The Development of the Ant Algorithm for Solving the Vehicle Routing Problems

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Abstract: This article presents the results of research and development of modification of ant algorithms for solving vehicle routing problems with a variety of verification. The problem is NP-hard - this class of problems has a no polynomial complexity, they do not have accurate decisions now. The ant algorithm belongs to a class of algorithms based on Swarn intelligence. The concept of swarm intelligence was introduced by Gerardo Beni and Wang jing in 1989 [1]. Swarm intelligence is a self-organizing system, consisting of many agents, representing a multi-agent system. Agents obey simple rules of behavior in the environment. Their simple interaction determines a collective adaptation. Thus, the formation of swarm intelligence is based on the behavior of simple agents. Due to the interaction between the agents, the system forms a collective "mind", "memory", which is used by all the participants of the system. Examples of such systems are ant colony [2-3], a swarm of bees [4-5], a flock of birds, fish, etc.

Key words: Ant algorithms · "Swarm intelligence" · Simple agents

INTRODUCTION

Standard ant Algorithm: Research in the field of ant algorithms began in the mid 90-ies of XX century, the author of the idea is Marco Dorigo [6-8]. This idea is based on modeling the behavior of ant colonies. Ant colony is a system with very simple rules for autonomous behavior of individuals. However, despite the primitive behavior of each individual ant, the behavior of the whole colony is quite judicious [9]. The basis of the behavior of an ant colony is a low-level communication, through which, overall, the colony is a judicious multi-agent system. A special chemical substance - a pheromone secreted by ants on the passed way, determines the "vision" defines the "greed" of the ants' choice. The closer is the vertex of the graph, the better it is "seen" and the more the agent wants to go into it. Experience of other ants whose information it gets directly from the level of pheromone on each way. Each ant is able to capture the pheromone trail, which the concentration of pheromones on the best route would maintain longer [9]. Let's define the properties of ant according to the example of the Traveling Salesman Problem (TSP). This problem has a particular interest also because it refers to other graph tasks. Based on it, we can solve the following tasks [12]: the search for a Hamiltonian cycle, the task of finding an Euler cycle, planning, the development of the shortest framework, assignments, etc.

- Each ant has its own "memory" that stores the list of cities $J_i$ (tabu list), that the ant $k$, which is in the city $i$ has to visit.
- Ants have a "vision": $\eta = 1/D$, "Vision" defines the "greed" of the ants' choice. The closer is the vertex of the graph, the better it is "seen" and the more the agent wants to go into it.
- Each ant is able to capture the pheromone trail, which will determine the ant's desire to pass on this edge. The pheromone level at time $t$ on the edge $D_i$ will match $\tau(t)$.
- The probability of the ants' transition from the peak $i$ to the peak $j$ will be determined by the following equation [6]:

\[\Delta \tau_{ij,k}(t) = \begin{cases} \frac{Q}{L_k(t)}, & (i,j) \in T_k(t) \\ 0, & (i,j) \notin T_k(t) \end{cases}\]

where \(Q\) – is a parameter with a value of the range of the optimal path, \(L_k(t)\) – is the length of the route \(T_k(t)\). The evaporation of pheromone is determined by the following expression:

\[
\tau_{ij}(t+1) = (1 - p) \cdot \tau_{ij}(t) + \sum_{k=1}^{m} \Delta \tau_{ij,k}(t)
\]

where \(m\) - is the number of ants, \(p\) – is evaporation coefficient (0 ≤ \(p\) ≤ 1)

In this simple ant algorithm, the initial position of the ant colony is defined as followed: the number of agents is equal to the number of peaks in the graph and each agent corresponds to a peak, from which it begins its journey. In the article [10] there are further modifications of ant algorithm. Experiments were conducted on standard benchmarks Eilon [14] - graphs with 30, 50, 75 and 98 peaks. The results were compared with the known best solutions obtained by using the modified genetic algorithm [15].

All the considered graphs are fully connected, so we give only the coordinates of the peaks, the edge weights is defined as the Cartesian distance between the peaks. A computer program was developed for studies. Fig. 2 shows a screenshot of the graphic of program solution for solving the travel agents task, depending on benchmarks Eilon with 30 peaks.

As we can see from the graph, the algorithm coincided in less than a second. Let us consider in detail this experiment in Fig. 3. On the left there is a picture of the solution. Note that the solved problem is the
verification of the classical TSP - geometric TSP. Each peak has two-dimensional coordinates and the length of the edges is equal to the Euclidean distance between the connected peaks. The number of "useful" iterations to stagnation - 7, the size of the colony - 1000 ants. On the right, there is a complete detailing of the solution, which shows that the initial solution has been improved twice. Fig. 4 displays the graph of the CF, which shows that the ant algorithm quickly finds a "good" solution to the first iterations.

A Modified Ant Algorithm for Solving the Problem of Vehicles with Multiple Depots and Time Windows Routing: The developed algorithm was used also for solving transport problems. To adapt the ant algorithm to solve the problem of vehicle routing with (VRP) [15] we
should impose additional restrictions on the properties of ant. When collecting food, the ant, according to the model described above, tries to go round all the points (the location of food) by the shortest way, but it is able to "take the load" of only limited weight. After earning the maximum possible load, the ant returns to the colony and "gets unloaded". Then it repeats these steps in the not visited locations of food, until all the food is collected. The described model of the ants' behavior can solve the verification of the problem of vehicle routing CVRP (with a restricted carrying capacity of the vehicles). Figure 7 shows an example of an ant's behavior for the tasks VRP. A strip in Figure 7 reflects the load of the ant. Reaching the peak 4, the ant definitely returns to the colony (depot) without computing the probability of transition to the other peaks. Next, the trip of this ant will continue with zero loads and the peaks 1, 6, 5, 4 will remain prohibited according to the taboo-list (a list of prohibited peaks). It should be noted that, if we accept transport carrying capacity equal to infinity or sufficiently large, the problem is reduced to finding the minimum of a Hamiltonian cycle.

In the simplest case, the criterion for the optimization problem is the total length of the routes traveled over by the auto park. Also, one of the important criteria to optimize vehicle routing problem is the number of used vehicles. The optimization goal in this case is to reduce this number. Denote the number of involved vehicles by variable m'.

Fig. 5: A benchmark with 75 peaks.

Fig. 6: A benchmark with 98 peaks.

Fig. 7: The behavior of an ant with an additional constraint.
The other boundary condition is the speed of the route. Terms of the task may change dynamically; there are different reasons for this - the changing of the delivery address, the rejection by the customer of goods, the changing of the time window, the human factor in information collection, etc. It is therefore necessary to recalculate the route, which is unfavorable for labor-intensive algorithms. In this situation, the recalculating of the route becomes idle time for the driver. "Acceptable" is the time of recalculating to 10 minutes. Note that at the initial stage the calculation time can be about 30 minutes, as all the transports are initially in the fleet in the initial positions.

Based on the real model of the task, on the example of the transports' department work, we can make a logical conclusion that the problem is a multicriterion and the criteria prices during the period are not constant values. The objective function has to be a multiplicative function of the form:

\[
F^* = \left( \frac{m'}{m} \right)^a \cdot \left( \frac{F}{Q} \right)^b \quad \text{subject to} \quad 0 \leq a, b \leq 1, \quad F \leq Q
\]

where

- \( m' \) is the size of the fleet involved;
- \( m \) is the size of the whole fleet;
Fig. 8: An example of CVRP solution with the following parameters: $\alpha = 1$, $\beta = 4$, working time = 5 seconds.

The model specification. Note that if the coefficient $a$ is zero, the size of the fleet involved does not affect the final solution and the task becomes a classic one-criterion. Conversely, if $b = 0$, the length of the route does not affect.

The listed modification (elite ants, the initial location of the colony, templates and rectifiers) remain actual for this behavior of ants. However, for the considered verification VRP, in consideration of its specificity, the strategy of initial location of the ants' colony may be only "focusing" - a strategy in which the whole colony is located at a one peak [10], as shown in Fig. 8.

In this case, the agents will be initially located at the peak which corresponds to the depot. When solving the MDVRP task, when there are many depots, we use the strategy of "shotgun" - agents are placed at the peaks which correspond to the depot / stores and consistently find the routes. Figure 9 shows an example of solving MDVRP.

In solving the verification VRPTW (with time windows) we must add dependence on the time frames in the calculation of the transition probability of the $k$ ant from peak $i$ to peak $j$. For this, we introduce the following rules.

**Rule 1:** If the load of the agent when it reaches peak $j$ from the peak $i$, exceeds the given carrying capacity $c$, the transition probability $P{i}{j} = 0$. 

Fig. 9: The behavior of an ant with additional restrictions.

$F$ - is total length of the route;

$Q$ - is the total length of the routes of the initial solution;

$a$ - is a coefficient characterizing the "importance" or "price" of the criterion of the number of transports involved;

$b$ - is a coefficient characterizing the "importance" or "price" of the criterion of the total length of routes.

The goal of the optimization - minimization of the function of $F'$. The weights $a$ and $b$ are input parameters for the developed algorithm and should be regulated by the controller. This allows to change the assessment of the effectiveness of problem solving for the same algorithm without major changes in
Rule 2: If routes time by reaching the peak $j$ from the peak $i$, exceeds the interval of the time window $f_j$, the transition probability $P_{ij} = 0$.

Rule 3: If the probability of transition to any other previously not visited peak, insufficient depot, from the peak $i$ is equal to zero, the agent completes the route returning to the depot.

Considering the first two rules, the expression (1) takes the following form:

$$ P_{ij,k}(t) = \frac{[\tau_{ij}(t)]^\alpha \cdot [\eta_{ij}(t)]^\beta}{\sum_{k \in J_{ij,k}} [\tau_{ij}(t)]^\alpha \cdot [\eta_{ij}(t)]^\beta} $$

where
$$ P_{ij,k}(t) = 0, j \notin J_{i,k} $$
$$ P_{ij,k}(t) = 0, T_{k,t} + D_{i,j} > f_j $$
$$ P_{ij,k}(t) = 0, W_{k,i} + d_j > c $$

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CONCLUSION

This article gives a modified algorithm based on the ideas of swarm intelligence for solving the vehicle routing problem, considering the verifications CVRP, VRPTW, MDVRP. A modified ant algorithm was developed, it takes into account the specificity and the boundary conditions of the problem. A mathematical model of the problem is presented, a multiplicative objective function was developed, it takes into account all the criteria for the task. Computer software applications were developed, they implement the described algorithms. The conducted experimental researches showed the effectiveness of the proposed modifications of the ant algorithm compared to the standard ant algorithm.
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