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Heuristic and Meta-Heuristic Algorithms and Their Relevance to the Real World: A Survey

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Abstract— Nowadays computers are also used to solve incredibly complex problems. To solve these problems we have to develop some advanced algorithms. Exact algorithms of such problems might need unacceptably huge time & space to discover the solutions. For making the solution-finding algorithms acceptable approximation algorithms have been developed. These approximation algorithms use the heuristics and meta- heuristics functions to find out the solutions. Heuristic algorithms use the special designed functions to find out solution space intelligently.

Meta-heuristics algorithms are the iterative generation process which guides a subordinate heuristic for exploring and exploiting the search space. Learning strategies in meta-heuristics helps to find efficient near-optimal solutions. Meta-heuristic algorithms make the complex problems solvable in acceptable time. This survey paper is trying to explain heuristic and Meta-heuristic techniques to solve the complex problems.

Index Terms— Heuristics, Meta-heuristic, genetic algorithm(GA), tabu search(TS), simulated annealing(SA), Local search, Evolutionary Algorithms, Migrating Birds Optimization(MBO), Particle Swarm optimization(PSO), Artificial bee colony algorithm(ABC), Cuckoo search algorithm(CSA), Firefly algorithm(FA) , Harmony search(HS), Bat search algorithm(BSA).

1 Introduction

1.1 Problem Complexity

The most important among a variety of topics that relate to computation are algorithm validation, complexity estimation and optimization. Wide part of theoretical computer science deals with these tasks. Complexity of tasks in general is examined studying the most relevant computational resources like execution time and space. The ranging of problems that are solvable with a given limited amount of time and space into well-defined classes is a very intricate task, but it can help incredibly to save time and money spent on the algorithms design. Modern problems tend to be very intricate and relate to analysis of large data sets. Assuming that normally the optimal solution is unknown, this problem can be a real challenge involving strong mathematical analysis. In connection with the quality issue the goal of the heuristic algorithm is to find as good solution as possible for all instances of the problem. There are general heuristic strategies that are successfully applied to complex problems. But in reality it is often sufficient to find an approximate or partial solution. We are going to discuss heuristic algorithms which suggest some approximations to the solution of optimization problems. In such problems the objective is to find the optimal of all possible solutions, that is one that minimizes or maximizes an objective function. The objective function is a function used to evaluate a quality of the generated solution. Many real-world issues are easily stated as optimization problems. The collection of all possible solutions for a given problem can be regarded as a search space, and optimization algorithms, in their turn, are often referred to as search algorithms [2], [6].

1.2 Optimization problems

Optimization problems can be divided into two major category, as exact and approximate. Exact algorithms gives exact solution to the problem as name suggested. Approximate algorithm may give exact or may not give exact solution , in other words they gives approximate solutions to the problems. Approximate algorithm further divided into two major categories as heuristic and meta-heuristics algorithms. Heuristics algorithm includes Local search, Divide and conquer, Branch-and-bound, Dynamic programming, cut & plane etc. meta-heuristics algorithms includes evolutionary algorithm, genetic algorithm, scatter search, simulated annealing, tabu search, guided local search, hill climbing, Iterated local search, stochastic algorithm, which are to be discuss further in the paper.

1.3 Techniques

It is difficult to imagine the variety of existing computational tasks and the number of algorithms developed to solve them. Algorithms that either give nearly the right answer or provide a solution not for all instances of the problem are called heuristic algorithms. This group includes a plentiful spectrum of methods based on traditional techniques as well as specific ones. For the beginning we sum up the main principles of traditional search algorithms. The simplest of search algorithms is exhaustive search that tries all possible solutions from a predetermined set and subsequently picks the best one.

Local search [1], [3], [11], is a version of exhaustive search that only focuses on a limited area of the search space. Local search can be organized in different ways. Popular hill-climbing techniques belong to this class. Such algorithms consistently replace the current solution with the best of its neighbors if it is better than the current. For example, heuristics for the problem of intra-group replication for multimedia distribution service based on Peer-to-Peer network is based on hill-climbing strategy.

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Divide and conquer [1], [3], algorithms try to split a problem into smaller problems that are easier to solve. Solutions of the small problems must be combinable to a solution for the original. This technique is effective but its use is limited because there is no a great number of problems that can be easily partitioned and combined in a such way.

Branch-and-bound [1], [3], technique is a critical enumeration of the search space. It enumerates, but constantly tries to rule out parts of the search space that cannot contain the best solution.

Dynamic programming [1], [3], is an exhaustive search that avoids re-computation by storing the solutions of sub-problems. The key point for using this technique is formulating the solution process as a recursion. A popular method to construct successively space of solutions is greedy technique, that is based on the evident principle of taking the (local) best choice at each stage of the algorithm in order to find the global optimum of some objective function. Usually heuristic algorithms are used for problems that cannot be easily solved by traditional methods in reasonable time.

1.4 Taxonomy of optimization Problems

Following figure.1 shows taxonomy of different optimization Problems (methods), Which are basically divided into two prime categories such as Exact Algorithms and Approximate algorithms. Which are further divided into two categories Heuristics algorithm and Meta-Heuristics algorithm. Heuristics algorithm includes local search, branch & bound, dynamic programming, cutting plane, and Branch & cut algorithms and so on. Whereas meta-heuristics algorithms give optimal solution or near-optimal solution instead of exact one, they are again divided into two categories:

(1.) P

opulation-Based and (2.) Trajectory-Based.

These algorithms include genetic algorithm, tabu search, ant colony optimization, hill climbing, simulated annealing ,GRASP, hybrid search and so on, which are suitable for large size problem to find optimal solution but they required massively parallel computing on very large instances. Some algorithms are solution-based (LSM) such as hill climbing, simulated annealing, tabu search , evolutionary algorithm, scatter search etc. And some of them are population–based algorithms such as evolutionary algorithms, ant colony optimization and so on.

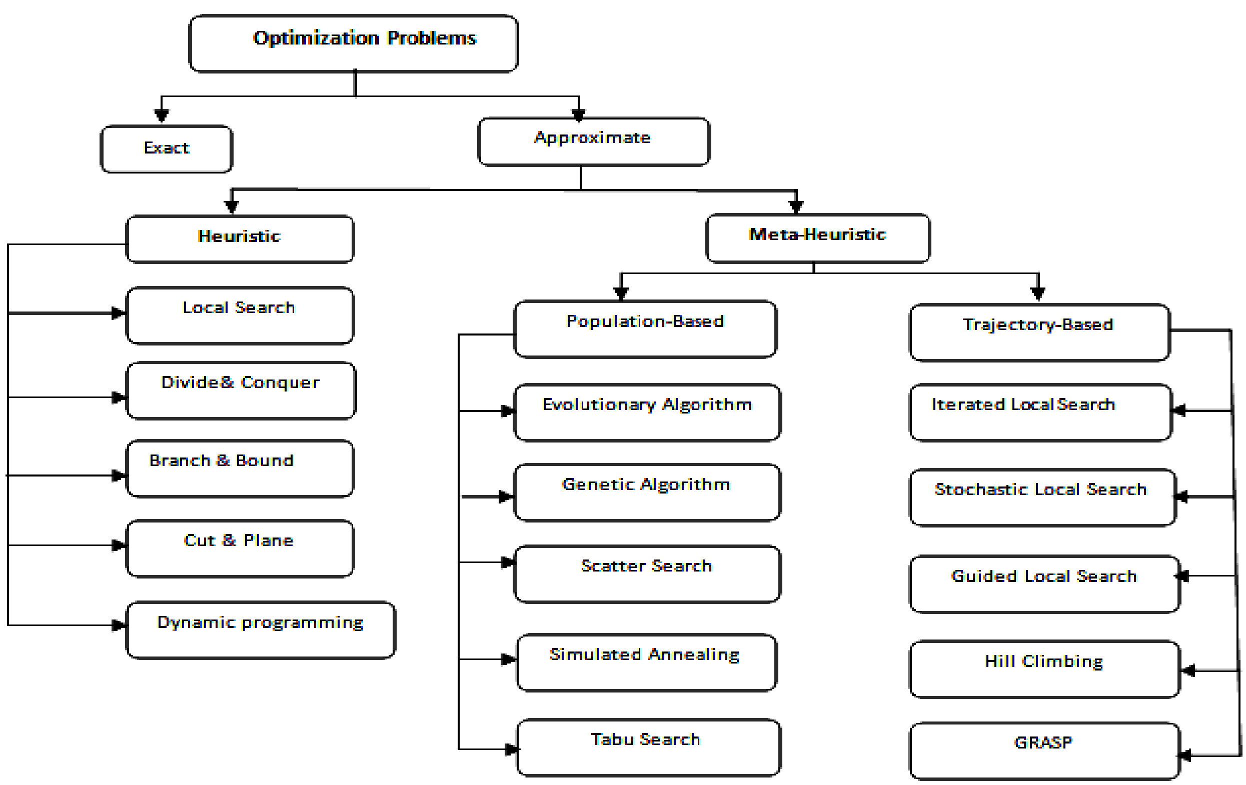

Figure.1 Taxonomy of Optimization Problems

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1.5 Paper Containments

The paper is organized as follows. Section-I includes introduction of optimization algorithms along with diagram of taxonomy of different optimization algorithms. Section-II describes prevalent heuristic techniques, Support Vector Machines and Evolutionary Algorithms are presented. Some intractable problems that could help to understand deeper importance of heuristics are also mentioned. Section-III presents Meta-heuristics algorithms and techniques over heuristics algorithms. Section-IV describes recent developments in heuristics and meta-heuristics algorithms including chart and table and next portion of paper states some well known applications of these algorithms. And ultimately conclusion is give about these specified algorithms.

2. HEURISTIC ALGORITHM

2.1 Introduction:

Heuristic [2], [12], refers to experience-based techniques for problem solving, learning, and discovery**.** Where an exhaustive search is impractical, heuristic methods are used to speed up the process of finding a satisfactory solution. Examples of this method include using a rule of thumb, an educated guess, an intuitive judgment, or common sense. In more precise terms, heuristics are strategies using readily accessible, though loosely applicable, information to control problem solving in human beings and machines. In computer science, artificial intelligence, and mathematical optimization, a heuristic is a technique designed for solving a problem more quickly when classic methods are too slow, or for finding an approximate solution when classic methods fail to find any exact ones ,but they do not guarantee that the best will be found, therefore they may be considered as approximately and not accurate algorithms. These algorithms, usually find a solution close to the best one and they find it fast and easily. Sometimes these algorithms can be accurate, that is they actually find the best solution, but the algorithm is still called heuristic until this best solution is proven to be the best.

Trade-off

The trade-off criteria for deciding whether to use a heuristic for solving a given problem include the following [2]:

Optimality: When several solutions exist for a given problem, does the heuristic guarantee that the best solution will be found? Do we actually need the best one?

Completeness: When several solutions exist for a given problem, can the heuristic find them all? Do we actually need all solutions? Many heuristics are only meant to find one solution.

Accuracy and precision: Can the heuristic provide a confidence interval for the purported solution? Is the error bar on the solution unreasonably large?

Execution time: Is this the best known heuristic for solving this type of problem? Some heuristics converge faster than others.

Some heuristics are only marginally quicker than classic methods [1], [2]. In such problems the objective is to find the optimal of all possible solutions that is one that minimizes or maximizes an objective function. The objective function is a function used to evaluate a quality of the generated solution.. In some cases, it may be difficult to decide whether the solution found by the heuristic is good enough, because the theory underlying that heuristic is not very elaborate. We are going to discuss heuristic algorithms which suggest some solution. This is achieved by trading optimality, completeness, accuracy, or precision for speed. Approximate algorithms entail the interesting issue of quality estimation of the solutions they find. Taking into account that normally the optimal solution is unknown, this problem can be a real challenge involving strong mathematical analysis.

2.2 Techniques:

Branch-and-bound technique and dynamic programming are quite effective but their time-complexity often is too high and unacceptable for NP-complete tasks. Hill-climbing algorithm is effective, but it has a significant drawback called pre-mature convergence. Since it is ”greedy”, it always finds the nearest local optima of low quality. The goal of modern heuristics is to overcome this disadvantage.

Simulated annealing [6], [10], algorithm, invented in 1983, uses an approach similar to hill-climbing, but occasionally accepts solutions that are worse than the current. The probability of such acceptance is decreasing with time.

Tabu search [10], [14], extends the idea to avoid local optima by using memory structures. The problem of simulated annealing is that after ”jump” the algorithm can simply repeat its own track. Tabu search prohibits the repetition of moves that have been made recently.

Swarm intelligence [19], was introduced in 1989. It is an artificial intelligence technique, based on the study of collective behavior in decentralized, self-organized, systems. Two of the most successful types of this approach are Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO).In ACO artificial ants build solutions by moving on the problem graph and changing it in such a way that future ants can build better solutions. PSO deals with problems in which a best solution can be represented as a point or surface in an n-dimensional space. The main advantage of swarm intelligence techniques is that they are impressively resistant to the local optima problem.

Neural Networks [9], are inspired by biological neuron systems. They consist of units, called neurons, and interconnections between them. After special training on some given data set Neural Networks can make predictions for cases that are not in the training set. In practice Neural Networks do not always work well because they suffer greatly from problems of under fitting and over fitting. These problems correlate with the accuracy of prediction. If a network is not complex enough it may simplify the laws which the data obey. From the other point of view, if a -network is too complex it can take into account the noise that usually assists at the training data set while inferring the laws. The quality of prediction after training is deteriorated in both cases. The problem of premature convergence is also critical for Neural Networks.

3. META-HEURISTIC ALGORITHMS

3.1 Introduction: In computer science, meta-heuristic designates a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. Meta-heuristics make few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. However, meta-heuristics do not guarantee an optimal solution is ever found. Many meta-heuristics implement some form of stochastic optimization. Other terms having a similar meaning as meta-heuristic, are: derivative-free, direct search, black-box, or indeed just heuristic optimizer. Following are properties that characterize most meta-heuristics:

- Meta-heuristics are strategies that guide the search process. The goal is to efficiently explore the search space in order to find near–optimal solutions.
- Techniques which constitute meta-heuristic algorithms range from simple local search procedures to complex learning processes.
- Meta-heuristic algorithms are approximate and usually non-deterministic.
- Meta-heuristics are not problem-specific.

Meta-heuristics may make few assumptions about the optimization problem being solved, and so they may be usable for a variety of problems. One of the best quote I've heard some time ago to describe the difference between heuristic and meta-heuristic: "A heuristic is a pretty good rule. A meta-heuristic is a pretty good rule for finding pretty good rules".

3.2 Techniques:

A Meta-heuristic [5], [11], [24], is formally defined as an iterative generation process which guides a subordinate heuristic by combining intelligently different concepts for exploring and exploiting the search space, learning strategies are used to structure information in order to find efficiently near-optimal solutions. Meta-heuristic algorithms are among these approximate techniques which can be used to solve complex problems. Most widely known Meta-heuristic algorithms are Genetic algorithm (GA), simulated annealing (SA) and Tabu search (TS).Genetic algorithm (GA) emulate the evolutionary process in nature, whereas tabu search (TS) exploits the memory structure in living beings, simulated annealing (SA) imitates the annealing process in crystalline solids.

A. Genetic algorithm

Genetic Algorithm [14], is a Meta-heuristic algorithm that aims to find solutions to NP-hard problems. The basic idea of Genetic Algorithms is to first generate an initial population randomly which consist of individual solution to the problem called Chromosomes, and then evolve this population after a number of iterations called Generations. During each generation, each chromosome is evaluated, using some measure of fitness. To create the next generation, new chromosomes, called offspring, are formed by either merging two chromosomes from current generation using a crossover operator or modifying a chromosome using a mutation operator. A new generation is formed by selection, according to the fitness values, some of the parents and offspring, and rejecting others so as to keep the population size constant. Fitter chromosomes have higher probabilities of being selected. After several generations, the algorithms converge to the best chromosome, which hopefully represents the optimum or sub optimal solution to the problem.

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B. Tabu Search

Tabu search [17], is the technique that keeps track of the regions of the solution space that have already been searched in order to avoid repeating the search near these areas. It starts from a random initial solution and successively moves to one of theneighbors of the current solution. The difference of tabu search from other Meta-heuristic approaches is based on the notion of tabu list, which is a special short term memory. That is composed of previously visited solutions that include prohibited moves. In fact, short term memory stores only some of the attributes of solutions instead of whole solution. So it gives no permission to revisited solutions and then avoids cycling and being stuck in local optima.

C. Simulated annealing

Simulated Annealing [4], [6], is an early Meta-heuristic algorithm originating from an analogy of how an optimal atom configuration is found in statistical mechanics. It uses temperature as an explicit strategy to guide the search. In Simulated Annealing, the solution space is usually explored by taking random tries. The Simulated Annealing procedure randomly generates a large number of possible solutions, keeping both good and bad solutions. As the simulation progresses, the requirements for replacing an existing solution or staying in the pool becomes stricter and stricter, mimicking the slow cooling of metallic annealing. Eventually, the process yields a small set of optimal solutions. Simulated Annealing advantage over other methods is its ability to obviate being trapped in local minima.

4. RECENT DEVELOPMENTS IN META-HEURISTIC ALGORITHMS:

Following are the recent meta-heuristics algorithms which are nature- inspired: Migrating Birds Optimization, Particle Swarm optimization , Artificial bee colony algorithm, Cuckoo search algorithm, Firefly algorithm , Improved Harmony search , Bat search algorithm, Monkey Algorithm, Ant Colony optimization and so on. Let us discuss each algorithm briefly.

4.1.Migrating Birds Optimization (MBO):

It is a new nature inspired meta-heuristic approach based on the V flight formation of the migrating birds which is proven to be an effective formation in energy minimization [28]. Its performance is compared with other algorithms. The quality of the solutions turned out to be better than simulated annealing, tabu search and guided evolutionary simulated annealing approaches.The V formation is the most famous formation that the migrating birds use to fly long distances. It gets this name because of the similarity of the shape the birds make to the letter "V. Here there is a bird leading the flock and two lines of other birds following it.In the V formation the leader bird is the one spending most energy. The birds in the other positions gets benefit from the birds in their front. It sounds reasonable that the energy saving is higher as we go back in the line but we could not find a study in the literature to support this idea. However it was stated that, the savings of the birds other than the leader bird are either the same or the saving is a bit more for the birds in the middle part.

4.2. Particle Swarm Optimization(PSO):

Particle Swarm Optimization (PSO) [8], [29], is a biologically inspired or natured-inspired computational search and optimization method developed by Eberhart and Kennedy in 1995 based on the natural behavior of swarms and their capbilities. On the other hand, basic PSO is more appropriate to process static, simple optimization problem. Theory of particle swarm optimization (PSO) has been growing rapidly. PSO has been used by many applications of several problems. The precise definition of PSO : "It is a global swarm algorithm which uses multiple individual particles to explore the search space to find the optimal solution ". Basic idea for PSO optimization is came from about from watching some swarm moving together such as swarm of animal like honeybees, ants, fish etc. It not only uses a momentum of individual particle at the direction in which it is already moving but also uses an information of that particle's "previous best solution" called as personal best , ***pbest***. and also the "best solution in overall population" to move this particle around in the search space (This value is called ***gbest***).

4.3. Artificial Bee Colony (ABC) algorithm :

Artificial Bee Colony (ABC) algorithm was proposed by Karaboga for optimizing numerical problems in. The algorithm simulates the intelligent foraging behavior of honey bee swarms. It is a very simple, robust and population based stochastic optimization algorithm. In ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. A bee waiting on the dance area for making a decision to choose a food source is called onlooker and one going to the food source visited by it before is named employed bee. The other kind of bee is scout bee that carries out random search for discovering new sources.

4.4. Firefly Optimization (FA):

Nature-inspired meta-heuristic algorithms, especially those based on swarm intelligence, have attracted much attention in the last ten years. Firefly algorithm appeared in about five-six years ago, its literature has expanded dramatically with diverse applications. In this paper, we will briefly review the fundamentals of firefly algorithm together with a selection of recent publications. A subset of meta-heuristics are often referred to as swarm intelligence (SI) based algorithms, and these SI-based algorithms have been developed by mimicking the so-called swarm intelligence characteristics of biological agents such as birds, fish, humans and others.

Firefly Algorithm:

Firefly Algorithm (FA) [24], was first developed by Xin-She Yang in late 2007 and 2008 at Cambridge University, which was based on the flashing patterns and behavior of fireflies. In essence, FA uses the following three idealized rules:

• Fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex.

• The attractiveness is proportional to the brightness, and they both decrease as their distance increases. Thus for any two flashing fireflies, the less brighter one will move towards the brighter one. If there is no brighter one than a particular firefly, it will move randomly.

• The brightness of a firefly is determined by the landscape of the objective function.

4.5.Improved Harmony Search algorithm:

Harmony search algorithm (HS) [25], developed by Geem has been successfully applied to various benchmark and real world problems. It is a meta-heuristic optimization algorithm conceptualized by using the musical process of searching for a perfect state of harmony. Musical performances seek to find pleasing harmony (a perfect state) as determined by an aesthetic standard, just as the optimization process seeks to find a global solution (a perfect state) as determined by an objective function.

4.6. Cuckoo Search Algorithm (CSA):

Cuckoo search algorithm (CSA) [26], is a novel population based stochastic global search meta-heuristic algorithm developed by Yang and Deb. CSA is inspired by natural mechanisms and mimics, the breeding behavior of some cuckoo species that lay their eggs in the nests of host birds. Each egg represents a solution, and a cuckoo egg represents a new solution. The goal is to use new and potentially improved solutions (cuckoos) to replace worse solutions in the nests. CSA can be briefly described using the following three idealized rules:

1. Each cuckoo lays one egg at a time, and dumps it in a randomly chosen nest.
2. The best nests with high quality of eggs (solutions) will carry over to the next generations.
3. The number of available host nests is fixed, and a host can discover an alien egg
4. with a probability Pa [0,1].

Following Figure-chart 1 given below is to describe the illustration of devlopment of differnet algorithms with respect to their development years.

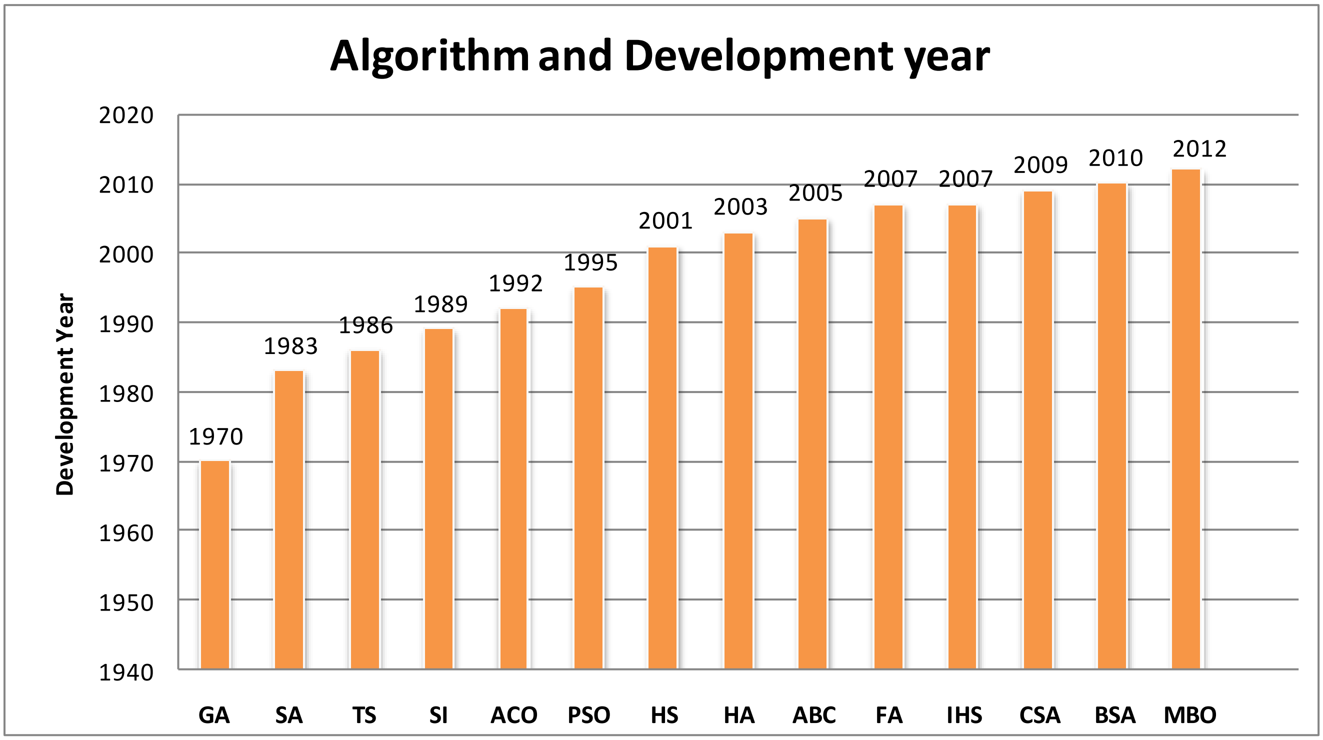

Chart 1. Heuristics and Meta-Heuristic Algorithms as per development year

Following Table 1 illuminate the details of different heuristics and meta-heuristics algorithms accordring to their development year and their respective developers or authors.

Sr. No.	Acronym	Name of Algorithm	Development Year	Developed By
1.	GA	Genetic Algorithm [14]	1970	J. Holland , K. DeJong, D. Goldberg
2.	SA	Simulated Annealing [4], [6]	1983	Scott Kirkpatrick, C. Daniel Gelatt, Mario P. Velachi
3.	TS	Tabu Search [17]	1986	Fred W. Glover
4.	SI	Swarm Intelligence [19]	1989	Jing Wang, Gerardo Beni
5.	ACO	Ant Colony Optimization [20], [30]	1992	Marco Dorigo
6.	PSO	Partical Swarm Optimization [8], [29]	1995	James Kennedy, Russell Eberhart
7.	HS	Harmony Search [21]	2001	Zong Woo Geem
8.	HA	Hybrid Algorithm [22]	2003	Detcher, Rina, Morgan Kanfumann
9.	ABC	Articificial Bee Colony Algorithm [23]	2005	Karaboga
10.	FA	Firefly Algorithm [24]	2007	Xin-She Yang
11.	IHS	Improved Harmony Search [25]	2007	M. Mahdavi et al., Fesanghary M, and Damangir E.
12.	CSA	Cuckoo Search Algorithm [26]	2009	Xin-She Yang, Suash Deb
13	BSA	Bat Search Algorithm [27]	2010	Xin-She Yang
14.	MBO	Migrating Bird Optimization Algorithm [28]	2012	Ekrem Duman, mital Uysal, Ali Fuat Alkaya

Table 1 .Heuristics and Meta-Heuristic Algorithms as per development year

5. THE APPLICATIONS OF HEURISTICS AND META-HEURISTICS ALGORITHMS:

Heuristics and Meta-heuristics are used for combinatorial optimization in which an optimal solution is sought over a discrete search-space. An example problem is the travelling salesman problem where the search-space of candidate solutions grows faster than exponentially as the size of the problem increases, which makes an exhaustive search for the optimal solution infeasible. Following are some well known applications of heuristics and meta-heuristics algorithms.

1. Solving NP-hard Optimization Problems

- Traveling Salesman Problem
- Maximum Clique Problem
- Flow Shop Scheduling Problem
- P-Median Problem

2. Search Problems in Many Applications

- Feature Selection in Pattern Recognition
- Automatic Clustering
- Machine Learning (e.g. Neural Network)

6. CONCLUSION:

A *heuristic* is a technique designed for solving a problem more quickly when classic methods are too slow, or when classic methods fail to find any exact solution. The objective of a heuristic is to produce a solution in a reasonable time frame that is good enough for solving the problem at hand. This solution may not be the best of all the actual solutions to this problem, or it may simply approximate the exact solution. But it is still valuable because finding it does not require a prohibitively long time.

Meta-heuristics are strategies that "guide" the search process. The goal is to efficiently explore the search space in order to find (near-) optimal solutions. Meta-heuristic algorithms are approximate and usually non-deterministic. For NP-hard optimization problems and complicated search problems, Meta-heuristic methods are very good choices for solving these problems. Meta-heuristics are not problem-specific and may make use of domain-specific knowledge in the form of heuristics that are controlled by the upper level strategies. Meta-heuristics can obtain better quality solutions than heuristic methods.

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