# Cellular Automata in Shell Coat Pattern

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## ABSTRACT
The increasing prominence of computers has led to a new way of viewing nature as a form of computation. The Modern generation is more enthusiastic to know about the dynamical behavior of non-linear system. It is an in-depth study which is speculative and thought provoking. This paper highlights the importance of cellular Automata in short application of non-linear dynamics. Cellular Automata has been used in a variety of applications viz. modeling traffic, modeling chemical reactions, cryptography etc. This paper has been designed to be a descriptive version of non-linear dynamics system to get brief view of the cellular Automata and its application to shell coat pattern within the mathematical work by means of a computer programming.

## KEY WORDS
Cellular Automata, coat pattern, discrete dynamical system, non –linear.

## 1. CELLULAR AUTOMATA

## INTRODUCTION
It is a branch of Automata which is a branch of computer Science. It is a dynamical system in which cells are generated according to some law[10]. It is an array of identically programmed automata or cells which interact with one another[5]. Dynamics of Cellular Automata is entirely discrete. It is ROBOT, which gives specific responses to specific inputs. The space of the system, which consists of cells of one, two or more dimensions, may be finite or infinite. In each cell, the system can assume a discrete number of state values, say ‘k’ values. The configuration of the entire system at any time is defined by the set of state values $\{s_i\}$ in all cells $\{i\}$.

For example, $s_i$ may have the possible values,

$S_i = 0, 1, 2, 3, \ldots\ldots, k-1$.(State space, s) and $i = 0, 1, 2, \ldots\ldots$(Over the entire space finite or infinite).

We can say Cellular Automata, a perfect feedback machines. More precisely, they are mathematical finite state machines, which change the state of their cells step by step. Each cell has one of ‘k’ possible states. Sometimes of a k-state Cellular Automaton[10].

It is a dynamical system ($A^Z$, F) such that $Fo\sigma = \sigma o\ F$, (i.e) the transition rule of a CA commutes with the shift map $\sigma: A^Z \to A^Z$ ,where $A^Z$ is a phase space. Cellular automata evolve after a finite number of time steps from almost all initial states to a unique homogenous state, in which all sites have the same value. Such Cellular Automata may be considered to evolve to simple ‘limit points’ in phase space. These limit points to which all sites are attracted towards are called attracting fixed points. If the sites repel away from a fixed point, then those points are known as repelling fixed points.

Eg. f (a b c) = (b + c) (mod 2), A = {0, 1}

Local rule table:

| a | b | c | f (a, b, c) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 0 |

The automaton can be dimensional where its cells are simply linked up like a chain or dimensional where cells are arranged in an array covering the plane[5]. Sometimes we like to draw the succeeding steps of dimensional CA one below the other and call the steps ‘layers’. When running the machine it grows layer by layer.

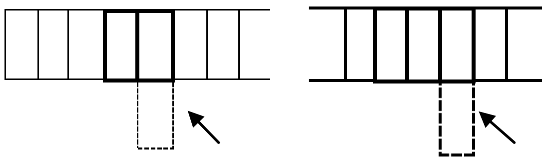
To run a Cellular Automaton we need two entities of information: (i) An initial state of its cells (i.e. an initial layer) and (ii) A set of rules or laws. These rules describe how the state of a cell in a new layer (in the next step) is determined from the states of a group of cells from the preceding layer[9]. The rules should not depend on the position of the group within the layer.

## 2. AUTOMATA RULES

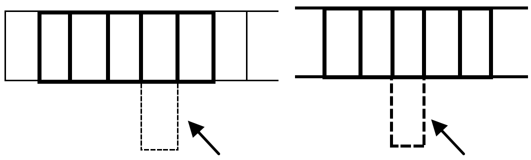
There are several ways a rule may determine the state of a cell in the succeeding layers.

In fig (a), the state of a new cell is determined by the states of 2 cells. In fig (b), by the state of 3 cells. In fig (c) and (d) the states of 5 cells determine the states of a new cell, But note that the position of the new cell with respect to the group is different in (c) and (d)[5].

Old Layer Group



a)Cell of resulting layer) b) Cell of resulting layer



c) Cell of resulting layer d) Cell of resulting layer

Eg. Consider the infinite one-dimensional CA,
$S_i = 0, 1$ ($i = 0, \pm 1, \pm 2, \ldots\ldots\ldots\ldots$) Here $k = 2$.
We define the dynamics by
$s_i(t + 1) = [s_{i-1}(t) + s_{i+1}(t)] \pmod 2$
with these consideration we generate CA as

00000001011000000 (t = 0) (initial value)

00000010011100000 (t = 1)

00000101110110000 (t = 2)

00001001010111000 (t = 3)

00010110000101100 (t = 4)
00100111001001110 (t = 5)

These results can be represented in a more compact form by replacing the state s = 1 with the black mark and making to mark when s = 0. We get a figure through which one can get the behavior of any dynamical system. For different initial configuration CA can be generated. We get different figures. A simple underlying mechanism is sufficient to support a whole hierarchy of structures, phenomena and properties.

## 3. COAT PATTERN

The natural world abounds in eye-catching patterns. Other patterns in nature are just as dynamic, but develop so slowly that they appear as snapshots to the human eye[1]. The living world is filled with striped and mottled patterns of contrasting colour[6], with sculptural equivalents of those patterns realized as surface crests and troughs, with patterns of organization and behavior even among individual organisms.

Although several models for animal pattern formation have been proposed, either in biology or in mathematics, the actual mechanism responsible for the patterns is still an open question in biology for most patterns. Moreover, the literature lacks a good taxonomy for existing models, in specific for animal coat patterns.

The intricate patterns found on the animals, birds and other form of nature seem to me a phenomenal sight[2],[7]. One seldom ponders about these varied patterns that are in perpetual existence. One is amazed to see the distinct patterns formed by the movement of the wind on the sand dunes or admires a school of fish gliding through the water in an organized manner with such beauty and grace. Certainly there is neither an organizer nor a choreographer to guide them.

### *3.1 Shell Coat Pattern*

A special case of biological pattern formation is the emergence of the pigment patterns on the shells of mollusks. These patterns are of great diversity and frequently of great beauty. The shells consist of calcified material[2]. The animals can increase the size of their shells only by accretion of new material along a marginal zone, the growing edge of the shell. In most species, pigment becomes incorporated during growth at the edge. In these case, the pattern formation proceeds in a strictly linear manner[8]. The second dimension is a protocol of what happens as function of time along the growing edge. The shell pattern is, so to say, a space-time plot. The shells provide a unique situation in that the complete history of a highly dynamic process is preserved. This provides the opportunity to decode this process.

In normal development, a strong evolutionary pressure exists to reproduce faithfully a given structure[8]. In contrast, the functional significance of the pigment patterns on shells is not clear. There is presumably no strong selective pressure to preserve a given shell pattern. Thus, nature was able to play[2],[3],[4]. Although the patterns look overtly very different, it is to be expected that similar molecular mechanism are at work[8]. The challenge was to find corresponding models. With some additions to the standard patterning reactions, the models were able to describe many patterns in great detail.

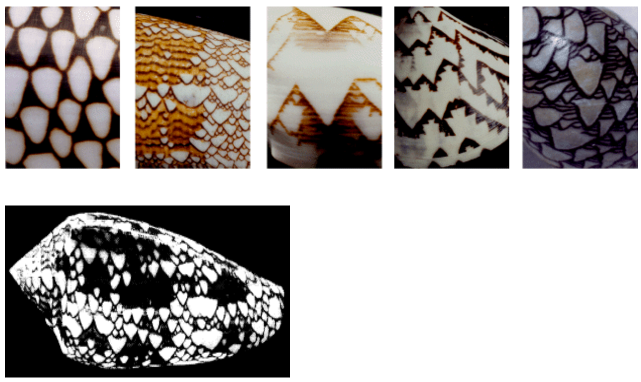


fig-01

## 4. METHODOLOY

In this section I am generating pattern through Cellular Automata by C++ program. C++ programs are used for many purposes. One of the applications is generating patterns in nature or animal designs. Animal designs such as Zebra coat design, fish skin design, Butterfly skin design, flower design etc.

### *4.1 Rules to generate figures and working*

I have used the following rules to generate shell skin designs such as rule no. 30, 86, 126, 110. By iterating the rules several

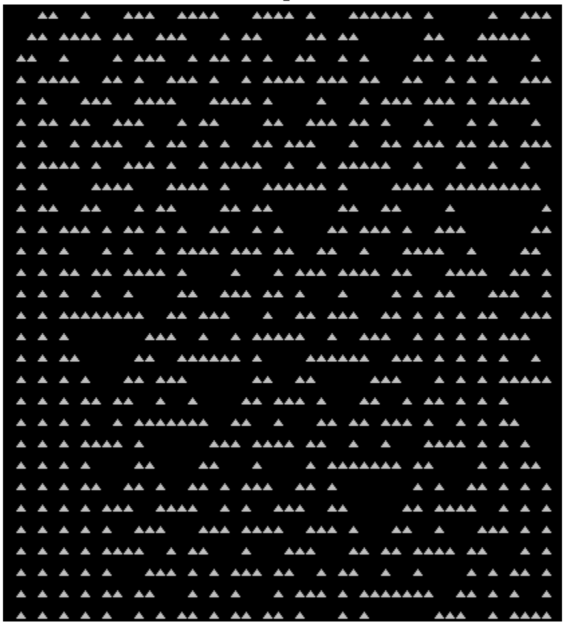
times we observe the following patterns which resemble shell skin designs.
The state of each cell is either 0 or 1. Each cell " i "(current position) interacts with only its neighbors "i-1" and "i+1 ".

## 5. OUTPUTS

**Rule 30 for Input $456_{10}(111001000_2)$**

| $x_{i-1}^n$ | $x_i^n$ | $x_{i+1}^n$ | $x_i^{n+1}$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 0 |
| 1 | 1 | 1 | 0 |

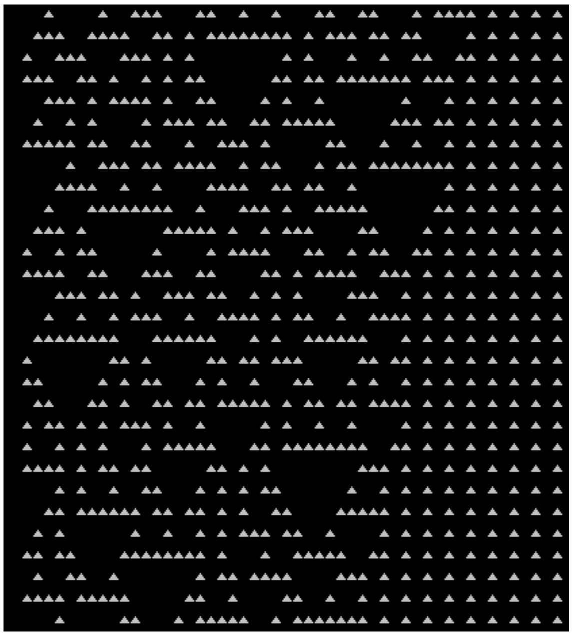
**Output**



**Rule 86 for Input $456_{10}(111001000_2)$**

| $x_{i-1}^n$ | $x_i^n$ | $x_{i+1}^n$ | $x_i^{n+1}$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 0 |

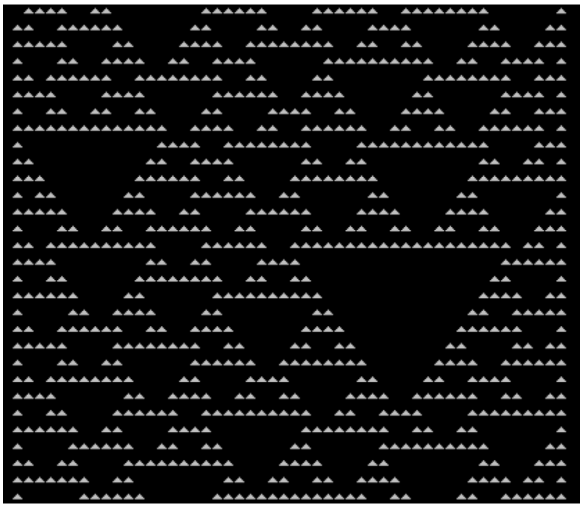
**Output**



**Rule 126 for Input $456_{10}$(111001**

| $x_{i-1}^n$ | $x_i^n$ | $x_{i+1}^n$ | $x_i^{n+1}$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 0 |

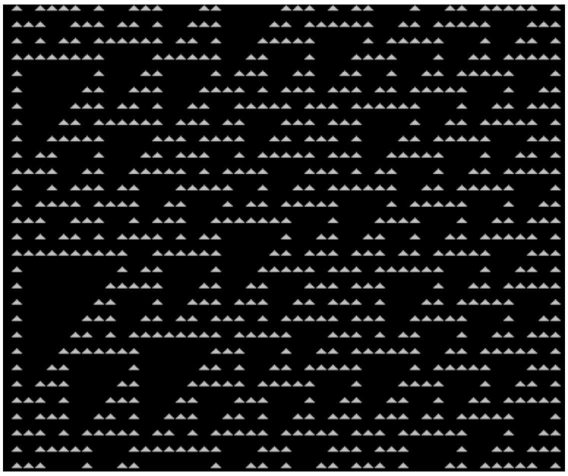
**Output**



**Rule 110 for Input $456_{10}(111001000_2)$**

| $x_{i-1}^{n}$ | $x_i^n$ | $x_{i+1}^n$ | $x_i^{n+1}$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 0 |

**Output**



## 6. CONCLUSION

In this paper I have displayed coat pattern of shell. Cellular Automata is used to generate such a pattern. Similarly so many patterns can be generated through Cellular Automata in various fields such as fungus growth, bacterial growth and cancerous growth. Research is going on to find the replica of cancer cell growth, plant growth and so many in medicines.

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