ARTICLE IN PRESS

Information Sciences xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Information Sciences

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

Evolutionary membrane computing: A comprehensive survey and new results ☆

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A R T I C L E I N F O

Article history:
Received 30 April 2013
Received in revised form 24 February 2014
Accepted 8 April 2014
Available online xxxx

Keywords:
Membrane computing
Evolutionary computation
Evolutionary membrane computing
Membrane-inspired evolutionary algorithm
Automated design of membrane computing model

A B S T R A C T

Evolutionary membrane computing is an important research direction of membrane computing that aims to explore the complex interactions between membrane computing and evolutionary computation. These disciplines are receiving increasing attention. In this paper, an overview of the evolutionary membrane computing state-of-the-art and new results on two established topics in well defined scopes (membrane-inspired evolutionary algorithms and automated design of membrane computing models) are presented. We survey their theoretical developments and applications, sketch the differences between them, and compare the advantages and limitations.

1. Introduction

Natural computing is a fast growing interdisciplinary field interested in developing concepts, computational paradigms and theories inspired from various natural processes and phenomena. A thorough overview of this field has been recently produced [63]. Membrane computing and evolutionary computations are two nature-inspired theories which are discussed in this paper. Membrane computing (MC) refers to the branch of natural computing that investigates a class of computing models, also called membrane systems or P systems, abstracted from the compartmentalized structure and functioning of biological membranes within a living cell, cell tissues or colonies of cells [55]. The first P system model was introduced by Gheorghe Păun in 1998, and since then the MC research has been continuously and rapidly progressing. There are, basically, three main types of P systems: cell-like P systems, tissue-like P systems and neural-like P systems [55]. In all cases, there are basic components (membranes, cells, neurons, etc.) hierarchically arranged, through a rooted tree, for cell-like P systems, or distributed across a network, like a directed graph, for tissue-like P systems, with a common environment.

☆ This paper is written according to the invited plenary lecture presented at the 2012 Asian Conference on Membrane Computing. GZ acknowledges the support by the National Natural Science Foundation of China (61170016 and 61373047), the Program for New Century Excellent Talents in University (NCET-11-0715) and SWJTU supported project (SWJTU12CX008). MG acknowledges the support of CNCSIS-UE-FISCSU Project Number PNII-IDEI 643/2008. LP acknowledges the support of National Natural Science Foundation of China (61033003, 91130034 and 61320106005).
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http://dx.doi.org/10.1016/j.ins.2014.04.007
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Neural-like P systems consider neurons as their cells organized with a network structure as a directed graph. In the past fourteen years, plenty of research results have been achieved at the theoretical level, for example, various variants of P systems with Turing computing power have been developed and polynomial or linear solutions to a variety of computationally hard, NP-complete or PSPACE-complete, problems have been obtained [55]. Applications of MC in various fields, including parallel and distributed algorithms, graphics, linguistics, economy [10] and more recently in systems and synthetic biology [16], have been investigated. To date, the applications with a practical or engineering use are intensively investigated and deserve more attention.

Evolutionary computation (EC) is a branch of natural computing that covers a wide range of problem-solving optimization techniques based on principles of biological evolution, such as natural selection and molecular genetics, and the collective behavior of decentralized and self-organized systems [12]. The main evolutionary paradigms are: genetic algorithm (GA) [24,23], genetic programming (GP) [34–36], evolution strategies (ES) [65,1], evolutionary programming [15], particle swarm optimization [32,53], ant colony optimization [11], differential evolution [60] and quantum-inspired evolutionary algorithm [82]. Each paradigm uses population-based probabilistic search, a powerful tool for broad exploration and local exploitation of the model space [31]. This strategy improves algorithms for local search and other global search algorithms such as simulated annealing [33] and tabu search [22]. Also, their stochasticity improves the heuristic artificial intelligence [46,47] and machine-learning algorithms [44,66]. EC mostly involves meta-heuristic optimization techniques and generally includes two broad areas: evolutionary algorithms (EAs) and swarm intelligence [4]. These techniques are being increasingly widely applied to various problems, ranging from practical applications in industry and commerce to leading-edge scientific research [12]. Amongst various research directions in EC, it is widely acknowledged that the appropriate hybridization of EC and various techniques is very useful to improve the algorithm performance [3,2,82].

MC has the rigor and sound theoretical development for all variants of membrane systems and provides a parallel-distributed framework and flexible evolution rules. While EC has outstanding characteristics, such as easy-understanding, robust performance, flexibility, convenient use for real-world problems and a very large scope of applications. These features suggest the exploration of the interactions between MC and EC, called evolutionary membrane computing (EMC) in this paper. Until now, the possible interplay of MC and EC has produced two research topics: membrane-inspired evolutionary algorithms (MIEAs) and automated design of membrane computing models (ADMCM). On the one hand, MIEAs, initially called membrane algorithms (MA) [50,94], creates a bridge between MC and various real-world applications. This hybrid method is considered as the application with a practical use of MC in computer science [55]. It is worth pointing out that it is more appropriate to use the concept MIEA, instead of MA, to describe this kind of approximate optimization algorithms in this paper due to three reasons: (1) MA is normally associated with the name of the implementation algorithms of MC models, instead of the hybrid optimization algorithms; (2) only a small portion of publications on MIEAs used the term MA; and (3) In *Chapter 19* of the collective paper [21], this class of hybrid optimization algorithms has been generically called MIEA. The automated synthesis of MC models or of a high level specification of them is envisaged to be obtained by applying various EC algorithms. On the other hand, ADMCM aims to circumvent the programmability issue of membrane based models for membrane systems [14,30]. The difference between MIEA and ADMCM can be illustrated by using Fig. 1, where they have different inputs and outputs.

Since the introduction of MC, attention has been paid to EMC. In recent years, research into EMC, a novel and promising interdisciplinary research direction, has become a rapidly expanding field, as shown in Fig. 2. The preparation of this survey paper is motivated by the following points:

1. No survey on EMC has yet appeared in the specialized literature. It is necessary to provide an overview of the state-of-the-art of EMC so as to allow newcomers to the area to obtain a clear understanding of key research problems and developments in this field, including those that are currently under way.
2. An introduction of EMC to the broader scientific community for research purposes is aimed.
3. Some confusing aspects related to the EMC research that appeared in the current literature has to be clarified.

This paper presents an overview of the state-of-the-art of EMC and new results. The main contributions can be summarized as follows:

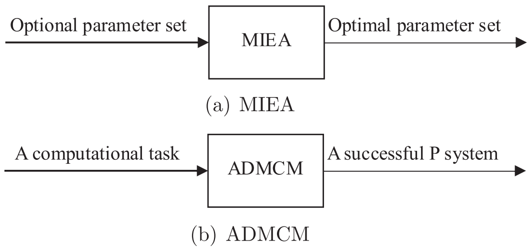

Fig. 1. Difference between MIEA and ADMCM.

Please cite this article in press as: G. Zhang et al., Evolutionary membrane computing: A comprehensive survey and new results, Inform. Sci. (2014), http://dx.doi.org/10.1016/j.ins.2014.04.007