1. Introduction

There are two equally acceptable ways to describe the computational universe of cellular automata (CA), depending on whether one chooses to emphasize homogeneity or multiplicity. These two complementary approaches reflect a relationship between the organizational notions of insulation and interaction.

Consider first the notion of homogeneity. A cellular automaton (CA) is a computational model composed of small simple cells, each one embedding the same finite automaton, and the n-Euclidean space in which it operates is also subject to these rules of behavior. This inherent functional regularity gives the cellular space an intrinsic homogeneity, which is reinforced by the neighborhood relation defined on this space. The neighborhood relation defines a finite list of neighboring cells for each cell. Since these spatial connections are the same for all the cells in every direction, the cellular structure is functionally isotropic, exhibiting an interaction symmetry which is crystalline in nature. Finally, the inherent homogeneity of a CA is temporal as well as spatial, and introduces a massive parallelism into the CA’s computation universe. The transition rule that governs the overall behavior of the automaton is executed synchronously by each cell during a given discrete unit of time. The rule specifies which state a cell will enter at time $t + 1$ as a function of its current state and the state of the cell’s neighbors at time $t$.

The notion of multiplicity presents the problem of the differentiation and the individualization of the cells. How different can cells be from one another? Are there several ways to be different? Even though each cell has the same finite automaton, it is possible that some are active while others are not. During one unit of time, a subset of cells distributed in the Euclidean space executes the transition rule. Furthermore, each state, which can be defined as a transient value, is an indivisible and independent unit, different states determining different behaviors. For one time period, some cells will propagate information in a particular direction, acting as transmitters, while others will disappear or kill neighboring cells, and still others will act as builders, creating cellular material in quiescent space. From this interaction of individual behaviors a complex global cellular organization emerges, which is necessarily more complicated and of higher type than the underlying productive organization.
John von Neumann, who initiated research on CA, based his work on self-reproduction on these facts. In 1949, he wrote \[41\]: “One can show that on the site when one could expect complication to be degenerative it is not necessarily degenerative at all, and, in fact, the production of a more complicated object from a less complicated object is possible.”

The ideas of multiplicity and differentiation are more explicitly manifest in a single non-deterministic or probabilistic CA. In a deterministic CA, as was indicated above, the transition rule yields a unique state for each cell, such that the automaton has a unique history through time. In a non-deterministic automaton, the transition rule yields a set of possible next states for a cell, and the state of a particular cell can be determined by several other cells at a given moment. The execution of a probabilistic automaton’s rule is non-deterministic, with a distribution probability on the possible states of a cell \[2\].

Thanks to their functional homogeneity and their diverse execution behaviors, CA make excellent computational models particularly to exhibit the action of an organization principle latent in a state-rich computational substrate. This organization principle is exhibited both in a limited cellular universe with a constrained number of rules and states, like Fredkin’s XOR automaton (see \[14\]), or Conway’s Game of Life (see \[10\]), and in a more complex universe with a large number of states, like von Neumann’s 29-state CA. In both cases, the organization principle is endogenous to the initial configuration, which can be amorphous or structured, although it is revealed when the CA is used to simulate an observed physical reality, for instance in the simulations done with the CAM-6 \[36\] or with the R.A.P.1 \[5\] machines. Nevertheless, in this last situation there is no “exteriority” involved in the calculations, which there would be with “nature/artefact” conceptual scheme. In fact, everything seems to happen as though the evaluation of the automaton reflected nature’s evolution itself. This is reinforced by the fact that in CA, there is no distinction between data and instructions for this computer. This characteristic introduces a kind of reflection into the automaton: the organization (or auto-organization) is both that which is made observable by what is produced (the configuration) and becomes the constitutive principle of what is, and what will be, produced.

We will develop our paper around these themes of homogeneity, multiplicity and organization. First we will give a brief and non-chronological history of CA since their appearance at the end of the 1940s. Then we will examine the first, and most complex, of these, von Neumann’s 29-state CA. Finally, we will discuss the implementation of its transition rule on a single instruction multiple data (SIMD) machine.

2. A Brief History of Cellular Automata

Even though the analysis and the formalization of the concept of CA was initiated by John von Neumann \[41\] in the beginning of the 1950s, the true founder