

GOLDILOCKS

NI

FISATDAND

40

Harun Šiljak

A cellular automaton is, loosely put, a grid in which the cells change their states based on the states of the neighbouring cells together with a set of local rules. For example, the rule for a two-dimensional cellular automaton might be to put a cell in state "1" if the cell to its left and the cell below it are in state "0"; otherwise put the cell in state "0". Cellular automata are a powerful computing paradigm: they can do anything a general computing machine can do. A popular example of a (two-dimensional) cellular automaton is John H. Conway's Game of Life a set of simple rules that manage the life and death of cells in an infinite 2-D grid, that often results in complex, intricate functional patterns.

IN
109

REVERSIBLE MATTER

GOLDBLOCKS

REVERSIBLE
COMPUTATIONAL
MATTER

For the full comfort of the reader, now is the right time to imagine they are living in a two-dimensional cellular automaton. Fans of Lisberger and MacBird's *Tron* might enthusiastically imagine a descent into a computing mechanism; fans of Abbott's *Flatland* will be in a slightly more advantageous position in imagining their existence in a 2-D geometry, just very pixelated into cells of the automaton.

A cellular automaton by default, like many other concepts in our everyday life, is not reversible. Many patterns in Game of Life end up in the state where all the cells are dead, and observing that state of the automaton is not enough to deduce what the previous state of it was, even though we know the rules that the automaton evolves by. This is why we can speak of a special class of *reversible cellular automata*: they evolve in one direction in time by one set of rules, but a different set of rules can recreate their history as it rewinds them in time.

In our fantasy of living in a two-dimensional (irreversible) cellular automaton, our world is an infinite matrix of cells, extending in all directions. Let us, for a moment, examine a single row (or column) of that matrix. If its evolution was governed just by the states of cells within that one row, and a set of rules that determines the state of a cell based on the state of its neighbours within the row, it would be a 1-dimensional cellular automaton. This is where the *Flatland* fans may recognise their advantage: the inhabitants of the 2-D world can feel smug while observing a 1-D world with their benefit of an extra dimension. Similarly, the 2-D world inhabitant could look at the horizon of their world and see something resembling a 1-D flattened projection of everything in front of them, a horizon line that resembles a 1-D cellular automaton.

We're left with one more concept to introduce before we can fully appreciate the allegory of our cellular Flatland. Computational matter as an abstract computing medium is a concept we borrow here from the Italian-American physicist Tommaso Toffoli. It was Toffoli who proved that an arbitrary n -dimensional cellular automaton could be simulated on a $n+1$ -dimensional reversible cellular automaton.

This, in simple terms, means that, when considering an arbitrary 2-dimensional automaton, we can come up with a design of a 3-dimensional reversible cellular automaton which will, in 2 dimensions, have the appearance of the 2-dimensional irreversible automaton we had in mind.

Here, the sense of particulate matter as the abstract resource of computation arises from the locality and reversibility of reversible cellular automata. Consider, for example, a 2-dimensional billiard ball model: such a reversible cellular automaton captures the mechanics of a billiard ball bouncing off the solid walls. On a different scale, consider a gas model, where a reversible cellular automaton captures the motion of gas molecules, bouncing off walls and colliding with other molecules. Both of these illustrate what we mean by the 'sense of particulate matter': our perspective on the microscopic world as one obeying fundamentally reversible dynamics, symmetrical relationships that break at a scale above the elementary interactions.

Let us, for the purpose of imagination, abuse the notion of 'could be' in simulation of the n-dimensional reversible cellular automaton, and replace it with 'is'. Whenever we imagine an n-dimensional cellular automaton, we will be imagining an n+1-dimensional reversible cellular automaton simulating it. Furthermore, let us say that the two are one and the same, so that all irreversible cellular automata are n-dimensional projections of the reversible cellular automata that simulate them, and that we are simply not able to access the extra dimension needed to maintain reversibility.

A reader accustomed to thinly veiled didactic writing will recognise the setup in the cellular automaton Flatland: just like the horizon is a projection for the inhabitant of the 2-D space, the 2-D space will, in our case, be a projection of a 3-D reversible cellular automaton that simulates the world we chose to live in.

It is attractive to imagine an extra dimension outside our world that could facilitate information preservation. A cynical read of religious beliefs would find use for this dimension to store history for Judgement Day purposes, while a demonic interpretation would allow for the existence of the Laplace's demon – Laplace's demon would be a hypothetical entity capable of knowing all past and all future of the universe based on the knowledge of position and momenta of all particles constituting it. A common refutation of the plausibility of demon's existence is the thermodynamic capacity of our universe to hold that information/computation: an extra dimension helps with that as well.

We managed to insert (a toy version of) our world between two reversible systems at very different scales: the material particles obeying their reversibility, and the computational particles obeying theirs. It's not hard to imagine (as we've imagined more difficult things already in this text) that cells in our cellular automata world are made of matter we are familiar with, and elementary particles in that matter have fundamentally time-reversible rules to follow. Squeezed in realms between those particles and those of the computational matter executing the computation of our world dynamics, there is the irreversible world; too big to be reversible by virtue of matter, and too small to be reversible in the computation. In this Goldilocks zone we get to spend our lives, and get to think that irreversibility is the default state of the world.