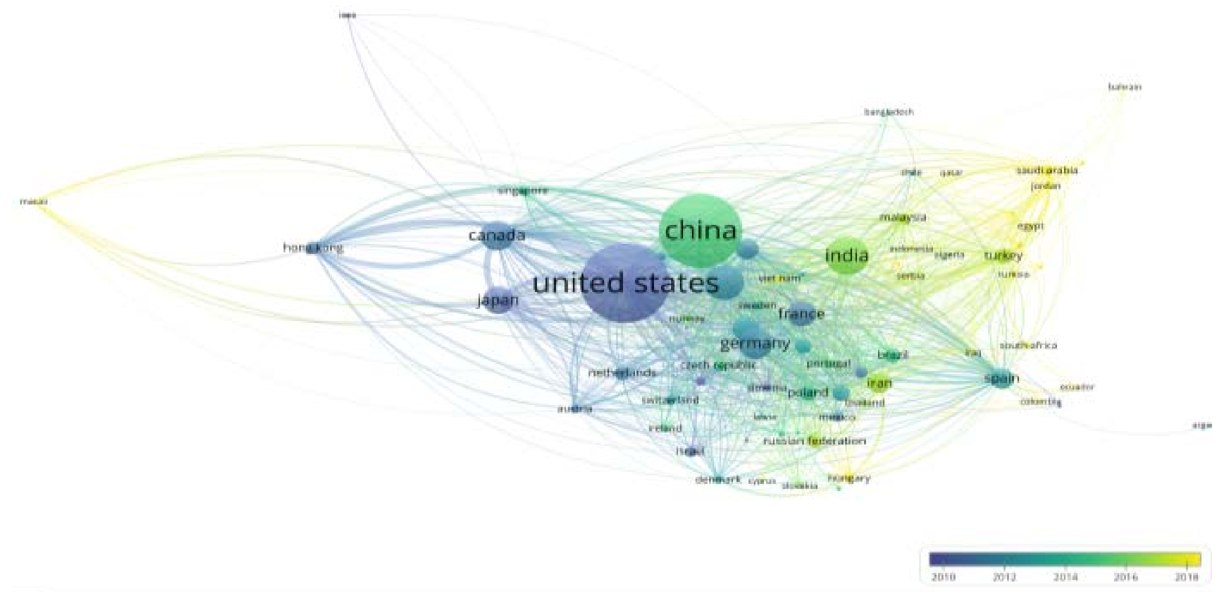

Figure 7. Distribution of Connections Between Countries- Overlay visualization

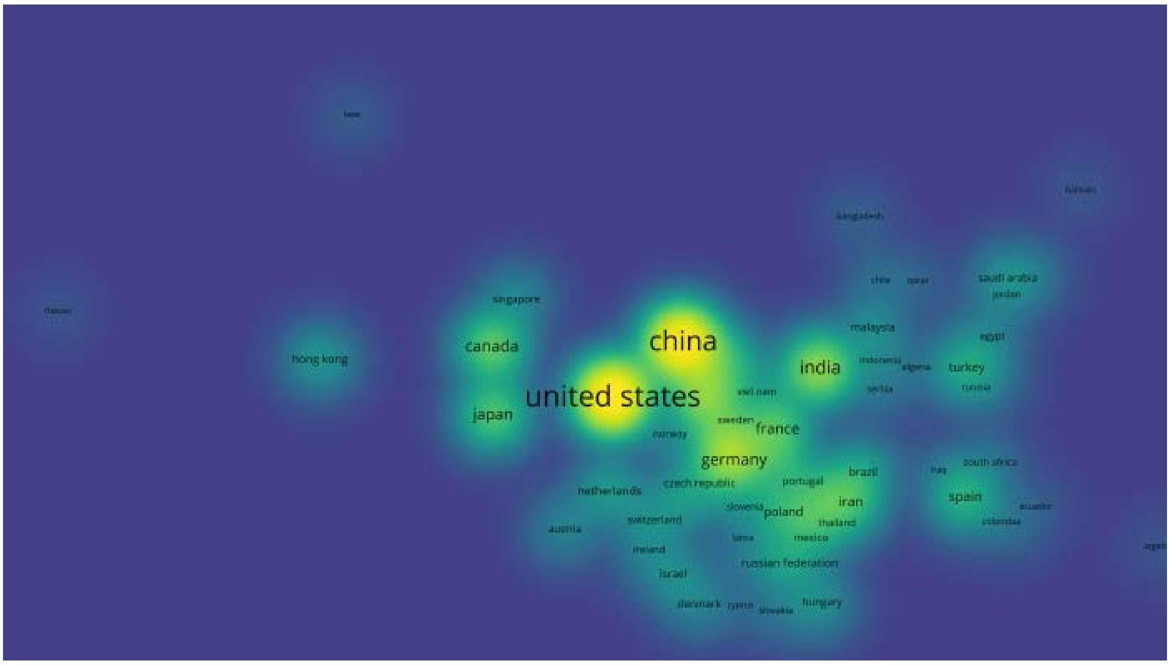

Figure 8. Density visualization

This image (Figure 8) is a density visualization map, which is used to represent the intensity and concentration of connections between entities—in this case, countries. It highlights areas of high activity or interaction by the brightness or density of color. In such visualizations, commonly seen in bibliometric analyses, the areas where the color is most intense typically indicate higher levels of collaboration or publication output. The map does not show the individual lines between countries, focusing instead on the overall pattern of activity. This type of visualization is useful for identifying which countries are most central or active in a given context, such as scientific research, based on the dataset analyzed.

4. Conclusion

Throughout this investigation, we have engaged in a meticulous examination of the interconnected landscape that underpins research in mathematics and artificial intelligence (AI). Initiating the inquiry with a bibliometric approach, we delved into Scopus, a comprehensive repository of scientific output, to extract data using specific keywords that embody our research focus. The deployment of VOSviewer software facilitated the exploration of this data, bringing to light the complex networks of keywords and the international collaborations they entail.

In analyzing the visualizations generated by VOSviewer, we observed the dominance of certain keywords, such as "artificial intelligence" and "mathematics," highlighting their centrality within the academic discourse. The country collaboration network revealed the strategic importance of the United States, China, India, and United Kingdom underscoring the geographical nodes of prolific scientific production and exchange. The shift from individual connections to a density visualization further illuminated the broader patterns of international research engagement.

From these insights, one can extrapolate the trajectory of future research directions and international collaboration trends. This analysis underscores the value of bibliometric methods in gauging the pulse of academic progress. Recommendations stemming from this study could advocate for a strengthened focus on emerging areas where AI intersects with other disciplines, the fostering of collaborative networks, and the promotion of research initiatives that address gaps identified in the less connected regions. The dynamism depicted in these visual representations is a testament to the ever-evolving nature of the scientific endeavor, where cross-disciplinary synergy and global cooperation are not only beneficial but necessary for impactful advancements.

Research limitations and further research

Research limitations in bibliometric studies often stem from the data sources themselves—databases may not be comprehensive, leading to potential bias. Another limitation is the reliance on keywords, which can miss nuances in research themes or fail to capture emerging trends not yet solidified in the lexicon. Future research could expand by integrating alternative metrics such as altmetrics, which consider the impact of research in online and social media platforms, to provide a more holistic view of research influence. Moreover, qualitative analyses could complement the quantitative focus of bibliometric methods, capturing the substance behind the statistics.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	Ş.B.U.	N.M.M.	İ.D.A.
C	40	30	30
D	40	30	30
S	40	30	30
DCP	40	30	30
DAI	40	30	30
L	40	30	30
W	40	30	30
CR	40	30	30
SR	40	30	30
PM	40	30	30
FA	40	30	30

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

This study is a bibliometric analysis that includes a systematic review of the existing literature and does not involve human or animal subjects.

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