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Bibliometric Analysis of Animal-Inspired Optimization Algorithms in Computer Science and Engineering

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Animal-inspired optimization algorithms have been widely explored and used in many disciplines. This paper investigates research trends and application patterns of animal-inspired optimization algorithms over a twenty-year period across computer science and engineering-related Web of Science (WoS) database categories. The results are gathered from the Web of Science (WoS) platform and analyzed using WoS-embedded tools and the VOSViewer software. We built a complex query and found over 19000 results. An increasing publication trend is confirmed for the period 2004-2023. The most influential authors and authorship connections are stated. Some very old algorithms (like Ant Colony from 1991) are still used frequently, however the most used in the explored areas is Grey Wolf (from 2014). Also, there are very recent ones such as Harris Hawks (from 2019) and Manta Ray (from 2020) being frequently used in specific engineering sub-areas. The keyword co-occurrence clustering discovered the sub disciplines where animal-inspired algorithms are used. Recently, the proliferation has been indicated in the artificial intelligence field, where animal-inspired optimization is used in hybrid algorithms and techniques.

Keywords: AIO algorithms, Metaheuristics, Nature-inspired algorithms, VOSViewer, WoS

Introduction

In the pursuit of solving complex optimization problems, researchers and practitioners have turned to nature for inspiration, leading to the development of Animal-Inspired Optimization (AIO) algorithms. The family of AIO algorithms garnered significant attention due to their ability to emulate the efficiency and adaptability observed in various species. These algorithms are inspired by behaviors and hunting strategies exhibited by animals in their natural environments, offering a unique perspective for tackling optimization challenges.[1]

In the last twenty years, a large number of algorithms have been developed that are inspired by observing various species of animals in nature and their behavior. Some of the widely used algorithms in solving different optimization problems are: Gray Wolf Optimizer (GWO), Ant Colony Optimization (ACO) Algorithm, Whale Optimization Algorithm (WOA), Firefly algorithm (FA), Artificial Bee Colony (ABC) algorithm, Cookoo Search (CS), Harris Hawks Optimization (HHO), etc.[2,3]

This paper embarks on a bibliometric exploration of AIO algorithms, aiming to provide a systematic and quantitative overview of the literature in this domain. Bibliometrics, the statistical analysis of bibliographic data, offers a powerful lens through which we can examine publication trends, key contributors, and the evolution of research themes over time. By employing bibliometric tools and methodologies, this analysis seeks to uncover patterns and insights that can inform researchers, guide future investigations, and contribute to the evolution of the observed field. The bibliometrics analysis has been ordinarily used in various research areas over the past years.[4] It has gathered a lot of attention in nature-inspired optimization algorithm.[5] Accordingly, the study does not focus on computer engineering as a separate discipline. Instead, it maps the use of AIO algorithms across the WoS categories associated with (1) computer science and (2) engineering, with the aim of identifying the application areas in which particular algorithms are most frequently represented.

Many authors have conducted detailed research related to the review of works in the field of applying AIO algorithms in various areas of engineering and computer science. The presentation of related literature dealing with bibliometric analysis of some significant AIO algorithms will be shown in the following text. Makhadmeh *et al.*[6] gave a precise review of the GWO algorithm implementation and its

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efficacy has been displayed across a wide range of optimization problems. It is used in different domains, including engineering, scheduling and planning, vehicle routing problems, business, bioinformatics, biomedical etc.[7,8] The interest of many researchers in using WOA as an optimization algorithm capable of solving real-world problems is presented by Nadimi-Shahraki *et al.*[9] This growth in the number of WOA citations shows the popularity of this algorithm. The application of some significant algorithms such as ACO, ABC, and FA is given in the analysis for solving TSP-based scheduling optimization problems. Autors Toaza *et al.*[10] presented about 120 metaheuristic algorithms which are based on a large number of citations. A bibliometric analysis of ACO was presented by Deng *et al.*[11] from 1996-2010. ACO algorithm has been successfully applied to solve different optimization problems, such as traveling salesman problems, vehicle routing problems, resource-constrained project scheduling problems, etc. Bongale *et al.*[12] explore a bibliometric analysis of the implementation of the FA with applications in the field of wireless sensor networks. This paper provides an overview of collecting the details of published articles from the Scopus database. In this article, the collected data is key in contributing geographical locations, subject area statistics, author-keyword mapping, and many more essential aspects of bibliometric analysis. All these papers describing the bibliometric analysis of well-known AIO algorithms indicate that it is necessary to perform an analysis of the entire group of algorithms to obtain some significant data about prominent researchers.

This study intends to answer critical questions surrounding the research landscape of AIO algorithms. What are the key journals and conferences driving this field? Who are the prolific authors, and what are the most cited works? How has the interest in these algorithms evolved? By addressing these inquiries, we aim to not only offer a snapshot of the current state of the field but also to lay the groundwork for future advancements and collaborations in the exciting realm of AIO algorithms.

In the following sections first, the methodology is presented, with essential background of bibliometric methods, and then the results are presented and discussed. Finally, the conclusion and future work are presented.

Materials and Methods

Bibliometric Analysis

Bibliometrics is a discipline combining statistics and bibliography and represents a quantitative literature bibliography study. It can be considered a subset of a broader discipline, informetric, which considers quantitative aspects of information in any form.[13]

Conducting bibliometric analysis allows researchers to summarize large quantities of bibliometric data to present the state of the intellectual structure and emerging trends of the examined research topic.[14–16] It is a convenient method when the dataset is too large for manual review.

Databases such as Clarivate's Web of Science, Elsevier's Scopus, Google Scholar, or Cambia's Lens enable access to millions of research results. Such scientific records are equipped with rich metadata, enabling advanced search. Also, many databases provide sophisticated tools for data analysis, letting valuable information on the spot. For extensive analysis, revealing various research insights, such as co-citation, bibliographic coupling, and co-authorship relations, there are several powerful tools available: VOSViewer, Bibliometrix, Gephi, etc. These tools also offer visualization, providing a vibrant preview of important research features.

Research Questions

The established research questions are as follows:

Q1: Which authors demonstrate the highest productivity and which have the most citations concerning algorithms in engineering and computer science inspired by the animal kingdom?

Q2: Which algorithms are the most popular?

Q3: What is the time dimension of the research in this field?

Q4: Is it viable to identify the grouping of algorithms with their applications in areas of engineering and computer science?

Methodology

The bibliographical workflow is based on the PRISMA methodology.[17] The starting challenge for this research was to find as many relevant records as possible. As the observed topic is specific, it is required to form a complex query, which is not a one-pass job and it gets finished after recurring iterations involving new keywords, based on the results of the previously executed query.

The research workflow is shown in Fig. 1.

First, the initial query was composed, according to the related review literature. We gathered numerous animal-based syntagms that inspired the algorithms and paired them with words related to the algorithms and optimization methods. Such descriptors are "optimization techniques", "heuristic algorithm",", "search" and "classification". Additionally, since the investigation is focused on engineering and computer science, we focused the search on these two areas, using the Web of Science research area filter. The keywords and syntagms are used for querying the Author's Keywords (AK). To identify the application areas of AIO algorithms, the search was restricted using the Web of Science research-area filter to categories related to computer science and engineering. In this study, the term *engineering* therefore denotes the relevant engineering-related WoS categories included in the retrieved dataset, rather than computer engineering alone. The purpose of this selection was to map where AIO algorithms are used across computer science and engineering and to identify the algorithms most frequently associated with specific subject areas.

It is worth noting that The Web of Science platform provides an additional keyword-based search mechanism, called Keyword Plus. It enables finding publications where certain keywords are not in the title, but are in the titles of the referenced literature. Building queries using Keyword Plus is supposed to provide circumstantial publications and bring out new keywords for the baseline query. However, this is still up to be explored, as the researchers found out the Keyword Plus content depends on the research area and it was not proved that this feature provides better results in searching publications.[18,19]

The timespan used was 20 years, from 1.1.2004 – 1.1.2024. This period is estimated as long enough to screen all relevant results and trends in the field, since we found that the remaining period WoS was indexing papers (1996-2003) introduced a negligible number of results. To capture all relevant data, we included a complete Web of Science Core collection, including SCI-EXPANDED, Conference proceedings, and the Emerging Sources Citation Index (ESCI).

After several iterations (according to the workflow in Fig. 1), the following query was composed:

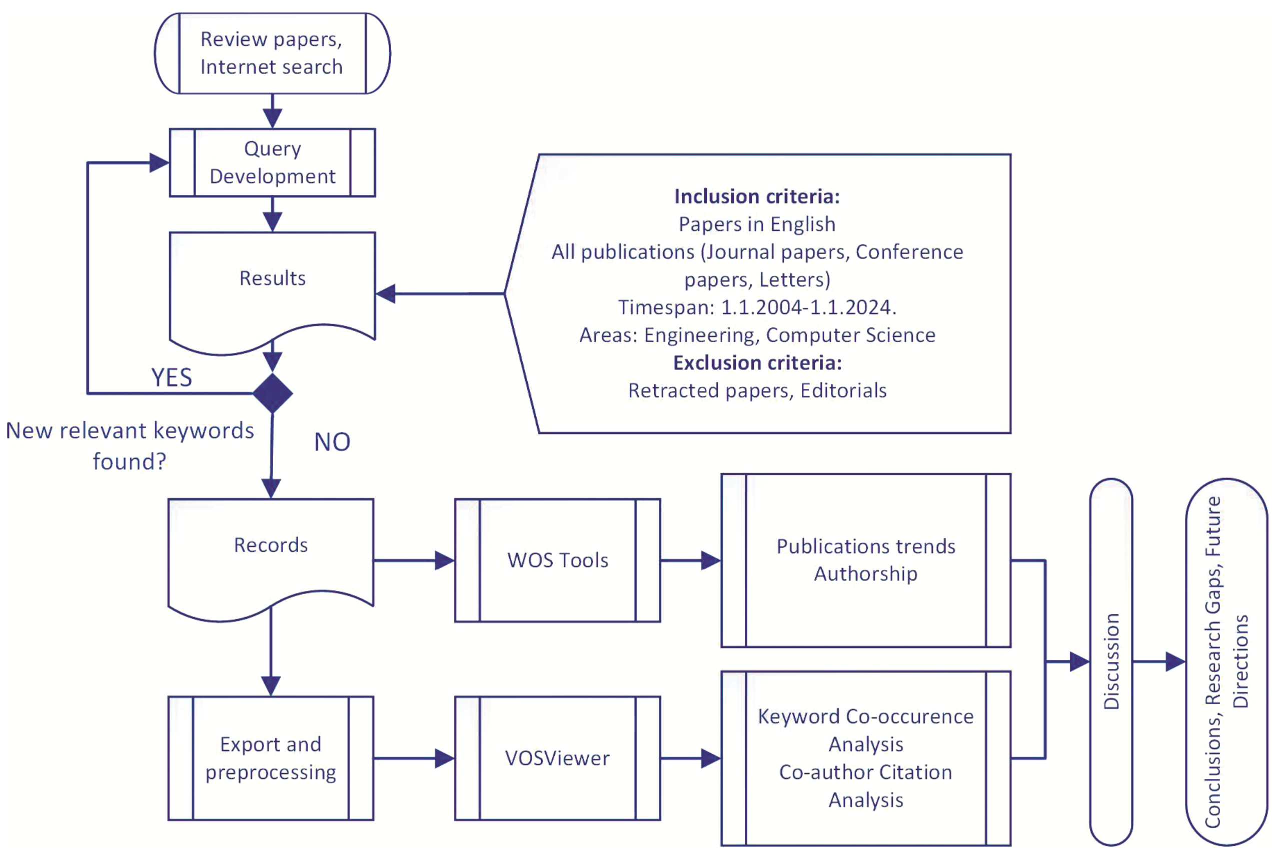

Fig. 1 — The research workflow

((AK=("Heuristic algorithm") OR AK=("Cat optimization") OR AK=("Bee colony") OR AK=("Ant colony ") OR AK=(Firefly) OR AK=("Monarch Butterfly") OR AK=("Artificial Bee Colony ") OR AK=("Ant Lion") OR AK=(whale) OR AK=("Slap Swarm") OR AK=(Cuckoo) OR AK=(crow) OR AK=("Grey wolf") OR AK=("buffalo") OR AK=("African wild dog") OR AK =("orca") OR AK=("pelican") OR AK=(racoon) OR AK=("pigeon") OR AK=("shark") OR AK=("snake") OR AK=("squirrel") OR AK=("Tasmanian devil") OR AK=("termite") OR AK=("tuna swarm") OR AK=("wolf colony") OR AK=("Harris Hawks") OR AK=("manta ray") OR AK=(grasshopper) OR AK=("honey badger") OR AK=("red deer") OR AK=(" sheep flock") OR AK=(worm) OR AK=(eagle) OR AK=(termite) OR AK=(mosquito) OR AK=(monkey) OR AK=(camel) OR AK=(kangaroo) OR AK=(cheetah) OR AK=(spider) OR AK=(krill) OR AK=(dolphin) OR AK=(pigeon) OR AK=(octopus) OR AK=(giraffe) OR AK=(woodpecker) OR AK=(sparrow) OR AK=("caterpillar swarm") OR AK=(FROG) OR AK=(seagull) OR AK=(jellyfish) OR AK=(chameleon) OR AK=(owl) OR AK=(RAVEN) OR AK=(bowerbird) OR AK=(hyena) OR AK=(butterfly) OR AK=("bumble bee") OR AK=(beetle) OR AK=("fruit fly") OR AK=(locust) OR AK=(mayfly) OR AK=(moth) OR AK=(roach) OR AK=("water strider") OR AK=(vulture) OR AK=("Dwarf Mongoose") OR AK=(gazelle) OR AK=(anaconda) OR AK=(nutcracker) OR AK=("red panda") OR AK=(mantis) AND (AK=(optimisation) OR AK=(optimization) OR AK=("Optimization techniques ") OR AK=("Optimisation techniques ") OR AK=("heuristic algorithm") OR (AK=Metaheuristics) OR AK=(Hybridization) OR AK=("search algorithm") OR AK=("PARAMETER-ESTIMATION") OR AK=(classification)))

The results in English are considered.

To limit the search to engineering disciplines and computer science, WoS filter was used. It is worth noting that a significant portion of research in the field of optimization and metaheuristics is multidisciplinary, therefore the disciplines not explicitly chosen, still show up in the results. (e.g. if the article combines computer science and operational research, both disciplines will show up with their result counter.)

Results are refined by excluding the retracted papers and editorials.

The first round of results analysis is conducted on the Web of Science platform.

Further, the records are exported in plain text format files, including full metadata and references. Such files are analyzed in VOSViewer software, version 1.6.20.[(20)] Since the data gathered from the WoS is highly heterogenous, it is very important to construct a thesaurus file, so all variations of keywords, authors, or papers are correctly jointly identified. The issue of basically duplicated information is especially expressed in algorithm keywords, involving singular/plural, US/British English options and acronyms, resulting in variations such as ant colony optimization (ACO) and ant colony optimization; or grey wolf algorithm and grey wolf optimizer, etc. It is mandatory to process all such data, especially for the terms with high number of occurrences.

VOSViewer is capable of producing graphical representations of all data supplied by different indexing services, including Web of Science, Scopus, Dimensions, Lens, and PubMed. Additionally, it supports direct download from platforms such as Crossref and importing data from reference managers files (e.g. Endnote). VOSViewer can bring precious insights on various metadata (e.g. authorships, journals with most publications, most used keywords, countries) and provide the distribution of publications through the time dimension.[21,22] The feature providing arguably the most valuable information is the coupling of data, i.e. finding and presenting connections between various publications, such as co-authors, and co-citations and clustering such data. This way researchers can get various, other ways invisible, information, e.g. on which keywords are coupled with keywords from the starting subject.

Data search and exports were performed on February 10th 2024.

Results and Discussion

A total of 19,241 results is delivered from the Web of Science platform. The distribution of papers through time is shown in Fig. 2.

A clear long-term increase in the annual number of publications on AIO algorithms in computer science and engineering-related WoS categories could be seen in Fig. 2. The growth is not uniform; it can be broadly divided into three periods: 2004–2009, 2010–2016, and 2017–2022. The latter period shows the most

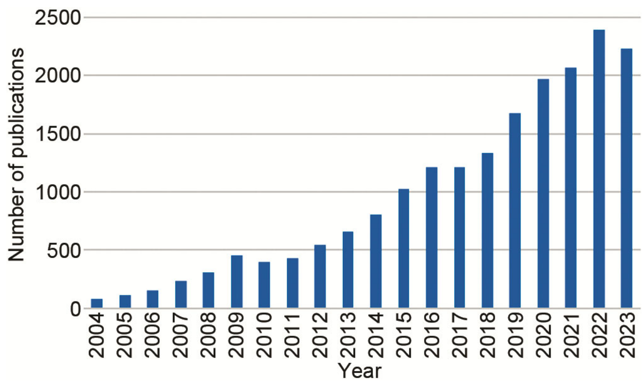

Fig. 2 — Distribution of results per year

Table 1 — Top ten most productive authors (Source: Web of Science Core Collection; data retrieved on 10 February 2024)

Rank	Authors	Documents	Citations
1	Chen H L	128	**11139**
2	Zhang J	124	2792
3	Mirjalili S	121	**39368**
4	Wang L	112	3213
5	Kumar A	96	2069
6	Zhang Y	95	1088
7	Wang Y	92	1471
8	Wang H	91	1957
9	Heidari A A	90	**9327**
10	Liu Y	87	1487

substantial publication activity, indicating a growing research interest in the topic.

This pattern may be associated with the continuing introduction of new AIO algorithms, as well as their adaptation and hybridization for emerging technological problems. In particular, the increasing use of such algorithms in artificial intelligence, cloud computing, Internet of Things applications, and power-engineering problems may have contributed to the observed growth. However, these factors cannot be established as causal explanations solely from the publication-count data and should therefore be examined in dedicated future studies.

One can notice there is a certain number of authors who are very productive in the number of published paper and citations of those papers by analyzing the obtained data. The ten most productive authors in the retrieved dataset, ranked by the number of published documents are presented in Table 1. Chen HL ranks first with 128 documents, followed by Zhang J with 124 and Mirjalili S with 121 documents.

Publication productivity, however, does not necessarily correspond to citation impact. When citation counts are considered, Mirjalili S is the most influential author in this group, with 39,368 citations, followed by Chen HL with 11,139 citations and Heidari AA with 9,327 citations. This difference indicates that a smaller number of highly influential publications may generate substantial citation impact, particularly when they introduce or substantially advance widely adopted algorithms. Citation counts should be interpreted as a time-dependent indicator because they were recorded on the data-collection date and may subsequently change.

Analysis in the VOSViewer has provided additional insights regarding the citations. The co-citation analysis shown in Fig. 3 maps the intellectual structure of the field by linking authors who are frequently cited together in the same publications. For clarity, only authors with at least 20 citations were included in the visualization. Larger nodes represent authors with higher co-citation frequencies, whereas links indicate the strength of their co-citation relationships.

Several influential clusters can be identified, centred around Mirjalili S, Yang X S, Dorigo M, Karaboga D, and Heidari A A. These authors are associated with major AIO approaches, including Grey Wolf Optimizer, Whale Optimization Algorithm, Cuckoo Search, Ant Colony Optimization, Artificial Bee Colony, and Harris Hawks Optimization. The cluster structure suggests that the field has developed around several established algorithmic traditions, while the connections between clusters indicate that these approaches are frequently considered together in subsequent research.

The co-authorship network of researchers with at least ten publications in the retrieved dataset is presented in Fig. 4. In the visualization, nodes represent authors, links represent co-authorship relationships, and the size of a node reflects the author’s relative weight in the network. Authors assigned the same colour belong to the same collaboration cluster.

The network contains several distinct clusters, indicating established research groups that frequently publish together. At the same time, several highly productive authors are positioned at the periphery of the network or have comparatively few strong links to the major clusters. This pattern suggests that the field combines closely collaborating research groups with influential researchers whose contributions are distributed across more independent or less connected

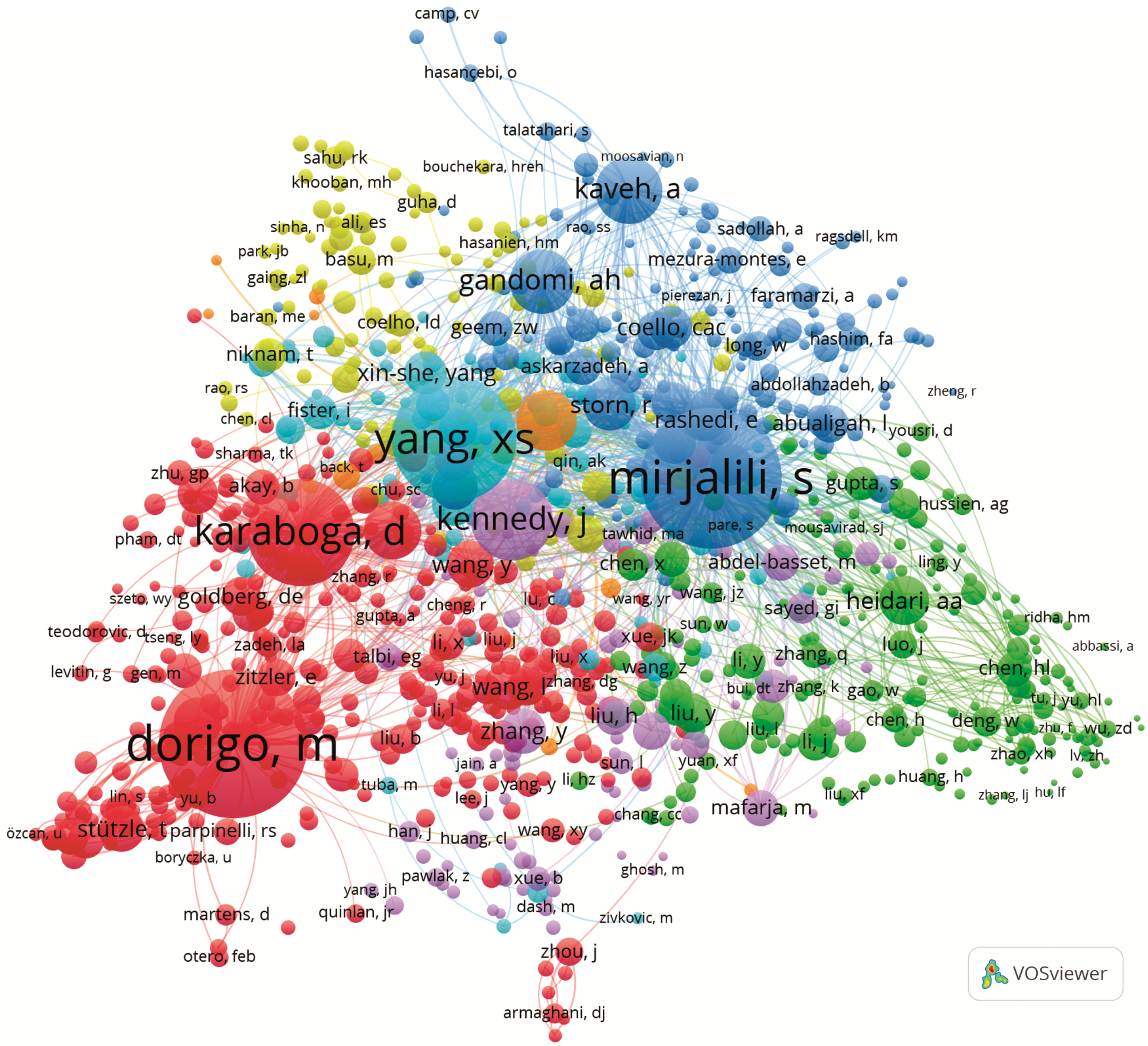

Fig. 3 — The co-citation analysis

publication networks. The observed fragmentation also indicates potential opportunities for broader cross-cluster collaboration.

To further examine how these collaboration patterns evolved, the temporal overlay visualization is presented in Fig. 5.

The colour of each node represents the average publication year of the author's documents in the dataset, with darker colours indicating earlier activity and lighter colours indicating more recent activity.

The visualization suggests that the co-authorship structure has evolved over time. Earlier research is associated mainly with smaller and more weakly connected groups, whereas more recent activity appears in larger and denser clusters. This pattern indicates that research on animal-inspired optimization has gradually moved from relatively isolated contributions towards broader collaborative networks involving multiple authors and application areas.

The overlay also helps identify researchers and groups that have been active more recently, which may be useful for recognizing emerging collaboration networks and potential partners for future interdisciplinary research. However, the visualization reflects publication-based collaboration patterns and should not be interpreted as evidence of the quality or effectiveness of individual collaborations.

The ten most cited publications in the retrieved dataset are presented in Table 2. The results show that

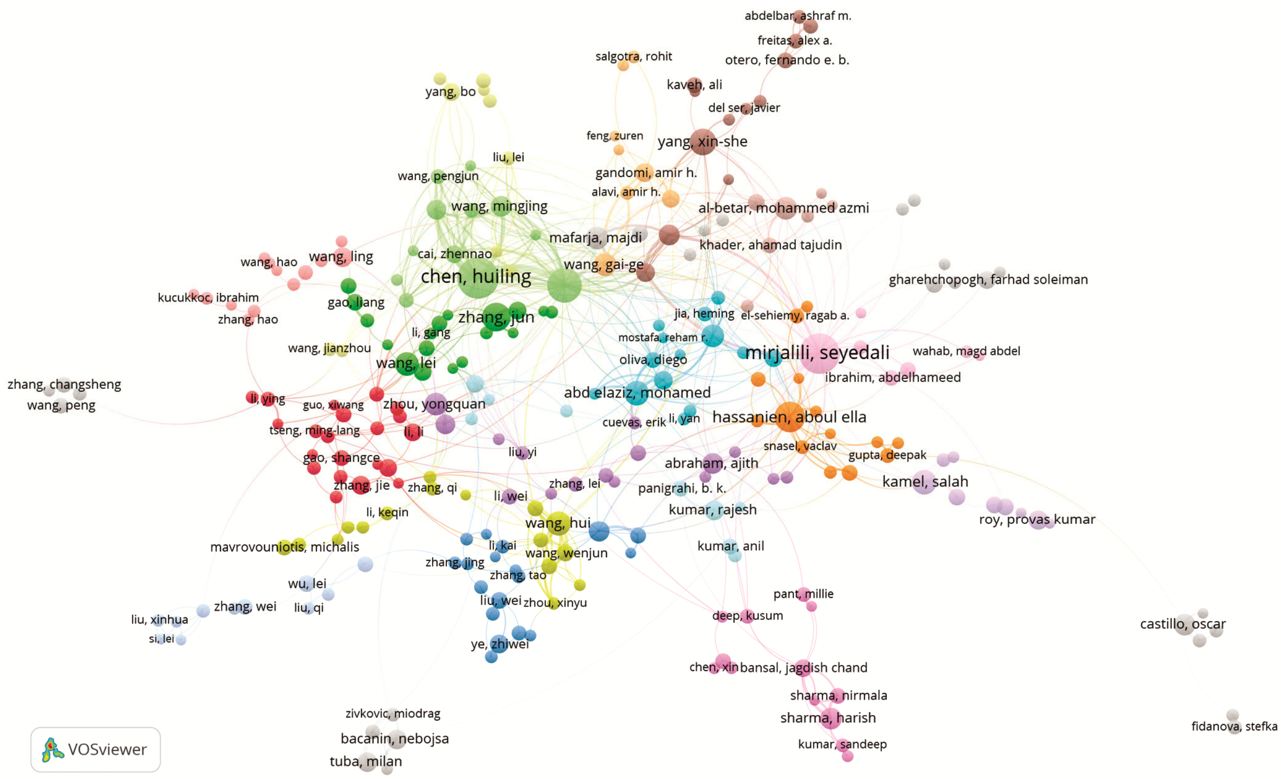

Fig. 4 — Co-authorship analysis

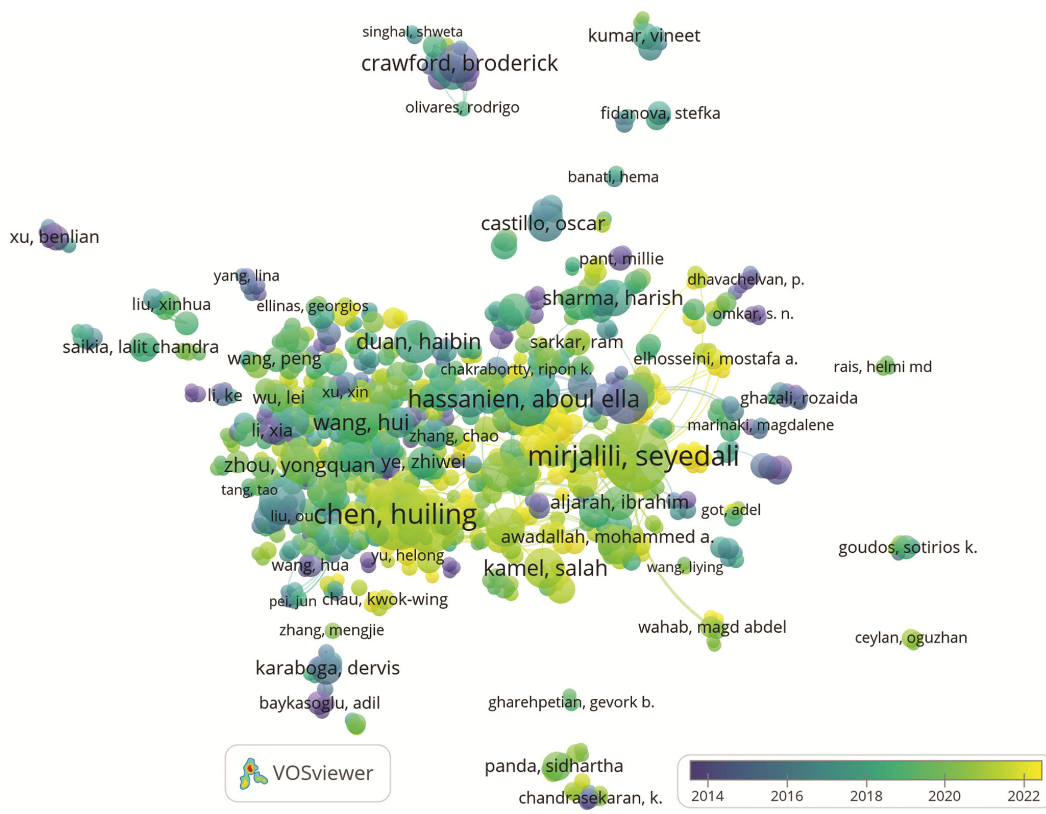

Fig. 5 — Co-authorship overlay vizualization

Table 2 — The most cited papers (Source: Web of Science Core Collection; data retrieved on 10 February 2024.)

Rank	Paper title	Journal/Conference	Year	Authors	Citations
1.	Grey Wolf Optimizer[23]	*Advances in Engineering Software*	2014	Mirjalili S, Mirjalili S M & Lewis A	9847
2.	The Whale Optimization Algorithm[24]	*Advances in Engineering Software*	2016	Mirjalili S & Lewis A	6963
3.	Cuckoo Search via Levey Flights[25]	*2009 World Congress on Nature & Biologically Inspired Computing (Nabic 2009)*	2009	Yang X S & Deb S	4810
4.	Salp Swarm Algorithm: A bio-inspired optimizer for engineering design problems[26]	*Advances in Engineering Software*	2017	Mirjalili S *et al.*	2970
5.	Harris hawks optimization: Algorithm and applications[27]	*Future Generation Computer Systems*	2019	Heidari A A *et al.*	2925
6.	On the performance of artificial bee colony (ABC) algorithm[28]	*Applied Soft Computing*	2008	Karaboga D & Basturk B	2770
7.	The Ant Lion Optimizer[29]	*Advances in Engineering Software*	2015	Mirjalili S	2086
8.	Grasshopper Optimisation Algorithm: Theory and application[30]	*Advances in Engineering Software*	2017	Saremi S, Mirjalili S & Lewis A	1684
9.	Firefly algorithm, stochastic test functions and design optimisation[31]	*International Journal of Bio-Inspired Computation*	2010	Yang X S	1628
10.	Ant colony optimization theory: A survey[32]	*Theoretical Computer Science*	2005	Dorigo M & Blum C	1560

the most influential papers are predominantly those that introduced or established widely used AIO algorithms. The paper on the Grey Wolf Optimizer ranks first, followed by the foundational paper on the Whale Optimization Algorithm and the work introducing Cuckoo Search.

The high citation counts of these publications indicate their continuing importance as methodological references for following studies in computer science and engineering. Several papers published between 2014 and 2019 are particularly prominent, which reflects the rapid adoption of newer algorithms, such as Grey Wolf Optimizer, Whale Optimization Algorithm, Salp Swarm Algorithm, Ant Lion Optimizer, Grasshopper Optimization Algorithm, and Harris Hawks Optimization.

Citation counts should nevertheless be interpreted with caution. Older publications have had more time to accumulate citations, whereas recent algorithms may have lower citation counts despite strong current growth. Moreover, the numbers shown in Table 2 represent the citation data available in Web of Science on 10 February 2024 and can change as new publications are indexed.

It is worth noting there are several limits one should be aware of, taking the number of citations into account. First of all, the number of citations provided is the one available on the Web of Science platform. This number can vary in practice, since the Web of Science may not gather all data. Also, the number of citations given here is one figuring at the time of writing this article (February 2024). This number can increase literally daily, as new articles get published. Still, no critical change is likely to occur.

To examine the application landscape of AIO algorithms, we analyzed the Web of Science categories in which the retrieved publications were indexed. The categories with the highest number of records and the three most frequently occurring AIO algorithms in each category are presented in Table 3. The results provide an overview of where these algorithms are most commonly applied across computer science and engineering-related research areas.

The results demonstrate that AIO algorithms are applied across diverse areas of computer science and engineering. Electrical and electronic engineering contains the largest number of records, followed by artificial intelligence, information systems, computer science theory and methods, and telecommunications. This distribution indicates that the use of AIO algorithms is not restricted to a single technical domain, but spans both computational and engineering-oriented applications.

Table 3 — The most used algorithms in the WoS categories ((Source: Web of Science Core Collection; data retrieved on 10 February 2024)

Category	Number of results	Top 3 algorithms
Engineering Electrical Electronic	6873	CS (2009) GWO (2014) MRO (2020)
Computer Science Artificial Intelligence	6228	CS (2009) ABC (2005) FA (2008)
Computer Science Information Systems	3556	HHO (2019) FA (2008) ACO (1991)
Computer Science Theory Methods	3447	HHO (2019) FA (2008) ACO (1991)
Telecommunications	2990	WO (2016) GWO (2014) ACO (1991)
Computer Science Interdisciplinary Applications	2807	GWO (2014) WO (2016) SSA (2017)
Engineering Multidisciplinary	1697	GWO (2014) WO (2016) SSA (2017)
Operations Research Management Science	1290	GWO (2014) FLA (2006) MSA (2018)
Automation Control Systems	1250	MRO (2020) ABC (2005) CS (2009)
Computer Science Software Engineering	1063	GWO (2014) WO (2016) SSA (2017)

The most prominent algorithms differ across categories. For example, Cuckoo Search, Grey Wolf Optimizer, and Manta Ray Foraging Optimization are highly represented in electrical and electronic engineering, whereas Cuckoo Search, Artificial Bee Colony, and Firefly Algorithm are prominent in artificial intelligence. Harris Hawks Optimization occurs frequently in information systems and theory and methods, while Grey Wolf Optimizer and Whale Optimization Algorithm are strongly represented in interdisciplinary applications and software engineering. These differences suggest that the selection and adoption of algorithms depend on the characteristics of optimization problems addressed in particular application areas.

Overall, Table 3 answers the question of where AIO algorithms are used by mapping their presence across WoS categories. It also shows that both established algorithms, such as Ant Colony Optimization and Artificial Bee Colony, and newer methods, such as Harris Hawks Optimization and Manta Ray Foraging Optimization, have found applications in multiple areas.

The co-occurrence network of author keywords is presented in Fig. 6. To improve the clarity of the visualization, only keywords occurring at least 20 times were included, while generic terms such as “optimization” and “system” were excluded. A thesaurus file was used to merge synonymous expressions, spelling variants, and abbreviations referring to the same algorithm or concept, such as “ant colony optimization”, “ACO”, and “ant colony system”.

In the network, the size of a node reflects the frequency of a keyword, whereas links indicate how often two keywords occur together in the same publications. The colored clusters represent groups of closely related research topics. Five major clusters were identified. The red cluster is primarily associated with artificial intelligence and machine-learning-related applications, while the yellow cluster is related to cloud computing and networking. The blue cluster is associated with power-engineering applications. The violet cluster is centered on Ant Colony Optimization, whereas the green cluster groups several AIO algorithms and related optimization topics.

Ant Colony Optimization is the most frequent algorithm-related keyword in the network, which confirms its continued relevance despite being one of the earliest methods in the field. More generally, the clustering pattern demonstrates that AIO algorithms are embedded in several distinct application domains, rather than being used within a single homogeneous research area.

The overlay visualization of author keywords is presented in Fig. 7 and shows the temporal evolution of research topics in the field. The colour of a keyword reflects its average publication year: darker colours indicate topics that were more prominent in earlier publications, whereas lighter colours indicate topics that have appeared more frequently in recent research.

The cluster centred on Ant Colony Optimization is predominantly associated with earlier research, confirming the long-standing role of this algorithm in the development of AIO. In contrast, the lighter-coloured keywords are more closely associated with artificial intelligence and related contemporary

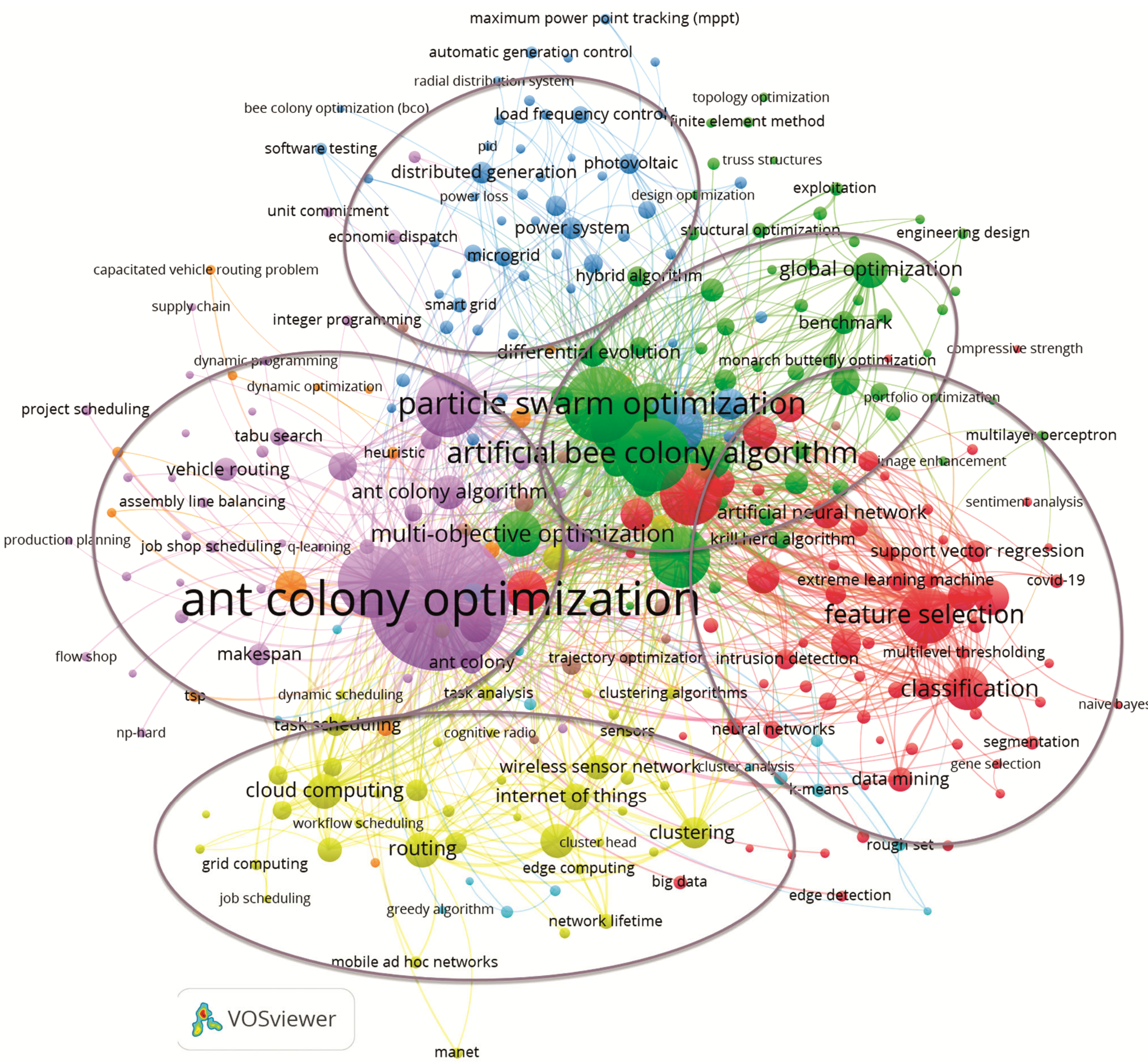

Fig. 6 — Keywords analysis in VOSViewer

application areas. This pattern suggests that recent research increasingly integrates AIO algorithms with AI-based methods, including hybrid optimization and machine-learning applications.

The temporal distribution also indicates that the field is expanding beyond the application of individual algorithms toward their integration into broader computational systems. Thus, the overlay visualization complements the category-level results in Table 3 by showing not only where AIO algorithms are applied, but also which application themes have become more prominent over time.

The far-right cluster is mostly formed out of older research. This is research centered around ant colony optimization. The lighter tones are mostly in the right part, devoted to artificial intelligence. This points to the conclusion that the recent research related to animal kingdom inspired algorithms, tends to couple with artificial intelligence. This trend is not surprising, considering the explosion of AI tools.[33]

Grouping of algorithms with their applications in engineering and computer science is identified as the answer to research question Q4.

Although VOSViewer and WoS enable analysis of inter-country and inter-organizational collaborations, in this study we deliberately focused on authors, algorithms and subject-area categories. This decision was guided by our research questions, which target

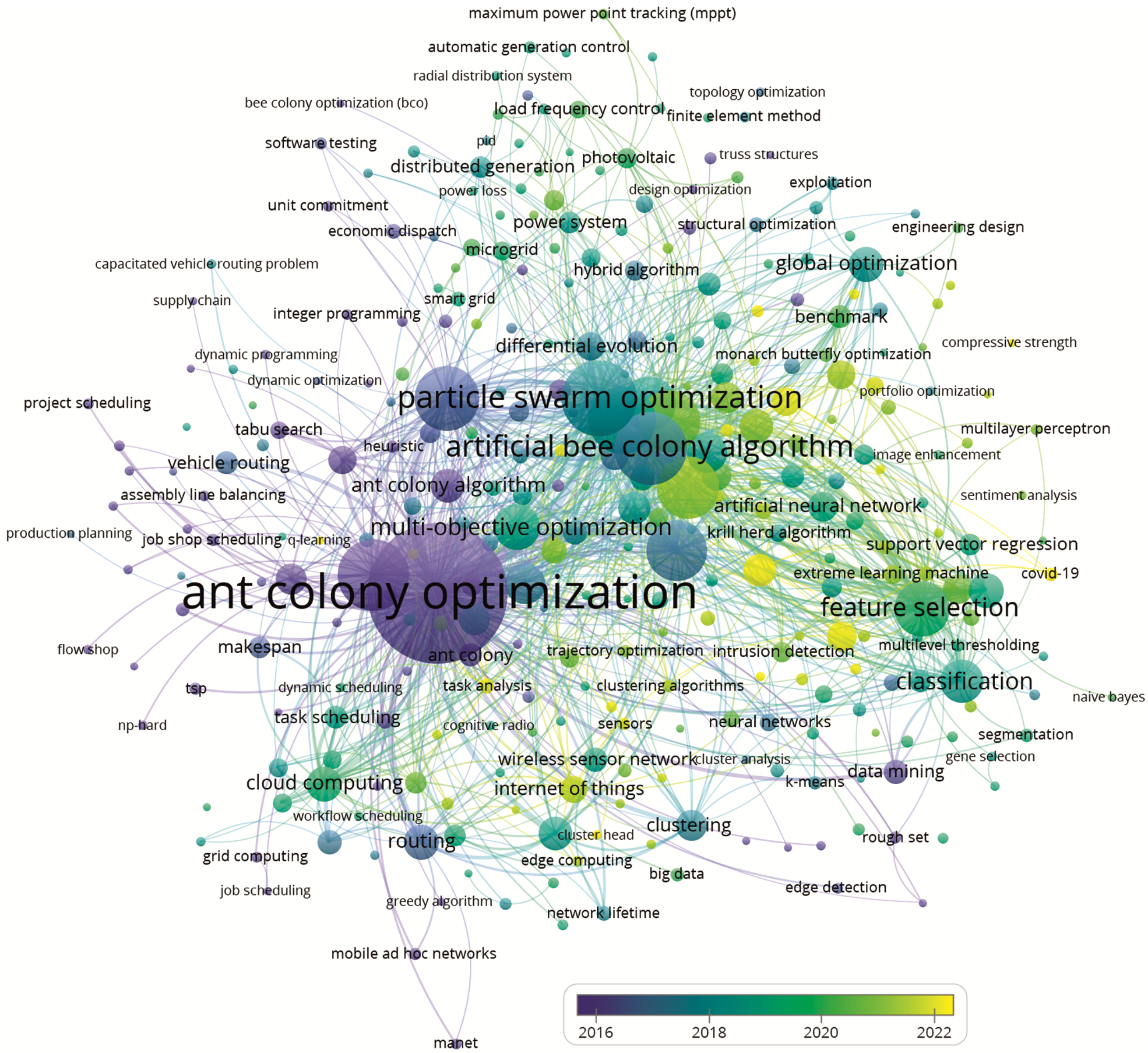

Fig. 7 — Overlay Visualization

the influential algorithms, application domains and leading authors, rather than geographical or institutional patterns.

Conclusions

Algorithms inspired by the animal kingdom have flourished in recent years. Trends indicate that the use of such algorithms in engineering and computer science is increasing in surges in the monitored period of 20 years. In this regard, it can be expected that the application of such algorithms will continue, with the refinement and adaptation of existing algorithms and commencing of new ones. The application of AIO algorithms in areas close to their origin, such as soft computing is particularly noticeable. As artificial intelligence has become ubiquitous, the optimization algorithms got along. Moving towards hardware, the application is found in cloud computing, followed by the Internet of Things, and ultimately in power engineering. The algorithms that have emerged in recent years are in expansion, while among the older algorithms, ant colony and artificial bee colony algorithms are particularly prevalent.

Beyond summarizing the main trends, the results have several implications for researchers and practitioners. (1) The dominance of algorithms such as GWO, WOA and ACO in specific WoS categories suggests that future methodological developments and hybridizations should consider their established role in electrical engineering, artificial intelligence, and information systems. (2) The observed shift of AIO algorithms towards AI-related fields indicates that new metaheuristics are increasingly evaluated within machine learning pipelines; this highlights an opportunity for closer collaboration between optimization and AI communities. (3) The identification of influential authors, journals, and keyword clusters can help researchers in building strategic collaborations.

The study is limited by its reliance on records indexed in the Web of Science Core Collection, the selected search query, and the inherently dynamic nature of bibliographic and citation data. In addition, it was not possible to include every AIO algorithm, because the number and terminology of such methods are continuously expanding. Future work may extend this bibliometric analysis in several directions. First, future studies may combine Web of Science data with records from Scopus or other indexing databases to broaden the coverage of publications and citations. Second, a more focused analysis could examine the practical use and comparative performance of individual AIO optimization algorithms within specific application domains, such as power systems, cloud computing, Internet of Things, and machine-learning. Third, country- and organization-level collaboration networks could be analyzed in a dedicated study to provide a complementary geographical and institutional perspective. Finally, longitudinal analyses could investigate whether recently introduced algorithms maintain their visibility and citation impact over time, or whether their adoption follows short-term publication trends.

Acknowledgments

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The authors used Perplexity AI Tool for language polishing and minor editing. Complete scientific content, interpretation and conclusions were authored and verified by the authors.

References

1 Rajwar K, Deep K & Das S, An exhaustive review of the metaheuristic algorithms for search and optimization: Taxonomy, applications, and open challenges, *Artif Intell Rev*, **56** (2023) 13187–13257, https://doi.org/10.1007/s10462-023-10470-y.

2 Khadem M, Toloie Eshlaghy A, & Fathi Hafshejani K, Nature-inspired metaheuristic algorithms: Literature review and presenting a novel classification, *J Appl Res Ind Eng*, **10(2)** (2023) 286–339, https://doi.org/10.22105/jarie.2021.287733.1330.

3 Ezugwu A E, Shukla A K, Nath R, Akinyelu A A, Agushaka J O, Chiroma H & Muhuri P K, Metaheuristics: A comprehensive overview and classification along with bibliometric analysis, *Artif Intell Rev*, **54** (2021) 4237–4316, https://doi.org/10.1007/s10462-020-09952-0.

4 Dragoi E N, Dafinescu V, Review of metaheuristics inspired from the animal kingdom, *Mathematics*, **9(18)** (2021) 2335, https://doi.org/10.3390/math9182335.

5 Molina D, Poyatos J, Ser J D, García S, Hussain A & Herrera F, Comprehensive taxonomies of nature- and bio-inspired optimization: inspiration versus algorithmic behavior, Critical Analysis Recommendations, *Cogn Comput*, **12** (2020) 897–939, https://doi.org/10.1007/s12559-020-09730-8.

6 Makhadmeh S N, Al-Betar M A, Doush I A, Awadallah M A, Kassaymeh S, Mirjalili S & Zitar R A, Recent advances in grey wolf optimizer, its versions and applications: Review, *IEEE Access*, **12** (2024) 22991–23028. https://doi.org/10.1109/ACCESS.2023.3304889.

7 Praveen V, Keerthika P, Modelling an efficient hybrid optimizer for handling vehicle routing problem, *J Sci Ind Res*, **81(6)** (2022) 651–662, https://doi.org/10.56042/jsir.v81i06.61849.

8 Faris H, Aljarah I, Al-Betar M A & Mirjalili S, Grey wolf optimizer: A review of recent variants and applications, *Neural Comput & Applic*, **30** (2018) 413–435, https://doi.org/10.1007/s00521-017-3272-5.

9 Nadimi-Shahraki M, Zamani H, Asghari Varzaneh Z & Mirjalili S, A systematic review of the whale optimization algorithm: Theoretical foundation, improvements, and hybridizations, *Arch Computat Methods Eng*, **30** (2023) 4113–4159, https://doi.org/10.1007/s11831-023-09928-7.

10 Toaza B, Esztergár-Kiss D, A review of metaheuristic algorithms for solving TSP based scheduling optimization problems, *Appl Soft Comput*, **148** (2023) 110908, https://doi.org/10.1016/j.asoc.2023.110908.

11 Deng G F & Lin W T, Citation analysis and bibliometric approach for ant colony optimization from 1996 to 2010, *Exp Syst with Applic*, **39(6)** (2012) 6229–6237, https://doi.org/10.1016/j.eswa.2011.12.001.

12 Bongale M A, Joshi R & Kadam K, Bibliometric analysis of firefly algorithm applications in the field of wireless sensor *Libr Philos Pract*, (2020) 4567, https://digitalcommons.unl.edu/libphilprac/4567.

13 Bar-Ilan J, Informetrics at the beginning of the 21st century—A review, *J Informetr,* **2(1)**, (2008), 1–52, ISSN 1751-1577, https://doi.org/10.1016/j.joi.2007.11.001.

14 Donthu N, Kumar S, Mukherjee D, Pandey N & Lim W M, How to conduct a bibliometric analysis: An overview and guidelines, *J Bus Res*, **133** (2021) 285–296, ISSN 0148-2963, https://doi.org/10.1016/j.jbusres.2021.04.070.

15 Dhiman S, Singh R & Singh Yadav R, Mapping the geography of sustainability transitions research: A bibliometric analysis, *J Sci Ind Res*, **82** (2023) 378–388.

16 Pathak M & Prasanna Kumari N K, A Bibliometric analysis of quassinoids research: A class of bioactive compounds, *J Sci Ind Res*, **79** (2020) 1017–1023.

17 Page M J, McKenzie J E, Bossuyt P M, Boutron I, Hoffmann T C, Mulrow C D, Shamseer L, Tetzlaff J M, Akl E A, Brennan S E, Chou R, Glanville J, Grimshaw J M, Hróbjartsson A, Lalu M M, Li T, Loder E W, Mayo-Wilson E, McDonald S, McGuinness L A, Stewart L A, Thomas J, Tricco A C, Welch V A, Whiting P & Moher D, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, *BMJ* **n71** (2021) 372, http://dx.doi.org/10.1136/bmj.n71.

18 Zhang J, Yu Q, Zheng F, Long C, Lu Z & Duan Z, Comparing Keywords Plus of WOS and Author Keywords, *J Assn Inf Sci Tec*, **67** (2016) 967–972. https://doi.org/10.1002/asi.23437.

19 Tripathi M, Kumar S, Sonker S K & Babbar P, Occurrence of author keywords and keywords plus in social sciences and humanities research: A preliminary study, *COLLNET J Scientomet Inf Manag*, **12(2)** (2018) 215–232, DOI: 10.1080/09737766.2018.1436951.

20 Van Eck N J & Waltman L, *VOSViewer manual*. Leiden: Univeristeit Leiden, 1.6.18 (2022) 1–53, https://www.VOSViewer.com/documentation/Manual_VOSViewer_1.6.18.pdf

21 Donthu N, Kumar S, Mukherjee D, Pandey N & Lim W M, How to conduct a bibliometric analysis: An overview and guidelines, *J Bus Res*, 133 (2021) 285–296, https://doi.org/10.1016/j.jbusres.2021.04.070.

22 Echchakoui S, Why and how to merge Scopus and Web of Science during bibliometric analysis: The case of sales force literature from 1912 to 2019, *J Market Anal*, **8** (2020) 165–184, https://doi.org/10.1057/s41270-020-00081-9.

23 Mirjalili S, Mirjalili S M & Lewis A, Grey Wolf Optimizer, *Adv Eng Softw*, **69** (2014) 46–61, https://doi.org/10.1016/j.advengsoft.2013.12.007.

24 Mirjalili S & Lewis A, The Whale Optimization Algorithm, *Adv Eng Softw*, **95** (2016) 51–67, https://doi.org/10.1016/j.advengsoft.2016.01.008.

25 Yang X S & Deb S, Cuckoo Search via Lévy flights, in *2009 World Congress on Nature & Biologically Inspired Computing (NaBIC)*, Coimbatore, India, (2009) 210–214, https://doi.org/10.1109/NABIC.2009.5393690.

26 Heidari A A, Mirjalili S, Faris H, Aljarah I, Mafarja M & Chen H, Harris hawks optimization: Algorithm and applications, *Future Gener Comp Syst*, **97** (2019) 849–872, https://doi.org/10.1016/j.future.2019.02.028

27 Mirjalili S, Gandomi A H, Mirjalili S Z, Saremi S, Faris H & Mirjalili S M, Salp Swarm Algorithm: A bio-inspired optimizer for engineering design problems, *Adv Eng Softw*, **114** (2017) 163–191, https://doi.org/10.1016/j.advengsoft.2017.07.002

28 Karaboga D & Basturk B, On the performance of artificial bee colony (ABC) algorithm, *Appl Soft Comput*, **8(1)** (2008) 687–697, https://doi.org/10.1016/j.asoc.2007.05.007.

29 Mirjalili S, The Ant Lion Optimizer, *Adv Eng Softw*, **83** (2015) 80–98, https://doi.org/10.1016/j.advengsoft.2015.01.010

30 Saremi S, Mirjalili S & Lewis A, Grasshopper optimisation algorithm: Theory and application, *Adv Eng Soft*, **105** (2017) 30–47, https://doi.org/10.1016/j.advengsoft.2017.01.004.

31 Yang X-S, Firefly algorithm, stochastic test functions and design optimisation, *Int J Bio-Insp Comp*, **2(2)** (2010) 78–84. https://doi.org/10.1504/IJBIC.2010.032124.

32 Dorigo M & Blum C, Ant colony optimization theory: A survey, *Theor Comput Sci*, **344(2–3)** (2005) 243–278, https://doi.org/10.1016/j.tcs.2005.05.020.

33 Dorigo M, Maniezzo V & Colorni A, The ant system: An autocatalytic optimizing process, *Technical Report TR91–016*, (1991) Politecnico di Milano

34 Shao Z, Zhao R, Yuan S, Ding M & Wang Y, Tracing the evolution of AI in the past decade and forecasting the emerging trends, *Expert Syst Appl*, **209** (2022) 118221, https://doi.org/10.1016/j.eswa.2022.118221.