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Playing with complexity: From cellular evolutionary algorithms with coalitions to self-organizing maps

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ABSTRACT

Since its origins, Cellular Automata (CA) has been used to model many type of physical and computational phenomena. Interacting CAs in spatial lattices combined with evolutionary game theory have been very popular for modeling genetics or behavior in biological systems. Cellular Evolutionary Algorithms (cEAs) are a kind of evolutionary algorithm (EA) with decentralized population in which interactions among individuals are restricted to the closest ones. The use of decentralized populations in EAs allows to keep the population diversity for longer, usually resulting in a better exploration of the search space and, therefore in a better performance of the algorithm. A new adaptive technique (EACO) based on Cellular Automata, Game Theory and Coalitions uses dynamic neighborhoods to enhance the quality of cEAs. In this article we compare the characteristics EACO with classical Self-organizing Maps (SOM), and we discuss the possibilities for using Game Theory and Coalitions in the SOM scenario.

1. Introduction

A Cellular Automata (CA) is a regular grid of cells, or lattice, each one having a finite number of states. CAs have been used as models for describing physical and computational phenomena with many applications [1] in physics, computational theory, mathematics, complexity theory, urban traffic modeling, artificial intelligence, biology, etc. Every cell, also denoted as cellular automaton, has a defined neighborhood to interact with. Time is discrete, and in every iteration any cell interacts with its neighborhood to find its new state depending on its own state and its neighbors' state.

Game Theory [2] provides useful mathematical tools to understand the possible strategies that self-interested agents may follow when choosing a course of action. Evolutionary Game Theory (EGT) [3] models the application of interaction dependent strategies in populations along generations. EGT differs from classical game theory by focusing on the dynamics of strategy change more than the properties of strategy equilibrium. In EGT participants do not possess unfailing Bayesian rationality. Instead, they play with limited computing and memory resources. The only requirement is that the players learn by trial and error, incorporate what they learn in their future behavior, and die or somehow 'change' if they do not.

Evolutionary algorithms (EA) are well-known population based metaheuristics [4]. They work on a set of solutions (called *population*), evolving them simultaneously towards (hopefully) better ones by applying some stochastic operators (typically called *evolutionary operators*, e.g., selection, recombination, and mutation). Cellular EAs (cEAs) [5] are structured population algorithms with a high explorative capacity. The individuals composing their population are arranged into a (usually) two dimensional toroidal mesh, and only neighbor individuals are allowed to interact during the breeding loop. Structuring the

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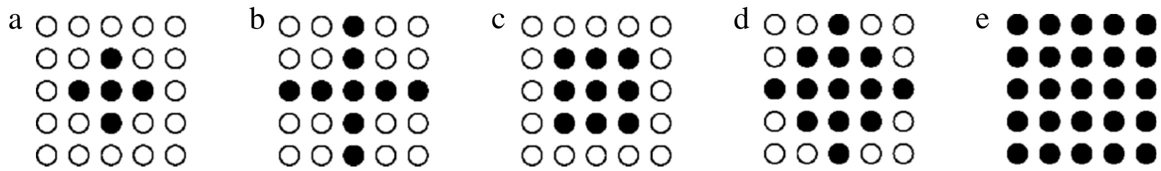

Fig. 1. Five possible neighborhoods used in CA. Among them, we can see von Neumann's neighborhood in (a) and Moore's neighborhood in (c).

population in this way we can achieve a good exploration/exploitation trade off on the search space, thus improving the capacity of the algorithm for solving complex problems [6].

This article first introduces the areas of Cellular Automata, Evolutionary Game Theory, Coalitions and Cellular Evolutionary Algorithms applied to function optimization. For this, we describe the EACO algorithm that integrates all these topics in a way to obtain a synergy in the development of Evolutionary Algorithms, with the advantages of different classical distributed models, but avoiding some of their limitations. This can be done thanks to the use of spatial cellular approaches with neighborhoods, allowing the formation of coalitions among cells as a way to create dynamic islands of evolution in order to preserve diversity. Besides, EACO uses Game Theory to consider every cell as a player of a game arranged in a two dimensional torus. Cells will be able to evolve depending on their payoff with respect to their neighbors, and have also the support provided by their coalition members. This approach allows the payoff of a given solution to be defined in terms of how much such solution has improved in the last generations. The idea is to speed up the evolution of individuals grouped in high-quality coalitions that are quickly converging to promising solutions. Once EACO has been introduced, we do so with Self-organizing Maps (SOM), a type of self-organizing neural networks with many applications described along the last two decades [7]. Finally, we compare both approaches to explore the possibilities of merging both techniques to get a richer and eclectic combination to apply in the areas of optimization and prediction.

Therefore, the main contribution of this work is: first to compare these two literature independent models (cEAs and SOM) to evaluate their similarities; and second to consider the possibility of using game theory and coalitions, as dynamic neighborhoods in SOM networks.

The next sections are structured as follows. Section 2 introduces Cellular Automata. Section 3 provides a short introduction to Game Theory and Coalitions. Then, Section 4 introduces Evolutionary Algorithms (EAs), Cellular Evolutionary Algorithms (cEAs) and describes a recent cEA with Coalitions (EACO) and its promising results. Section 5 describes the main characteristics of Self-organizing Maps (SOM), and afterwards Section 6 discusses the promising possibilities of using game theory and coalitions in SOM models. Finally Section 7 outlines some conclusions and future work.

2. Cellular automata

A Cellular Automata (CA) is a regular grid of cells, or lattice, each one having a finite number of states [8]. CAs have been used as models for describing physical and computational phenomena with many applications in physics, computational theory, mathematics, complexity theory, urban traffic, biology, etc. Every cell, also denoted as cellular automaton, has a defined neighborhood to interact with. Time is discrete, and in every iteration any cell interacts with its neighborhood to find its new state depending on its own state and its neighbors' state.

CAs are simulated by a finite grid, which can be a line in one dimension, or a rectangle in 2D. In 2D usually cells are represented by squares, but triangles and hexagons can also be used. In these domains neighborhoods are usually based on the Euclidean distance, but other conventions can be considered as stochastic distance functions, social networks and many more. The same happens with the rules that define the transition function from one state to the next, where many types of functions can be defined.

The CA designer has to define the behavior of the cells in the frontier and, to solve this, several alternatives have been usually applied:

- *Open frontier*: the cells outside the lattice have a constant state.
- *Periodic frontier*: the frontiers of the lattice are in contact, i.e., a circumference in 1D, a toroidal shape in 2D, etc.
- *Reflection frontier*: outside cells take the value of their internal mirror cells.
- *No frontier*: the frontier expands when needed.

The origins of CA go back to the 40s when John von Neumann desired to design a machine able to self-reproduce and to provide complex computation. Together with his colleague Stanislaw Ulam, von Neumann developed a theory of CAs considering a model in 2D where cells can be in 29 possible states. In this model, the neighborhood defined for any cell was the cell itself plus the four orthogonal cells around, i.e., above, below, right and left; known as von Neumann's neighborhood (see Fig. 1). The result was a universal copier and constructor for a particular initial configuration [8].

In 1970 Conway produced the most popular CA, the Game of Life, which was published by Martin Gardner at Scientific American [9]. Life is a 2D CA game, where the neighborhood of a cell is composed by the cell itself and the 8 ones surrounding it, known as Moore's neighborhood (see Fig. 1). In Life cells can be dead or alive (2 states) and evolve using 3 very