ACO for Continuous and Mixed-Variable Optimization

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Abstract. This paper presents how the Ant Colony Optimization (ACO) metaheuristic can be extended to continuous search domains and applied to both continuous and mixed discrete-continuous optimization problems. The paper describes the general underlying idea, enumerates some possible design choices, presents a first implementation, and provides some preliminary results obtained on well-known benchmark problems. The proposed method is compared to other ant, as well as non-ant methods for continuous optimization.

1 Introduction

Optimization algorithms inspired by the ants’ foraging behavior proposed by Dorigo in his PhD thesis in 1992 have been initially used for solving combinatorial optimization problems. They have been eventually formalized into the framework of the Ant Colony Optimization (ACO) metaheuristic [7]. ACO has proven to be an efficient and versatile tool for solving various combinatorial optimization problems. Several versions of ACO have been proposed, but they all follow the same basic ideas:

– search performed by a population of individuals, i.e. simple independent agents,
– incremental construction of solutions,
– probabilistic choice of solution components based on stigmergic information,
– no direct communication between the individuals.

Since the emergence of ant algorithms as an optimization tool, some attempts were also made to use them for tackling continuous optimization problems. However, at the first sight, applying the ACO metaheuristic to continuous domain was not straightforward. Hence, the methods proposed often drew inspiration from ACO, but did not follow exactly the same methodology.

Up to now, only a few ant approaches for continuous optimization have been proposed in the literature. The first method – called Continuous ACO (CACO) – was proposed by Bilchev and Parmee [2] in 1995, and also later used by some others [17, 12]. Other methods include the API algorithm by Monmarché [13], and Continuous Interacting Ant Colony (CIAC), proposed by Dréo and Siarry [9, 8].
Although both CACO and CIAC claim to draw inspiration from the ACO metaheuristic, they do not follow it closely. All the algorithms add some additional mechanisms (e.g. direct communication – CIAC and API – or nest – CACO) that do not exist in regular ACO. They also disregard some other mechanisms that are otherwise characteristic of ACO (e.g. stygmergy – API – or incremental construction of solutions – all of them). CACO and CIAC are dedicated strictly to continuous optimization, while API may also be used for discrete problems.

Contrary to those earlier approaches, this paper presents a way to extend a generic ACO to continuous domains without the need to make any major conceptual changes. Such extended ACO, due to its closeness to the original formulation of ACO, provides an additional advantage – the possibility of tackling mixed discrete-continuous optimization problems. In other words, with ACO it should be now possible to consider problems where some variables are discrete and others are continuous.

The reminder of the paper is organized as follows. Section 2 presents the idea and enumerates the possible design choices. Section 3 provides a short discussion of the proposed solution with regard to other methods for continuous and mixed-variable optimization. Section 4 presents the choices made for the first implementation and compares some initial results with those obtained by competing methods. Finally, Sec. 5 presents the conclusions and future work plans.

2 ACO Extended to Continuous Domain

When ACO is used for combinatorial optimization problems, ants construct solutions incrementally. Each ant starts with an empty solution $S^0$ and at each construction step $i$ a component of the solution is added. The definition of a solution component depends on the problem tackled. In case of the popular example of Traveling Salesman Problem (TSP), a component of the solution is a city that is added to a tour. For other problems the solution components may be defined differently.

In order to choose, which of the available solution components $C^i$ should be added to the current partial solution $S^i$, a probabilistic choice is made. This decision is usually influenced by amount of pheromone $\tau$ associated with available choices, and by heuristic information about the problem. Without the loss of generality, we focus on a case when no heuristic information is used. The probability of choosing a solution component $c \in C^i$ at step $i$ in iteration $t$, assuming that the partial solution constructed so far is $S^i$, is a normalized pheromone value associated with this component:

$$p_{S^ic}(t) = \frac{\tau_{S^ic}(t)}{\sum_{j \in C^i} \tau_{S^ij}(t)} \quad (1)$$

Hence, in case of combinatorial optimization problems, at each construction step the ants make a probabilistic decision according to some discrete probability distribution.