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A theoretical and empirical study of the trajectories of solutions on the grid of Systolic Genetic Search

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ABSTRACT

Systolic Genetic Search (SGS) is a recently proposed optimization algorithm based on the circulation of solutions through a bidimensional grid of cells and the application of evolutionary operators within the cells to the moving solutions. Until now, the influence of the solutions flow on the results of SGS has only been empirically studied. In this article, we theoretically analyze the trajectories of the solutions along the grid of SGS. This analysis shows that, in the grids used so far, there are cells in which the incoming solutions are descendants of a pair of solutions that have been previously mated. For this reason, we propose a new variant of SGS which uses a grid that guarantees that, given a pair of solutions that coincide in any cell, a pair of ancestors of these two solutions have not been previously mated. The experimental evaluation conducted on three deceptive problems shows that SGS has a better numerical efficiency when it uses grids that limit the mating of descendants of pairs of solutions that have already been mated. It also shows that this property helps to keep a larger diversity in the pairs of solutions that are mated in each cell.

1. Introduction

Evolutionary Algorithms (EAs) are stochastic search methods inspired by the natural process of evolution of species. EAs are guided by the *survival of the fittest* principle applied to candidate solutions through the selection of the best fitted individuals for reproduction, and it involves the probabilistic application of evolutionary operators to find better solutions. In the traditional sequential EA, the population is organized into a single group, mating individuals without limitations. Due to the emergence of Parallel EAs [3,22], two different population models have gained great popularity: the distributed or island model and the cellular model. In the island model [1,5], the population is partitioned into subpopulations that evolve semi-independently and the selection of parents for reproduction is limited to individuals that belong to the same subpopulation. In the cellular model [2], the population is structured in many small overlapping neighborhoods and the selection of parents for reproduction is local to each neighborhood.

Systolic Genetic Search (SGS) [26,29] is a recently proposed optimization algorithm that merges ideas from *Systolic Computing* and *Genetic Algorithms*. The algorithm was explicitly designed to exploit the high degree of parallelism available in

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modern GPU architectures. It has already shown its potential for tackling benchmark and real world problems, finding optimal or near optimal solutions in short execution times. SGS optimizes a set of solutions that flows through a bidimensional grid of cells following a synchronous and structured plan through a horizontal and a vertical data flow. In each cell, adapted evolutionary operators are applied to the tentative circulating solutions in order to obtain better solutions that continue moving across the cells of the grid.

SGS differs from the population models mentioned above because the interactions in SGS are limited by the subpopulations, being only possible interactions between two solutions that belong to the two different data flows. Also, the selection of parents for reproduction in SGS is implicit (SGS does not have an explicit selection process), and it is determined by the flow of solutions through the grid. In spite of the success of SGS for solving hard binary optimization problems, little is known about how the underlying search engine affects the general behavior of the algorithm. This motivates us to conduct a formal analysis of the trajectories described by the solutions along the grid, in order to gain insight into the operating mechanism of SGS.

In this article, we investigate the relation between the pairing of solutions of the subpopulations of SGS_B (one of the most effective flows for SGS) and the numerical efficiency of the algorithm. With this in mind, we theoretically analyze the trajectories described by the solutions for two different grids that have been used experimentally, examining especially the pairing of solutions of the two subpopulations that are produced along the grid. In this analysis, we found that there are cells in which both incoming solutions are direct descendants of a pair of solutions that have already been mated in another cell of the grid. This could prevent that highly fitted genetic material of the best circulating solutions of a data flow can be shared with a large part of the solutions of the other data flow, potentially compromising the exploitation of good regions of the search space. Because of this, we design a new variant of SGS that uses an original grid specially conceived to overcome this limitation. The novel variant of SGS has better theoretical properties than the variants used so far. In addition to the theoretical analysis, an experimental evaluation is also conducted to examine how the different grids impact on the effectiveness of SGS for solving three deceptive problems. We can summarize the contributions of this work as follows:

- It presents a theoretical analysis of the trajectories described by the solutions in two different grids that have been previously used for SGS [28,30]. As a result of this analysis, a new variant of SGS is designed, introducing a new grid with better theoretical properties that prevents the mating of descendants of pairs of solutions that have already been mated.
- It shows that the new variant proposed of SGS is the best performing algorithm in the experimental evaluation, being able to obtain optimal or almost optimal solutions for the three deceptive problems studied in this article. It also shows that the second best performing algorithm also uses a grid topology in which the mating of descendants of solution pairs that have already been mated is limited.
- It shows that SGS consistently outperforms two competitive genetic algorithms with the same evolutionary operators as the SGS algorithms for the three deceptive problems considered. This result corroborates that the success of SGS for solving these problems is caused by the underlying search engine of SGS.
- It reveals that the diversity in each cell of the grid of SGS (how different are the individuals that are being mated in each cell) is larger when the mating of descendants of pairs of solutions that have already been mated is prevented or limited, as in the newly proposed grid.

This article is organized as follows. Section 2 presents the main features of the SGS algorithm used in this work and it also discusses related papers from the literature. Then, in Section 3, we provide a theoretical analysis of the trajectories of the solutions on two different grids already used, as well as, we introduce a new grid that produces different pairing of solutions for mating in each cell of the grid in each step of the algorithm. The experimental design used for evaluating the three different grids and the results of the experimental evaluation are presented in Section 4. Finally, in Section 5, we outline the conclusions of this work and suggest future research directions.

2. Systolic genetic search

Systolic Computing is inspired by the physiology of the cardiovascular system [16,21]. In particular, in the systole phase, the heart contracts, increasing the pressure inside the cavities. As a result, the heart ejects blood into the arterial system with a regular cadence to meet the metabolic needs of the tissues. Systolic computing architectures are composed of simple data processing units, which are usually called cells, that are connected through a network. The cells are able to compute relatively simple operations to data received from neighboring units. The network allows a data flow between neighboring cells with a regular cadence, as in the systole phase of the cardiac cycle.

SGS [26–30] is a recently proposed optimization algorithm that adapts the operation of genetic algorithms to a systolic computing architecture. Several aspects of the SGS algorithm have to be defined such as the flow of solutions through the grid (how is the interconnection topology of the systolic structure and how do the solutions move through this structure), the dimension of the grid, and the computation of the cells (which operations are applied to the tentative solutions in each cell). In the rest of this section, we describe those aspects of the SGS used in this work, and we also discuss related papers from the literature.