Advances in the Evolutionary Design of Complex Cellular Automata

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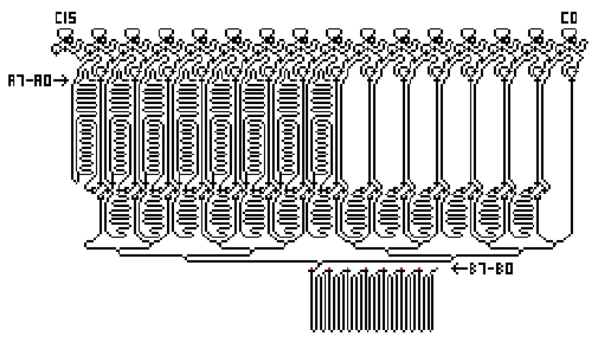
1 Overview

Cellular automata (CA) represent massively parallel models with universal computational capabilities. For example, the famous Game of Life (a binary 2D CA) or so-called Wire World (a 4-state 2D CA) exhibit such feature – see examples in the following Figures.

8-bit binary multiplier using Wireworld, http://mathworld.wolfram.com/WireWorld.html



Generating Sequences of Primes in Conway's Game of Life, http://www.njohnston.ca/2009/08/generating-sequences-of-primes-in-conways-game-of-life/

2 Motivation and goals

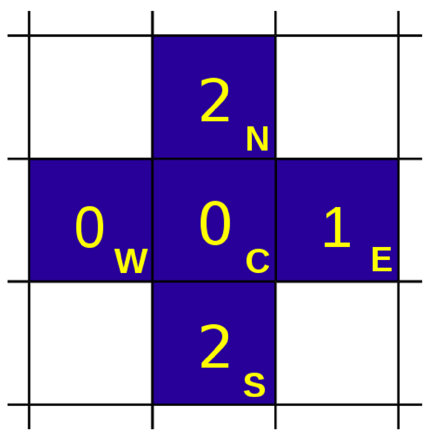
It was shown several times in the past that various trantition functions can be devised in order to solve specific problems in multistate CA (both benchmark and real-world applications). The main problem is how to effectively design the transition function for a given task.

This work is motivated by the need of searching for new methods combining both traditional and unconventional techniques, e.g. evolutionary algorithms.

Our goal is to compare two ways of transition function representation and evaluate them in evolutionary design of transition rules by means of a variant of Evolution Strategy. A non-trivial pattern development problem will be considered as a case study.

3 The proposed CA setup

In our experiments, 2D CA with 4 to 16 states and 5-cell neighbourhood were considered and evolved by means of:



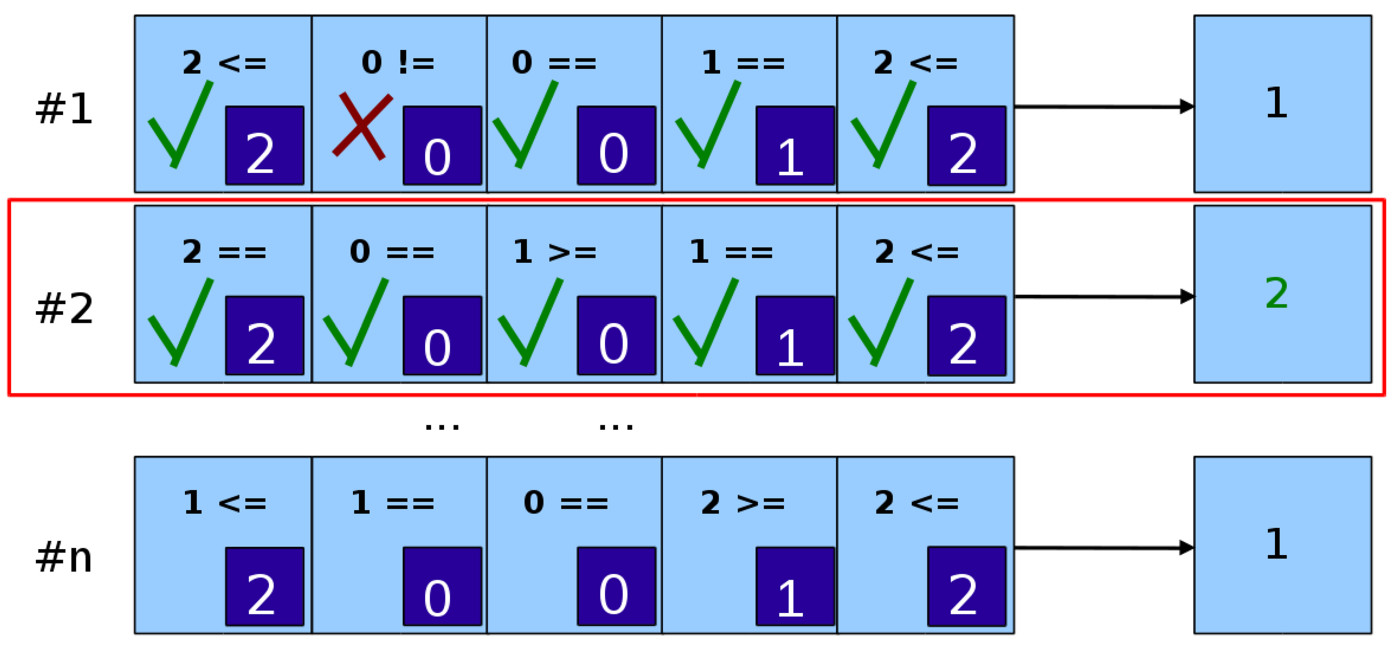
1. Conventional table representation:
A complete transition function is evolved in the form of a linear chromosome that encodes the new states (Cnew) for every possible combination of states N W C E S.

N	W	C	E	S	Cnew
0	0	0	0	0	0
0	0	0	0	1	1
0	0	0	1	0	1
....					
2	0	0	1	2	2
....					
2	2	2	2	2	1

For example, the transition function for a 4-state CA will be represented as an array of $4^5=1024$ integers.

2. Conditionally Matching Rules (CMRs):
A CMR is specified in a form of 5 conditions, evaluated for each cell in the neighbourhood, followed by a next state value for the central cell (Cnew) that is acquired by this cell if all conditions of the CMR are satisfied.
A finite sequence of CMRs constitutes a trans. function.

For example:



The CMRs are evaluated sequentially, the first matching rule (#2 for the example neighbourhood above) is used to determine the next cell state. The remaining rules do not need to be evaluated.

Therefore, in this example, the central cell gets state 2.

4 Evolutionary system setup

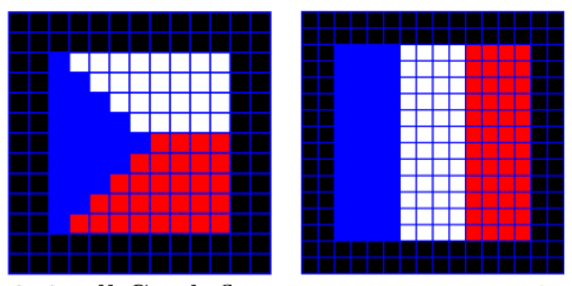
A (μ, λ)-Evolution Strategy (ES) was applied with the settings:

(2, 8)-ES, 2 mil. generations
(4, 16)-ES, 1 mil. generations
(8, 32)-ES, 500 thousand gens.

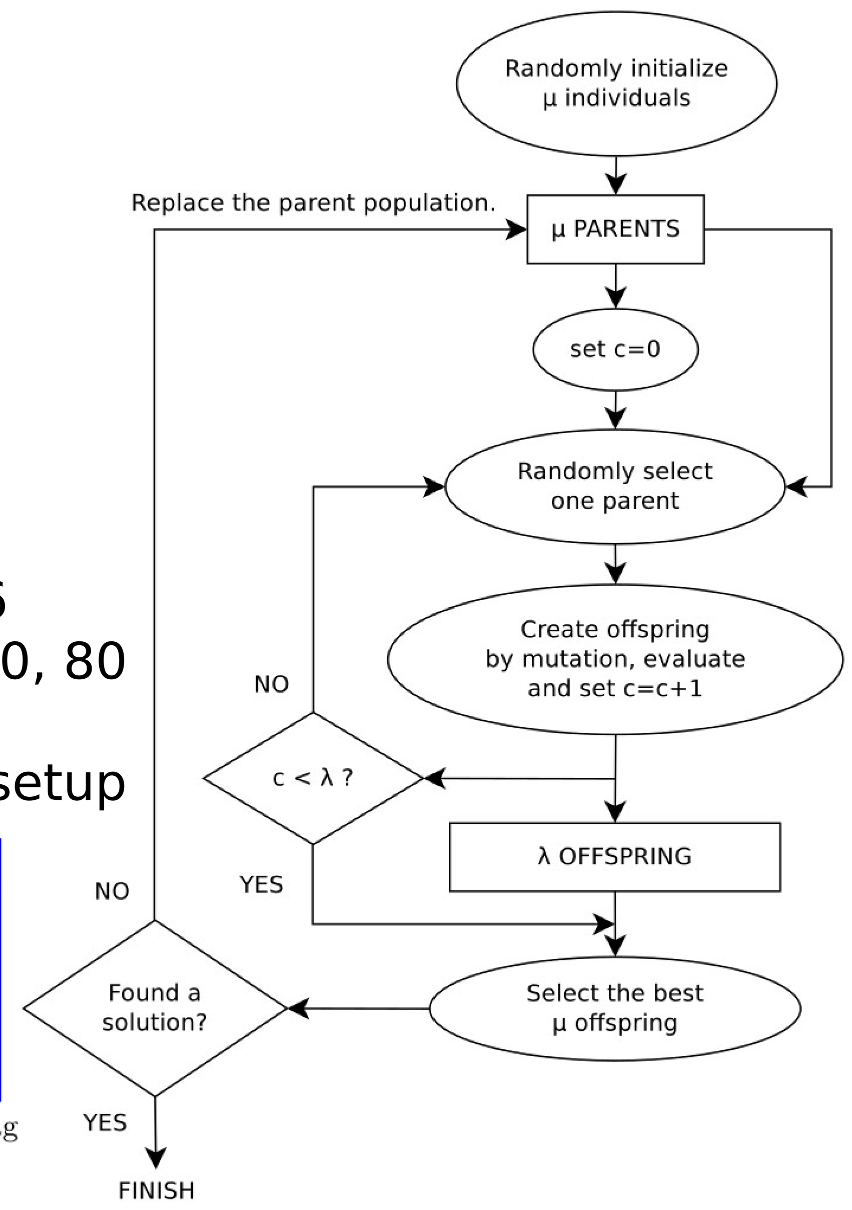
CA states: 4, 6, 8, 10, 12, 14, 16
\# of CMRs: 20, 30, 40, 50, 60, 70, 80

100 independent runs for each setup

Target patterns:



9x9-cell Czech flag 12x12-cell French flag

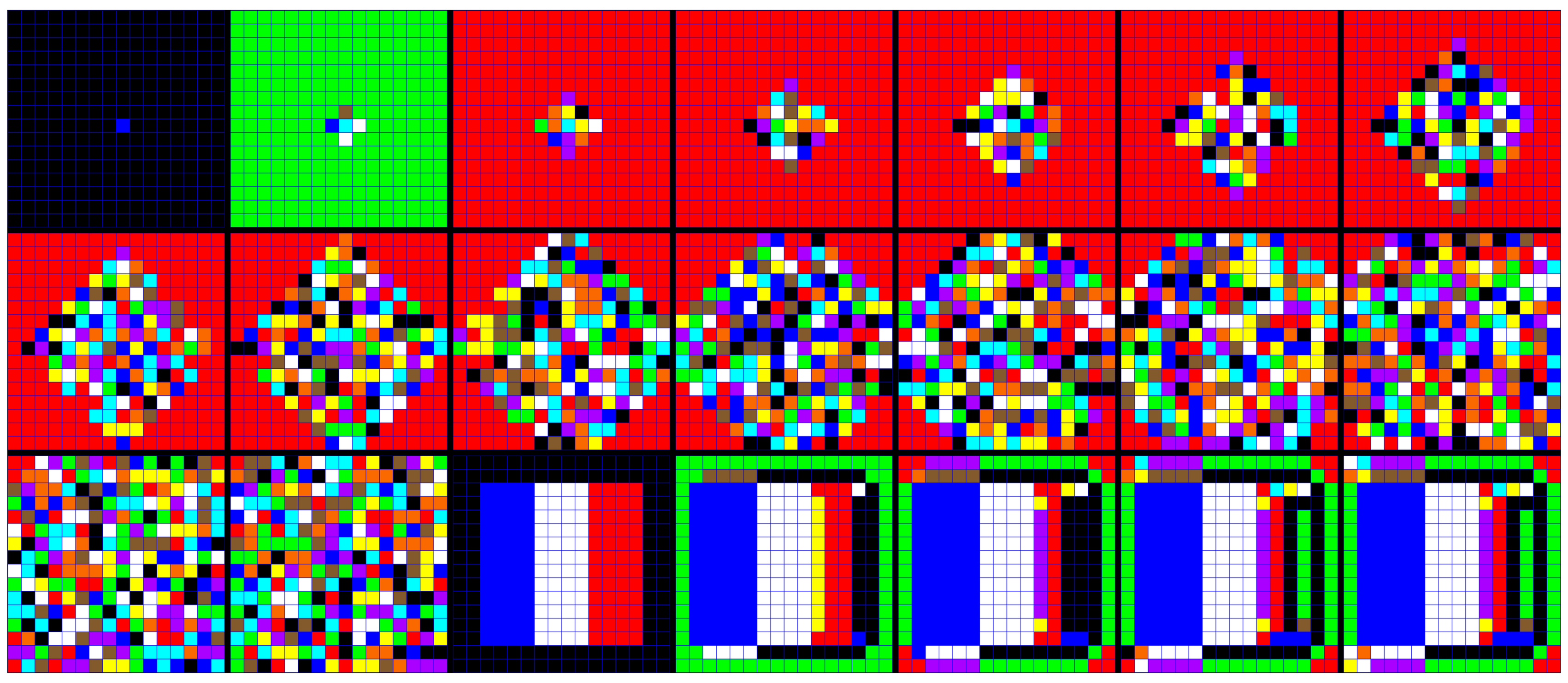


5 Experimental Results

Success rates for the evolution of trans. functions using:

1. Table-based representation

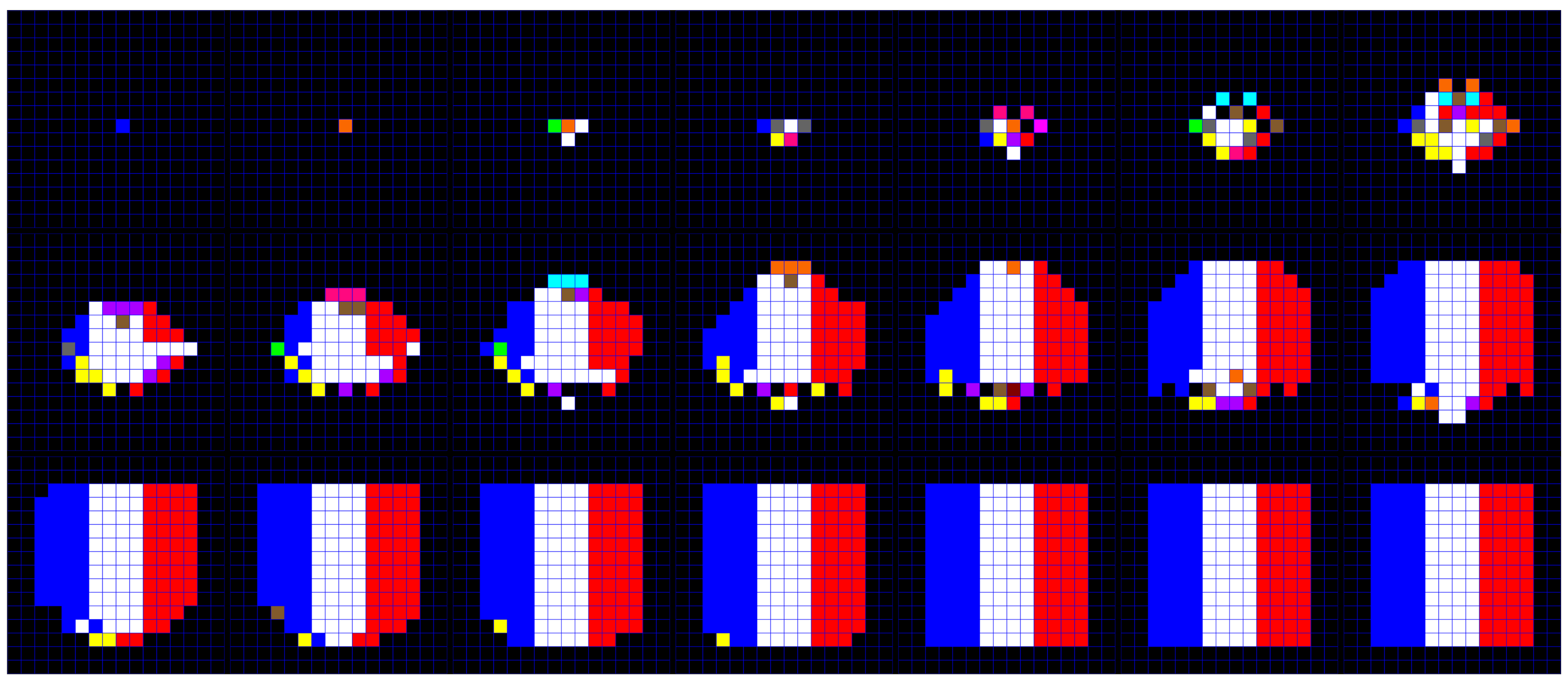
Target pattern	9x9 Czech flag							12x12 French flag						
#states	4	6	8	10	12	14	16	4	6	8	10	12	14	16
Evol. setup	The num. of results out of 100 runs													
(2, 8)-ES	0	5	1	8	7	1	0	0	0	1	4	2	4	0
(4, 16)-ES	0	2	0	3	4	0	0	0	1	1	0	3	0	0
(8, 32)-ES	0	0	0	0	0	0	0	0	0	0	0	0	0	0



The pattern *emerges from chaos*, then it is destroyed and never restored again. No stable solution was detected in this setup.

2. CMR representation

Target pattern	9x9 Czech flag							12x12 French flag						
#states	4	6	8	10	12	14	16	4	6	8	10	12	14	16
Evol. setup	The num. of results out of 100 runs													
(8, 32)-ES, 20 CMRs	0	0	0	4	1	0	1	0	0	0	0	0	0	0
(8, 32)-ES, 30 CMRs	0	4	6	12	7	11	14	0	0	0	0	0	1	0
(8, 32)-ES, 40 CMRs	0	6	6	8	12	9	9	0	0	1	2	2	1	1
(8, 32)-ES, 50 CMRs	0	5	11	13	8	9	9	0	0	3	3	4	1	2
(8, 32)-ES, 60 CMRs	0	5	5	8	9	4	10	0	0	0	1	1	1	4
(8, 32)-ES, 70 CMRs	0	3	3	5	6	7	7	0	0	0	0	1	1	1
(8, 32)-ES, 80 CMRs	0	1	4	3	3	6	5	0	0	0	0	1	1	0



The construction of the pattern is more systematic and some solutions exhibit stable pattern during furtner CA development.

6 Conclusions

The results showed that the representation significantly influences both the success rates of the evolution and the behavior of the CA itself.

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