Pareto-optimality approach for flexible job-shop scheduling problems: hybridization of evolutionary algorithms and fuzzy logic

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Abstract

Most scheduling problems are complex combinatorial problems and very difficult to solve [Manage. Sci. 35 (1989) 164; F.S. Hillier, G.J. Lieberman, Introduction to Operations Research, Holden-Day, San Francisco, CA, 1967]. That is why, lots of methods focus on the optimization according to a single criterion (makespan, workloads of machines, waiting times, etc.). The combining of several criteria induces additional complexity and new problems. In this paper, we propose a Pareto approach based on the hybridization of fuzzy logic (FL) and evolutionary algorithms (EAs) to solve the flexible job-shop scheduling problem (FJSP). This hybrid approach exploits the knowledge representation capabilities of FL [Fuzzy Sets Syst. 1 (1989)] and the adaptive capabilities of EAs. The integration of these two methodologies for the multi-objective optimization has become an increasing interest. The objective considered is to minimize the overall completion time (makespan), the total workload of machines and the workload of the most loaded machine. Many examples are presented to illustrate some theoretical considerations and to show the efficiency of the suggested methodology.
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1. Introduction

In most combinatorial optimization problems, we have to simultaneously optimize a set of conflicting objective functions. The literature presents many possible considerations and techniques that can be useful to evaluate solutions [4,5]. Mainly, we can distinguish two classes: the Pareto-optimality approaches and the non-Pareto-optimality approaches.

In a previous work, we have proposed an aggregative approach for solving multi-objective optimization problems (MOPs) based on the hybridization of fuzzy logic (FL) and evolutionary algorithms (EAs) [6].

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This approach makes it possible to construct a set of satisfactory solutions according to the preferences of the decision-maker. In this work, we aim to complete the suggested approach and we propose an extension of the application of such a hybridization. Thereafter, we show how FL can be useful to make EAs more efficient for finding a set of Pareto-optimality solutions.

This paper is organized as follows: In Section 2, we shortly describe the Pareto-optimality concepts used for solving MOPs and those especially applied in EAs. Then, the mathematical formulation of FJSP is presented in Section 3. The proposed fuzzy evolutionary approach will be described in Section 4. Section 5 focuses on the illustration of the suggested approach by applying it to solve FJSP and highlights some practical aspects of the application of such an approach for solving hard combinatorial problems. Finally, the last section deals with concluding remarks and shows the efficiency of the hybridization of FL and EAs through different numerical experiments.

2. Pareto-optimality concept and multi-objective optimization

In most cases, a MOP can be described, without loss of generality, using the following formulation:

$$\min_{x \in \Omega} f_1(x), f_2(x), \ldots, f_L(x) \tag{1}$$

where x is a possible solution for the considered problem, Ω is the feasible solution space and $f_q(\cdot)$ is the qth objective function (for $1 \leq q \leq L$). It is obvious that in general there does not exist an exact solution to such a problem.

However, to use such a description, the optimality notion should be reformulated when the objective functions to be minimized are not linear. As one of the most known multi-objective optimality notions, the Pareto-optimality concept has been intensively used in the literature and has significantly contributed in the elaboration of a large set of works.

Such a concept is expected in MOPs to provide flexibility and a large set of choices for the decision-maker. Solutions included in the Pareto-optimal set are those that cannot be improved along any dimension without simultaneously being deteriorated along other dimension(s). The optimality notion in the Pareto approaches can be formulated as follows:

- the Pareto-optimal set is constituted of non-dominated solutions;
- x dominates y if $\forall 1 \leq q \leq L$, $f_q(x) \leq f_q(y)$ and at least one index r exists such that $f_r(x) < f_r(y)$;
- a solution is non-dominated, if it is not dominated by any other one.

As an example, in Fig. 1, we consider a two objective functions case. The solutions C, D, and F are dominated and {A, B, E, G} is the Pareto-optimal set of solutions. We can notice that Pareto-optimal set (Pareto frontier) is constituted of several non-dominated solutions. The main aim of such an approach is to find all the elements of this set in order to give more choices to the decision-maker [7].

Recently, EAs have been proposed for solving MOPs [8–11]. These algorithms are applied by many users in different areas of engineering framework, computer science and operation research. The main advantage of such an optimization technique consists in its special modular aspect; it operates on data without using preliminary knowledge on the processed problem and it evolves from an initial population of possible solutions iteratively bringing a global improvement according to a predefined criterion [12,13]. Therefore, the EAs can represent a suitable technique for the implementation of the multi-objective optimization based on the aggregative evaluation. As one of the most used aggregative evaluations, a