Chapter II
Multi-Objective Particles Swarm Optimization Approaches

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ABSTRACT

The multiple criteria nature of most real world problems has boosted research on multi-objective algorithms that can tackle such problems effectively, with the smallest possible computational burden. Particle Swarm Optimization has attracted the interest of researchers due to its simplicity, effectiveness and efficiency in solving numerous single-objective optimization problems. Up-to-date, there are a significant number of multi-objective Particle Swarm Optimization approaches and applications reported in the literature. This chapter aims at providing a review and discussion of the most established results on this field, as well as exposing the most active research topics that can give initiative for future research.

INTRODUCTION

Multi-objective optimization problems consist of several objectives that are necessary to be handled simultaneously. Such problems arise in many applications, where two or more, sometimes competing and/or incommensurable, objective functions have to be minimized concurrently. Due to the multicriteria nature of such problems, optimality of a solution has to be redefined, giving rise to the concept of Pareto optimality.

In contrast to the single-objective optimization case, multi-objective problems are characterized by trade-offs and, thus, there is a multitude of Pareto optimal solutions, which correspond to different settings of the investigated multi-objective problem. For example, in shape optimization, different Pareto optimal solutions correspond to different structure configurations of equal fitness but different properties. Thus, the necessity of finding the largest allowed number of such solutions, with adequate variety of their corresponding properties, is highly desirable.

Evolutionary algorithms seem to be particularly suited to multi-objective problems due to their ability to synchronously search for multiple Pareto optimal solutions and perform better global exploration of the search space (Coello, Van Veldhuizen, & Lamont, 2002; Deb, 1999; Schaffer, 1984). Up-to-date, a plethora of evolutionary algorithms have been proposed, implementing different concepts such as fitness sharing and niching (Fonseca & Fleming, 1993; Horn, Nafpliotis, & Goldberg, 1994; Srinivas & Deb, 1994), and elitism (Deb, Pratap, Agarwal, & Meyarivan, 2002; Erickson, Mayer, & Horn, 2001; Zitzler & Thiele, 1999). External archives have also been introduced as a means of memory for retaining Pareto optimal solutions. This addition enhanced significantly the performance of some algorithms, but it has also raised questions regarding the manipulation of the archive and its interaction with the actual population of search points.

Particle Swarm Optimization (PSO) is a swarm intelligence method that roughly models the social behavior of swarms (Kennedy & Eberhart, 2001). PSO shares many features with evolutionary algorithms that rendered its adaptation to the multi-objective context straightforward. Although several ideas can be adopted directly from evolutionary algorithms, the special characteristics that distinguish PSO from them, such as the directed mutation, population representation and operators must be taken into consideration in order to produce schemes that take full advantage of PSO's efficiency.

Up-to-date, several studies of PSO on multi-objective problems have appeared, and new, specialized variants of the method have been developed (Reyes-Sierra & Coello, 2006a). This chapter aims at providing a descriptive review of the state-of-the-art multi-objective PSO variants. Of course, it is not possible to include in the limited space of a book chapter the whole literature. For this reason, we selected to present the approaches that we considered most important and proper to sketch the most common features considered in the development of algorithms. Thus, we underline to the reader the fundamental issues in PSO-based multi-objective approaches, as well as the most active research directions and future trends. An additional reading section regarding applications and further developments is included at the end of the chapter, in order to provide a useful overview of this blossoming research field.

The rest of the chapter is organized as follows: Section 2 provides concise descriptions of the necessary background material, namely the basic multi-objective concepts and the PSO algorithm. Section 3 is devoted to the discussion of key concepts and issues that arise in the transition from single-objective to multi-objective cases. Section 4 exposes the established PSO approaches reported in the relative literature, and highlights their main features, while Section 5 discusses the most active research directions and future trends. The chapter concludes in Section 6.

BACKGROUND MATERIAL

Although the basic concepts of multi-objective optimization have been analyzed in another chapter of this book, we report the most essential for completeness purposes, along with a presentation of the PSO algorithm.

Basic Multi-Objective Optimization Concepts

Let $S \subset \mathbb{R}^n$ be an n-dimensional search space, and $f_i(x)$, i=1,…,k, be k objective functions defined over S. Also, let **f** be a vector function defined as

$$\mathbf{f}(x) = [\, f_1(x), f_2(x), \ldots, f_k(x)], \qquad (1)$$

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