Exploring Neural Cellular Automata

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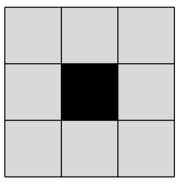
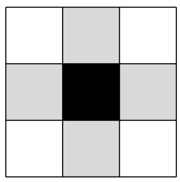
Abstract

Based on [1], cellular automata (CA) are *discrete*, *abstract computational systems* which have been exploited widely in various scientific areas. These system consists of elemental units, called *cells*, which, at each time step of the system's evolution, represent one of a finite set of possible states. Moreover, the cells that form a CA evolve (typically) in a parallel fashion following *dynamical transition rules* which, for each unit, consider only the states of cells in its local neighborhood (*local interactions*), forbidding interactions between "distant" cells. It is important to point out that a *discrete dynamic* is assumed for the study of these systems.



(a) Example of a *Moore* neighborhood: it is made of the eight nearest cells.



(b) Example of a *von Neumann* neighborhood: it is made of the four nearest cells.

The purpose of the project is the application of the CA in the biological sciences. Indeed, it is straightforward to draw parallelism between CAs and biological networks of cells in living organisms. We will focus on the ability of these tiny blocks to efficiently *self-organise*, giving rise to the process of *morphogenesis*. In particular, attention will be dedicated to the translation in a computational fashion of the specific cell-level rules which collectively contribute to the macroscopic regenerative behavior typical of any living creature.

We will start by reviewing the literature concerning the application of neural networks to cellular automata, exploring the parallelism with biology and current neural network architectures, the work on this field is already vast and ranges from learning a CA that will grow into a lizard[2], to the classification of MNIST digits[4], and adversarially attacking these CAs to change their behaviour[3].

To give some context a neural CA is like a classical CA: $c_{t+1} = F(neighbours(c_t))$, but the function F is modeled with a neural network and learned to accomplish some task[1].

After this initial review phase we will try to perturb a non-regenerative version of the lizard CA to confer it regenerative properties, this is very similar to[3] where they turned the lizard CA from green to blue, or removed its tail. We hope that this work will provide insights on biological systems and the applications of neural CAs as a new neural network architecture

References

[1] Francesco Berto and Jacopo Tagliabue. "Cellular Automata". In: *The Stanford Encyclopedia of Philosophy*. Ed. by Edward N. Zalta. Spring 2021. Metaphysics Research Lab, Stanford University, 2021.

[2] Alexander Mordvintsev et al. "Growing Neural Cellular Automata". In: *Distill* (2020). https://distill.pub/2020/growing-ca. DOI: `10.23915/distill.00023`.

[3] Ettore Randazzo et al. "Adversarial Reprogramming of Neural Cellular Automata". In: *Distill* (2021). https://distill.pub/selforg/2021/adversarial. DOI: `10.23915/distill.00027.004`.

[4] Ettore Randazzo et al. "Self-classifying MNIST Digits". In: *Distill* (2020). https://distill.pub/2020/selforg/mnist. DOI: `10.23915/distill.00027.002`.

[1] In case you are wondering, the loss is applied at time $t = T$, so the networks learns to produce the result within T iterations