# Chapter 1

## Unconventional computing art in cellular automata

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Cellular automata are arrays of finite state machines (cells), which update their rules in a discrete time and by the same rule. Each cell updates its state depending on states of its closest neighbours. Cellular automata are widely used as fast prototyping tools for developing unconventional computing devices. The automaton models of the such devices exhibit rich space-time dynamics, which can be interpreted as an art. In the paper we briefly overview the topic of cellular automata in unconventional computing and arts.

The exploration of unconventional computing in its diverse forms is not only, and not primarily a result of the natural human pursuit for innovation but rather a response to challenges faced by the current information

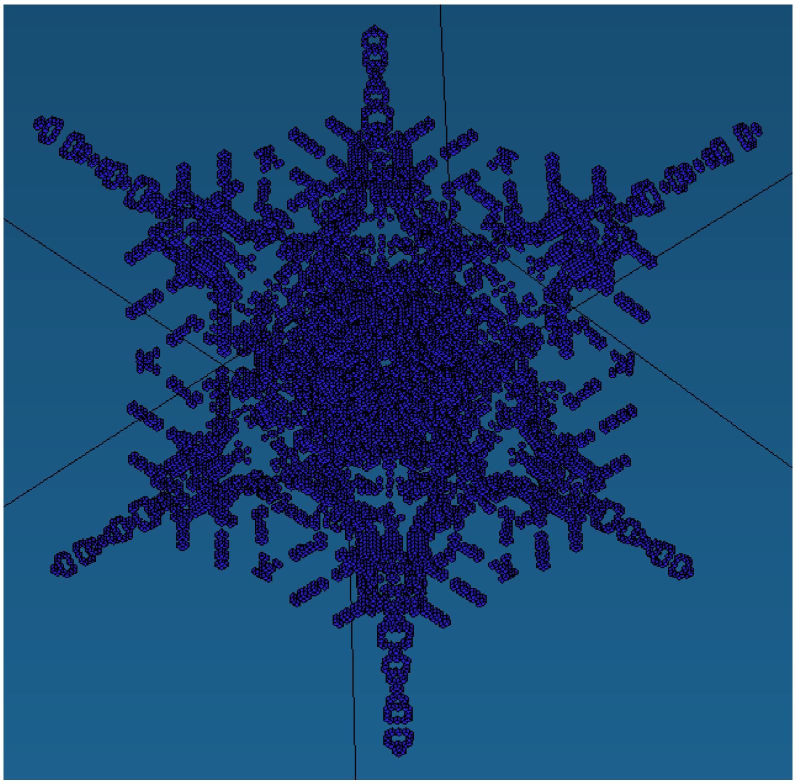

Fig. 1. A three-dimensional cellular automaton Life-like rule $B4/S9$. It is a projection of the two-dimensional Life-like rule $B2/S7$, the *Diffusion Rule*.[25] The rule is a chaotic rule although it supports complex patterns as oscillators, gliders, puffer trains, and an ample diversity of gliders guns. This rule is proved logical universal by realisation of computing circuits via collisions between particles. This evolution displays the result of two particles colliding, thus later of 112 steps we can see symmetric complex structures emerging during the evolution, traveling, expanding and interacting with others.

technology. Some of these challenges are not new, e.g. the expected end of applicability of Moore's Law or the von Neumann bottleneck in the transfer of data between the CPU (central processing unit) and RAM (random-access memory). However, the bottleneck in the past was just a nuisance, but at present the need for massive processing of synaptic weights in the network for machine learning which requires multiple transfer makes this primary tool of AI (artificial intelligence) inefficient and hopeless in the competition with the natural, biological systems of information processing.

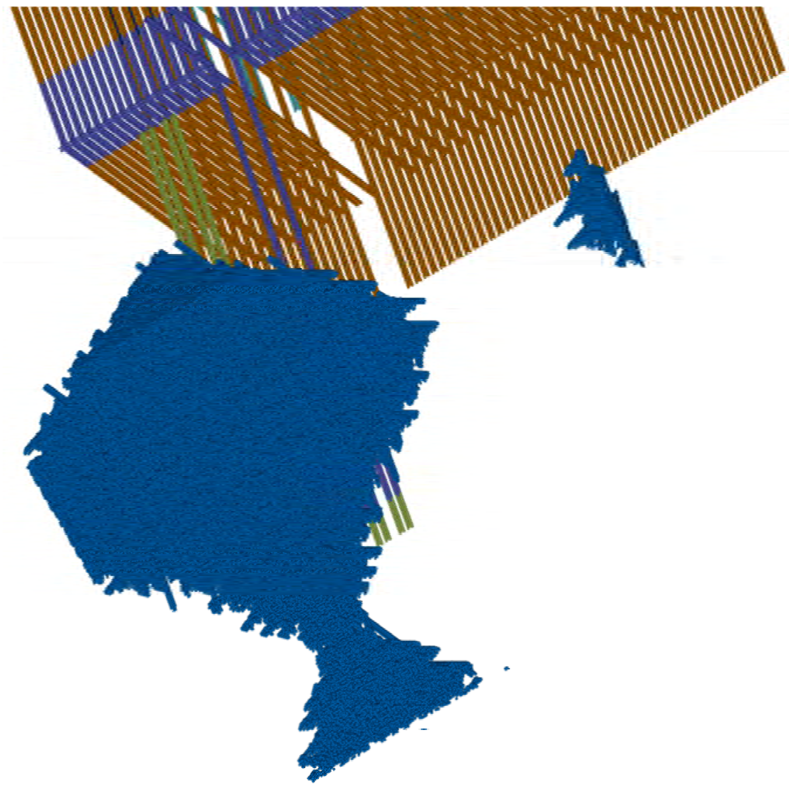

Fig. 2. Three-dimensional projection of the two-dimensional Life-like rule $B2/S7$, the *Diffusion Rule*.[25] The rule is classed as chaotic although it supports complex patterns as oscillators, gliders, puffer trains, and a diversity of gliders guns. The rule is proved logical universal via collisions of particles. This evolution displays the result of two particles in vertical position colliding. The reaction produces a replication of particles periodically in thousands of generations. With time a symmetry is lost and the automaton dynamics becomes chaotic. We call it *the cellular automata origin*. `https://youtu.be/BqTU_uW-zaI`

An example of another challenge of a very different "down to the earth" type is the high energetic cost of machine learning estimated already as a substantial portion of the energetic needs of the industrial societies which in the near future is expected to become the main consumer of energy. Thus, the question about the frugality of nature in the energetic budget for the human or animal brain is worth billions or trillions of the future dollars.

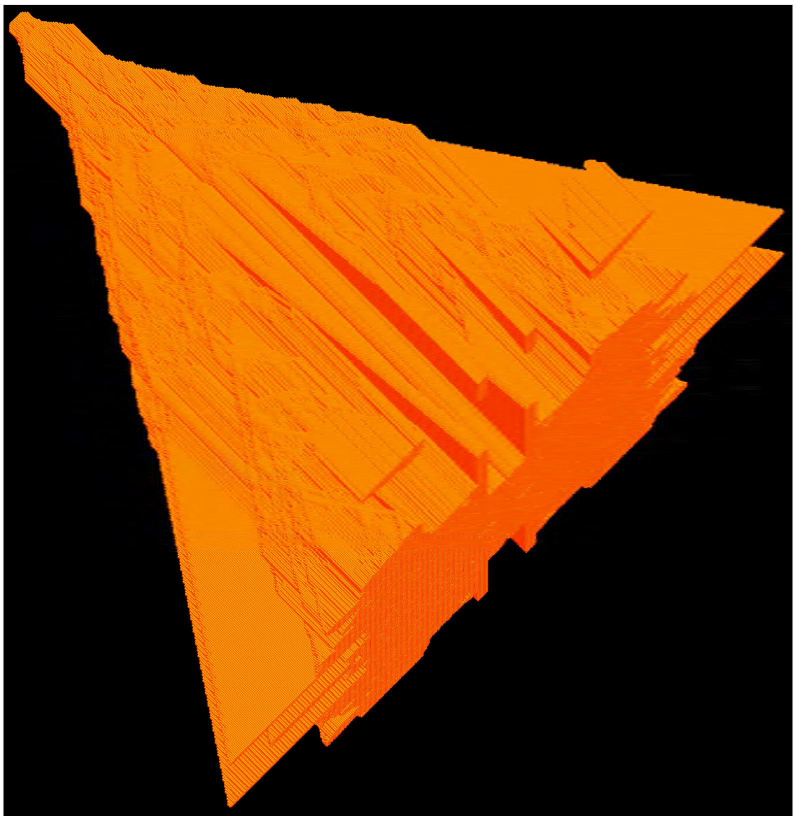

Fig. 3. Three-dimensional projection of a two-dimensional cellular automaton *Life without Dead*, rule $B3/S012345678$. This rule is able to support complex behaviour and logic computability.[17] From random initial conditions you can see the emergence of worms and interesting designs when the worms interact with each other. This evolution start with an initial condition defined by a line of eleven alive cells.

These and other challenges direct the research towards unconventional forms of computing with the special interest in its natural forms identified in living organisms on the one hand and in the utilization of new, natural, physical phenomena in information processing.

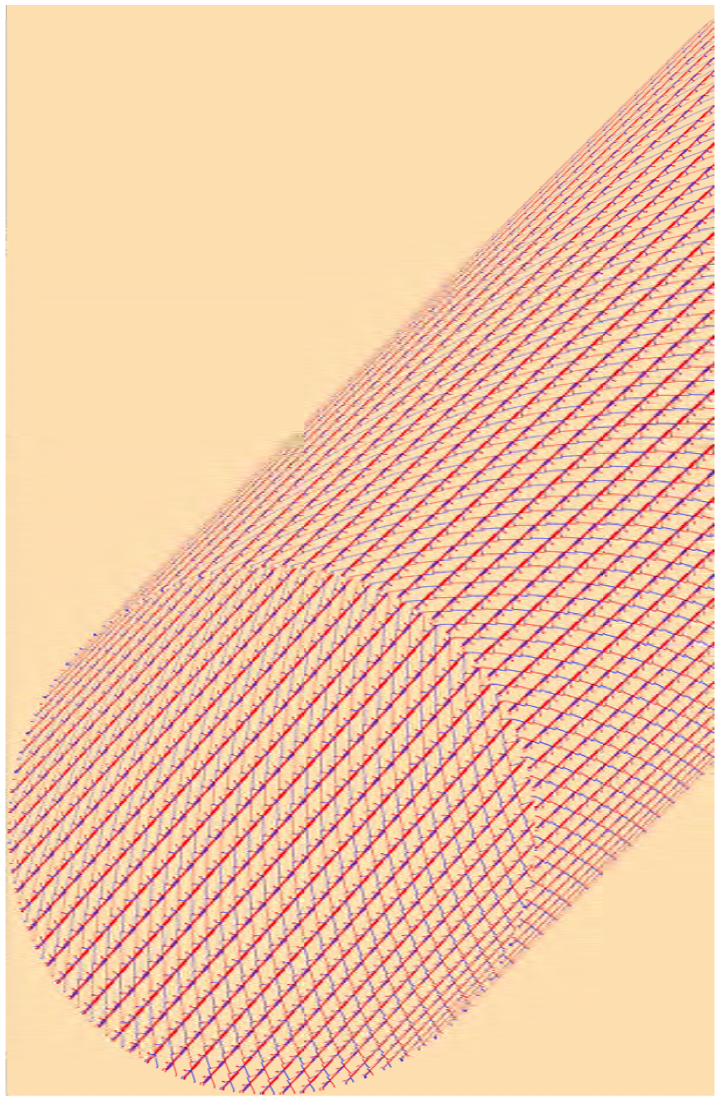

Fig. 4. Metaglider (mesh) designed with the elementary cellular automaton rule 54 synchronising multiple collisions evolving in a ring. It is a three-dimensional projection of a typical two-dimensional evolution. Rule 54 is a logically universal automaton.[22] Logic computation in rule 54 is performed by collisions of particles in its evolution space.

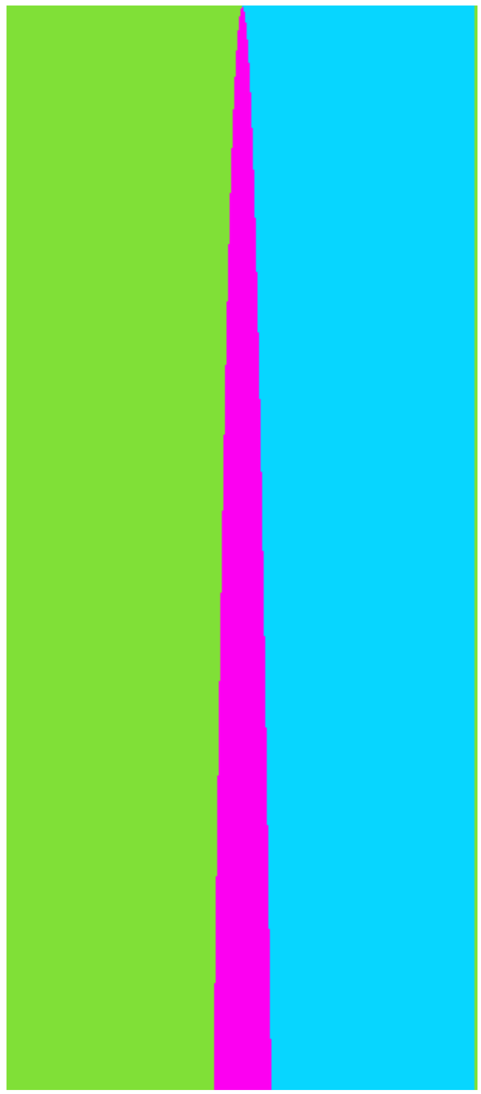

Fig. 5. Two-dimensional representation by colours of a Turing machine that doubles the number of ones as a cellular automaton.[25,31]

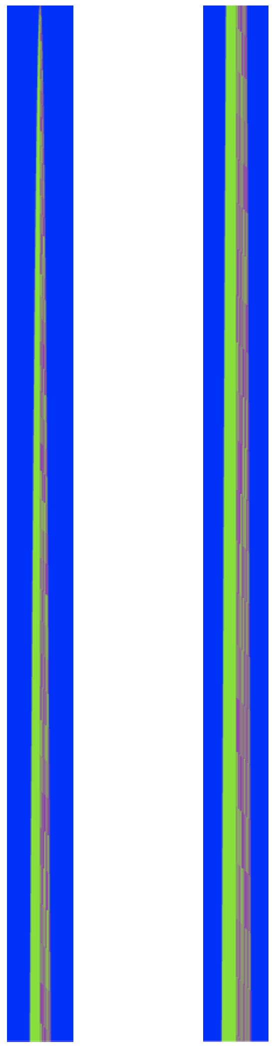

Fig. 6. Two-dimensional representation by colours of a Turing machine that simulates the behaviour of ECA rule 110. The history of the Turing machine is represented as a cellular automaton.[25] The initial condition start with the string $B^*010B^*$ showing in two snapshots the evolution to 10,000 steps.

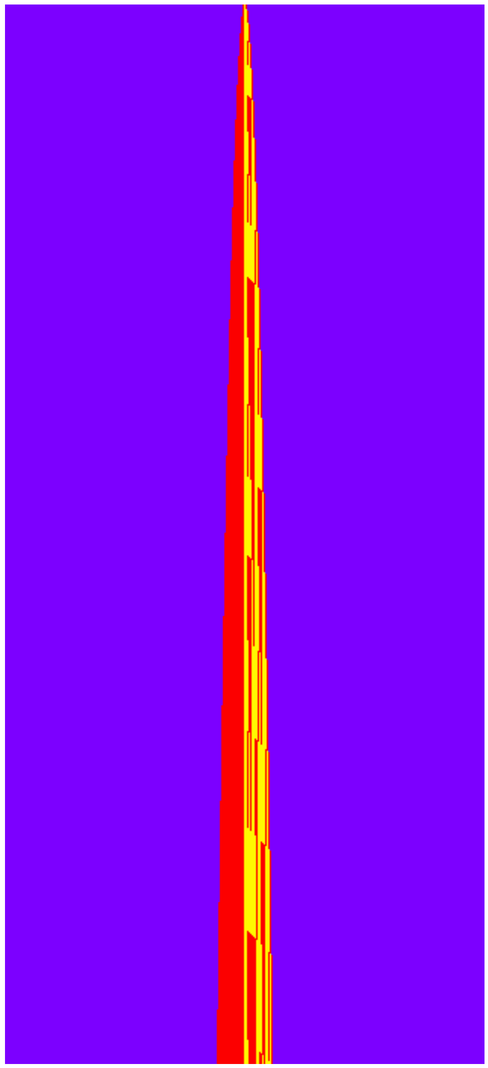

Fig. 7. Two-dimensional representation by colours of a Turing machine that simulates the behaviour of ECA rule 110. The history of the Turing machine is represented as a cellular automaton.[25] The initial condition start with the string $B^*010B^*$ showing the evolution to 700 steps.

This brings us to a more general and theoretical question overarching the interests in natural forms of information processing about what constitutes the fundamental distinction between the traditional form of computing originating in the theoretical model of a Turing machine and unconventional, natural computing. One of the possible answers is that the Turing machine model is based on the principle of a one-way, goal- oriented action initiated and controlled by a pre-defined program, while all natural processes are dynamic, i.e. they are based on mutual interactions within the processing system and with its environment.[32]

It is possible to consider a modification of the Turing machine model in which instead of the one-way action of the head on the tape the processing is performed by mutual reading and mutual re-writing of the two interacting central components.[33] This model of symmetric inductive machine remains within the Turing limit of computability as soon as the dynamics of interaction is computable, but nothing makes this computability unavoidable.[11]

The shift of the focus on the dynamic, interaction based forms of information processing can be implemented in the most natural way in the information processing in cellular automata where the art of unconventional computing begins.

Unconventional and natural computing[14,27,35] has the capacity to handle information at an atomic and molecular level, the first stage. A diversity of scientific fields study and research all these ways on continuous and discrete domains. Lines of research can be found in Table 1.

Table 1. Some ways to unconventional computers.

| | |
|---|---|
| Quantum computers[13] | Reaction-diffusion computers[8] |
| DNA computers[30] | Hot ice computers[2] |
| Physarum computers[3] | Collider computers[6] |
| Optical computers[39] | Thermodynamic computers[19] |

In this way, the cellular automata theory conceived by von Neumann in the late 1950s years as a tool of super computation.[37] He has been working with primitive and indivisible elements and where this theory offers an inherently and massively computation in parallel. Von Neumann had discussed that universal Turing machines cannot exploit the process in nature and the universe. This way, the existence of universal constructors becomes essential for the universe.[36]

An actual problem is how to control and design reliable components from unreliable organisms.[36] Indeed, this issue is preserved in any unconventional computing architecture. In the literature of cellular automata theory we can see a diversity of designs without any particular architecture. This way, we can think that these machines are adapted for a specific environment. Therefore, we can imagine how these machines are working simultaneously in nature or the universe, each with its own architecture and environment. A list of computable cellular automata can be found in: *Complex Cellular Automata Repository* `https://www.comunidad.escom.ipn.mx/genaro/Complex_CA_repository.html`.

Cellular automata are adequate mathematical machines to represent unicelular computers (Fig. 1) because of their architectural properties: array of infinite state machines matches arrays of these units. Historically cellular automata theory has been analyzed as supercomputers, as we can see in.[1,21,38] On the other hand, cellular automata are explored in an artistic way as was presented in the book *Designing Beauty: the Art of Cellular Automata*.[9]

We can think of *unconventional computers* as the physical devices and *unconventional computing* as the logic medium where these devices work (Fig. 2, 3 4 5 6 7). This way, we can complement the Table 1 with some unconventional computing models listed in the Table 2.

Table 2. Some ways to unconventional computing.

| | |
|---|---|
| Reversible computing[10,29] | Conservative computing[15,28] |
| Chaotic computing[12] | Crystalline computing[26] |
| Molecular computing[34] | Tiling computing[18] |
| Competing patterns computing[24] | Symmetric inductive computing[11] |
| Soliton computing[20] | Slime mould computing[5] |

Free software used to create the simulations in this paper.

- Ready (Tim Hutton, Robert Munafo, Andrew Trevorrow, Tom Rokicki, `https://github.com/gollygang/ready`)
- CAviewer (José Antonio Jiménez Amador, Genaro J. Martínez, `https://www.comunidad.escom.ipn.mx/genaro/Papers/Thesis_files/CAviewer.tar.gz`)
- CATM (Sergio Eduardo Juárez Martínez, César Iván Manzano Mendoza, `https://www.comunidad.escom.ipn.mx/genaro/Papers/Thesis_files/maquinaTuring.java.tar.gz`)

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