Optik 126 (2015) 3883–3888

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

A novel membrane-inspired algorithm for optimizing solid waste transportation

Juanjuan He[a,b], Jianhua Xiao[c], Xin Liu[d], Tingfang Wu[d], Tao Song[e,*]

[a] School of Computer Science, Wuhan University of Science and Technology, Wuhan 420081, China
[b] Hubei Province Key Laboratory of Intelligent Information Processing and Real-time Industrial System, Wuhan 430081, China
[c] The Logistics Research Center, Nankai University, Tianjin 300071, China
[d] Key Laboratory of Image Processing and Intelligent Control, School of Automation, Huazhong University of Science and Technology, Wuhan 430074, China
[e] Faculty of Engineering, Computing and Science, Swinburne University of Technology, Sarawak Campus, Kuching 93350, Malaysia

ARTICLE INFO

Article history:
Received 20 June 2014
Accepted 19 July 2015

Keywords:
Membrane computing
Membrane algorithm
Cell-like framework
Vehicle routing problem

ABSTRACT

Membrane computing is a new branch of natural computing, whose aim is to abstract computing ideas from the structure and the functioning of living cells to construct computing models and algorithms. The obtained algorithms are generally called membrane-inspired algorithms or membrane algorithms, which are known as a class of intelligent algorithms inspired by biological behaviors of living cells. In this work, a membrane algorithm with a three-levels of hierarchical cell-like structure is proposed, where elementary membranes can dynamically evolve to generating working space (performing cell division) during the computation. We test our method by solving 14 instances of a benchmark of the vehicle routing problem, as well as a numerical example of solid waste management in Chengdu, China. Experimental results show that our method performs well on solving the 14 instances of the benchmark of the vehicle routing problem comparing with the genetic algorithm, tabu search algorithm, simulated annealing algorithm, ant system algorithm, and evolutionary algorithm. In practice, our method can quickly obtain the global optimal solution of the numerical example of solid waste management.

1. Introduction

Membrane computing is a new branch of natural computing, which has become a popular area in computer science in recent years. The aim is to abstract computing ideas (data structures, ways to process information, communication, etc.) from the structure and the functioning of a single cell and from complexes of cells, such as tissues and organs to construct computing models and intelligent algorithms. The obtained distributed and parallel computing devices, usually called P systems, and the algorithms investigated in membrane computing, called membrane-inspired algorithms or membrane algorithms, are known as a class of intelligent algorithms inspired by the biological behaviors of living cells. There are three classes of P systems mainly investigated, including cell-like P systems [1], tissue P systems [2] and spiking neural P systems (SN P systems, for short) [3].

Most of P systems have been proved to be universal, that is, do what Turing machine can do, as number acceptors/generators, language generators and function computing devices, such as P system with symport/antiport rules can generated and accept any set of Turing computable natural numbers [4,5], tissue P systems with channel states are universal as number generators [6], asynchronous SN P systems can generate any set of languages accepted by Turing machine [7], SN P systems with weights can generate and accept any set of natural numbers which are Turing computable [8], SN P systems with antis-spikes can compute any Turing computable function [9–11].

P systems have also been applied to solve realistic problems. Some variants of P systems with cell reproduction can generate exponential working space during the computation, thus give a theoretical manner to solve computational hard problems, particular to solve **NP**-hard problems, in feasible (polynomial or linear) time. For instance, P systems with active membranes were used to compute NP-hard problems, such as Ramsey numbers in polynomial time [12], SAT problems [13], tissue P systems with cell separation can solve partition problem and Tripartite matching problem in polynomial times [14,15], SN P systems with cell division and budding can solve SAT problem in polynomial time [16,17], and we can use SN P systems with pre-computed resources to solve SAT and 3SAT problems in feasible times [18]. All the mentioned results on solving computational hard problems by P systems are obtained at the theoretical level.

* Corresponding author. Tel.: +86 15271818921.
E-mail address: taosong@hust.edu.cn (T. Song).

http://dx.doi.org/10.1016/j.ijleo.2015.07.152
0030-4026/

Inspired by the ways that living cells process information and communicate with each other, a class of intelligent algorithms, called membrane-inspired algorithms or membrane algorithms have been proposed to solve practical problems. The membrane-inspired algorithm, initialed by Nishida in 2005 [19], was inspired by the structure of the cells and the biological behaviors of living cells communicating with each other by delivering chemical objects. In [16], a membrane algorithm with nested membrane structure was developed for solving the traveling salesman problem (TSP), where the simulation results showed that the algorithms were rather efficient for solving the TSP. Till now, many membrane algorithms with different structures or communicating strategies have been developed to solve computational hard problems in practice, such as solving the min storage problem [20], the single-objective problem [21] and multi-objective numerical optimization problem [22], broadcasting problems [23], image processing [24] and parameter estimation for proton exchange membrane fuel cell model [25]. In [26], a membrane algorithm using one level membrane structure was proposed for knapsack problem.

In the present work, we propose a new membrane algorithm with a three levels of hierarchical cell-like structure, where some membranes can evolve (performing cell division) according to the size of the problems to be solved. Specifically, the structure of our algorithm was initialized with three nested membranes, and when the size of the problem to be solve becomes large, some cells can be divided into two cells during the computation to generate new working space by the cell division operations. We test our algorithm on 14 instances of a benchmark of the vehicle routing problem.

The vehicle routing problem (VRP, for short) is a class of combinatorial optimization in fields of transportation, distribution and logistics proposed in [27]. The context of VRP is that a fleet of vehicles delivery goods located at one or several depots to a number of customers who have known demands and required service time. Vehicles have maximal loading capacity and fixed limit for each trip. The objective is to find a set of routes which minimizes the traveling cost. As it is stated in [28], VRP is easy to describe but difficult to solve, which is actually NP-hard.

In the past few years, many algorithms have been used for optimizing vehicles routing problem. Among them, heuristic approaches are a class of practical methods, such as savings algorithm [29], the granular tabu search algorithm [30] and sweep algorithm [31]. In recent years, it is shown in [32,32] that the tabu search (TS) algorithm was a powerful heuristics for VRP, but it often traps into local optima and cannot find the global optimal solution. To avoid the defect, recently, some intelligent algorithms have been used to solve the VRP problem, such as genetic algorithm [34], simulated annealing algorithm [35], ant system algorithm [36], and evolutionary algorithm [37].

Experimental results show that our algorithm performs well on detecting globally optimal solutions of the 14 instances of the benchmark of the VRP, comparing with the results by using genetic algorithm from [34], simulated annealing algorithm from [35], ant system algorithm from [36], and evolutionary algorithm from [37]. Specifically, our algorithm achieves eight globally optimal solutions of the 14 instances. Some analysis on the parameters used in the method has been done, and the most suitable pair to achieve good balance between convergence and diversity is achieved. In practice, we use our method to solve a numeral example of solid waste management in Chengdu. Experimental results show that our algorithm can quickly obtain the global optimal solution of the instance.

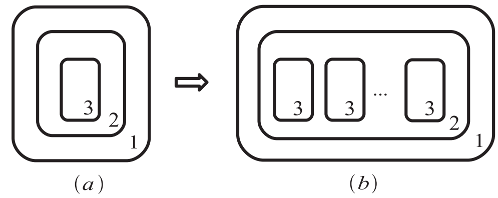

Fig. 1. The structure of the algorithm.

2. The membrane algorithm for VRP

2.1. The membrane algorithm

Cell is the fundamental unit of all living organisms. It is a complex system with well-organized structure, where a great amount of elaborate reactions take place all the time. One of the most important reactions of a cell is reproduction, called mitosis. In this process, two cells are created by division a cell into two identical copies, and each of them can continue the process. Cells can communicate with each other by delivering molecules and chemical objects.

These biological facts provide a framework to construct membrane algorithms. In the framework of membrane algorithm, it consists of a number of regions, operators, and solution transporting mechanisms. The workspace is separated by membranes into multiple regions. In every region, tentative solutions are updated by operators. The membrane can be divided into two membranes during the computation to generate new working space, when the size of the problem to be solved becomes large. In membrane algorithms, solutions in each region can be sent to its upper region or inner region in a parallel way.

The algorithm consists of three elements:

(1) A number of regions. In the beginning, there are three regions which are separated by nested membranes, see Fig. 1(a). In the first n steps of computation, the innermost cell can be divided into 2^n cells, see Fig. 1(b).
(2) A number of tentative solutions. Tentative solutions of the optimization problem are encoded as genome and treated as molecules in a living cell, such as reproduction, recombination, and mutation.
(3) Solution transporting mechanisms. Tentative solutions can be transport to inner regions or outer region by transporting mechanisms with symport/antiport rules.

Initially, there are three regions labeled with 1, 2, 3 (see Fig. 1(a)), which separate the workspace to three regions. After n steps of division, we obtain 2^n copies of region 3 (see Fig. 1(b)). In every region 3, there are reactions for updating initial solutions, and in region 2 a selection operator is associated. All the regions labeled 3 can emit optimal solutions to region 2, and then the best tentative solution in region 2 is sent to region 1, which can be improved by local search in region 1 with by operating frequency NI. The left tentative solutions in region 2 will be sent back to region 3 as new initial solutions for the next iteration. In region 1, if the obtained solution cannot be improved in l steps (l is a given parameter), the result corresponding the solution will be sent out to the environment. The pseudo code for the whole process is shown in Appendix A.

2.2. Solving VRP by the algorithm

The vehicle routing problem is a typical combinatorial optimization problem. It is defined on an undirected network $G=(V, E)$ with a node set $V = \{v_0, v_1, \ldots, v_n\}$ and an edge set $E = \{(v_i, v_j)/v_i,$