Knowledge-Based Systems 105 (2016) 38–47

Contents lists available at ScienceDirect

Knowledge-Based Systems

journal homepage: www.elsevier.com/locate/knosys

A hybrid evolutionary algorithm based on tissue membrane systems and CMA-ES for solving numerical optimization problems

Chuang Liu*, Linan Fan

School of Information Engineering, Shenyang University, Liaoning, China

ARTICLE INFO

Article history:
Received 29 December 2015
Revised 21 March 2016
Accepted 26 April 2016
Available online 3 May 2016

Keywords:
Tissue membrane system
CMA-ES
Numerical optimization problems
Membrane computing
Optimization

ABSTRACT

In this paper, a new hybrid algorithm is proposed to solve the single objective real-parameter numerical optimization problems, named as CETMS. The proposed CETMS is based on tissue membrane systems(TMS), and the evolution strategy with covariance matrix adaptation (CMA-ES) algorithm is employed to find the optimal solution in each cell of TMS. Some features of Tissue Membrane Systems, such as membrane structure, evolution mechanism and communication mechanism among cells, are introduced into CETMS. In addition, the optimal information of different cells can be shared by communication mechanism of TMS after the appointed cycle. The simulation experiments are conducted on thirty benchmark functions on the CEC14 test suite, which evaluate the performance of the proposed algorithm on solving single objective real-parameter numerical optimization problems. Numerical results show that the proposed CETMS has a very good performance in comparison with some of the state-of-the-art algorithms.

1. Introduction

Numerical optimization problems exist widely in different areas of science research and engineering practice. In the past decades, these optimization problems are solved by using the traditional mathematical methods. With increasing complexity of these optimization problems, the traditional mathematical methods cannot find the satisfactory solutions. Therefore, the effective optimization algorithms are needed to solve these kinds of optimization problems. One class of the optimization algorithms inspired by natural computing is effective method to solve these problems, such as genetic algorithm [6], evolutionary strategy [9], particle swarm optimization (PSO) [38], ant colony optimization (ACO) [5], artificial bee colony (ABC) [13], cat swarm optimization (CSO) [3], and firefly algorithm (FA) [40]. There algorithms have been proved that their solutions found are closer to the global optimum one. However, when applying these evolutionary algorithms to solve the real-world problems, some new mechanisms need to be introduced into them in order to obtain the desired results.

Membrane computing is proposed by Păun from the European Academy of Sciences in 1998 [23]. It is an abstract computational idea or model, which is inspired by the structure and functioning of living cells, such as processing chemical compounds in tissues or higher order structures. The device computational model of membrane computing is called as membrane system or P system. A membrane system, as we will see later on, is a distributed and parallel theoretical computing device and whose aim is mimicking the inner mechanism of the living cell [24,25]. Now, three kinds of membrane systems are proposed, which include cell-like membrane system, tissue-like membrane systems and neural-like membrane systems. The key difference among the three kinds of membrane systems that cell-like membrane system provides the hierarchical framework of membranes, and tissue-like membrane system contains multiple single-cell structures connected each other, and neural-like membrane system is an extend model of tissue-like membrane system which is based on the concept of spikes. Many of their variants may be found in literature [22,33,41,46,47]. Most of these membrane systems could tackle specific problems (i.e., optimization problems) in a feasible time. At presents, applications of the membrane system have been expanded to various fields, e.g., medicine, biology, linguistics, fuzzy reasoning, data clustering, image processing and ecology [2,4,21,26–30,34,45].

The membrane system in optimization is called as membrane algorithm. Membrane algorithm provides the opportunity to apply evolutionary algorithms or swarm intelligence in a parallel and distributed environment [32]. The study on membrane algorithm has been an increasing interest, because membrane algorithm can solve the challenging and complicated optimization problems. At present, many kinds of membrane algorithms have been proposed, most of them will be discussed as follows. Nishida proposed a

* Corresponding author.
E-mail address: chuang.liu@mail.dlut.edu.cn (C. Liu).

http://dx.doi.org/10.1016/j.knosys.2016.04.025
0950-7051/

compound membrane algorithm to solve the traveling salesman problem [19]. Zhang et al. proposed a membrane-inspired approximate algorithm for traveling salesman problems, which implemented the rules of ant colony optimization in membrane systems. Huang et al. presented an optimization algorithm inspired by the membrane system to solve optimization problems [48]. Zhao et al. proposed the bio-inspired algorithm based on membrane systems (BIAMC) for solving both unconstrained and constrained problems [49,50]. Zhang et al. proposed a hybrid algorithm based on the quantum-inspired evolutionary approach and membrane systems to solve a well-known combinatorial optimization the knapsack problem [42,43]. Huang et al. presented a dynamic multi-objective optimization algorithm [12], which is inspired by membrane systems. Simulation results verify the effectiveness of the algorithm. Buiu et al. proposed a membrane controller based on membrane systems for mobile robots [1]. Xiao et al. proposed a membrane evolutionary algorithm for the DNA sequence design problem. The results of computer experiments are reported, in which the new algorithm is validated and out-performs certain known evolutionary algorithms for the DNA sequence design problem [39]. Liu et al. presented a novel algorithm based on the membrane system for solving multi-objective optimization problems. The proposed algorithm could quickly obtain the approximate Pareto front and satisfy the requirement of diversity of Pareto front [15]. In [31], the authors have studied the ways in which rules of particle swarm optimization have been implemented in membrane systems. In each of these membrane algorithms, modification is done either by using a new variant of PSO or by changing the way of intercommunication among the membranes. Each of these membrane based algorithms is designed for specific problems and hence is implemented on different problems. Xiao et al. proposed a dynamic membrane evolutionary algorithm to solve the DNA sequences design. The results of simulation experiments show that the proposed algorithm is valid and outperforms other evolutionary algorithms [37]. He et al. proposes an adaptively chosen parameters membrane algorithm to solve combinatorial optimization problems. Compared with the genetic algorithm, simulated annealing algorithm, neural net-work and a fine-tuned non-adaptive membrane algorithm, the proposed algorithm performs better than them [10]. Xiao et al. proposed a hybrid membrane evolutionary algorithm to solve constrained optimization problems. The simulation results show that the proposed algorithm is valid and outperforms the state-of-the-art algorithms [36]. Zhang et al. proposes a novel way to design a membrane system for directly obtaining the approximate solutions of combinatorial optimization problems without the aid of evolutionary operators [44]. Extensive experiments on knapsack problems have been reported to experimentally prove the viability and effectiveness of the proposed neural system. Niu et al. proposes a membrane algorithm based on ant colony optimization to solve the capacitated vehicle routing problem. Experimental results show that the proposed algorithm is better than other algorithms proposed in the previous literature [20].

To the best of our knowledge, membrane algorithms have been successfully applied to solve many kinds of optimization problems. However, the study on the membrane algorithm is less to solve the real-parameter single objective optimization problems. Therefore, our goal is to design a novel membrane algorithm to find the global optimal solutions of the optimization problems. Based on our previous work [7,8,15,16], a hybrid evolutionary algorithm based on tissue membrane systems and CMA-ES is proposed in order to focus on solving numerical optimization problems, named CETMS. Compared with our previous work, the proposed CETMS has two improvements. On the one hand, the proposed algorithm has the different membrane structure, which is based on the tissue membrane systems. The previously proposed algorithm is based on cell membrane systems. Since CETMS is based on a tissue-like membrane system, it inherits three ingredients of the membrane system, such as objects, membrane structure and reaction rules. An object in CETMS represents a candidate solution of optimization problems. The structure consists of multiple single-cell connected each other, which is conducive to the proposed algorithm for the parallel exploration of the solution space. On the other hand, in terms of evolutionary mechanisms, the proposed algorithm employees CMA-ES. CMA-ES is employed directly as reaction rules to evolve the candidate objects in each cell.

To evaluate the performance of CETMS, the simulation experiment will be executed on the set of benchmark functions provided for IEEE CEC 2014 special session and competition on single objective real-parameter numerical optimization [14]. In addition, this paper carries out experiments on the sensitivity analysis in comparison with some state-of-the-art algorithms which include L-SHADE [35], POBL-ADE [11], and OptBees [17] from the literature. The simulation results indicate that the proposed algorithm can balance of exploration and exploitation.

The main purposes of this paper are:

- To present CETMS, which is an algorithm based on the tissue membrane system for optimization in continuous spaces;
- and to evaluate its performance by applying it to all thirty minimization problems proposed for the IEEE 2014 Congress on Evolutionary Computation Competition on Real-Parameter Single Objective Optimization (CEC'2014), considering spaces of 10, 30, 50 and 100 dimensions;
- and to compared with some of state-of-the-art evolutionary algorithms, indicate the distinguishing feature of CETMS.

The rest of this paper is organized as follows. In Section 2, we briefly discuss on some concepts of a membrane system, a tissue membrane system, and CMA-ES. In Section 3, the description of the proposed CETMS is elaborated. In Section 4, the simulation results are evaluated on the benchmark test problems in comparison with some state-of-the-art evolutionary algorithms. Moreover, this section includes a sensitivity analysis for the proposed CETMS. Finally, Section 5 summarizes the concluding remarks and future work of this paper.

2. Related work

2.1. Tissue membrane system

A tissue Membrane system is proposed by Martin-Vide in 2003, which can simulate the inter-cellular communication with protein channels in a net of cells [18]. In the tissue membrane system, each cell has a finite state memory, which processes multisets of objects. These cells can communicate with their neighboring cells. Such cell nets are shown to be rather powerful, which can simulate a Turing machine. Fig. 1 shows an example of network membrane structure of a Tissue Membrane System. The structure consists of several cells in a current environment. Each cell has a certain number of protein channels connecting the other cells.

The general form of a tissue membrane system can be described as follows. The tissue membrane system has a network membrane structure. Multisets of objects are placed in the cells, which can be evolved according to the reaction rules of the current cell. It is noteworthy that the cells can communicate with the neighboring cells by borrowing protein channels. It is benefit that the information of different cells can be shared in the current environment. For further details about the tissue membrane system can be found in [18]. The model of the tissue membrane system with the degree $n \geq 1$ can be constructed in Eq. (1).

$$\prod = (O, \delta_1, \cdots, \delta_n, syn, i_{out}) \quad (1)$$

where,