

Ant Algorithms: Review and Future Applications

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Extended Abstract

A search for a robust optimization methodology for addressing dynamic problems in business and engineering has been in research for the past decade. One such tool in the array of algorithms is the Ant algorithms, inspired by the behavior of the real ants. These algorithms fall in the category of search meta-heuristics, which are used to arrive at the best possible solution from an initial one. The natural ant colonies exhibit the application of adhoc and dynamic decision-making process in their day-to-day living activities such as foraging and brooding that can definitely be used as a tool to tackle the mercurial scenarios present in the current industrial and manufacturing environment. This paper presents an overview of the concept of Ant algorithms and provides a review of its applications to solve real world problems.

Keywords

Ant algorithms, meta-heuristics, search algorithm

1. Introduction

The ever-increasing customer satisfaction and variety of products are making the business environment very dynamic. This changing market scene is making many industries to shuffle their manufacturing and distribution strategies and be focused on retaining the customers. A production schedule based on the last forecast is becoming impractical; allocation of resources and changing capacities are becoming more probabilistic. In these dynamic situations application of conventional operation research techniques is time consuming and there is a need for a heuristics that can provide an optimal or near optimal solution. To solve such practical combinatorial optimization problem, in the year 1986 Fred-Glover coined the term Meta-heuristics, which is basically oriented towards generating a global optimal solution for a given problem. Meta-heuristics are a general class of heuristics for solving hard problems. They are sometimes considered as intelligent heuristic search, which can avoid the local optimality.

Ever since the usage of Meta-heuristics they have dramatically undergone change. Laguna [1] classified meta-heuristics based on the design methods into one that uses adaptive memory, another that uses the neighborhood solution space exploration and another as the one that takes into account the number of solutions that is passed along successive iterations. According to Digalakis and Margaritis [2], “Meta heuristics for optimization problem may be described summarily as a walk through neighborhoods search trajectory through the solution domain of the problem”. Meta-heuristics incorporate various strategies inspired from natural behaviors of species, mathematical reasoning, physical science, nervous systems, and statistical mechanics. Studies indicate that the meta-heuristic based search procedures help to arrive at solutions of higher quality to practically hard problems in business and industry. Hao [3] identifies four main approaches in the meta-heuristic algorithms adopted to solve combinatorial optimization problems. They are construction approach, local search approach, evolution approach, and hybrid approach. Current research work is focused on the hybrid approach because of its wide adaptability and applicability to real world problem.

Meta-heuristics find many applications in a variety of practical and difficult combinatorial optimization problems in wide fields ranging from management science to computer science. Under the umbrella of meta-heuristics there are variety of heuristic procedures such as genetic algorithms, greedy random adaptive search procedures, simulated annealing, tabu search and ant algorithms. The applicability of meta-heuristics is problem specific but the primary goal is to find an optimal or a near optimal solution for a given problem. They can be applied to solve difficult network and graph problem, scheduling and control problem, Traveling Salesman Problem (TSP), and vehicle routing problems.

The insect societies exhibit stable and adaptive behaviors required in the industry without a central planning or management [4]. Bios group [5] reports that ant algorithms have been proved to be a quick global optimal solution finder when compared to other heuristic methods such as simulated annealing and genetic algorithms. It also states that the ant algorithms have the quality to find new optimal solution without reinitiating the computations from

scratch [5]. But the condition is that the ant algorithms should have learnt the problem structure to solve so that it can adopt itself to find new solutions similar to the real ant's obstacle overcoming nature. It claims that due to this, "Ant algorithms are ideal for solving problems in the rapidly changing world businesses face today"[5].

This paper describes significant developments and application of the ant algorithms to solve complex optimization problems. The paper is organized as follows. Section 2 describes ant algorithms and the nature of problems that can be solved by using them. Section 3 gives a detailed description of the various practical applications that can be solved by the implementation of ant algorithms followed by a concluding section.

2. Ant Algorithms

The ant algorithms are basically a colony of artificial ants or cooperative agents, designed to solve a particular problem. They are a class of heuristics based search algorithms used to solve many combinatorial optimization problems. These algorithms are probabilistic in nature because they avoid the local minima entrapment and provide very good solutions close to the natural solution. They are inspired by the co-operative behavior exhibited by the real ants in performing various day-to-day activities such as brooding and foraging. Individual real ants are incapable of performing a structured task but an ant colony has great potential to carry out a coordinative activity. The ants' main medium of communication is through the building up of the path through an artificial chemical substance called 'pheromone'. This method of indirect communication is referred to as 'stigmergy' [6]. Whenever an ant leaves their nest to search for food, they lay a trail of pheromone on their path. The number of ants that has traveled on the path determines the strength of the pheromone trail. The ant, which travels the shortest path, reinforces the path with more amount of pheromone, which aids others to follow. After an initial randomization the ants finally arrive at a shortest path. This behavior is known as 'auto catalytic' behavior or the positive feedback mechanism in which reinforcement of the previously most followed route, is more desirable for future search [7]. The famous double bridge experiment by Goss et al. [6] gives a probabilistic model for this type of foraging behavior of ants. The probability with which that the $n+1^{\text{th}}$ ant chooses the upper path ($P_U(n)$) or the lower path ($P_L(n)$) in the bridge is given by the function as given below, where n is the number of ants. The parameters h and k are used to match the model represented with the experimental data. This model is used as the basis for the simulation of ants over a given problem domain.

$$P_U(n) = \frac{(U_n + k)^h}{(U_n + k)^h + (L_n + k)^h} \quad (1)$$

$$P_L(n) + P_U(n) = 1 \quad (2)$$

Inspired by this probabilistic behavior of the real ants, ant algorithms are the software agents that coordinate by updating the information of a common memory similar to the pheromone trail of the real ants. When a large number of these simple artificial agents coordinate based on the memory updation they are able to build good solutions to hard combinatorial optimization problems. Similar to the pheromones, which had a rate of evaporation, the unwanted or the poor quality solution is removed from the solution space. Thus a collective memory is formed which allows the artificial ants to find good solutions in short period of time. In case of dynamic problems, the artificial ants adapt rapidly to the new problem and provide good solutions. The constructive solution building procedure is also driven by problem data and the heuristic function, which is formulated to identify and evaluate further solution space and steps.

Figure 1 represents a generalized flow chart of the ant algorithms. The problem is defined in the form of a network or a graph. All possible links between the components of the network and limiting criteria's are identified. The distance between the nodes and an initial amount of pheromone deposition on the nodes are given as the input to the system. Based on the given constraints the possible feasible solutions are identified and a potential search list is created. This creates the initial solution phase of the system. Once this is created, number of artificial ant agents walk through the neighborhood of the solution to find the optimal solution. When the artificial ant agents travel from one node to another the memory is updated based on the goodness of the solution. The iteration continues until the best solution is obtained based on the terminating conditions specified. In most cases the minimization of the objective function is the goal and the terminating condition is either the number of iterations or the computation time of the problem.

The artificial ant agents have many properties that differentiate them from the real ants and thus evolve different ant algorithms based systems [8]. Along with these unique features that enhances the capabilities of the artificial agents there are other governing parameters such as the optimum number of ants, the pheromone decay rate, and the

constants that make the solution to converge to the experimental results. The various ant algorithms based heuristics, which have had a variety of application in solving practical problems, are discussed in the next section.

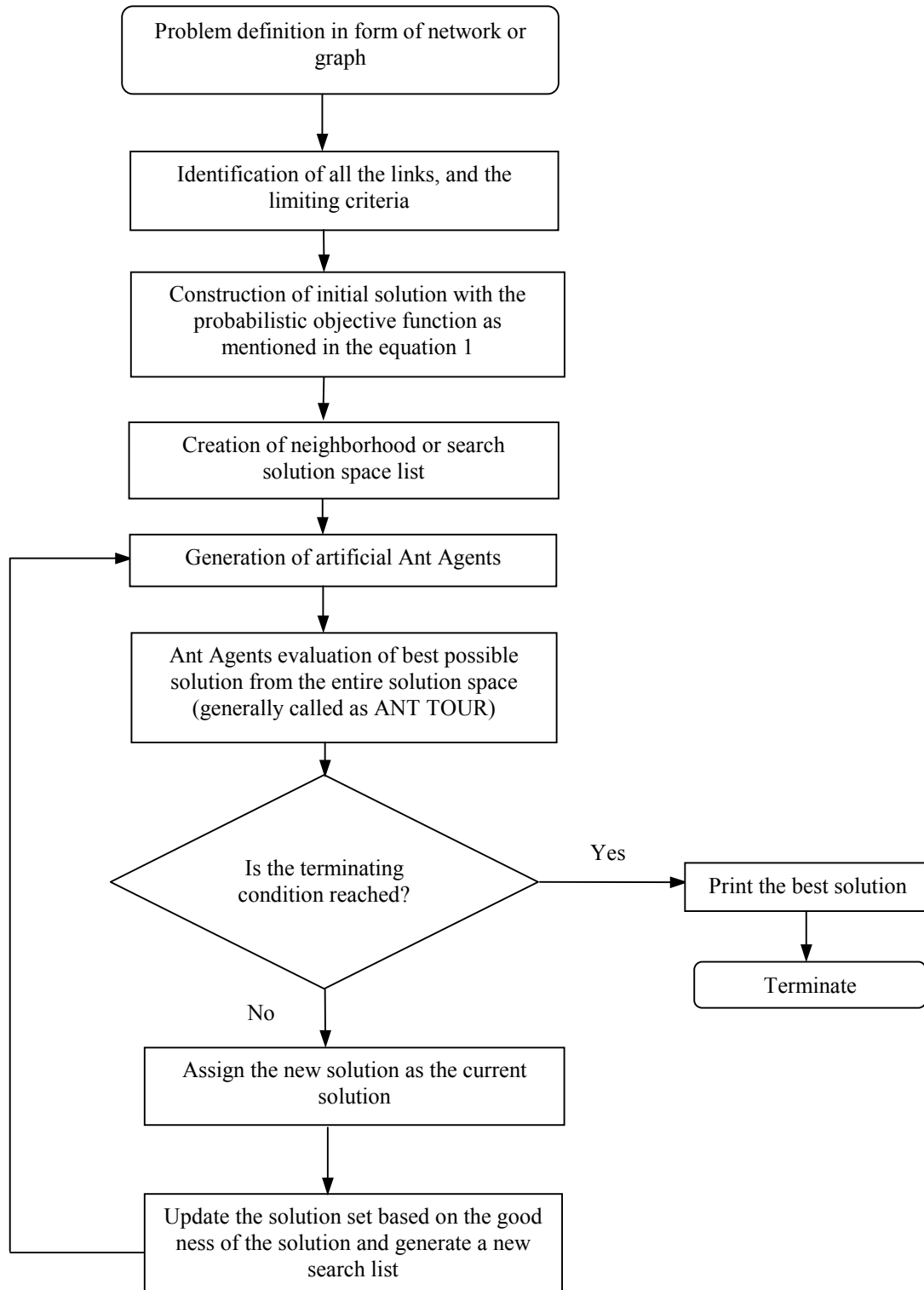


Figure 1: Generalized flow chart for ant algorithms

3. Applications

Industry environment has many optimization applications that span from task allocation jobs like factory scheduling to complex business decision-making process. According to the computer world report [9], real ants exhibit great level of centralized and dynamic behavior of reorienting its path around an obstacle, which is a result of a collective decision making process. This report states that, this behavior is similar to, "General Motors Corporation's Saturn subsidiary which uses distributed systems to control the flow of part assemblies. Instead of having each factory machine's actions preprogrammed and unvarying, Saturn's machines can sense the type and state of a part and adapt their actions on the fly" [9]. This indicates that the new artificial ant agents can be successfully programmed for dynamic environments.

There are many different heuristics named based on the general ant algorithms structure. Dorigo, Maniezzo and Colomi [7, 10] proposed the first class of ant algorithms called the ant system and introduced three types of ant algorithms called the ant-density, the ant quantity, and the ant cycle. The typical problem, which was researched, was the well-known Traveling Salesman Problem (TSP). With the initial success on this there has been an active research contribution towards applying the ant algorithms to the various problem domains. The application of ant algorithms with the related heuristic name as applied to the quadratic assignment problem, traveling salesman problem, vehicle routing problem, connection-oriented network routing, sequential ordering, graph coloring, shortest common sequence problem, frequency assignment problem, multiple knapsack problem, optical network problem, single machine total tardiness problem are dealt extensively by Dorigo and Di Caro [6,11] and Dorigo and Stutzle [12, 13]. In an effort to identify the real time application other than the conventional combinatorial problems, consolidated information about ant algorithms to various practical scenarios are provided in this paper.

According to Cartwright and Hopkins [14] evolutionary algorithms have curtail applications in the development and synthesis of chemicals. The authors provide comparative analysis of algorithms used for the purpose and detail the application of ant system to the chemical synthesis problem. A ten-step reaction was used as an example to compare the results. To highlight the complexity of the problem, imagine that there are 8^{10} (1,073,741,824) possible routes for the chemical reactions right from the initial starting substance to the final synthesized chemical. For this problem the ant system algorithm produced a maximum yield of 70%, which is 30% more than result of the genetic algorithm. This clearly indicates the goodness of ant algorithms and its practical application.

Many applications for the job shop scheduling problems can be found in the literature. Maniezzo and Carbonaro [15] reviewed the various ant algorithms under the framework of Ant Colony Optimization (ACO) algorithm. They also provide a comparative results obtained by the applications of ACO algorithm to many combinatorial optimization problems including job shop scheduling and vehicle routing.

Zwaan and Marques [16] proposed an ant system for the job shop scheduling with reference to the Muth-Thompson 6/6/G/ C_{max} job shop problem. Ten jobs 10 machines and 20 jobs 10 machines problems were studied for a range of C_{max} and the effects of parameters, which govern the ant algorithms, and fine tuning of them was reported. For a known value of C_{max} the optimal solution obtained from ant system was reported to vary from 8 to 14% in case of 10 jobs problem and 26 to 31.9% in case of 20 jobs problem. This elucidates that the optimization of the parameters of the ant algorithms greatly influences the problem it can solve.

Cicirello and Smith [17] introduced the application of AC^2 ant algorithms for decentralized decision-making policies in the shop floor. Typical scenarios considered were the two machines one job, two assembly lines one job, two machines two job and four machines two job types. AC^2 algorithm is compared with two other heuristics such as the random selection heuristic and earliest completion time heuristic. In all the cases for a simulation time frame of 1000 units and 2000-5000 units the AC^2 algorithm was found to give better solution than the other two heuristics.

Gravel et al. [18] applied ant algorithms to the scheduling of jobs in a foundry environment. The algorithm type used was the ACO algorithm with look-ahead features by which the authors obtained better solution than the ACO algorithm without look-ahead features. This elucidates the practical applicability of ant algorithms to common problems faced in the manufacturing industry.

Balad [19] elucidated the application of ant colony optimisation (ACO) algorithm with tabu search for designing a transmission tower. The objective was to design for the minimum tower weight. This application illustrates a discrete-variable optimal structural design process, which has to overcome the local minima. It also states that the lowest weight obtained by using ACO method is superior to many other latest heuristics.

Artificial ants are also used for creating on-line digital arts with the colour deposition tool called the 'ANTBRUSH' [20]. The ant brush is inspired by the food collection process of the real ants, which is done by the transfer of small chunks of food samples from source to home. The colour selection process by the experienced painter involves picking of colours of different intensity based on their previously used sets of colours. Ant algorithms govern the colour selection process resulting in an efficient set of colours that can be cached in the memory for future reference.

By using the ant brush a smooth colour distribution; smooth colour blending and fish bone strokes on images can be created easily than the usage of conventional paintbrushes.

Based on the foraging behavior of the *pachycondyla apicalis ponerin* ants, API (APIcalis) ant algorithms for solving numerical optimization problem was proposed by Monmarché, N., Venturini, G., and Slimane, M [30]. The API ant algorithms proved to outperform genetic algorithm to obtain global solution for a typical search heuristic problem. The general structure of the API ant algorithms also proves to be a possible area of future research to solve continuous and discrete optimization problems.

About 118 papers were reviewed for identifying typical application of ant algorithms for practical industrial and business problems. Only a brief overview of some of the typical applications in real world situations particularly in the manufacturing environment is summarized. Table 1 provides the classification of ant algorithms with the author, year of publication, reference number, the algorithm name and the problem type it can solve. It is arranged in the descending order of the year of the publications.

The authors of this paper are working on the applicability of the ant algorithms to supplier selection process, which is in its novice research stage. Supplier selection process has been extensively researched because of its value adding potential to the customers and suppliers. There are very many algorithms being adopted to select and develop a smart and efficient set of suppliers. Supplier selection problem is a typical multi-criteria decision-making process in which for a given product the best supplier should be selected from an exhaustive list of potential suppliers with various limiting criterions such as price, quality, delivery time and shipment methods. As this proves to be a crucial decision making process for a business, companies are moving towards consolidating their supplier base in an effort to harness great benefits in their supply chain operations. The ant algorithms based supplier selection process will facilitate to pick the best supplier quickly and easily, there by serving as an excellent decision support system. The possibility of application of the ant algorithms to the geometric tolerance synthesis and allocation are some of the future possible areas being explored.

Table: 1 Application of ANT Algorithms

Authors	Year	Reference Number	Algorithm Name	Problem Type
Gravel M., Price W., and Gagn C	2001	18	ACO	Job scheduling in aluminum foundry
Bland, J.A	2001	19	ACO	Structural design problem
Jayaraman, V.K., Kulkarni, B.D., and Gupta, K., et al.	2001	21	ACO	Bioreactors optimization
Doerner, K., Hartl, R.F., and Reimann, M	2001	22,23	ACO	Pickup and delivery problems
Doerner, K., Hartl, R.F., and Reimann, M	2001	24	ACO	Full truck load transportation problems
Jong, de, J and Wiering, M	2001	25	Multiple Ant Colony Systems	Bus stop allocation problem
Baboglu O., Meling, H., Montesor, A	2001	26	Anthill	Peer-to-peer (P2P) networks
Cicirello, V.A	2001	27	AC ²	Shop floor routing
Ramos, V., and Almeida, F	2000	28	Cognitive map model	Image segmentation- Pattern reorganization
Tzafestas, E.S	2000	29	Painter Ants	Digital Art
Monmarché, N., Venturini, G., and Slimane, M	2000	30	API	Numeric optimization
Zhou, Z., and Liu, Z	1999	31	Intelligent Ant algorithm	Dynamic routing in telecommunication networks
Bland, J.A	1999	32	AS (TS)	Layout of facilities
Bland, J.A	1999	33	ACO	Space-planning
Stützle, T	1998	34	ACO	Flow manufacturing
Forsyth, P., and Wren, A	1997	35	Ant System (AS)	Bus driver scheduling

4. Conclusions

Ant algorithms belong to a class of Meta heuristics, which have a gamut of application to practical problems faced in business and industrial environments. The various applications described above highlights that ant algorithms can be applied to many of these practical scenarios. These algorithms are basically inspired by the observation of and applying the various behaviors of real ants such as foraging and brooding behaviors which can provide good solutions to real time optimization problems. The indirect communication and the co-operative interaction of the artificial ant agents, which is inspired from their real living counterpart, exhibit great flexibility and responsiveness to dynamic problems. The application of these algorithms and experimental validation of them is greatly researched owing to their capability to provide near global optimal solution to a given complex problem structure like local search, image mapping and compression, database search. Other than the examples enumerated above there are many unexplored paths where in the ant algorithms can be successfully applied and latest research emphasis is on the use of such swarm-intelligence methodologies.

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