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Continuous Optimization

An evolutionary artificial immune system for multi-objective optimization

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Abstract

In this paper, an evolutionary artificial immune system for multi-objective optimization which combines the global search ability of evolutionary algorithms and immune learning of artificial immune systems is proposed. A new selection strategy is developed based upon the concept of clonal selection principle to maintain the balance between exploration and exploitation. In order to maintain a diverse repertoire of antibodies, an information-theoretic based density preservation mechanism is also presented. In addition, the performances of various multi-objective evolutionary algorithms as well as the effectiveness of the proposed features are examined based upon seven benchmark problems characterized by different difficulties in local optimality, non-uniformity, discontinuity, non-convexity, high-dimensionality and constraints. The comparative study shows the effectiveness of the proposed algorithm, which produces solution sets that are highly competitive in terms of convergence, diversity and distribution. Investigations also demonstrate the contribution and robustness of the proposed features.

Keywords: Evolutionary algorithms; Artificial immune systems; Multi-objective optimization; Clonal selection principle

1. Introduction

Many real-world problems involve the simultaneous optimization of various competing specifications and constraints that are difficult, if not impossible, to solve without the aid of powerful optimization algorithms. In the recent years, many different population-based stochastic optimization methods such as evolutionary algorithms (EA), evolutionary strategies (ES) and particle swarm optimization (PSO) have been successful developed and applied to solve multi-objective (MO) problems. While it has been shown that these biologically inspired heuristics offers better performances over classical optimization approaches in complex MO problems, they are plagued by their own limitations such as premature convergence and poor exploitation abilities.

Artificial immune system (AIS) is a computational intelligence paradigm inspired by the biological immune system, which has found application in pattern recognition (Carter, 2000; Carvalho and

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Freitas, 1991), scheduling (Mori et al., 1998; Cui et al., 2001), control (Bersini, 1991; Kim and Lee, 2004), machine-learning (Hunt and Cooke, 1996; Timmis and Knight, 2001) and information systems security (Harmer et al., 2002; Dasgupta and Gonzalez, 2002). AIS has also been applied successfully to a variety of optimization problems and studies have shown that it possesses several attractive immune properties that allow EAs to avoid premature convergence (Fukuda et al., 1999) and improve local search (Bersini and Varela, 1991). However, the issue of MO optimization is rarely considered and the success of AIS in single objective (SO) problems may not extend well into MO problems where MO techniques are required to maintain a diverse and uniformly distributed solution set.

This paper considers the development of an evolutionary multi-objective immune algorithm (EMOIA) to exploit the complementary features of EA and AIS. The algorithm incorporates the features of clonal selection and immune memory to improve evolutionary search by identifying potential regions to explore while avoiding over emphasis in any region of the search space. The proposed clonal selection (CS) is different from many existing works in the sense that the selection and clonal rate of memory cells are based on the diversity in the evolving population. An entropy-based density assessment scheme (EDAS) is also proposed in this paper to distribute non-dominated individuals along the discovered Pareto-front uniformly for MO optimization. Unlike existing density assessment schemes, the assessment is based on the individuals' contribution to the total information content of the archive, and can be applied in either the decision or objective domain space depending on the nature of the problem involved.

The remainder of this paper is organized as follows: Section 2 provides a brief introduction to MO optimization while Section 3 provides some background information on AIS for MO optimization. The computational framework of AIS for MO optimization, details of EMOIA implementation and the proposed features of CS and EDAS are described in Section 4. Extensive empirical studies are conducted in Section 5, including a comparative study of the proposed algorithm with well-known MO optimization algorithms on a number of benchmark problems, further investigation on the effects of the proposed EDAS and parameter sensitivity analysis. Conclusions are drawn in Section 6.

2. Background information

In general, many real-world applications involve complex optimization problems with various competing specifications and constraints. Without loss of generality, we consider a minimization problem with decision space, $\boldsymbol{X}$, a subset of real numbers. For the minimization problem, it tends to find a parameter set $\boldsymbol{P}$ for

$$\mathrm{Min}_{\boldsymbol{P}\in X}\boldsymbol{F}(\boldsymbol{P}),\quad \boldsymbol{P}\in\mathbb{R}^D, \tag{1}$$

where $P=\{p_1,p_2,\ldots,p_D\}$ is a vector with D decision variables and $F=\{f_1,f_2,\ldots,f_M\}$ are M objectives to be minimized.

The solution to MO optimization problem exists in the form of an alternate tradeoff known as Pareto optimal set where each objective component of any non-dominated solution in the set can only be improved by degrading at least one of its other objective components. Pareto dominance can be used to assess the relative strength or fitness between any two candidate solutions in MO optimization and the concept has been widely adopted in the research of MO optimization since it was proposed by Pareto et al. (1896). Specifically, a vector $\boldsymbol{F}_a$ is said to dominate another vector $\boldsymbol{F}_b$, denoted as

$$\begin{aligned}F_a \prec F_b,\ &\text{iff } f_{a,i}\leqslant f_{b,i}\ \forall i\\ &=\{1,2,\ldots,M\}\text{ and }\exists j\\ &\in\{1,2,\ldots,M\}\text{ where } f_{a,j}<f_{b,j}.\end{aligned} \tag{2}$$

3. Artificial immune systems

AIS for optimization have been proposed and implemented in different ways. For instance, immune algorithms developed by Bersini and Varela (1991), Toma et al. (2000) are based on the immune network theory while other researchers such as Cui et al. (2001) and Coello Coello and Cortes (2005) developed AIS based on the concepts of clonal selection principle. Similar to the other stochastic optimization techniques, the AIS maintains and adapts a repertoire of candidate solutions to the problem at hand, which is analogous to immune system's response to antigens (Ag). In this context, the candidate solutions are called antibodies (Ab), and are associated with an affinity measure that provides an indication of its performance.