Evolution of Cellular Automata Development Using Various Representations

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ABSTRACT

This paper introduces a comparative summary regarding an evolution of multi-state cellular automata by means of various representations of their transition functions. In particular, a conventional table-based representation and an advanced approach using so-called Conditionally Matching Rules is applied. The French flag development from a seed is considered as a case study. The results show some remarkable differences in the cellular automata behaviour that are evidently caused by the representation used. They include the issue of emergence of the pattern from a chaotic state or rather a more systematic construction, a stability of the pattern developed and a limitation of its successful construction to fixed-size automata only. The comparison of the results is enabled by using a custom variant of genetic algorithm that provided working solutions for both representations of the transition function.

CCS CONCEPTS

• **Mathematics of computing → Evolutionary algorithms**; **Developmental representations**;

KEYWORDS

cellular automaton; transition function; development; evolutionary algorithm

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1 INTRODUCTION

Cellular automata (CAs) have been introduced in [5] as a mathematical model of complex systems in which the space, time and states are discrete. A cell represents a basic CA element, typically arranged in a regular lattice, whose state develops in steps according to a local transition function. Although CAs have extensively been studied both theoretically (e.g. [6], [1]) and practically (e.g. designing nano-scale arithmetic circuits [4] or performing computations [3]), the design of the transition function in order to achieve a given (global) CA behaviour (i.e. a solution to a given task) represents a difficult problem because this behaviour *emerges* from local interactions between many cells and is hard to predict it from the transition function itself. Therefore, the aim is to automate this process, e.g. using evolutionary algorithms (EAs) to design CAs.

In this paper we mention some approaches that may be utilised for the evolutionary design of CA and compare them with respect to the properties of the solutions obtained. Specifically, two representation techniques of the CA transition functions will be considered: (a) a conventional table-based representation and (b)a method called Conditionally Matching Rules (CMRs). Whilst the conventional approach utilises a set of rules, each of which determines a new state of a cell for a given valid combination of states in its neighbourhood (typically in the form $N\ W\ C\ E\ S \rightarrow C_{new}$, where C represents the state of the (*C*entral) cell to be updated and N, W, E and S is the state of its *N*orth, *W*est, *E*ast and *S*outh neighbour, respectively, and C_{new} is the new cell state), the CMRs use more general relations between the cell states and values specified in the CMRs as described in Section 2.

The goal of this paper is to show some initial results that indicate that both aforementioned representation techniques can be applied for the evolution of complex 2D CA but the latter may provide remarkably more robust and efficient solutions.

2 CONDITIONALLY MATCHING RULES

The concept of Conditionally Matching Rules and their evolutionary design is described in detail in [2]. For the purposes of this paper, let us consider a 2D CA working with 5-cell neighbourhood (including the *N*orth, *W*est, *C*entral, *E*ast and *S*outh cell). A conditional rule for such CA is defined as $(cnd_N\ s_N)\ (cnd_W\ s_W)\ (cnd_C\ s_C)\ (cnd_E\ s_E)\ (cnd_S\ s_S) \rightarrow s_{new}$, where cnd_x denote a condition operator ($=$, $\neq$, $\leq$ or $\geq$) and s_y represent a state value. Each CMR contains a pair *(a condition and a state value)* that corresponds to (is evaluated with respect to) a specific cell in the neighbourhood. A finite sequence of CMRs represents a transition function that, for example, contains a rule $(\neq 1)(\neq 2)(\leq 1)(\geq 2)(= 3) \rightarrow 2$. Let c_N, c_W, c_C, c_E, c_S be cells in states $2, 3, 0, 3, 3$ respectively, and a new state of c_C needs to be determined. The CMRs are evaluated sequentially until a rule is found whose all conditions are true with respect to the cell states in the given neighbourhood. According to the aforementioned rule, $c_N \neq 1$ is true as $2 \neq 1$, similarly $c_W \neq 2$ is true $(3 \neq 2)$ and the remaining conditions are also true. Therefore, this CMR is said to match, i.e. $s_{new} = 2$ on its right side will be the new state of c_C. If no matching rule is found, then the cell keeps its current state. Note that the CMR-based transition functions can be transformed to the appropriate table rules which preserves the original concept of CAs [2].

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Table 1: Successful runs (out of 100) of our custom EA generating 16 offspring from the best half of 8 individuals.

#states	6	8	10	12	14	16
Table repr.	0	1	7	4	1	0
40 CMRs	0	0	0	0	0	1
50 CMRs	1	0	2	5	3	2
60 CMRs	11	15	18	14	14	15
70 CMRs	19	21	34	39	43	36

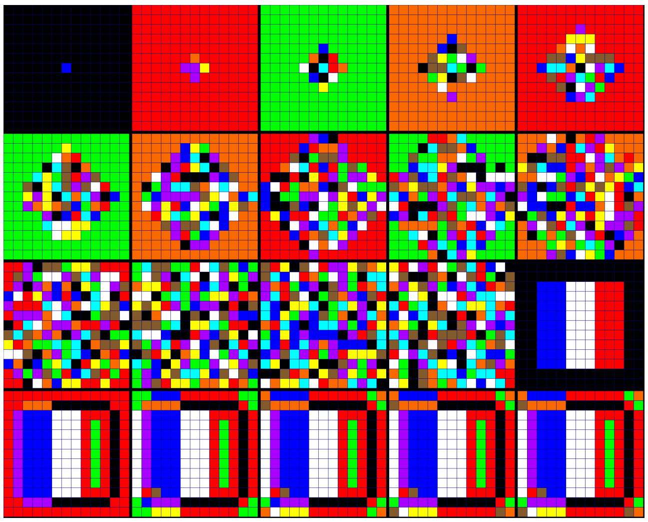

Figure 1: The French flag solution evolved using the conventional table-based approach in a CA working with 10 states[1].

3 EXPERIMENTAL RESULTS

We are tuning several evolutionary techniques which has shown necessary for obtaining working results. For example, the standard genetic algorithm failed in all cases of experiments we conducted so far. Therefore, a custom EA was applied whose preliminary results (the success rates of the CA evolution using both the table-based representation and the CMR method) are shown in Table 1.

Two samples of resulting CA development are shown in Fig. 1 (for the table representation) and Fig. 2 (for the CMR representation). As evident, the development of both CAs is different despite the fact that the CA concept is the same (the evolved CMRs were converted to the equivalent table rules). It was determined that the table-based solution does not work in CA of other sizes, the emergence of the pattern is rather chaotic and at a single step only, then it is destroyed and never restored again.. The CMR solution can develop a stable pattern that is independent on the CA size, the construction of which is progressive (and more systematic) from the initial seed. The evolved solution from Fig. 1 utilises 1274 active rules (i.e. those changing the cell state) whilst the converted CMR solution from Fig. 2 works with 129 rules only. Note that we observed such remarkably distinguished features in all results obtained for various patterns in CAs working with various numbers of states using the two representations. The evolution of CMRs also exhibits significantly higher success rates than the table-based representation.

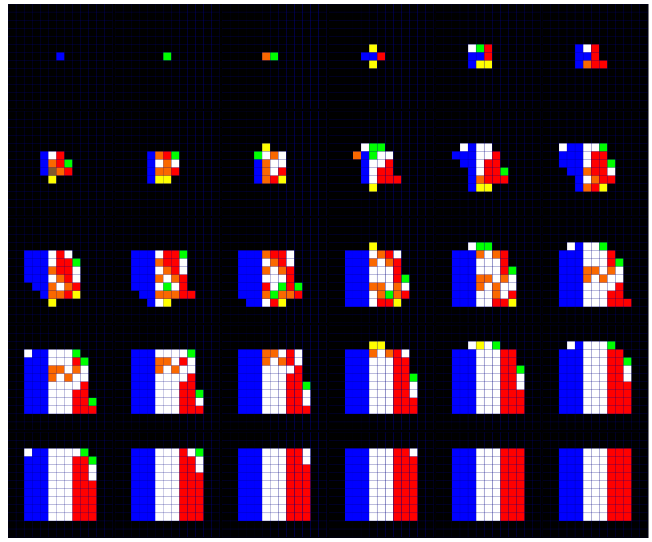

Figure 2: The French flag solution evolved using the CMR representation in a CA working with 8 states[1].

4 CONCLUSIONS

The results obtained may definitely be important for the future research of CAs since they clearly show how the representation influence not only the process of evolution but the also the form and features of the results. We also identified the importance of searching new variants of EAs which allowed us to design complex multi-state CAs that have not been obtained before. Therefore, the detailed statistical evaluation of the EA used, analysis of the results and solution of other problems in CAs represent our main work for the future research. We believe that a systematic study in this area may provide a better understanding of complex systems and help us optimise their automatic design using evolutionary techniques.

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[1]See an interactive simulator with this CA: https://github.com/bidlom/GECCO2019