Expert Systems With Applications 255 (2024) 124857

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

Review

Review of the metaheuristic algorithms in applications: Visual analysis based on bibliometrics

Guanghui Li [a,1], Taihua Zhang [a,b], Chieh-Yuan Tsai [c], Liguo Yao [a,b,*,2], Yao Lu [a,b], Jiao Tang [a]

[a] School of Mechanical and Electrical Engineering, Guizhou Normal University, Guiyang, Guizhou 550025, China
[b] Technical Engineering Center of Manufacturing Service and Knowledge Engineering, Guizhou Normal University, Guiyang, Guizhou 550025, China
[c] Department of Industrial Engineering and Management, Yuan Ze University, Taoyuan 32003, Taiwan

ARTICLE INFO

Keywords:
Metaheuristic algorithms
Application
CiteSpace
Bibliometric
Visualization analysis

ABSTRACT

Metaheuristic algorithms have gradually become the mainstream way to solve complex optimization problems with their streamlined structure and robust performance. Innovative achievements have increasingly emerged with the development and widespread application of metaheuristic algorithms. In order to provide a better overview of relevant work in this field and clarify its prospects, this paper analyzed 1676 literature on the application of metaheuristic algorithms from 1994 to 2023, based on the Web of Science database. Firstly, utilizing a large amount of literature data, the overall trend of the application field development of metaheuristic algorithms, core authors, and mainstream journals was analyzed from the perspective of bibliometrics. Secondly, combined with the visualization software CiteSpace, major cooperation maps in the application field of metaheuristic algorithms were drawn, and the correlation relationships between authors, countries, and institutions in the area were obtained. Thirdly, co-word and cluster analyses were used to explore the research hotspots of applying metaheuristic algorithms, and six prevalent research topics in this field were obtained. Finally, through the co-cited literature cluster map and time-zone map, vital citing literature in the metaheuristic algorithms' application field and the evolution of time-based development frontiers were summarized, and three development stages of this field were obtained. The overall review of the application of metaheuristic algorithms can provide assistance for researchers interested in this field.

1. Introduction

With the rapid iterative growth of knowledge and the amount of data, increasing optimization problems appear in industrial production and theoretical research. These problems mostly have the characteristics of high dimensionality, nonlinearity, and multi-objective (Corne et al., 1999; Gill et al., 2019), covering multiple industries such as manufacturing, economics (Mousavi-Avval et al., 2017), medical care (Wang et al., 2018), information (Sabireen & Venkataraman, 2023), and transportation (Olivares-Benitez et al., 2013). Traditional optimization methods based on mathematical theories have been brutal to meet the needs, while metaheuristics combined with computer science is gradually becoming the mainstream method to solve optimization problems (Ikotun et al., 2023).

Inspired by nature and biological spontaneous group activities (Beheshti & Shamsuddin, 2013), some metaheuristic algorithms have been proposed and applied, such as genetic algorithm (Holland, 1992), ant colony algorithm (Dorigo et al., 2006), particle swarm algorithm (Kennedy & Eberhart, 1995), etc. These algorithms enrich modern optimization techniques and provide practical solutions for complex

* Corresponding author at: School of Mechanical and Electrical Engineering, Guizhou Normal University, Guiyang, Guizhou 550025, China.
E-mail addresses: ghli@gznu.edu.cn (G. Li), zhangth542@gznu.edu.cn (T. Zhang), cytsai@saturn.yzu.edu.tw (C.-Y. Tsai), lgyao@gznu.edu.cn (L. Yao), yao.lu@gznu.edu.cn (Y. Lu), jiaotang@gznu.edu.cn (J. Tang).
[1] ORCID: https://orcid.org/0009-0001-8322-5357.
[2] ORCID: https://orcid.org/0000-0003-0349-3106.

https://doi.org/10.1016/j.eswa.2024.124857
Received 9 October 2023; Received in revised form 25 June 2024; Accepted 20 July 2024
Available online 23 July 2024

functions and combinatorial optimization problems with multi-extremum characteristics (Jia et al., 2023; Smith, 1978).

As an advanced iterative algorithm independent of the problem, metaheuristic is used to find the optimal or approximate optimal to the optimization problem (Rajabi Moshtaghi et al., 2021). When the computing power or calculation conditions are insufficient, obtaining an exact solution is difficult or impossible. Compared with the exact optimization algorithm, the metaheuristic algorithm can quickly find an approximate solution to the problem and has ease of development and high robustness (Desale et al., 2015; Yao et al., 2023). Compared with other AI algorithms, such as deep learning, it requires fewer parameters to be tuned, resulting in shorter computation time and lower computational cost. The metaheuristic algorithm first sets the initial solution through the input parameters and enters the main loop when the iteration conditions are met. Then, follow the strategy to iterate, compare, and store the optimal value of each loop. Finally, output the optimal result when the iteration condition is not satisfied. To some extent, most optimization problems can be solved through metaheuristic algorithms, which abstract the actual problem into a mathematical equation (fitness function or evaluation function) and use the iterative update strategy in the algorithm (Xue & Shen, 2023). The extreme or optimal value is obtained within a set finite number of iterations. An application example of a population-based metaheuristic algorithm is shown in Fig. 1.

Metaheuristic algorithm has developed rapidly in the past 20 years with an unstoppable trend. According to incomplete statistics, there are more than 500 different algorithms (Rajwar et al., 2023; Sadollah et al., 2015). Developing metaheuristic algorithms is a mature optimization technology with a relatively reasonable evolution process. The predecessor of the metaheuristic algorithm is the heuristic algorithm. The heuristic optimization algorithm (approximate optimization) is roughly divided into heuristic with deterministic features and probabilistic features (Ezugwu et al., 2021). Early Heuristic algorithms were iterative algorithms for specific problems. Later, it was discovered that population-based algorithms have universal applicability in solving problems. Since then, various metaheuristic algorithms have appeared one after another and have been favored by some researchers for their superior performance (Yao et al., 2023). From the perspective of the inspiration sources of various algorithms, metaheuristic algorithms based on biological behavior account for a large proportion. From the perspective of the types of agents, population-based metaheuristic algorithms account for the vast majority. Most metaheuristic algorithms are based on processable phenomena, behaviors, processes, and mechanisms, such as natural laws, biological behaviors, natural phenomena, and biological intrinsic mechanisms. A classification of some typical metaheuristic algorithms based on inspiration sources, as shown in Fig. 2.

With the rapid increase in the number and types of metaheuristic algorithms, it is of practical significance to summarize their research status, research hot spots, development context, and evolutionary trends, provide directional explanations, and provide application guidelines for researchers in this field.

Many review studies that are not based on bibliometrics have received some attention. Singh et al. (2023) presented a comprehensive taxonomic review and analysis of recent metaheuristic scheduling techniques using exhaustive evaluation criteria in the cloud and fog environment. Kaur et al. (2022) conducted a systematic review of metaheuristic-based image encryption techniques. Teoh et al. (2015) conducted a review of state of the art for metaheuristic techniques in academic scheduling problems. Akinola et al. (2022) presented a systematic survey of literature for solving multiclass feature selection problems utilizing metaheuristic algorithms. Liao and Li (2020) surveyed and summarized previous works in metaheuristic-based inverse design of various materials. Pillai and Rajasekar (2018) reviewed the existing metaheuristic-based parameter extraction techniques on PV models. Melman and Evsutin (2023) presented an overview of data hiding techniques based on metaheuristic optimization. Sharma (2023) discussed and compared the performance of different metaheuristic algorithms for uniform linear array (ULA), circular, concentric ring, conformal and planar antenna array pattern synthesis. Although these researches have brought many inspirations and reflections to other researchers, they often carry the subjectivity and incompleteness of the author's viewpoint.

A bibliometric survey and review can avoid the subjectivity of the author's viewpoint and comprehensively and objectively reflect the development status of a field. Many researchers have presented bibliometric analyses in different disciplinary fields. Meerow et al. (2016)

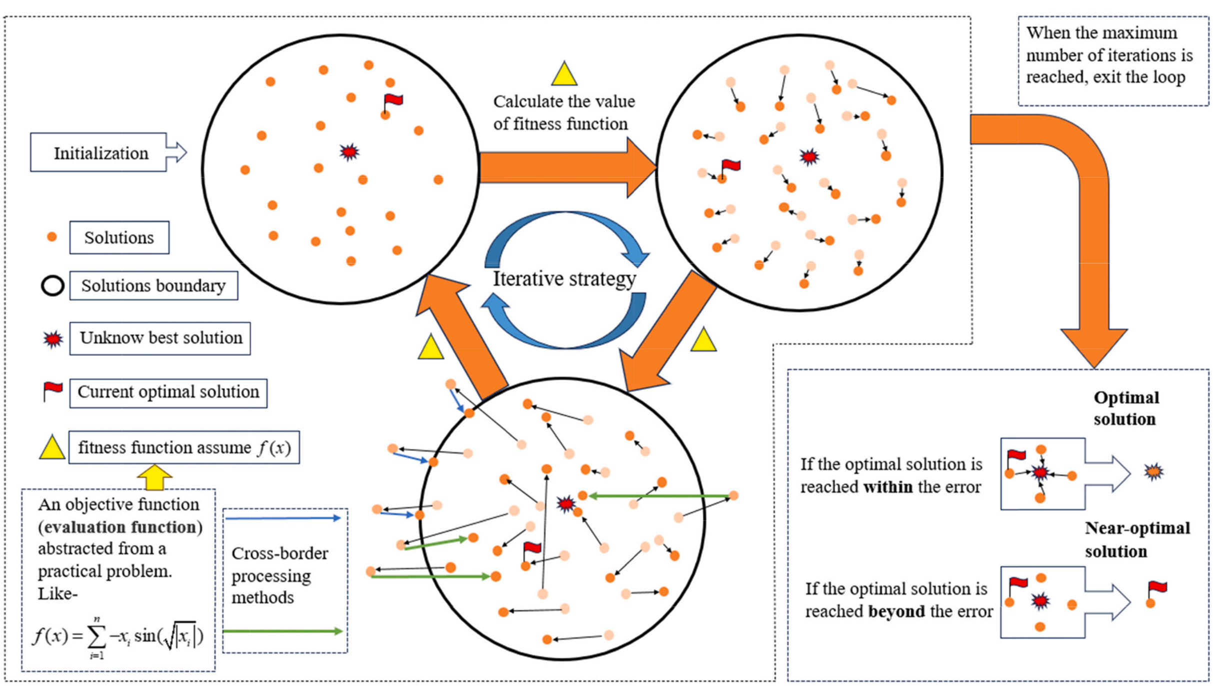

Fig. 1. An example of how to apply metaheuristic algorithm.

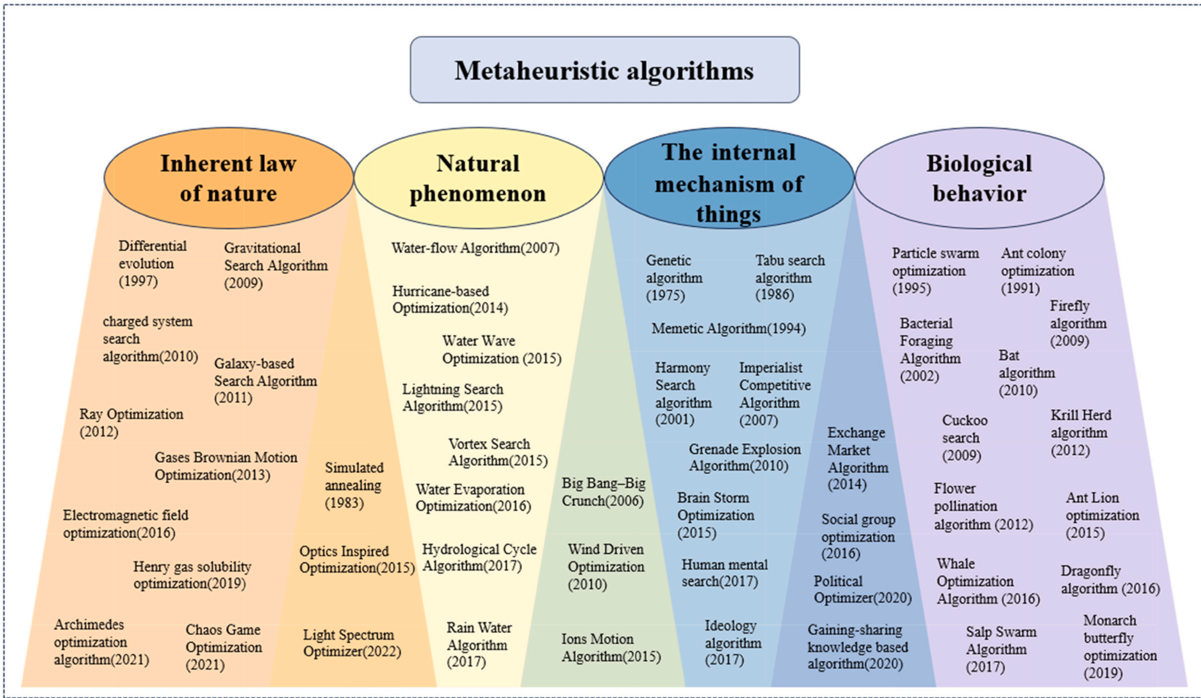

Fig. 2. A classification of some typical metaheuristic algorithms based on inspiration sources.

reviewed the scholarly literature on urban resilience and concludes that the term has not been well defined. Geissdoerfer et al. (2017) conducted an extensive literature review, employing bibliometric analysis and snowballing techniques to synthesize the similarities, differences and relationships between the terms Circular Economy and sustainability. Ben-Daya et al. (2019) explored the role of Internet of Things (IoT) and its impact on supply chain management (SCM) through an extensive literature review. Zhang et al. (2022) provided a comprehensive bibliometric analysis to better understand the evolution of Artificial Intelligence in Renewable Energy (AI&RE) research from 2006 to 2022. Catumba et al. (2023) provided bibliometric study focused on illustrating the overview of hydrogen production research, conducting a systematic survey of current research. Yang et al. (2024) employed bibliometric methods to accurately and objectively review the progress in Named Entity Recognition (NER).

In the bibliometric research of the metaheuristic algorithm, some scholars have also done similar work. Progress in similar research: Kar (2016) identified commonly used algorithms in bio-inspired metaheuristic algorithms and discussed their principles, development, and range of applications; Yang (2020) introduced the search mechanism and mathematical basis of recent nature-inspired metaheuristic algorithms and discussed unsolved and challenging problems; Agarwal and Kumar (2021) comprehensively reviewed the bat algorithm and investigated its biological implications and roles; Ezugwu et al. (2021) conducted a systematic taxonomical review and bibliometric analysis of the trends and progress in nature-inspired metaheuristic clustering algorithms; Guo et al. (2021) presented a comprehensive bibliometric review of bacterial foraging optimization algorithms by constructing a knowledge mapping using CiteSpace.

Although similar studies have achieved impressive results, there are few in-depth discussions on the application of the overall metaheuristic algorithm in most of the literature reviews. Generally, it is to analyze the application scope and scenario of a single metaheuristic algorithm or elaborate on a small part or category of metaheuristic algorithms. Meanwhile, among all similar studies, traditional review literature accounts for the vast majority, while papers based on bibliometrics account for the minority. The former relies on the author's knowledge reserve and comments on the development of a specific field based on their own experience, which has a certain degree of subjectivity. However, based on a large number of literature data, the latter makes an objective and quantitative analysis of a certain discipline field through the laws of statistical metrology, which can scientifically and accurately reflect the area's development.

CiteSpace (Chen, 2004, 2006) is a visual analysis software based on bibliometrics that can process a large amount of unstructured scientific literature data, depict a series of network science knowledge graphs and cluster science knowledge graphs, and explore the knowledge structure, research hotspots, cooperation models, and cutting-edge trends in specific fields. It first derives a sequence of co-citation networks from a series of equal-length time interval slices. Then, network merging and clustering are performed using CiteSpace's built-in algorithms. Finally, the intellectually significant document content and visual map can be obtained by calculating the combination of different subject words and important document parts. Excellent bibliometric research enables scholars to gain a one-stop overview, identify gaps in knowledge, drive novel research ideas, and position their desired contributions to the field (Donthu et al., 2021).

Therefore, based on bibliometrics and visualization software CiteSpace, this paper reviews the applications of metaheuristic algorithms. The main contributions are as follows.

- From an objective perspective, applying co-word analysis and cluster analysis methods revealed the development status, research hotspots, and evolution trends of metaheuristic algorithms at the application level over the nearly 30 years.
- In visual maps, the correlation between subject fields, authors, institutions, and countries at the application level of metaheuristic algorithms over the past approximately 30 years is displayed.
- Using bibliometric methods, representative evaluation indicators were quantified, and core authors and publications in the research field were obtained.
- The academic influence of relevant research subjects was measured through CiteSpace analysis software. It can provide assistance for relevant scholars to quickly grasp past trends in approximately 30

years and future developments in the field, providing certain reference values for positioning their contribution expectations.

The remainder of this paper is organized as follows. Section 2 introduces the data source, research methods, theoretical support, and research process. Section 3 presents the overall analysis of applications of the metaheuristic algorithm's publications, journal distribution, and subject basis in the past nearly 30 years. Section 4 introduces the cooperation networks of authors, countries, and institutions, as well as the scale of their cooperation and development, The distribution of core authors, and the academic influence of countries and institutions. Section 5 introduces keyword co-occurrence and cluster maps, analyzes the research hotspots in applications of metaheuristic algorithms, and verify the significance of metaheuristic algorithm. Section 6 presents the vital citing references, co-cited reference clusters, and the evolution of the forefront based on keyword time-zone map and keyword citation bursts. In the end, the summary and future works are briefly stated in Section 7.

2. Data source and methods

2.1. Data source

Web of Science (WoS) provides more comprehensive field categories and literature coverage. In addition, the citation analysis tools provided by WOS are better suited to the bibliometrics method used in this paper. At the same time, we learned that WOS has earlier literature records compared to other databases. Retrieved on the WoS with "metaheuristic algorithm" (topic) and "application" (all fields), on April 21, 2023, selected the WoS Core Collection and screened out non-English literature and review papers, and preliminarily obtained 2051 documents. Although the WoS system can directly filter a part of the literature data by qualifiers, this function does not seem to be able to completely separate the noise in the literature data. The noise in the data is the literature that does not meet the research requirements of this paper. The non-compliant literatures often lead to deviations in the research results of this article due to abnormal keyword frequencies and literature quality issues. Therefore, further screening is needed to ensure the objectivity and integrity of the data. After further filtrating, 1676 literature data were finally obtained.

2.2. Research methods

Scientometrics analysis is one of the indispensable approaches for quantitative analysis when evaluating research performance (Donthu et al., 2021). Bibliometrics is a scientific measurement method based on literature, which can be regarded as a branch of scientometrics. First, co-word analysis has recently been a prevalent literature research method. It emphasizes the importance of the content represented by the keyword through the recurrence degree of the same keyword in different documents (He, 1999). Therefore, keywords can be used as the minimum composition of the document to describe the content of the paper (Romesburg, 2004). Second, cluster analysis is a method to measure the relationship between variables or samples based on the numerical characteristics of objects. By grouping variables with substantial homogeneity into one class, the cohesion between objects in the same class is more robust than that between objects in other types (Blashfield & Aldenderfer, 1978).

Constructing a correlation matrix is the basis of co-word and cluster analysis (Wang et al., 2012). The process of the correlation matrix's construction is as follows.

Step 1. Count the number of publications appearing in the thesaurus to obtain the frequency of occurrence for each.

Step 2. Extract the co-occurrence frequencies of each two thesauruses from indexed publications.

Step 3. Use the equivalent index to evaluate links between co-thesauruses.

Step 4. Construct a correlation matrix based on the equivalent index values of each co-thesaurus.

The mathematical expression for constructing the correlation matrix is shown in Eq. (1).

$$s(\sigma_i, \sigma_j) = \frac{n_{ij}}{\sqrt{n_i \times n_j}} \tag{1}$$

where σ_i and σ_j is the thesauruses in the set of publications, n_i and n_j are used to represent the occurrence frequencies of the thesaurus σ_i and σ_j in the set of publications, n_{ij} is used to represent the number of publications in which the thesaurus pair appears (σ_i and σ_j).

CiteSpace integrates various bibliometrics methods, including co-word analysis, cluster analysis, betweenness centrality measurement analysis, burst measurement analysis, and others. CiteSpace identifies the potential of the literature through the selection of citations by scholars in the field. Its design concept comes from Price's scientific frontier theory (Price, 1965), the structural hole method of social network theory (Burt, 2002), and burst detection technology (Kleinberg, 2002). In CiteSpace, the betweenness centrality of nodes in the network is used to measure structural holes (Freeman, 1977) and turning points (Chen, 2004). The measurement of key nodes utilizes the Burst algorithm for detecting sudden increases in frequency, and the global measurement of the overall network structure adopts the modular analysis method (Chen & Chen, 2013). Based on a large amount of data, CiteSpace conducts quantitative analysis on research objects, and the results are achieved through algorithms which embed in software. The parameters setting of the software are shown in Table 1.

This paper completes the statistical analysis, bibliometric analysis, and visual analysis of the research content through three major tools: bibliometric methods, CiteSpace analysis software, and WoS database. Firstly, the retrieved data is processed and imported into CiteSpace software for statistical analysis. Secondly, CiteSpace software is used for bibliometric and visual analysis. The research process is shown in Fig. 3.

3. Overall analysis of the literature

3.1. Trend analysis of publications

The total number of publications in a field can reflect the development status of that field, and the overall development trend can be seen from the annual publication numbers and growth curve. The statistics of the publications and growth trend fitting curve of 2051 literature data collected from WoS are shown in Fig. 4.

Based on Fig. 4 and the law of literature accumulation and growth discovered by Price (1976), it can be preliminarily estimated that the overall number of literature on the applications of metaheuristic algorithms is exponentially increasing. The exponential fitting model is used to fit the curve, and the R^2 (Coefficient of determination) is used to measure the model's fitting degree and prediction accuracy to the observation data. The approximate fitting curve model is shown in Eq. (2). The R^2 is calculated by Eq. (3).

$$N = 3.07 + 2.68e^{\left(\frac{y-2002.66}{3.82}\right)} \tag{2}$$

$$R^2 = \frac{SSR}{SST} = \frac{\sum_{i=1}^{n} (\widehat{y}_i - \overline{y})^2}{\sum_{i=1}^{n} (y_i - \overline{y})^2} \tag{3}$$

Table 1
Parameters setting of CiteSpace.

Item	Settings	Item	Settings
time span (year)	1995–2023	slice (year)	1
pruning algorithm	pathfinder	g-index	k = 25
top N	50	links strength	cosine

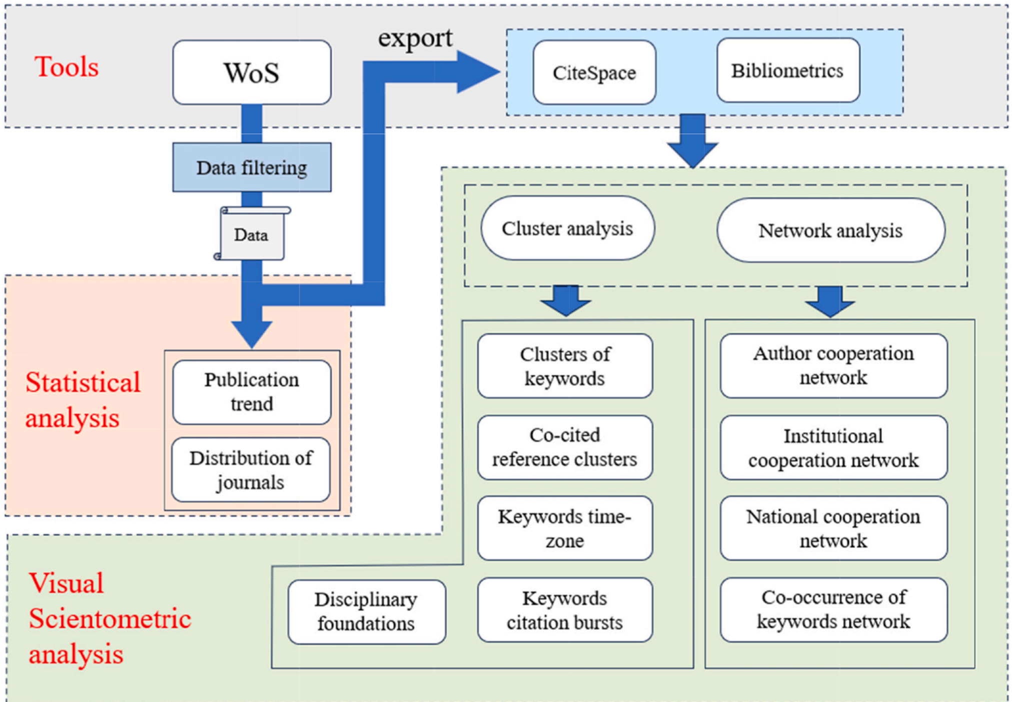

Fig. 3. Research process.

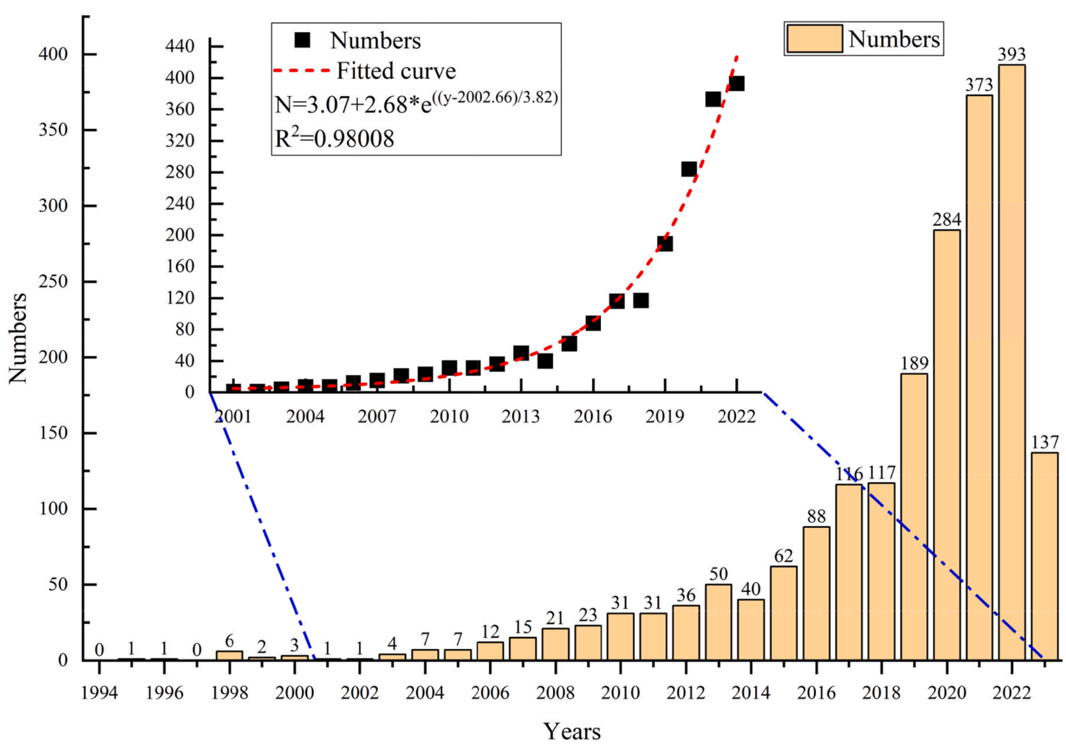

Fig. 4. Annual publication statistics, trend fitting curve.

where y represents the year, and N represents the number of publications in that year, the total sum of squares (SST) reflects the total error between all observed values of the dependent variable and its mean, the sum of squares of regression (SSR) reflects the impact of changes in the independent variable on the value change of the dependent variable, the R^2 indicates the proportion of the SSR to the SST.

The value of the R^2 is between [0,1], and the closer it approaches 1, the better the regression equation fits, while the nearer it approaches 0, the worse the regression equation fits. The calculated value of R^2 is 0.98008, which proves the good fitting degree of the formula. In other words, the number of published papers in this field is increasing exponentially, and the development is desirable.

3.2. Distribution of journals

Analyzing the journals' distribution of the application of metaheuristic algorithm-related literature can identify critical journals in this field, infer the publication direction of the journal, and guide relevant researchers to devote themselves to this field. Fig. 5 shows the journals with more than 0.68 % of published papers. Table 2 shows the subject classification of the top 15 source journals in WoS.

APPLIED SOFT COMPUTING and IEEE ACCESS rank at the forefront with 87 and 86 publications, respectively. The disciplines include computer science artificial intelligence, computer science interdisciplinary application, computer science information systems, and engineering electrical and electronics. From the disciplinary classification of all journals, a category of journals related to computer science accounts for about two-thirds of all top 15 journals. It has a greater demand for the applications of metaheuristic algorithm-related literature. According to Fig. 5, the top 15 journals account for approximately 38.4 % of all published papers.

In bibliometrics, the number of core journals can be obtained by ranking the number of papers published in each journal, and the threshold value (r_0) for determining whether to be a core journal is calculated by Eq. (4).

$$r_0 = 2\ln\left(e^E * Y\right) \tag{4}$$

where E is the Euler-Maskroni constant, with a value of nearly 0.57721, and Y is the number of papers published in the top 1 journal.

It is known that the journal APPLIED SOFT COMPUTING has published papers of 87, ranking first. After calculation, r_0 is equal to 10.086. Thus, the journals with the top 10 publications are core journals, and according to the chart, 517 documents were published by core journals, accounting for 25.134 % of the total number of publications, less than 1/3. The amount of literature published by journals in the core area must account for 1/3 of the total number of papers to form a mainstream core area journal collection in this field, which is Bradford's law (Brookes, 1977). Although it has not yet met the requirements of that law, it can be seen that the development of journals in the applications of the metaheuristic algorithm has begun to take shape, and the core journal collection will be formed soon.

3.3. Disciplinary foundations of metaheuristic algorithms' applications

Dual-map overlay analysis is a unique feature of CiteSpace as a literature visualization analysis software. Dual-map overlay of the journal display the distribution of the research topic in the main research subject areas, as well as the citation between journal literature, which can intuitively reflect the disciplinary distribution and interdisciplinary situation in the field. Dual-map overlay of journals is shown in Fig. 6.

The left side is the map of citing journals, and the right is the map of cited journals. The cited journals can be regarded as the foundation of the research field, and the citing journals can be viewed as the development of the research field. The ellipse size in the left map is proportional to the number of journal publications and authors, and the connecting line uses the z-score function to highlight a firmer and smoother citation curve to display more critical citation information. It can be known that the collection of journals related to computer science, systems science, mathematics, and mechanics is the foundational journal in the field of applications of metaheuristic algorithms.

4. Collaboration networks analysis

4.1. Analysis of core authors and authors collaboration network

Authors with a certain number of publications may have long-term thinking in a field. In other words, they have a certain degree of influence on this field's development level and direction. This paper selects representative authors to analyze their research fields and achievements, which helps to sort out some critical points in application areas of metaheuristic algorithms.

The author's prominence index can be quantified through the way of bibliometrics, and the law of Price (1976) is a prevailing method used by scholars to determine whether to be the core authors in a field. Through the concrete formula of the law, the threshold value (λ) of the author's publication numbers can be quantitatively calculated. The threshold value λ is calculated by Eq. (5).

$$\lambda = 0.749\sqrt{\chi_{max}} \tag{5}$$

where λ represents the threshold value for determining whether it is a core author, χ_{max} is author's number of publications with the highest

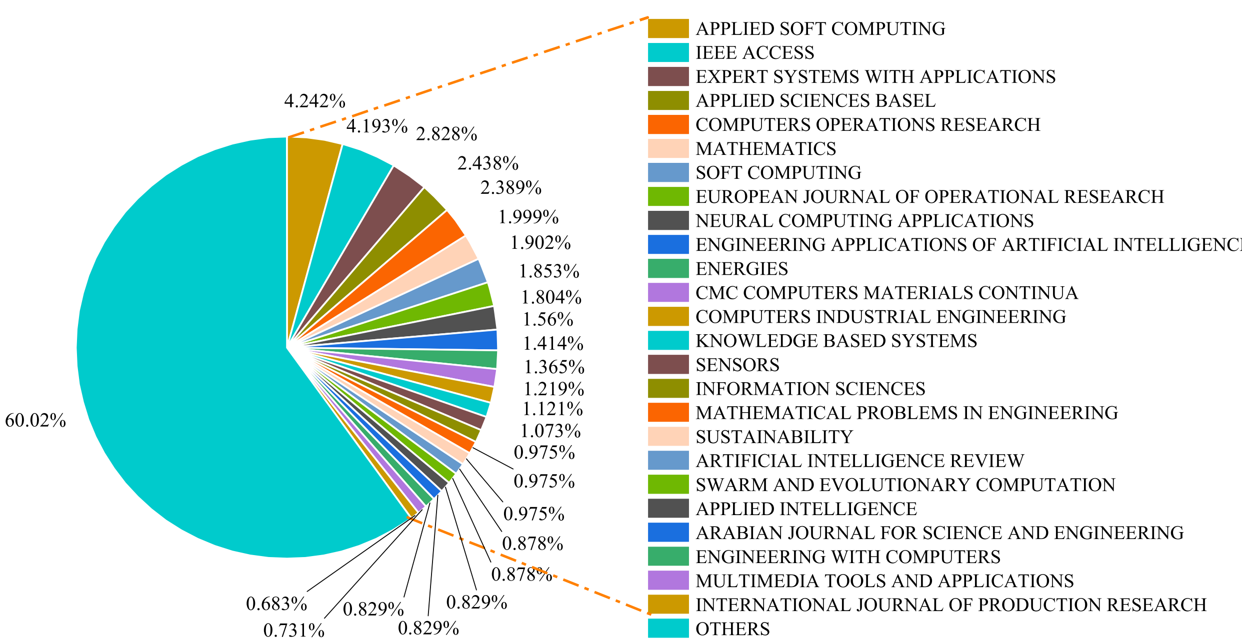

Fig. 5. Proportion of the source journals.

Table 2
Number of published papers and subject category in the top 15 source journals.

Publication title	Number of published papers	Subject category
APPLIED SOFT COMPUTING	87	Computer Science Artificial Intelligence, Computer Science Interdisciplinary Applications
IEEE ACCESS	86	Computer Science Information Systems, Engineering Electrical Electronic, Telecommunications
EXPERT SYSTEMS WITH APPLICATIONS	58	Computer Science Artificial Intelligence, Engineering Electrical Electronic, Operations Research Management Science
APPLIED SCIENCES BASEL	50	Chemistry Multidisciplinary, Engineering Multidisciplinary, Materials Science Multidisciplinary, Materials Science Multidisciplinary
COMPUTERS&OPERATIONS RESEARCH	49	Computer Operations Research, Engineering Industrial, Operations Research Management Science
MATHEMATICS	41	Mathematics
SOFT COMPUTING	39	Computer Science, Automation Control Systems, Robotics
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH	38	Business Economics, Operations Research Management Science, Engineering, Computer Science, Mathematics
NEURAL COMPUTING APPLICATIONS	37	Computer Science, Automation Control Systems, Robotics
ENGINEERING APPLICATIONS OF ARTIFICIAL INTELLIGENCE	32	Automation Control Systems, Computer Science, Engineering, Robotics
ENERGIES	29	Energy Fuels, Engineering, Mathematics, Business Economics
CMC COMPUTERS MATERIALS CONTINUA	28	Computer Science, Engineering, Mathematics
COMPUTERS INDUSTRIAL ENGINEERING	25	Computer Science, Engineering, Mathematics, Business Economics, Automation Control Systems
KNOWLEDGE BASED SYSTEMS	23	Computer Science, Automation Control Systems, Robotics, Mathematics
SENSORS	22	Engineering, Instruments Instrumentation, Chemistry, Spectroscopy

published papers among all authors.

According to Price's inference, if an author's publications exceed that threshold value, the author can be considered a core author. From the data exported by CiteSpace, "Abd elaziz, Mohamed" has the highest number of publications, 19. Calculated according to Eq. (5), λ is approximately equal to 3.26, so the author whose published papers are over three can be regarded as the core author. According to statistics, there are 40 core authors, as shown in Table 3.

The author cooperation map displays the connection information between various nodes, including connection strength and time span, which can reflect the scale of cooperation among authors in the field of applications of metaheuristic algorithms. At the same time, the information of nodes is also reflected in different forms. In CiteSpace, it is set to use rainbow color bands to distinguish different years, which can obtain the clearest comparison and more intuitive results. Among them, red, orange, yellow, green, blue, blue, purple, and black represent time from near to far. The top 9 large-scale collaboration networks can be selected by adjusting the author collaboration map, as shown in Fig. 7.

Detailed analysis of nodes can further explore the information of author cooperation fields. Among them, the largest network is headed by "Abd elaziz, Mohamed", "Abuualigah, Laith", "Ewees, Ahmed A" and "Mirjalili, Seyedali", followed by "Islam, Abu Reza Md Towfiqul", "Dehghani, Mohammad", "Bekdas, Gebrail", "Crawford, B", "Moayedi, Hossein", "Marti, Rafael", "Glover, Fred" and other small cooperation networks.

The research areas of the two-level cooperation network led by "Abd elaziz, Mohamed" include an improved alternative multilevel thresholding image segmentation method, optimization scheme of energy system prediction model, optimization of fine-tuning random vector functional link (RVFL) model, solving unrelated parallel machine scheduling problems, task scheduling problems in cloud computing, job shop scheduling, lightweight feature selection methods in human activity recognition systems, and others. Mohamed is a highly cited scholar whose research fields include economics, energy, engineering, industrial manufacturing, environment, geography, etc. The main content related to applications of metaheuristic algorithms includes accurate solar cell design of industrial and household energy systems (Oliva et al., 2019), new models for training and forecasting long-term monthly gold price fluctuations (Alameer et al., 2019), novel models for predicting the productivity of active solar stills developed in combination with artificial neural network (ANN) (Essa et al., 2020), an improved COVID-19 image classification method proposed in combination with convolutional neural network (Abd Elaziz et al., 2021), training and improving the RVFL to predict kerf quality indices during CO2 laser cutting of polymethylmethacrylate sheets (Elsheikh et al., 2021), an improved intrusion detection system technology that relies on deep learning and applies metaheuristic algorithm to perform feature extraction and selection (Dahou et al., 2022), and others.

The two-level cooperation network led by "Abualigah, Laith" includes the following research fields: solving the optimal power flow (OPF) problem of the power system, software vulnerability prediction model, design of proportional-integral-derivative (PID) controller for functional electrical stimulation system, feature selection in medical diagnosis, optimization of long short-term memory recursive neural network model, task scheduling in cloud computing, and dynamic data replication problem in fog computing. Research fields of Abualigah include computer science, mathematics, automatic control systems, robotics, and others. The main contents include combining text clustering technology to propose a new feature selection method (Abualigah & Khader, 2017) a unique solution to multi-objective scheduling problems in a cloud computing environment (Abualigah & Khader, 2017), and an efficient solution to single-objective and double-objective economic emissions dispatch problems considering valve point effects (Hassan et al., 2021). Abualigah also has written some reviews of the metaheuristic algorithm.

The research fields of the two-level cooperation network led by "Mirjalili, Seyedali" include parameter extraction methods for the electrical equivalent circuit of the photovoltaic cell based on the double-diode model (Abbassi et al., 2019) and optimization of selective harmonic elimination methods (Ürgün et al., 2023). Mirjalili is a highly cited scholar in computer and engineering, proposing dozens of novel metaheuristic algorithms and establishing some performance evaluation indicators for metaheuristic algorithms. Research areas include computers, energy, medicine, biology, and engineering. The contents include: developing feature extraction methods applied to medical data (Loey et al., 2022), solving OPF problems in power systems (Nadimi-Shahraki et al., 2021), designing truss structures with optimal weights (Tejani et al., 2018), and developing methods for securing digital video that can achieve reversible data hiding (Kumar et al., 2022).

The cooperation structure of other small cooperative networks is

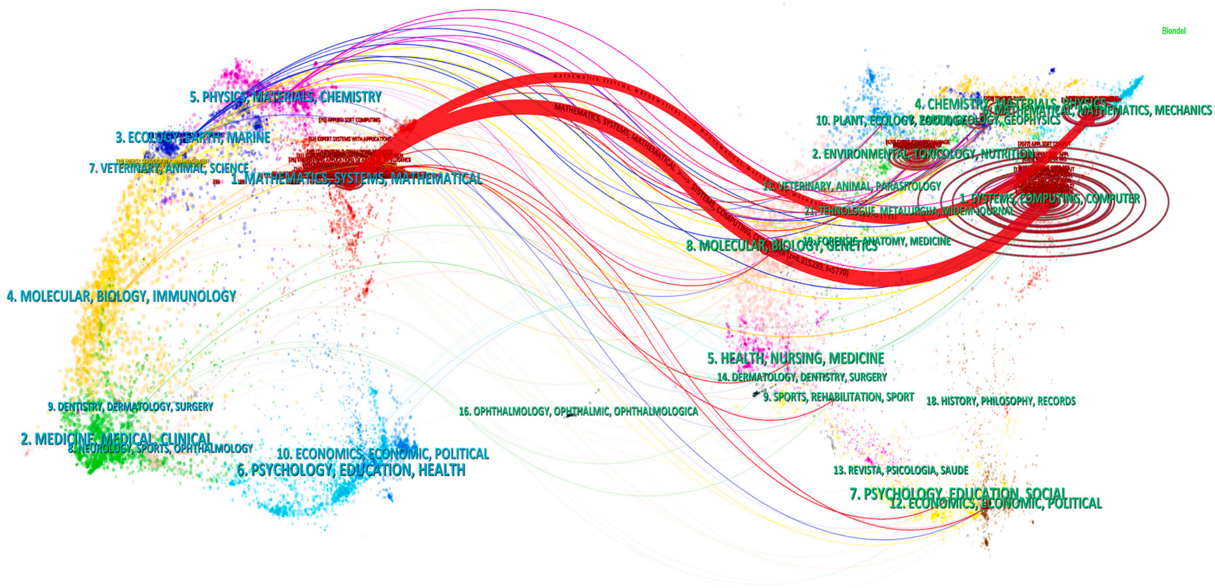

Fig. 6. Dual-map overlay of journals.

Table 3
Ranking of core authors.

Count	Author	Count	Author	Count	Author	Count	Author
19	Abd elaziz, Mohamed	7	Trojovsky, Pavel	5	Carbas, Serdar	4	Elhoseny, Mohamed
17	Abualigah, Laith	6	Bureerat, Sujin	5	Isa, Nor Ashidi Mat	4	Essa, Khalid S
15	Mirjalili, Seyedali	6	Chou, Jui-Sheng	5	Izci, Davut	4	Juan, Angel A
10	Dehghani, Mohammad	6	Crawford, Broderick	5	Kaveh, A	4	Kayabekir, Aylin Ece
10	Ewees, Ahmed A	6	Faris, Hossam	5	Lim, Wei Hong	4	Kisi, Ozgur
9	Bekdas, Gebrail	6	Heidari, Ali Asghar	5	Nigdeli, Sinan Melih	4	Mohamed, Ali Wagdy
9	Kuo, R J	6	Lu, Songfeng	5	Rezk, Hegazy	4	Montoya, Oscar Danilo
8	Al-qaness, Mohammed A A	6	Moayedi, Hossein	5	Yildiz, Ali Riza	4	Mostafa, Reham R
8	Houssein, Essam H	6	Soto, Ricardo	4	Duarte, Abraham	4	Paredes, Fernando
7	Chen, Huiling	5	Artar, Musa	4	Ekinci, Serdar	4	Trojovska, Eva

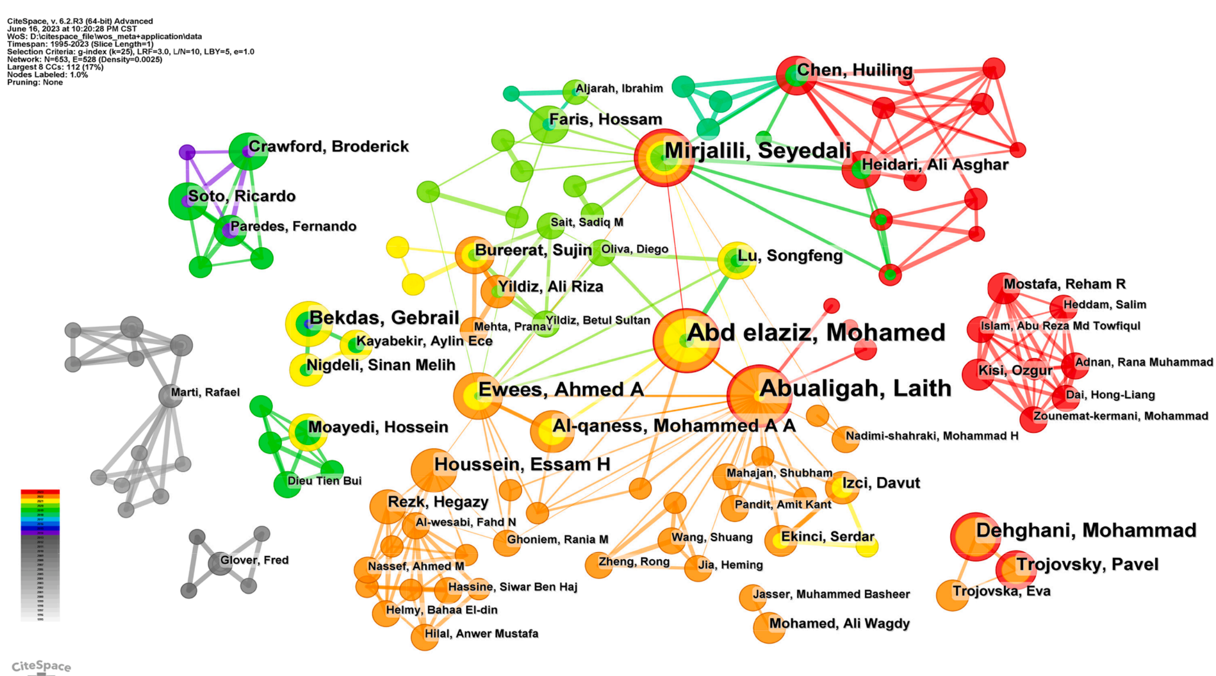

Fig. 7. Author cooperation network.

generally similar, characterized by a smaller scope and scale of cooperation. Among them, the cooperation of "Islam, Abu Reza Md Towfiqul", "Ikram, Rana Muhammad Adnan", "Mostafa, Reham R" and others mainly focuses on prediction in the field of Hydrology. The collaboration between "Dehghani, Mohammad", "Trojovsky, Pavel" and others mainly focuses on the new algorithms and their applications to typical engineering design, including pressure vessel design (Trojovský & Dehghani, 2022), reducer design (Dehghani et al., 2022), welded beam design (Trojovský et al., 2022), etc. The cooperation of "Bekdas, Gebrail", "Nigdeli, Sinan Melih" and others mainly focuses on structural optimization design in control, engineering, and architecture, including parameter optimization of tuned mass damper (Bekdaş et al., 2019), tuned PID controller (Ulusoy et al., 2021), prediction of optimum dimensions of reinforced concrete cantilever-type retaining walls (Yücel et al., 2021), optimization of large space frame structure (Bekdaş et al., 2021). Cooperations of "Crawford, B", "Soto, Ricardo" and others include set cover problems in operations research test data sets (Olivares-Suarez et al., 2014), relay node placement problems in wireless sensor networks (WSN) (Lanza-Gutiérrez et al., 2019), and manufacturing cell design problem in the production line (Soto et al., 2019). The main areas of collaboration between "Moayedi, Hossein", "Dieu Tien Bui" and others are focus on the improvement of accuracy of the conventional multilayer perceptron technique for analyzing the stability of soil slopes (Moayedi et al., 2021), metaheuristic algorithm for fine-tuning of neural network in the field of concrete slump prediction (Moayedi et al., 2019), and performance improvement for ANN in drag reduce prediction of crude oil pipeline (Huang et al., 2022).

The cooperation networks with a relatively early time are those led by "Marti, Rafael" and "Glover, Fred", which are mainly based on applying early search algorithms (such as tabu search and neighborhood search). Those algorithms solve problems with high dimensional solution space, combinatorial optimization, nonlinear continuity, global optimization, and other characteristics.

Generally, the largest group of authors is led by "Abd elaziz, Mohamed", "Abuualigah, Laith", "Mirjalili, Seyedali", "Ewees, Ahmed A". The areas of cooperation mainly include engineering optimization, feature selection, image segmentation, prediction model optimization, and scheduling processing. Moreover, the cooperative relationship between the authors with the most publications was established only in the past two years. Before that, those authors had formed their secondary cooperation networks, proving they had found a decent influence in this field.

4.2. Country-institution conjoint analysis

Cooperation between countries and institutions, as a whole, is often based on cross-border cooperation between institutions. From a macro development perspective, institutional collaboration generally starts with domestic partnerships and then develops into cooperation between multinational institutions. From a micro development perspective, it is based on the cross-border exchange of researchers, developing cross-border cooperation between institutions, and forming inter-country collaboration in a field.

The size of the nodes represents the number of papers published by each country in the research field and reflects the development scale of each country in the subject area. The links between the nodes can show the cooperative relationship between each country. The number of papers published by each institution and the time point when the first cooperation appeared are shown in Table 4. The number of papers published by each country and the time point when the first cooperation appeared are shown in Table 5. The institutional cooperation network is shown in Fig. 8. The national cooperation network is shown in Fig. 9.

In terms of institutions, the National Institute of Technology (NIT) and the Islamic Azad University are far ahead of other institutions with 58 and 57 publications, respectively, and the first cooperation was established earlier. The NIT has established preliminary collaboration with many institutions with a high number of publications, such as Universiti Sains Malaysia (University of Science Malaysia) in Malaysia, Prince Sattam Bin Abdulaziz University in Saudi Arabia, Huazhong University of Science and Technology in China, etc. NIT's first cooperative relationship appeared in 2009 when Kumar and Rao (2009) applied data mining methodologies to explore the patterns in data generated by an ant colony algorithm and to develop a rule set scheduler. And its first cross-border institutional cooperation in 2017. After 2020, its international exchanges, including China, Iran, Egypt, Turkey, Australia, Malaysia, and others, increased rapidly.

Table 4
Cooperation counts ranking of institutions.

Institution	Count	Year	Institution	Count	Year
National Institute of Technology (NIT)	58	2009	Mansoura University	19	2021
Islamic Azad University	57	2008	Prince Sattam Bin Abdulaziz University	19	2021
Universiti Sains Malaysia (University of Science Malaysia)	30	2011	Ton Duc Thang University	17	2019
Zagazig University	28	2017	University of Tehran	16	2017
Iran University Science & Technology	24	2007	Indian Institute of Technology System (IIT System)	16	2017
National Taiwan University of Science & Technology	23	2007	Centre National de la Recherche Scientifique (CNRS)	16	2004
RLUK- Research Libraries UK	22	2007	Cairo University	16	2016
Huazhong University of Science & Technology	22	2010			

Table 5
Cooperation counts ranking of countries.

Country	Count	Year	Country	Count	Year
PEOPLES R CHINA	360	2007	MALAYSIA	64	2010
INDIA	259	2004	BRAZIL	54	1998
IRAN	211	2007	FRANCE	58	1998
TURKEY	126	2010	ENGLAND	37	2001
USA	110	1998	MEXICO	20	2013
SAUDI ARABIA	104	2011	AUSTRALIA	16	2007
EGYPT	101	2016	SOUTH KOREA	12	2006
SPAIN	60	1998			

From the national perspective, China is the largest node in the national cooperation map, and the cooperation scale of Huazhong University of Science and Technology is the largest. The earliest cooperation timeline was in 2008 when Hong Kong Polytechnic University in China and the University of Queensland in Australia contributed new solutions to problems related to power system planning through metaheuristics. On the one hand, China has primarily completed cooperation in the discussed field globally, except for a few countries such as Spain, Poland, the Czech Republic, Greece, and others. Subsequent development may deepen the cooperative relationship on the existing basis or expand its cooperation scope. On the other hand, in the national cooperation map, China has the highest frequency of cooperation, and in terms of scale, it is approximately 1.5 times larger than Iran or India, but the number of its domestic institutions with a larger cooperation scale is still small.

Most current cooperative relationships are established through domestic institutional cooperation in each country. There are two forms of cooperative relationships: one is cooperation between universities and universities, and the other is research institutes and universities in the respective countries. Taking China as an example, the research institution base is relatively large, with cooperation between local universities being the main focus. Most research institutions may have a small

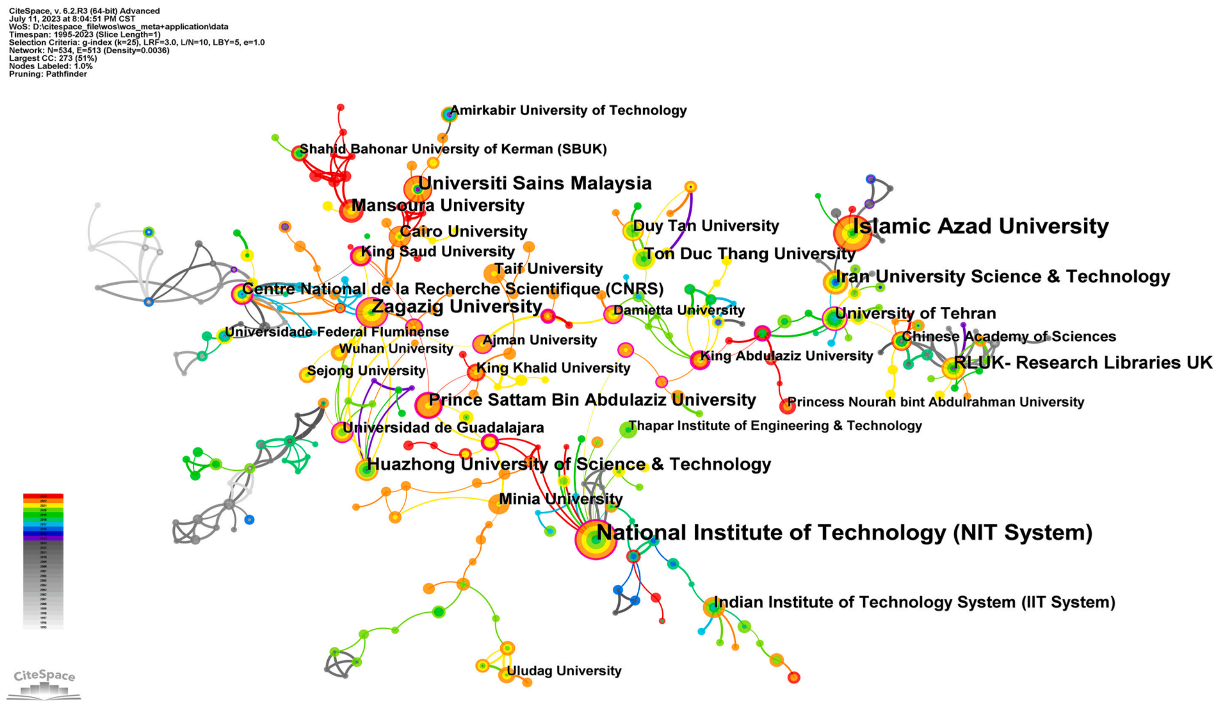

Fig. 8. Institutional cooperation network.

Fig. 9. National cooperation network.

number of cooperating units, paramount international cooperation in a model of point-to-point, single-line. Currently, there is no institutional cluster of external cooperation in a considerable number.

4.3. Academic influence analysis

Institutions and countries with a large number of publications generally have relatively high influence. The following will discuss their respective academic influences from the perspective of betweenness centrality.

Betweenness centrality measures are used to highlight potential vital points of paradigm shifts over time (Freeman, 2002; White & Borgatti, 1994). Betweenness centrality provides information on the load capacity of a given node, making it a core indicator for network nodes. The more considerable the amount of data passing through a node and the more frequent the data transmissions, the stronger the node's influence on the network map and the more critical its position (Qian, 2014). In the network structure, if a node is on the path between many other two nodes, it occupies an essential role because it can control the interaction between the other two (Shao, 2022). That is, its betweenness centrality is high. In CiteSpace, the nodes whose betweenness centrality is beyond 0.1 are pivotal and occupy a core position. Some institutions with betweenness centrality greater than 0.1 are shown in Table 6. Some countries with betweenness centrality greater than 0.1 are shown in Table 7.

The Tables, show that the betweenness centrality and frequency of

Table 6
Centrality ranking of institutions.

Institution	Count	Centrality	Institution	Count	Centrality
King Abdulaziz University	10	0.21	Centre National de la Recherche Scientifique (National Center for Scientific Research)	16	0.14
National Institute of Technology (NIT)	58	0.19	Ajman University	10	0.12
Aswan University	7	0.18	Damietta University	10	0.12
Zagazig University	28	0.16	Galala University	8	0.12
Prince Sattam Bin Abdulaziz University	19	0.16	Fayoum University	6	0.12
Wenzhou University	7	0.16	National Institute of Technology Patna	6	0.11
University of Tehran	16	0.15	National Yunlin University Science & Technology	3	0.11
King Saud University	13	0.15	Universidad de Guadalajara (University of Guadalajara)	13	0.1

Table 7
Centrality ranking of countries.

Country	Count	Centrality	Country	Count	Centrality
NORWAY	16	0.53	GREECE	21	0.2
PORTUGAL	15	0.48	PALESTINE	6	0.19
SWITZERLAND	8	0.42	CHILE	29	0.19
ENGLAND	60	0.29	SCOTLAND	10	0.18
FRANCE	61	0.29	AUSTRIA	14	0.18
GEORGIA	4	0.28	COLOMBIA	17	0.18
USA	126	0.28	ITALY	48	0.18
RUSSIA	20	0.24	MOROCCO	10	0.17

the “NIT (58, 0.19)” are ranked higher among institutions, indicating its more substantial influence in this field and higher correlation with other institutions, with more development achievements in this field. The second most prominent ones are “King Abdulaziz University (10, 0.21)”, “Zagazig University (28, 0.16)” and “Prince Sattam Bin Abdulaziz University (19, 0.16)” with a betweenness centrality greater than 0.1, indicating that their development in this field also holds a solid foundation and international reputation. On the national level, “NORWAY (16, 0.53)”, “PORTUGAL (15, 0.48)” and “SWITZERLAND (8, 0.42)” ranked in the top three with a betweenness centrality of over 0.4, indicating that these countries hold a core position in the field and are pivotal nodes for international cooperation in this field. In addition, “ENGLAND (60, 0.29)”, “FRANCE (61, 0.29)”, and “USA (129, 0.28)” also provided powerful development momentum in this field.

5. Research hotspots analysis

5.1. Keyword co-occurrence analysis

Keywords are the most refined expression of the main content of literature. Keywords co-occurrence analysis is a relatively mainstream and mature analysis method of CiteSpace. A total of 1177 keywords were obtained through the calculation of CiteSpace, and there were 283 keywords with a word frequency of 1. The word frequency threshold model of high and low was obtained by (Donohue, 1972) in his inference research on Zipf’s law, which mathematical expression is shown in Eq. (6).

$$C = \frac{\sqrt{1+8k}}{2} - \frac{1}{2} \tag{6}$$

where C is the threshold value of high and low word frequency in a field, and k is the number of keywords with a frequency of 1 in that field.

Through Eq. (6), it can be calculated that the threshold value of high and low word frequency in the applications of the metaheuristic algorithm is approximately equal to 23.29, and the number of high-frequency keywords greater than or equal to 24 can be obtained as 45. The word frequency of some keywords is shown in Table 8.

Keyword frequencies above 200 include “genetic algorithms”, “algorithm”, “optimization”, and “particle swarm optimization”, their betweenness centrality is also greater than 0.1, indicating that the application research of genetic algorithm and particle swarm optimization is still favored. The keywords related to applications of metaheuristic algorithms include “design”, “model”, “system”, “prediction”, “selection”, and “classification”, which can be seen as the hotspot fields. Fig. 10 shows the keyword co-occurrence network map, where the node size is proportional to word frequency.

The purple nodes on the periphery represent high betweenness centrality and are pivotal nodes in the metaheuristic algorithm applied field. They are highly connected and also show the cross direction of this field. The keywords with high betweenness centrality generally include “genetic algorithms”, “algorithm”, “optimization”, “differential evolution”, “global optimization”, “tabu search”, “ant colony optimization”, “evolutionary algorithms” and “evolutionary algorithms”. These keywords play a crucial role in the field and cannot be ignored.

5.2. Keyword cluster analysis

After obtaining the keyword co-occurrence network, the keywords are further clustered, and the clusters’ average silhouette value (S) is 0.9047. It is generally believed that S>0.7 indicates that clustering is convincing, while S<0.5 means unreasonable clustering, which CiteSpace will automatically conceal. In CiteSpace, the LLR (log-likelihood ratio, p-level) algorithm is generally used for cluster labeling, and the label with the highest log-likelihood ratio value is used as the name of the cluster. Within the same cluster, the higher the log Likelihood ratio value, the stronger the representativeness of the label. Fig. 11 shows the keyword cluster map, and Table 9 shows the clusters and clusters’ label information.

Cluster labels were classified, and metaheuristic algorithm applications’ hotspot topics were analyzed. The detail as follows.

(1) Scheduling

Essentially, the scheduling problem is an optimization problem, processing the optimization procedure through reasonable and economic strategies, which undoubtedly quickly reminds people of the metaheuristic algorithm. In fact, the metaheuristic algorithm has made considerable achievements in its application in scheduling. The labels related to this subject include “economic dispatch (12.95, 1.0E-3)” in cluster # 0, “parallel machine scheduling (15.49, 1.0E-4)” in cluster # 2, “power generation dispatch (11.55, 1.0E-3)”, and “response time variability (16.35, 1.0E-4)”, “fair sequences (16.35, 1.0E-4)” in cluster # 9.

Economic dispatch is a term in the field of electric power. Chowdhury and Rahman (1990) divided the research of economic dispatch into four main areas: OPF, economic dispatch related to automatic generation control, dynamic dispatch, and economic dispatch with non-conventional generation sources, economic dispatch of power generation sources. In recent years, with the explosive growth of the number of metaheuristic algorithms, more and more excellent algorithms have been applied to the field of economic dispatch. Adarsh et al. (2016) used

Table 8
Frequency ranking of keywords.

Frequency	Betweenness centrality	Year	Keyword	Frequency	Betweenness centrality	Year	Keyword
290	0.2	1998	genetic algorithms	83	0.05	2000	system
283	0.23	1998	algorithm	80	0.24	1995	tabu search
282	0.17	1998	optimization	66	0.02	2011	prediction
254	0.05	2007	Particle swarm optimization	64	0.03	2013	performance
177	0.03	2000	design	56	0.07	2011	selection
159	0.1	2007	differential evolution	54	0.21	2004	ant colony optimization
151	0.02	2011	metaheuristic algorithms	54	0.28	2003	evolutionary algorithms
123	0.04	2013	model	51	0.1	2000	local search
118	0.03	2003	search	49	0.03	2006	swarm intelligence
101	0.15	2005	global optimization	47	0.08	2010	classification

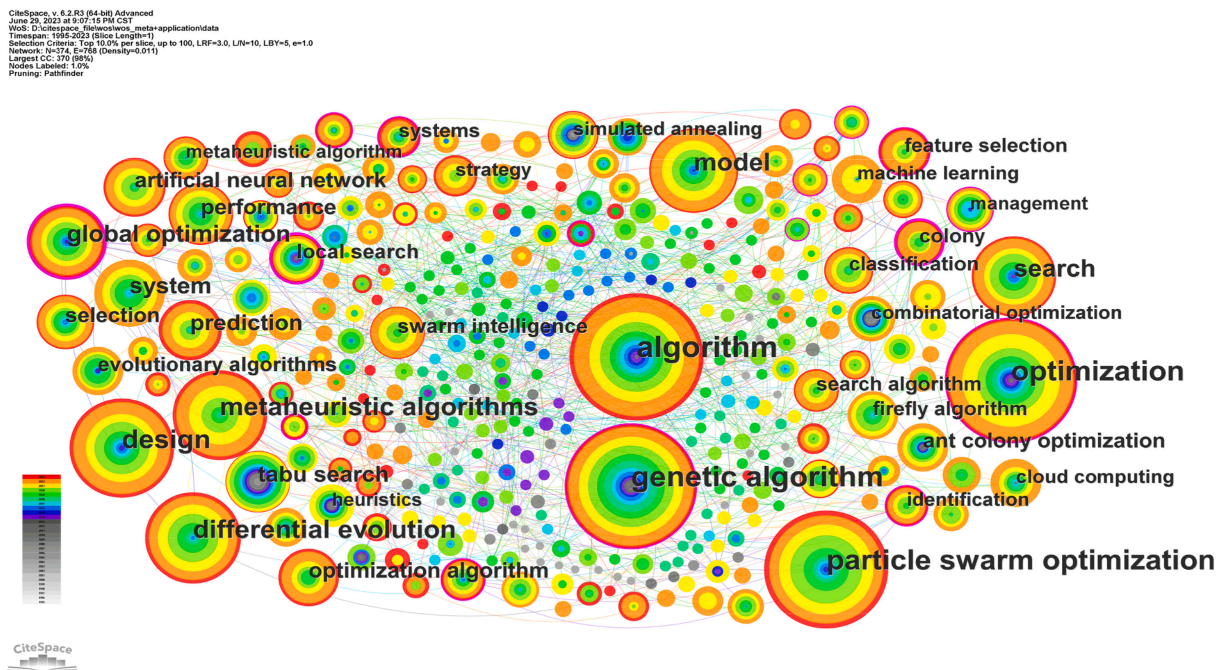

Fig. 10. Co-occurrence of keywords.

the chaotic bat algorithm for economic dispatch in 2015.

Parallel machine scheduling (PMS) can be seen as a class of problems relaxed from the multiple-machine scheduling problem (Cheng & Sin, 1990; Li et al., 2016), which revolves around how to make the best match or close to the best match between machines and jobs, then determine the processing sequence of the jobs on each machine, usually to achieve the optimal value of a sure performance indicator (such as maximum process time). Fathollahi-Fard et al. (2019) applied a social engineering optimizer to PMS.

Fair sequence (Kubiak, 2004) originated from the production Assembly line, a tentative solution to balance the utilization rate of all parts and the productivity of different models and reduce shortages and excessive inventory. Kubiak (2004) defined fair sequences as the solution to the production rate variation (PRV) problem and simplified the PRV problem into an allocation problem, providing an effective algorithm. Moradi and Zandieh (2013) applied a metaheuristic algorithm to minimize PRV.

The response time variability problem (García-Villoria & Pastor, 2010) is a scheduling problem recently defined in the literature, which is widely embodied in the mixture model assembly line, computer system, network environment, etc. Moradi and Zandieh (2013) applied the genetic algorithm to solve the response time variability problem.

(2) Vehicle routing

The labels for vehicle routing problems include “vehicle routing problem (15.49, 1.0E-4)” in cluster # 2, “Vehicle routing (23.86, 1.0E-4)” and “pickup and delivery (13.67, 1.0E-3)” in cluster # 5, “capacitated vehicle routing problem (11.1, 1.0E-3)” in cluster # 19.

The vehicle routing problem (VRP) (Braekers et al., 2016; Toth & Vigo, 2002) is determining vehicle routes with the minimum travel cost under the constraint conditions while satisfying the specified needs or goals to the greatest extent. With the development of theoretical research, a large number of variants of the VRP have appeared, such as VRP with time window, VRP with backhauls, and VRP with pickup and delivery (Golden et al., 2008).

VRP is a kind of non-deterministic polynomial hard combinatorial optimization problem. Metaheuristic algorithm has superior adaptability in handling such problems, and Schneider et al. (2014) applied it to VRP with time windows.

(3) Energy

The labels associated with the energy field include “energy efficiency (25.63, 1.0E-4)” in cluster # 8, “combined heat and power (17.47, 1.0E-4)”, “cost minimization (16.07, 1.0E-4)”, “hybrid energy system (12.29, 1.0E-3)” and “solar energy (12.29, 1.0E-3)” in cluster # 18, “biomass (11.1, 1.0E-3)” and “wind energy (7.62, 1.0E-2)” in cluster # 19. The content represented behind these labels primarily utilizes metaheuristic algorithms to evaluate and optimize the parameters of various energy

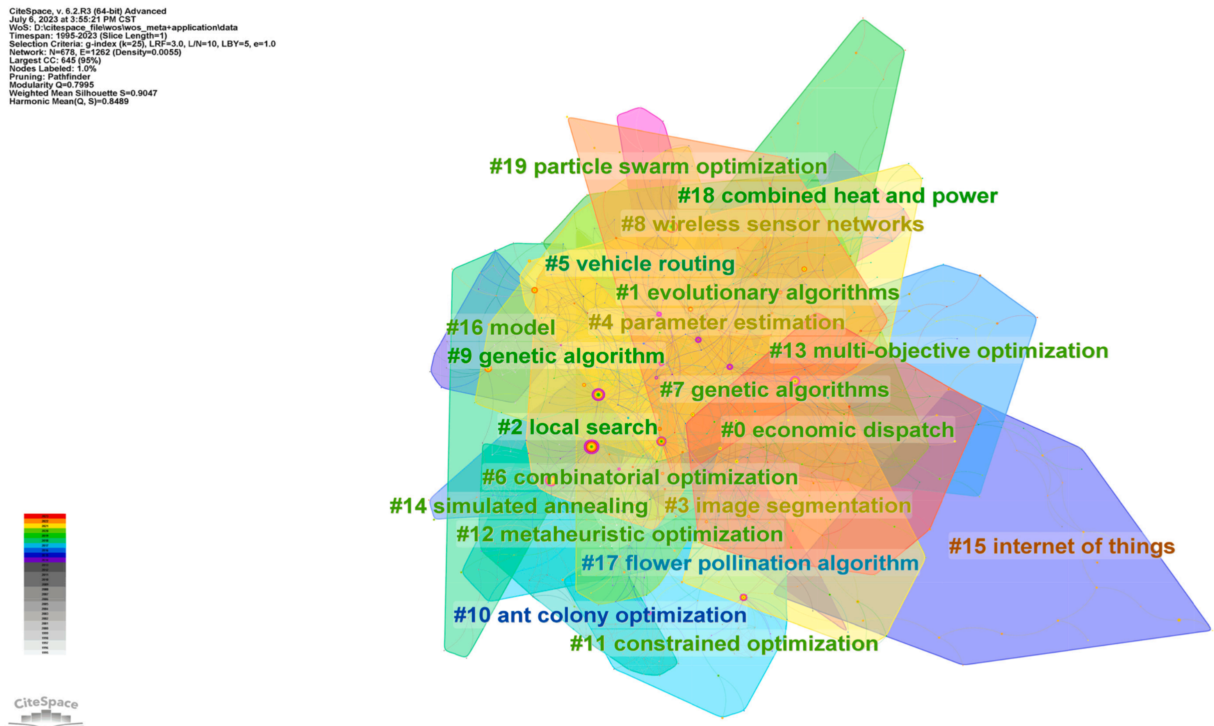

Fig. 11. Clusters of keywords.

systems or models, such as energy system efficiency (Nasr et al., 2023), production capacity cost (Zhao et al., 2019), and model evaluation and optimization of microgrids (Samy & Barakat, 2019).

(4) Control system

Labels associated with controls are "fuzzy control (16.55, 1.0E-4)" in cluster # 8, "tuned mass damper (15.45, 1.0E-4)" in cluster # 12.

Fuzzy control (Passino et al., 1998; Sugeno, 1985) is a control method that uses fuzzy mathematics to change the inherent structure of the system to achieve the desired goal. It is based on fuzzy set theory, fuzzy language variables, and fuzzy reasoning (Sugeno, 1985). Because of its abstract thinking that imitates the human brain, it is often considered a branch of artificial intelligence (Driankov et al., 2013). The metaheuristic algorithm is used chiefly for parameter optimization of fuzzy controllers, and Pozna et al. (2022) used it for optimal tuning of proportional-integral-fuzzy controllers.

Tuned mass dampers can protect mechanical systems by suppressing random vibrations (Gutierrez Soto & Adeli, 2013). They are mostly used to prevent large mechanical systems and large building structures from failing (McNamara, 1977). To improve the seismic safety of the structure, Kayabekir et al. (2022) applied a hybrid metaheuristic algorithm to the optimization of the active tuned mass damper.

(5) Internet and communication

The combined application of metaheuristic algorithms and some cutting-edge technologies has achieved remarkable results and promoted the development of some new fields. The labels of related clusters are # 3 "image segmentation (32.27, 1.0E-4)", # 4 "parameter estimation (33.68, 1.0E-4)", "parameter extraction (22.15, 1.0E-4)", "mathematical models (15.4, 1.0E-4)", # 6 "cloud computing (21.45, 1.0E-4)", "scalability (11.69, 1.0E-3)", "anomaly detection (10.38, 5.0E-3)", # 8 "wireless sensor networks (34.64, 1.0E-4)", # 10 "data mining (16.79, 1.0E-4)", "neural networks (14.04, 1.0E-3)", "Monte Carlo simulation (8.13, 5.0E-3)", # 15 "internet of things (28.96, 1.0E-4)", "fog computing (19.25, 1.0E-4)", "edge computing (18.02, 1.0E-4)", "intrusion detection system (15.96, 1.0E-4)", # 16 "model (13.05, 1.0E-3)", "parameter identification (5.98, 5.0E-2)".

The WSN are collections of nodes organized into collaborative networks (Hill et al., 2000), the foundation of the Internet of Things (IoT). Due to its enormous potential, it has been rapidly deployed in areas such as the environment, military, transportation, healthcare, national defense, and entertainment. However, some issues, such as security, energy optimization, and mobile localization, must be addressed. Wang et al. (2018) used the genetic algorithm to improve energy efficiency and prolong the WSN life cycle. Lanza-Gutiérrez et al. (2019) utilized a metaheuristic to solve the node placement problem in WSN.

Cloud computing provides powerful data processing capabilities for the IoT and meets its scalability requirements, while fog computing and edge computing enhance the data processing capabilities of cloud computing. Saravanan et al. (2023) used the improved Mustang optimization algorithm to realize effective task scheduling in cloud computing. Abdel-Basset et al. (2020) used the improved marine predator algorithm for task scheduling in fog computing. Hajisalem and Babaie (2018) improved intrusion detection systems with a hybrid metaheuristic algorithm for anomaly detection.

Data mining automatically discovers valuable information from large amounts of data, intending to build a decision-making model that predicts future behavior based on past action data (Chen et al., 1996; Hand, 2007). Boushaki et al. (2021) applied a modified sine cosine algorithm to data clustering. Derouiche et al. (2017) used chemical reaction optimization algorithms to solve association rule mining problems.

Image segmentation is one of the critical technologies in computer vision and an essential step in image processing. It has been applied in various fields, such as medical diagnosis. Chouksey et al. (2020) applied metaheuristics to image segmentation.

(6) Industrial manufacturing and design

The labels distributed in the manufacturing industry and engineering

Table 9
Labels on each cluster.

Cluster	Count	Silhouette value	Mean year	Label
0	50	0.837	2018	**economic dispatch** (12.95, 1.0E-3), power generation dispatch (11.55, 1.0E-3), chemical reaction optimization (11.55, 1.0E-3), metaheuristic methods (11.33, 1.0E-3), computational intelligence (10.83, 1.0E-3)
1	49	0.95	2012	**evolutionary algorithms** (39.27, 1.0E-4), differential evolution (30.12, 1.0E-4), support vector machine (15.15, 1.0E-4), compressive strength (14.98, 1.0E-3), prediction (14.38, 1.0E-3)
2	48	0.944	2006	**local search** (47.73, 1.0E-4), tabu search (41.8, 1.0E-4), graph theory (20.66, 1.0E-4), vehicle routing problem (15.49, 1.0E-4), parallel machine scheduling (15.49, 1.0E-4)
3	45	0.893	2018	**image segmentation** (32.27, 1.0E-4), swarm intelligence (27.22, 1.0E-4), structural optimization (26.81, 1.0E-4), crow search algorithm (16.82, 1.0E-4), engineering design (16.82, 1.0E-4)
4	43	0.86	2016	**parameter estimation** (33.68, 1.0E-4), parameter extraction (22.15, 1.0E-4), metaheuristic algorithms (16.18, 1.0E-4), metaheuristic algorithm (15.69, 1.0E-4), mathematical models (15.4, 1.0E-4)
5	42	0.849	2013	**vehicle routing** (23.86, 1.0E-4), iterated local search (19.87, 1.0E-4), pickup and delivery (13.67, 1.0E-3), heuristic algorithms (11.34, 1.0E-3), grasp (8.76, 5.0E-3)
6	40	0.856	2015	**combinatorial optimization** (30.93, 1.0E-4), cloud computing (21.45, 1.0E-4), scalability (11.69, 1.0E-3), grey wolf optimization (11.69, 1.0E-3), anomaly detection (10.38, 5.0E-3)
7	38	0.876	2012	**genetic algorithms** (29.07, 1.0E-4), cuckoo search algorithm (17.17, 1.0E-4), artificial bee colony algorithm (14.92, 1.0E-3), particle swarm optimization (11.68, 1.0E-3), levy flights (8.57, 5.0E-3)
8	33	0.818	2018	**wireless sensor networks** (34.64, 1.0E-4), energy efficiency (25.63, 1.0E-4), fuzzy control (16.55, 1.0E-4), benchmark functions (16.08, 1.0E-4), ant lion optimization (16.08, 1.0E-4)
9	31	0.892	2010	**genetic algorithm** (49.93, 1.0E-4), neural network (17.09, 1.0E-4), response time variability (16.35, 1.0E-4), fair sequences (16.35, 1.0E-4), bat algorithm (8.33, 5.0E-3)
10	29	0.905	2009	**ant colony optimization** (30.38, 1.0E-4), data mining (16.79, 1.0E-4), neural networks (14.04, 1.0E-3), metaheuristic profiling (11.83, 1.0E-3), Monte Carlo simulation (8.13, 5.0E-3)
11	29	0.981	2012	**constrained optimization** (23.01, 1.0E-4), global optimization (21.47, 1.0E-4), harmony search (17.6, 1.0E-4), particle swarm optimization (PSO) (16.1, 1.0E-4), metaheuristic search (14.93, 1.0E-3)
12	27	0.951	2009	**metaheuristic optimization** (17.59, 1.0E-4), tuned mass damper (15.45, 1.0E-4), fitness function (9.5, 5.0E-3), harmony search algorithm (9.5, 5.0E-3), HVAC (6.73, 1.0E-2)
13	25	0.911	2018	**multi-objective optimization** (33.39, 1.0E-4), shape optimization (17.65, 1.0E-4), multi-objective optimization (12.17, 1.0E-3), vehicle design (11.76, 1.0E-3), machine learning (10.92, 1.0E-3)
14	25	0.939	2005	**simulated annealing** (38.36, 1.0E-4), artificial neural networks (22.95, 1.0E-4), salp swarm algorithm (10.5, 5.0E-3), graph partitioning (10.48, 5.0E-3), prediction algorithms (9.31, 5.0E-3)
15	24	0.99	2019	**internet of things** (28.96, 1.0E-4), fog computing (19.25, 1.0E-4), edge computing (18.02, 1.0E-4), intrusion detection system (15.96, 1.0E-4), environmental protection (15.05, 1.0E-3)
16	23	0.984	2006	**model** (13.05, 1.0E-3), cellular manufacturing (11.1, 1.0E-3), group technology (7.42, 1.0E-2), parameter identification (5.98, 5.0E-2), bi-objective (5.82, 5.0E-2)
17	17	0.93	2009	**flower pollination algorithm** (28.13, 1.0E-4), JAYA algorithm (23.05, 1.0E-4), teaching–learning-based optimization (12.89, 1.0E-3), dynamic learning (8.32, 5.0E-3), nonlinear stress–strain relation (8.32, 5.0E-3)
18	17	0.965	2016	**combined heat and power** (17.47, 1.0E-4), hybrid metaheuristic optimization (16.07, 1.0E-4), cost minimization (16.07, 1.0E-4), hybrid energy system (12.29, 1.0E-3), solar energy (12.29, 1.0E-3)
19	10	0.96	2005	**particle swarm optimization** (57.41, 1.0E-4), biomass (11.1, 1.0E-3), capacitated vehicle routing problem (11.1, 1.0E-3), wind energy (7.62, 1.0E-2), sequence-dependent setup times (7.42, 1.0E-2)

optimization design are as follows: # 3 “structural optimization (26.81, 1.0E-4)”, # 13 “shape optimization (17.65, 1.0E-4)”, “Multi objective optimization (12.17, 1.0E-3)”, “Vehicle design (11.76, 1.0E-3)”, # 16 “cellular manufacturing (11.1, 1.0E-3)”.

The applications of metaheuristic algorithms in industrial design include: Miguel and Miguel (2012) used two metaheuristic algorithms to optimize the truss structures in shape and size; Dillen et al. (2021) applied a hybrid metaheuristic algorithm to optimize steel structures in Eurocode-compliant size, shape, and topology. Also relevant are structural design (Zavala et al., 2016), structure optimization (Kumar et al., 2021), wind turbine blade geometry design (Neto et al., 2018), structural design of vehicle components (Ozkaya et al., 2020), vehicle lightweight design (Liu et al., 2019), and others.

Cellular manufacturing (CM) has now become an international trend, integrating equipment, people, and systems into “key factories”, “micro-enterprises”, or “cells” with clear customers, responsibilities, and boundaries (Bazargan-Lari, 1999). According to many statistics, this kind of scheme can significantly improve the economic benefits of manufacturing enterprises from one or more aspects. Onwubolu and Mutingi (2001) used the genetic algorithm to solve the cell formation problem. Mejía-Moncayo and Battaia (2019) applied a metaheuristic algorithm to the design of the CM system.

After obtaining the six major themes in the metaheuristic algorithms application field, the "metaheuristic" and "AI algorithm" were combined with keywords related to the six themes which mention above and others for retrieval. Through investigation and screening, the publication date of these themes was obtained based on the retrieved results of the WoS database, as shown in Fig. 12.

From the figure, metaheuristic algorithms have become essential for solving complex problems in the above eight fields. With the widespread application of modern intelligent algorithms, metaheuristic algorithms already have excellent characteristics that rival some excellent artificial intelligence algorithms. From the collected data, in the research of metaheuristic algorithms with scheduling as the theme, its application in economic power dispatching of power systems and workshop scheduling is more extensive. In vehicle routing, the road planning method based on metaheuristic algorithms has become a hot research object, which is also the reason for its large number of publications. In the other fields, the metaheuristic algorithm has achieved good application results in one or some problems in these fields due to its characteristics, so it has a considerable number of publications. For other AI algorithm, Taking deep learning as an example, Yin et al. (2018) proposed a relaxed deep learning method to solve economic generation dispatch. Dörner et al. (2018) built a complete communications system solely composed of neural networks using unsynchronized off-the-shelf software-defined radios and open-source deep learning software libraries. Li et al. (2018) designed a manufacture inspection system with fog computing and proposed a classification model based on deep learning to improve the accuracy and robustness of the system. Zhang et al. (2019) proposed a synergic deep learning (SDL) model to medical image classification. Mo et al. (2021) designed a physics-informed deep learning car-following model (PIDL-CF) architectures and demonstrated its superiority at some levels. Metzler et al. (2023) conducted phenotype of urban built and natural environments with high-resolution satellite images and unsupervised deep learning. Deep learning obtains the optimal control performance with a smaller frequency deviation but requires longer calculation time, higher calculation cost, and more parameters to be tuned in pre-training. The excessively long computation times are typically intolerable, whereas metaheuristic algorithms do the opposite.

Moreover, general metaheuristic algorithms can be applied to many problems without adjusting many parameters and achieve good results. Metaheuristic algorithms are not restricted by the assumptions of continuity and the existence of derivatives of the objective function, which have also attracted much attention. However, according to the no free lunch law (Adam et al., 2019; Wolpert & Macready, 1997), one algorithm does not exist to solve all problems. In summary, although it is impossible to compare the advantages and disadvantages of metaheuristic algorithms and other AI algorithms, it undoubtedly proves the significance of metaheuristic algorithms.

6. Frontier evolution

6.1. Significant citing literature analysis

If two (or more) papers are cited simultaneously by one (or more) later papers, the two papers constitute a co-citation relationship (Marshakova-Shaikevich, 2004; Small, 1973). Co-cited documents are the knowledge base of the field, and the citing literature that cites this knowledge base represents the research frontier of the area (Marshakova-Shaikevich, 1996; Zitt & Bassecoulard, 1994).

Fig. 13 shows the document co-citation cluster map, the average modularity is 0.9342, and the mean silhouette value is 0.956. Using the LLR algorithm to name and select the top 12 most significant clusters for display, the software automatically ignored the clusters with a silhouette value less than 0.5, and nine main clusters were obtained. The information of each cluster, the most representative cluster labels, and important citing literature information are shown in Table 10.

The content of these clusters represents the development frontier of metaheuristic algorithm' application to a certain extent. The specific

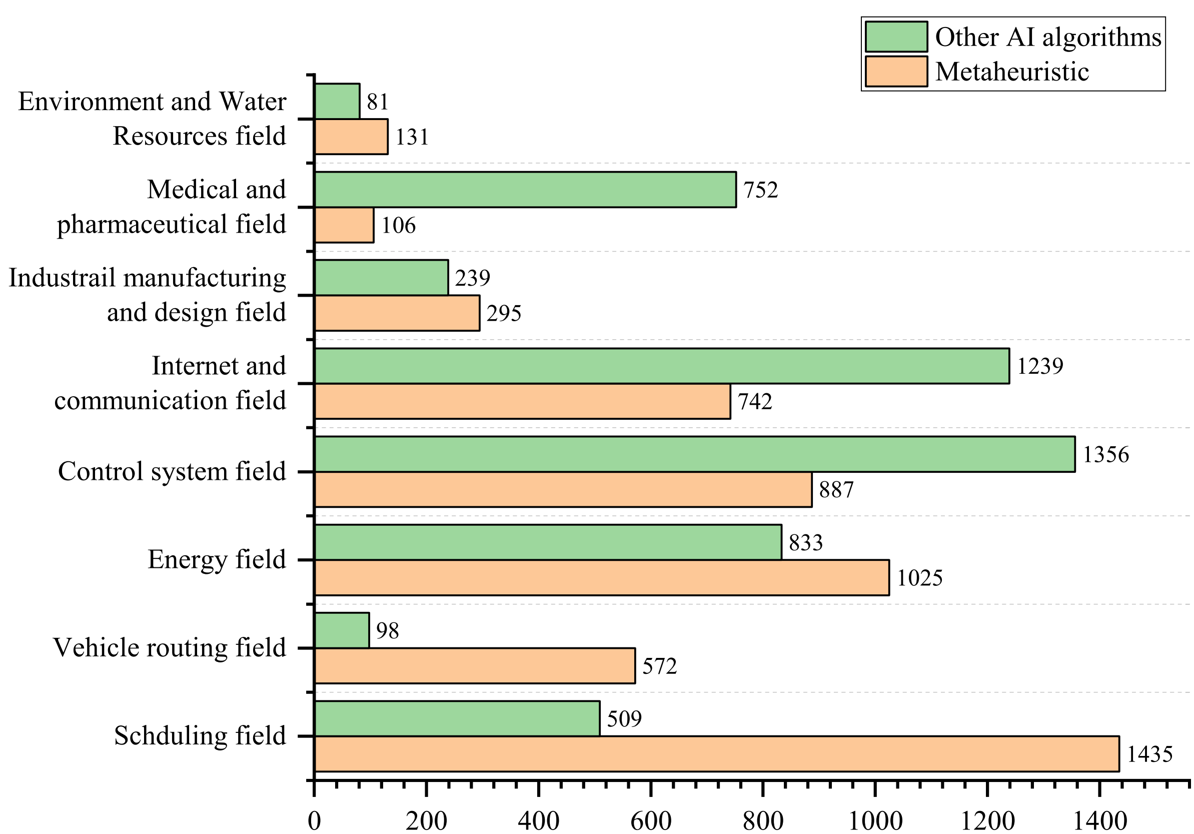

Fig. 12. The publication date of eight themes.

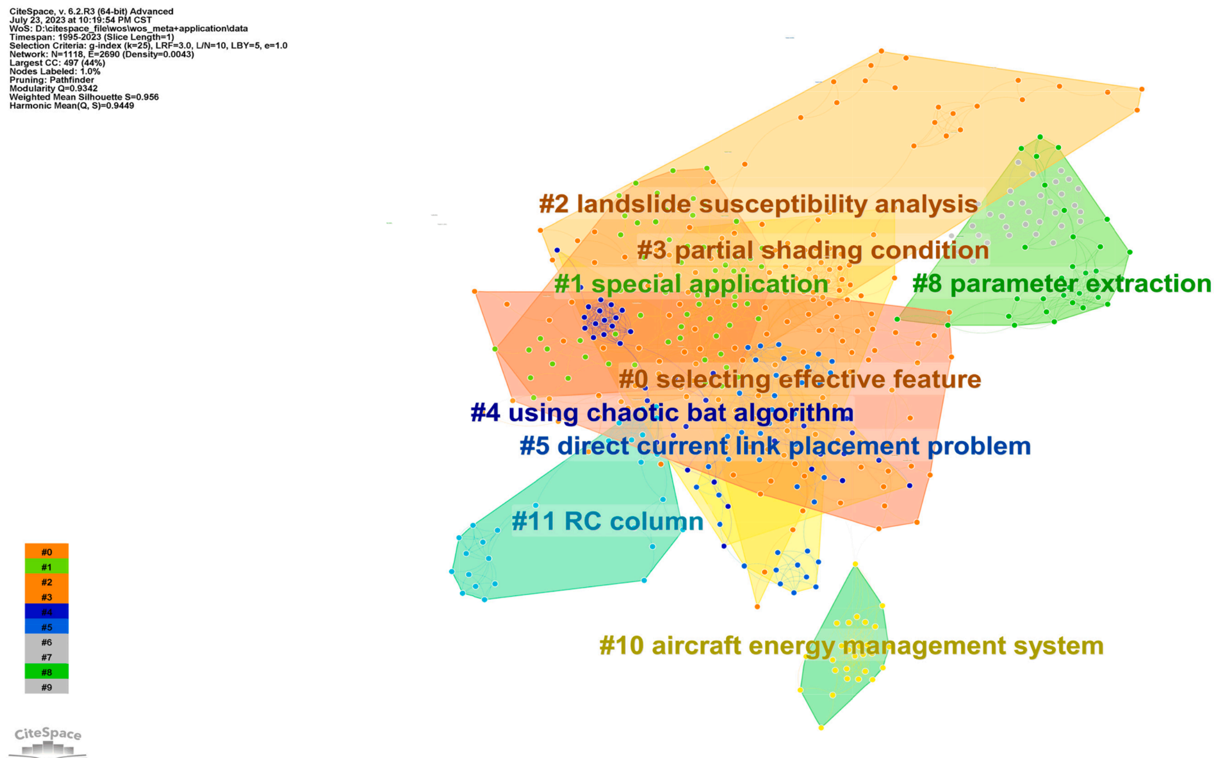

Fig. 13. Co-cited reference clusters.

analysis of the critical forward-looking literature in each cluster is as follows.

Cluster # 0 “selecting effective feature”. The largest cluster (# 0) has 73 members and a silhouette value of 0.867. Representative labels for this cluster include “selecting effective feature”, “medical data” and “intelligent fault diagnosis”. The representative literature was published by Nadimi-shahraki in 2022. This paper mainly studies the development of effective feature extraction methods using a modified metaheuristic algorithm in the context of medical data mining.

Cluster # 1 “special application”. The second largest cluster (# 1) has 69 members and a silhouette value of 0.915. The representative literature was published by Yildiz in 2020. The application of a metaheuristic algorithm in the optimal design of automotive components is clarified.

Cluster # 2 “landslide susceptibility analysis”. The third largest cluster (# 2) has 49 members and a silhouette value of 0.974. The representative literature was published by Moayedi in 2019. This paper describes the application of the metaheuristic algorithm in geology and studies the landslide susceptibility mapping at a landslide-prone area.

Cluster # 3 “partial shading condition”. The fourth largest cluster (# 3) has 40 members and a silhouette value of 0.969. The representative literature was published by Nassef in 2022. This paper applies the improved metaheuristic algorithm to solve the partial shading conditions in the photovoltaic system, which enhances the power of the photovoltaic array.

Cluster # 4 “using chaotic bat algorithm”. The fifth largest cluster (# 4) has 40 members and a silhouette value of 0.997. Adarsh published the representative literature in 2016, which mainly expounds on applying the improved metaheuristic algorithm in economic dispatch.

Cluster # 5 “direct current link placement problem”. The sixth largest cluster (# 5) has 40 members and a silhouette value of 0.951. The representative literature was published by Prasad in 2017, which applied the metaheuristic algorithm to solve the OPF problem based direct current link placement problem.

Cluster # 8 “parameter extraction”. The seventh largest cluster (# 8) has 32 members and a silhouette value of 0.984. The representative literature was published by Xiong in 2019, the main content is to verify a metaheuristic algorithm’s effectiveness in applying parameter extraction of solar photovoltaic models.

Cluster # 10 “aircraft energy management system”. The eighth largest cluster (# 10) has 28 members and a silhouette value of 0.996. The representative literature was published by Huo in 2021, which validated the advantages of the metaheuristic algorithm used in improving the efficiency of aircraft energy management systems.

Cluster # 11 “RC column” (reinforced concrete column). The ninth largest cluster (# 11) has 27 members and a silhouette value of 0.991. The representative literature was published by Ozturk, which proposed the optimum cost design scheme for RC columns.

6.2. Analysis of development trajectory

The time-zone map is a map that defines the time span of the research field by delimiting its time-zone position when the keyword first appeared and expresses the interconnection and co-occurrence relationship between its nodes through connections. The frequency of citations defines the burst of keywords in a short period, which can reflect the research hotspots and frontier in a period and the evolution of research objects in the entire time zone. Fig. 14 shows the keyword time-zone map, and Fig. 15 shows the strongest citation of 21 keywords.

For Fig. 14, each column of equal width represents a time zone, and each small square represents a keyword. Since circles are used to represent keywords, the frequency of a few keywords is too high, which is not conducive to displaying most other keywords. This paper uses squares to represent all keywords and sets them to a consistent size. The frequency of the keyword is represented by the size of the text and the number of connecting lines. Based on the time-zone map and keywords bursts, the development of metaheuristic applications can be summarized in the following stages.

Groundbreaking phase (1994–1998): The burst keyword at this stage is “tabu search”. Metaheuristic methods represented by tabu search, neighborhood search, greedy randomized adaptive search, genetic

Table 10
Vital citing reference in each cluster.

Cluster ID	Size	Silhouette	Mean year	Label (LLR)	Vital citing reference
0	73	0.867	2018	**selecting effective feature**, (83.02, 1.0E-4) medical data (83.02, 1.0E-4), multi-trial vector-based monkey king evolution algorithm (67.87, 1.0E-4), dynamic stochastic search algorithm (60.31, 1.0E-4), intelligent fault diagnosis (56.53, 1.0E-4)	Nadimi-shahraki, MH (2022) Binary aquila optimizer for selecting effective features from medical data: a covid-19 case study.
1	69	0.915	2015	**special application** (108.72, 1.0E-4), metaheuristic approach (68.51, 1.0E-4), adolescent identity search algorithm (68.51, 1.0E-4), metaheuristic research (64.34, 1.0E-4), software engineering (62.95, 1.0E-4)	Yildiz, BS (2020) The spotted hyena optimization algorithm for weight-reduction of automobile brake components.
2	49	0.974	2019	**landslide susceptibility analysis** (69.18, 1.0E-4), novel neural-evolutionary predictive technique (69.18, 1.0E-4), concrete slump (65.01, 1.0E-4), tree seed algorithm (61.94, 1.0E-4), framework evaluation (60.88, 1.0E-4)	Moayedi, H (2019) Two novel neural-evolutionary predictive techniques of dragonfly algorithm and biogeography-based optimization for landslide susceptibility analysis.
3	40	0.969	2020	**partial shading condition** (51.72, 1.0E-4), new human-inspired metaheuristic algorithm (50.55, 1.0E-4), sewing training (50.55, 1.0E-4), driving training process (45.62, 1.0E-4)	Nassef, AM (2022) Optimal reconfiguration strategy based on modified runge kutta optimizer to mitigate partial shading condition in photovoltaic systems.
4	40	0.997	2011	**using chaotic bat algorithm** (84.76, 1.0E-4), indirect approach (65.72, 1.0E-4), cell formation problem (56.25, 1.0E-4), hybrid genetic-variable neighborhood search algorithm (56.25, 1.0E-4), grouping efficacy (56.25, 1.0E-4)	Adarsh, BR (2016) Economic dispatch using chaotic bat algorithm.
5	40	0.951	2013	**direct current link placement problem** (101.21, 1.0E-4), chaotic krill herd algorithm (101.21, 1.0E-4), global exploration capability (92.68, 1.0E-4), processing unit (84.16, 1.0E-4), parallel metaheuristics (84.16, 1.0E-4)	Prasad, D (2017) Application of chaotic krill herd algorithm for optimal power flow with direct current link placement problem.
8	32	0.984	2016	**parameter extraction** (148.91, 1.0E-4), solar photovoltaic model (122.75, 1.0E-4), collaborative swarm intelligence (65.64, 1.0E-4), PV parameter (65.64, 1.0E-4), discrete symbiosis organism search (59.36, 1.0E-4)	Xiong, G (2019) Application of supply–demand-based optimization for parameter extraction of solar photovoltaic models.
10	28	0.996	2019	**aircraft energy management system** (54.3, 1.0E-4), using chao (54.3, 1.0E-4), proton exchange membrane fuel (44.24, 1.0E-4), model identification (44.24, 1.0E-4), extreme learning machine (44.24, 1.0E-4)	Huo, Z (2021) Aircraft energy management system using chaos red fox optimization algorithm.
11	27	0.991	2011	**RC column** (72.29, 1.0E-4), using artificial bee colony algorithm (72.29, 1.0E-4), weber problem (61.82, 1.0E-4), feasible region (61.82, 1.0E-4), mini autonomous surface vehicles application (51.4, 1.0E-4)	Ozturk, HT (2013) Optimum cost design of RC columns using artificial bee colony algorithm.

algorithm, evolutionary algorithm, and simulated annealing algorithm have gradually been applied in some fields, such as mathematics, computer, operations research, manufacturing, electronics, systems, and controls. The main problems solved include nonlinear optimization (Glover, 1994), vehicle routing (Chiang & Russell, 1996), multiprocessor task scheduling (Blazewicz et al., 1996; Porto & Ribeiro, 1995), linear bilevel programming and quadratic assignment problems (Gendreau et al., 1996), and digital filter design (Fanni et al., 1998).

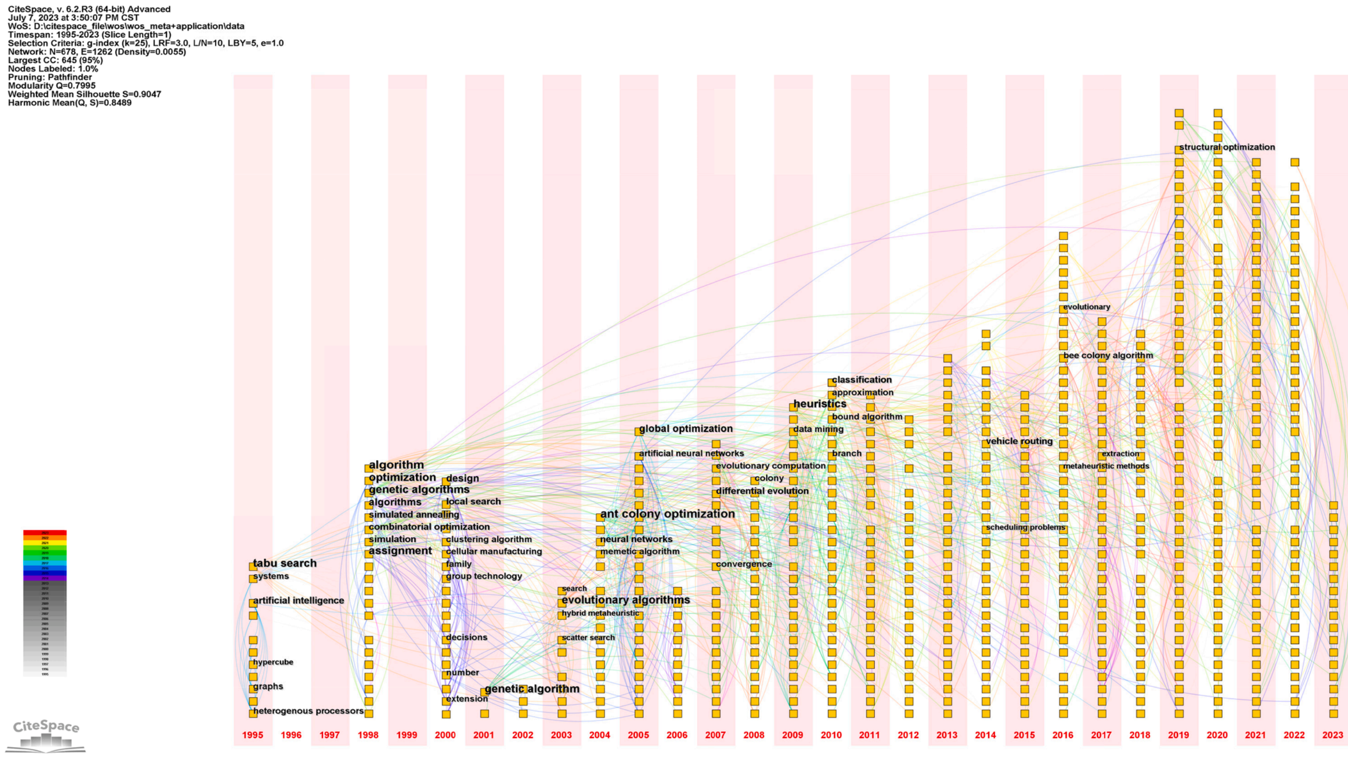

Fig. 14. Keywords time-zone.

Although it has been preliminarily applied in many fields, the development of metaheuristic algorithms is still slow, and its application level is relatively shallow, dealing with rather classic problems.

Mainstream formation stage (1999–2008): Burst keywords in this stage include: “algorithm”, “combinatorial optimization”, “simulated annealing”, “assignment”, “local search” and “ant colony optimization algorithms”. The keywords that appeared during this period but did not form burst citation features include “genetic algorithm”, “optimization”, “variable neighborhood search” and “system”. At the same time, “tabu search” also maintains its burst features. Since 1999, the application of classical metaheuristic algorithms has rapidly developed, and more scholars have discovered its unique advantages and become interested in the problems it applies to. A large number of new metaheuristic algorithms have also emerged. The application field rapidly expanded at this stage, and in the later stage, it reached about 70 % of the current research field. In addition, with the attention of researchers, metaheuristic has been widely used to solve problems in some areas, such as hardware construction (Duin & Voß, 1999), industrial manufacturing (Onwubolu & Songore, 2000), engineering design (de Sousa et al., 2003), communication (Carello et al., 2004), integrated systems (Alupoaei & Katkoori, 2004), and power systems (Favuzza et al., 2006).

Booming stage (2009–2023): From 2009 to 2015, it can be seen that existing metaheuristic algorithm application fields have become even more favorite. Among them, not only do the burst keywords before 2009 still maintain the burst characteristic, but also the two keywords “genetic algorithm” and “optimization” that first appeared in 1998 still show the burst characteristic, and the burst keyword “heuristic” is added, it is evidence that the number of scientific researchers studying this field is increasingly augmented. The growth rate of new metaheuristic algorithms at this stage has also reached a record high. The related problems generated by the development of new technologies and cross-technologies guide the road of metaheuristic algorithms’ application. At this stage, the number of issues solved by the metaheuristic algorithm has increased in an all-around way. However the growth rate of the scope of application has slowed down, and new additions such as informatics applications (Montemanni & Smith, 2009), industrial management (Bożejko et al., 2012), and ecological managemen (Li et al., 2010; Rytwinski & Crowe, 2010).

Since 2015, there have been as many as ten burst keywords, and the application of some new algorithms has begun to show burst features. The phenomenon of using the algorithm name as a keyword to show burst features has a growing trend, proving that the types of algorithms and their applications are rapidly increasing. Representative burst keywords include “harmony search”, “system”, “flow”, “framework”, “machine learning”, “search problem” and “task analysis”. By exploring the information of keyword nodes, it is found that the cutting-edge content includes task scheduling and task analysis of data in cloud computing, fog computing, edge computing, parameter optimization of control systems, feature extraction, feature selection, etc. There is another point worth noting that most of the burst spans in this period lasted for one to two years, which proves that the overall research in this field has a relatively large scale, and its direction has a trend of refinement.

7. Conclusions and future works

In order to ensure the authority of the data and the rationality of the analysis, the internal statistical analysis of the WoS core collection database and the CiteSpace visualization software analysis are used to comprehensively discuss the overall literature distribution characteristics, research cooperation, discipline-field intersection, research Hotspots, development evolution and frontier trends of metaheuristic algorithm application’ fields.

From the perspective of publications number, the number of publications related to applying metaheuristic algorithms has grown exponentially, which is in line with the law of literature accumulation growth in general research fields. Between 1994 and 2001, the publications showed a steady trend without a significant increase. From 2002 to 2017, it has gradually increased, and from 2017 to now, the number of papers published has proliferated. Regarding journal distribution, the top 15 journals account for 38.4 % of the total publications of all journals, and it is expected to form a core journal collection soon. In terms of

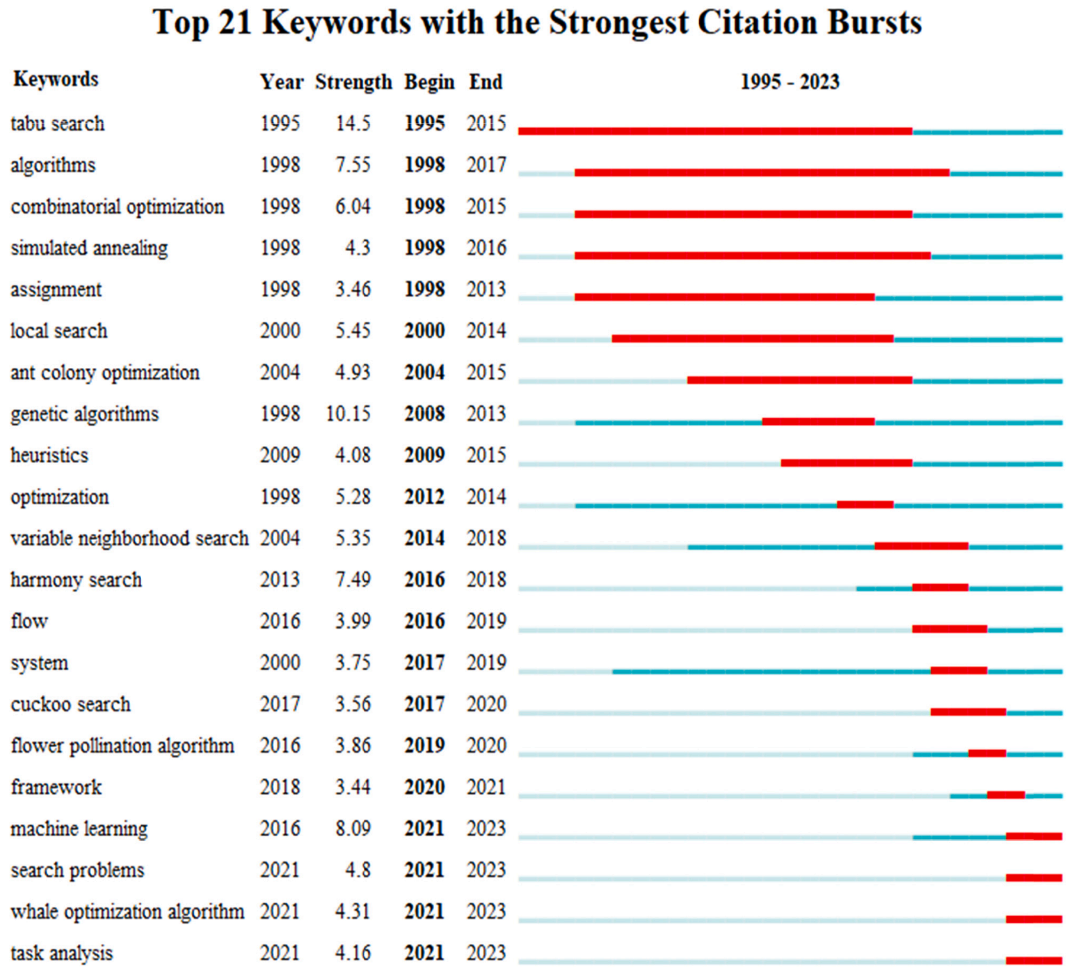

Fig. 15. Keywords citation bursts.

disciplines, metaheuristic algorithms' applied research is based on computer science, systems science, mathematics, etc.

A particular scale of core author groups has been formed for authors, and the top-ranked authors have cooperated mainly. The areas of cooperation include image segmentation, parameter optimization, scheduling, etc. Regarding the overall country and institutions, the NIT ranks first in frequency and has established cooperation relationships with most of the top-ranked mainstream institutions. At the same time, its domestic cooperation scale is relatively large, and the cooperation relationship is close. China occupies the top spot in the frequency of national cooperation and leads other countries by a large margin. However, the cooperation network is relatively scattered, and institutions with a large scale of cooperation still need to be formed.

Through the keyword co-occurrence map and cluster map, six thematic hotspots of the research object of this paper are obtained, namely "scheduling", "vehicle routing", "energy", "control system", "internet and communication technology" and "industrial manufacturing and design". The research status and practical performance of metaheuristic algorithms in various fields are expounded. Obtain the development frontier of the research object through the keywords burst chart, citing literature chart, and co-cited literature cluster map, which is a new algorithm established by a novel idea, and a new application of the algorithm has been proposed, such as application to task analysis, feature selection, parameter extraction, search problems, and others.

Based on the time-zone map and keyword burst, the staged progress and overall evolution of the research object are obtained, and three stages are sorted out: the groundbreaking stage, the mainstream formation stage, and the booming stage. In the groundbreaking phase, the classic metaheuristic algorithm was gradually applied in fields such as mathematics, computer, operations research, manufacturing, electrical and electronics, systems, and control, which attracted scholars' attention and laid the foundation for the research object. The mainstream formation stage assembled many researchers to join the field, rapidly expanded the development scale of applying metaheuristic algorithms, and focused on directions such as hardware and structure, industrial manufacturing, information and software technology, engineering design, integrated system, and power system construction. The characteristics of the booming stage are large-scale development, accelerated refinement of research directions, and rapid increase in algorithm types.

This paper comprehensively discusses the existing achievements, development, and research trends in metaheuristic algorithms' application from an objective point of view, supplemented by the visual analysis method of scientometrics. In general, the metaheuristic algorithm has penetrated various fields, and the development presents a spiral trajectory, but some issues still need attention. Nowadays, the story of the metaheuristic algorithm seems to have entered a bottleneck, with a small number of innovative points in the main logic of the new algorithm, and the growth of applied innovative research is relatively slow. Furthermore, the applicability of the theoretical foundation of the metaheuristic algorithm needs further verification, requiring more milestone research results. The deficiencies of this paper are that the analysis based on CiteSpace is not in-depth enough, and the literature data only comes from one database, which may result in an insufficient analysis of the literature data. Future work can be carried out from the perspective of national geographic maps, different ways of cluster maps (such as topic selection words and abstract methods), essential stakeholders, top funding agencies, and other aspects.

CRediT authorship contribution statement

Guanghui Li: Conceptualization, Writing – original draft, Formal analysis, Visualization, Software. **Taihua Zhang:** Writing – review & editing, Supervision. **Chieh-Yuan Tsai:** Writing – review & editing, Supervision. **Liguo Yao:** Methodology, Conceptualization, Writing – review & editing, Supervision. **Yao Lu:** Methodology, Supervision. **Jiao Tang:** Software.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

This work was supported by the Guizhou Provincial Science and Technology Projects (Grant No. Qiankehejichu-ZK[2022]General 320), National Natural Science Foundation (Grant No. 72061006), Natural Science Research Project of Guizhou Provincial Education Department (Youth Science and Technology Talent Development Project) (Grant No. Qianjiaoji [2024]42) and Academic New Seedling Foundation Project of Guizhou Normal University (Grant No. Qianshixinmiao-[2021]A30).

References

Abbassi, R., Abbassi, A., Heidari, A. A., & Mirjalili, S. (2019). An efficient salp swarm-inspired algorithm for parameters identification of photovoltaic cell models. *Energy Conversion and Management, 179*, 362–372. https://doi.org/10.1016/j.enconman.2018.10.069

Abd Elaziz, M., Dahou, A., Alsaleh, N. A., Elsheikh, A. H., Saba, A. I., & Ahmadein, M. (2021). Boosting COVID-19 image classification using MobileNetV3 and aquila optimizer algorithm. *Entropy*, *23*(11), Article 1383. https://doi.org/10.3390/e23111383.

Abdel-Basset, M., Mohamed, R., Elhoseny, M., Bashir, A. K., Jolfaei, A., & Kumar, N. (2020). Energy-aware marine predators algorithm for task scheduling in IoT-based fog computing applications. *IEEE Transactions on Industrial Informatics, 17*(7), 5068–5076. https://doi.org/10.1109/TII.2020.3001067

Abualigah, L. M., & Khader, A. T. (2017). Unsupervised text feature selection technique based on hybrid particle swarm optimization algorithm with genetic operators for the text clustering. *The Journal of Supercomputing, 73*, 4773–4795. https://doi.org/10.1007/s11227-017-2046-2

Adam, S. P., Alexandropoulos, S.-A.-N., Pardalos, P. M., & Vrahatis, M. N. (2019). No free lunch theorem: A review. *Approximation Optimization: Algorithms, Complexity Applications, 57–82*. https://doi.org/10.1007/978-3-030-12767-1_5

Adarsh, B. R., Raghunathan, T., Jayabarathi, T., & Yang, X.-S. (2016). Economic dispatch using chaotic bat algorithm. *Energy, 96*, 666–675. https://doi.org/10.1016/j.energy.2015.12.096

Agarwal, T., & Kumar, V. (2021). A systematic review on bat algorithm: Theoretical foundation, variants, and applications. *Archives of Computational Methods in Engineering, 1–30*. https://doi.org/10.1007/s11831-021-09673-9

Akinola, O. O., Ezugwu, A. E., Agushaka, J. O., Abu Zitar, R., & Abualigah, L. (2022). Multiclass feature selection with metaheuristic optimization algorithms: A review. *Neural Computing and Applications, 34*(22), 19751–19790. https://doi.org/10.1007/s00521-022-07705-4

Alameer, Z., Elaziz, M. A., Ewees, A. A., Ye, H., & Jianhua, Z. (2019). Forecasting gold price fluctuations using improved multilayer perceptron neural network and whale optimization algorithm. *Resources Policy, 61*, 250–260. https://doi.org/10.1016/j.resourpol.2019.02.014

Alupoaei, S., & Katkoori, S. (2004). Ant colony system application to macrocell overlap removal. *IEEE Transactions on Very Large Scale Integration (VLSI) Systems, 12*(10), 1118–1123. https://doi.org/10.1109/TVLSI.2004.832926

Bazargan-Lari, M. (1999). Layout designs in cellular manufacturing. *European Journal of Operational Research, 112*(2), 258–272. https://doi.org/10.1016/S0377-2217(98)00164-7

Beheshti, Z., & Shamsuddin, S. M. H. (2013). A review of population-based meta-heuristic algorithms. *Int. j. adv. soft comput. appl, 5*(1), 1–35.

Bekdaş, G., Kayabekir, A. E., Nigdeli, S. M., & Toklu, Y. C. (2019). Tranfer function amplitude minimization for structures with tuned mass dampers considering soil-structure interaction. *Soil Dynamics and Earthquake Engineering, 116*, 552–562. https://doi.org/10.1016/j.soildyn.2018.10.035

Bekdaş, G., Yucel, M., & Nigdeli, S. M. (2021). Evaluation of metaheuristic-based methods for optimization of truss structures via various algorithms and Lèvy flight modification. *Buildings, 11*(2), 49. https://doi.org/10.3390/buildings11020049

Ben-Daya, M., Hassini, E., & Bahroun, Z. (2019). Internet of things and supply chain management: A literature review. *International Journal of Production Research, 57* (15–16), 4719–4742. https://doi.org/10.1080/00207543.2017.1402140

Blashfield, R. K., & Aldenderfer, M. S. (1978). The literature on cluster analysis. *Multivariate Behavioral Research, 13*(3), 271–295. https://doi.org/10.1207/s15327906mbr1303_2

Blazewicz, J., Drozdowski, M., de Werra, D., & Weglarz, J. (1996). Deadline scheduling of multiprocessor tasks. *Discrete Applied Mathematics, 65*(1–3), 81–95. https://doi.org/10.1016/0166-218X(95)00020-R

Boushaki, S. I., Bendjeghaba, O., & Brakta, N. (2021, 27-30 Jan. 2021). Accelerated modified sine cosine algorithm for data clustering. In 2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC), https://doi.org/10.1109/CCWC51732.2021.9376122.

Bożejko, W., Hejducki, Z., & Wodecki, M. (2012). Applying metaheuristic strategies in construction projects management. *Journal of Civil Engineering and Management, 18* (5), 621–630. https://doi.org/10.3846/13923730.2012.719837

Braekers, K., Ramaekers, K., & Van Nieuwenhuyse, I. (2016). The vehicle routing problem: State of the art classification and review. *Computers and Industrial Engineering, 99*, 300–313. https://doi.org/10.1016/j.cie.2015.12.007

Brookes, B. C. (1977). Theory of the Bradford law. *Journal of Documentation, 33*(3), 180–209. https://doi.org/10.1108/eb026641

Burt, R. S. (2002). The social capital of structural holes. *The New Economic Sociology: Developments in an Emerging Field, 148*(90), 122.

Carello, G., Della Croce, F., Ghirardi, M., & Tadei, R. (2004). Solving the hub location problem in telecommunication network design: A local search approach. *Networks: An International Journal, 44*(2), 94–105. https://doi.org/10.1002/net.20020

Catumba, B. D., Sales, M. B., Borges, P. T., Filho, M. N. R., Lopes, A. A. S., Rios, M. A. D., & dos Santos, J. C. S. (2023). Sustainability and challenges in hydrogen production: An advanced bibliometric analysis. *International Journal of Hydrogen Energy, 48*(22), 7975–7992. https://doi.org/10.1016/j.ijhydene.2022.11.215

Chen, C. (2004). Searching for intellectual turning points: Progressive knowledge domain visualization. *Proceedings of the National Academy of Sciences*, *101*(suppl_1), 5303-5310.

Chen, C. (2006). CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for Information Science and Technology, 57*(3), 359–377. https://doi.org/10.1002/asi.20317

Chen, C., & Chen, C. (2013). Mapping science. *Springer*. https://doi.org/10.1007/978-1-4471-5128-9

Chen, M.-S., Han, J., & Yu, P. S. (1996). Data mining: An overview from a database perspective. *IEEE Transactions on Knowledge and Data Engineering, 8*(6), 866–883. https://doi.org/10.1109/69.553155

Cheng, T. C. E., & Sin, C. C. S. (1990). A state-of-the-art review of parallel-machine scheduling research. *European Journal of Operational Research, 47*(3), 271–292. https://doi.org/10.1016/0377-2217(90)90215-W

Chiang, W.-C., & Russell, R. A. (1996). Simulated annealing metaheuristics for the vehicle routing problem with time windows. *Annals of Operations Research, 63*, 3–27. https://doi.org/10.1007/BF02601637

Chouksey, M., Jha, R. K., & Sharma, R. (2020). A fast technique for image segmentation based on two meta-heuristic algorithms. *Multimedia Tools and Applications, 79* (27–28), 19075–19127. https://doi.org/10.1007/s11042-019-08138-3

Chowdhury, B. H., & Rahman, S. (1990). A review of recent advances in economic dispatch. *IEEE Transactions on Power Apparatus and Systems, 5*(4), 1248–1259. https://doi.org/10.1109/59.99376

Corne, D., Dorigo, M., Glover, F., Dasgupta, D., Moscato, P., Poli, R., & Price, K. V. (1999). *New ideas in optimization.* UK: McGraw-Hill Ltd.

Dahou, A., Abd Elaziz, M., Chelloug, S. A., Awadallah, M. A., Al-Betar, M. A., Al-Qaness, M. A. A., & Forestiero, A. (2022). Intrusion detection system for IoT based on deep learning and modified reptile search algorithm. *Computational Intelligence and Neuroscience, 2022*. https://doi.org/10.1155/2022/6473507

de Sousa, F. L., Ramos, F. M., Paglione, P., & Girardi, R. M. (2003). New stochastic algorithm for design optimization. *AIAA Journal, 41*(9), 1808–1818. https://doi.org/10.2514/2.7299

Dehghani, M., Trojovská, E., & Zuščák, T. (2022). A new human-inspired metaheuristic algorithm for solving optimization problems based on mimicking sewing training. *Scientific Reports, 12*(1), 17387. https://doi.org/10.1038/s41598-022-22458-9

Derouiche, A., Layeb, A., & Habbas, Z. (2017). Chemical reaction optimization metaheuristic for solving association rule mining problem. *2017 IEEE/ACS 14th International Conference on Computer Systems and Applications (AICCSA)*.

Desale, S., Rasool, A., Andhale, S., & Rane, P. (2015). Heuristic and meta-heuristic algorithms and their relevance to the real world: A survey. *International Journal of Computer Engineering in Research Trends, 351*(5), 2349–7084.

Dillen, W., Lombaert, G., & Schevenels, M. (2021). A hybrid gradient-based/metaheuristic method for Eurocode-compliant size, shape and topology optimization of steel structures. *Engineering Structures, 239*, Article 112137. https://doi.org/10.1016/j.engstruct.2021.112137

Donohue, J. C. (1972). A bibliometric analysis of certain information science literature. *Journal of the American Society for Information Science, 23*(5), 313–317. https://doi.org/10.1002/asi.4630230506

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

Dorigo, M., Birattari, M., & Stutzle, T. J. I. c. i. m. (2006). Ant colony optimization. *1*(4), 28-39.

Dörner, S., Cammerer, S., Hoydis, J., & ten Brink, S. (2018). Deep learning based communication over the air. *IEEE Journal of Selected Topics in Signal Processing, 12*(1), 132–143. https://doi.org/10.1109/JSTSP.2017.2784180

Driankov, D., Hellendoorn, H., & Reinfrank, M. (2013). An introduction to fuzzy control. *Springer Science & Business Media*. https://doi.org/10.1007/978-3-662-11131-4

Duin, C., & Voß, S. (1999). The Pilot method: A strategy for heuristic repetition with application to the Steiner problem in graphs. *Networks: An International Journal, 34* (3), 181–191. https://doi.org/10.1002/(SICI)1097-0037(199910)34:3<181::AID-NET2>3.0.CO;2-Y

Elsheikh, A. H., Shehabeldeen, T. A., Zhou, J., Showaib, E., & Abd Elaziz, M. (2021). Prediction of laser cutting parameters for polymethylmethacrylate sheets using random vector functional link network integrated with equilibrium optimizer. *Journal of Intelligent Manufacturing, 32*, 1377–1388. https://doi.org/10.1007/s10845-020-01617-7

Essa, F. A., Abd Elaziz, M., & Elsheikh, A. H. (2020). An enhanced productivity prediction model of active solar still using artificial neural network and Harris Hawks optimizer. *Applied Thermal Engineering, 170*, Article 115020. https://doi.org/10.1016/j.applthermaleng.2020.115020

Ezugwu, A. E., Shukla, A. K., Agbaje, M. B., Oyelade, O. N., José-García, A., & Agushaka, J. O. (2021). Automatic clustering algorithms: A systematic review and bibliometric analysis of relevant literature. *Neural Computing and Applications, 33*, 6247–6306. https://doi.org/10.1007/s00521-020-05395-4

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

Fanni, A., Marchesi, M., Pilo, F., & Serri, A. (1998). Tabu search metaheuristic for designing digital filters. *COMPEL-The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, 17*(6), 789–796. https://doi.org/10.1108/03321649810221422

Fathollahi-Fard, A. M., Ranjbar-Bourani, M., Cheikhrouhou, N., & Hajiaghaei-Keshteli, M. (2019). Novel modifications of social engineering optimizer to solve a truck scheduling problem in a cross-docking system. *Computers and Industrial Engineering, 137*, Article 106103.

Favuzza, S., Graditi, G., & Sanseverino, E. R. (2006). Adaptive and dynamic ant colony search algorithm for optimal distribution systems reinforcement strategy. *Applied Intelligence, 24*, 31–42. https://doi.org/10.1007/s10489-006-6927-y

Freeman, L. C. (1977). A set of measures of centrality based on betweenness. *Sociometry, 35–41*. https://doi.org/10.2307/3033543

Freeman, L. C. (2002). Centrality in social networks: Conceptual clarification. *Social network: critical concepts in sociology. Londres: Routledge, 1*, 238-263. https://doi.org/10.1016/0378-8733(78)90021-7.

García-Villoria, A., & Pastor, R. (2010). Solving the response time variability problem by means of a genetic algorithm. *European Journal of Operational Research, 202*(2), 320–327. https://doi.org/10.1016/j.ejor.2009.05.024

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy A new sustainability paradigm? *Journal of Cleaner Production, 143*, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Gendreau, M., Marcotte, P., & Savard, G. (1996). A hybrid tabu-ascent algorithm for the linear bilevel programming problem. *Journal of Global Optimization, 8*, 217–233. https://doi.org/10.1007/BF00121266

Gill, P. E., Murray, W., & Wright, M. H. (2019). *Practical optimization*. Society for Industrial and Applied Mathematics.

Glover, F. (1994). Tabu search for nonlinear and parametric optimization (with links to genetic algorithms). *Discrete Applied Mathematics, 49*(1–3), 231–255. https://doi.org/10.1016/0166-218X(94)90211-9

Golden, B. L., Raghavan, S., & Wasil, E. A. (2008). *The vehicle routing problem: latest advances and new challenges* (Vol. 43). Springer.

Guo, C., Tang, H., Niu, B., & Lee, C. B. P. (2021). A survey of bacterial foraging optimization. *Neurocomputing, 452*, 728–746. https://doi.org/10.1016/j.neucom.2020.06.142

Gutierrez Soto, M., & Adeli, H. (2013). Tuned mass dampers. *Archives of Computational Methods in Engineering, 20*, 419–431. https://doi.org/10.1007/s11831-013-9091-7

Hajisalem, V., & Babaie, S. (2018). A hybrid intrusion detection system based on ABC-AFS algorithm for misuse and anomaly detection. *Computer Networks, 136*, 37–50. https://doi.org/10.1016/j.comnet.2018.02.028

Hand, D. J. (2007). Principles of data mining. *Drug Safety, 30*, 621–622. https://doi.org/10.2165/00002018-200730070-00010

Hassan, M. H., Kamel, S., Abualigah, L., & Eid, A. (2021). Development and application of slime mould algorithm for optimal economic emission dispatch. *Expert Systems with Applications, 182*, Article 115205. https://doi.org/10.1016/j.eswa.2021.115205

He, Q. (1999). *Knowledge discovery through co-word analysis* (p. 48). Trends: Libr.

Hill, J., Szewczyk, R., Woo, A., Hollar, S., Culler, D., & Pister, K. (2000). System architecture directions for networked sensors. *Sigplan Notations, 35*(11), 93–104. https://doi.org/10.1145/356989.356998

Holland, J. H. (1992). Genetic algorithms. *Scientific American, 267*(1), 66–73. http://www.jstor.org/stable/24939139.

Huang, X. X., Moayedi, H., Gong, S., & Gao, W. (2022). Application of Metaheuristic Algorithms for Pressure Analysis of Crude Oil Pipeline. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 44*(2), 5124–5142. https://doi.org/10.1080/15567036.2019.1661550

Ikotun, A. M., Ezugwu, A. E., Abualigah, L., Abuhaija, B., & Heming, J. (2023). K-means clustering algorithms: A comprehensive review, variants analysis, and advances in the era of big data. *Information Scientist, 622*, 178–210. https://doi.org/10.1016/j.ins.2022.11.139

Jia, H., Li, Y., Wu, D., Rao, H., Wen, C., & Abualigah, L. (2023). Multi-strategy Remora Optimization Algorithm for solving multi-extremum problems. *Journal of Computational Design and Engineering, 10*(4), 1315–1349. https://doi.org/10.1093/jcde/qwad044

Kar, A. K. (2016). Bio inspired computing – A review of algorithms and scope of applications. *Expert Systems with Applications, 59*, 20–32. https://doi.org/10.1016/j.eswa.2016.04.018

Kaur, M., Singh, S., Kaur, M., Singh, A., & Singh, D. (2022). A systematic review of metaheuristic-based image encryption techniques. *Archives of Computational Methods in Engineering, 29*(5), 2563–2577. https://doi.org/10.1007/s11831-021-09656-w

Kayabekir, A. E., Nigdeli, S. M., & Bekdaş, G. (2022). A hybrid metaheuristic method for optimization of active tuned mass dampers. *Computer-Aided Civil and Infrastructure Engineering, 37*(8), 1027–1043. https://doi.org/10.1111/mice.12790

Kennedy, J., & Eberhart, R. (1995, 27 Nov.-1 Dec. 1995). Particle swarm optimization. Proceedings of ICNN'95 - International conference on neural networks, https://doi.org/10.1109/ICNN.1995.488968.

Kleinberg, J. (2002). *Bursty and hierarchical structure in streams* Proceedings of the eighth ACM SIGKDD international conference on Knowledge discovery and data mining, Edmonton, Alberta, Canada. https://doi.org/10.1145/775047.775061.

Kubiak, W. (2004). Fair Sequences. In.

Kumar, M., Aggarwal, J., Rani, A., Stephan, T., Shankar, A., & Mirjalili, S. (2022). Secure video communication using firefly optimization and visual cryptography. *Artificial Intelligence Review*, 1–21.

Kumar, S., & Rao, C. (2009). Application of ant colony, genetic algorithm and data mining-based techniques for scheduling. *Robotics Computer-Integrated Manufacturing, 25*(6), 901–908.

Kumar, S., Tejani, G. G., Pholdee, N., & Bureerat, S. (2021). Multi-Objective Passing Vehicle Search algorithm for structure optimization. *Expert Systems with Applications, 169*, Article 114511. https://doi.org/10.1016/j.eswa.2020.114511

Lanza-Gutiérrez, J. M., Caballé, N., Gómez-Pulido, J. A., Crawford, B., & Soto, R. (2019). Toward a robust multi-objective metaheuristic for solving the relay node placement problem in wireless sensor networks. *Sensors, 19*(3), 677.

Li, K., Zhang, X., Leung, J. Y. T., & Yang, S.-L. (2016). Parallel machine scheduling problems in green manufacturing industry. *Journal of Manufacturing Systems, 38*, 98–106.

Li, L. Z., Ota, K., & Dong, M. X. (2018). Deep learning for smart industry: Efficient Manufacture inspection system with fog computing. *IEEE Transactions on Industrial Informatics, 14*(10), 4665–4673. https://doi.org/10.1109/TII.2018.2842821

Li, Y., Zhou, J., Zhang, Y., Qin, H., & Liu, L. (2010). Novel multiobjective shuffled frog leaping algorithm with application to reservoir flood control operation. *Journal of Water Resources Planning and Management, 136*(2), 217–226. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000027

Liao, T. W., & Li, G. Q. (2020). Metaheuristic-based inverse design of materials - A survey. *Journal of Materiomics, 6*(2), 414–430. https://doi.org/10.1016/j.jmat.2020.02.011

Liu, Z., Li, H., & Zhu, P. (2019). Diversity enhanced particle swarm optimization algorithm and its application in vehicle lightweight design. *Journal of Mechanical Science and Technology, 33*(2), 695–709. https://doi.org/10.1007/s12206-019-0124-5

Loey, M., El-Sappagh, S., & Mirjalili, S. (2022). Bayesian-based optimized deep learning model to detect COVID-19 patients using chest X-ray image data. *Computers in Biology and Medicine, 142*, Article 105213.

Marshakova-Shaikevich, I. (1996). The standard impact factor as an evaluation tool of science fields and scientific journals. *Scientometrics, 35*(2), 283–290. https://doi.org/10.1007/bf02018487

Marshakova-Shaikevich, I. (2004). Journal co-citation analysis in the field of women's studies. International Workshop on Webometrics, Informetrics and Scientometrics (2-5 March 2004, Roorkee).

McNamara, R. J. (1977). Tuned mass dampers for buildings. *Journal of the Structural Division, 103*(9), 1785–1798.

Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning, 147*, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011

Mejía-Moncayo, C., & Battaia, O. (2019). A hybrid optimization algorithm with genetic and bacterial operators for the design of cellular manufacturing systems. *IFAC-PapersOnLine, 52*(13), 1409–1414.

Melman, A., & Evsutin, O. (2023). Image data hiding schemes based on metaheuristic optimization: A review. *Artificial Intelligence Review, 56*(12), 15375–15447. https://doi.org/10.1007/s10462-023-10537-w

Metzler, B., Nathvani, R., Sharmanska, V., Bai, W. J., Muller, E., Moulds, S., & Ezzati, M. (2023). Phenotyping urban built and natural environments with high-resolution

satellite images and unsupervised deep learning. *The Science of the Total Environment, 893*, Article 164794. https://doi.org/10.1016/j.scitotenv.2023.164794
Miguel, L. F. F., & Miguel, L. F. F. (2012). Shape and size optimization of truss structures considering dynamic constraints through modern metaheuristic algorithms. *Expert Systems with Applications, 39*(10), 9458–9467. https://doi.org/10.1016/j.eswa.2012.02.113
Mo, Z. B., Shi, R. Y., & Di, X. (2021). A physics-informed deep learning paradigm for car-following models. *Transportation Research Part C-Emerging Technologies, 130*, Article 103240. https://doi.org/10.1016/j.trc.2021.103240
Moayedi, H., Kalantar, B., Foong, L. K., Tien Bui, D., & Motevalli, A. (2019). Application of three metaheuristic techniques in simulation of concrete slump. *Applied Sciences, 9* (20), 4340.
Moayedi, H., Osouli, A., Nguyen, H., & Rashid, A. S. A. (2021). A novel Harris hawks' optimization and k-fold cross-validation predicting slope stability. *Engineering Computations, 37*, 369–379.
Montemanni, R., & Smith, D. H. (2009). Heuristic algorithms for constructing binary constant weight codes. *IEEE Transactions on Information Theory, 55*(10), 4651–4656. https://doi.org/10.1109/TIT.2009.2027491
Moradi, H., & Zandieh, M. (2013). An imperialist competitive algorithm for a mixed-model assembly line sequencing problem. *Journal of Manufacturing Systems, 32*(1), 46–54.
Mousavi-Avval, S. H., Rafiee, S., Sharifi, M., Hosseinpour, S., Notarnicola, B., Tassielli, G., & Renzulli, P. A. (2017). Application of multi-objective genetic algorithms for optimization of energy, economics and environmental life cycle assessment in oilseed production. *Journal of Cleaner Production, 140*, 804–815.
Nadimi-Shahraki, M. H., Taghian, S., Mirjalili, S., Abualigah, L., Abd Elaziz, M., & Oliva, D. (2021). Ewoa-opf: Effective whale optimization algorithm to solve optimal power flow problem. *Electronics, 10*(23), 2975.
Nasr, R., Abou-Zalam, B., & Nabil, E. (2023). Metaheuristic optimization algorithm-based enhancement of photovoltaic energy system performance. *Arabian Journal for Science and Engineering*, 1–22.
Neto, J. X. V., Guerra, E. J., Moreno, S. R., Ayala, H. V. H., Mariani, V. C., & Coelho, L. D. (2018). Wind turbine blade geometry design based on multi-objective optimization using metaheuristics. *Energy, 162*, 645–658. https://doi.org/10.1016/j.energy.2018.07.186
Oliva, D., Abd Elaziz, M., Elsheikh, A. H., & Ewees, A. A. (2019). A review on meta-heuristics methods for estimating parameters of solar cells. *Journal of Power Sources, 435*, Article 126683.
Olivares-Benitez, E., Rios-Mercado, R. Z., & Gonzalez-Velarde, J. L. (2013). A metaheuristic algorithm to solve the selection of transportation channels in supply chain design. *International Journal of Production Economics, 145*(1), 161–172. https://doi.org/10.1016/j.ijpe.2013.01.017
Olivares-Suarez, M., Palma, W., Paredes, F., Olguín, E., & Norero, E. (2014). A binary coded firefly algorithm that solves the set covering problem. *Science and Technology, 17*, 252–264.
Onwubolu, G. C., & Mutingi, M. (2001). A genetic algorithm approach to cellular manufacturing systems. *Computers and Industrial Engineering, 39*(1–2), 125–144.
Onwubolu, G. C., & Songore, V. (2000). A tabu search approach to cellular manufacturing systems. *Production Planning and Control, 11*(2), 153–164.
Ozkaya, H., Yildiz, M., Yildiz, A. R., Bureerat, S., Yildiz, B. S., & Sait, S. M. (2020). The equilibrium optimization algorithm and the response surface based metamodel for optimal structural design of vehicle components. *Materials Testing, 62*(5), 492–496. https://doi.org/10.3139/120.111509
Passino, K. M., Yurkovich, S., & Reinfrank, M. (1998). *Fuzzy control* (Vol. 42). Reading, MA: Addison-wesley.
Pillai, D. S., & Rajasekar, N. (2018). Metaheuristic algorithms for PV parameter identification: A comprehensive review with an application to threshold setting for fault detection in PV systems. *Renewable and Sustainable Energy Reviews, 82*, 3503–3525. https://doi.org/10.1016/j.rser.2017.10.107
Porto, S. C. S., & Ribeiro, C. C. (1995). A tabu search approach to task scheduling on heterogeneous processors under precedence constraints. *International Journal of High Speed Computing, 7*(01), 45–71.
Pozna, C., Precup, R.-E., Horváth, E., & Petriu, E. M. (2022). Hybrid particle filter–particle swarm optimization algorithm and application to fuzzy controlled servo systems. *IEEE Transactions on Fuzzy Systems, 30*(10), 4286–4297.
Price, D.d. S. (1976). A general theory of bibliometric and other cumulative advantage processes. *Journal of the American Society for Information Science, 27*(5), 292–306.
Price, D. J. D. S. (1965). Networks of scientific papers: The pattern of bibliographic references indicates the nature of the scientific research front. *Science, 149*(3683), 510–515.
Qian, G. (2014). Scientometric sorting by importance for literatures on life cycle assessments and some related methodological discussions. *International Journal of Life Cycle Assessment, 19*, 1462–1467. https://doi.org/10.1007/s11367-014-0747-9
Rajabi Moshtaghi, H., Toloie Eshlaghy, A., & Motadel, M. R. (2021). A comprehensive review on meta-heuristic algorithms and their classification with novel approach. *Journal of Applied Research on Industrial Engineering, 8*(1), 63–89.
Rajwar, K., Deep, K., & Das, S. (2023). An exhaustive review of the metaheuristic algorithms for search and optimization: Taxonomy, applications, and open challenges. *Artificial Intelligence Review, 56*(11), 13187–13257. https://doi.org/10.1007/s10462-023-10470-y
Romesburg, C. (2004). *Cluster analysis for researchers*. Lulu. com.
Rytwinski, A., & Crowe, K. A. (2010). A simulation-optimization model for selecting the location of fuel-breaks to minimize expected losses from forest fires. *Forest Ecology and Management, 260*(1), 1–11. https://doi.org/10.1016/j.foreco.2010.03.013
Sabireen, H., & Venkataraman, N. (2023). A hybrid and light weight metaheuristic approach with clustering for multi-objective resource scheduling and application placement in fog environment. *Expert Systems with Applications, 223*, Article 119895. https://doi.org/10.1016/j.eswa.2023.119895
Sadollah, A., Choi, Y., & Kim, J. H. (2015). Metaheuristic optimization algorithms for approximate solutions to ordinary differential equations. In 2015 IEEE congress on evolutionary computation (CEC).
Samy, M. M., & Barakat, S. (2019). Hybrid invasive weed optimization-particle swarm optimization algorithm for biomass/PV micro-grid power system. In 2019 21st international Middle East power systems conference (MEPCON).
Saravanan, G., Neelakandan, S., Ezhumalai, P., & Maurya, S. (2023). Improved wild horse optimization with levy flight algorithm for effective task scheduling in cloud computing. *Journal of Cloud Computing, 12*(1), 24.
Schneider, M., Stenger, A., & Goeke, D. (2014). The electric vehicle-routing problem with time windows and recharging stations. *Transportation Science, 48*(4), 500–520.
Shao, Y. (2022). Bibliometric study of trends in the diabetic nephropathy research space from 2016 to 2020. *Oxidative Medicine and Cellular Longevity, 2022*. https://doi.org/10.1155/2022/8050137
Sharma, A. (2023). Antenna array pattern synthesis using metaheuristic algorithms: A review. *IETE Technical Review, 40*(1), 90–115. https://doi.org/10.1080/02564602.2022.2051616
Singh, R. M., Awasthi, L. K., & Sikka, G. (2023). Towards metaheuristic scheduling techniques in cloud and fog: An extensive taxonomic review. *ACM Computing Surveys, 55*(3), Article 50. https://doi.org/10.1145/3494520
Small, H. (1973). Co-citation in the scientific literature: A new measure of the relationship between two documents. *Journal of the American Society for Information Science, 24*(4), 265–269.
Smith, J. M. (1978). Optimization theory in evolution. *Annual Review of Ecology and Systematics, 9*(1), 31–56. https://doi.org/10.1146/annurev.es.09.110178.000335
Soto, R., Crawford, B., González, F., Vega, E., Castro, C., & Paredes, F. (2019). Solving the manufacturing cell design problem using human behavior-based algorithm supported by autonomous search. *IEEE Access, 7*, 132228–132239.
Sugeno, M. (1985). An introductory survey of fuzzy control. *Information Scientist, 36* (1–2), 59–83.
Tejani, G. G., Savsani, V. J., Patel, V. K., & Mirjalili, S. (2018). Truss optimization with natural frequency bounds using improved symbiotic organisms search. *Knowledge-Based Systems, 143*, 162–178.
Teoh, C. K., Wibowo, A., & Ngadiman, M. S. (2015). Review of state of the art for metaheuristic techniques in Academic Scheduling Problems. *Artificial Intelligence Review, 44*(1), 1–21. https://doi.org/10.1007/s10462-013-9399-6
Toth, P., & Vigo, D. (2002). The vehicle routing problem. *Society for Industrial and Applied Mathematics.*
Trojovský, P., & Dehghani, M. (2022). Pelican optimization algorithm: A novel nature-inspired algorithm for engineering applications. *Sensors, 22*(3), 855.
Trojovský, P., Dehghani, M., & Hanuš, P. (2022). Siberian tiger optimization: A new bio-inspired metaheuristic algorithm for solving engineering optimization problems. *IEEE Access, 10*, 132396–132431.
Ulusoy, S., Nigdeli, S. M., & Bekdaş, G. (2021). Novel metaheuristic-based tuning of PID controllers for seismic structures and verification of robustness. *Journal of Building Engineering, 33*, Article 101647.
Ürgün, S., Yiğit, H., & Mirjalili, S. (2023). Investigation of recent metaheuristics based selective harmonic elimination problem for different levels of multilevel inverters. *Electronics, 12*(4), 1058.
Wang, S. B., Liu, F., Lian, L., Hong, Y., & Chen, H. Z. (2018). Integrated post-disaster medical assistance team scheduling and relief supply distribution. *International Journal of Logistics Management, 29*(4), 1279–1305. https://doi.org/10.1108/IJLM-06-2017-0152
Wang, T., Zhang, G., Yang, X., & Vajdi, A. (2018). Genetic algorithm for energy-efficient clustering and routing in wireless sensor networks. *Journal of Systems and Software, 146*, 196–214.
Wang, Z.-Y., Li, G., Li, C.-Y., & Li, A. (2012). Research on the semantic-based co-word analysis. *Scientometrics, 90*(3), 855–875.
White, D. R., & Borgatti, S. P. (1994). Betweenness centrality measures for directed graphs. *Social Networks, 16*(4), 335–346.
Wolpert, D. H., & Macready, W. G. (1997). No free lunch theorems for optimization. *IEEE Transactions on Evolutionary Computation, 1*(1), 67–82.
Xue, J., & Shen, B. (2023). Dung beetle optimizer: A new meta-heuristic algorithm for global optimization. *The Journal of Supercomputing, 79*(7), 7305–7336.
Yang, J., Zhang, T. H., Tsai, C. Y., Lu, Y., & Yao, L. G. (2024). Evolution and emerging trends of named entity recognition: Bibliometric analysis from 2000 to 2023. *Heliyon, 10*(9), Article e30053. https://doi.org/10.1016/j.heliyon.2024.e30053
Yang, X.-S. (2020). Nature-inspired optimization algorithms: Challenges and open problems. *Journal of Computational Science, 46*, Article 101104.
Yao, L., Li, G., Yuan, P., Yang, J., Tian, D., & Zhang, T. (2023). Reptile search algorithm considering different flight heights to solve engineering optimization design problems. *Biomimetics, 8*(3), 305.
Yao, L., Yuan, P., Tsai, C.-Y., Zhang, T., Lu, Y., & Ding, S. (2023). ESO: An enhanced snake optimizer for real-world engineering problems. *Expert Systems with Applications, 230*, Article 120594. https://doi.org/10.1016/j.eswa.2023.120594
Yin, L., Yu, T., Zhang, X., & Yang, B. (2018). Relaxed deep learning for real-time economic generation dispatch and control with unified time scale. *Energy, 149*, 11–23. https://doi.org/10.1016/j.energy.2018.01.165
Yücel, M., Bekdaş, G., Nigdeli Sinan, M., & Kayabekir Aylin, E. (2021). An artificial intelligence-based prediction model for optimum design variables of reinforced concrete retaining walls. *International Journal of Geomechanics, 21*(12), Article 04021244. https://doi.org/10.1061/(ASCE)GM.1943-5622.0002234
Zavala, G., Nebro, A. J., Luna, F., & Coello, C. A. C. (2016). Structural design using multi-objective metaheuristics. Comparative study and application to a real-world

problem. *Structural and Multidisciplinary Optimization, 53*(3), 545–566. https://doi.org/10.1007/s00158-015-1291-3

Zhang, J. P., Xie, Y. T., Wu, Q., & Xia, Y. (2019). Medical image classification using synergic deep learning. *Medical Image Analysis, 54*, 10–19. https://doi.org/10.1016/j.media.2019.02.010

Zhang, L. L., Ling, J., & Lin, M. W. (2022). Artificial intelligence in renewable energy: A comprehensive bibliometric analysis. *Energy Reports, 8*, 14072–14088. https://doi.org/10.1016/j.egyr.2022.10.347

Zhao, J., Ramadan, H. S., & Becherif, M. (2019). Metaheuristic-based energy management strategies for fuel cell emergency power unit in electrical aircraft. *International Journal of Hydrogen Energy, 44*(4), 2390–2406. https://doi.org/10.1016/j.ijhydene.2018.07.131

Zitt, M., & Bassecoulard, E. (1994). Development of a method for detection and trend analysis of research fronts built by lexical or cocitation analysis. *Scientometrics, 30*(1), 333–351. https://doi.org/10.1007/BF02017232