Lenia in a petri dish: Interactions between organisms and their environment in a Lenia with growth based on resource consumption

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Introduction

Lenia (Chan, 2019) is an extension of Game of Life (Gardner, 1970) based on continuous space/time/state and generalized local rules, which yields various life-like patterns resembling microscopic lifeforms, showing biological properties such as spatially localized organization and spontaneous movements.

Recently, Lenia has been extended to a framework for considering the adaptive behavior and the evolution of organisms. Hamon et al. proposed an approach, based on curriculum learning, diversity search, and gradient descent methods, to obtain self-organizing agents capable of reacting to the perturbations induced by the environment (Hamon et al. 2022). The obtained creatures were able to regenerate and preserve their integrity and structure, dealing with obstacles or other creatures. Plantec et al. proposed an extended version, called Flow Lenia, which realized mass conservation (i.e., the sum of the CA's activations remains constant over time) (Plantec et al., 2022). This extension enabled the integration of the parameters of the CA update rules within the CA dynamics, making them dynamic and localized, and interestingly, it further brought about the genetic diversity of their update rules among creatures, which can lead to the intrinsic evolution of creatures.

To understand the ecological and evolutionary characteristics of Lenia, focusing on the interaction between creatures and their environment, we propose an extension of Lenia that assumes the growth of creatures based on the consumption of resources distributed over their environment. This simple extension was inspired by the question of what would happen if Lenia creatures were grown in a Petri dish with culture medium. We explain the details of the extension and show that the upper resource limit of each cell has a significant effect on the morphology and behavior of the creatures that emerge from interactions between the organisms and the environment.

Lenia with Growth Based on Resource Consumption

The state update of the original Lenia (Chan, 2019) follows the rule shown in Fig. 1. The convolution function **K**, called the kernel determined for each species, is applied to the 2D state values of the cells $\mathbf{A}^t$ at time t, called the world, to calculate the energy values **U** (=$\mathbf{K}*\mathbf{A}^t$) over the cells. The growth rate of $\mathbf{A}^t$ is determined by the growth function G of **U**.

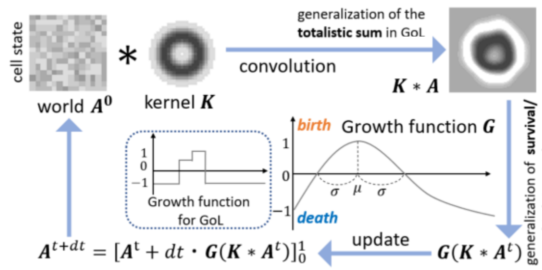

Fig. 1: State transition in Lenia.

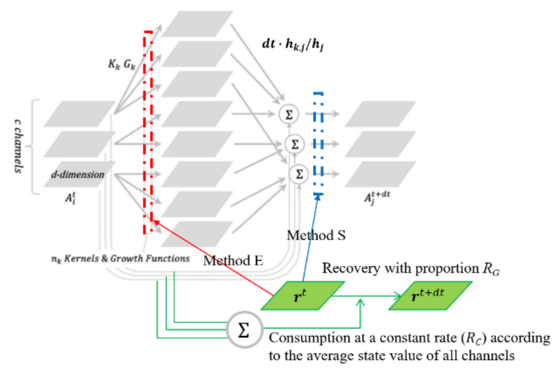

Fig. 2: Lenia with growth based on resource consumption.

We adopt a multichannel and multikernel version of the original Lenia. There are multiple channels that store different state values and multiple kernels for convolution of state values, as illustrated in Fig. 2. See (Chan, 2020) for details. This extension enables the creatures to exhibit complex morphological and behavioral patterns.

We further extended the above model by adding a new channel that represents the local distribution of resources over the cells $\boldsymbol{r}^t \in [0, r_{max}]$, which is updated at each step by Eq. (1). The resource decreases by an amount proportional to the average of the state values over all channels and recovers by an amount proportional to the difference between r_{max} and the focal amount of the resource. The small parameters R_C and R_G

$$\boldsymbol{r}^{t+dt} = \boldsymbol{r}^t + R_G \cdot (r_{max} - \boldsymbol{r}^t) - R_C \cdot \frac{1}{n}\sum_{i=1}^{n} \mathbf{A}_i^t \quad (1)$$

$$\text{(Rule S)} \quad \mathbf{A}_j^{t+dt} = \left[\left(\mathbf{A}_j^t + dt \sum_{i,k} \frac{h_k}{h} G_k\left(\mathbf{K}_k * \mathbf{A}_i^t\right)\right) \circ \boldsymbol{r}^t\right]_0^1 \quad (2)$$

$$\text{(Rule E)} \quad \mathbf{A}_j^{t+dt} = \left[\mathbf{A}_j^t + dt \sum_{i,k} \frac{h_k}{h} \mathrm{G}_k\left(\mathbf{K}_k * \mathbf{A}_i^t \circ \boldsymbol{r}^t\right)\right]_0^1 \quad (3)$$

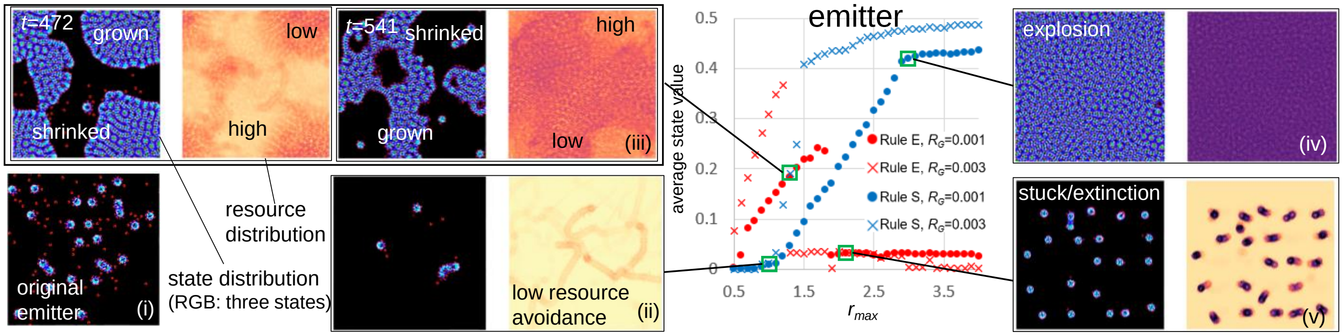

Fig. 3: Effects of the maximum resource value (r_{max}) and snapshots of the state values and the resource distribution. Video link: https://doi.org/10.6084/m9.figshare.22925015.

determine the degree of the effects of the former and latter factors, respectively. This represents that the greater amount of resource is consumed to keep the state values (body mass) of creatures, while the resource recovers at a certain amount.

In addition, the state value $\mathbf{A}_j^t$ of the channel j is updated by Eqs. (2) or (3). The state value $\mathbf{A}^t$ or energy $\mathbf{U}^t$ is multiplied by the current local resource $\mathbf{r}^t$, which directly or indirectly (through the change in the energy based on local interactions among cells) affects the state value of the creatures. When the resource value is 1, the update process is equivalent to that of the original Lenia, and when it is less (or greater) than 1, the state value or energy becomes smaller (or greater) than that of the original due to resource shortage (or excess).

Preliminary Experiments and Discussion

Fig. 3 illustrates the preliminary experimental results. We used an existing species with 3 channels called "emitter" (Chan, 2023), which emits small glider-like patterns (i), and show the explosion of their morphologies occupying the whole space due to accidental collisions among them. The experiments were conducted under the conditions: the number of steps=1000, R_C=0.005, R_G=0.001 or 0.003, r^0 = **1**, world size = 1024 x 1024, and r_{max} was set in the range of 0.5 to 4.0 in increments of 0.1. We used JAX for GPU acceleration of the execution of multiple experiments with a large grid size.

The graph in Fig. 3 shows the average state values of all channels for various cases of the upper resource limit r_{max} in a trial. r_{max} reflects the abundance of resources in the environment, and the average state value reflects the abundance of creatures. In the case of Rule E, there was a peak of the average state value at 1.3 (R_G=0.003) and 1.7 (R_G=0.001) while it increased with increasing r_{max} in the case of Rule S. This indicates that the resource-growth relationship can strongly affects the behavior, which can be classified into three cases of r_{max}: small, intermediate, and large.

When r_{max} was small, the number of creatures was smaller and their morphological structure was simpler (e.g., small and no emitting gliders) than the original emitter creatures. This is because the low maximum resource made them difficult to maintain their original structure. It should be noted that they showed the low resource avoidance behavior (ii). They tended to change their direction to move when they came across the trajectory of low resources created by other creatures. While not clear whether it is merely due to the side effects of the model extension or due to selection for such adaptive behavior in the low resource environment, this implies that the interactions between creatures and their environment can lead to the intrinsic evolution of creatures in Lenia.

When r_{max} was intermediate, more dynamic interactions between creatures and their environment emerged (iii). In the case of Rule S, They began to grow their morphology, composed of a different type of units from the original one, quickly over the space. However, the amount of resources occupied by the creatures earlier time steps decreased, which brought about shrink of the grown creatures and the survival of a few original emitters around them. This further yielded a recovery of resource and further growth repeatedly. As r_{max} increased, the time during which the whole space was occupied by the creatures increased. We observed the similar pattern with Rule E, but the growing patterns were different.

When r_{max} was large, the emerging patterns were different between the rules. In the case of Rule S, the whole space was occupied by the creatures with similar mechanism to the above and no further shrinking of their morphology (iv). This is because the existence of resources substantially increased the state values directly in this case. We also observed that changing patterns of resource distribution and accidental extinction of a few creatures made the whole structure keep moving through the trial. On the contrary, in the case of Rule E, the creatures moved slowly or got stuck within the hole of the resource (v). This is due to the similar effect to the overcrowding of living cells in Game of Life. That is, the too large resource value increased largely the energy of each cell even if the state value was small, which rather made the growth rate small by exceeding the peak in the growth function. Thus, the creatures went back and forth among the neighboring low resource area and went extinct if there was no place to move. It is interesting that an overnutrition can affect the emerging pattern of Lenia creatures in such a way.

We also conducted experiments using another creature "aquarium", which has several modes of morphological and behavioral patterns (e.g., paired up, rotating, gliding). We observed similar effects of r_{max} on creatures, and various morphologies and behavioral patterns appeared to have emerged simultaneously when r_{max} was intermediate.

Conclusion

We proposed an extended version of Lenia in which interactions between creatures and their environment were incorporated. We observed that the abundance of resources can substantially affect the emerging morphology and behavior of creatures, while needing further investigation.

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