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Research Article

Improvement and Implementation of Best-worst Ant Colony Algorithm

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Abstract: In this study, we introduced the ant colony algorithm of best-worst ant system based on the pheromone update. By update improvements of local pheromone and global pheromone, as well as the optimal solution enhancement to a greater extent and the weakening of the worst solution, the algorithm further increased the difference of pheromone amount between the edge of the optimal path and the edge of the worst path and allowed the ant colony search behavior more focused near the optimal solution. Finally, through simulation experiments to prove that the algorithm can get the optimal solution and the convergence rate is faster than the average ant colony algorithm.

Keywords: Best-worst ant system, pheromone, TSP

INTRODUCTION

Ant Colony Algorithm is a population-based evolutionary algorithm by research on nature collective behavior of ant colony. The algorithm is a stochastic search algorithm, proposed by Italian scholar M. Dorigo for the first time. The algorithm takes full advantage of the process of ant colony search for food for solving TSP, in order to distinguish it from real ant colony system, saying that the algorithm is the artificial ant colony algorithm. With ant colony method for solving NP-complete problems such as TSP problem, the assignment problem and job-shop scheduling problems and good results have been achieved (Marco and Gambardela, 1991). The past 10 years research on ant colony algorithm showed: ant colony algorithm has a strong ability to find solutions for solving combinatorial optimization problems with advantages of distributed computing, easily combined with other methods and strong robustness; in a dynamic environment it showed a high degree of flexibility and robustness (Marco and Gambardela, 1997). In addition to previously recognized genetic algorithm, simulated annealing, taboo search algorithm, neural network algorithm and other popular evolution methods, new entrants to ant colony algorithm also started to emerge and provided a new method for solving system optimization problem of complex and difficult system (Wu, 2007). Although some thinking is still in its infancy, but people have a vague understanding that the man was born in nature, the inspiration seeming to solve the problem should come from nature (Hu *et al*., 2007). This novel and improved system optimization idea put forward by the European scholars, is attracting more and more the attention and research of scholars, the scope of application start all through many scientific and engineering fields (Li and Chen, 2009).

In computation process of ant colony algorithm, transfer of ant colony is guided by the strength of information amount left on to the paths and the distance between cities. Path of ant colony movement is always close to the most informative path. Research of ant colony and ant colony algorithm show that paths of the strongest amount of information are closer to the optimal paths whether real ant colony or artificial ant colony system under normal circumstances (Duan *et al*., 2006). However, it still exists that the most informative path is not the optimal path required, in the artificial ant colony system, this phenomenon often exists. Due to the artificial ant colony systems, the initial amount of information on the path is the same; the information obtained by ant colony on the first path is the distance information between the cities, for this time ant colony algorithm is equivalent to greedy algorithm. Information left for the first cycle of ants on the path does not necessarily reflect the most excellent direction of the path, especially when less number of individuals in the ant colony or more calculated path combination, there is no reason to ensure that the first path ant colony created guided ant colony to the global optimal path. After the first iteration, information left by ant colony group because of a positive feedback made this path not optimal path and may enhance path which may be very far from the optimal path, thereby to prevent ants from finding better global optimal path.

Not only for the first cycle the path established may be misleading the ant colony, for any one cycle, the used information is more evenly distributed in all directions for this cycle, the release of pheromones may mislead decision-making later. Solutions identified by ant colony may be certainly enhanced by a method, pheromone released by ant colony as much as possible do not mislead the later ant colony.

At the same time, ant colony algorithm has shortcomings of long searching time and easy-to-stagnation. Recent studies show that there is a certain relationship between solution quality and the distance of the optimal solution. So the search was focused near the optimal solution found out in the search process and it is basic emphasis for improving algorithm performance.

The Ant Colony Algorithm (ACA) developed a simulation of ants foraging behavior of bionic optimization algorithm. Algorithm through artificial ants randomly search the solution space and the introduction of the pheromone evaporation and enhanced operation to guide the ant colony transfer, the volatilization mechanism of positive feedback, the algorithm has a certain optimization ability. The algorithm has a simple structure, easy to implement and nature of the characteristics of parallelism, in recent years been widely used in solving the Job-shop scheduling, quadratic assignment, backpacks and other issues. Easy to fall into a local extreme point for the basic ant colony algorithm, slow convergence insufficient in the literature on the basis of the Ant Colony System algorithm (ACS), the best-and worst ant swarm optimization (Best-Worst Ant System BWAS) and the largest-smallest ant colony algorithm (MMAS) and the above algorithm is analyzed and compared. A number of classic Traveling Salesman Problem (TSP) application examples show that the improved ant colony algorithm has the accuracy of convergence, global search capability and to reduce the search cost of a significant increase.

In this study, we introduced the ant colony algorithm of best-worst ant system based on the pheromone update. By update improvements of local pheromone and global pheromone, as well as the optimal solution enhancement to a greater extent and the weakening of the worst solution, the algorithm further increased the difference of pheromone amount between the edge of the optimal path and the edge of the worst path and allowed the ant colony search behavior more focused near the optimal solution. Finally, through simulation experiments to prove that the algorithm can get the optimal solution and the convergence rate is faster than the average ant colony algorithm.

SYSTEMS MODEL OF BASIC ANT COLONY ALGORITHM SYSTEM

The basic ant colony algorithm system is the basis of our study on improved ant colony algorithm and it plays a vital role in recent years, we will introduce the model and the description of improved algorithm.

According to the results of the bionics home study, the ability of the ants by virtue of the path optimization can find the shortest path between nest and food, the principle is: the ants leave a volatile secretions (called pheromone on the path), pheromone will gradually over time. Volatile disappear. ants in the foraging process, able to sense the presence of this substance and its strength and in order to guide their direction of motion, tend to move in that movement of high strength and direction of the substances, i.e., the probability to select the path with the path on the strength of the material is proportional to the pheromone intensity of the higher path, select it any more, left in the path the strength of the pheromone, while the intensity of information elements also attract more ants, which form a positive feedback through this positive feedback, the ants could eventually find the best path, resulting in most of the ants will go this path.

Basic ant colony algorithm under TSP problem: Ant system was first used to solve the Traveling Salesman Problem (TSP), the following example was illustrated TSP problem with Ant System. Assign m as the number of ant colony; Assign d_{ij} as distance between cities of i and j; Assign τ (t) residual amount of information on the path (i, j) of connecting cities of i and j at time t, at the initial time amount of information is equal, τ(0) = C is a constant); η said desired degree from city i to city j, it may be determined according to some heuristic algorithms, $\eta_{ij} = 1/d_{ij}$, which was generally taken in the TSP problem.

Ant k (k = 1, 2, ..., m) according to the amount of information on the path decided the shift direction, at time t the formula of probability $P_{ij}^k(t)$ of ant k transferring from city i to city j as follows:

$$P_{ij}^k = \begin{cases} \dfrac{\tau_{ij}^\alpha(t) \times \eta_{ij}^\beta(t)}{\sum \tau_{is}^\alpha(t) \times \eta_{is}^\beta} \\ 0 \quad otherwise \end{cases} \tag{1}$$

where, $j \in allowed_k$, $s \in allowed_k$, $allowed_k = \{0, 1,\ldots, n-1\} - tabu_k$ said the allowed city for ant k to select in next step. Difference between natural ant colony system and artificial ant colony system is a certain memory, $tabu_k$ (k = 1, 2,…, m) is used to record the cities for ant k to traverse, $tabu_k$ has a dynamic adjustment for process of evolution. Artificial ant colony retained the characteristics of pheromone volatile of natural ant colony, with the pass of time, information gradually disappeared for the former, the parameter ρ (0≤ρ<1) indicates the persistence of the pheromone, 1-ρ indicates that the attenuation of the pheromone. After every ant completed access of all cities (n) (ending one cycle), the pheromone amount of each path was adjusted according to (2) and (3):

$$\tau_{ij}(t+n) = \rho.\tau_{ij}(t) + (1-\rho)\Delta\tau_{ij} \quad (2)$$

$$\Delta\tau_{ij} = \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \quad (3)$$

In (3),

$\Delta\tau_{ij}^{k}$: The pheromone amount left in the path (i, j) for ant k in this cycle

$\Delta\tau_{ij}$: The pheromone increment on this cycle in the path (i, j):

$$\Delta\tau_{ij}^{k} = \begin{cases} \frac{Q}{L_k} & \text{if at time } t+1 \text{ for ant } k \text{ passed}(i,j) \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

In (4),

Q : A constant indicating the amount of pheromone left by ants

L_k : The length of the path for ant k in the loop. At the initial time, $\tau_{ij}(0) = C$, $\Delta\tau_{ij} = 0$ (i, j = 0, 1,.., n-1)

η_{ij} : The desired degree going from city i to city j, choosing a different heuristic algorithm based on the specific issues to determine

τ_{ij}, $\Delta\tau_{ij}$, & P_{ij}^{k} : Representation of different forms

M. Dorigo defined three different models: Ant cycle system, Ant quantity system and Ant density system, the difference between them is different from of (4).
In ant quantity system model:

$$\Delta\tau_{ij}^{k} = \begin{cases} \frac{Q}{d_{ij}} & \text{if at time } t+1 \text{ for ant } k \text{ passed}(i,j) \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

In ant density system model:

$$\Delta\tau_{ij}^{k} = \begin{cases} Q & \text{if at time } t+1 \text{ for ant } k \text{ passed}(i,j) \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

Ant quantity system model and ant density system model use the local information, ant cycle system model utilizes the whole information, it has better performance when solving TSP and it is usually adopted as the basic model.

Steps of basic ant colony algorithm: The main steps of the basic ant colony algorithm are as follows:

1. nc = 0 (nc is the number of search). Initialization of τ_{ij} and $\Delta\tau_{ij}$, m ants on n vertices
2. Starting point of each ant were in the solution set, according to the transition probability P_{ij}^{k} for ant k (k = 1, 2, ..., m) to transfer to next vertex j, update the solution set of (j in solution set)
3. Calculate objective function value of the ants (the length of the path through the search), recording the best solution (path)
4. Update the pheromone
5. After one search completed, $\Delta\tau_{ij}$, set to 0, nc + +
6. If nc was less than default number of iterations, then go to step 2

Time complexity of algorithm is O ($nc.m.n^2$). Algorithm parameter selection is currently no theoretical basis, the parameters Q, α, β, ρ can be based on testing to determine the optimal, combination of empirical results is $1 \le \alpha \le 5$; $1 \le \beta \le 5$; $0.5 \le \rho \le 0.99$, 0.7 is the best, $1 \le Q \le 10000$.

Several improved ant colony optimization algorithms: In recent years, research on ant colony optimization algorithm is focused on how to improve the performance of ant colony algorithm. The improved algorithm also tested TSP. They have different specific control aspects of search algorithm; all of these improvements are based on more powerful development for the optimal solution to guide the search process. Listed below are the five kinds of improved ant systems, they are Ant System with elitist strategy (A Selite), Rank-Based Version of Ant System (AS rank), Ant Colony System (ACS), Max-Min Ant System (MMAS) and we want to achieve Best-Worst Ant System (BWAS).

Through improved strategy of path selection and global correction of information amount rules, introduction of the idea of ants division of labor and collaborative learning in ant colony and collaborative work, it can improve adaptive capacity of ant colony algorithm. Based on this idea, the introduction of an optimization algorithm-adaptive ant colony algorithm, it appears also to bring great change of the development of ant colony algorithm.

BEST-WORST ANT SYSTEM (BWAS)

Best-worst ant system is further enhanced the guidance of search process based on ant colony algorithm, made search of ant more concentrated within the field of best path in the current cycle. The task of ant colony algorithm guided the solution of problem to evolve towards the direction of global optimum. This establishment of the mechanism is based on that it is more likely to find a better solution with a better solution, therefore search concentrated on a near optimal solution is reasonable.

The basic idea of best-worst ant system is a greater extent of enhancement to optimal solution, while a greater extent weakened to the worst solution, pheromone differences further increase between the optimal path and the edge of the worst path, so that the search behavior of ants is more focused near optimal solution. The followings are specific about update strategy and main steps of best-worst ant system.

In order to overcome the shortcomings of slow convergent speed and low searching efficiency existing in traditional best-worst ant system, an Improved Best-Worst Ant System Algorithm (IEABWAS) was presented based on heuristic evolutionary algorithm. The principle of the algorithm is as follows: Firstly, a heuristic crossover operator was imported; in iteration of the algorithm, the heuristic evolving operators were used to crossover between the best ant and the second-best ant for generating superior ant to replace the worst ant. Meanwhile, the searching ability of the algorithm was improved by adjusting the updating method of the pheromone of best-worst ant system. The experiment results show that, compared with the traditional best-worst ant system algorithm, this new algorithm to solve complex Traveling Salesman Problem (TSP) has not only stronger searching ability but also can accelerate convergent speed and the algorithm performance is improved greatly in the end.

Pheromone trajectory update of ant colony system model: The pheromone update of ant colony system model is built in on the basis of overall information, which made superiority of ant colony system embody compared to other models and it's update formula:

$$\tau_{ij}(t+n) = \rho_1 \cdot \tau_{ij}(t) + \Delta\tau_{ij}(t, t+n)$$
$$\Delta\tau_{ij}(t, t+n) = \sum_{k=1}^{k} \Delta\tau_{ij}^{k}(t, t+n) \quad (7)$$

where, ρ_1 and ρ are different, because this equation is no longer to be updated on track at each step, but to update the amount of track after a complete path (n steps).

Global update rule and local update rule for ant colony system:

Global update rule: In ant colony system, only the global best ants are allowed to release pheromones. The aim of using this choice and pseudo-random proportional rule is to make the search process more guidance: ants search mainly concentrated in the current best fields so far identified in the circulation areas. Global update performed after all ants have completed their paths, applied (8) to update paths established:

$$\tau(r,s) \leftarrow (1-\alpha)\cdot\tau(r,s) + \alpha\cdot\Delta\tau(r,s)$$
$$\Delta\tau(r,s) = \begin{cases} (L_{gb})^{-1} & \text{if}(r,s) \in \textit{global optimal path} \\ 0 & \textit{otherwise} \end{cases} \quad (8)$$

Among them,
α : The pheromone volatile parameter, $0<\alpha<1$
L_{gb} : The global optimal path so far to be identified

Only pheromone on the edge of those belonging to the global optimal path will be enhanced.

The local update rule: In the establishment process of a solution, ants used the local update rules of (9) to update hormone on the passing sides:

$$\tau(r,s) \leftarrow (1-\rho)\cdot\tau(r,s) + \rho\cdot\Delta\tau(r,s) \quad (9)$$

Among them, ρ is a parameter, $0<\rho<1$. It was found from the experiment that settings of $\tau_0 = (nL_{nn})^{-1}$ can produce good results, where n is the number of cities, L_{nn} is a path length inspired by the shortest field. When an ant moved from city i to city j, application of the local update rules makes the appropriate amount of pheromone track gradually reduced. Experiments show that the local update rules can effectively prevent the ants from converges to the same path.

Working process of best-worst ant system: Best-worst ant system modifies the global update formula in ant colony system. After all ants completed one cycle, pheromone update of the passed path increased. If (r, s) is one side of ants paths of the worst ant and it is not side of the best ant, the pheromone amount of the edge according to Eq. (10) to update:

$$\tau(r,s) = (1-\rho)\cdot\tau(r,s) - \varepsilon\cdot\frac{L_{worst}}{L_{best}} \quad (10)$$

Among them,
ε : A parameter the algorithm introduced
L_{worst} : The worst ant's path length in the current cycle
L_{best} : The path length of optimal ant in current loop
τ (r, s) : The amount of track between city r and city s

Specific steps of the algorithm as follows:

1. Initialization
2. According to formula (1) and (7) for ants to choose the path
3. Once generated an ant's path according to the formula (9) to conduct a local update rules
4. Repeat step (2) and (3) until every ant generated a path
5. Select the best and worst of ants
6. The best ant according to the formula (8) to perform a global update rule
7. The worst ant according to the formula (10) to perform a global update rule

Repeat steps (1) and (7) until the number of perforation achieved a specified number or no better solution appears in a number of continuous steps.

The ant colony algorithm for cluster analysis, inspired by ants piled their bodies and classification of their larvae. From the principle of ant colony algorithm-based clustering method can be divided into two types: one is the formation of principles to achieve data clustering based on the ant heap, the other is the use of ants foraging principle, the use of information to the cluster analysis. Ant colony algorithm is introduced into the discovery of classification rules, is the use of ant colony foraging theory in the database search on randomly generated a set of rules to select the optimal coverage until the database can be the set of rules, thus

Table 1: 20 cities coordinate data

υ_0	υ_1	υ_2	υ_3	υ_4
(5.294, 1.588)	(4.286, 3.622)	(4.719, 2.744)	(4.185, 2.230)	(0.915, 3.821)
υ_5	υ_6	υ_7	υ_8	υ_9
(4.771, 6.041)	(1.524, 2.871)	(3.447, 2.111)	(3.718, 3.665)	(2.649, 2.556)
υ_{10}	υ_{11}	υ_{12}	υ_{13}	υ_{14}
(4.339, 1.194)	(4.660, 2.949)	(1.232, 6.440)	(5.036, 0.244)	(2.710, 3.140)
υ_{15}	υ_{16}	υ_{17}	υ_{18}	υ_{19}
(1.072, 3.454)	(5.855, 6.203)	(0.194, 1.862)	(1.762, 2.693)	(2.682, 6.097)

Table 2: Comparative calculations between improved ant colony algorithm and basic ant colony algorithm

Algorithm name	Best computing solution	Average solution	Actual optimal solution	Average solution relative error /%
Basic ant colony algorithm	24.526	26.207	24.522	6.9
Improved ant colony algorithm	24.522	24.522	24.522	0.0

excavated is implicit in the database in the rules, to establish the optimal classification model. The initial conditions of the ant colony algorithm to search for the set of discovery rules are empty and the training set contains all the training samples. Ants search time to complete the rule generation, rule pruning and pheromone updating the three tasks. A search to generate a rule and this rule to the discovery rule set, covered by the rule of training samples from the training set to delete. If not covered by the number of training samples is greater than the user-defined threshold that is not covered by the number of samples, repeat the above process, the final algorithm will be a set of optimal set of classification rules.

The earliest study in this area Deneubourg *et al*. according to the similarity of data objects and their surrounding objects, so that the ants move randomly picked up or put down the data object in order to achieve the objective of clustering data, the basic model been successfully applied to the field of robotics. The Lumer first improve this algorithm, the LF algorithm. Wu (2007) and Hu *et al*. (2007) from a different perspective on the LF algorithm to improve and achieved certain results in the cluster analysis using the ant colony algorithm. In recent years, scholars in this area has never ceased and also made certain findings.

SIMULATION EXPERIMENTS AND RESULTS ANALYSIS

Taking 20 cities TSP problem as an example, 20 cities TSP problem is a simple TSP problem, it is mainly to solve the shortest path for a connection between all the cities under a traversal of all cities. Given the coordinates of the 20 cities, such as shown in Table 1.

Parameter settings for the basic ant colony algorithm are $\alpha = 1$, $\beta = 2$, $\rho = 0.7$, $Q = 1$, $m = 20$, the number of iterations is 100. ε Which the improved ant colony algorithm added is equal to 1.0. Experimental results are shown in Table 2.

Corresponding path Obtained by the optimal solution is:

υ_0-υ_{13}-υ_{10}-υ_3-υ_7-υ_9-υ_{14}-υ_{18}-υ_6-υ_{17}-υ_{15}-υ_4-υ_{12}-υ_{19}-υ_5-υ_{16}-υ_8-υ_1-υ_{11}-υ_2-υ_0

Experiments show that for each execution cycle global update formula of the worst ant can improve the performance of the algorithm. Convergence rate of best-worst ant system is faster than ant colony system.

This is mainly because in each cycle trajectory update being in this way, the amount of pheromone on the worst path will be further weakened and for the next cycle, the worst side of the path is increasingly less attractive to the ants, then they are more inclined to choose side of the optimal path in a loop, thus ants search for new paths in the vicinity of the optimal path with a higher probability. In short, the search focused on the identified near the optimal solution more quickly, which makes the algorithm faster to converge.

Analysis of the rate of convergence can also know that the choice of the biggest number of ant's cycle is to ensure a large enough search space, so the possibility of the optimal solution will increase. Therefore, when the scale of the problem the expands, the maximum number of ant cycle should be appropriately expanded, but in order to ensure the enforceability of the program, the maximum number of ants cycle should not be too large.

CONCLUSION

In this study, the main achievement of basic ant colony algorithm and another ant colony algorithm with superior optimization of the global and local pheromone update rule to improve search efficiency and quality, in order to compare and confirm the superiority of ant colony algorithm.

Ant colony algorithm was founded more than a decade; groundbreaking research progresses have taken place both in algorithm theory and algorithm application. As a cutting-edge of the hot research field, ant colony algorithm has aroused concern of more and more domestic and foreign researchers, its range of applications involved almost too various optimization fields, also the ant colony algorithm bionic hardware shows this new optimization algorithm has shown strong vitality and broad prospects for development. Although ant colony algorithm has been studied not long, there are still some problems in this area need further study and solve, but the theoretical study and practical application show that it is a promising bionic optimization method.

With the acceleration of progress and social development of human knowledge, bionic intelligent and optimization of systems theory will increasingly become a powerful tool for scientific understanding and engineering practice. Therefore, research on ant colony algorithm theory and its applications is bound to be a long-term research project. It is believed that with the deepening of bionic intelligent systems theory and applied research, ant colony algorithm as the emerging bionic optimization algorithm will show a broader, more compelling prospects for development.

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