

Exploring the Impact of Computational Algebra: A Bibliometric Perspective on Research Growth

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Abstract

This bibliometric analysis examines the impact of Computational Algebra on the fields of mathematics and computer science. Computational Algebra is the discipline that develops and applies algorithmic methods and computer software to perform symbolic computations and solve problems within algebraic structures. The study leverages the Scopus bibliographic database to extract comprehensive publication data. Advanced software tools such as Biblioshiny and VOSviewer were utilized to visualize and analyze the data. Annual scientific productions were scrutinized to reveal the evolution and growth trajectory of the field. The analysis identified the most relevant authors and sources, highlighting key contributors and influential journals. A Three-Field Plot was generated to illustrate the relationships between authors, publication sources, and countries. Trend topics and thematic maps were constructed to uncover emerging research themes and evolving scholarly interests. Network visualizations of co-citation among cited authors provided insights into the intellectual structure of Computational Algebra research. Finally, the co-occurrence of author keywords and network visualizations of country collaborations further demonstrated the interdisciplinary nature and global reach of the field.

Keywords: Computational Algebra, Bibliometric Analysis, Biblioshiny, VOSviewer

1. Introduction

Computational algebra is a dynamic and evolving branch of mathematics that synthesizes abstract algebraic concepts with algorithmic methodologies to solve complex algebraic problems [1], [2]. It builds upon the traditional theories of groups, rings, fields, and other algebraic structures, and harnesses the power of modern computing to facilitate the exact, symbolic manipulation of mathematical expressions [3], [4]. In this realm, the challenge is not only to understand the underlying algebraic systems but also to develop efficient algorithms capable of handling large and intricate computations that would otherwise be unmanageable by hand [5], [6]. As a result, computational algebra stands at the intersection of pure mathematics, computer science, and engineering, making it a critical tool for both theoretical research and practical applications in today's technologically driven world [7], [8].

The roots of computational algebra can be traced back to the early days of abstract algebra, when mathematicians began formalizing the study of algebraic structures during the 19th and 20th centuries [9], [10]. As these foundational theories evolved, researchers encountered increasingly complex problems that required innovative computational techniques [3]. The advent of digital computers in the mid-20th century revolutionized the field, enabling the practical implementation of algorithms for tasks such as polynomial factorization, solving systems of equations, and analyzing symmetries [5]. The development of early computer algebra systems marked a significant turning point, as they provided a new paradigm for exploring and validating algebraic theories through computational experiments [2], [6]. These

pioneering efforts not only bridged the gap between abstract theory and computation but also set the stage for the sophisticated methods used in modern research [4].

At the heart of computational algebra lies the concept of symbolic computation, which distinguishes itself from numerical approaches by preserving exactness in mathematical expressions [11], [12]. Symbolic computation manipulates formulas and expressions in their inherent algebraic form, ensuring that precision is maintained throughout the calculation process [13], [14]. This is particularly important for tasks such as computing Gröbner bases, performing polynomial ideal operations, and executing factorization algorithms, where even minor numerical approximations can lead to significant errors or misinterpretations [15]. By leveraging efficient data structures and advanced algorithmic techniques, researchers are able to simplify complex expressions and uncover deep structural insights within algebraic systems [16], [17]. This meticulous handling of algebraic data not only enhances the accuracy of the results but also enriches our understanding of the underlying mathematical phenomena [14].

The applications of computational algebra extend far beyond the realm of theoretical mathematics, impacting a diverse array of scientific and technological disciplines [18]. In cryptography, for instance, algebraic algorithms underpin many encryption schemes that safeguard digital communications, ensuring data integrity and security in an increasingly connected world [19], [20]. Coding theory also relies heavily on these methods to design robust error-correcting codes, which are essential for reliable information transmission across noisy channels [21]. Additionally, fields such as robotics, control theory, and computational biology benefit from the precision and efficiency of computational algebra when modeling complex systems and solving non-linear equations [9], [22]. By providing a rigorous framework for problem-solving, computational algebra has become instrumental in driving innovations and solving practical challenges across multiple domains [23], [24].

Looking ahead, the future of computational algebra is poised for further breakthroughs as advancements in both computational power and algorithm design continue to evolve [25], [26]. Emerging technologies, including quantum computing and machine learning, present exciting new opportunities for applying algebraic methods to problems that were once considered intractable [27]. Researchers are actively developing more sophisticated tools to tackle high-dimensional and non-linear systems, promising to extend the capabilities of computer algebra systems even further [28], [29]. Interdisciplinary collaborations will likely foster innovative approaches that merge theoretical insights with practical applications, ensuring that computational algebra remains at the forefront of scientific discovery and technological progress [30]. As the field continues to mature, its role in addressing complex real-world challenges will only become more prominent, solidifying its importance in the broader landscape of modern mathematics and applied science [31].

Bibliometric analysis serves as a powerful lens through which the evolution and structure of research fields can be understood, and its application to computational algebra is particularly illuminating [32], [33]. Computational algebra, a field that marries abstract algebraic theories with modern computational methods, has witnessed rapid growth as both theoretical frameworks and computational capabilities have advanced. Through bibliometric methods, we can quantitatively assess publication trends, authorship patterns, and thematic developments, thereby gaining a clearer picture of how the field has evolved over time [34], [35].

In this study, two advanced tools—biblioshiny and VOSviewer—are employed to perform a comprehensive bibliometric analysis [36], [37]. Biblioshiny, a web-based interface of the bibliometrix R package, facilitates in-depth statistical analysis and visualization of bibliographic data [38], [39], [40]. Meanwhile, VOSviewer offers robust visualization capabilities that enable the mapping of co-authorship networks, keyword co-occurrences, and citation linkages [41], [42]. Together, these tools complement one another by combining rigorous quantitative metrics with intuitive graphical representations, providing a multidimensional view of research dynamics within computational algebra.

The scope of the study encompasses a wide range of bibliometric indicators derived from a curated dataset of scholarly publications related to computational algebra. This includes an analysis of publication outputs over a specified time period, identification of leading authors and influential institutions, and the mapping of thematic clusters based on keyword co-occurrence. The study also delves into citation patterns and collaborative networks, offering insights into both the intellectual and social structure of the field. By setting these parameters, the analysis aims to capture the global research landscape and highlight both historical milestones and emerging trends in computational algebra.

Ultimately, the integration of biblioshiny and VOSviewer in this bibliometric study not only enhances our understanding of the current state of computational algebra but also provides a roadmap for future research directions. The insights drawn from this analysis are expected to inform researchers, funding agencies, and policy-makers about the critical areas of growth and potential collaborative opportunities within the field. By systematically dissecting the scholarly output, the study lays the groundwork for a more informed and strategic approach to advancing computational algebra research in the coming years.

2. Materials and Methods

We extracted scientific publications pertinent to our investigation from the Scopus database [43], [44] by employing a TITLE-ABS-KEY query for "Computational Algebra." The search, unrestricted by language, encompassed a range of sources including peer-reviewed journal articles, book chapters, and conference papers. In total, our dataset comprised 313 articles drawn from 204 distinct sources spanning the period from 1981 to 2023. To ensure data integrity, we meticulously screened the Scopus records to eliminate duplicates, saved the refined results in a CSV file, and then conducted a bibliometric analysis using VOSviewer and Biblioshiny software.

3. Results and Findings

3.1. Annual Scientific Productions

Figure 1 highlights the annual scientific production in computational algebra has experienced significant growth over the decades, evolving from a niche field in the 1980s and 1990s with sporadic publications to a well-established research domain. Initially, research output was minimal, with occasional publications between 1981 and 1999, peaking at only five articles in 1999. However, a sharp rise occurred in the early 2000s, with a notable jump from one article in 2001 to 14 in 2004, reflecting increased interest and advancements in computational methods, particularly in symbolic computation and algebraic algorithms. The publication trend remained steady with minor fluctuations, peaking at 19 articles in 2019 and maintaining an average of 10–19 articles per year in the last decade. The decline in 2013 (6 articles) and 2020 (11 articles) suggests temporary shifts in research priorities, possibly influenced by funding

trends or external factors like the COVID-19 pandemic. However, the resurgence in 2023 (17 articles) indicates a sustained interest in computational algebra, likely driven by its interdisciplinary applications in cryptography, artificial intelligence, and quantum computing. This trend underscores the field's maturity and its evolving role in modern mathematical and computational research.

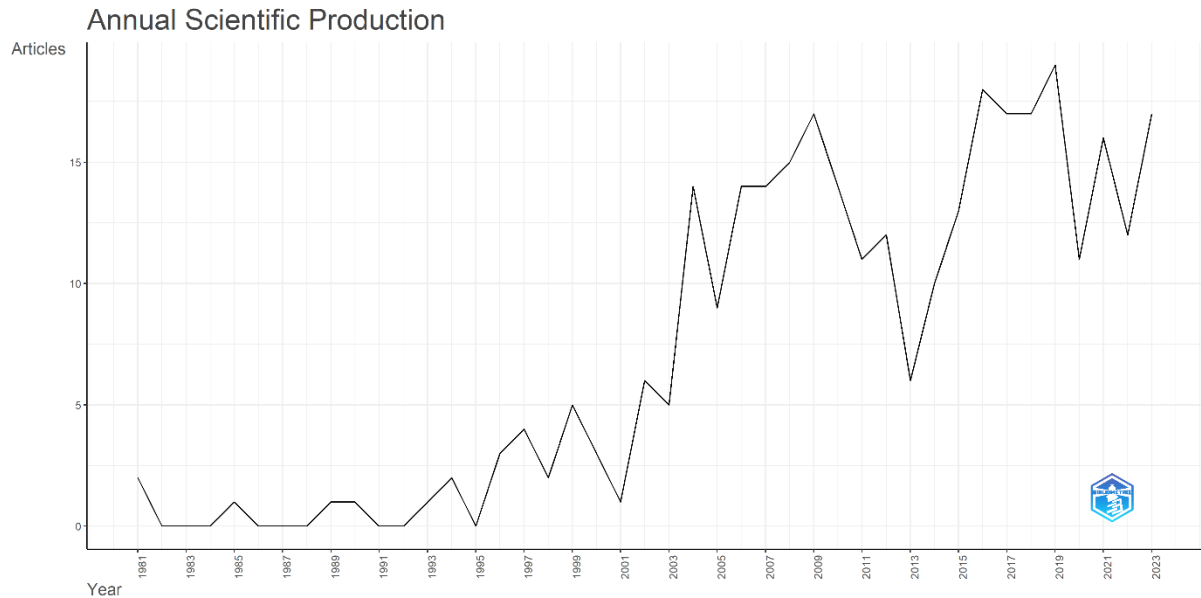


Figure 1. Annual scientific production

3.2. Most Relevant Authors

Figure 2 highlights the most prolific researchers based on the number of documents published. José A. López Ortí and Valery G. Romanovski emerge as the leading contributors, each with 12 publications, indicating their substantial influence in the field. They are followed by Alexander Konovalov and Christos Koukouvinos, both with 9 publications, suggesting their active role in advancing computational methods. Miguel Barreda Rochera, Ilias S. Kotsireas, and Steve Linton have each contributed 8 documents, showing a strong presence in the research community. Additionally, Brigita Ferčec and Reinhard Laubenbacher have 7 publications each, while Graham Ellis follows with 6 publications. The distribution of authors suggests that computational algebra research is diverse yet dominated by a few key figures, contributing significantly to its development. These leading researchers are likely involved in areas such as symbolic computation, polynomial algebra, and algorithmic solutions for algebraic structures. Their high publication counts indicate consistent research output, collaborations, and possibly leadership in major research projects or institutions. Future studies could further analyze citation impact, co-authorship networks, and institutional affiliations to gain deeper insights into the academic influence of these authors.

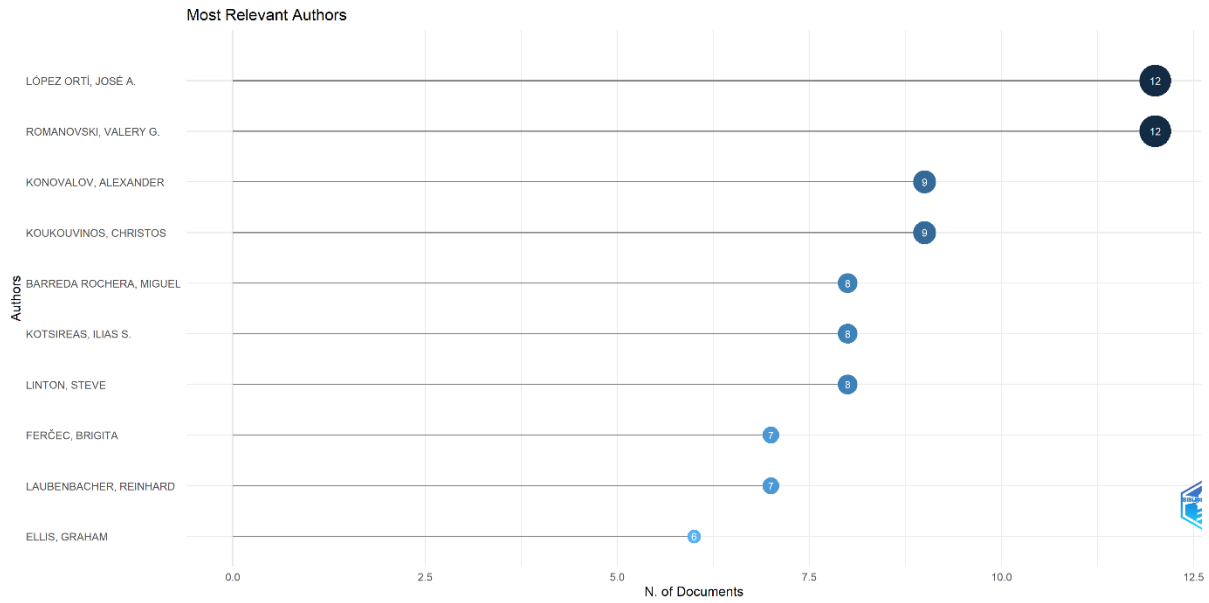


Figure 2. Most relevant authors

3.3. Most relevant sources

Table 1 highlights the leading journals and conference proceedings that have published research in Computational Algebra. The Lecture Notes in Computer Science (LNCS), which includes subseries in Artificial Intelligence and Bioinformatics, is the most influential source, with 25 articles, indicating its critical role in disseminating computational research. The Journal of Symbolic Computation, a well-established journal specializing in algebraic and symbolic computation, follows with 19 articles, underscoring its central position in the field. The Proceedings of the International Symposium on Symbolic and Algebraic Computation (ISSAC), a premier venue for computational algebra research, has contributed 10 articles, reflecting the importance of conference proceedings in this domain. Other notable sources include the Journal of Computational and Applied Mathematics (9 articles) and the Bulletin of Mathematical Biology (6 articles), suggesting interdisciplinary applications of computational algebra, especially in mathematical biology. Traditional algebra and combinatorics journals, such as the Journal of Algebra (4 articles), Australasian Journal of Combinatorics (3 articles), and Communications in Algebra (3 articles), also contribute, highlighting the theoretical foundations of the field. Additionally, Experimental Mathematics (3 articles) and Fundamenta Informaticae (3 articles) indicate a growing interest in the experimental and algorithmic aspects of computational algebra. This distribution of sources demonstrates the field's interdisciplinary nature, spanning from pure and applied mathematics to computer science, AI, and biological computations.

Table 1. Most relevant sources

Sources	Articles
Lecture notes in computer science	25
Journal of symbolic computation	19
Proceedings of the international symposium on symbolic and algebraic computation, issac	10
Journal of computational and applied mathematics	9

Bulletin of mathematical biology	6
Journal of algebra	4
Australasian journal of combinatorics	3
Communications in algebra	3
Experimental mathematics	3
Fundamenta informaticae	3

3.5. Three-Field Plot

Figure 3 illustrates the relationships between authors, publication sources, and contributing countries in computational algebra research, highlighting key players and their publication preferences. Prominent authors such as Alexander Konovalov, Steve Linton, and José A. López Ortí have strong associations with high-impact journals like the Journal of Computational and Applied Mathematics, Lecture Notes in Computer Science, and the Journal of Symbolic Computation, which serve as major publication venues for the field. The geographical distribution indicates that leading contributions originate from countries such as the United Kingdom, USA, Spain, Slovenia, and Germany, with emerging research interest from Greece, Portugal, Turkey, and China, showcasing a global expansion of computational algebra studies. Furthermore, publication sources such as ISSAC, Bulletin of Mathematical Biology, and the Australasian Journal of Combinatorics emphasize the interdisciplinary nature of the field, bridging pure and applied mathematics, symbolic computation, and combinatorial analysis. This visualization underscores the collaborative and international scope of computational algebra research, with strong institutional networks driving innovation. Future analysis of co-authorship networks and citation impact could provide deeper insights into influential research clusters and knowledge dissemination patterns.

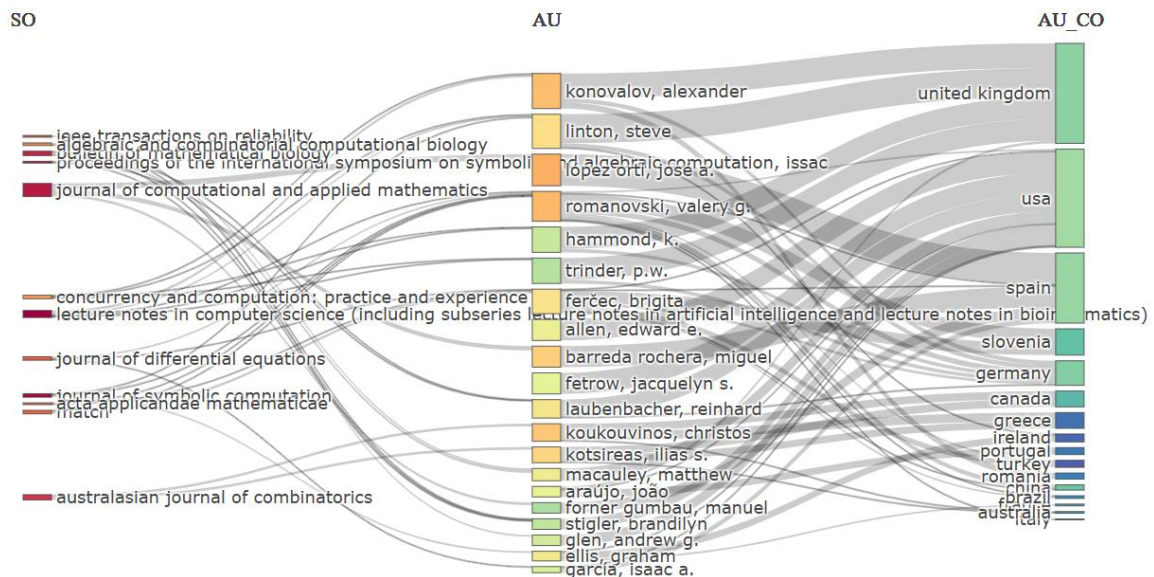


Figure 3. Three-Field Plot highlighting the relationships between authors, publication sources, and countries.

3.6. Trend Topics

Figure 4 presents a temporal analysis of trending topics in Computational Algebra, highlighting the evolution of research focus over time. The x-axis represents the timeline (2001–2019),

while the y-axis lists the key research terms. The size of each bubble indicates the term frequency, meaning larger bubbles correspond to higher occurrences in research publications. One of the most persistent and dominant topics in computational algebra is Gröbner bases, which appears as a highly relevant research term since the early 2000s. Similarly, terms like computer algebra, algorithms, and perturbation theory have had a sustained presence, demonstrating their foundational role in the field. The computational tool "Maple", used for symbolic computation, has gained prominence in recent years, signifying the growing reliance on software in algebraic problem-solving.

The emergence of Boolean models, limit cycles, and celestial mechanics in the later years suggests new interdisciplinary applications of computational algebra, particularly in dynamical systems, physics, and complex mathematical modeling. The increasing frequency of terms such as cyclicity and polynomial identities in the 2010s indicates a shift towards more specialized algebraic structures and their computational applications. The trends also reveal an evolution from theoretical developments (Gröbner bases, polynomial identities) to more applied areas such as perturbation theory, computational mechanics, and symbolic computation in physics. This analysis suggests that computational algebra is expanding beyond pure mathematics into applied sciences, AI, and computational physics, making it a continually evolving research domain. Future studies may focus on the interplay between machine learning and algebraic computations, as well as the increasing role of high-performance computing in symbolic algebra.

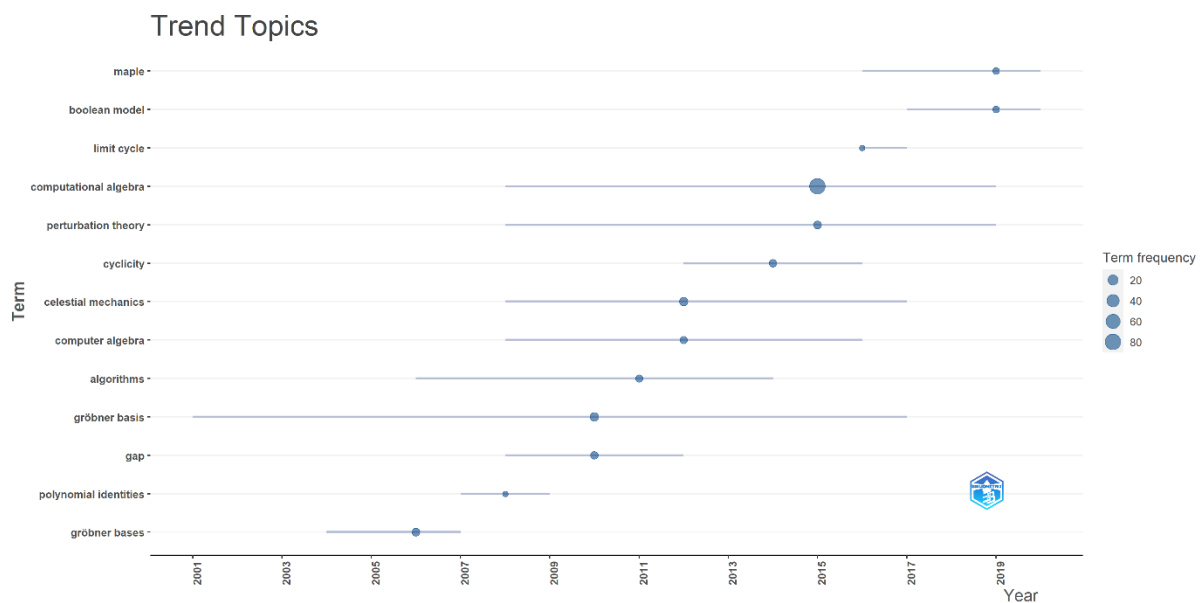


Figure 4. Trending topics in the realm of research

3.7. Thematic Map

Figure 5 presents a thematic map, which categorizes research themes based on development degree (density) and relevance degree (centrality). The x-axis (centrality) measures the importance of a topic in the broader research field, while the y-axis (density) represents its level of development and internal coherence. The map is divided into four quadrants: Motor Themes (top-right), Basic Themes (bottom-right), Niche Themes (top-left), and Emerging/Declining Themes (bottom-left).

In the Motor Themes quadrant (top-right), topics such as Gröbner bases, Boolean models, reverse engineering, and computational algebraic geometry are highly central and well-developed, indicating their strong influence and ongoing research activity. These topics are essential in computational algebra, particularly in symbolic computation, cryptography, and mathematical modeling. The presence of "Maple", a widely used symbolic computation software, further highlights the computational tools that drive innovation in the field. Additionally, computer algebra and the GAP system (Groups, Algorithms, and Programming) suggest strong connections between algebraic structures and algorithmic applications.

The Basic Themes quadrant (bottom-right) includes computational algebra, celestial mechanics, and computational topology, indicating fundamental yet less specialized topics that serve as a foundation for broader research applications. These areas provide core methodologies for algebraic computations, particularly in physics, engineering, and theoretical mathematics. In contrast, the Niche Themes quadrant (top-left) contains projective character tables, computational algebra systems, and fundamental group theory, which are highly specialized but less central to the overall research field, often explored within smaller, specialized communities. Lastly, the Emerging or Declining Themes quadrant (bottom-left) features linear codes, minimum distance, and statistical control, suggesting that these topics are either in early development or losing significance in current research. This map indicates that while Gröbner bases and symbolic computation remain dominant, computational algebra continues to evolve toward interdisciplinary applications in physics, topology, and machine learning.

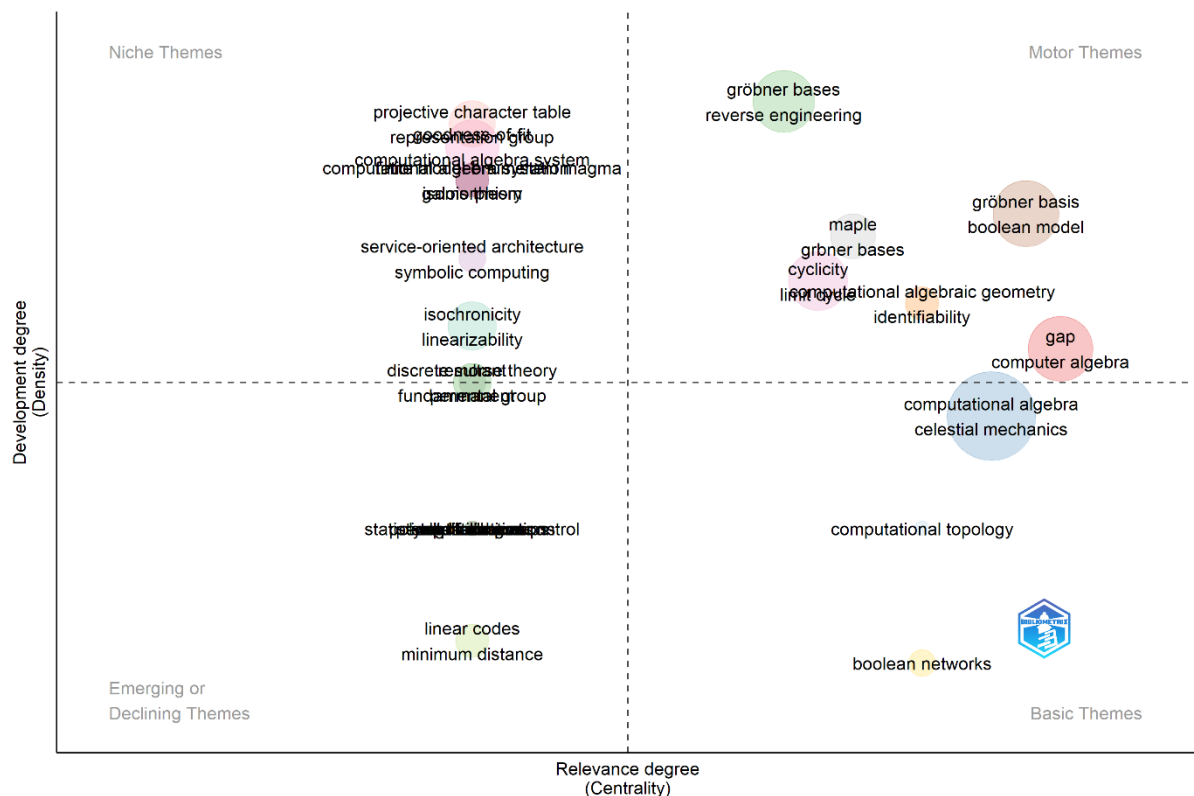


Figure 5. Thematic visualisation of author keywords

3.8. Co-occurrence of Author keywords

Figure 6 presents a co-occurrence network of author keywords, generated using VOSviewer. The nodes represent keywords, with their size indicating frequency of occurrence, while the edges (connections) denote co-occurrence relationships. The color-coded clusters group related topics, reflecting thematic structures within the field. The largest and most central node, "computational algebra", is the dominant research theme, closely linked to Gröbner bases, algorithms, finite fields, and polynomial identities, indicating their foundational role in symbolic computation. The red cluster highlights topics such as cyclicity, isochronicity, and polynomial identities, suggesting connections to dynamical systems and algebraic structures. The green cluster, including GAP, Haskell, and finite fields, points to research related to computer algebra systems and algebraic programming. The blue cluster, containing Boolean models and resultant theory, signifies applications in logic, cryptography, and combinatorial algebra. Emerging areas such as computational topology, planetary theories, and computational biology (orange and yellow clusters) suggest interdisciplinary applications of computational algebra in physics, space sciences, and biological modeling. The network structure indicates that computational algebra research is expanding beyond pure mathematics, integrating with computational sciences, AI, and applied mathematical modeling.

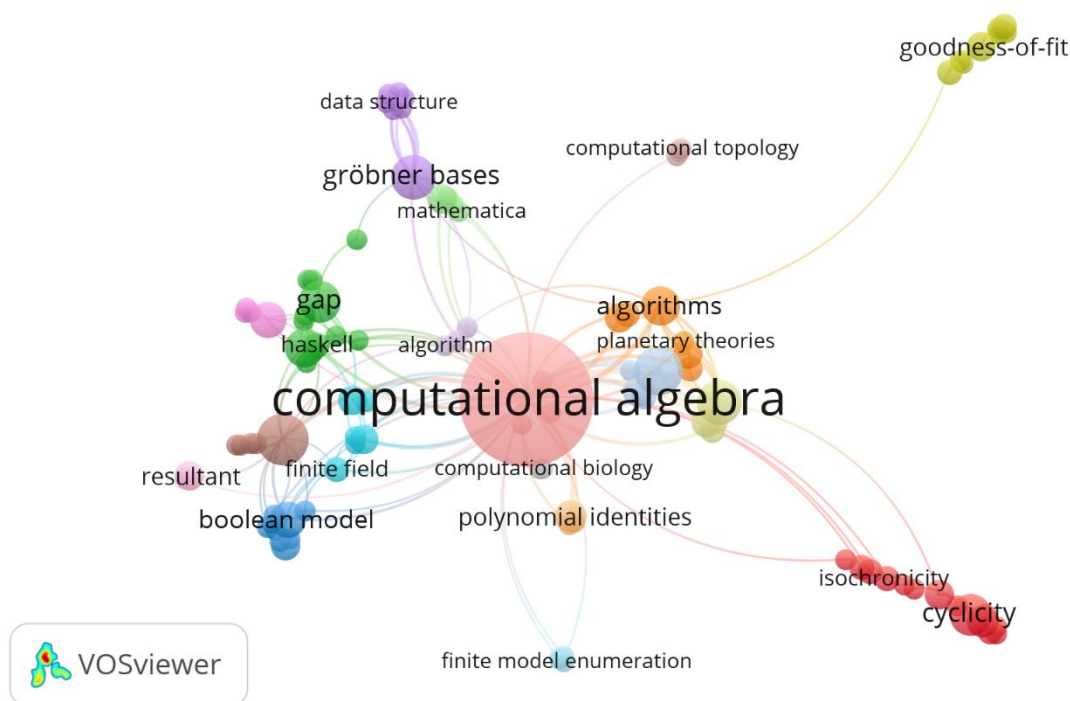


Figure 6. Co-occurrence of author keywords

3.9. Co-Citation of Cited Authors

Figure 7 presents a co-citation network visualization of cited authors, highlighting the intellectual structure of the field. The red cluster, featuring David O'Shea and Bernd Sturmfels, represents research on Gröbner bases, algebraic geometry, and symbolic computation, indicating their foundational influence. The blue cluster, with authors like Valery G. Romanovski and Gerhard Pfister, is closely linked to algebraic structures and computational methods, whereas the green cluster, centred around Reinhard Laubenbacher and Benjamin

Stigler, suggests a focus on mathematical modelling and interdisciplinary applications, particularly in computational biology. The yellow cluster, with Omar Lezama, represents a smaller but distinct research theme. The dense interconnections between clusters indicate that computational algebra is a highly interdisciplinary field, integrating pure mathematical theory with applied research areas. The strong citation links around Sturmfels, O’Shea, and Laubenbacher suggest their works are central references, demonstrating the field’s reliance on both theoretical advancements and algorithmic applications.

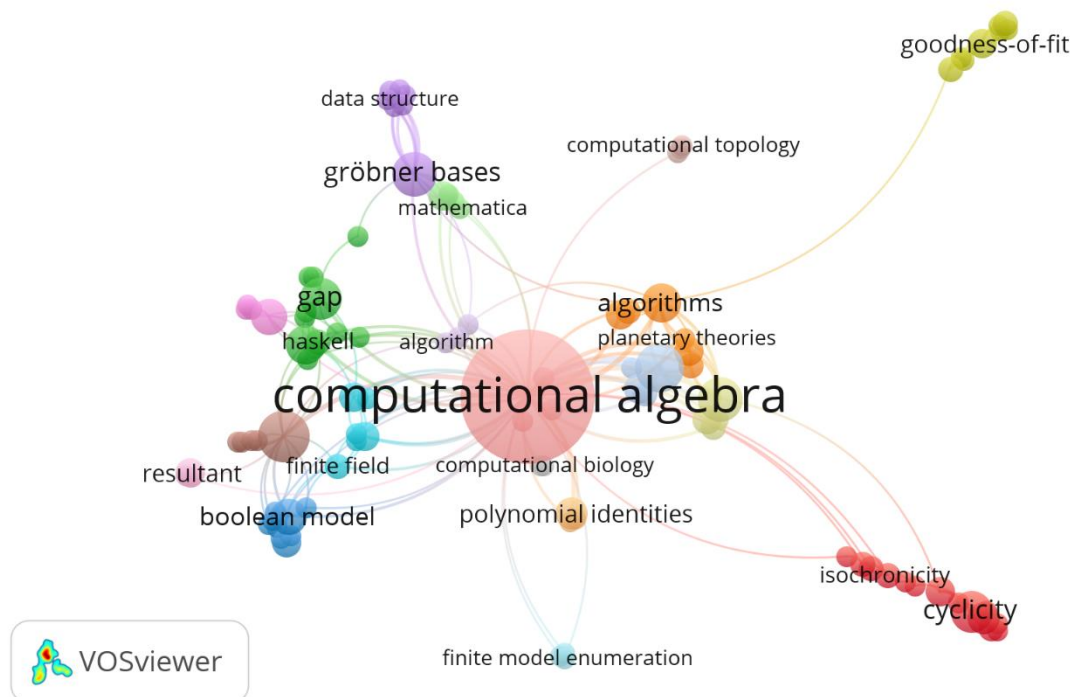


Figure 7. Network Visualization of cited authors

3.10. Countries Collaborations

Figure 8 presents a co-authorship network of countries in Computational Algebra, generated using VOSviewer, illustrating international research collaborations. Each node represents a country, and the size of the node corresponds to the number of publications, while the edges (connections) indicate co-authorship links between countries. The color-coded clusters reveal distinct collaboration groups. The United States (US) is the dominant node, indicating its leading role in computational algebra research, with extensive collaborations with Germany, the United Kingdom, Spain, and Italy. Germany and Japan also appear as significant contributors, fostering strong partnerships with other European and North American countries. The United Kingdom and Spain form an active European cluster, collaborating with Portugal, Italy, and France, while Canada, Australia, and Greece contribute through interdisciplinary partnerships. The red cluster, featuring China, Slovenia, and Turkey, suggests emerging research groups in computational algebra. India, Romania, and Sweden are also present, indicating a global interest in the field. The overall structure of the network suggests that computational algebra research is highly international, with strong intercontinental

collaborations, particularly between North America, Europe, and Asia, driving innovation in symbolic computation, algebraic geometry, and algorithmic mathematics.



Figure 8. Network Visualization of co-authorship of countries

4. Discussions

The bibliometric analysis of Computational Algebra using Biblioshiny and VOSviewer has provided significant insights into the evolution, key contributors, and thematic developments in the field. The annual scientific production has shown a steady increase since the early 2000s, highlighting the growing research interest in symbolic computation, algebraic structures, and algorithmic applications. The most relevant authors, such as José A. López Ortí and Valery G. Romanovski, have played a crucial role in shaping the field, with substantial contributions in computational methods and algebraic modeling. Additionally, leading publication sources like the Journal of Symbolic Computation and Lecture Notes in Computer Science reflect the interdisciplinary nature of computational algebra, integrating pure mathematics, applied sciences, and AI-driven computation. The Three-Field Plot further revealed strong associations between key authors, influential publication venues, and contributing countries, emphasizing the global and collaborative nature of research in this domain.

The trend analysis of topics uncovered a gradual shift from foundational theoretical concepts like Gröbner bases and polynomial identities toward more applied fields, such as perturbation theory, Boolean models, and computational mechanics. This indicates that computational algebra is becoming more integrated with physics, engineering, and AI applications. The thematic map categorized research themes into motor themes (highly developed and influential areas), basic themes (fundamental concepts), niche themes (specialized areas), and emerging/declining themes (potential future trends or fading interests). Key motor themes like

Gröbner bases, reverse engineering, and algebraic geometry continue to drive computational algebra research, while emerging themes such as statistical control and linear codes suggest new directions. The co-occurrence of author keywords reinforced these findings, showing strong research clusters around symbolic computation, computer algebra systems, and interdisciplinary applications in cryptography, biology, and space sciences.

Despite these advancements, several research gaps remain evident. While Gröbner bases, symbolic computation, and Boolean models dominate computational algebra, there is limited research on AI-driven algebraic solutions and machine learning integration for symbolic reasoning. The co-citation network of cited authors indicated that much of the research remains centered around a few dominant scholars, suggesting the need for diversification and newer contributions. Furthermore, the co-authorship network of countries highlighted a strong North American and European influence, with emerging contributions from Asia, particularly China and India. However, there is still a lack of high-impact research collaborations from developing regions, which could benefit from increased funding and international partnerships.

From a practical perspective, the findings have significant implications for academia, industry, and technological innovation. The growing emphasis on algorithmic solutions and computational methods suggests that future research should focus on enhancing computational efficiency, integrating AI techniques, and developing advanced algebraic modeling tools for real-world applications in cybersecurity, quantum computing, and complex systems analysis. Interdisciplinary collaborations between mathematics, computer science, and engineering will be essential in driving the next wave of innovations in computational algebra. Additionally, increased global collaborations and research funding can help bridge existing geographical disparities, enabling a more inclusive and diverse research ecosystem. Future bibliometric studies could explore the impact of AI advancements on symbolic computation and the role of quantum computing in algebraic problem-solving, paving the way for next-generation computational frameworks.

5. Conclusion

This bibliometric analysis has provided valuable insights into the evolution and impact of computational algebra research. The annual scientific production indicates a consistent growth in publication output and global collaboration. Notable contributions from leading authors and influential sources underscore the field's interdisciplinary reach. Our analysis of trend topics, thematic maps, and network visualizations reveals emerging research directions and evolving scholarly relationships. We recommend that future studies expand the bibliographic scope by incorporating additional databases to achieve a more comprehensive view of the field. Furthermore, enhancing collaborative networks through targeted initiatives could deepen insights into research dynamics and facilitate cross-disciplinary innovation. Finally, stakeholders are encouraged to invest in interdisciplinary research projects that bridge computational algebra with other domains, thereby fostering innovative applications and sustainable academic growth.

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