4OR (2006) 4:255–258
DOI 10.1007/s10288-006-0002-8

PHD THESIS

Design of cooperative algorithms for multi-objective optimization: application to the flow-shop scheduling problem

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Received: 14 September 2005 / Published online: 6 July 2006

Abstract This is a summary of the main results presented in the author's PhD thesis. This thesis was supervised by El-Ghazali Talbi, and defended on 21 June 2005 at the University of Lille (France). It is written in French and is available at http://www.lifl.fr/~basseur/These.pdf. This work deals with the conception of cooperative methods in order to solve multi-objective combinatorial optimization problems. Many cooperation schemes between exact and/or heuristic methods have been proposed in the literature. We propose a classification of such schemes. We propose a new heuristic called adaptive genetic algorithm (AGA), that is designed for an efficient exploration of the search space. We consider several cooperation schemes between AGA and other methods (exact or heuristic). The performance of these schemes are tested on a bi-objective permutation flow-shop scheduling problem, in order to evaluate the interest of each type of cooperation.

Keywords Combinatorial optimization · Multi-objective optimization · Cooperative methods · Exact method · Meta-heuristic · Flow-shop scheduling

MSC Classification 90C27 · 90C29 · 90B50

1 Introduction

The author's PhD thesis (Basseur 2005) focuses on the conception of cooperative methods for multi-objective optimization problems. Our main goal is to determine which methods can be efficiently associated and to test the

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performance of several cooperation schemes. Indeed, many different methods to solve optimization problem exist in the literature, with different particularities: exact methods, which try to find the best solution, and prove its optimality; population-based metaheuristics, efficient in the search space exploration and well suited to multi-objective optimization; single solution metaheuristics, efficient in intensifying the search around one solution, and able to find good solutions in a short computation time.

We have focused our experimentations on a bi-objective flow-shop problem (BOFSP). We consider the flow-shop problem with N jobs and M machines. Among the numerous objectives studied in the literature, we propose to minimize two well known objectives: the maximum completion time ($C_{\max}$), and the sum of lateness ($\bar{T}$). The experimentations are realized on Taillard's benchmarks (Taillard 1993), which have been extended to the bi-objective case (http://www.lifl.fr/~basseur/benchs_matth.html).

2 A taxonomy of cooperative optimization methods

In order to classify cooperative optimization methods, we propose several classification criteria. Two main criteria are defined, the cooperation level (dependence between methods) and mode (parallel cooperation scheme, or not); several secondary classification criteria are defined, such as the resolution approach (exact, heuristic), the search space envisaged, the uniformity of the problems solved (does the methods solve the same optimization problem, or two different problems?), and the implementation (sequential or parallel).

We have classified cooperative approaches, by restricting our search to cooperation between exact and heuristic optimization methods. As shown in our survey, cooperative approaches between heuristic and exact methods have often been proposed in the literature. We classify them according to the above criteria.

3 An adaptive genetic algorithm

We first propose a multi-objective genetic algorithm (MOGA) with Pareto approach. MOGAs are known to be well suited to solve multi-objective optimization problems (MOPs) (Deb 2001). We propose the use of classical genetic operators, with two adaptive mechanisms:

- A dynamic mutation seletion operator allowing the use of several mutation operators during MOGA, and leading the best ones to be used. This mechanism increases the size of the reachable neighborhood and selects the most effective mutation operator without preliminary experimentations.
- An adaptive sharing radius parameter that favors efficient diversification and allows for a dynamic setting of parameters.

These mechanisms have been applied on our initial MOGA to set an adaptive genetic algorithm (AGA), and tested to solve BOFSP (Basseur et al. 2002).

They show their effectiveness, especially in the exploration of the search space, on test problems up to 50 jobs and 20 machines.

4 Cooperative approaches

We explore different ways of cooperation between AGA and intensification methods.

4.1 Memetic algorithms

To set up our memetic algorithm (AMA), we design first a Pareto local search (PLS), a population-based local search, which uses the Pareto dominance concept during the search. Then, AMA is designed by replacing mutation operators by PLS. Then, in order to keep the exploration capacity of AGA, we propose two new cooperations between AGA and AMA:

- AGA+AMA: a simple cooperation, with a predefined transition between AGA and AMA (Basseur et al. 2002).
- AGMA: an adaptive cooperation, in which transitions between the two algorithms are dynamically set during the search: each time AGA's convergence becomes too slow, an intensification phase of search is launched with AMA (Basseur et al. 2003).

Experiments show the effectiveness of memetic approaches. Moreover, comparisons between AMA, AMA+AGA and AGMA show the interest of the cooperation of memetic algorithms with AGA, and of a dynamic cooperation mechanism.

4.2 Cooperation with path-relinking algorithm

We propose several mechanisms to establish a multi-objective path relinking (MOPR) algorithm (Basseur et al. 2005b). In order to apply MOPR to BOFSP, we propose a distance measure that is correlated to the most efficient mutation operator highlighted by AGA: the *shift* operator. We also propose a mechanism to generate only the useful neighborhood for joining solutions. As a consequence, the complexity of MOPR remains limited. Computational experiments show the potential of this type of cooperation.

4.3 Cooperation with a bi-objective exact method

We focus on cooperation between heuristics and exact methods (Basseur et al. 2004, 2005a). We propose different types of cooperation between AGMA and TPM (two-phases method), a bi-objective exact method (Ulungu and Teghem 1995). We show the interest of these cooperations in two particular cases:

(1) exact resolution, when AGMA solutions are used as the initial ones for TPM; (2) heuristic resolution, when TPM performs an exact resolution on restricted search areas to improve initial solutions found by AGMA.

For many of these approaches, we have also experimented parallel cooperation approaches. The models implemented were for parallel machines or for peer to peer applications. Experimentations reveal the robustness and quality of the results.

With different tests on the presented algorithms applied for BOFSP, we show the interest in exact cooperative methods on the smallest instances (with 20 jobs and from 5 to 10 machines). For medium sized instances, with 50 jobs, cooperative metaheuristics with dynamic transitions give the most interesting results. Parallel cooperative metaheuristics are the most efficient on large instances (50 and 100 jobs). Lastly, cooperative heuristics approaches with TPM and AGMA are really efficient for the largest instances (200 jobs and 10 machines).

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