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Nature-Inspired Metaheuristic Algorithms: Literature Review and Presenting a Novel Classification

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Abstract

Over the past decade, solving complex optimization problems with metaheuristic algorithms has attracted many experts and researchers. Nature has always been a model for humans to draw the best mechanisms and the best engineering out of it and use it to solve their problems. The concept of optimization is evident in several natural processes, such as the evolution of species, the behavior of social groups, the immune system, and the search strategies of various animal populations. For this purpose, the use of nature-inspired optimization algorithms is increasingly being developed to solve various scientific and engineering problems due to their simplicity and flexibility. Anything in a particular situation can solve a significant problem for human society. This paper presents a comprehensive overview of the metaheuristic algorithms and classifications in this field and offers a novel classification based on the features of these algorithms.

Keywords: Optimization, Metaheuristic algorithms, Nature-inspired metaheuristic algorithms, Classification.

1 | Introduction

Today, optimization applications have become widespread in all areas such as engineering design, production planning, and financial markets, so the concept of optimization has become particularly important. The purpose of optimization is to minimize time, cost, and risk or maximize profit, quality, or effectiveness. There are exact methods and approximate methods to solve optimization problems. The exact methods can find the optimal solution to the problem. Non-derivative methods such as two-point, three-point, Fibonacci, and Golden Ratio methods, and derivative methods such as the semi-sectional method and the Newton-Raphson method, are precise methods. Many of the problems in nature are NP-hard. They cannot solve by exact methods, and the time required to solve those increases exponentially with the size. Often approximation algorithms are the only possible way to achieve near-optimal solutions with relatively low computational cost [1]. Approximate algorithms divide into three groups of heuristic, metaheuristic, and hyper-heuristic algorithms.

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The two main problems of heuristic algorithms are falling into local optimal points and early convergence to these points. Metaheuristics are solution methods that harmonize interaction between local improvement methods and higher-level strategies to escaping from local optima [1]. Most of these algorithms are inspired by nature or biology, based on the successful evolutionary behavior of natural systems, by learning from nature. Nature has solved complex problems in more than millions or even billions of years. In nature, only the best and lasting solutions remain. This paper classifies these algorithms by comprehensively reviewing the literature.

2 | Literature Review of Metaheuristic Algorithms

In recent decades, due to the capabilities of nature-inspired metaheuristic algorithms in solving various problems, the number of these algorithms has grown significantly and has been expanding. Represents the cumulative trend of presented metaheuristic algorithms.

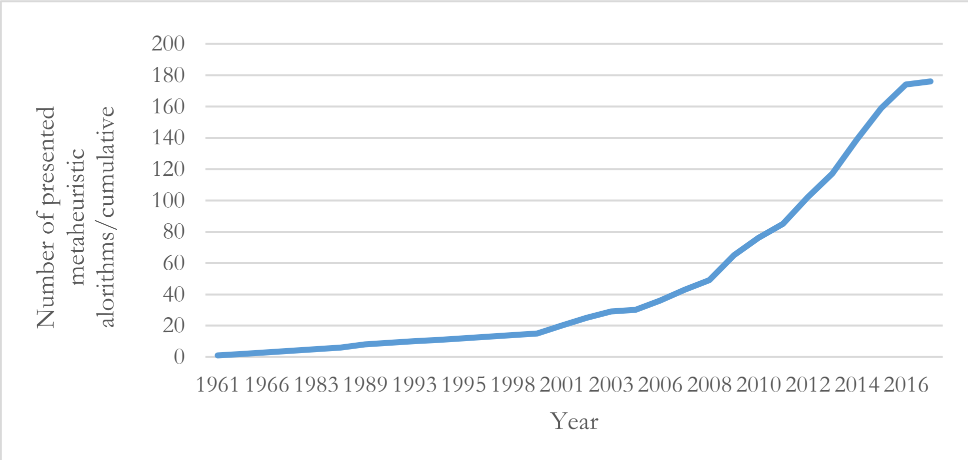

Fig. 1. The trend of presented metaheuristic algorithms.

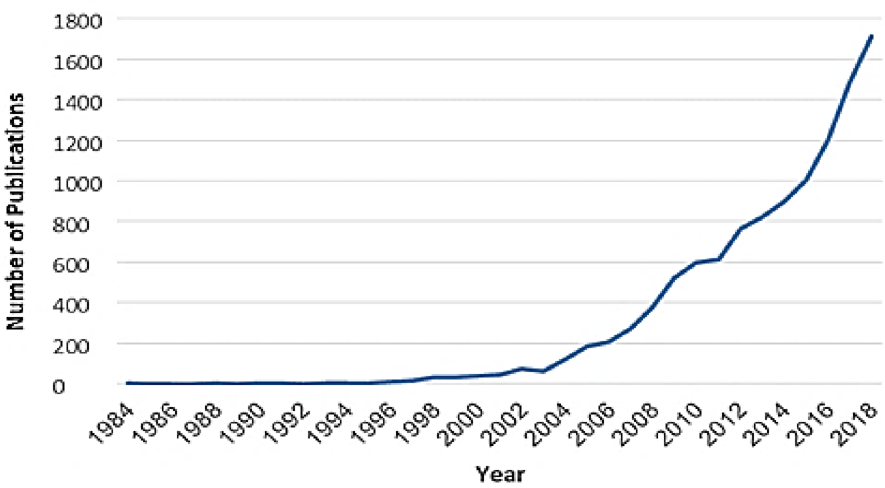

Fig. 2. The trend of papers published in the metaheuristic area (source: scopus).

Fig. 2 illustrates the trend of papers published in the metaheuristic area.

As shown in *Fig. 2*, the number of papers presented in the metaheuristic area have been significant growth after 2000.

Table 1 shows a glimpse of the perspective of the emergence of metaheuristic algorithms.

Table 1. History of metaheuristic algorithms.

Year	Author/Presenter	Algorithm	Description
1960	Holland [191]	Genetic Algorithm (GA)	University of Michigan-biological evolution of species
1966	Fogel et al. [192]	Evolutionary programming	US
1983	Kirkpatrick et al. [146]	Simulated Annealing (SA)	Inspired by the annealing process of metals
1986	Glover [162]	Tabu search	Use memory
1988	Koza [193]	Genetic programming	
1992	Dorigo [194]	Ant Colony Optimization (ACO)	Swarm intelligence-ant colony
1995	Kennedy and Eberhart [122]	Particle Swarm Optimization (PSO)	Swarm Intelligence-bird flock
1996	Storn and Price [195]	Differential Evolution (DE)	
2001	Geem et al. [90]	Harmony search	Inspired by musicians
2005	Karaboga [196]	Artificial Bee Colony (ABC)	Simulates the foraging behavior of honey bees
2005	Pham et al. [190]	Bees algorithm	Foraging behavior of honey bees
2005	Krishnanand and Ghose [78]	Glowworm Swarm Optimization (GSO)	Behavior of glowworms
2006	Chu et al. [35]	Cat swarm optimization	Inspired by the behavior of cats
2007	Atashpaz-Gargari and Lucas [97]	Imperialist competitive algorithm	Simulation of human social evolution
2007	Rabanal et al. [133]	River formation dynamics	Imitating how water forms rivers
2009	Husseinzadeh Kashan [108]	League championship algorithm	The sports league championship inspires this algorithm.
2009	Yang and Deb [47]	Cuckoo search	Inspired by the brood parasitism of cuckoo
2010	Yang [24]	Bat algorithm	Inspired by the echolocation behavior of microbats
2011	Tamura and Yasuda [156]	Spiral Optimization (SPO) algorithm	Inspired by spiral phenomena in nature
2012	Yang [69]	Flower pollination algorithm	Based on the pollination process of flowering plants
2013	Eesa et al. [49]	Cuttlefish optimization algorithm	Inspired by skin color changing behavior of cuttlefish
2014	Mirjalili et al. [87]	Grey Wolf Optimizer (GWO)	Mimics the leadership hierarchy and hunting mechanism of grey wolves in nature
2015	Mirjalili [117]	The ant lion optimizer	Mimics the hunting mechanism of antlions in nature
2016	Mirjalili and Lewis [174]	The whale optimization algorithm	Mimics the social behavior of humpback whales

Fig. 3 shows that the most relevant areas of metaheuristic algorithms are computer science with 34.9%, engineering 21%, and mathematics 17.8%, respectively.

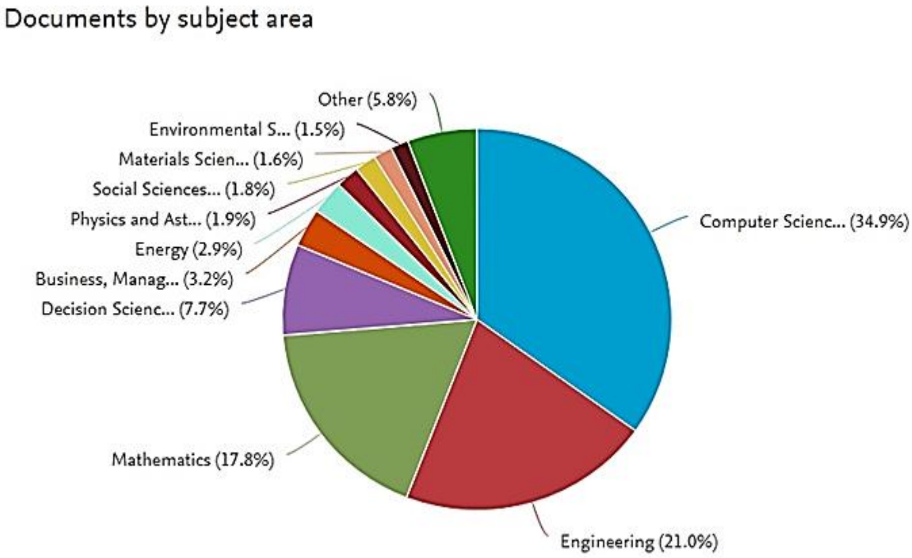

Fig. 3. Application areas of metaheuristic algorithms.

In 2017, Rajpurohit et al. [2] afforded a glossary of the metaheuristic algorithms.

Table 2 shows the metaheuristic algorithms presented from the beginning with a brief description, authors, the year of publication, the source of inspiration, the scope of their application, and the number of citations to them in the papers presented.

Table 2. Metaheuristic algorithms with a brief description, authors, the year of publication, the source of inspiration, the scope of their application, and the number of citations.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
1	African buffalo optimization	Odili et al. [3]	2015	Mimics foraging and organizational skills of African buffalos	32	17	10	Traveling salesman's problem, design of PID controller
2	African wild dog algorithm	Subramanian et al. [4]	2013	African wild dogs' hunting behavior inspires it	6	3	-	Design of steel structures, flow shop scheduling problems
3	Anarchic society optimization	Shayeghi and Dadashpour [5]	2012	Inspired by instability in the anarchistic group in society	23	8	7	PID control, flow-shop scheduling problem
4	Animal migration optimization algorithm	Li et al. [6]	2014	Mimics the migration behavior of animals	139	15	6	Clustering analysis, association rules mining

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
5	ACO	Colorni et al. [7]	1991	Inspired by ants path search behavior to find a food source	11276	14397	8925	Traveling salesman problem, vehicle routing problem, open shop scheduling, resource-constrained project scheduling, data mining, Wireless Sensor Networks (WSNs), image edge detection, feature selection, classification, object segmentation, JIT sequencing problem, power load forecasting, etc.
6	Ant Lion	Mirjalili [8]	2015	Inspired by ant lions hunting behavior	597	14	9	Automatic Generation Control (AGC), feature selection, economic load dispatch problem, design of skeletal structures, multi-layer perceptions trainer, optimal power flow, renewable distributed generations, flexible process planning
7	Artificial algae algorithm	Uymaz et al. [9]	2015	Imitates the adaption and movement behavior of algae.	62	17	17	Knapsack problem, binary optimization problems, wind turbine placement problem, parameter selection strategy
8	ABC	Karaboga and Basturk [10]	2007	Inspired by the action of searching food in the bee colonies.	1063	1200	244	Traveling salesman problem, distribution network configuration, reliability Redundancy Allocation Problem (RAP), discrete optimum design of truss structures, reconfiguring distribution network, job scheduling problem, Parameter estimation, WSN
9	Artificial chemical reaction optimization algorithm	Alatas [11]	2011	Inspired by chemical reactions	133	14	10	Knapsack problem, neural networks, sustainable network design problem, flexible job-shop scheduling problem, task scheduling in grid computing
10	Artificial cooperative search	Civicioglu [12]	2013	It inspires the mutual advantages of living species by organic interactions.	78	19	12	Energy consumption forecasting, quadratic approximation, parameter identification

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
11	Artificial ecosystem algorithm	Adham and Bentley [13]	2014	Inspired by characteristics of the ecosystem	5	5	3	Traveling salesman problems, clustering
12	Artificial fish school algorithm	Li [14]	2002	Inspired by fish swarm features such as avoiding dangers and searching for food	131	69	31	Design of robust PID controller, traveling salesman problem, clustering, parameter optimization, neural network, coverage problem, protein folding structure prediction
13	Artificial plant optimization algorithm	Li et al. [15]	2012	Inspired by the growing process of plants	34	20	10	Protein folding, WSNs, coverage problem
14	Artificial searching swarm algorithm	Chen [16]	2009	Inspired from principles of the bionic intelligent optimization algorithm	18	11	4	Reactive power optimization, constrained optimization problems
15	Atmosphere clouds model	Yan and Hao [17]	2013	Mimics from the spreading and moving of clouds	18	3	-	Optimal reactive power dispatch problem
16	Backtracking search optimization	Civicioglu [18]	2013	The algorithm has crossovers and mutation operators and a memory.	491	111	82	Distributed generators, optimal power flow, parameter identification, environmental power dispatch problems, feature selection
17	Bacteria chemotaxis algorithm	Muller et al. [19]	2002	Survival tactics adopted by bacteria, such as getting information from the environment	378	2	1	Economic emission load dispatch, assembly sequence planning
18	Bacterial colony optimization	Niu and Wang [20]	2012	Inspired by behaviors of Escherichia coli like migration, reproduction, elimination, and communication	65	23	16	Economic power dispatch, reactive power optimization

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
19	Bacterial evolutionary algorithm	Das et al. [21]	2009	Based on microbial evolution, it Utilizes two operator's gene transfer operation and bacterial mutation.	44	63	39	Data clustering, fuzzy system design, Nurse Scheduling Problem (NSP)
20	Bacterial foraging algorithm	Passino [22]	2002	Utilizes natural selection, such as supporting individuals with proper foraging and eliminate inadequate foraging.	2813	495	332	Economic emission load dispatch, parameter estimation, image segmentation, economic emission dispatch problem etc.
21	Bacterial swarming	Chu et al. [23]	2008	The algorithm uses the swarming and foraging process of E-coli.	71	94	73	Power transformer winding, optimal allocation, distributed optimal power flow, optimal estimation of harmonics
22	Bat algorithm	Yang [24]	2010	Imitates the echolocation behavior of bats.	2605	1628	1177	Feature selection, economic dispatch, image matching, path planning, economic load, and emission dispatch
23	Big bang-big crunch	Erol and Eksin [25]	2006	Inspired by the big-bang theory	793	316	226	Design of space trusses, design of skeletal structures, fuzzy PID controller, data clustering, parameter estimation
24	Biogeography based optimization	Simon [26]	2008	Imitates the biological organisms' geographical distribution.	2229	1068	917	Economic load dispatch problems, power flow problem, optimal power flow, flexible job shop scheduling problem
25	Bird mating optimizer	Askarzadeh [27]	2014	Imitates the mating behavior of birds.	73	25	22	Structural damage detection, parameter estimation
26	Bird Swarm	Meng et al. [28]	2016	Mimics the birds swarm flight and foraging behaviors.	95	75	31	Parameter estimation for chaotic systems, optimal power flow problems, parameters optimization, neural network

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
27	Black holes algorithm	Hatamlou [29]	2013	Imitates the black hole's features.	424	74	-	Optimal power flow, supply chain, set covering problem, optimal design of electromagnetic devices, software architecture recovery, optimal reactive power dispatch problem
28	Blind, naked mole-rats algorithm	Taherdangkoo et al. [30]	2013	Mimics blind, naked mole-rats behaviors such as foraging and protecting the colony.	18	1	-	Robust clustering
29	Brainstorm optimization	Shi [31]	2015	Mimics the brainstorming idea for solving problems.	256	196	139	Control parameter, wind speed forecasting, WSNs deployment, economic dispatch, clustering, optimal reactive power dispatch problem, TSP, classification, portfolio optimization
30	Bull optimization algorithm	Findik [32]	2015	The algorithm modifies the selection process of the GA.	_	1	1	_
31	Bumble bees mating optimization	Comellas and Martinez [33]	2009	The algorithm modifies the selection process of the GA.	16	9	8	Vehicle routing problem, feature selection, flow shop scheduling problem
32	Camel algorithm	Ibrahim and Ali [34]	2016	Imitating ground conditions, temperature, and water supply in a camel journey in the desert.	_	_	_	_
33	Cat swarm optimization	Chu et al. [35]	2006	Imitating the behavior of cats and has two sub-models, namely tracing and seeking mode.	342	293	188	Clustering, workflow scheduling, feature selection, artificial neural networks, power distribution network
34	Central force optimization	Formato [36]	2007	Imitates the movement of bodies under gravitational force	254	83	62	Training neural networks, antenna design, 3D UAV path planning, water distribution networks, clustering

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
35	Charged system search	Kaveh and Talatahari [37]	2010	Inspired by electromagnetic and gravitational forces	704	146	144	Optimal design of skeletal structures, economic power dispatch problem, data clustering, multilayer perceptron neural networks training, facility layout problems, structural reliability analysis, water distribution networks optimization
36	Chicken swarm	Meng et al. [38]	2014	Imitates the hierarchical of chicken swarms.	178	109	72	Feature selection, optimal trajectory planning, WSN, distributed wireless sensor node localization, parameter estimation, distribution network reconfiguration, solving flexible job-shop scheduling
37	Clonal selection algorithm	De Castro and Von Zuben [39]	2000	Inspired by the responses of the immune system to antibodies	1292	1041	668	Hydrothermal scheduling, windpower forecast, parameter estimation, image classification, dynamic facility layout problems, traveling salesman problem, power filter optimization, classification, virus detection, maintenance schedule
38	Cockroach swarm optimization	Obagbuwa and Adewumi [40]	2014	Mimics by the behavior of cockroaches like interaction and searching food and dispersion in danger.	30	15	11	TSP, vehicle routing problems, travel planning, product disassembly sequence planning, motion planning of mobile robot, traveling salesman problem
39	Colliding bodies optimization	Kaveh and Mahdavi [41]	2014	Mimics the collision of bodies to search for better situations in the space	272	109	116	Design of truss structures, optimal power flow, design of arch dams, damage detection of bridge structures, design and optimization of water distribution systems, design of truss structures

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
40	Community of scientist optimization	Milani and Santucci [42]	2012	Inspired by the community of scientist's behavior to gain research funds and share results for their research activities.	18	1	1	_
41	Consultant-guided Search	Iordache [43]	2009	Inspired from information exchange between individuals and the real-world based on advice by a consultant.	34	11	7	Quadratic assignment problem, traveling salesman problem, job shop scheduling problem
42	Coral reefs optimization algorithm	Salcedo-Sanz [44]	2014	Imitates life and reproduce of coral reef colonies.	77	42	29	Offshore wind farm design, optimal mobile network deployment, clustering problems, cluster ensembles optimization
43	Covariance matrix adaptation-evolution strategy	Hansen et al. [4]	2003	This algorithm accelerates the convergence by reducing the number of generations and using a larger population size.	47	524	377	Electromagnetics design problems, path integral policy improvement, PID controller, real parameter optimization
44	Crystal energy optimization algorithm	Feng et al. [46]	2016	Inspire by the self-organizational feature of the lake freezing.	1	1	1	_
45	Cuckoo search algorithm	Yang and Deb [47]	2009	Mimics the behavior of cuckoo in brood parasitic and levy flight.	3743	1548	1100	Traveling salesman problem, neural network training, structural design optimization, economic dispatch, image segmentation, flow shop scheduling, truss design optimization, feature selection, clustering of web search results, optimal path planning, face recognition, etc.

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
46	Cultural algorithms	Reynolds [48]	1994	It is a kind of evolutionary computation that has a knowledge component in addition to the population component.	987	690	212	Set covering problem, automatic fault isolation, designing electronic circuits, image segmentation, array antenna pattern synthesis, intelligent logistics
47	Cuttlefish algorithm	Eesa [49]	2013	Mimics from cuttlefish in changing color behavior.	35	17	9	Diagnosis of Parkinson's disease, feature extraction, traveling salesman problem, feature selection
48	Dialectic search	Kadioglu and Sellmann [50]	2009	The mental concept of dialectic inspires it.	34	2	1	_
49	DE	Storn and Price [51]	1997	It is inspired by the information exchange feature of chromosomes to generate better offsprings.	19916	16399	14997	Scheduling flow shops, automatic clustering, neural networks training, environmental/economic power dispatch problem, reactive power dispatch, design of digital FIR filters, implementation of PID controller tuning, water distribution system optimization
50	Differential search algorithm	Civicioglu [52]	2012	The brownian-like random walk movement inspires it.	275	100	76	Optimal power flow problem, structure design, knapsack problem, optimal reactive-power dispatch, reliability optimization problem
51	Dolphin echolocation	Kaveh and Farhoudi [53]	2013	It is inspired by dolphin echolocation behavior.	195	113	92	Optimum design of steel frame structures, solving manufacturing cell design problems, optimum design of trusses, layout optimization
52	Dolphin partner optimization	Shiqin et al. [54]	2009	The communication characteristics of dolphins inspire it.	39	5	3	_

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
53	Dragonfly algorithm	Mirjalili [55]	2016	Mimics from dragonflies behavior such as foraging and avoiding dangers.	399	153	99	Wireless node localization, feature selection, economic dispatch, parameter optimization, clustering, distribution networks
54	Eagle strategy	Yang and Deb [56]	2010	It is a hybrid search algorithm that combines the firefly algorithm and levy flight.	165	23	28	Power loss minimization, optimum design of frame structures, parameters identification
55	Eco-inspired evolutionary algorithm	Parpinelli and Lopes [57]	2011	It inspires by the successions of ecology in environment relationships.	25	1	-	Protein structure prediction problem, hierarchical clustering strategy
56	Egyptian vulture optimization	Sur et al. [58]	2013	It is inspired by searching the food skills of Egyptian vultures.	29	8	3	Travelling Salesman Problem (TSP), road traffic management, manufacturing cell design problem, vehicle routing problem
57	Electro-magnetism optimization	Cuevas et al. [59]	2012	Electromagnetic problems inspire it.	84	5	4	PID controller, array pattern optimization, inventory control, circle detection, single machine scheduling problem, layout design
58	Elephant herding optimization	Wang et al. [60]	2015	The herding behavior of elephants inspires it.	110	55	34	Vehicle path planning, PID controller tuning, energy-based localization, power flow problem, WSN localization problem
59	Elephant search algorithm	Deb et al. [61]	2015	Imitates the elephant searching strategy in which male elephants do a global search, and female elephants do local searches.	28	15	13	Data clustering, TSP

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
60	Evolutionary programming	Fogel and Fogel [63]	2005	It is the foundation of modern evolutionary methods.	73	2752	1914	Economic load dispatch, power flow algorithm, traveling salesman problems, HVAC system optimization, distribution network reconfiguration, reactive power planning
61	Exchange market algorithm	Ghorbani and Babaei [64]	2014	Inspired by the mechanism of trade in the stock market	57	21	20	Combined Heat and Power Economic Dispatch (CHPED)
62	FIFA world Cup	Razmjooy et al. [65]	2016	The soccer world cup competitions inspire it.	29	968	772	Image segmentation, robust control of power system
63	Firefly algorithm	Yang [66]	2009	Fireflies flashing light behavior inspired it.	2521	2882	2110	Optimization of a multi-zone HVAC system, vehicle routing problems, image segmentation, scalable parallel clustering, optimum design of structures, set covering problems
64	Fireworks algorithm	Tan and Zhu [67]	2010	Inspired by the explosion of firecrackers	522	302	224	Power loss minimization, multilevel image thresholding problem, image registration, portfolio optimization problem, resource scheduling problem, RFID network planning problem, WSN coverage problem, big data optimization, parameter estimation of chaotic systems

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
65	Fish-school search	Li [68]	2008	Mutual collaboration in the group of fishes to surviving from dangers inspired It.	118	56	43	Data clustering, reactive power optimization, parameter tuning method of robust PID controller, optimal multiuser detection, image segmentation, UCAV path planning
66	Flower pollination algorithm	Yang [69]	2012	The pollination process of flowers inspires it.	899	569	439	Parameter estimation, economic load dispatch, sizing optimization of truss structures, feature selection
67	Flying elephants algorithm	Xavier and Xavier [70]	2016	This algorithm is a generalization of the hyperbolic smoothing approach.	5	_	_	_
68	Forest optimization algorithm	Ghaemi and Feizi Derakhshi [71]	2014	The seeding process of trees inspires it.	49	18	10	Feature selection, image segmentation
69	Fruit fly optimization algorithm	Pan [72]	2012	The fruit flies foraging behavior inspire it.	839	491	314	Power load forecasting model, knapsack problem, PID controller designing, traveling salesperson problem, flow-shop scheduling problem, task scheduling, and resource allocation
70	Galaxy-based search algorithm	Shah Hosseini [73]	2011	The spiral galaxies inspire it.	104	17	9	Image segmentation, economic and emission dispatch
71	Gases brownian motion optimization	Abdechiri et al. [73]	2013	Mimics from the gas molecules dynamic motion.	39	10	8	_
72	Gene expression programming	Ferreira [74]	2002	It is a comprehensive phenotype-genotype system.	442	1379	1005	Date assignment in a simulated job shop, extracting fuzzy classification rules
73	General relativity search algorithm	Beiranvand and Rokrok [74]	2015	The general relativity theory inspires it.	6	3	3	_

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
74	GA	Goldberg [75]	1989	The darwinian evolution theory inspires it.	2095	182985	111782	Job shop scheduling, traveling salesman problem, feature selection, design of water distribution networks, placement of wind turbines, flow shop scheduling problems, optimization of system reliability, resource allocation, power system damping controllers, pattern recognition, chemical laser modeling, traveling salesman problem, control system optimization, manufacturing systems design, optimization of antenna array patterns, vehicle routing, power distribution systems, etc.
75	Glowworm swarm optimization	Krishnanand and Ghose [78]	2009	The bioluminescence characteristic of glowworms inspires it.	362	345	182	Signal source localization, clustering analysis, optimal power flow, economic dispatch problem, knapsack problem, tsp problem, vehicle routing problem, multi-dimensional knapsack problem
76	Golden ball	Osaba et al. [79]	2014	Mimics from the soccer game	41	7	6	Capacitated vehicle routing problem, flow shop scheduling problem
77	Good lattice swarm algorithm	Su et al. [80]	2007	This algorithm inspires by number theory.	11	1	1	Constrained engineering design optimization

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
78	Grasshopper optimization algorithm	Saremi et al. [81]	2017	Mimics the grasshopper's swarm behavior.	226	109	65	Feature selection, financial stress prediction, automatic voltage regulator system, power loss minimization, data clustering, design of linear antenna arrays, robot path planning
79	Gravitational search algorithm	Webster and Bernhard [82]	2003	The gravitational force inspires it.	3259	1697	1356	Filter modeling, optimal power flow, economic and emission dispatch, optimal capacitor placement, unit commitment problem, reactive power dispatch, parameter adaptation, data clustering and classification, feature selection
80	Great deluge algorithm (and record-to-record travel)	Dueck [83]	1993	It has only one parameter. Initially, one set of values pick, then each step slightly adjusts the values and fitness is compared with the former one. If the new fitness value is better than the new set of values is treated as past values.	916	1	-	Vehicle routing problem, rough set attribute reduction, reliability optimization
81	Great salmon run	Mozaffari [84]	2012	Inspired by millions of salmon fishes return from the Pacific Ocean to the streams of North America.	37	7	9	Design of truss structures
82	Greedy politics optimization	Melvix [85]	2014	It simulates the politician's behavior to win elections.	-	1	1	Hierarchical clustering
83	Grenade explosion method	Ahrari and Atai [86]	2010	It inspires by grenades explosion.	109	20	18	Optimal power flow, dynamic cell formation problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
84	GWO	Mirjalili et al. [87]	2014	Mimics the hierarchical leadership and hunting behavior of grey wolves.	2083	714	482	Training multi-layer perceptions, economic dispatch, parameter estimation, flow shop scheduling problem, optimal power flow, vehicle path planning, image segmentation, feature selection
85	Group counseling optimization	Eita and Fahmy [88]	2010	It inspires by counseling problem-solving behavior.	12	4	4	–
86	Group search optimizer	He et al. [89]	2009	It inspires by animal searching food behavior.	566	191	148	Economic dispatch problem, truss structure design, neural network training, breast cancer diagnosis, optimal structural design, flow shop scheduling problem, power system dispatch
87	Harmony search	Geem et al. [90]	2001	The improvision process of jazz musicians inspires it.	4459	3109	2666	Water distribution networks, power economic dispatch, discrete structural optimization, optimal network reconfiguration, design of steel frames, optimal power flow problem, feature selection, time-cost trade-off, flow shop scheduling problem
88	Heart	Hatamlou [91]	2014	The heart and vascular system inspire it.	16	2	1	Knapsack problem
89	Hierarchical swarm model	Chen et al. [92]	2010	The algorithm proposed a hierarchical model for swarm-based metaheuristic algorithms.	26	1	1	Economic dispatch, data clustering
90	Honey-bees mating optimization algorithm	Abbass [93]	2001	Honey bee's mating behavior inspires it.	420	78	21	Euclidean traveling salesman problem, financial classification problems, vehicle routing problem, process planning problem, water distribution networks, feature selection problem, task assignment

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
91	Hoopoe heuristic optimization	El-Dosuky et al. [94]	2012	Mimicking hoopoes levy flight and searching food behavior.	4	1	1	Parameter optimization
92	Human-inspired algorithm	Zhang [95]	2009	It is simulating by mountaineers to explore the peak.	22	2	2	_
93	Hunting search	Oftadeh and Mahjoob [96]	2009	Animal hunting techniques inspire it.	153	38	25	Real-time seizure prediction, flow shop scheduling, design of PID fuzzy controller
94	Imperialist competitive algorithm	Atashpaz-Gargari and Lucas [97]	2007	Mimics the behavior of the imperialists in expanding their colonies.	1715	950	853	Design of skeletal structures, product mix-outsourcing problem, a robust PID controller, economic power dispatch, scheduling of the assembly flow shop problem, PID controller design, color segmentation, traveling salesman problems, capacitated hub covering location problem
95	Intelligent water drops algorithm	Shah-Hosseini [98]	2009	Imitates the rivers to find the best route between origin and destination.	341	115	47	Knapsack problem, job-shop scheduling, WSNs, feature selection, economic load dispatch, vehicle routing problem, cloud computing, road graph network, robot path planning problem, parallel machines scheduling, graph coloring
96	Interior design and decoration	Gandomi [99]	2014	It is an optimization algorithm inspired by buildings internal design and decoration.	161	18	11	Economic load dispatch, machine allocation, optimal power flow
97	Invasive tumor growth optimization algorithm	Tang et al. [100]	2015	An invasive Tumor growth mechanism inspires it.	7	2	2	Data clustering

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
98	Invasive weed optimization	Mehrabian and Lucas [101]	2006	This algorithm base on the growth of weed colonies.	952	574	391	Antenna configurations, unit commitment problem, traveling salesman problem, economic dispatch of power systems, flow shop scheduling problem, capacitated vehicle routing problem, parameter estimation
99	Ions motion algorithm	Javidy et al. [102]	2015	This algorithm imitates the movement of ions.	60	8	3	Short-term hydrothermal scheduling
100	Jaguar algorithm with learning behavior	Chen et al. [103]	2015	Based on the hunting behavior of jaguars.	6	1	1	_
101	Japanese tree frogs calling	Hernández and Blum [104]	2012	Mimics the Japanese tree frogs calling behavior.	33	5	7	Graph coloring
102	Kaizen programming	Melo [105]	2014	Mimics the kaizen approach in solving problems.	30	11	9	Classification, breast cancer detection
103	Keshtel algorithm	Hajiaghaei and Aminnayeri [106]	2014	Based on the food searching strategy of a bird called a keshtel.	41	4	3	Scheduling of production, rail transportation problem
104	Krill herd	Gandomi and Alavi [107]	2012	Emulates the krills behavior in herding and searching food.	887	297	308	Economic load dispatch, design of truss structures, optimal power flow, clustering, network route optimization, feature selection, hydrothermal scheduling problem, tuning of a PID controller, reactive power dispatch, flexible job-shop scheduling problem, breast cancer detection, the portfolio selection problem

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
105	League championship algorithm	Husseinzadeh Kashan [108]	2009	The sports league championship inspires this algorithm.	99	46	34	Optimal power flow, tasks scheduling technique, cloud computing, Resource Allocation Mechanism, cloud scheduling, production scheduling, job scheduling, flow-shop scheduling problem, clustering, manufacturing cell formation
106	Lightning search algorithm	Shareef et al. [109]	2015	Based on the natural lightning phenomenon.	101	50	43	Power systems, the learning process of feed forward neural networks, a fuzzy logic speed controller, Parameter extraction
107	Lion optimization algorithm	Yazdani and Jolai [110]	2016	Lions' cooperative and social behavior inspires this algorithm.	123	75	43	Community detection, task scheduling in cloud computing, WSN
108	Locust swarms	Chen [111]	2009	Imitates the locust swarms, the exploration agents begin with the least distance from the previous optimum.	42	96	57	Joint replenishment problem, intrusion detection systems
109	Magnetotactic bacteria optimization algorithm	Mo and Xu [112]	2013	That inspires by the behavior of magnotactic bacteria in the geomagnetic field.	16	12	8	Multimodal optimization
110	Migrating birds optimization	Duman et al. [113]	2011	Imitates the "V" arrangement of bird migration to minimize energy.	9	77	55	Quadratic assignment problem, fraud detection, closed-loop layout in flexible manufacturing systems, flow shop sequencing problem, machine-part cell formation problems, knapsack problem, flexible job shop scheduling problem, university course timetabling problem, low-carbon scheduling problem, multi-objective task allocation problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
111	Mine blast algorithm	Sadollah et al. [114]	2012	A mine blast inspires it.	118	35	34	Optimization of truss structures, optimal sizing of hybrid PV-wind-FC system, water distribution systems, economic load dispatch, ANFIS training
112	Monarch butterfly optimization	Wang et al. [115]	2015	Monarch butterflies' massive journey from North America to California and Mexico inspire it.	20	47	25	Solving 0–1 knapsack problem, neural network training, dynamic vehicle routing problem, localization in WSNs, TSP problem, RFID network planning, denoising brain images, patch antenna design, optimal power flow, facility layout design, optimal design of PID controller, classification, breast cancer diagnosis, resolve resource contention for multi-tier cloud service
113	Monkey Search	Mucherino and Seref [116]	2007	It inspires by the behavior of monkies in climbing trees for searching for the food.	180	29	17	Clustering analysis, traveling salesman problem, optimal sensor placement in structural health monitoring, WSNs, 0-1 knapsack problem, flow shop scheduling problem, transmission network expansion planning, allocation of capacitor banks in distribution systems, hybrid power systems optimization, multidimensional assignment problem
114	Moth-flame optimization algorithm	Mirjalili [117]	2015	Mimics by the behavior of moths in flying and traveling	531	87	58	Determine optimal machining parameters, parameters extraction for the multi-crystalline solar cell/module, power load forecasting, feature selection, tomato diseases detection, optical network unit placement, power system operation, web service composition in cloud computing
115	Multi-verse optimizer	Mirjalili et al. [118]	2015	It inspires by cosmology theories, namely blackhole, warm hole, and white hole	309	74	39	Intrusion detection systems, fuzzy-PID controller, image segmentation, power distribution networks

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
116	Optics inspired optimization	Kashan [119]	2015	The optical phenomenon inspires it.	59	10	8	Design of steel tower structures, optimal PID parameters tuning
117	Paddy field algorithm	Premaratne [120]	2009	It inspires by dispersing the seed.	48	8	6	RBF neural network parameters optimization
118	Parliamentary optimization algorithm	Borji [121]	2007	Group competitions in a parliament inspire it.	11	5	5	Community detection in social networks, web pages classification, automatic mining of numerical classification rules
119	PSO	Eberhart and Kennedy [122]	1995	The intelligent movements of bird swarms inspire it.	54331	61214	42557	Recurrent network design, flow shop sequencing problem, optimal power flow, environmental/economic power dispatch, capacitated vehicle routing problem, training feed forward neural networks, task assignment in distributed systems, loT-sizing problem, thermodynamic optimization, image clustering, structural design optimization
120	Pattern search	Hooke and Jeeves [123]	1961	An optimization technique proposed by Hooke and Jeeves and has two steps, namely pattern movement and exploratory search.	4847	2463	1721	Motor design optimization, mixed variable optimization, optimize the control system, Induction motor electromagnetic design optimization, economic dispatch problem, optimize the control sy stem
121	Penguins search optimization algorithm	Gheraibia and Moussaoui [124]	2013	The hunting behavior of penguins inspires it.	36	19	3	Traveling salesman problem, optimal operation of reservoir systems, vehicle routing problem, quadratic assignment problem, features selection

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
122	Photosynthetic learning algorithm	Murase and Wadano [125]	1998	Mimics the Benson Calvin cycle in photosynthesis process in plants.	1	-	2	Training of neural network, finite element inverse analysis, machine learning, TSP
123	Plant growth optimization	Cai et al. [126]	2008	The growth process of plants inspires it.	27	11	5	_
124	Plant propagation algorithm	Salhi and Fraga [127]	2011	Mimics plants runners' behavior to search for light and nutrients.	50	14	8	Constrained engineering optimization problems, traveling salesman problem, image segmentation, economic load dispatch problem
125	Partial optimization metaheuristic under special intensification conditions	Taillard and Voss [128]	2001	An optimization algorithm that partitioned a problem into subsections and locally optimized them.	109	7	5	Berth allocation problem, traveling salesman problem, large-scale vehicle routing problem, world location-routing problem
126	Queen-bee evolution	Jung [129]	2003	It imitates by the queen bees' role in a bee colony.	139	9	7	Economic power dispatch, tuning of scaling factors of fuzzy knowledge base controller, boost converter controller design, WSNs, task scheduling in grid computing, voltage regulation enhancement
127	Raven roosting optimization algorithm	Brabazon et al. [131]	2014	The social roosting habits of raven inspired it.	10	4	2	Task scheduling in cloud computing
128	Ray optimization	Kaveh and Khayatazad [130]	2012	The refraction of light rays inspires it.	254	33	28	Design of truss structures, optimal design of cantilever retaining walls
129	Reincarnation	Sharma [132]	2010	It mimics the rebirth of a human soul in a different body.	4	-	1	_

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
130	River formation dynamics	Rabanal et al. [133]	2007	The algorithm Inspires by the formation of rivers by water drops.	110	42	32	Dynamic TSP, mobile robot navigation, generating optimal paths in dynamic environments, sequence-dependent disassembly line balancing problem, steiner tree problem, WSNs, generating optimal paths in dynamic environments, CMOS analog circuit optimization, optimal placement of PMUs, analyze VLSI power grid networks, optimal data aggregation tree in WSNs, routing protocol for wireless mesh network
131	Roach infestation optimization	Timothy et al. [134]	2008	It is based on the individual and collective behavior of cockroaches to search for food.	82	10	5	Clustering, dynamic step-size adaptation
132	Root growth optimizer	He et al. [135]	2015	Mimics the self-similar distribution of plant roots.	2	1	2	–
133	Rooted tree optimization algorithm	Labbi et al. [136]	2016	The growth process of plant roots inspires it.	45	4	3	Economic dispatch
134	Runner-root Algorithm	Merrikh-Bayat [137]	2015	It simulates the purpose of runners and the roots of plants.	38	16	6	Multi-objective electric distribution network reconfiguration, feature selection
135	Saplings growing up algorithm	Karci and Alatas [138]	2006	Based on the growing up process of saplings	21	5	4	–
136	Scatter search	Glover et al. [139]	1977	This algorithm is based on systematic methods to produce new solutions.	1665	832	799	Vehicle routing problem, feature selection, nurse rostering problem, capacitated clustering problem, disassembly sequence problem, flow shop scheduling problem, graph coloring
137	Scientificalgorithms for the car renter salesman problem	Felipe et al. [140]	2014	Modeled the scientific research methodology	4	1	1	Car renter salesman problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
138	Seven-spot ladybird optimization	Wang et al. [141]	2013	Mimics the behavior of foraging in the seven-spot ladybird.	7	5	5	Feature selection
139	Shark smell optimization	Wang et al. [142]	2016	It inspires the smelling behavior of the shark in the ocean.	70	16	14	Short-term wind power prediction, planning of distribution networks, optimal placement of capacitors in the radial distribution system, optimal distribution of reactive power
140	Sheep flocks heredity model	Kim and Ahn [143]	2001	Sheep flocks' reproduction behavior inspires it.	8	6	2	Scheduling problem, job shop scheduling problems, scheduling of AGVs and machines in FMS, transportation problem, cell formation problem, spur gear design
141	Shuffled frog leaping algorithm	Eusuff and Lansey [144]	2003	The collaborative behavior of frogs inspires it in search of food.	1392	909	536	Water distribution network design, clustering, Unit commitment problem, assembly line sequencing problem, resource-constrained project scheduling problem, TSP, optimal tuning of multivariable PID controllers, flow-shop problem,0/1 knapsack problem, reservoir flood control operation, vehicle routing problem, set covering problem, fault diagnosis, Color image segmentation, Power control algorithm, training strategy for neural network, power system, tasks scheduling problem, parameter estimation, fuel management optimization, maintenance scheduling
142	Simplex heuristic	Pedroso [145]	2001	This algorithm is an extension of the Nelder and Mead simplex algorithm for non-linear problems.	2	4	2	Timetabling problem

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
143	SA	Kirkpatrick et al. [146]	1983	It imitates the heating and cooling process at metallurgy.	44469	33556	23264	Job shop scheduling, automated docking of substrates to proteins, vehicle routing problem, economic dispatch algorithm, clustering, transmission system expansion planning, water distribution network design, quadratic assignment problems, economic dispatch, complex portfolio selection problems, resource-constrained project scheduling problem, VLSI design, analog circuit design optimization, maintenance scheduling, dynamic layout problem etc.
144	Small-world optimization algorithm	Du et al. [147]	2006	It inspires the scientific experiments of the psychology of human communication.	52	22	12	Predictive controller, robot path planning, feature selection, neural network predictive control, job scheduling, clustering, image edge detection, economic load dispatch problem, wind power prediction, multi-dimensional knapsack problem
145	Soccer game optimization	Purnomo and Wee [148]	2012	The algorithm is based on an innovative combination of swarm intelligence and evolutionary algorithms by sharing information.	13	6	3	–
146	Social cognitive optimization	Xie et al. [149]	2002	Inspired by the social learning process in humans.	77	24	13	Reactive power optimization, power economic dispatch
147	Social-emotional optimization	Xu et al. [150]	2010	It inspires human beings' effort to achieve higher social status.	30	32	15	Chaotic systems, machine training and parameter settings for support vector machine, optimal coverage problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
148	Social spider algorithm	Cuevas et al. [151]	2013	It inspires the collaborative behavior of spiders in a colony.	248	42	33	Economic load dispatch problem, designing evolutionary feed forward neural networks, clustering, electromagnetic optimization, transmission expansion planning problem, base station switching problem for green cellular networks, task scheduling in cloud computing, flexible job-shop scheduling
149	Society and Civilization	Ray and Liew [152]	2003	It inspires social behavior in all human and insect societies.	358	48	23	_
150	Sperm motility algorithm	Raouf and Hezam [153]	2017	Inspired by the human reproduction system.	1	1	1	_
151	Sperm whale algorithm	Ebrahimi and Khamehchi [154]	2016	The sperm whale's lifestyle inspires it.	28	4	3	Power load forecasting
152	Spider monkey optimization	Bansal et al. [155]	2014	Mimics the social behavior of spider monkey to search for food.	172	79	51	Antenna optimization, optimal placement, and sizing of the capacitor, WSN, optimal design of pida controller, economic dispatch problem
153	Spiral dynamics inspired optimization	Tamura and Yasuda [156]	2011	The algorithm modeled the spiral patterns observed in nature.	65	5	3	Controller design, mixed-integer nonlinear programming problems, combined economic and emission dispatch, design of digital filters, modeling of flexible systems
154	Stochastic diffusion search	Bishop [157]	1989	Inspired by "the restaurant game," in which delegates in a new city search for the best restaurant to dine.	185	82	47	Resource allocation, euclidean steiner minimum tree

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
155	Stochastic fractal search	Salimi [158]	2015	Mimics the natural phenomenon of growth named fractal.	165	67	59	Design of PID controller, system reliability optimization, surface grinding process, meshed power networks, optimization of neural network parameters, environmentaleconomic dispatch,3D protein structure prediction
156	Strawberry algorithm	Merrikh-Bayat [159]	2014	The strawberry plant runner and the roots inspire it.	23	11	12	Multi-objective knapsack problem, demand side management in smart grid, energy management
157	Swallow swarm optimization algorithm	Neshat et al. [160]	2013	Imitates the Swallow swarms movement behavior.	38	8	6	Traveling salesman problem
158	Symbiotic organisms search	Cheng and Prayogo [161]	2014	It inspires the relationship of the species that depend on each other for survival.	442	221	145	Structural design optimization, optimal power flow of power system, congestion management, scheduling of tasks on cloud computing environment, economic dispatch problem, capacitated vehicle routing problem, traveling salesman problem, training feed forward neural networks, power loss minimization, truss optimization problem,0-1 knapsack problem
159	Tabu search	Glover [162]	1986	Enhancement of local search by essential rules modifications	4823	9809	9240	Vehicle routing problem, graph coloring, job-shop scheduling problem, timetabling and rostering, quadratic assignment problem, network synthesis, clustering, optimal power flow, location routing problem, berth-allocation problem, feature selection, balancing assembly lines, RAP, knapsack problem, traveling salesman problem, container loading problem, project scheduling problem, transportation problem, capacitated network design, machine sequencing problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
160	Teaching-learning based optimization	Rao et al. [163]	2011	The teaching-learning process inspires it.	1604	1133	812	Design of planar steel frames, sizing truss structures, data clustering, dynamic economic emission dispatch, optimal power flow, fuzzy-PID controller, flexible job-shop scheduling problem, parameters identification of solar cell models, quadratic assignment problem, simultaneous allocation of distributed resources
161	Termite colony optimization	Hedayatzadeh et al. [164]	2010	It is inspired by termites' intelligent behaviors to adjust their search paths.	44	10	8	WSN, retail market recommendations, optimizing retail inventory market, satellite image contrast enhancement
162	Viral systems	Cortés et al. [165]	2008	Viruses' characteristics, such as infection and replication, Inspire it.	39	1	_	Optimization of wind turbine placement, traveling salesman problem, optimize the car dispatching in elevator group control systems of tall buildings, optimize the daily drayage problem
163	Virus colony search	Li et al. [166]	2016	It is inspired by spreading and growth strategies used with viruses.	70	10	9	Optimal placement of distributed generators, unit commitment in smart grids with wind farms
164	Virus optimization algorithm	Juarez et al. [167]	2009	Virus growth, replication, and infection strategies modeled in this algorithm.	18	9	7	Flexible job-shop scheduling problem, multilevel image thresholding
165	Vortex search algorithm	Doğan and Tamer [168]	2015	Imitates the vertical flow shape of fluids.	108	26	19	Filter component selection problem, energy optimization, protein folding problem, economic load dispatch, analog filter group delay optimization
166	Wasp swarm optimization	Pinto et al. [169]	2005	The foraging behavior and wasps inspire it.	19	6	6	Clustering, feature selection, logistic systems
167	Water cycle algorithm	Eskandar et al. [170]	2012	This algorithm modeled the hydrological cycle of water.	415	138	118	Optimal operation of reservoir systems, optimal reactive power dispatch, optimization of truss structures, design of water distribution systems

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
168	Water evaporation optimization	Kaveh and Bakhshpoori [171]	2016	Water molecules' evaporation property inspires it.	63	8	7	Optimization of skeletal structures, economic dispatch, optimal power flow problems
169	Water wave optimization	Zheng [172]	2015	The water wave theory inspires it.	174	33	-	Flow shop scheduling problem, traveling salesman problem, economic dispatch problems
170	Water-flow algorithm	Tran and Ng [173]	2011	It bases on ablation due to the hydrological cycle.	19	15	15	Manufacturing cell formation problems, object grouping problems, text line segmentation, flexible flow shop scheduling, segmentation, and text parameters extraction
171	Whale optimization algorithm	Mirjalili and Lewis [174]	2016	This algorithm imitates the hunting habits of whales.	949	209	272	Feature selection, image segmentation, optimizing connection weights in neural networks, parameter estimation of photovoltaic cells, distribution network, optimization of skeletal structures, wind speed forecasting, flow shop scheduling problem, economic dispatch problem, mobile robot path planning
172	Wind-driven optimization	Bayraktar et al. [175]	2010	Mimics by wind generation by moving air from high-pressure regions.	78	48	82	Image segmentation, robust control of power system,0-1 knapsack problem, a cloud resource allocation, estimation of solar photovoltaic parameters, vehicle path planning, transformer design, robust optimizations of electromagnetic devices under interval uncertainty
173	Wolf search algorithm	Tang et al. [176]	2012	Mimics the hunting behavior of wolves.	123	9	16	Numeric association rule mining, feature selection, classification
174	Worm optimization	Arnaout et al. [177]	2014	Inspired by unique properties of Caenorhabditis Elegans	2	3	3	Traveling salesman problem, layout problem, energy management system
175	Zombie survival optimization	Nguyen and Bhanu [178]	2012	Mimics the questionable behavior of zombies.	1	1	1	_

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
176	Keshtel algorithm	Hajiaghaei-Keshteli and Aminnayeri [182]	2014	Inspired by Keshtel's feeding	72	48	43	Solving the integrated scheduling of production and rail transportation problem
177	Keshtel algorithm	Hajiaghaei-Keshteli [183]	2013	Inspired by Keshtel's feeding	42	14	14	Vehicle routing problem
178	Red Deer Algorithm (RDA)	Fathollahi-Fard [184]	2020	A new optimization algorithm inspired by red deer mating is developed. The scottish red deer (cervus elaphus scoticus) is a sub-species of red deer, which lives in the british isles.	86	72	69	12 standard functions were considered. A number of realworld engineering problems including SMSP, TSP, FCTP and VRP were used. Furthermore, the multi-objective version of the RDA was considered and evaluated by a multi-objective NRP via four assessment metrics to analyze pareto optimal sets.
179	Tree Growth Algorithm (TGA)	Cheraghalipour Hajiaghaei-Keshteli [185]	2018	The proposed algorithm is inspired by trees competition for acquiring light and foods.	68	68	76	Single machine scheduling problems with earliness and tardiness costs without allowing standstill as NP-hard problem has been studied.
180	The Social Engineering Optimizer (SEO)	Fathollahi-Fard et al. [186]	2018	Social engineering optimization is defined as indirect attacks to obtain the people revealing their information by using certain techniques. Attackers want to reach their desired goals or objectives usually by advance technologies.	114	110	110	A single machine scheduling problem is considered. Single-machine scheduling or single-resource scheduling is the process of assigning a group of tasks to a single machine or resource.
181	Find-Fix-Finish-Exploit-Analyze (F3EA) meta-heuristic algorithm	Husseinzadeh Kashan and Tavakkoli-Moghaddam [187]	2019	The F3EA algorithm is classified into the population based algorithm which simulates battleground and mimics the F3EA targeting process of object or installations selection for destruction in the warfare.	18	14	19	-

Table 2 illustrates a list of the applications of metaheuristic algorithms to solve various problems. Metaheuristic algorithms have essential applications in solving complex problems in different domains, such as industrial engineering, mechanical & chemical engineering, control & electrical & power & telecommunication engineering, civil engineering, data & computer science, image processing, neural networks & fuzzy systems, mathematics, medical.

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Table 3. Classification of applications of metaheuristic algorithms for solving problems.

Industrial Engineering	Mechanical and Chemical Engineering	Control and Electrical and Power and Telecommunication Engineering		Civil Engineering	Data and Computer Science	Image Processing	Neural Networks and Fuzzy Systems	Mathematics	Medical	Other
Flow shop scheduling problems	Inventory control	Thermodynamic optimization	Design of PID controller	Design of steel structures	Clustering analysis	Image edge detection	Multi-layer perceptrons trainer	Traveling Salesman's Problem	Breast cancer diagnosis	Parameter selection strategy
Vehicle routing problem	Assembly sequence planning	HVAC system optimization	Power load forecasting	Design of skeletal structures	Association rules mining	Denoising brain images	ANFIS training	Knapsack problem	Protein folding problem	Portfolio optimization problem
Resource-constrained project scheduling	RAP	Energy consumption forecasting	AGC	Berth allocation problem	Feature selection	Image segmentation	Fuzzy system design	Graph coloring	Virus detection	University course timetabling problem
JIT sequencing problem	Manufacturing cell design problems	Wind turbine placement problem	Economic load dispatch problem	Container loading problem	JIT sequencing problem		Fraud detection	Quadratic approximation	NSP	
Flexible process planning	Reliability optimization	Chemical laser modeling	Optimal power flow	Structural damage detection	Task scheduling in grid computing		Extracting fuzzy classification rules	Coverage problem	Diagnosis of parkinson's disease	
Job scheduling problem	Intelligent logistics	Spur gear design	Economic emission load dispatch	Rail transportation problem	Software architecture recovery		rough set attribute reduction	Circle detection		
The flexible job-shop scheduling problem	Maintenance scheduling	Power transformer winding	VLSI design	Structural damage detection	Cloud computing					
RFID network planning	Robot path planning	Water distribution networks	Optimal reactive power dispatch problem	Damage detection of bridge structures						
Facility layout problem	Quadratic assignment problem	Distribution network configuration	Antenna design	Structural reliability analysis						
	Fault prediction		Power filter optimization	Road traffic management						
				Road graph network						

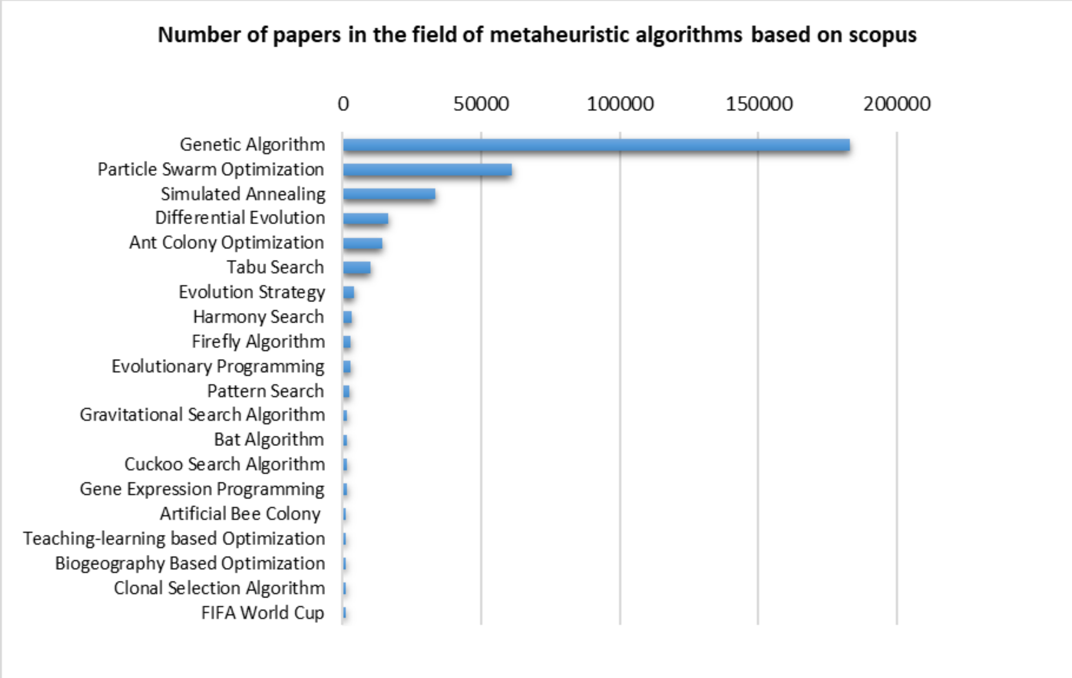

Fig. 4. Display the most number of papers in the subject of metaheuristic algorithms based on the scopus scientific database.

According to this database, GA algorithm with 182985 articles and 51.1% share in first place, PSO algorithm with 61214 papers and 17.1% in second place, and SA algorithm with 33556 in the third and the 9.4% of the articles, respectively, accounted for 77.5% of the total number of items in the field of metaheuristic algorithms.

Table 5. Number of papers in the subject of metaheuristic algorithms based on the scopus scientific database.

Rank	Algorithm	Number of Papers in Scopus	Percent of the Total
1	GA	182985	51.1
2	PSO	61214	17.1
3	SA	33556	9.4
4	DE	16399	4.6
5	ACO	14397	4.0
6	Tabu search	9809	2.7
7	Evolution strategy	4167	1.2
8	Harmony search	3109	0.9
9	Firefly algorithm	2882	0.8
10	Evolutionary programming	2752	0.8
11	Pattern search	2463	0.7
12	Gravitational search algorithm	1697	0.5
13	Bat algorithm	1628	0.5
14	Cuckoo search algorithm	1548	0.4
15	Gene expression programming	1379	0.4
16	ABC	1200	0.3
17	Teaching-learning based optimization	1133	0.3
18	Biogeography based optimization	1068	0.3
19	Clonal selection algorithm	1041	0.3
20	FIFA world cup	968	0.3

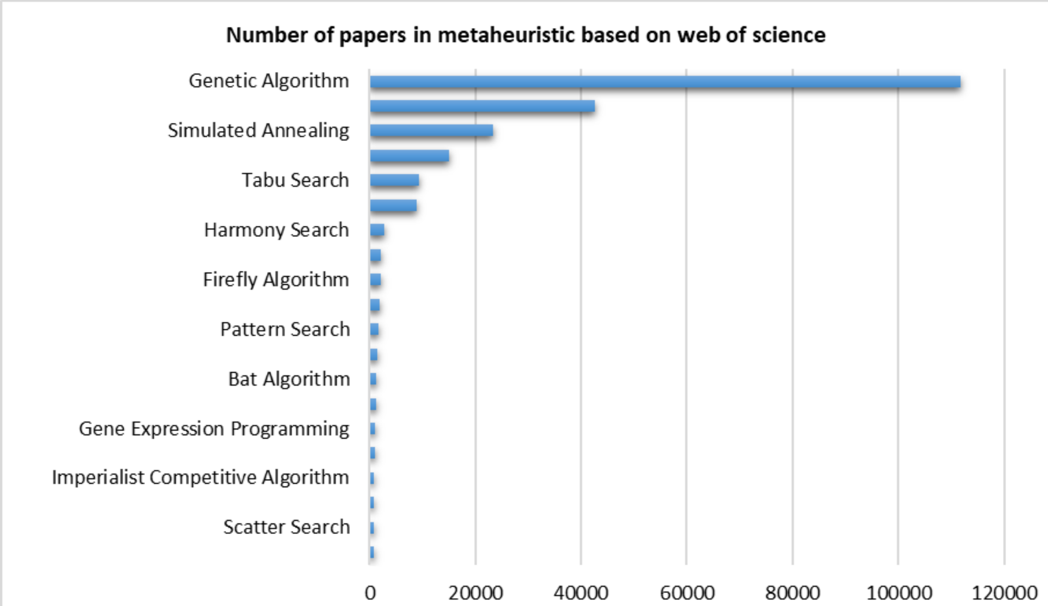

Fig. 5. Rank of metaheuristic algorithms based on number of papers (web of science).

Tabel 6 and *Fig. 6* represent the number of citations of metaheuristic algorithms based on google scholar. As shown, the PSO, SA, and DE algorithms are ranked first, second, and third, respectively, with 54331, 44469, and 19916 citations. These three algorithms together account for almost 60% of the total citations in the field of metaheuristic.

Table 6. Number of citations of metaheuristic algorithms based on google scalar.

Rank	Algorithm	Number of Citation in "Google Scholar"	Percent of the Total
1	PSO	54331	27.4
2	SA	44469	22.5
3	DE	19916	10.1
4	ACO	11276	5.7
5	Pattern search	4847	2.4
6	Tabu search	4823	2.4
7	Harmony search	4459	2.3
8	Cuckoo search algorithm	3743	1.9
9	Gravitational search algorithm	3259	1.6
10	Bacterial foraging algorithm	2813	1.4
11	Bat algorithm	2605	1.3
12	Firefly algorithm	2521	1.3
13	Biogeography based optimization	2229	1.1
14	GA	2095	1.1
15	GWO	2083	1.1
16	Imperialist competitive algorithm	1715	0.9
17	Scatter search	1665	0.8
18	Teaching-learning based optimization	1604	0.8
19	Shuffled frog leaping algorithm	1392	0.7
20	Clonal selection algorithm	1292	0.7

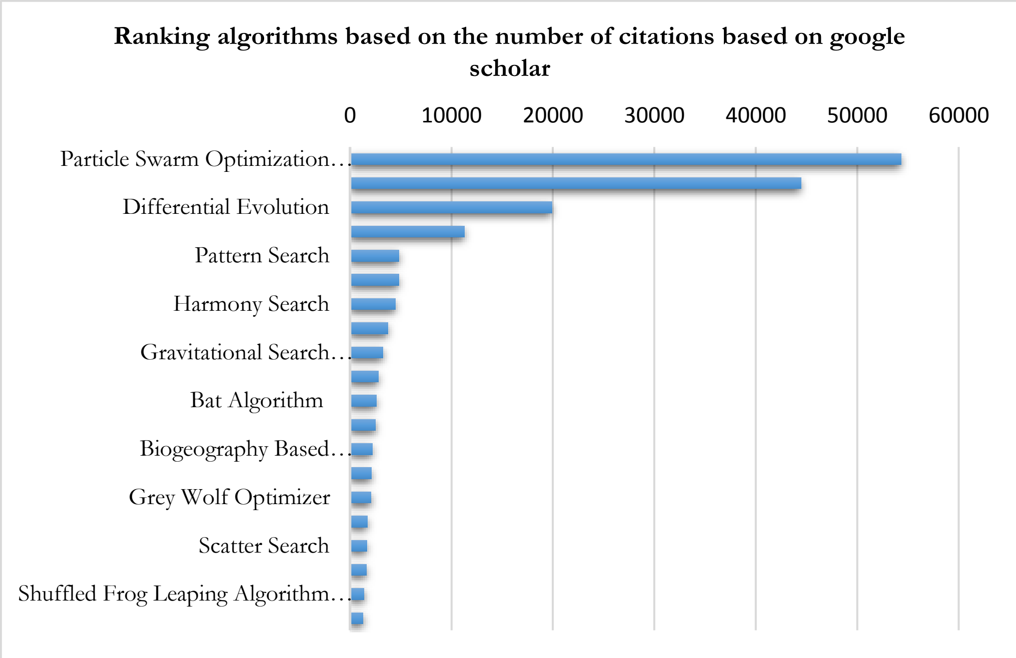

Fig. 6. Rank of metaheuristic algorithms citations (google scholar).

3 | A Review of the Classification of Nature-Inspired Metaheuristic Algorithms

Birattari et al. [179] divided the metaheuristic algorithms into four groups continuous and discrete, population-based and single-solution, memory and non-memory, one-neighbor, and several neighborhoods, a static and dynamic objective function, inspired by nature and without inspiration from nature.

Mirjalili and Lewis [174] categorized the metaheuristic algorithms in four categories of evolutionary algorithms, swarm-based algorithms, physics-based algorithms, human-based algorithms.

Dhiman and Kumar [180] classified metaheuristic algorithms into five groups of evolutionary algorithms, physics-based algorithms, swarm-based algorithms, biology-based algorithms, and nature-inspired algorithms.

Memari et al. [181] classified the metaheuristic algorithms into three categories of single solution algorithms, population-based algorithms, and hybrid algorithms.

Rajpurohit et al. [2] classified metaheuristic algorithms into three categories: evolutionary, logical search, and other nature-inspired algorithms.

4 | Presenting a Novel Classification for Metaheuristic Algorithms

This paper categorized metaheuristic algorithms according to the characteristics and source of inspiration for each of the algorithms described in *Table 7*.

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Table 7. Proposed classification for metaheuristic algorithms.

Level 1	Level 2	Level 3	Inspiration	Paper
Living things	Animals	Mammals	Foraging/ Hunting	African buffalo optimization (2016) African wild dog algorithm (2013) Cat swarm optimization (2006) Egyptian vulture optimization (2013) GWO (2014) Wolf search algorithm (2012) Jaguar algorithm with learning behavior (2015) Monkey search (2007) whale optimization algorithm (2016)
Living things	Animals	Mammals	Social behavior	Elephant herding optimization (2015) Elephant search algorithm (2015) Sperm whale algorithm (2016) Lion optimization algorithm (2016)
Living things	Animals	Mammals	Change in group size	Spider monkey optimization (2014)
Living things	Animals	Mammals	Biosonar/ Echolocation	Bat algorithm (2010) Dolphin echolocation (2013)
Living things	Animals	Mammals	Reproduction	Sheep flocks heredity model (2001)
Living things	Animals	Mammals	Protect the territory	Blind, naked mole-rats algorithm (2013)
Living things	Animals	Mammals	Travel/Immigration	Animal migration optimization (2014) Camel algorithm (2016) Penguins search optimization (2013)
Living things	Animals	Birds	Foraging	Hoopoe heuristic optimization (2012) Keshtel algorithm (2014) Cuckoo search algorithm (2009)
Living things	Animals	Birds	Fly	Hoopoe heuristic optimization (2012) Swallow swarm optimization algorithm (2013)
Living things	Animals	Birds	Nesting	Raven roosting algorithm (2014)
Living things	Animals	Birds	Mating	Bird mating optimizer (2014)
Living things	Animals	Fishes	Smell	Shark smell optimization (2018)
Living things	Animals	Fishes	Migration	Great salmon run (2012)
Living things	Animals	Fishes	Escape from danger	Artificial fish school algorithm (2002) Fish-school search (2008)
Living things	Animals	Insects	Foraging	ABC algorithm (2007) Dragonfly algorithm (2016) Fruit fly optimization algorithm (2012) Seven-spot ladybird optimization (2013) Wasp swarm optimization (2005) Ant lion (2015)
Living things	Animals	Insects	Routing	Termite colony optimization (2010)
Living things	Animals	Insects	Mating	Honey-bees mating optimization algorithm (2001)
Living things	Animals	Insects	Migration	Locust swarms (2009) Monarch butterfly optimization (2015)
Living things	Animals	Insects	Escape from the danger	Roach infestation optimization (2008)
Living things	Animals	Crustaceans	Foraging	Krill herd (2012)

Table 7. Continued.

Level 1	Level 2	Level 3	Inspiration	Paper
Living things	Animals	Crustaceans	Social relations	Social spider algorithm (2013)
Living things	Animals	Worms	Nervous system	Worm optimization (2014)
Living things	Animals	Worms	light	Firefly algorithm (2009) GSO (2009)
Living things	Animals	Coelenterata	Reproduction	Coral reefs optimization algorithm (2014)
Living things	Animals	Mollusca	Color change	Cuttlefish algorithm (2013)
Living things	plants		Growth and reproduction	Invasive weed optimization (2006)
Living things	plants		Rooting	Flower pollination algorithm (2012) Paddy field algorithm (2009) Root growth optimizer (2015) Rooted tree optimization algorithm (2016) Runner-root algorithm (2015) Strawberry algorithm (2014)
Living things	plants		Photosynthesis	Artificial plant optimization algorithm (2012) Photosynthetic learning algorithm (1998)
Living things	Protist	Algae		Artificial algae algorithm (2015)
Living things	Bacteria		Reproduction	Bacterial colony optimization (2012) Bacterial swarming (2008)
Living things	Bacteria		Evolution	Bacterial evolutionary algorithm (2009)
Living things	Bacteria		Foraging	Bacterial foraging algorithm (2002)
Living things	Bacteria		Magnet	Magnetotactic bacteria optimization (2013)
Living things	Bacteria		Survive	Bacteria chemotaxis algorithm (2002)
Human interactions			Social behavior	Society and civilization (2003) Social emotional optimization (2010) Social cognitive optimization (2002) Anarchic society optimization (2012) Group counseling optimization (2010) Community of scientist optimization (2012) Consultant-guided search (2009) Small-world optimization algorithm (2006)
Human interactions			Education	Teaching-learning based optimization (2011) Brainstorm optimization (2015)

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Table 7. Continued.

Level 1	Level 2	Level 3	Inspiration	Paper
Human interactions			Politics	Greedy politics optimization (2014) Parliamentary optimization algorithm (2007) Imperialist competitive algorithm (2007)
Human interactions		Sport	Soccer	Fifa world cup (2016) Golden ball (2014) Soccer game optimization (2012)
Human interactions		Sport	Championship	League championship algorithm (2009)
Human interactions		Sport	Mountaineering	Human-inspired algorithm (2009)
Human interactions		Culture		Cultural algorithms (1994)
Natural phenomena	Atmospheric phenomena		Vortex	Vortex search algorithm (2015)
Natural phenomena	Atmospheric phenomena		Lightning	Lightning search algorithm (2015)
Natural phenomena	Atmospheric phenomena		Clouds	Atmosphere clouds model (2013)
Natural phenomena	Water flow		Flood	Great deluge algorithm (1993)
Natural phenomena	Water flow		Water drops	Intelligent water drops algorithm (2009)
Natural phenomena	Water flow		River	River formation dynamics (2007)
Natural phenomena	Water flow		Rotation	Water-flow algorithm (2011) Water cycle algorithm (2012)
Natural phenomena	Water flow		Evaporation	Water evaporation optimization (2016)
Natural phenomena	Water flow		Waves	Water wave optimization (2015)
Science	Natural sciences	Medical	Reproduction system	Sperm motility algorithm (2017)
Science	Natural sciences	Medical	Heart and circulatory system	Heart (2014)
Science	Natural sciences	Medical	Immune system	Clonal selection algorithm (2000) Invasive tumor growth optimization algorithm (2015)
Science	Natural sciences	Medical	Viruses	Viral systems (2008) Virus colony search (2016) Virus optimization algorithm (2016)
Science	Natural sciences	Medical	Inheritance	GA (1989)
Science	Natural sciences	Physics	Classical mechanics/ Gravitational force	Central force optimization (2007) Gravitational search algorithm (2003)

Table 7. Continued.

Level 1	Level 2	Level 3	Inspiration	Paper
Science	Natural sciences	Physics	Classical mechanics/ Energy	Wind driven optimization (2010) Gases brownian motion optimization (2013) Colliding bodies optimization (2014)
Science	Natural sciences	Physics	Thermodynamics	Crystal energy optimization algorithm (2016) Sa (1983)
Science	Natural sciences	Physics	Electromagnetism	Charged system search (2010) Electro-magnetism optimization (2012)
Science	Natural sciences	Physics	Quantum theory	General relativity search algorithm (2015)
Science	Natural sciences	Physics	Light	Optics inspired optimization (2015) Ray optimization (2012)
Science	Natural sciences	Chemistry		Artificial chemical reaction optimization algorithm (2011) ions motion algorithm (2015)
Science	Natural sciences	Mathematics and statistics	Dynamic planning	Popmusic: partial optimization metaheuristicunder special intensification conditions (2002)
Science	Natural sciences	Mathematics and statistics	Statistical dispersion	Covariance matrix adaptation-evolution strategy (2006)
Science	Natural sciences	Mathematics and statistics	Simplex	Simplex heuristic (2007)
Science	Natural sciences	Mathematics and statistics	Number theory	Good lattice swarm algorithm (2007)
Science	Natural sciences	Mathematics and statistics	Markov chain theory	Evolution strategy (1965)
Science	Natural sciences	Mathematics and statistics	Geometry/ Fractal	Stochastic fractal search (2015)
Science	Natural sciences	Mathematics and statistics	Geometry/ Spiral	Spiral dynamics inspired optimization (2011)
Science	Natural sciences	Astronomy	The galaxy	Galaxy-based search algorithm (2011)
Science	Natural sciences	Astronomy	Black holes	Multi-verse optimizer (2015)
Science	Non natural sciences	Philosophy and religion		Dialectic search (2009)
Science	Non natural sciences	Management		Kaizen programming (2014)
Science	Non natural sciences	Research methodology		Scientific algorithms for the car renter salesman problem (2014)
Science	Non natural sciences	Art	Architecture	Interior design and decoration (2014)
Science	Non natural sciences	Art	Music	Harmony search (2001)

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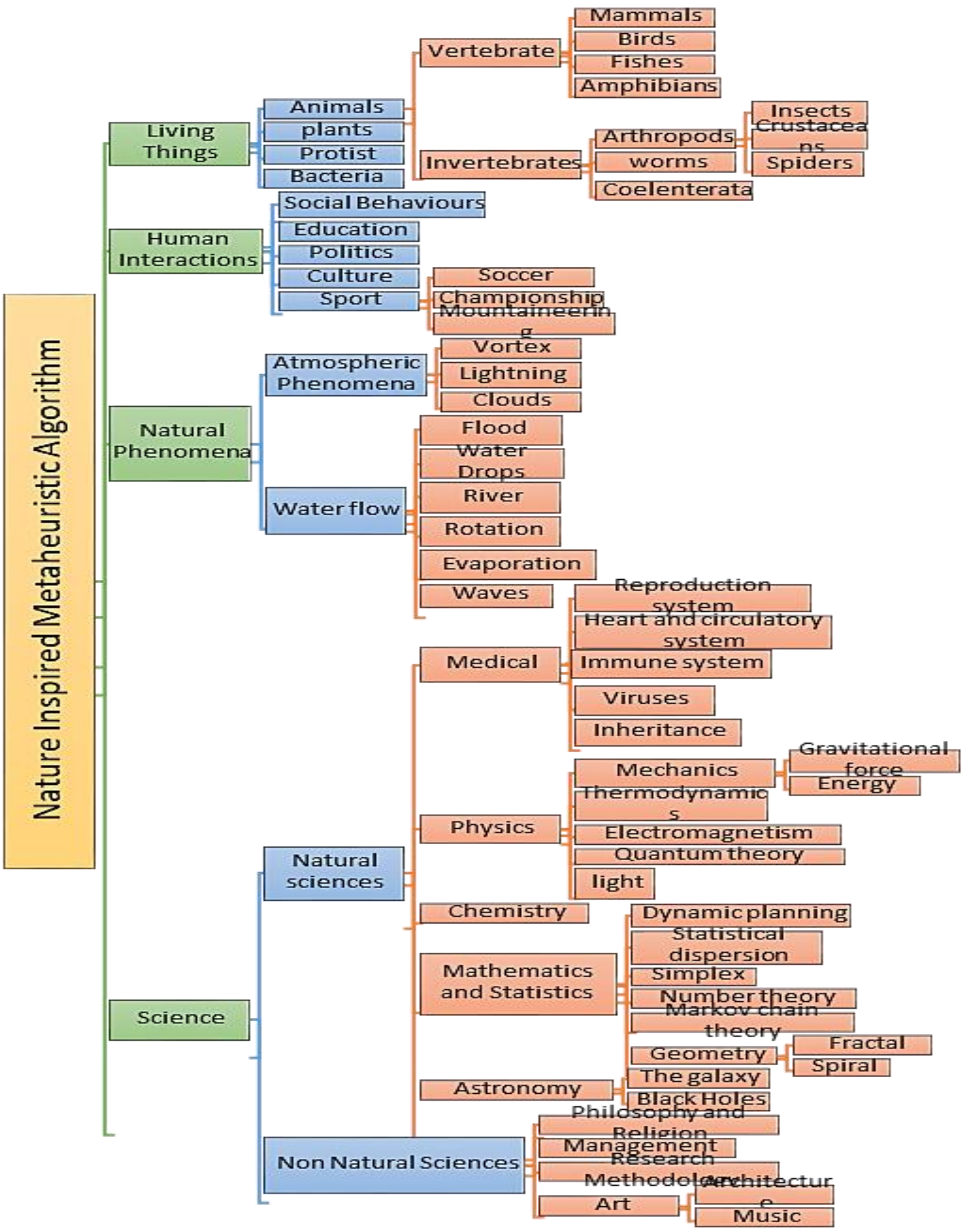

Fig. 7. Chart of metaheuristic algorithms classification.

Fig. 7 and *Fig. 8* illustrate the classification of metaheuristic algorithms in this paper, including living things, natural phenomena, human interactions, and science.

Living things involved animals, plants, protist, and bacteria. Animals divided into vertebrates and invertebrates. Vertebrate divide into mammals, birds, fishes, and amphibians. Invertebrates include arthropods, worms, and coelenterata. Arthropods divide into insects, crustaceans, and spiders. Human interactions include social behaviors, education, politics, culture, and sport.

Natural phenomena includes atmospheric phenomena and water flow. Atmospheric phenomena involved vortex, lightning, and clouds. Water flow inspired by flood, water drops, river, rotation, evaporation, and waves.

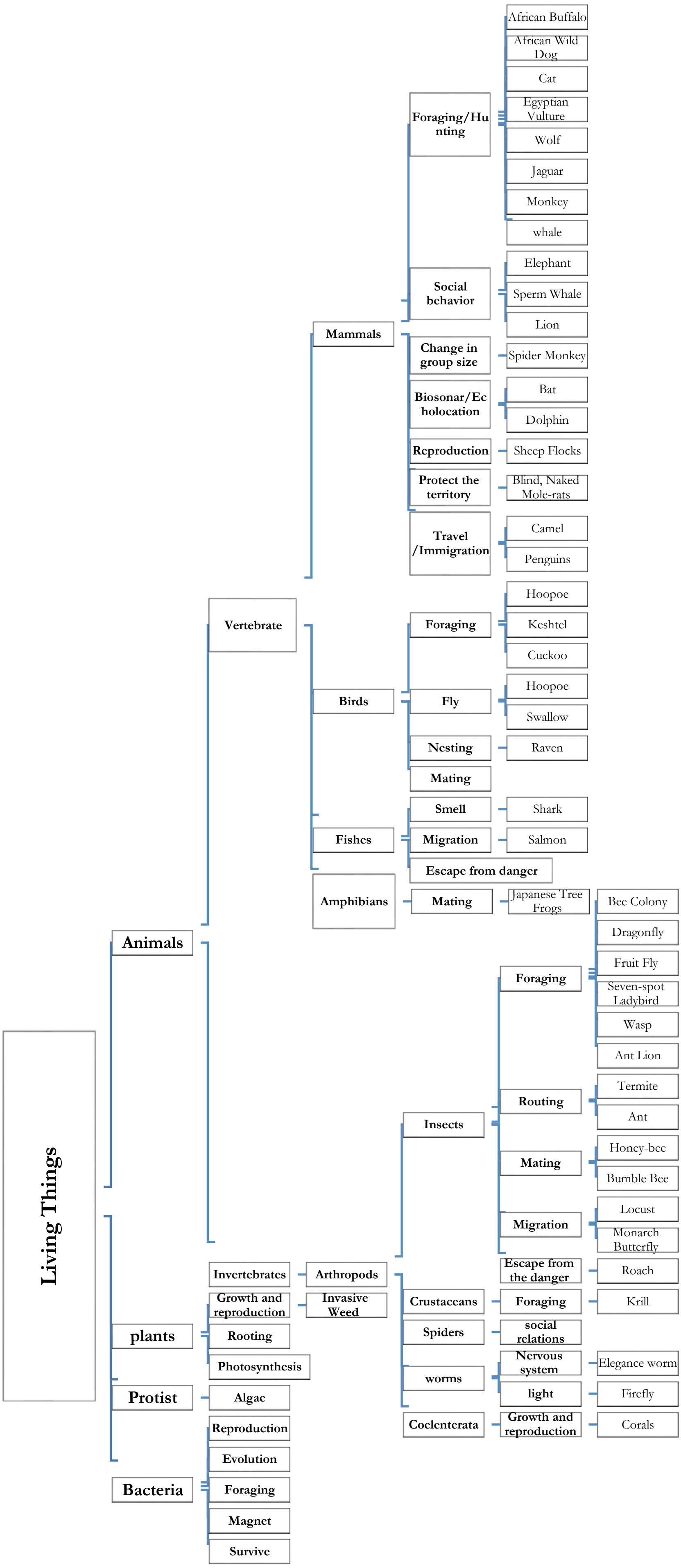

Fig. 8. Chart of metaheuristic algorithms classification (living things).

Science subset divided into natural sciences and non-natural sciences. Natural sciences involved medical, physics, chemistry, mathematics and statistics, and astronomy. Medical include reproduction system, heart and circulatory system, immune system, viruses, inheritance. Physics-based algorithms inspired by mechanics, thermodynamics, electromagnetism, quantum theory, and light. Mathematics and statistics include dynamic planning, statistical dispersion, simplex, number theory, markov chain theory, and geometry. Astronomy section inspired by the galaxy and black holes. Philosophy and religion, management, research methodology, and art fall into the category of non-natural sciences. Art, in turn, consists of architecture and music.

Fig. 8 and *Fig. 9* demonstrate the trends for presenting papers in the field of metaheuristic algorithms in the essential subcategories.

Table 8. The trends for presenting papers in the field of metaheuristic algorithms in the essential subcategories (source: web of science).

Echolocation	Reproduction	Fly	Mating	Migration	Routing	Plants	Bacteria	Water flow	Sport	politics
4	79	60	22	98	542	562	60	13	20	3
7	131	106	27	167	833	813	80	42	43	2
4	142	66	27	135	651	697	85	26	29	3
16	168	75	29	131	646	679	83	26	30	4
5	104	60	30	120	612	586	81	22	22	4
9	49	63	27	145	642	537	91	20	42	3
2	63	52	25	126	599	500	118	16	44	1
2	58	53	36	134	531	521	81	11	30	2
2	70	29	57	109	503	576	65	13	15	0
1	64	29	39	101	519	512	64	18	14	1
1	72	49	44	90	518	460	67	11	11	4
0	66	40	29	63	446	453	70	15	9	1
1	55	33	24	69	347	326	60	7	6	2
0	53	32	23	49	277	271	53	9	11	0
0	40	23	18	51	229	234	38	8	5	1
2	64	20	16	42	198	231	31	8	5	0
0	32	13	16	38	131	175	22	2	3	0
0	29	6	12	41	106	159	13	4	4	1
1	35	8	11	30	71	113	15	6	5	0
0	32	7	10	19	53	142	12	0	2	1
0	43	2	18	19	51	99	9	0	3	0
0	44	4	13	17	47	98	9	2	0	0
0	36	3	6	19	30	76	6	4	2	0
0	29	5	6	8	40	83	12	2	0	0
0	28	0	5	14	42	50	8	0	1	0
0	21	2	8	13	34	41	7	0	1	0
2	15	0	4	5	18	31	1	0	0	0
0	6	1	2	3	11	19	5	0	1	0
59	1628	841	584	1856	8727	9044	1246	285	358	33

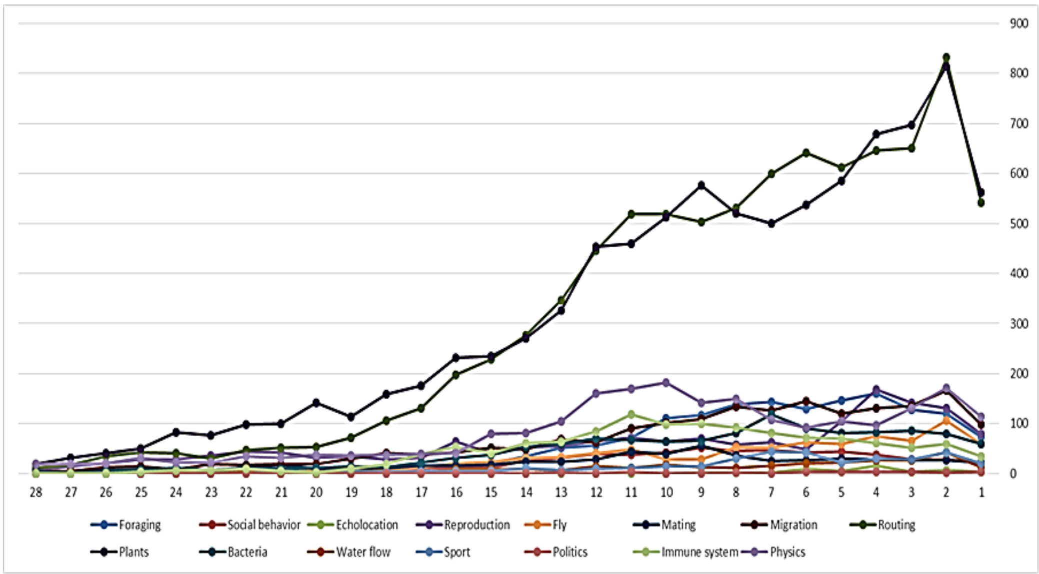

Fig. 9. The trend of metaheuristic algorithms by the source of inspiration.

Table 9 shows that many of the complex problems solved by metaheuristic algorithms inspired by plant growth, routing, and chemistry.

Table 9. The complex problems solved by metaheuristic algorithms based on features and inspiration source.

Rank	Source of Inspiration	Number of Paper
1	Plants	9044
2	Routing	8727
3	Chemistry	3605
4	Travel	2444
5	Physics	2273
6	Migration	1856
7	Reproduction	1628
8	Foraging	1550
9	Bacteria	1246
10	Immune system	1245
11	Fly	841
12	Mating	584
13	Social behavior	567
14	Sport	358
15	Water flow	285
16	Echolocation	59
17	Politics	33

Fig. 10 shows the number of metaheuristic algorithms sponsored by the world's leading scientific centers. Plant-inspired heuristic algorithms, routing, and chemistry are at the top.

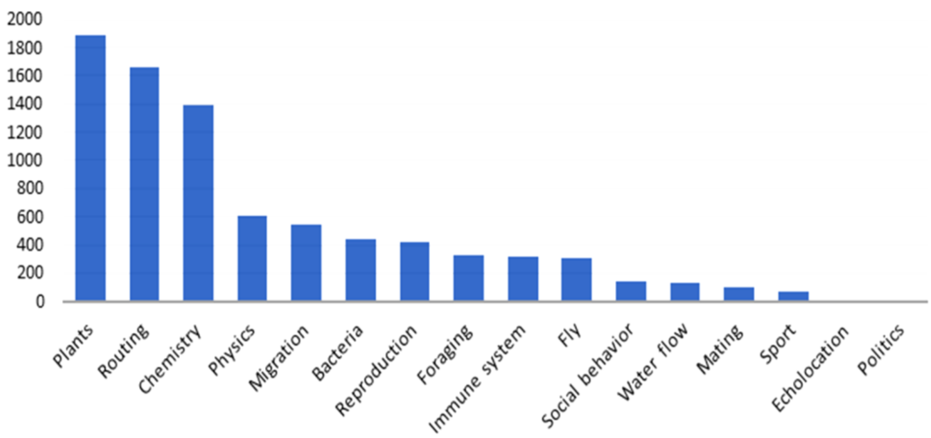

Fig. 4. Number of sponsored metaheuristic by the source of inspiration.

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Table 10 shows the grants awarded in the field of metaheuristic algorithms by institutions and universities around the world in various fields of meta-heuristic algorithms.

Table 7. The most critical sponsoring science centers in the field of metaheuristic algorithms by the source of inspiration.

Source of Inspiration	Institutions	Number	Institutions	Number	Institutions
Plants	National natural science foundation of China	513	Fundamental research funds for the central universities	83	Conselho nacional de desenvolvimento científico e tecnológico
Routing	National natural science foundation of China	516	Fundamental research funds for the central universities	65	National science foundation
Chemistry	National natural science foundation of China	246	National institutes of health	100	National science foundation
Physics	National natural science foundation of China	113	National science foundation	55	U.S. department of energy
Migration	National natural science foundation of China	162	Fundamental research funds for the central universities	23	National science foundation
Plants	National natural science foundation of China	513	Fundamental research funds for the central universities	83	Conselho nacional de desenvolvimento científico e tecnológico
Routing	National natural science foundation of China	516	Fundamental research funds for the central universities	65	National science foundation
Chemistry	National natural science foundation of China	246	National institutes of health	100	National science foundation
Physics	National natural science foundation of China	113	National science foundation	55	U.S. department of energy
Migration	National natural science foundation of China	162	Fundamental research funds for the central universities	23	National science foundation
Bacteria	National natural science foundation of China	65	National science foundation	30	National institutes of health
Reproduction	National natural science foundation of China	87	National science foundation	16	National institutes of health
Foraging	National natural science foundation of China	81	National science foundation	9	Fundamental research funds for the central universities
Immune system	National natural science foundation of China	61	Engineering and physical sciences research council	8	Conselho nacional de desenvolvimento científico e tecnológico
Fly	National natural science foundation of China	61	Fundamental research funds for the central universities	11	National basic research program of China
Social behavior	National natural science foundation of China	21	Conselho nacional de desenvolvimento científico e tecnológico	5	Federación española de enfermedades raras
Water flow	National natural science foundation of China	22	National research foundation of Korea	4	Ministry of education
Mating	National natural science foundation of China	13	National science council	5	National science foundation
Sport	National natural science foundation of China	6	National science foundation	4	China postdoctoral science foundation
Echolocation	National natural science foundation of China	2	Distinguished middle-aged and young scientist encourage and reward foundation of shandong province	1	Eusko jaurlaritza
Politics	Bureau of energy, ministry of economic affairs, republic of Taiwan	1	Inoue foundation for science	1	Korea agency for infrastructure technology advancement

5 | Conclusion

Optimization has many applications for solving different problems. In recent decades, with the increasing complexity of problems, metaheuristic algorithms have been able to demonstrate their performance by providing near-optimal solutions within a reasonable time. Many metaheuristic algorithms inspired by nature. Nature is a source of inspiration, fascinating, and diverse to solve very complex problems. Nature has had the opportunity for billions of years to create, revise, and edit species to adapt to it, and has been able to provide a solution to each challenge.

In this article, we provide a comprehensive overview of the metaheuristic algorithms and categories. We then present a novel classification with emphasis on the source of inspiration and features of these algorithms. The presented classification includes four main categories of living things, human interactions, natural phenomena, and sciences. Each of these main sections divides into several subcategories. The category of living things includes animals, plants, protists, and bacteria. Features of metaheuristic algorithms include foraging/hunting, social behaviors, group size change, bio sonar/echolocation, reproduction, territory protection, immigration/travel, flying, nesting, mating, smell, hearing, escape from danger, illumination, nervous system, discoloration, rooting, pollination, photosynthesis. Metaheuristic algorithms inspired by natural phenomena include atmospheric phenomena such as vortex, lightning, and clouds, and water flows, including waves, flows, evaporation, floods, and rivers.

Science-inspired metaheuristic algorithms include the natural sciences and the non-natural sciences. The natural sciences include medicine, physics, chemistry, mathematics and statistics, and astronomy, and engineering sciences. Non-natural sciences include philosophy and religion, management, research, and the arts. A survey of world-renowned scientific sites such as google scholar, scopus, and web of science showed that attention to nature-inspired algorithms is growing. Many grants are awarding by universities and prestigious scientific centers for research in these fields. Because the environment and nature-inspired computing algorithms are so young, there is still room for growth in this community.

This paper categorizes and briefly introduces a range of different nature-inspired algorithms. For future work, it is suggested to combine this classification with the previous ones, to make a new classification and to complete the taxonomy of metaheuristic algorithms.

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