CELLULAR AUTOMATA
AND ALGORITHMIC VISUAL CREATION

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Abstract

The cellular automaton concept, a reduced form of automaton concept (specific , in the beginning, to cybernetics and computer science) relates to the notion of local order, dear to Abraham Moles, and refers to the creation of a complex order in a set of cells (or pixels for digital images) based on a simple law which determine the colorimetric state of each pixel according to the colorimetric state of its nearest neighbours.

I will examine one-dimensional automata and then two-dimensional ones. I will study their morphogenetical properties in the case of neutral values and then of chromatic ones.

I will talk about my own creative work, closely related to an "orientated morphogenesis".This latter has its place quite naturally in Generative Art . I will look at paradigmatic explorations, parametric creations, programming perturbations, conditional choices, "chromatisation" and hybridation.

To finish, I will describe the last stage of the work which consists, if necessary, of reworking the initial files so as to modify then through "software creation".

(The actual editorial version does not allow colour images)

I - INTRODUCTION

The cellular automaton concept came to light at the beginning of the forties with the work of John von Neumann and Stanislas Marcin Ulam, both of whom were mathematicians and physicists.

This concept does not seem to have spread beyond the scientific community until Martin Gardner's article [1] about the "Game of Life" of John Horton Conway which had an enormous success among computer specialists.

It was surely Stephen Wolfram [2] who, at the beginning of the eighties, will contributed most to the theoretical and (thanks to computers) experimental development of cellular automata ; the work of Christopher G. Langton, Tommaso Toffoli, Norman Margolus [3]...must also be cited.

Principle

Cellular automata are dynamic deterministic discrete systems. They are not defined by equations but by rules. They get their simplest expression with a regular tiling (**figure 01**) of cells (a set of pixels in a digital image) to which one applies an exploratory algorithm on the neighbourhood of each cell (pixel). Thanks to a set of conditional rules, the colorimetric state of the neighbouring cells allows us to define the next state of the cell being examined.
By iteration, this set of near order rules induces a global order, i.e. a form, on the total explored surface. Iteration, loop applied on the whole space-image, suggests the developement of a temporal axis (linked to the calculating capabilities of the machine).

II - MAIN CELLULAR AUTOMATA FEATURES

1 - Dimensions of the explored space

The cells (pixels), regularly arranged, give rise to a one- two- or n- dimensional space.
To simplify the representation and to reduce the calculus-time, the dimensions do not exceed two. If one works in a one-dimensional space (a single line), it is possible to simulate a two-dimensional space : the horizontal line, after each iteration, is moved down one place; that operation allows the surface to be filled by the working algorithm (**figure 02**).

2 - Dimension of the cell

A priori, it has no theoretical interest, but strongly determines the final aspect of the image. The smaller the dimension , the higher the number of cells (the surface being equal) and so, the greater the number of shapes.

3 - Colorimetric state of a cell

One may work with neutral values (or, simply, with black and white) or with colours. In that case, one needs three values corresponding to the three coordinates (R, G, B) of the colour.
The higher the number of colours, the higher the number of conditional rules in the cellular automaton software.

4 - Number of neighbours

The number of next nearest neighbours is two for a one-dimensional space (one on each side) and a maximum of eight for a two-dimensional space (**figure 03**).

One may extend the choice beyond the nearest neighbours, this increases the number of conditional rules. One could consider the extreme case where the neighbours of one cell would be all of the other cells.

5 - Initial filling of the space subjected to algorithmic exploration

Random structure : One lays out, at the start, a tiling of cells the colorimetric states of which are chosen at random from among all the possible values. These cells will be arranged on a part (**figure 13**) or on the totality (**figure 01**) of the surface.

Fixed structure (**figure 04**) : One lays out, at the start, a limited occupation of the surface with cells whose space coordinates and colorimetric state are determined by the programmer. In this case, the programmer imposes an initial order (...an initial shape) which will be progressively destroyed by the exploratory algorithm but which will, nevertheless, influence the final overall shape.

6 - Extent of the substratum space and toric conditions

Three cases may be distinguished :

a)-That of an infinite network of cells : it is the case of a theoretical automaton which explore an infinite space.

b)-That of a pseudo-infinite network of cells : it is the case of an automaton which explores a toric space (a looping of the two dimensions of the display surface).

c)-That of a finite network of cells : it is the case of an automaton which explore only the display surface.

7 - Conditional Rules

It is an almost impossible task to make a typology of these rules. I will therefore only talk about the ones, which are among the simplest, that I have worked on in particular.

In all cases, one can separate the conditions which take into account only the neighbours from those which also take the examined cell itself into account.

In the case of a one-dimensional automaton, the colorimetric state of the cell, at a time [t], may be given by the following formula :

$$Ct(i) = F[Ct-1(i-r), Ct-1(i-r-1),\dots Ct-1(i),\dots Ct-1(i+r-1), Ct-1(i+r)]$$

F is the transfer function which expresses the conditional rules built on the colorimetric states of the neigbhouring cells (and of the cell itself) at time t-1. The variable r is linked to the distance between the cell and its neighbours.

8 - Temporal progression

The iteration process, created by the algorithm, suggests the progress of an operating time linked to the periodic structure of that process. For a one-dimensional automaton, the period T is the time during which the line is explored and then copied below the immediately preceeding line. If the display window has 600 lines, the duration is limited to 600 T . For a two-dimensional automaton, the period T is the time during which all the cells of the display window are examined. This exploration is renewed until the procedure is stopped by the artist or because the visual shape has ceased to change. These remarks could more than likely enable a morphogenetical kinetics to be developed.
We can distinguish approximately four possible temporal evolutions if we consider that the initial state (i.e.a random drawing of the values of the colorimetric states of the cells) corresponds to the maximal complexity [4].
a)-The first leads , in a continuous fashion, to a state of equilibrium, the complexity of which is more or less great (**figure 05**).
b)-The second goes through a succession of states of weak complexity and then returns to relatively complex configurations (**figure 06**).
c)-The third goes through a periodic succession of states of variable complexity. This is often the case with toric automata (**figure 07**).
d)-The fourth goes through a succession of states of average complexity and then returns to maximal complexity (**figure 08**).

III - CELLULAR AUTOMATA AND MORPHOGENESIS

Cellular automata, capable of self-organization, can be considered as "morpho-chromatic" generators and it is possible, in their case, to talk about "digital morphogenesis", which allows us to discover completely unknown visual territories.
I am not then talking about artificial-life modelling, in the largest sense of the term, nor about how a network of neurons functions, but really about an exploration into the field of visual possibilities.
I would like to enlarge on this idea for a little.

Imagine all the existing pictures (whatever their origins ; we should, in order to be as general as possible, speak rather of surfaces made up of shapes and colours) and imagine each of them, represented as a point in a two-dimensional euclidian space which is, a priori, infinite.
It is quite understandable that these points would form, depending on their affinities, a complex map, not unlike a sky chart, with its own stars, galaxies, star clusters and super star clusters...
All of Van Gogh's pictures would be closer to Chagall's than to the zone where the pictures from a "bubble chamber" would be concentrated... And the latter would, no doubt, be nearer to Kandinski's galaxy than to the one devoted to Mondrian.
This suggestion is a careless one since I have not defined "affinities" and "distances" in that space. Defining them would force me to revisit these surfaces of shapes and colours from within (rather than basing myself on related arguments be they : historical, sociological, psychoanalytical...) and, therefore, out of all context.
More than 110 years after Maurice Denis'assertion [5], a "meta-morpho-chromatic theory" still remains to be written.
This space of "picture-points", despite its theoretical imprecision, does allow one to make some comments. This space is occupied in a discontinuous way, even if some areas expand and become denser. Some large zones are still unoccupied. The empty sub-space then constitutes the "virtual-picture" and that is the very domain offered for our exploration. One of the discovery modes is mathematics which offers visual search engines. Cellular automata are one of these.
We will look first at some works in black and white and then in color all the while maintaining the distinction between a one-dimensional space and a two-dimensional space. I will not insist on the programming details but on the large plastic variety of the results obtained.

1 - Neutral values

- One-dimensional space.

All the examples below are constructed on a non toric space ; the colorimetric states are either black or white. The first example (**figure 09**) is created by conditions like :

IF [Ct-1(i-1)=100 AND Ct-1(i)=0 AND Ct-1(i+1)=100] THEN Ct(i)= 0

Here, black is coded 0 and white 100.
One can write eight similar conditions to explore the set of combinations between 0 and 100.
Numerous derivations may be obtained using combinations of the principal logic operators : AND, OR, XOR.

The second example (**figure 10**) is based on a substratum space initially occupied in a non-random manner (the colorimetric states are initially defined by the programmer : one speaks about "seeds").
The third example (**figure 11**) is constructed using a transfer function, similar to the first example but with four nearest neigbhours :

IF [Ct-1(i-2)=100 AND [Ct-1(i-1)=100 AND Ct-1(i)=0 AND Ct-1(i+1)=100
AND Ct-1(i+2)=100] THEN Ct(i)= 0

The fourth example (**figure 12**) is constructed using a transfert function such as :

Ct(i)= [a*Ct-1(i-1)+b*Ct-1(i)+c*Ct-1(i+1)]
where a+b+c=1

- Two-dimensional space

Here, the number of neighbours being, a priori, higher the number of conditions may also increase, but the artist is free to make choices. The creations will, thus, be very different. I have selected an image built on a special non toric space. Initially only a small part was random filled, the rest was empty (figure 13). This example clearly shows the passage from a simple to a complex shape (figure 14).

2 - Chromatic values

- One-dimensional space
- Two-dimensional space

IV - CELLULAR AUTOMATA AND VISUAL DIGITAL CREATION: AXED MORPHOGENESIS

The examples given above zero in on some "visual territories" where the virtual is revealed in a judicious way. Therefore, if , like the astrophysicist discovering new galaxies ,I have discovered here some of these new “visual areas”, I can, from them, continue the exploration in the adjoining neighbourhood. In what follows, I will enlarge on some of the processes involved.

1 - Spatial loop

I have already spoken of the possible need to maintain the appearance of continuation in a finite space.

If we make this space similar to a rectangle, we will have to loop the first horizontal line with the last horizontal one and to loop the first vertical line, too, with the last vertical line. This will constitue the conditions of the lines.We also have to loop the vertices of the rectangle , which corresponds to a second series of conditions.

We have, thus, 4 ways of writing :

a)-without torus conditions (loop conditions)

b)-with torus conditions on lines and vertices

c)-with torus condition on lines only

d)-with torus conditions on vertices only

To illustrate this : If we consider **figure 14**, which corresponds to case (a) above, **figure 15** corresponds to case (b).

2 - Paradigmatic exploration We can consider each automaton as a paradigm overlapping a number of similar forms which will be actualised each time the program (corresponding to the automaton) is run.

Since the initial state of the matrical space is randomly filled, we could, it is true, expect to see an infinite number of similar but, nevertheless, different forms.

However, tests performed on non torus one-dimensional automata, invalidate this assertion.We could seek the reason in the limited number of pixels (640) involved, in the feature of insufficiently rigorous random provided by the computer and in the feature of the unlooped space. Whatever the result may be, the limited number of forms obtained in this way could form the basis for a formal reflection on style.

This could be included in this “ morphochromatic metatheory” which still remains to be written.

I will now present a series of declensions (from **figure 16 to 21**) corresponding to a one-dimensional toric automaton with 4 nearest neighbours.

3 - Parametrical creation

Another way of continuing the exploration of a zone consists in varying the value of one or more of the parameters. This, generally, leads to continuous variations for tiny variations in the value of the considered parameter(s) which is (are) being considered.

4 - Programmatical perturbation

This is, from an established program, the name given to the partial alterations which, while respecting the overall structure of the established program, could lead to new and significant pictures. These alterations could, in particular, concern the description of the selected neighbours and the logic operators involved in the writing.

5 - Probabilistic conditions

With each new iteration, several paths are proposed, each of them occuring with a certain probability.

If the bifurcations are written inside the exploration loop, it indicates that the conditions are different from one cell to another.These differences generally introduce a background noise which prevents an overall order from being etablished.

The study consists, in that case, of minimizing these differences so as to introduce only some small perturbations, which will generate formal modulations, leading to new, significant pictures.

This part could be considered, in fact, as a part of the section dealing with programmatical perturbation.

If the bifurcations are written outside of the loop, the exploration conditions remain constant during a phase of the exploration and evolution is, then, more continuous.

6 - Hybridation

This process has been studied on one-dimensional automata. I associate several programs, each running successively and scanning the surface area horizontally : several format styles succeed one another depending on transitions, the kinetics of which have to be regulated. (**figures 22-23** give examples of such hybridations).

7 - Cell (pixel) size

It may seem of little theoretical interest to speak about the variations in size of the picture-unit (pixel). However, the size of the display area being constant, the visual impact is significantly modified.

8 - "Chromatisation"

Generally, the new colorimetric state of a pixel-cell, (which is, as already explained, linked to the state of its neighbours) is expressed by a number K, which refers to a (R,G,B) triplet included in a table of values set by the program. However, it is possible to define a new (R,G,B) triplet defined by the K variable and the values of the coordinates of the examined cell. In this case, spatial chromatic variations appear, creating a new network of shapes/colours. It is superposed on the system created by the automaton and, as a result, the picture is enhanced. I call “chromatisation” this new action which increases, in a way, the generative field of automata.

V - CELLULAR AUTOMATA AND "SOFTWARE CREATION" : SOME EXAMPLES.

"Software creation" means the digital visual creation which uses commercial software.

1 - Spatial associations

- Juxtapositions

This means working on pictures issued from the same engine and combining them linearly in order to emphasize the common directions.This principle of overlapping is shown in **figures 24-25**.

- Symmetry

Symmetry can be simple, as in **figure 26** or be carried out by rotation as in **figure 27**.

- Superimpositions

This classical effect in photography is reproduced digitally. The possibilities are, obviously , infinite.

- Morphing

These progressive transformations between two shapes, are well known and were commonly practiced by the first computer artists.

2 - Picture processing

Here are listed the main effects I use in my pictures.

- Anamorphosis

These continuous distortions have been well known for centuries.

- Anachromosis

Continuous variations of the colour balance.

- Partial colouring

Selecting and acting on small parts of the picture to vary colours.This is not far removed from what a painter does .

- Filters

These plug-ins, in addition to anamorphosis and anachromosis, allow rough variations in shapes and colours and, sometimes, result in an interesting new reading of the initial digital picture.

3 - Applying genetic algorithms

We can also imagine that pictures created by cellular automata form a corpus to which it is possible to apply axed-algorithms (based on a genetic model) on various successive states of this corpus to deviate the morpho-chromatic structure according to the creator's wishes.

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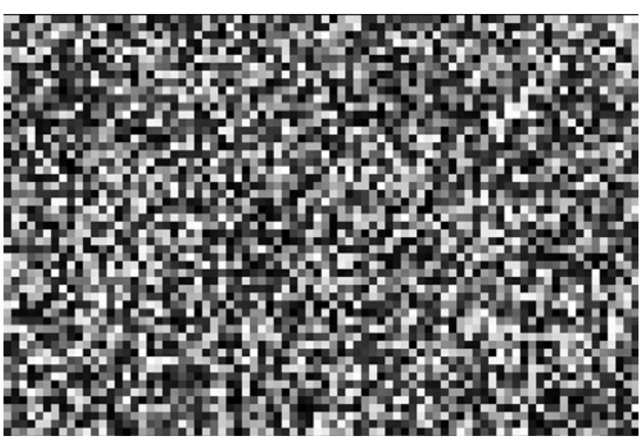
[4]-Abraham MOLES -*Théorie de l'information et perception esthétique* - first french publishing : Paris-Flammarion-1958.

[5]- « Se rappeler qu'un tableau, avant d'être un cheval de bataille, une femme nue ou une quelconque anecdote, est essentiellement une surface plane recouverte de couleurs en un certain ordre assemblées » - in : *Définition du Néo-Traditionalisme* - 1890.



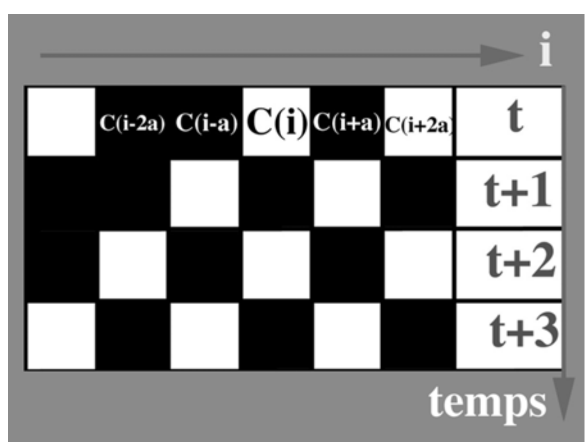
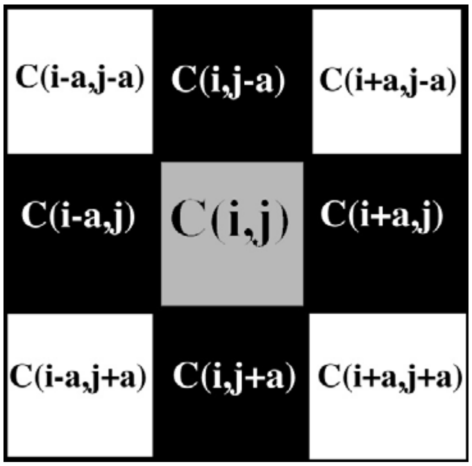


Figure 01 - Random occupation of the surface by neutral value cells

Figure 02 - Filling of the surface by a one-dimensional automaton



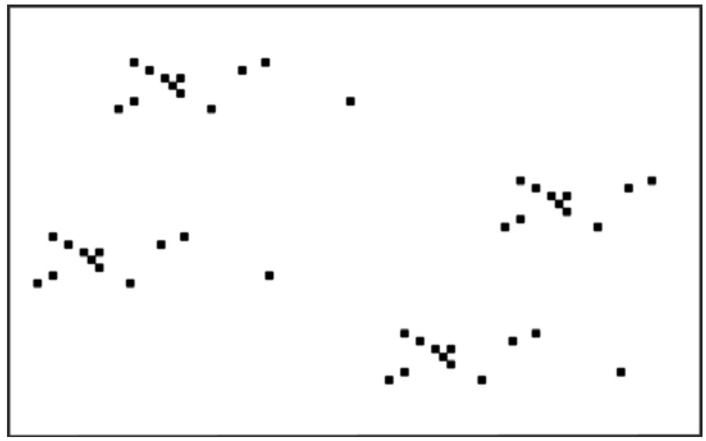
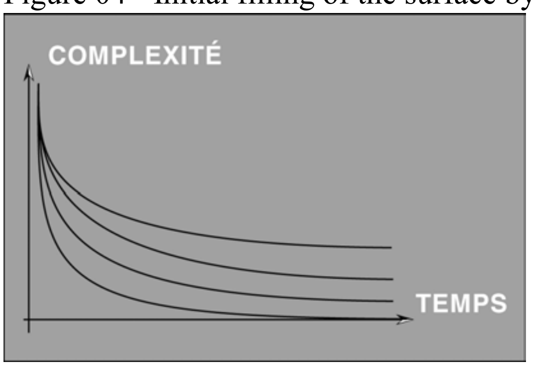


Figure 03 - Nearest neighbours of a cell C(i,j)

Figure 04 - Initial filling of the surface by "seeds"



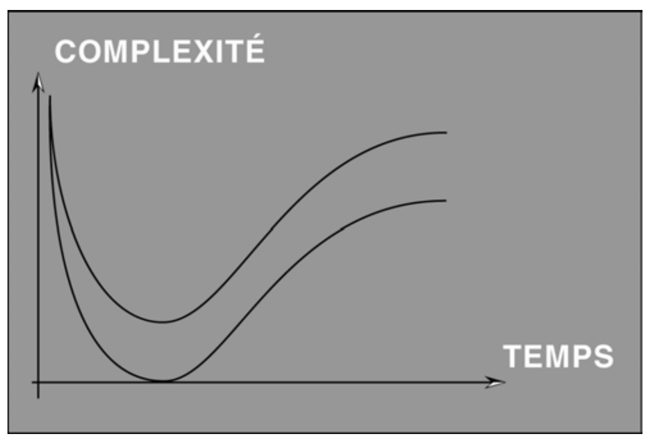
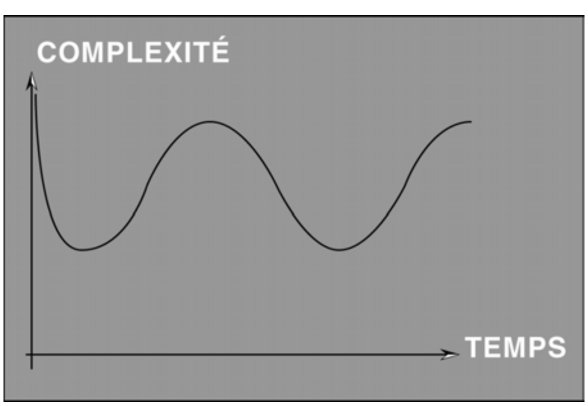


Figure 05 - Kinetics of filling : first case

Figure 06 - Kinetics of filling : second case



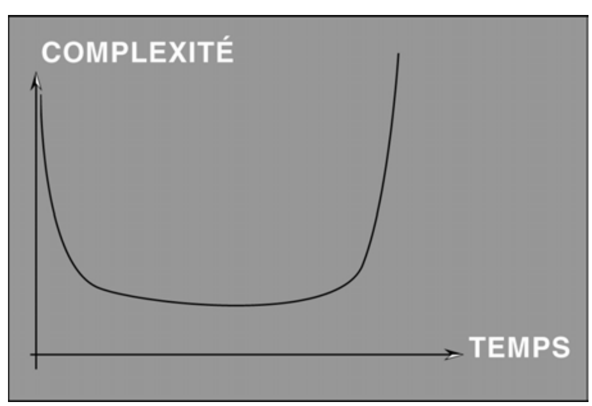
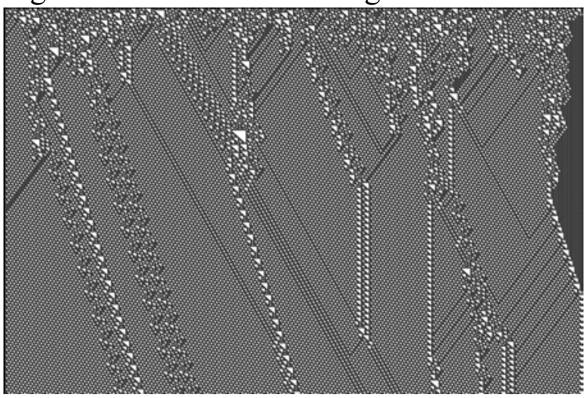


Figure 07 - Kinetics of filling : third case

Figure 08 - Kinetics of filling : fourth case



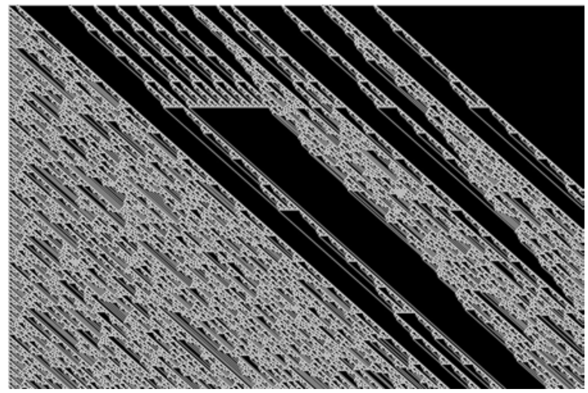
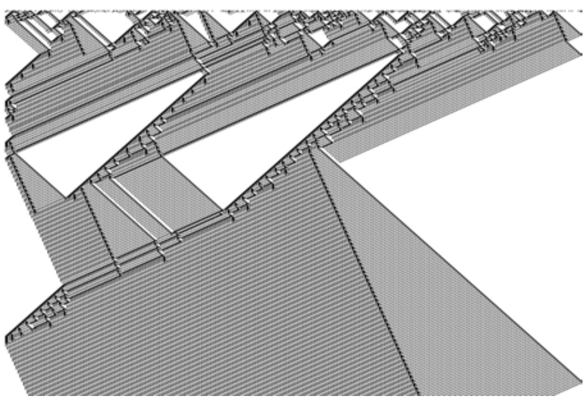


Figure 09 - One-dimensional automaton with two nearest neighbours : random initiation

Figure 10 - One-dimensional automaton with two nearest neighbours : initiation by "seeds"



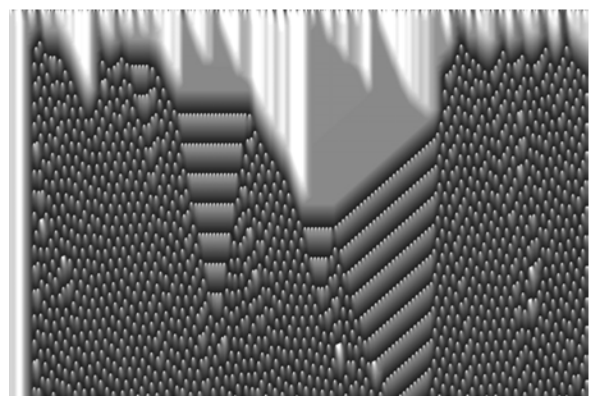
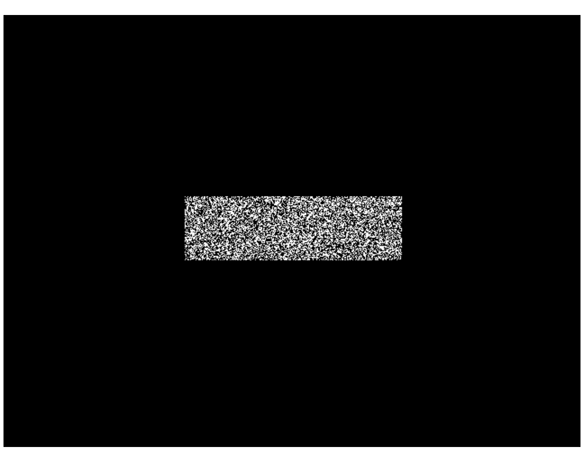


Figure 11 - One-dimensional automaton with four nearest neighbours : random initiation

Figure 12 - One-dimensional automaton with two nearest neighbours : transfer function distributed over the three cells



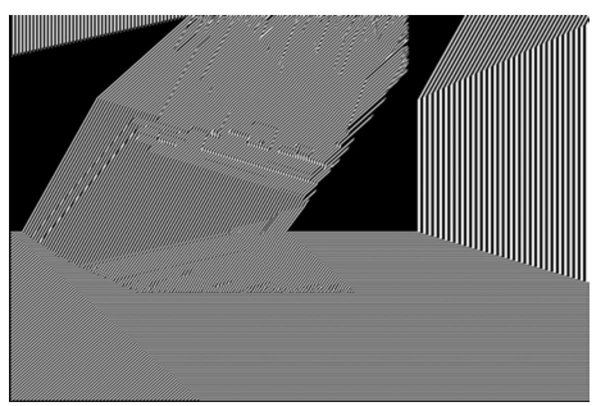
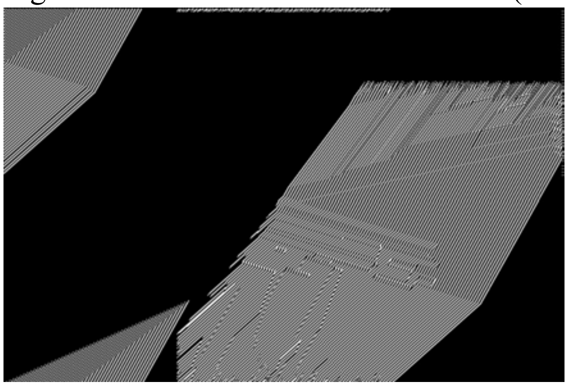


Figure 13 - Two-dimensional automaton : partial initial occupation of the substratum space

Figure 14 - Evolution of the automaton (see figure 13) : non looping space



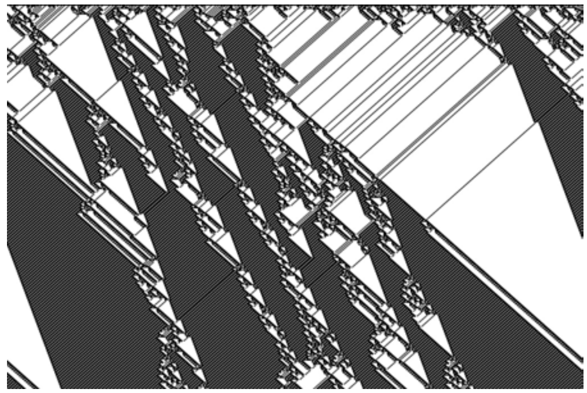
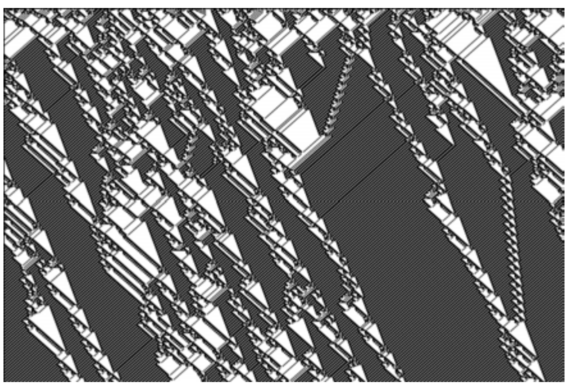


Figure 15 - Evolution of the automaton (see figure 13) : looping space

Figure 16 - One-dimensional automaton with four nearest neighbours : paradigmatic evolution



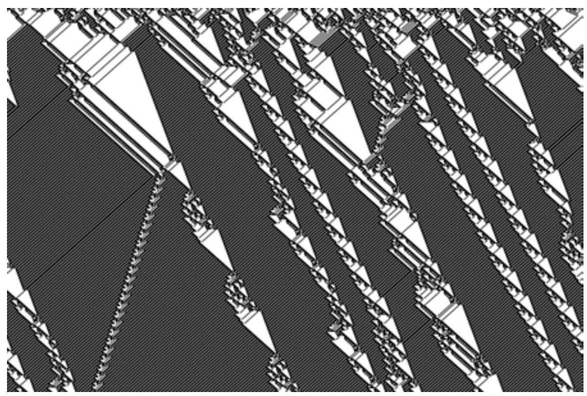
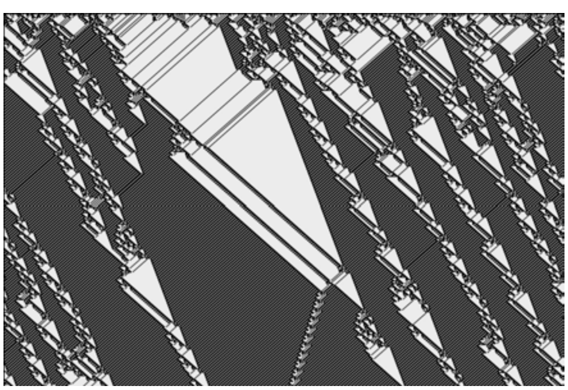


Figure 17 - One-dimensional automaton with four nearest neighbours : paradigmatic evolution

Figure 18 - One-dimensional automaton with four nearest neighbours : paradigmatic evolution



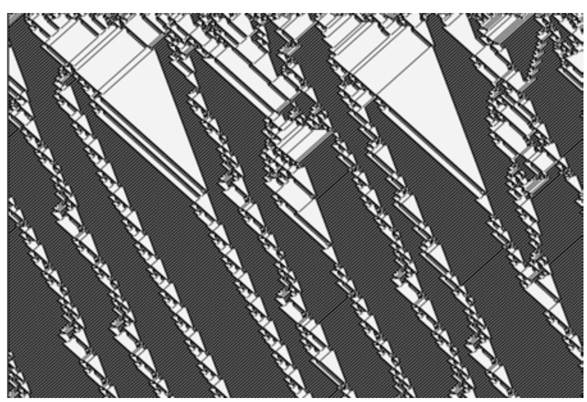
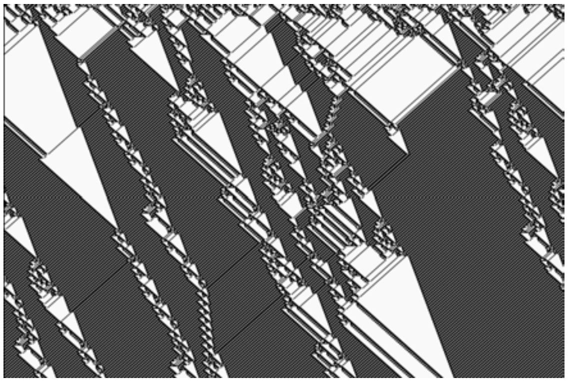


Figure 19 - One-dimensional automaton with four nearest neighbours : paradigmatic evolution

Figure 20 - One-dimensional automaton with four nearest neighbours : paradigmatic evolution



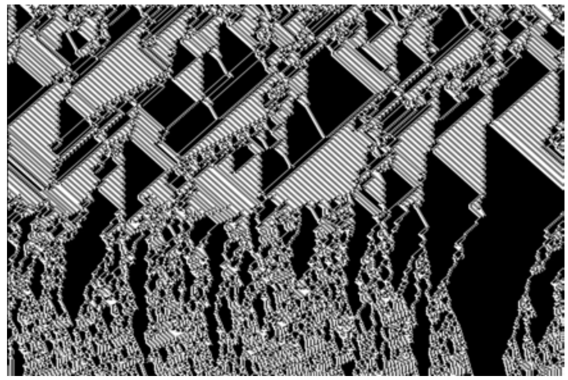
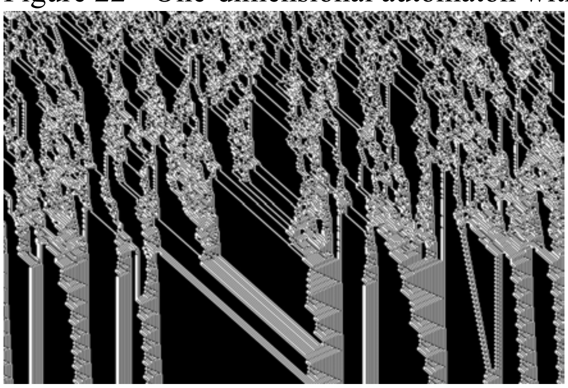


Figure 21 - One-dimensional automaton with four nearest neighbours : paradigmatic evolution
Figure 22 - One-dimensional automaton with four nearest neighbours : hybridation



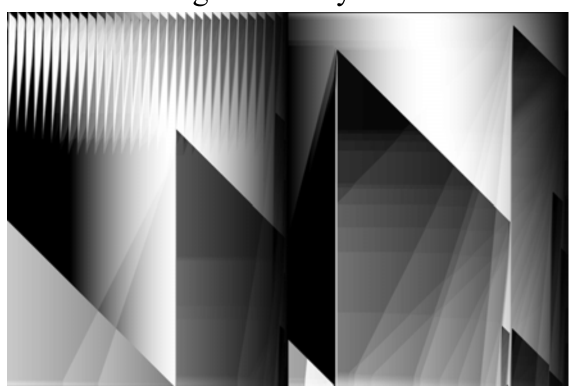
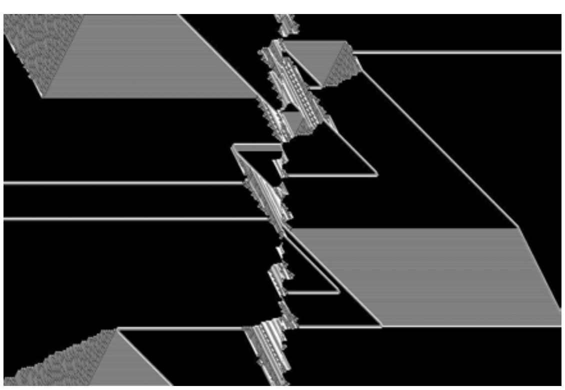


Figure 23 - One-dimensional automaton with four nearest neighbours : hybridation
Figure 24 - Juxtaposition of cellular automata



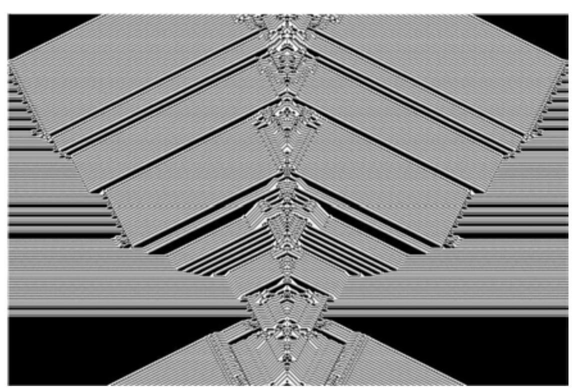


Figure 25 - Juxtaposition of cellular automata
Figure 26 – Symmetry

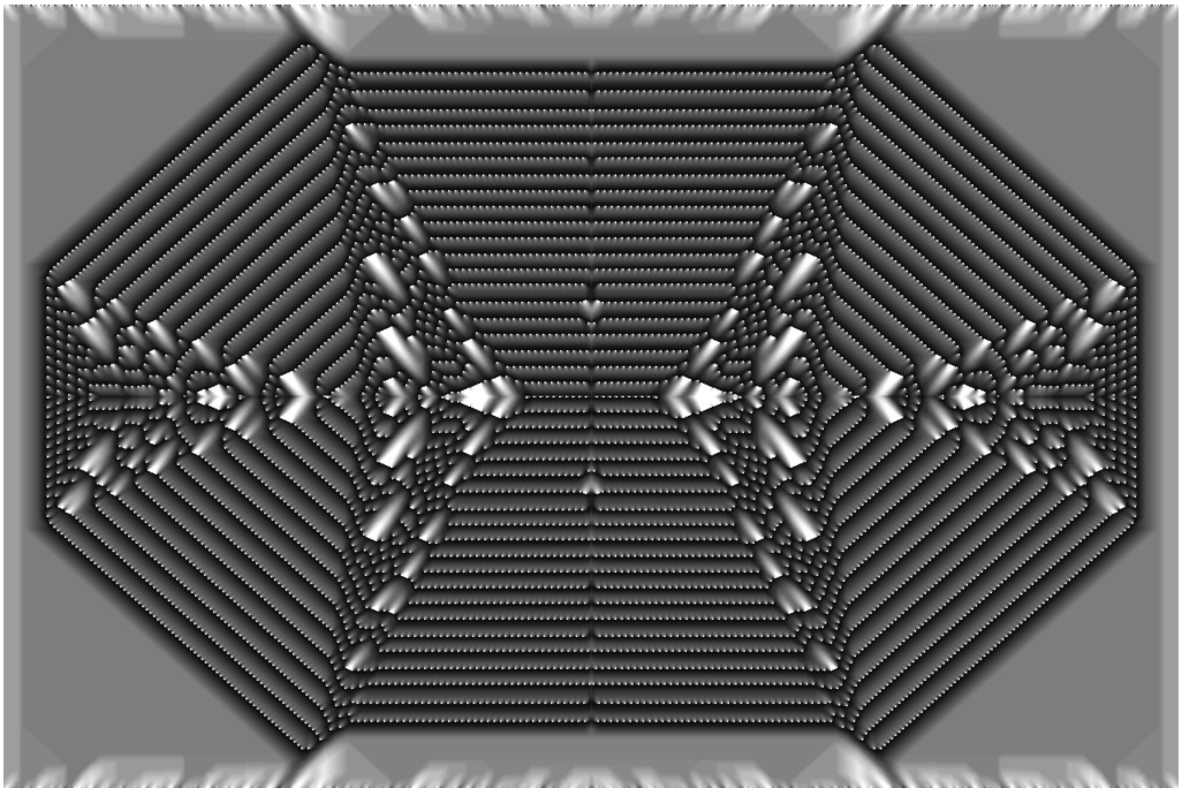


Figure 27 - Symmetry and rotation