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Nature Inspired Optimization For Real World Problems

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Abstract:
Background*: Nature Inspired Optimization techniques are meta-heuristic techniques which are inspired from nature's laws and behavioral patterns. This field of study comes under artificial intelligence space search techniques which involve space explorations and exploitations to search for solutions while involving randomness in overall procedure. The pattern imitate some of the nature's manner of evolving solutions through generation's evolutions and iterative refinement. The philosophy to involve randomness in space searches just like nature do, enable these techniques to reach to near to optimal solutions even for NP hard problem domains. Therefore such techniques have seen a great applications in many computational optimization problems in complex real world domains. In past three decades many such algorithmic techniques have been developed by researchers. However, their modelling to suit specific application area seems an interesting and open area of research. The research work presented here is focused towards putting light on recent techniques, trends and application areas of these nature inspired meta-heuristic algorithms to some very interesting real world problems. The discussion in this paper identifies application of nature inspired optimization in primarily five main application area named health sector, social networks, transportation and education sector. The work presented will provide a consolidated reference for researchers for current state of the art in this area of research and guide for future research directions.*

Keywords*: Nature Inspired Optimization; Meta-Heuristics; Particle Swarm Optimization; Genetic Algorithm; NP Hard.*

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I. Introduction

The field of artificial intelligence in computer science studies is focused on making computers work the manner humans do. The applicability and research studies in artificial intelligence range from making computers solve problems which humans' do[1] at best such as game playing, image recognition, prediction of trends, identification of patterns so on and so forth. The primary ideology behind making computer to behave intelligently lies in the knowledge representations which needs to be extracted by computer space searching mechanisms in an organized fashion to reach to an acceptable solution. Different problem domain needs different knowledge base modelling and state space search mechanisms which in together we term as a complete production system.

The primary and most critical component of any production system is its space search mechanism which can efficiently find out solutions to problem under study within an acceptable timeframe while scrolling though enormously large and complex knowledge space. The searching mechanisms employed in artificial intelligent systems primarily fall under two categories: Deterministic and Stochastic[2]. Deterministic algorithms are algorithms which are designed to find optimal solutions through mathematical modelling. Linear and non-linear programming are two main methodologies which come under this area of artificial intelligence. Stochastic algorithmic techniques on the other hand involve some randomness in the searching mechanisms to curb the vast solution space and evolve near to optimal solution instead of exact optimal solutions. Stochastic algorithmic techniques further are classified into two categories based on their design motivations. The first category of stochastic search algorithms are called as heuristic techniques and the second are called as meta-heuristic techniques. Heuristic solution methodologies involve apply natural guessing in curbing the solution search space , whereas meta-heuristics apply nature based randomness in searching through the vast solution spaces. Following Figure 1 depicts all these artificial intelligence state space search methodologies in a diagrammatic representation with some specific algorithmic techniques in each category. Looking under stochastic based heuristic methodologies, these methodologies are well known state space searching methodologies being readily employed in some classical game playing and other state space search problems which aim to find an acceptable solution and are not very hard on finding the optimal solutions. Some well-known techniques known to be heuristic are Hill climbing, AO*, and Best First Search to name some.

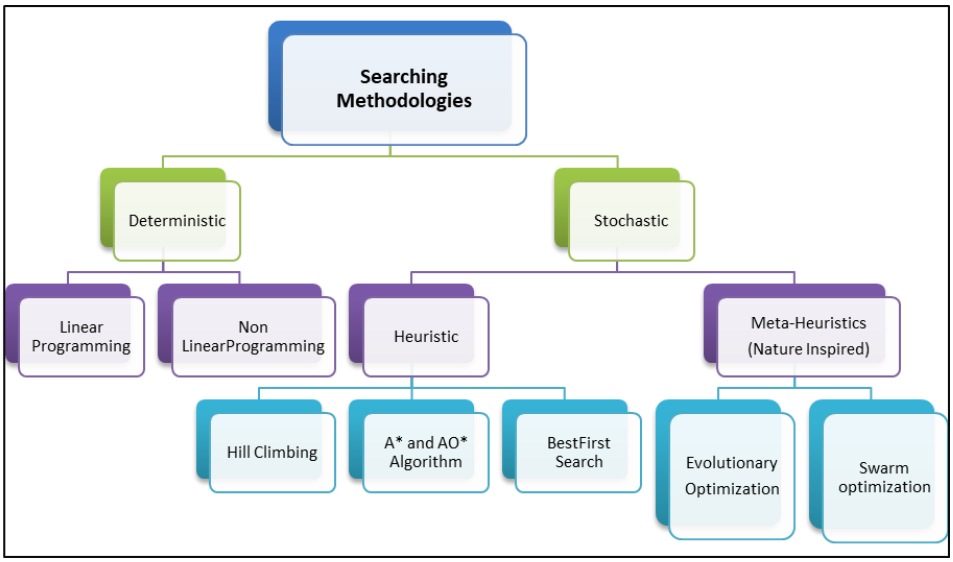

Fig. 1: Primary Searching Methodologies employed in AI production Systems

These techniques though are good at finding acceptable solutions but have some crucial drawbacks such as getting stuck in plateau area, local maxima and local minima. These are well-known issues with simple heuristic techniques, which become even more crucial with enormously large and complex search spaces in many real world highly complex problems. With these drawbacks, such techniques are applicable to AI problem domains which have well defined and limited search space. For highly complex real world problems, where search space is complex and searching through this search space can be modelled as optimizing some target function, such problems can be solved using meta-heuristic solution methodologies. Meta-heuristics are extensions to heuristic whereby randomness found in nature is utilized for searching solutions through large and complex search spaces. This randomness inclusion in state space exploration proves highly advantageous in making continuous progression towards solution searching and not letting algorithm to get stuck in local maxima or local minima.

The focus of this research work presented here is to scrutinize primary application areas in real world where meta-heuristic techniques have been successfully deployed by researchers in past decade. Through this research work, by identifying such problem domains, the efforts have been put to provide optimization perspectives to real world problems so that meta-heuristic application is clearly explained. The conducted research work is focused on five main real world application areas of meta-heuristic algorithms named health sector, social networks, transportation, and education sector. The next section presents the basic design methodologies behind meta-heuristic algorithms, followed by applications to five major real world sectors.

II. Design Methodologies

Nature Inspired or Meta-Heuristic techniques[3] primarily model the problem as an optimization problem whereby the strategy of state space search is guided by either maximization or minimization of the optimization function into consideration. As nature laws are also driven by fitness and optimization of the considered tasks using survival of the fittest mechanisms through generations, therefore nature inspired computational techniques are also motivated from these philosophies. Primarily nature inspired techniques fall under two sub categories: Evolutionary and swarm as shown in Figure 2.

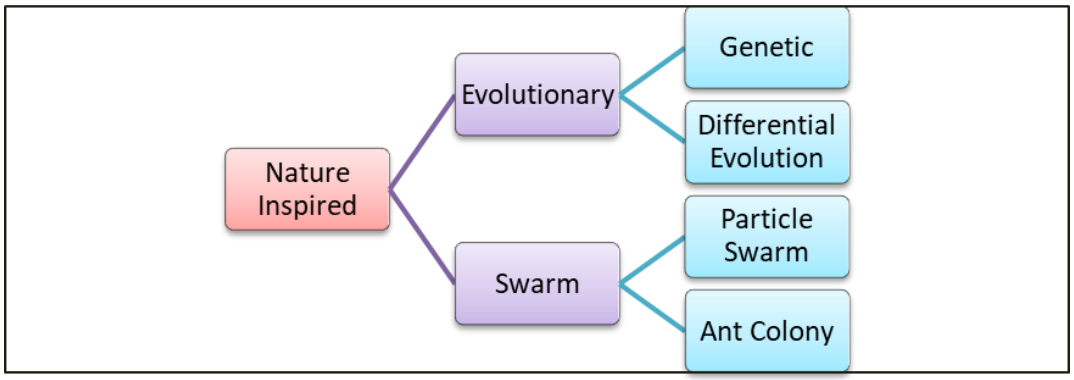

Fig. 2: Nature Inspired Techniques and their main types

Evolutionary algorithms[4] are motivated from optimization through generations and survival of the fittest. It follows genetic variations using crossover and mutations in genes to generate new population of solutions which are off springs from the previous solution set (population) and are fitter than their parents. Each solution in the initial solution set which form a generation is represented using set of genes. However, such gene representation may vary depending upon the problem under consideration. Crossover operations, as shown in fig 3,between two parent solution chromosomes(set of genes) allows parts of parents to be copied to offspring, however mutation operation is used to involve randomness by flipping some random genes of solutions. Both operations along with many other variants are utilized as per the problem domain's need so as to move towards generating newer off springs with better combination of genes. Exploration i.e. generating new solutions from old one is executed using crossovers while exploitation i.e. improving the already existing ones by minor variations is executed using mutation operation.

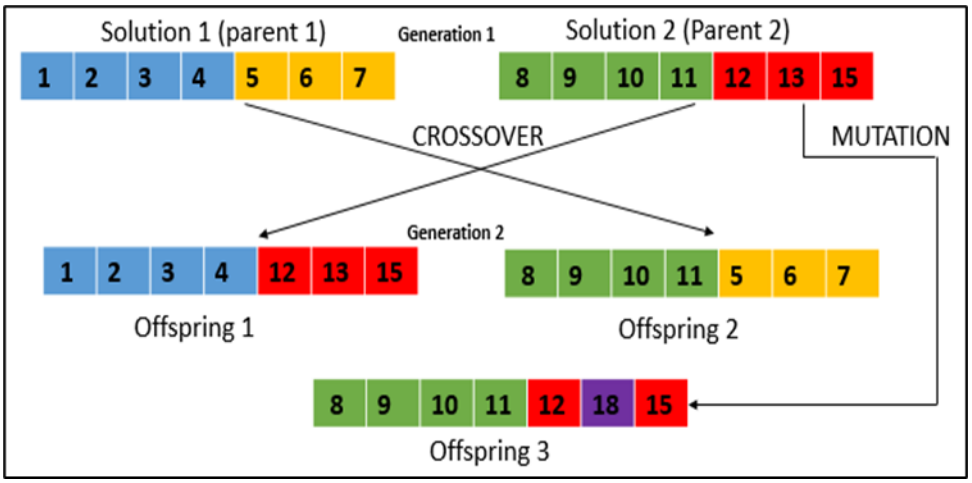

Fig 3: Crossover and Mutation operation in Evolutionary Algorithms

Swarm optimization techniques[5] drive their motivation from the group or swarm behavior of animals which live in groups. Such groups are also driven by survival of the fittest and follow hierarchical division of population based on fitness. Such behaviors are found in nature among ant colonies, animal herding, bird flocking and fish schooling to name some few. Swarm optimization use varied movement strategies to involve both exploration (calculated position movements) and exploitation (random position movements) by applying varied space position variations through vector mathematical equations as shown in Fig. 4. Some very well know swarm optimization methodologies are Particle swarm optimization, Ant colony optimization, and Group Search Optimization and Bat algorithms.

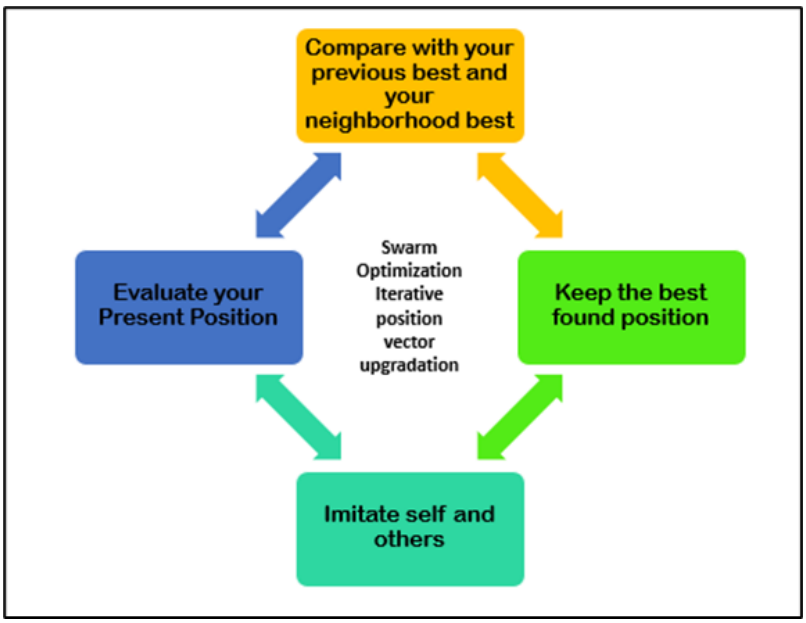

Fig 4: Swarm Optimization iterative mechanism

Both the nature inspired methodologies have been employed in solving various real world complex optimization problems and successfully reported finding acceptable solution. Next section elaborates on current state of the art in five main application areas of these two methodologies.

III. Real World Applications

Health Informatics: In health informatics, gene microarray data handling for gene selection and classification has been done using cukoo search[6] along with artificial bee colony optimization for exploitation of the microarray space and genetic algorithm for exploration of the microarray space. In another research[7], a multiobjective Grasshoper algorithm is used in the layers of neural network for Alzheimer's disease prediction. In another research[8], authors have developed hybrid metaheuristic algorithmic technique for selecting significant features from COVID datasets. The algorithm was named as "Manta Ray Foraging based Golden Ratio Optimizer (MRFGRO)". For heart disease diagnosis, another novel meta-heuristic technique was developed named "Evolution with Mathematical Diversification of Population (i.e., Ev-MDP)"[9]. The authors used the "Statlog Heart Dataset" from the UCI repository. In another research[10], meta-heuristics were successfully applied for assessing the type of breast cancer disease. Meta-heuristics have been successfully applied in the training phase of neural networks to detect MPOX disease[11].

Social Network Analysis: Social networks data is a complex data, whereby data is seen in the form of complex graphs. The graphs are complex as they show complex and dense connectivity among millions and billions of nodes. Many problems such as community detection, influence maximization and link prediction have been categorized as complex optimization problems in such a type of dataset. Therefore, such datasets has seen quite a good applications of meta-heuristic algorithms for solving these complex optimization problems. In a research [12], a nature inspired algorithm based on forest fire model was applied for modelling of spread of rumors. Another metaheuristic based cukkoo search algorithmic approach13 was developed for detecting communities in social networks. Another hybrid approach using Group Search optimization and TL-GSO (Teachers Learners based GSO)[14] was developed for identification of communities in social networks. A multiobjective Group search optimization approach was also developed[15] to identify communities from social networks.

Transportation and Traffic Management: Metaheuristics have been successfully deployed by various researchers to improve traffic simulation. In a research[16], "Genetic Algorithm (GA)", "Tabu Search (TS)", "Particle Swarm Optimization (PS)" and "Simultaneous Perturbation for Stochastic Approximation algorithm (SPSA)" were utilized to develop a traffic simulation model called SUMO. Utilization of meta-heuristics to solve "traffic signal scheduling (TSS)" problem[17] in a heterogeneous traffic networks was also done. An internal-external traffic metering strategy was developed by[18] for controlling traffic lights optimally by deploying meta heuristic algorithms in traffic networks which are highly congested and have high priority. In a recent research work conducted by[19], network traffic prediction was done by using a metaheuristic driven time series models.

Education: Education sector and optimizing its various resources for effective education has also seen good number of applications using meta-heuristics. In another research[20], an in-depth review on utilization of varied meta-heuristic techniques for University course timetable problem was presented by researchers. Application of meta-heuristic successfully for personalized learning enhancement[21] was also done by researchers. Hyper parameter tuning using metaheuristic for developing a regression based prediction model was done by [22]. Particle swarm optimization was utilized in another research by [23], for adaptively sequencing of curriculum and management of education system in an effective manner.

IV. Conclusion

Through presented research, it has been highlighted that Meta-heuristic algorithmic techniques are sought after algorithmic techniques which have shown significant success in solving many real world complex optimization problems. These techniques garner their motivation from nature in varied ways where exploration and exploitation mechanisms are used in a balanced manner to evolve acceptable solutions in complex search spaces. The presented research has highlighted the base design strategies behind swarm and evolutionary meta-heuristic algorithms. The discussion is presented in a simple manner to give reader a comprehensive and clear guide through the base mechanisms of such nature inspired methodologies. An in-depth applications in four major application areas named health sector, social network analysis, Transportation and traffic management and education is presented for researchers in this field to scrutinize current applications and future research prospects.

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