Parallelization Strategies for the Ant System

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**Abstract.** The Ant System is a new meta-heuristic method particularly appropriate to solve hard combinatorial optimization problems. It is a population-based, nature-inspired approach exploiting positive feedback as well as local information and has been applied successfully to a variety of combinatorial optimization problems. The Ant System consists of a set of cooperating agents (artificial ants) and a set of rules that determine the generation, update and usage of local and global information in order to find good solutions. As the structure of the Ant System highly suggests a parallel implementation of the algorithm, in this paper two parallelization strategies for an Ant System implementation are developed and evaluated: the synchronous parallel algorithm and the partially asynchronous parallel algorithm. Using the Traveling Salesman Problem a discrete event simulation is performed, and both strategies are evaluated on the criteria "speedup", "efficiency" and "efficacy". Finally further improvements for an advanced parallel implementation are discussed.

1. **Introduction**

The Ant System [5, 8, 10] is a new member in the class of meta-heuristics (cf. e.g. [15, 16]) to solve hard combinatorial optimization problems. Many well-known methods of this class are modeled on processes in nature. The same is true for the Ant System that imitates real ants searching for food. Real ants are capable to find the shortest path from a food source to their nest without strength of vision. They use an aromatic essence, called pheromone, to communicate information regarding the food source. While ants move along, they lay pheromone on the ground which stimulates other ants rather to follow that trail than to use a new path. The quantity of pheromone a single ant deposits on a path depends on the total length of the path and on the quality of the food source discovered. As other ants observe the pheromone trail and are attracted to follow it, the pheromone on the path will be intensified and reinforced and will therefore attract even more ants. Roughly speaking, pheromone trails leading to rich, nearby food sources will be more frequented and will grow faster than trails leading to low-quality, far away food sources.
The above described behavioral mechanism of real ants was the pattern for a new solving procedure for combinatorial optimization problems. It has inspired Ant System using the following analogies: artificial ants searching the solution space correspond to real ants searching their environment for food, the objective values are the equivalent to the food sources quality and an adaptive memory represents the pheromone trails. The artificial ants are additionally equipped with a local heuristic function to guide their search through the set of feasible solutions.

The application of the Ant System to Traveling Salesman [10], Quadratic Assignment [14], Vehicle Routing [3], Job Shop Scheduling [6], and Graph Coloring [7] is evidence for the methods' versatility. As problem size increases performance becomes a crucial criteria in combinatorial optimization problems. Several attempts on parallelizing heuristics for combinatorial optimization problems have been developed recently [12, 18]. This focus of research and the fact that the structure of the Ant System algorithm is highly suitable for parallelization was the motivation to improve the Ant Systems' performance on solving large problems using parallelization.

The remainder of the paper is organized as follows: initially we explain the Ant System algorithm and use the Traveling Salesman Problem for illustration purposes (Section 2). By identifying the problem-inherent parallelism we develop two parallelization strategies for the Ant System in Section 3. The performance of both strategies is compared using simulation experiments; algorithmic aspects as well as critical performance factors are discussed (Section 4), followed by a brief conclusion.

2. The Ant System Algorithm

In the following the Ant System algorithm is explained on the Traveling Salesman Problem (TSP), probably the most studied problem of combinatorial optimization, where a traveling salesman has to find the shortest route visiting several cities and returning to his home location.

More formally, the TSP can be represented by a complete weighted graph $G = (V, E, d)$ where $V = \{v_1, v_2, \ldots, v_n\}$ is a set of vertices (cities) and $E = \{(v_i, v_j) : i \neq j\}$ is a set of edges. Associated with each edge $(v_i, v_j)$ is a nonnegative weight $d_{ij}$ representing the distance (cost) between cities $v_i$ and $v_j$. The aim is to find a minimum length (cost) tour beginning and ending at the same vertex and visiting each vertex exactly once.

Given an $n$-city TSP, the artificial ants are distributed to the cities according to some rule. At the beginning of an iteration, all cities except