ERL Cellular Automata Model

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Abstract

In this study, we examine cell regeneration with cellular automata. Cellular automata was first introduced by Von Neumann, who determined the working principles of today's computer architecture to model the self-renewal capabilities of biological entities. Cellular automata includes a computational model based on state update logic due to interaction with cells around cells in the grid plane. Studies on cellular automata have shown that some situations interact dynamically with other states. Morphogenesis is the process of forming the shape of an organism and Morphogenesis is one of the most striking examples of a phenomenon called self-organization. We are trying to replicate some of the desired features with this artificial intelligence model that we have made, to help solve the morphogenetic code puzzle and also take advantage of biology's insights to create real-life self-healing systems.

1 Introduction

Most organisms (multicellular) begin their life with a single cell, which then multiplies and builds their own bodies. The ability to build their own bodies is probably the most basic skill every living creature possesses. Morphogenesis (the process of forming an organism's shape) is one of the most striking examples of a phenomenon called self-organization. Cells that are tiny building blocks; it decides the organs, how large each organ will grow and how to connect them. And to do all this, it communicates with the neighboring cell. Understanding the interplay of complex results emerging from simple rules and homeostatic feedback loops is an active area of research. What is clear here is that evolution has learned to use the laws of physics and computation to apply very powerful morphogenetic software running on genome-encoded cellular hardware.

This process is extremely resistant to complexity. Even when the organism is fully developed, some species still have the ability to repair damage. This process is called regeneration. Some creatures, such as salamanders, can completely regenerate vital organs, limbs, eyes and even parts of the brain. Morphogenesis is a surprisingly adaptable process. Sometimes even a very atypical developmental process can result in a viable organism. For example, when an early mammal embryo divides in two, each half forms a complete individual, an event called monozygotic twins.

The greatest complexity in this area is learning how the cell collective knows what to build and when to stop it. Genomics and stem cell biology are only one piece of the puzzle as they explain the distribution of certain components in each cell and the formation of different types of cells. While we know the many genes necessary for the regeneration process, we still do not know the algorithm enough for cells to know how to build or reshape complex organs for a very specific anatomical purpose. Therefore, an important mainstay of future studies in biomedicine is the discovery of the process by which large-scale anatomy is determined within cell collectives and how we can rewrite that knowledge to have rational control over growth and form. It is also understood that life software has a large number of modules or subroutines such as "build an eye here" that can be activated with simple signal triggers. The discovery of such subroutines and the mapping of developmental logic is a more recent area at the intersection of developmental biology and computer science.

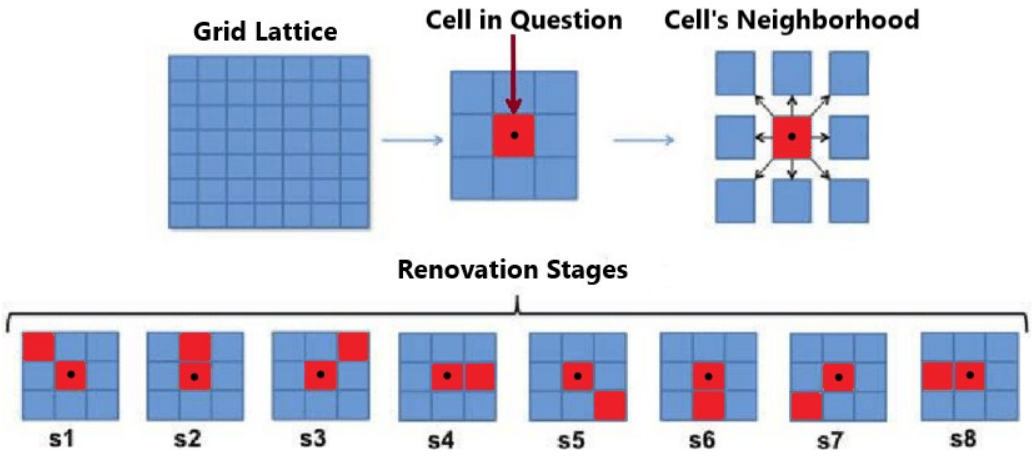
The next important step is to try to formulate computational models of this process, both to enrich the conceptual toolkit of biologists and to help transform biology's discoveries into better robotics and computational technology. By integrating the artificial intelligence technology we have into biology, studies on gene can be supported and it can be facilitated to simulate calculations. We are trying to replicate some of the desired features with this artificial intelligence model that we have made, to help solve the morphogenetic code puzzle and also take advantage of biology's insights to create real-life self-healing systems.

2 Model

Researchers and engineers often use many types of simulations, including partial derivative equation systems, particle systems, and various Cellular Automata systems. What we want to do is try to reverse engineer the split stage using these methods. We will focus and work on "Cellular Automata" models to determine the cellular rules that lead to regenerative behavior. In this task we will work on cell growth and regeneration. CAs typically consist of a whole cell. The same rules apply to each cell and repeated. This integrity; The state of a cell depends on the cells in its immediate vicinity. The cell is renewed according to the condition of the cells in its immediate vicinity.

A good start would be to create a multicellular model, starting from a single cell. To design the CA, we must determine the possible cell states and their update function. Although typical CA models represent cell states with a set of discrete values, variants using vectors of continuous values exist. The use of continuous values has the ability to allow the update rule to be a differentiable function of the states of the cell's region. The rules that guide individual cell behavior based on the local environment are similar to the low-level hardware specification encoded by an organism's genome. Running our model for a certain amount of steps from an initial configuration will reveal the modeling behavior enabled by such hardware.

Gathering differentiable functions together and optimizing their parameters to perform various tasks is ancient. In recent years, efforts to optimize parameters have developed under various names such as (Deep) Neural Networks, Deep Learning or Differentiable Programming.



Cellular automata model description with possible daughterstate positions. The distance between the centers of each state represents the approximate diameter of the fiber material as well as the diameter of an osteoblast. With the help of the cell in the center, the cells are renewed gradually. You can see eight stages above. Each new red piece is renewed with the help of the cell in the middle. Cells are renewed and developed with the help of the cell in question.

3 Learning To Regenerate

Apart from growing, some living creatures are also quite capable of maintaining the parts they have lost. Not only can it regenerate the skin, but also very severe damage to complex vital organs in some species can be regenerated. In fact, it is a well-known fact that in lizard species, the detached tail regenerates again. Are there any chance that the model that we showed above have regenerative abilities? We'll see it by training our cellular automata model.

The pictures above shows a trained model using the same settings. We let each of the models develop a pattern, then damage the final state with the help of our mouse. Once again, we see that these models show quite different out-of-training mode behavior. Every object shows us different results. For example “the lizard” develops quite strong regenerative capabilities, without being explicitly trained for it. That's why we are going to use "the lizard" for training to our model.

It seems logical to discover what can be achieved if every being, a cell, follows a single rule. The question is what kinds of rules can be used to produce a particular result. For example, if you think of a sequence of black or white pixels displaying a square or circle, you can turn it into outlines by telling each pixel to look at the color of its neighbors - "if you're black, it stays black if it's white, otherwise it turns white." it immediately selects the pixels and thus transforms them into an outline. Notice that every pixel follows the same rule, but not all do the same. Also remember that each pixel moves locally as you manage to choose a global feature, i.e. what resembles outlines.

This sort of apparel rule is what characterizes cellular automata. Each cell in the grid is given the identical rule which involves the cell's state and the state of the cells around them. Such a rule is local but, as proved by Conway's Game of Life, it can result in very compound organized behavior. The question is can we find simple rules obeyed by every cell that can produce a given compound shape? This is what the new research is all about.

The main idea is that system has to be differentiable so that a gradient can be derived and used to modify the rule to move the system towards a better outcome. This is how back propagation works and how neural networks learns, but it is a more general idea that allows more compound systems to "learn" to do better.

There are lots of practical details outlined in this model, but the most important if you are interested in getting the general idea is that the information about the neighbors that is sent to the NN is the difference in the state vectors plus the cell's state vector. The gradient is taken in the x and y directions and thus we are feeding the neural network a 48-dimensional vector summarizing the state of each cell and the gradient around it in turn.

The neural network is only provided with information on the gradient of the state vector. This is intended to model the fact that biological cells often respond to chemical gradients rather than absolute values. The NN has 8000 parameters and so is capable of learning a fairly complex function of the neighbor gradients and state. It is interesting to ask how much of this complexity is actually used in producing biologically plausible configurations.

4 Conclusions

ERL Cellular Automata model trained on an ability to regenerate. When the target pattern was achieved parts of it were damaged and the network trained to regenerate the target. This is interesting as a rule that has the target as an attractor would likely have regenerative properties.

This work suggests so many additional questions that it is clearly just the start of something. What it demonstrates is that a 16-dimensional state vector is enough to allow a CA-type rule to evolve to complex shapes with a good degree of stability and regeneration. What these dimensions might represent in the real world is a question for the biologists. What I'd like to know is how many dimensions are necessary for it to work at all?

References

Dr Mike James; The Programmer's Guide To Theory: Great ideas explained

Daniel B. Miller, Edward Fredkin; Circular Motion of Strings in Cellular Automata, and Other Surprises

Dr Mike James; The Meaning of Life

The chemical basis of morphogenesis, Turing 1951

Giovanni Pezzulo, Michael Levin; Top-down models in biology: explanation and control of complex living systems above the molecular level

G. Pezzulo, M. Levin; Re-membering the body: applications of computational neuroscience to the top-down control of regeneration of limbs and other complex organs

Vaibhav P. Pai, Sherry Aw, Tal Shomrat, Joan M. Lemire, Michael Levin; Transmembrane voltage potential controls embryonic eye patterning in Xenopus laevis

John E. Pearson; Complex Patterns in a Simple System

Martin Gardner; Mathematical games

N H Wulff and J A Hertz; Learning Cellular Automaton Dynamicswith Neural Networks

William Gilpin; Cellular automata as convolutional neural networks