An Artificial Immune Dynamical System for Optimization

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ABSTRACT

Many immue-inspired algorithms are based on the abstractions of one or several immunology theories, such as clonal selection, negative selection, positive selection, rather than the whole process of immune response to solve computational problems. In order to build a general computational framework by simulating immune response process, this chapter introduces a population-based artificial immune dynamical system, termed as PAIS, and applies it to numerical optimization problems. PAIS models the dynamic process of human immune response as a quaternion (G, I, R, Al), where G denotes exterior stimulus or antigen, I denotes the set of valid antibodies, R denotes the set of reaction rules describing the interactions between antibodies, and Al denotes the dynamic algorithm describing how the reaction rules are applied to antibody population. Some general descriptions of reaction rules, including the set of clonal selection rules and the set of immune memory rules are introduced in PAIS. Based on these reaction rules, a dynamic algorithm, termed as PAISA, is designed for numerical optimization. In order to validate the performance of PAISA, 9 benchmark functions with 20 to 10,000 dimensions and a practical optimization problem, optimal approximation of linear systems are solved by PAISA, successively. The experimental results indicate that PAISA has high performance in optimizing some benchmark functions and practical optimization problems.
INTRODUCTION

Biological inspiration can successfully be transferred into novel computational paradigms, as shown in the development and successful use of concepts such as artificial neural networks, evolutionary algorithms, swarm algorithms, and so on. Many bio-inspired algorithms are based on populations of agents trained to perform some task or optimization. The most obvious one is the area of evolutionary algorithms, based on analogy to populations of organisms breeding and selecting to become “fitter” (Stepney, Smith, Timmis, & Tyrrell, 2004).

In recent years, Artificial Immune Systems (AIS) have received a significant amount of interest from researchers and industrial sponsors. Some of the first work in applying human immune system (HIS) metaphors was undertaken in the area of fault diagnosis (Ishida, 1990). Later work applied HIS metaphors to the field of computer security (Forrest, Perelson, Allen, & Cherukuri, 1994), which seemed to act as a catalyst for further investigation of HIS as a metaphor in such areas as Anomaly Detection (Gonzalez, Dasgupta, & Kozma, 2002), Pattern Recognition (Carter, 2000; Timmis, Neal, & Hunt, 2000; White, & Garrett, 2003), Job shop Scheduling (Hart, & Ross, 1999; Coello Coello, Rivera, & Cortes, 2003), optimization (Jiao & Wang, 2000; de Castro & Von Zuben, 2002) and Engineering Design Optimization (Hajela, Yoo, & Lee, 1997; Gong, Jiao, Du, & Wang, 2005).

In order to build a general computational framework by simulating the whole process of immune response, this chapter introduces a model for population-based Artificial Immune Systems, termed as PAIS. PAIS models the dynamic process of human immune response as a quaternion \( (G, I, R, Al) \), where \( G \) denotes exterior stimulus or antigen, \( I \) denotes the set of valid antibodies, \( R \) denotes the set of reaction rules describing the interactions between antibodies, and \( Al \) denotes the dynamic algorithm describing how the reaction rules are applied to antibody population. PAIS can be considered as a general architecture of population-based artificial immune systems rather than an immune algorithm. Many immune phenomena, such as clonal selection, immune memory, negative selection, passive selection, can be modeled as corresponding reaction rules and added to the set of reaction rules \( R \). Based on the PAIS, our final aim is to build a self-adaptive dynamical system by simulating all the possible interactions between antibodies during immune response. Then the PAIS can automatically select reaction rules depending on antigen \( G \), and thereby the pending problems could be solved automatically. In order to solve numerical optimization problems, the set of clonal selection rules and the set of immune memory rules are introduced. Consequently, a dynamic algorithm based on these heuristic rules is designed, which can effectively solve numerical optimization problems even when the number of variable parameters is as many as 10 000.

The rest of the paper is organized as follows: Section 2 describes some related background. Section 3 describes the population-based artificial immune dynamical system architecture. Section 4 describes the experimental study on nine benchmark functions. Section 5 describes the experimental study on the optimal approximation of linear systems. Finally, concluding remarks are presented in Section 6.

RELATED BACKGROUND

The human immune system (HIS) is a highly evolved, parallel and distributed adaptive system. Human immune response relies on the prior formation of an incredibly diverse population of B cells and T cells (Abbas, Lichtman, & Pober, 2000). The specificity of both the B-cell receptors and T-cell receptors, that is, the epitope to which a given receptor can bind, is created by a remarkable genetic mechanism. Each receptor is created even though the epitope it recognizes may never have been present in the body. If an antigen with that epitope should enter the body, those few lymphocytes able to bind to it will do so. If they also receive a second co-stimulatory signal, they may begin repeated rounds of mitosis. In this way, clones of antigen-specific lymphocytes (B and T) develop providing the basis of the immune response. This phenomenon is called clonal selection (Burnet, 1978; Berek & Ziegner, 1993; Abbas, Lichtman, & Pober, 2000). In fact, besides the clonal selection, during the initial expansion of clones, some of the progeny cells neither went on dividing nor developed into plasma cells. Instead, they reverted to small lymphocytes bearing the same B-cell receptor on their surface that their ancestors had. This lays the foundation for a more rapid and massive response the next time the antigen enters the body, i.e. immune memory.
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