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Hybrid Ant Colony Optimization Using Memetic Algorithm for Traveling Salesman Problem

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***Abstract* - Ant colony optimization was originally presented under the inspiration during collective behavior study results on real ant system, and it has strong robustness and easy to combine with other methods in optimization. Although ant colony optimization for the heuristic solution of hard combinational optimization problems enjoy a rapidly growing popularity, but little research is conducted on the optimum configuration strategy for the adjustable parameters in the ant colony optimization, and the performance of ant colony optimization depends on the appropriate setting of parameters which requires both human experience and luck to some extend. Memetic algorithm is a population-based heuristic search approach which can be used to solve combinatorial optimization problem based on cultural evolution. Based on the introduction of these two meta-heuristic algorithms, a novel kind of adjustable parameters configuration strategy based on memetic algorithm is developed in this paper, and the feasibility and effectiveness of this approach are also verified through the famous Traveling Salesman Problem(TSP). This hybrid approach is also valid for other types of combinational optimization problems.**

I. INTRODUCTION

Algorithms based on the foraging behavior of ants have first been introduced by Dorigo in [1] and were formalized as a new meta-heuristic termed Ant Colony Optimization in 1999 [2]. Ant colony optimization has been inspired by the observation on real ant colony's foraging behavior, and on that ants can often find the shortest path between food source and their nest. A schematic diagram of the natural processes that the ant colony optimization mimic is shown in Fig. 1.

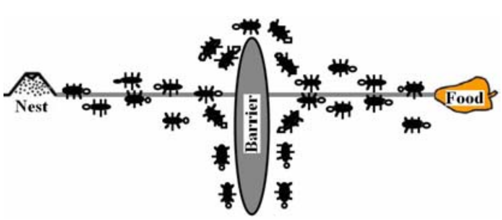

Fig. 1 Schematic diagram of ant colony optimization

The principle of this phenomenon is that ants deposit a chemical substance (called pheromone) on the ground, thus, they mark a path by the pheromone trail. In this process, a kind of positive feedback mechanism is adopted [3]. An ant encountering a previously laid trail can detect the dense of pheromone trail. It decides with high probability to follow a shortest path, and reinforce the trail with its own pheromone. The larger amount of the pheromone is on a particular path, the larger probability is that an ant selects that path and the path's pheromone trial will become denser. At last, the ant colony collectively mark the shortest path, which has the largest pheromone amount. Such simple indirect communication way among ants embodies actually a kind of collective learning mechanism. This process is thus characterized by a positive feedback loop, where the probability with which an ant chooses a path increases with the number of ants that previously chose the same path. With the above positive feedback mechanism, all ants will choose the shorter path in the end. The promising ant colony optimization is a relatively new optimization technique, which is also a model-based approach for solving hard combinatorial optimization problems. It has been applied extensively to benchmark problems such as the Traveling Salesman Problem(TSP), the Job-shop Scheduling Problem(JSP), the Vehicle Routing Problem(VRP), Gragh Coloring Problem(GCP), the Quadratic Assignment Problem(QAP). More recently, the approach has been extended to continuous search domains [4].

Memetic algorithm is population-based heuristic search approaches which can be used to solve combinatorial optimization problems based on cultural evolution [5, 6]. It is inspired by Dawkins' notion of a "meme" defined as a unit of information that reproduces itself while people exchange ideas. A meme is usually modified by the person before passing it to the next generation. Memetic algorithm is similar to genetic algorithm, but the elements that form a chromosome are called memes, not genes. The unique aspect of the memetic algorithm is that all chromosomes and offsprings are allowed to gain some experience, through a local search, before being involved in the evolutionary process. Memetic algorithm is a marriage between a population-based global search, like genetic algorithms, and the local search made by each of the individuals. A schematic diagram of the memetic algorithm is shown in Fig. 2.

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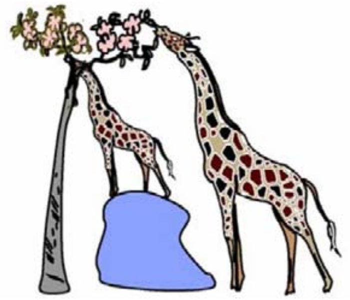

Fig. 2 Schematic diagram of memetic algorithm

Given a representation of an optimization problem, a certain number of individuals are created. The state of these individuals can be chosen randomly or according to a certain initialization procedure. After that, each individual makes local search. When the individual has reached a certain development, it interacts with the other members of the population. The local refinement strategy used to improve the individuals representing solutions provided by memetic algorithms is tabu search. The first element of the initial population is the one obtained when all cells are assigned to the nearest switch. This first chromosome is created therefore in a deterministic way. The creation of other chromosomes of the population is probabilistic. All chromosomes of the population verify the unique assignment constraint, but not necessarily the constraint of the switches' capacity.

Although ant colony optimization for the heuristic solution of combinational optimization problems enjoy a rapidly growing popularity, but little research is on the optimum configuration strategy for the adjustable parameters in the ant colony optimization [7, 8]. The appropriate setting of the adjustable parameters requires both human experience and luck to some extend. In this paper, a novel kind of adjustable parameters configuration strategy based on memetic algorithm is devised and implemented, and the feasibility and effectiveness of this scheme are verified through the famous TSP. The remainder of this paper is organized as follows. Section 2 introduces the mathematical model of ant colony optimization. Subsequently, a hybrid ant colony optimization using memetic algorithm is developed in Section 3, and the outline of the improved memetic algorithm is also given in this section. Then, in Section 4, series of experiments are conducted, which take the example of TSP. Our concluding remarks and future work are contained in Section 5.

II. MATHEMATICAL MODEL OF ANT COLONY ALGORITHM

The ant colony optimization mathematical model has first been applied to the TSP [9]. TSP defines the task of finding a tour of minimal total cost given a set of fully connected nodes(cities) and costs associated with each pair of nodes. The tour must be closed and contain each node exactly once. Instances of the TSP come in many different types, such as symmetric (euclidean or non-euclidean), asymmetric, dynamic and special TSP [10]. But even within the class of symmetric euclidean instances, where distance between two cities is taken to be the geometric distance between them, differences can be found.

We define the transition probability from city *i* to city *j* for the *k*-th ant as follows:

$$p_{ij}^k(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^\alpha [\eta_{ij}]^\beta}{\sum_{k \in allowed_k} [\tau_{ik}(t)]^\alpha [\eta_{ik}]^\beta} & if \quad j \in allowed_k \\ 0 & otherwise \end{cases} \quad (1)$$

Where $allowed_k$={*N*-tabu$_k$}, α and β are parameters that control the relative importance of trail versus visibility, η_{ij} is the heuristic desirability, and $\eta_{ij} = 1/d_{ij}$ where d_{ij} is the distance between city *i* and city *j*, τ_{ij} is the amount of pheromone trail on edge (*i*, *j*). After the ants in the algorithm ended their tours, the pheromone trail τ_{ij} values of every edge (*i*, *j*) are updated according to the following formula:

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

Where ρ is the local pheromone decay parameter, and $\rho \subset (0,1)$. Then, $1-\rho$ represents the evaporation of trail between time *t* and *t*+*n*,

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

Where $\Delta\tau_{ij}^k$ is the quantity of per unit length of pheromone trail laid on edge (*i*, *j*) by the *k*-th ant between time *t* and *t*+*n*. In the popular ant-cycle model, it is given by:

$$\Delta\tau_{ij}^k = \begin{cases} \dfrac{Q}{L_k} & if \quad k-th \quad ant \quad uses \quad (i,j) \quad in \quad its \quad tour \\ 0 & otherwise \end{cases} \quad (4)$$

Where *Q* is a constant and L_k is the tour length of the *k*-th ant.

This iteration process goes on until a certain termination condition: a certain number of iterations have been achieved, a fixed amount of CPU time has elapsed, or solution quality has been achieved.

III. HYBRID ANT COLONY OPTIMIZATION USING MEMETIC ALGORITHM

How to build a balanced point between exploitation and exploration is the key problem of ant colony optimization, where exploitation means exploiting accumulated knowledge about the problem(knowledge accumulates in the form of different amount of trail on edges), and exploration means exploring new edges(exploration is biased towards short and high trail edges).

The adjustable parameters, i. e., the pheromone decay parameter ρ, the parameter α and β, have direct influence on the convergence property of ant colony optimization. By now, we have not yet developed a mathematical analysis of an optimum configuration method for the parameters the ant colony optimization. Large scale of experiments need to be conducted to investigate the relative strengths and weaknesses of these parameters. In order to optimize the pertinent parameters α, β and ρ, a hybrid ant colony optimization scheme using memetic algorithm is developed in this section.

In the area of optimization, there are two kinds of search methods: global search and local search. Global optimizers are useful when the search space is likely to have many minima, making it hard to locate the true global minimum. Examples of global search methods are memetic algorithm. Memetic algorithm is a search algorithm that uses operators found in natural genetics to guide the trek through a search space. On the other hand, local improvement procedures can quickly find the exact local optimum of a small region of the search space, but are typically poor global searchers. Because local procedures do not guarantee optimality, in practice, several random starting points may be generated and used as input into the local search technique and the best solution is recorded. This optimization technique, commonly known as multi-start algorithm has been used extensively. Nevertheless it is a blind search technique since it does not take into account past information.

Local improvement procedures have been incorporated into memetic algorithm to improve its performance through what could be termed "learning". These techniques have been used successfully to solve a wide variety of realistic problems and will be used here in this paper. Memetic algorithm is population-based approaches for heuristic search in optimization problems. Basically, it is a genetic algorithm that apply a separate local search process to refine individuals. One big difference between memes and genes is that memes are processed and possibly improved by the people that hold them - something that cannot happen to genes.

In each iteration of the ant colony optimization, two memetic algorithm ants are selected from the ant population. This selection is done by using a tournament selection algorithm of size 2. Each of the two selected ants are then asked to build their TSP tours. Each memetic algorithm ant stores its values of the three encoded parameters. The α and β parameters are used by the ants to choose the next city to visit. Local update of the pheromone trail is done by each ant using the value of its ρ parameter. Once the tours are completed, the ant colony optimization is checked to see whether a new tour has been found. The global update of the pheromone trail is done by the ant that produced the best overall tour using the encoded value of the ρ parameter.

To construct a hybrid ant colony optimization system using memetic algorithm to optimize the pertinent parameters, the region of each parameter in ant colony optimization is defined according to simulation experience. After which, the memetic algorithm is used to optimize the pertinent parameters in ant colony optimization model. Basically, the nearest regions of each adjustable parameter in ant colony optimization system are shown as follows:

$$\begin{cases} 0 \le \alpha \le 5 \\ 0 \le \beta \le 5 \\ 0.1 \le \rho \le 0.99 \end{cases} \tag{5}$$

The following figure 3 describes the algorithm used to optimize the pertinent parameters in ant colony optimization system.

PROCEDURE Parameters optimization in ant colony optimization using memetic algorithm
BEGIN
Step 1: **Initialize**
Generate an initial memetic algorithm population according to each parameters(α, β and ρ) own range as in Eq. (5).
Step 2: **For** each individual in the population
(1) Perform local search on it according to corresponding range;
(2) Replace the genotype in the population with the locally improved solution.
End For
Step 3:
(1) Evaluate all individuals in the population;
(2) Apply standard memetic algorithm operators to create a new population; i.e., Selection, Mutation and Crossover.
Step 4: **Stopping condition satisfied?**
(1) **Yes:** stop and output results;
(2) **No:** goto step 2.
END

Fig. 3 The outline of the improved memetic algorithm

IV. EXPERIMENTAL RESULTS

In order to investigate the feasibility and effectiveness of the hybrid ant colony optimization scheme using memetic algorithm, a series of experiments are conducted on EIL51TSP (It is composed of 51 cities). The hybrid ant colony optimization using memetic algorithm has been coded in Matlab

Version 6.5 and implemented on PC-compatible with 512 Mb of RAM under the Windows XP.

Each memetic algorithm ant was encoded by a 27 bit string composed of three parameters (the pertinent parameters α , β and ρ) encoded using 9 bits each. Starting with random parameter combinations from a sensible range, our hybrid approach evolves the parameters at runtime. The evolved parameters are usually similar to the standard ones, but yield improved solutions for certain problem instances. The mean evolved values (20 times) of ant colony optimization parameters are as follows:

$$\begin{cases} \alpha^* = 1.3 \\ \beta^* = 4.7 \\ \rho^* = 0.8 \end{cases} \tag{6}$$

The initialized cities and the best tour (solution) of EIL51TSP are given in Fig. 4 and Fig. 5.

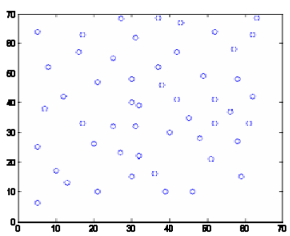

Fig. 4 The initialized cities of EIL51TSP

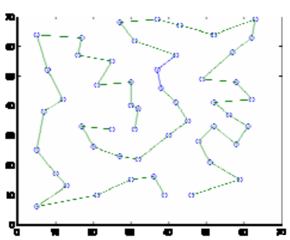

Fig. 5 The best tour (solution) of EIL51TSP

It is obvious that this novel approach can help to improve the performance by helping out good solutions stuck at local minima of the search space. For large TSP problems, where optimal solutions are intractable or not desired, this hybrid approach could also provide good solutions faster than the traditional ant colony optimization. It would be interesting to apply memetic models to other ant colony optimization algorithms and other combinatorial optimization problems.

V. CONCLUDSIONS AND FUTURE WORK

This paper has proposed a hybrid ant colony optimization with memetic algorithm. Memetic algorithm is used to optimize the adjustable parameters in ant colony optimization system, and this scheme is conducted on EIL51TSP. Case studies have shown that this approach is practical and effective. This suggests that this hybrid ant colony optimization with memetic algorithm may be an efficient way for other type of optimization problems.

In the future, we plan to apply the novel approach proposed in this paper to other combinatorial optimization problems. Another area of interest is dynamic pertinent parameters re-optimization of ants as agents as the ant's attitude towards risk. We are also interested to see how hybrid ant colony optimization with memetic algorithm performs in dynamic settings such as a TSP with changing distances between cities.

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