# Towards the Efficient Evolution of Particle-Based Computation in Cellular Automata

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## ABSTRACT

A fast compression based technique is proposed, capable of detecting promising emergent space-time patterns of cellular automata (CA). This information can be used to automatically guide the evolutionary search toward more complex, better performing rules. Results are presented for the most widely studied CA computation problem, the Density Classification Task (DCT), where incorporation of the proposed method almost always pushes the search beyond the simple block-expanding rules.

## Categories and Subject Descriptors

I.2.8 [**Artificial Intelligence**]: Problem Solving, Control Methods and Search

## General Terms

Algorithms, Design, Theory

## Keywords

cellular automata, density classification task

## 1. INTRODUCTION

Cellular Automata (CA) are a much studied class of discrete dynamical systems, where highly complex behavior may arise from local interactions. The most widely investigated problem refers to the density classification task - a prototypical distributed computational task for CAs [1]. The problem refers to determining the density of the initial configuration (IC) state, a task requiring global synchronization, which must arise from locally passed information.

There is an ample body of work using evolutionary search to find strategies for the CA DCT as a paradigm for the evolution of collective computation in locally interacting dynamical systems [1, 2, 3].

Mitchell et al. [1] identifies three types of evolved strategies, where the most complex, the so called particle strategies use interactions among larger-scale patterns in order to classify ICs. Particle rules typically have performance values of 0.72 and higher on bit strings of length 149.

It appears to be difficult to evolve high-performance CAs using the simple evolutionary mechanism. Many studies have shown that only a small number of runs produce CAs that use particle strategies.


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## 2. COMPLEX SPACE-TIME SIGNATURES

In this work we focus on detecting online the formation and propagation of "signals", the behavior that characterizes (or can lead to) particle based computing.

Complex rules exhibit a transient phase during which a spatial and temporal transfer of information about the density in local regions takes place. Figure 1 visually depicts the difference between the space-time diagram of a) a block-expanding rule dominated by large areas of homogeneous blocks of 1s and 0s, and b) a particle based rule, where the signal areas exhibit fractal like patterns, maintaining a local symmetry and balance between the density of 1s and 0s.

Our automatic signal detection proposals are based on the following observations: (1) In order to propagate, signals must maintain locally a roughly equal density of 1s and 0s. Therefore they do not compress well under run-length encoding (RLE), which replaces a long sequence of the same symbol as a single data value plus its count. Space-time diagrams of block-expanding rules compress very well with RLE. (2) Along with density $p$ close to $1/2$, signals are also characterized by repetition of patterns of 1s and 0s which are bilateral symmetric (mirror-like symmetry). This symmetry enables the propagation of the signal, by recursively transforming pattern of 1s in pattern of 0s and vice-versa.

## 3. EXPERIMENTS AND RESULTS

The space-time diagrams from 1000 unbiasedly generated ICs for DCT, of 50 block-expanding rules (randomly extracted from runs of the GA reported in [1]) with performances between 0.56% and 0.64% and highly fit particle rules reported in the literature (presented in Table 1) were compressed using RLE. The obtained result were normalized by dividing with the original space-time diagram sizes and an average was computed over the 1000 test cases. The

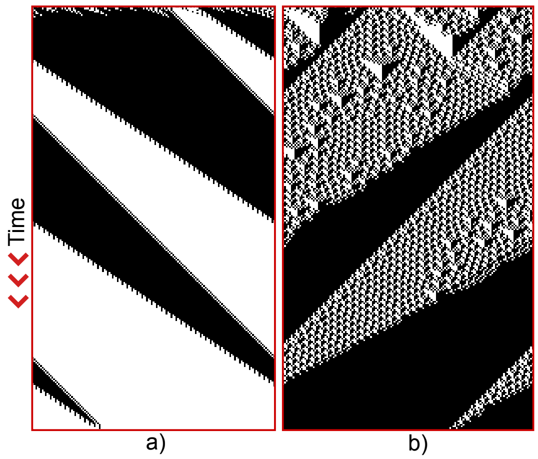


**Figure 1: Space-time plot of: a) a simple block-expanding rule (performance: 0.64%) b) a complex rule (performance: 0.89%).**

block-expanding rules exhibited a high compressibility, with a maximal average value of 0.074%. The particle rules exhibited a compression rate between 0.54% and 0.88%, empirically confirming the hypothesis that RLE compression is a good discriminant between poorer and higher performing rules for the DCT.

In a second step, the fitness function of a simple genetic algorithm was modified, to potentially append the fitness for individuals with original fitness greater than 0.6 with a bonus based on non-RLE compressibility. The bonus represented 10% of the normalized RLE compressed value of space-time diagrams and it was only awarded if this value exceeded a threshold of 0.02. In this way, we encouraged the departure of good enough individuals from block-expanding rules.

50 runs of the modified algorithm showed, that the dominant block-expanding rules are often replaced with high fitness rules, that exhibit enlarged transient portions in their space-time diagrams. Examples of such rules are depicted in Figure 2.

The experiments have indicated that rewarding the non-compressibility under RLE of space-time diagrams has the potential to guide the evolutionary search away from basic block-expanding rules and help automatic CA programming. However, if the non-compressibility arrises from "random" behavior and not useful signals, the classification performance of a rule will be weak. Thus, the two objectives incorporated in the modified fitness function are often opposing forces, which make it difficult to evolve both high performing, highly non-compressible rules. We believe a multiobjective optimization framework to be much more suitable for this task. Another observation is, that in most cases, the newly emerged, more frequent transient regions are short lived, because they lack symmetry. Albeit performing better, it is still hard for these rules to propagate information on very large scales. Therefore, future research will focus on developing computationally efficient pattern recognition methods and rewarding mechanisms, which coupled in a multiobjective optimization framework will hopefully facilitate the formation of transient regions exhibiting bilateral symmetry.

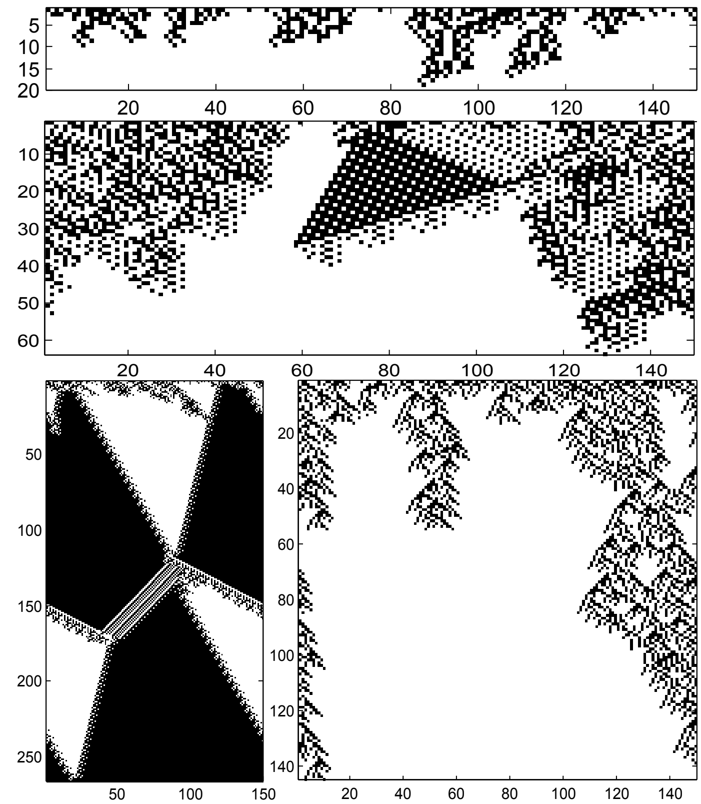

**Figure 2: Space-time plots of rules evolved with the modified fitness function.**

| Code | Rule (Hex) | Perf.% |
|---|---|---|
| GKL | 050005FF050005FF05FF05FF05FF05FF | 81.6 |
| K96 | 005500550055005555F55FF5F5F55FF5F | 82.3 |
| JP1 | 156043701700D25F15630F7714F3D77F | 85.1 |
| JP2 | 050C350F05007717058CF5FFC5F375D7 | 85 |
| O08 | 0203330F01DF7B17028CFF0FC11F79D7 | 88.9 |

**Table 1: Various high performance rules for the DCT, in hexadecimal coding**


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