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A knowledge-based heuristic particle swarm optimization approach with the adjustment strategy for the weighted circle packing problem

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ABSTRACT

The weighted circle packing problem is a kind of important combination optimization problem and has the NP-hard property. Inspired by the No Free Lunch Theorem, a knowledge-based heuristic particle swarm optimization approach with the adjustment strategy (KHPSOA) is developed for this problem. The knowledge (e.g., the relation between its weight matrix and better solution) is obtained from this problem itself and existing layout scheme diagrams and applied to form more effective ordering and positioning rules of the proposed heuristic method. A better layout scheme of larger circles is obtained through the heuristic method. The optimal solution of this problem is obtained by inserting a few residual smaller circles into the gaps of the better layout scheme and further optimizing it through the proposed particle swarm optimization with the adjustment strategy. The numerical experiments show that KHPSOA is superior to the existing algorithms in the performances.

1. Introduction

Layout problems with performance constraints have widely applied backgrounds (e.g., the layout design of the printed circuit board and spacecraft cabin, layout of the factory machine and equipment and cutting-stock of plates for iron and steel enterprises [1–3]). Each of them can be described as that several non-overlapping objects are placed in a container and the layout scheme of each problem satisfies several given constraints. In terms of different constraints, the layout problems mainly include weighted layout problems [2] and layout problems with equilibrium constraints [1]. The weighted circle packing problem (WCP problem) discussed in this paper belongs to the former, which is a kind of important combination optimization problem with following two performance constraints.

(i) There is not any overlapping area among objects and between each of the objects and the container.
(ii) Both the area of the container and the sum of weighted distances get to minimal values.

Because the WCP problem belongs to the NP-hard problem, it is significantly difficult to be solved in polynomial time. So, many scholars have been devoting themselves to the research of this problem for a long time and have proposed some

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effective algorithms. Li et al. [4] (2003) presented a parallel hybrid immune algorithm (PHIA), who introduces the immunity theory into the parallel genetic algorithm (GA) with the chaotic initial population and adaptive crossover and mutation operation Qian et al. [5] (2001) put forward a human–computer interactive genetic algorithm (HCIGA). Their key idea is that the artificial layout schemes are constantly coded into the unified normalization strings, and are added into the population of GA by replacing a worse individual in every few iteration steps. Thus, both the human and computer can exert their respective advantages to the utmost. Liu et al [6] (2005) proposed an interface technique of the human–computer interactive genetic algorithm (EN-HCIGA). Liu et al. [7] (2006) gave a human intelligence-diagram-computing-based layout design method (HDCLDM), which is the combo of a lot of successful experience of modern engineers, designers' wisdom, prior layout knowledge (the relevant layout diagrams), and advanced computer technology to solve the WCP problem. Wang et al. [8] (2007) suggested a cultural-based particle swarm optimization algorithm (CBPSO). Their idea is that the particle swarm optimization (PSO) is added into the cultural algorithm model, and double evolution systems are constructed in the PSO-based main population space and GA-based knowledge space, respectively. Two systems have their respective populations and evolve in parallel. Thanks to the human–computer interaction or the combination of different optimization algorithms, the above mentioned algorithms avoid the premature to some extent. So, in both the solution accuracy and computational efficiency, each of them is superior to the algorithms existing at that time, respectively. But there still exist the following two deficiencies for them.

(i) From the evolutionary mechanism view, a better individual is obtained by computing and comprising fitness values of population individuals at each iterative step. But the time-consuming interference (the overlapping area) calculation is a part of computing those fitness values and has become a bottleneck that restricts further improvement of performances of the evolutionary algorithms.

(ii) Although some scholars (for example, the author of [7]) introduce knowledge solutions into populations of algorithms, each of them has not tried to obtain the knowledge from the problem itself and existing layout scheme diagrams, and has not tried to combine it with his layout approach. But the No Free Lunch Theorem indicates that if not combining related knowledge of the problem with the respective algorithm, all performances of the optimization algorithms are equivalent [9].

Aiming at the above-dimensioned deficiencies of the evolutionary algorithms, Yang and Li [10] (2009) designed a fast heuristic ant colony optimization approach (FHACA) for the WCP problem. Both its computation efficiency and solution accuracy are improved. This is because all the initial individuals and offspring individuals of the ant colony optimization (ACO) of FHACA are feasible layout schemes (layout schemes without the overlapping area) constructed by the proposed heuristic method such that the time-consuming interference calculation is avoided. But an absence of a powerful ordering and positioning heuristic and heuristic-combining optimization method is a key obstacle to solving this problem. Inspired by the No Free Lunch Theorem, in this paper, the knowledge is obtained from the problem itself and existing layout scheme diagrams of the WCP problem, and a knowledge-based heuristic PSO approach with the adjustment strategy (KHPSOA) is proposed for the WCP problem. Experimental results show the effectiveness of the proposed KHPSOA.

The remainder of this paper is organized as follows. The statement of the problem is in Section 2. The heuristic method is proposed in Section 3. KHPSOA is presented in Section 4. Section 5 is the results and discussion of three experiments. The summary is shown in Section 6. The final part is acknowledgment.

2. Statement of the problem

Engineering background of the WCP problem is the layout design of VLSI and placing of the factory machine and equipment. This problem can be described as follows.

Let $A_1, A_2, \ldots, A_n$ denote n given circular objects (circles for short in this paper), w_{ij} be the weight of the relation between two circles A_i and A_j (for the layout design of VLSI, w_{ij} represents the connectivity between two integrated blocks A_i and A_j; for the layout of the factory machine and equipment, w_{ij} represents the adjacent requirement between two equipments A_i and A_j), where $i, j = 1, 2, \ldots, n$. Set $\boldsymbol{S_c} = \{A_1, A_2, \ldots, A_n\}$, then the WCP problem can be described as finding a feasible layout scheme of $\boldsymbol{S_c}$ and making $S + \lambda C$ as small as possible. Here S is the area of the envelope rectangle of n circles. C is defined by the following formula (1), which denotes the sum of their weighted distances. λ denotes the weight factor of C related to S:

$$C = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} w_{ij} d_{ij} \quad (i, j = 1, 2, \ldots, n). \tag{1}$$

In the formula (1), d_{ij} denotes the distance between A_i and A_j. Suppose the point (x_i, y_i) be the center of the circle A_i, int A_i be the internal area of the circle A_i, then a mathematical model of this problem may be described as the following formula (2):

$$\begin{aligned} &\text{Find } \boldsymbol{X} = \{(x_i, y_i),\ i = 1, 2, \ldots, n\} \\ &\min\ F(\boldsymbol{X}) = S + \lambda C \\ &\text{st. int } A_i \cap \text{int } A_j = \varnothing, \quad i, j = 1, 2, \ldots, n \text{ and } i \neq j. \end{aligned} \tag{2}$$