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NEW MAJORITY RULE FOR NETWORK BASED CELLULAR AUTOMATA

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Abstract. Cellular Automata represent useful and important tools in the study of complex systems and interactions. This study focuses on the evolution of both network topologies and majority rules for the density classification task. Results show that a variation in the classical definition of the majority rule could induce higher performance of the cellular automata.

1. Introduction

Cellular Automata (CAs) are decentralized structures of simple and locally interacting elements that evolve following a set of rules [8], usually based on a regular lattice topology. Watts and Strogatz [9, 10] studied the CAs computation on small-world networks. In [1, 2, 7], small-world type network topologies are evolved starting from an initial population of regular and random structures. In these studies, it is shown that the evolved topologies have better performance for the CA majority problem than regular lattice structures.

In [3] we investigate the evolution and dynamics of small-world networks for CA computation. The density classification task is addressed using network topologies evolved based on a simple standard genetic algorithm. Computational experiments and results indicate that the obtained networks have a competitive performance for CA density classification even when simply the majority rule is applied.

In this paper we extend our research on network based cellular automata by searching for a new majority threshold for the density classification problem. A standard evolutionary algorithm is used in order to evolve both network topologies and majority rules that induce higher CAs performances.

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2. Majority rule for network based Cellular Automata

The one-dimensional binary-state CA capable of performing computational tasks has been extensively studied in the literature [6, 4, 5]. A one-dimensional lattice of N two-state cells is usually used for representing the CA. The state of each cell changes according to a function depending on the current states in the neighborhood. The neighborhood of a cell is given by the cell itself and its r neighbors on both sides of the cell, where r represents the radius of the CA. The initial configuration of cell states (0s and 1s) for the lattice evolves in discrete time steps updating cells simultaneously according to the CA rule.

One of the most widely studied CA problems is the density classification task (DCT). The aim of DCT is to find a binary one-dimensional CA able to classify the density of 1s (denoted by ρ_0) in the initial configuration. If $\rho_0 > 0.5$ (1 is dominant in the initial configuration) then the CA must reach a fixed point configuration of 1s otherwise it must reach a fixed-point configuration of 0s within a certain number of time steps.

The performance of a rule is given by the classification accuracy of a CA based on the fraction of correct classifications over 10^4 initial configurations selected from an unbiased distribution.

The rule used for network based DCT states that at each time step, each node takes the state of the majority of its neighbor nodes in the graph (if the number of state 1s equals the number of state 0s in the neighbors list then the node is randomly assigned a state with equal probability between 0 and 1).

Therefore, in the classical approach there is a threshold of 0.5 which represents the density of neighbors with the same value that pass their state to the current cell. Let us call it the *majority threshold*. The aim of this paper is to identify a different *majority threshold* that induces higher performance CAs. For example, for a majority threshold of 0.7, it would mean that a cell should receive the state 1 only if there are more than 70% neighbors having the value 1. Our intention is to find whether there is another equilibrium point of the system, different than 0.5.

A basic coevolution scheme is used to evolve both better majority thresholds and network topologies with better performance for CAs. The goal of evolving both types of solutions is to obtain a network more suitable to the new majority rule and vice versa. The performance and the robustness of the obtained network will also be studied.

3. Experimental results

A standard evolutionary algorithm is engaged to evolve both network topologies for cellular automata and new majority thresholds, as described in

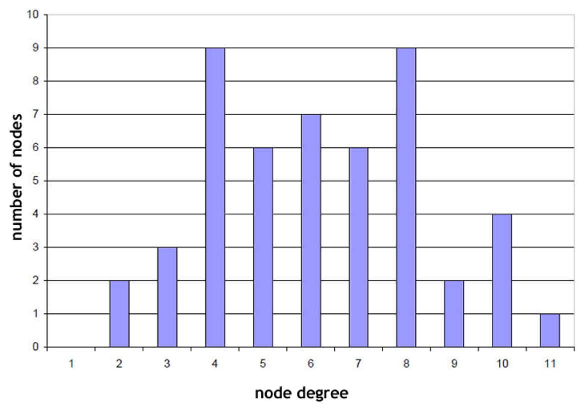

Figure 1. Node degree distribution for obtained network topology.

the previous section. There are two populations of individuals that evolve in parallel. There is one population of networks, where an individual is encoded as an array of integers representing nodes and a list of links for each node. The other population consists of individuals representing majority thresholds, therefore encoded as real number between 0 and 1. Both populations have 100 individuals and the number of generations is 100. Standard proportional selection, 10% elitism and weak mutation are applied for both populations. The fitness function is computed as the fraction of correctly classified 100 randomly generated initial configurations.

The evolution process starts with a regular lattice ring where each cell has 4 neighbors. At each generation, the best 20% individuals are fed into the other current population, which takes over the evolutionary process by searching for a better network and a better majority threshold, respectively.

As preliminary experiments, the described algorithm has been applied for cellular automata with 49 cells. In [3] we computed the performance of the obtained network with the fixed majority threshold of 0.5. For 49 cells CAs, the obtained performance was around 0.85. When evolving both network and majority threshold, we have obtained a slightly better performance (0.89) and a majority threshold around 0.6, out of 10 runs of the algorithm. These results indicate the fact that a better performance could be obtained when the majority is more strongly marked.

When analyzing the obtained network one can see that the average node degree is 6, which resembles the neighborhood of 7 usually used for regular lattice CAs. Figure 1 presents the distribution of node degrees in the obtained network. It can be noticed that the node degrees are close to the average.

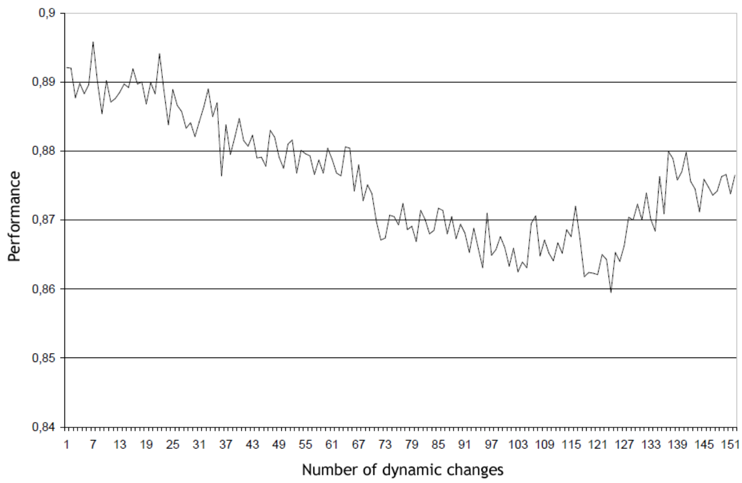

FIGURE 2. The performance of the network that is subject to dynamic changes with probability $p = 0.5$.

In order to evaluate the robustness of the evolved topology, the network has been subject to dynamic changes understood as random removal or addition of network links. The number of dynamic changes equals the number of edges in the network. At each step, a randomly selected link is either removed or added to the network with probability p and the resulting network is again evaluated with respect to the performance. Figure 2 depicts the performance of the considered network subject to dynamic changes with probability $p = 0.5$. The network is still able to trigger good performances on the DCT i.e. above 0.85. The high fluctuation in performance observed in the obtained network might be due to the fact that the algorithm has been able to find a good solution for this small network in its 100 generations, and a certain degree of destabilization is induced when the network is subject to further dynamic changes.

We further analyze the performance of the evolved network when the probability p of dynamic change ranges from 0.1 to 1 (see Figure 3). One can see that the performance for DCT remains good even when changes are induced with high probability. This is an indication of the robustness of the evolved network topology and its capability to obtain better results for the DCT (which can be potentially further improved in connection with more sophisticated rules compared to the fixed majority rule).

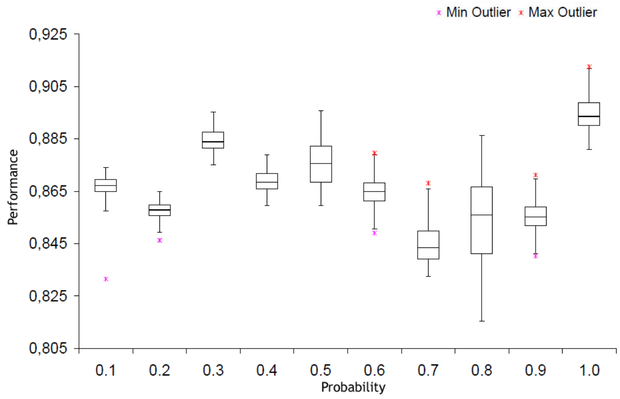

FIGURE 3. The performance of the 49 cells network subject to dynamic changes with different probabilities.

4. Conclusions and future work

A new approach to the standard understanding of majority rule for network based cellular automata has been proposed in this paper. On this purpose, a basic coevolution scheme has been applied in order to evolve a higher performance majority rule for network based CAs, and also a more suitable network topology. Preliminary results of our study led to the conclusion that there is a majority threshold different than 0.5 which might induce a higher performance for network based CAs. The performance of the obtained network topology is analyzed when the network is subject to dynamic changes. Our study will be further improved by considering CAs having more cells, especially the case of 149 cells which is considered by most of the studies found in the literature. We also plan to investigate the role of second degree neighbors when applying the majority rule for network based CAs, in order to further improve the CAs performance.

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References

[1] Darabos, C., Giacobini, M., Tomassini, M., Performance and Robustness of Cellular Automata Computation on Irregular Networks. Advances in Complex Systems 10: 85-110 (2007)

[2] Darabos, C., Tomassini, M., Di Cunto, F., Provero, P., Moore, J.H., Giacobini, M., Toward robust network based complex systems: from evolutionary cellular automata to biological models, Intelligenza Artificiale 5(1): 37-47 (2011)

[3] Gog, A., Chira, C., Dynamics of Networks Evolved for Cellular Automata Computation, HAIS (2), Lecture Notes in Computer Science, Springer, Vol. 7209, pp. 359-368 (2012)

[4] Mitchell, M., Thomure, M. D., Williams, N. L.: The role of space in the Success of Coevolutionary Learning. Proceedings of ALIFE X - The Tenth International Conference on the Simulation and Synthesis of Living Systems (2006)

[5] Oliveira, G.M.B., Martins, L.G.A., de Carvalho, L.B., Fynn, E., Some investigations about synchronization and density classification tasks in one-dimensional and two-dimensional cellular automata rule spaces, Electron. Notes Theor. Comput. Sci., 252 (2009), pp. 121-142.

[6] Tomassini, M., Venzi, M.: Evolution of Asynchronous Cellular Automata for the Density Task. Parallel Problem Solving from Nature - PPSN VII, Lecture Notes in Computer Science, Springer Berlin / Heidelberg, 2439, 934-943 (2002)

[7] Tomassini, M., Giacobini, M., Darabos, C., Evolution and dynamics of small-world cellular automata, Complex Systems 15 (2005), 261284.

[8] Wolfram, S., Theory and Applications of Cellular Automata, Advanced series on complex systems, World Scientific Publishing, 9128 (1986).

[9] Watts, D.J., Strogatz, S.H., Collective dynamics of 'smallworld' networks, Nature 393 (1998), 440442.

[10] Watts, D.J., Small Worlds: The Dynamics of Networks Between Order and Randomness, Princeton University Press, Princeton, NJ (1999)

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