# Artificial Ants

## *From Collective Intelligence to Real-life Optimization and Beyond*

**Edited by**

**Nicolas Monmarché**

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# Introduction

Artificial ants were established in the middle of the 1990s. After nearly 15 years of development and research, theses, and conferences, it seemed appropriate to take stock of the research progress, particularly in the French speaking community.

We do not claim to have written an exhaustive book on artificial ants, first because it would be almost certainly doomed to failure, the projects being so numerous, and also because too large a book would attract little interest from novice readers. The objective of this book is enable to a novice reader, to form an opinion on the issue of artificial ants, without tending to lapse into systematic overview, or mechanical enumeration, leaving space for analysis, results, and sometimes for frenzy.

It is for these reasons that the chapters vary in scope: some offer a wide panorama (combinatorial optimization, robotics, classification, etc.) focusing on the basic notions, while others focusing on a single area (natural languages, disability, bioinformatics, etc.), presenting several inputs on artificial ants, or on a particular problem (the optimization of the aluminum bar production, learning of hidden Markov models, routing in mobile networks, etc.).

So far, what conclusions can we draw from work on artificial ants? Has everything that we have learnt been exploited to solve computing or mathematical problems? One of the main characteristics in artificial ants is the use of pheromones to mark paths, but have we explored every possibility? Is sufficient to apply the conclusions, almost automatically, when a new problem (optimization, usually) arises? Finally, can we consider the study and use of artificial ants as a research field?

To answer these questions, we must begin by reading this book, but especially agree on a definition of an artificial ant. We suggest the following definition:

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Introduction written by Nicolas MONMARCHÉ, Frédéric GUINAND and Patrick SIARRY.

*An artificial ant is an object, virtual, real (e.g. a software agent or a robot) or symbolic (as a point in a search space) that has a link/similarity (i.e. a behavior, a common feature) with a real ant.*

An almost permanent feature in the realization of this definition involves the collective aspect of the ants' life. The great majority of studies, including those discussed in this book, take into account the collective work by manipulating a population, a colony of ants. This definition, in the singular, begins to take shape practically only in the plural. In this sense, the field of artificial ants, if it exists, is an integral part of the larger field of the "swarm intelligence." Swarm intelligence is freed from the bond with ants, and the models used sometimes go beyond the framework of animal inspiration (while remaining most often in the framework of the "bio-inspired").

Therefore, what is the advantage of concentrating on ants, except to limit the field of research? It is likely that this drive is directly related to the subject of inspiration: ants have their autonomy on Earth, their diversity, their rules, their ecological success that fascinate us. Their independence drives us to classify them separately in the question of swarm intelligence.

All these issues deserve several concrete examples and advice from several researchers using the concept of artificial ants, which is the focus of the remainder of this book.

We complete this introduction by summarizing the 21 chapters.

In Chapter 1, Alain Lenoir and Nicolas Monmarché briefly describe the organization of social life of real ants and their behaviors that have been translated into algorithms of artificial ants. The authors first present the morphology of real ants and some characteristics of their social life. Then, they describe some examples of modeling self-organized behaviors: pheromone trails, sorting objects, digging the nest, aggregation of individuals and modeling colonial smell. Finally, they outline the transition to the artificial ant, an agent created by computer scientists trying to solve their own problems by reproducing the collective intelligence of ants.

In Chapter 2, Antoine Dutot, Frédéric Guinand, Damien Olivier and Yoann Pigné reveal the general principles set out to resolve, thanks to algorithms of ant colonies, combinatorial optimization problems. One characteristic of ants in particular attracts the authors' attention: their ability to build and to maintain structures in their environment. In this chapter, structure is regarded as the central element in the resolution process of combinatorial optimization problems by ant colonies. The solution to a given problem can indeed be expressed as a structure in the search space. In the same way as ant colonies, systems based on artificial ants have the ability to build, emphasize, and maintain structures. However, the optimization of these ant colonies requires additional elements, corresponding to the problem addressed.

Chapter 3 provides an overview of combinatorial problems dealt with using artificial ants. Antoine Dutot and Yoann Pigné first review the main approaches concerning the ant colonies that we can find in the literature, distinguishing the ant colony optimization (ACO) family from the ant-based control algorithm. The different categories of combinatorial problems solved using these approaches are described in the second part of the chapter. Finally, the authors address open problems, with multifaceted objectives of optimization. They also claim that poorly formalized constraints must be taken into account – in particular, dynamic and decentralized environments, uncertainties or data errors.

In Chapter 4, Patrick Siarry, Johann Dréo, and Nicolas Monmarché analyze the exploitation of artificial ants for optimization in continuous variables. Several approaches have been suggested in the literature. Most approaches are inspired by the self-organization and external memory characteristics of ant colonies, leaving aside the iterative construction of the solution. However, there are also newer techniques that exploit the probabilistic feature of ACO formalism. This chapter provides an overview of published methods, classifying them into four families: the algorithms created from a direct model of ants behavior the algorithms based on binary discretization, the algorithms based on probabilistic sampling, and the algorithms based on hybrid approaches.

Chapter 5 reviews the optimization by an ant colony of the "configuration" in constraint programing: it is a formalism allowing us to represent combinatorial problems. Patrick Albert, Laurent Henocque, and Mathias Kleiner show that ant colonies can increase the size of the configuration problems that can be addressed by an enumerative search of the solutions. The authors develop an algorithm to adapt ACO to the ensemblist variables on open areas and to build solutions. The experimental study concluding the chapter shows that the size of the multidimensional space of the ACO parameter sets raises a difficulty. The fitting of the ACO parameters is then performed using the particle swarm optimization.

In Chapter 6, Guillaume Sandou, Stéphane Font, Sihem Tebbani, Christian Mondon, and Arnaud Hiret present an application implemented at EDF: the optimal allocation of units within an energy production site. This is a "mixed" optimization problem of a very large dimension, the binary variables characterizing the on/off condition of the facilities, and the real variables characterizing the amount of energy produced. The authors develop an ant colony algorithm in real variables adapted to the problem and show the interest of its coupling with a genetic algorithm. After this optimization phase, the solution that was found is an open-loop control of the system of production. However, the latter is subjected to many uncertainties, particularly relating to consumer demand. The predictive control principles are then implemented to extend the results of the optimization in a closed-loop context.

Another industrial application is described in Chapter 7: it is a scheduling problem arising from the production of aluminum bars in a factory in Quebec. The main difficulties lie in the high number of constraints and in the calculation time. Indeed, evaluating a solution requires a full simulation of production. Caroline Gagné and Marc Gravel show the importance of the visibility terms for obtaining effective guidance of the construction process of the solutions using the artificial ants. The main innovation here consists of using several visibilities related to the problem. In addition, a specific procedure for processing objectives is developed to obtain compromise solutions. This approach is preferable to the lexicographic treatment of the objectives, as it corresponds more to the concerns of a production planner.

In Chapter 8 the same authors, Caroline Gagné and Marc Gravel, describe the solution to the assembly scheduling problem line in the automobile industry found by ant colonies. It consists of determining the order in which a set of cars are manufactured on a line made of three consecutive workshops (sheet metal, paint, and assembly). This industrial problem was proposed by Renault, in the ROADEF'2005 challenge, so that we have the results provided by several concurrent algorithms. The authors have adapted the structure of the pheromone trail in the transition rule, and again they used several terms of visibility. The numerical experiments have shown the superiority of artificial ants for the construction of very good solutions with regard to the main objective, for large-size instances, comprising more than 1,000 vehicles.

Chapter 9 presents an algorithm an of ant colony, developed by Xavier Gandibleux, Julien Jorge, Xavier Delorme, and Joaqun Rodriguez, to measure and optimize the capacity of a railway network. Three features are worth noting in this application: the technique of pheromone perturbation, the self-parametrizing strategy that manages the convergence of the algorithm and a double-mode construction of solutions. The proposed algorithm uses a set of local searches *ad hoc* regarding the set-packing problem to be solved. The optimization model under consideration allows us to manage the entry hours of trains with a great flexibility, as well as the routes permitted in the infrastructure. It also allows us to manipulate preferences on the routes that are followed, to distinguish different categories of "saturating trains," and address the specific constraints encountered in stations (for example, stopping at a platform with sufficient capacity).

In Chapter 10, Amir Nakib, Raphaël Blanc, Hamouche Oulhadj, and Patrick Siarry explain a new method of image segmentation by magnetic resonance imaging (MRI) based on the criterion of "modified intraclass variance." This criterion takes into account not only the information on gray levels but also the spatial distribution of gray levels, using surfaces of segmented regions. The resulting algorithmic complexity raises a difficulty, especially for real-time applications. The problem is solved by a technique with artificial ants that provides a satisfactory segmentation of MRI images: the validation is performed on brain images, from CHU Henri Mondor in Créteil. The low calculation time of this approach allows its extension to a dynamic optimization problem: the segmentation of MRI image sequences.

Chapter 11 focuses on coloring the vertices of a graph by ant colony. Since 1997, several researchers have studied the use of artificial ants to treat this common problem, and it is clear that ant algorithms are now competitive with the best coloring algorithms known to date. The purpose of this chapter is to trace the history of the evolution of these ant algorithms. Alain Hertz and Nicolas Zufferey begin with a precise definition of the problem to be solved and then describe three approaches to solve it which differ according to the role assigned to each ant. The numerical results presented enable a comparison between the different approaches. The authors note, in this regard, that the scientific community is not unanimous by decided on the name to be given to the various metaheuristics used. Indeed, some researchers consider the ant algorithms as special cases of other older algorithms, while others regard them as generalizations or variations.

Chapter 12, written by Sébastien Aupetit, Nicolas Monmarché, and Mohamed Slimane, is devoted to hidden Markov models (HMM). These models are statistical tools enabling us to model, under the form of stochastic processes, temporal phenomena as one part of that which is observable. For example, if we take the picture of a car, the observable part is the pixels, while the non-observable part is the general organization of the picture. A learning stage is then necessary to adjust the model to the observation sequence, in order to conceptualize the car. The authors advocate the API artificial ants algorithm to carry out this learning stage. A statistical analysis of API shows, indeed, that its operators can be generalized and redefined, so as to improve the efficiency of API in learning a HMM.

In Chapter 13, Amira Hamdi, Violaine Antoine, Nicolas Monmarché, Adel Alimi, and Mohamed Slimane are interested in contributions of artificial ants on automatic classification. Although the search for an optimal classification is an optimization problem, new solving methods can be devised, inspired by ants, which do not involve their well-known ability to optimize. The authors describe these approaches, beginning by briefly recalling the main issues of the classification problem. They then expose the two families of algorithms based on artificial ants, which deal with classification: methods based on a grid, where ants move data, as they would do in nature with their brood or their waste, and methods where each ant is associated with data to be classified.

Chapter 14, written by Paulo Urbano, Nicolas Monmarché, and Pierre Gaucher, is devoted to collective and mobile robotics, inspired by ants. This chapter focuses on "bio-inspired" robots, namely, those whose hardware and/or software structure is based on the phenomena that can be observed in nature. The authors are primarily interested in mobile robotics (or autonomous robotics), the purpose of which is to design robots capable of moving alone, without centralized control. The approaches described here are inspired by individual behaviors observed in animals (not just ants). Then the chapter discusses the collective robotics, which aims at working out a general methodology for the development of autonomous agents interacting with a physical environment. This time, it is the collective behavior of ants that is mimicked, in particular, for the division of tasks and group navigation.

In Chapter 15, Nicolas Monmarché, Arnaud Puret, Pierre Gaucher, Mohamed Slimane, Pierre Lebocey, Julie Fortune, Cyrille Faucheux, and Didier Lastu describe the achievement of a popular science exhibition, entitled "Artificial insects," held in the French city of Tours' Museum of Natural History from October 2005 to August 2006. Its objective was the promotion of collective artificial intelligence and bio-inspired robotics. The purpose was to popularize the research in this area and also to encourage young visitors to specialize in scientific studies. In total, this exhibition required a large investment from the people involved, notably at the pedagogical and human levels. The completion of most of the modules was entrusted to engineering students of the Computer Department of Polytech' Tours, in the framework of mini-projects and graduation projects. The objective of reaching a wide audience was met, since more than 10,000 people visited the exhibition.

Chapter 16 of the volume focuses on solving, using an artificial ant algorithm, a dynamic optimization problem in line with the routing in *ad hoc* mobile networks, in an urban environments. The purpose is to discover and paths used to pass streams of data through a wireless network, by optimizing one or more performance measurements. The main difficulty inherent in this application is that it is both distributed and dynamic, as the situation in the network changes over time and decentralized solutions must be continuously built. Gianni A. Di Caro, Frederick J.A. Ducatelle, and Luca M. Gambardella detail their algorithm, which combines routing by ant colony with other learning approaches. The comparison with a reference algorithm is made using several scenarios, which are specific to the urban environment, in terms of radio propagation and mobility patterns.

In Chapter 17, Antoine Dutot and Damien Olivier show that artificial ants can be used to identify organizations in complex systems. A complex system is characterized by numerous entities, of the same nature or a different nature, which interact in a non-trivial way (nonlinear processes, presence of feedback loops, etc.), and the emergence at the global level of new properties, not observable at the level of basic entities. This ability to self-organize leads to the most evolved complex systems being adaptive. To detect the organizations existing in a complex system, and follow their evolution over time, an interaction graph may be associated with this system. It is then fruitful to use artificial ants, which are attracted, and afterward captured by the underlying organizations in the graph. A practical application given by the authors is the search for an optimal distribution of applications in a computing grid.

Chapter 18 examines the contributions of artificial ants in the field of disability. Alexis Sepchat, Sonia Colas, Romain Clair, Nicolas Monmarché, Pierre Gaucher, and Mohamed Slimane present three examples of works developed for the compensation of autonomy losses or the game of visually impaired people. The authors first describe an artificial ant algorithm designed to optimize the position of the keys of a virtual keyboard, depending its use. The second example relates to the accessibility to the Internet. It focuses on the design of a tool capable of producing, for a particular web site, a site map, whose complexity may be adjusted depending on the storage capacity of the blind user. The last example involves the adjustment of the difficulty level of a video game. The authors show that this level can automatically adapt to the disabled player, by introducing mechanisms inspired by ants' behavioral patterns.

In Chapter 19, Nicolas Monmarché and Romain Clair show that artificial ants are also capable of producing artistic works. We know that interactions between entities that are partly directed by chance, and are thus unpredictable at the microscopic level, can gradually build up an overall organized pattern–even harmonious pattern. The behavior of an ant colony may therefore be reflected in the form of computer programs producing artistic works. The chapter describes two artistic approaches based on artificial ants. The first relates to the production of paints: ants move on an image pixel by pixel, by depositing color, which may be considered as a form of pheromone. The second artistic approach discussed is on music. Ant colonies are capable of causing the emergence of a global organization, now music precisely follows from an organization of sounds in time.

Chapter 20, written by Frédéric Guinand and Mathieu Lafourcade, examines the processing of the natural language using artificial ants. Specifically, the authors focus on "disambiguation," which is to disambiguate a word by analyzing its context. In a text, the words are connected by syntactic relations, forming a tree structure. The overall meaning of the text is obtained by the propagation and composition, inside this tree, of the "conceptual vectors," representing the different meanings of the words. The classical approach to disambiguation suffers from a major weakness: it does not take into account the constraints between the meanings of words. To remedy this, the authors propose a new method, in which the different meanings of a word are competing to contribute in the building of particular structures, identified by "interpretation paths." These paths are based on bridges, whose strength and sustainability directly depend on their use by artificial ants. The technique described is proved to be capable of building solutions out of reach of traditional methods.

Finally, the last chapter (Chapter 21) is devoted to applications of artificial ants in the field of bioinformatics. In this chapter, Stefan Balev, Omar Gaci, and Yoann Pigné present three applications to problems arising in molecular biology. The first application is a sequencing technique using hybridization. The purpose is to determine the nucleotide sequence order of a given DNA fragment, from pieces of the sequence obtained using DNA chips. The second application concerns the alignment of several DNA sequences to highlight the similarities between them. Finally, the authors describe an algorithm for solving the problem of protein folding: it is based on the alignment of an amino acid sequence and a protein structure. In all the three cases, artificial ants proved capable of finding solutions usable by biologists, which is not always the case for the concurrent algorithms.

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