ELSEVIER

Future Generation Computer Systems 16 (2000) v–vii

FGCS
FUTURE GENERATION COMPUTER SYSTEMS

Guest editorial

Ant algorithms[☆]

1. Introduction

Colonies of social insects can exhibit an amazing variety of complex behaviors and have captured, since ever, the interest of biologists and entomologists. More recently, computer scientists have found in the study of social insects behavior a source of inspiration for the design and implementation of novel distributed multi-agent algorithms. In particular, the study of ant colonies behavior turned out to be very fruitful, giving rise to a completely novel field of research, now known as *ant algorithms*. In ant algorithms a colony of relatively simple agents, called *ants*, efficiently carries out complex tasks such as resource optimization and control. Ants act according to a sequential decision making scheme in which a stochastic decision policy is adaptively built and evaluated by the ants themselves.

As Dorigo, Bonabeau, and Theraulaz point out in the first paper of this special issue, the indirect *stigmergic* communication among the ants is the key characteristic of ant algorithms. *Stigmergy* defines a paradigm of indirect and asynchronous communication mediated by an environment. While carrying out their own tasks, ants deposit some chemical substance (called pheromones) or induce some other physical modifications of the environment. These modifications change the way the environment (and in a way, the problem under consideration) is sensed by the other ants in the colony, and implicitly act as signals triggering other ants' behaviors that again generate new modifications that will stimulate other ants and so on (the reader will find all the details about stigmergy in Dorigo, Bonabeau, and Theraulaz's paper). The use of a colony of agents communicating in stigmergic way turned out to be very effective in distributed and network environments, because of its asynchronous and indirect nature, and it revealed to be a very effective way to communicate 'memory' information when solving combinatorial optimization problems. In fact, currently there are many successful applications of ant algorithms to adaptive routing in communications networks and combinatorial optimization problems (see [3] for an overview). Recently, the ant colony optimization (ACO) metaheuristic has been defined [2] as a common framework for a wide set of algorithms developed since 1991 when Dorigo et al. [1,4] proposed the first ACO algorithm.[1] Their algorithm, called Ant System, was applied to the traveling salesman problem (TSP). This first application stimulated the interest of other researchers, leading to a constant growth in the number of researchers all around the world getting inspiration from the initial Ant System and developing successful algorithms for discrete optimization problems.

The growing interest in ACO algorithms, and more in general, in ant algorithms, led to *ANTS'98 — From Ant Colonies to Artificial Ants: First International Workshop on Ant Colony Optimization*, 15–16 October 1998, Brussels, Belgium. More than 50 researchers from all over the world attended this first workshop, which was organized by Marco Dorigo. The papers

[☆] A selection of the papers presented at ANTS'98 – From Ant Colonies to Artificial Ants: First International Workshop on Ant Colony Optimization, 15–16 October 1998, Brussels, Belgium.

[1] ACO algorithms are a particular instance of ant algorithms specialized for the solution of (constrained) shortest path and/or minimum cost problems on graphs.

PII: S0167-739X(00)00041-8

presented in this special issue are an outgrowth of some of the talks given at the workshop. Each paper underwent a rigorous review process by at least three referees. The selected papers are written from leading researchers in the field of ant algorithms. While capturing a reasonable representation of the research work in the field, they are not supposed to give a comprehensive survey of it. Rather, the main objective is to provide both the necessary information to stimulate new research starting from acquired results and the intuitions about the (many) open questions and interesting directions useful to direct the exploration and the implementation of novel parallel/distributed multi-agent algorithms.

2. About this issue

The first paper, already mentioned, by Dorigo, Bonabeau, and Theraulaz provides a general introduction to ant algorithms, focusing in particular on the concept of stigmergy and giving a literature overview of the most relevant implementations. The paper focuses rather on the description of 'innovative' algorithms and basic ideas, than on algorithms which already showed to be very competitive (typically those falling into the ACO framework), but which have been reviewed in earlier publications [2,3].

The second paper, by Stützle and Hoos, focuses on the TSP, the first problem attacked by an ant algorithm in 1991 [4,5] and on the quadratic assignment problem (QAP). Many ACO algorithms have been proposed since then. Stützle and Hoos give a reasoned overview of the best algorithms, relate specific design choices of these algorithms to search space characteristics of the attacked problems, and describe their $\mathcal{MAX}$–$\mathcal{MIN}$ Ant System, currently one of the best performing algorithms for the TSP and the QAP. The paper reports a detailed experimental analysis and comparative results accompanied by thorough discussions.

The paper by Gutjahr has a very special role, because it is the first to present a proof of convergence for a generic ACO algorithm. Gutjahr, departing from the implementation of Ant System, 'reduces' the behavior of an ant algorithm to a walk on a graph representing the instance of the problem (this representation is very similar to that used in the ACO framework). He shows that under reasonable assumptions his graph-based Ant System converges in probability to the problem's optimal solution.

The fourth paper, by Wagner, Lindenbaum, and Bruckstein, reports a proof of convergence of a very simple but effective algorithm for graph (network) covering. A simple ant-inspired motion rule (called VAW-rule) is used and for the single-ant case the authors report the system's theoretical upper-bounds to the time necessary to cover a dynamic graph: (i) with at least a stable spanning subgraph; (ii) with an edge having a known fault probability; and (iii) in the case the graph is a static tree. Moreover, some experimental results for the case of multiple ants are reported.

The special issue also includes two short papers. The first one, by Maniezzo and Carbonaro, presents the application of an ant algorithm to the frequency assignment problem in radio networks. The algorithm is an adaptation of a previous algorithm developed by the authors for the QAP. Experimental results are reported and the algorithm compares favorably to other state-of-the-art heuristics. The second one, by Monmarché, Venturini and Slimane, investigates the use of a cooperative strategy for optimization inspired by the prey searching behavior of the *Pachycondyla apicalis* ants. The algorithm uses different heuristics and simple communication mechanisms among the ants to implement an efficient trade-off between exploration and exploitation. Several experimental results for continuous function optimization problems are reported.

3. List of referees

Andrew Adamatzky, Edy Bertolissi, Eric Bonabeau, Bernd Bullnheimer, Christine Decaestecker, Federico Della Croce, Gianni Di Caro, Marco Dorigo, Luca Maria Gambardella, Martina Gorges-Schleuter, Walter Gutjahr, Jin-Kao Hao, Peter Scott Heck, Martin Heusse, Vittorio Maniezzo, Carlos Mariano Romero, Peter Merz, Martin Middendorf, Harald Meyer auf'm Hofe, Ann Nové, Henrique Miguel Pereira, Leon Rothkrantz, Olivier Roux, Lionel Sacks, Dominique Snyers, Thomas Stützle, Guy Theraulaz, Israel Wagner, Xin Yao and Marco Zaffalon.

Acknowledgements

We are grateful to all the people who got involved in this special issue. In particular, to the authors who submitted their work to the special issue, to the Future Generation Computer Systems editorial staff, and to the referees, listed above, who participated in the reviewing process and provided helpful comments to the authors, and were able to meet our deadlines.

References

[1] M. Dorigo, Optimization, learning and natural algorithms, Ph.D. Thesis, Dipartimento di Elettronica, Politecnico di Milano, Italy, 1992 (in Italian).

[2] M. Dorigo, G. Di Caro, The Ant Colony Optimization meta-heuristic, in: D. Corne, M. Dorigo, F. Glover (Eds.), New Ideas in Optimization, McGraw-Hill, London, UK, 1999, pp. 11–32.

[3] M. Dorigo, G. Di Caro, L.M. Gambardella, Ant algorithms for discrete optimization, Artif. Life 5 (2) (1999) 137–172.

[4] M. Dorigo, V. Maniezzo, A. Colorni, Positive feedback as a search strategy, Technical Report 91-016, Dipartimento di Elettronica, Politecnico di Milano, Italy, 1991.

[5] M. Dorigo, V. Maniezzo, A. Colorni, The Ant System: optimization by a colony of cooperating agents, IEEE Trans. Systems Man Cybernet. B 26 (1) (1996) 29–41.

Marco Dorigo, Gianni Di Caro, Thomas Stützle
Université Libre de Bruxelles
IRIDIA
CP 194/6
Avenue Franklin Roosevelt 50
1050 Brussels, Belgium

E-mail addresses: mdorigo@ulb.ac.be (M. Dorigo), gdicaro@iridia.ulb.ac.be (G. Di Caro), tstutzle@ulb.ac.be (T. Stützle)