



# Mortal Organisms Rescue Immortal Organisms from Evolutionary Inertness: Perspective of the Programmed Self-decomposition Model

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**Abstract.** Our previous molecular cell biology studies on altruistic phenomena suggested that altruistic self-decomposition for the greater good is universally embedded in living organisms. Our artificial life simulations also showed that by promoting evolutionary adaptation in a global environment, which has finite, heterogeneous conditions, mortal organisms with altruistic self-decomposition prosper better than immortal organisms. In addition, we recently reported notable results showing that mortal organisms capable of self-decomposition emerged from indigenous immortal organisms through mutation; such mortal organisms survived and left behind offspring, albeit very rarely, but when they survived, they surpassed immortal organisms without exception. Our present focus was to determine if the altruistic contribution of mortal organisms to the ecosystem provided an optimum solution for an evolutionary dead end. In our simulations, the residual lysing (Lyse: To break down into smaller molecules.) activity after self-decomposition of mortal organisms enabled immortal organisms at a standstill of proliferation to resume proliferation by recycling materials and space. Those immortal organisms then proceeded through evolutionary adaptation to inhabit a new environment. Mortal organisms, however, were shown to be more predominant and ultimately surpassed immortal organisms, causing the latter to perish naturally. Our results raise the possibility that the global ecosystem obtained an optimum solution for the ecosystem by ultimately selecting an altruistic life.

**Keywords:** Artificial life · Altruism · Autolysis · Death · Evolution  
Ecosystem

## 1 Introduction

Altruistic phenomena, as well as the concepts of cooperation and contribution, are currently attracting much scientific interest at a time of crisis for our global ecosystem and human society resulting from the toll imparted by modern civilization [1–5].

Various types of altruistic behaviors of animals have been rationally explained by kin selection, mutualistic symbiosis, mutual benefit, handicap theory, and so on. In their conditions, an altruistic animal should be able to both be capable of individual discrimination and store memories of experiences. Are there any altruistic phenomena among such primitive organisms as having no information processing capability or personal interaction? We also questioned whether a system that subsumes unspecified elements, such as a part of the global ecosystem or the ecosystem as a whole with its complex hierarchical structure as well as specific individuals or a group of individuals, could be designated as the beneficiary of altruism.

In addressing such questions, we have been performing original research on altruistic phenomena since 1987 [6], by utilizing artificial life as a critical tool for verification [6–14]. In doing so, we have meshed the following three approaches.

### 1.1 Constitution of the Programmed Self-decomposition (PSD) Model

We have developed a model for altruistic phenomena covering the above scope. Autolysis<sup>1</sup>, one of the fundamental pathways for actualizing the restoration of an ecosystem to its original state [15], has conventionally been regarded as uncontrollable, naturally self-acting disintegration. We have redefined this process as a major altruistic phenomenon that is beneficial to certain levels of an ecological system. We thus redefine autolysis as an active biochemical process built into cellular genetic programming by which a cell consumes its own metabolic energy. In accordance with this autolytic process, we posit that individual organisms autonomously decompose themselves into components to be optimally recycled by all other individual organisms, including competitors, and through this process to return to the environment and thus contribute to the restoration of the entire ecosystem. Next, we constructed a mathematical model of life activities exemplified by self-reproduction and self-decomposition (SRSD) using John von Neumann’s self-reproductive automaton [16] as our prototype. We called this model the “programmed self-decomposition (PSD) model” [6, 14].

### 1.2 Molecular Cell Biology Study

We have conducted exact comparison and verification of the PSD model with real-life phenomena using the principles and methodology of molecular cell biology. We obtained experimental results suggesting the real existence of the PSD using a eukaryotic unicellular organism, which adequately corresponds to our mathematical model, known as the protozoan *Tetrahymena*, as our experimental material [14]. That is, we succeeded in creating concrete experimental conditions in a flask that induced the self-decomposition process of *Tetrahymena*. Also, the decomposition of the cells was significantly suppressed by the inhibition of any of the following three processes: transcription from DNA to mRNA, energy-requiring metabolic processes, and hydrolytic enzyme activities (biological polymers to monomers).

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<sup>1</sup> Autolysis: The destruction of dying cells by using their own digestive enzymes.

### 1.3 Artificial Life Studies

We have conducted simulations of evolution using artificial life because, in order to verify our evolutionary model, we have to deal with an extremely complex ecosystem on a large spatiotemporal scale that far exceeds that associated with observations of and experiments on real individual organisms.

We conducted simulations in which both mortal virtual individual organisms (VIOs) that undergo autonomous death accompanied by an altruistic PSD mechanism and immortal VIOs that do not undergo autonomous death proliferate within the same virtual ecosystem as the global one whose environmental conditions are finite and heterogeneous. Results showed that the immortal VIOs ceased to proliferate after occupying the initial areas whose environmental conditions were amenable to their survival, whereas the mortal VIOs could endlessly self-reproduce by reusing the materials and space restored to the ecosystem following the death and self-decomposition of others. Thus, the evolutionary adaptation of the mortal VIOs was accelerated, i.e., mutant VIOs evolved one after another with characteristics that allowed them to survive in environmental conditions under which the initial VIOs were unable to survive. They succeeded in expanding their habitation area and overwhelmingly surpassed the immortal VIOs [7, 8]. Thus, it can be stated that individual organisms that renounce their struggle for existence become more prosperous than those that continue the pursuit. Our finding, therefore, seems to contradict the Darwinian principle.

Next, we designed three different mortal VIOs requiring differing amounts of energy with which they recycled their decomposed parts; we then conducted simulations in which these three types of mortal VIOs and immortal VIOs proliferated within the same ecosystem. The results showed that mortal VIOs endowed with the highest degree of altruism, hence requiring the least amount of energy, overwhelmingly prospered [14].

Furthermore, we investigated how such an effective gene for altruistic death has emerged in the evolution of life on earth. The simulations produced remarkable results in which mortal VIOs that emerged among indigenous immortal VIOs through mutation very rarely survived and left behind offspring, but when they did survive and reproduce, they surpassed immortal organisms without exception [11, 13].

### 1.4 Objective of the Present Study

Supposing that mortal organisms evolved from immortal ones in a primeval global ecosystem, immortal organisms would lapse into inertness in terms of both proliferation as well as evolution, after occupying their inhabitable areas before mortal organisms evolved. The areas occupied by immortal organisms would be rendered completely inactive and unavailable, which would be practically the same as losing land throughout the ecosystem. Therefore, in the present study, we focused on these problems of the ecosystem and investigated whether the expansion of the altruistic self-decomposition function of mortal organisms would solve the problems.

## 2 Methods

### 2.1 Basic Design of the SIVA Virtual Ecosystem

We have developed a virtual ecosystem series, SIVA<sup>2</sup> [7, 9, 14], configured with Oohashi's SRSD automaton installed in a finite, heterogeneous environment consisting of virtual biomolecules having chemical reactivity. We adopted SIVA-T05 [14], which was developed to have a realistic biomolecular hierarchy inspired by artificial network chemistry [17], as a simulator in this study.

**Environmental Design of SIVA-T05.** We designed the SIVA-T05 environment to be able to simulate the characteristics of a global environment with limited amounts of materials and energy heterogeneously distributed in a finite space. The virtual space of SIVA-T05 is a two-dimensional lattice consisting of  $16 \times 16$  (= 256) spatial blocks, each of which is defined as  $8 \times 8$  (= 64) pixels for habitation points, as shown in Fig. 1A. Environmental conditions of each spatial block can be defined independently, and those of the 64 habitation points in the same spatial block are always configured to be homogeneous. One habitation point is occupied by one VIO and vice versa. VIOs import substances in the environment into their bodies as materials for self-reproduction and export them through self-decomposition. Their activities change the quantity of available substances in the environment. Because all VIOs in one spatial block share the same environmental conditions, the population of VIOs in that block significantly affects local conditions.

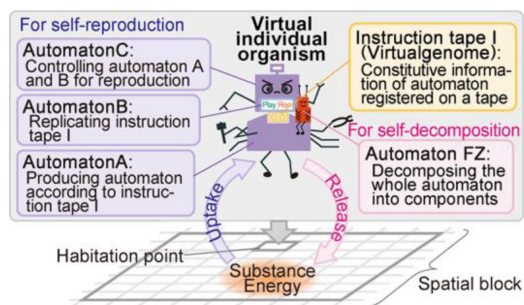


**Fig. 1.** Environmental conditions of the virtual ecosystem SIVA-T05 were designed to be finite and heterogeneous. (A) Spatial design. (B) Spatial distribution of the environmental conditions [14].

Similarly to previous studies [11, 13, 14], we configured the temperature gradient, the initial distribution of energy, and four types of virtual inorganic biomaterials, of which VIOs are composed, to be heterogeneous across the whole ecosystem, as shown in Fig. 1B. No substances other than the virtual inorganic biomaterials existed in the initial environment. A predefined amount of energy per time unit was refilled, and the total amount of energy in each spatial block must not exceed a predetermined threshold. Thermal conditions do not change in a simulation.

<sup>2</sup> SIVA will be available for academic use.

**Structure of Virtual Life in SIVA-T05.** Similar to previous studies [11, 13, 14], we adopted Oohashi's SRSD automaton G, which was designed on the basis of von Neumann's self-reproductive automaton model [16], as a VIO living in SIVA-T05 (see Fig. 2).



**Fig. 2.** Relationship between life activities of virtual individual organisms (VIOs) and the environment in SIVA-T05 [14]

$$G = D + FZ + I_{D+FZ}, \text{ where } D = A + B + C \quad (1)$$

Here, automaton A constituting automaton D was designed to produce any automata according to the instructions on data tape I (that is, a virtual genome). Automaton B was designed to read and replicate data tape I. Automaton C was designed to set the copy of data tape I replicated by automaton B into new automata produced by automaton A and separate these as a newly reproduced automaton D. Automaton FZ, which was newly designed as a modular subsystem plugged into automaton D by Oohashi, can decompose the whole automaton G into components suitable for reutilization when automaton G encounters serious environmental conditions in which it is unable to live or has reached the end of its life span. Data tape  $I_{D+FZ}$  was designed to carry instructions describing automaton D + FZ. Thus, automaton G, which corresponds to  $D + FZ + I_{D+FZ}$ , can reproduce an identical automaton G as well as decompose itself.

We designed artificial life based on artificial chemistry to actualize the above-mentioned logical actions and to reflect the principles of life on earth and its reproduction procedure as faithfully as possible, i.e., a VIO is constructed from 4 classes of virtual biomolecules: virtual biological polymers (VPs), virtual biological monomers (VMs) constituting any VP, virtual organic biomaterials (VOs) constituting any VM, and virtual inorganic biomaterials (VIs; substances 1–4 in Fig. 1B) constituting any VO. A virtual genome and virtual proteins belong to the VP class. The virtual genome consists of virtual nucleotides belonging to the VM class, and a virtual protein consists of virtual amino acids also belonging to the VM class. The virtual protein was produced as a sequence of four types of virtual nucleotides that determined the primary

sequence of eighteen types of virtual amino acids. SIVA-T05 actualizes virtual life activities by recognizing the sequence of the virtual amino acids contained in the virtual protein as coded program sentences of the SIVA language and executing the contained instructions. According to the given conditions, this mechanism enables a VIO to execute reproduction, division, and decomposition.

All VIOs in SIVA-T05 express their life activities by executing all sentences of the SIVA language they possess during one-time count (TC), which is the unit of virtual time in SIVA-T05. The order in which VIOs express their life activities within one TC is randomly determined at every TC. It takes at least 5 TCs for a newborn individual to reproduce itself in our current simulation experiments. Therefore, we use <passage duration> as a virtual time unit, which corresponds to the value of TC divided by 5. The passage duration is not the generation time; however, its concept is similar to that of generation time.

**Behavior of Virtual Individual Organisms.** We designed a mortal VIO to possess virtual proteins corresponding to Automata A, B, C, and FZ shown in Fig. 2, an additional automaton for initialization, and a virtual genome corresponding to instruction tape I for all automata. A VIO expresses its life activities by incepting materials and energy in the virtual environment. The degree of activities of each VIO is designed to depend on the amount of material and energy available as well as the temperature in its inhabited spatial block. In particular, optimum environmental conditions are connaturally defined for each VIO a priori, and its degrees of activities decrease when the environmental conditions of the habitation point change from their optimum points. A VIO cannot express its life activities when environmental conditions markedly deviate from their optimum, and, in the case of a mortal organism, it decomposes itself just as it does when it reaches the end of its life span. Concretely, Automaton FZ of a mortal VIO was designed to decompose the whole Automaton G (the VIO itself) in case either of the following if-clause judgments of the SIVA language returns 'true': (1) accumulated number of errors in the uptake of substances exceeds 2 or (2) virtual age of the VIO exceeds 20 TC (= 4 passage duration). The substances and space released by the decomposition of a mortal VIO are restored to the environment and become utilizable by other individuals, i.e., a VIO only interacts with its environment, while it does not interact directly with any other VIOs.

Next, we designed an immortal VIO based on a mortal VIO, i.e., the above-mentioned if-clause judgments of the SIVA language were configured to fix 'false' independently of the actual judgment, and the function of decomposition was disabled.

While preparing for reproduction, a point mutation (a replacement of one virtual nucleotide) can occur at a predefined probability during the replication of the virtual genome. The accumulation of mutations in an organism may change material composition of its body and introduce evolutionary adaptations to an environment in which it originally could not live because of the large difference of material composition between it and its environment.

The mutation rate was set to 0.002. Existent living organisms tend to have a higher mutation rate, as the length of their genome is shorter. For example, an organism with a genome of  $10^4$  molecules has a  $10^{-4}$  mutation rate. Because the virtual genomes of

VIOs in the present simulation consisted of 1,275 VM molecules, the adopted mutation rate was within a reasonable range.

## 2.2 Examination of the Contribution of Mortal Organisms to Rescuing Immortal Organisms from a Dead End of Proliferation and Evolution

We constructed an experimental model in which the self-decomposition function of mortal organisms simultaneously made another contribution to the ecosystem, and we observed how the mortal organisms contributed to that ecosystem.

**Inert Status Index.** First, we designed two indexes representing the inert status of immortal VIOs corresponding to the two conditions triggering the self-decomposition of mortal VIOs: (1) accumulated number of errors in the uptake of substances as an index representing unconformity with environmental conditions and (2) standstill duration of self-reproduction as an index corresponding to lifespan.

**Decomposition of Inert Immortal Organism by Residuals of FZ.** Next, we installed a mechanism into the mortal VIOs: when a mortal VIO executed self-decomposition near inert immortal VIOs with inert status index values above the threshold level, the residuals of automaton FZ, produced from the self-decomposition of the mortal VIO, decomposed those immortal VIOs and returned the space and substances to the environment. This mechanism was intended to free the immortal VIOs from the dead end and enable them to restart self-reproduction and evolutionary adaptation.

**Threshold Conditions.** Two types of inert status threshold level were examined because the effect of the decomposition by the residuals of lysing activity would change depending on the threshold level that occurred.

Threshold condition A:

- (1) Accumulated number of errors in the uptake of substances  $> 10$  or
- (2) Standstill duration of self-reproduction  $> 8$  passage durations

Threshold condition B:

- (1) Accumulated number of errors in the uptake of substances  $> 2$  or
- (2) Standstill duration of self-reproduction  $> 4$  passage durations

The latter condition B is almost equivalent to the condition in which mortal VIOs would conduct self-decomposition. The former condition A is weaker and more difficult to occur the decomposition.

For each of these conditions, we seeded an immortal VIO and a mortal VIO, which had the above-mentioned additional program installed, at the center habitation point of spatial blocks in the ecosystem shown in Fig. 1, whose environmental conditions had been determined to be suitable for both VIOs. We performed 200 simulations to test the effect of the decomposition by the residuals of lysing activity. Then, we continued the simulations up to 2000 passage durations and observed the long-time changes in the size of the habitation area, number of VIOs, and frequency of mutation.

### 3 Results

#### 3.1 Rescue Form Inertness by the Residuals of Lysing Activity

According to the simulation results, the lysing activity remaining in the environment after the self-decomposition of mortal VIOs enabled immortal organisms at a standstill of proliferation to resume proliferation in many trials. Percentages of accomplishment of the rescue or still inertness resulting from 200 simulations are shown in Table 1. Although the threshold conditions have a several-fold difference, the rescue of immortal VIOs from their inertness by the remaining lysing activity after mortal VIOs' self-decomposition was accomplished in approximately 80% of the 200 simulations in either case of the conditions. In the rest 20% of the simulations, mortal VIOs became extinct in the early phases of the simulations and did not rescue the immortals from their inertness.

**Table 1.** Percentage of rescue from inertness by the remaining lysing activity resulting from 200 simulations

	Still inertness	Accomplishment of rescue
Threshold condition A	22.5%	77.5%
Threshold condition B	18.5%	81.5%

#### 3.2 Proliferation and Evolution Following the Rescue

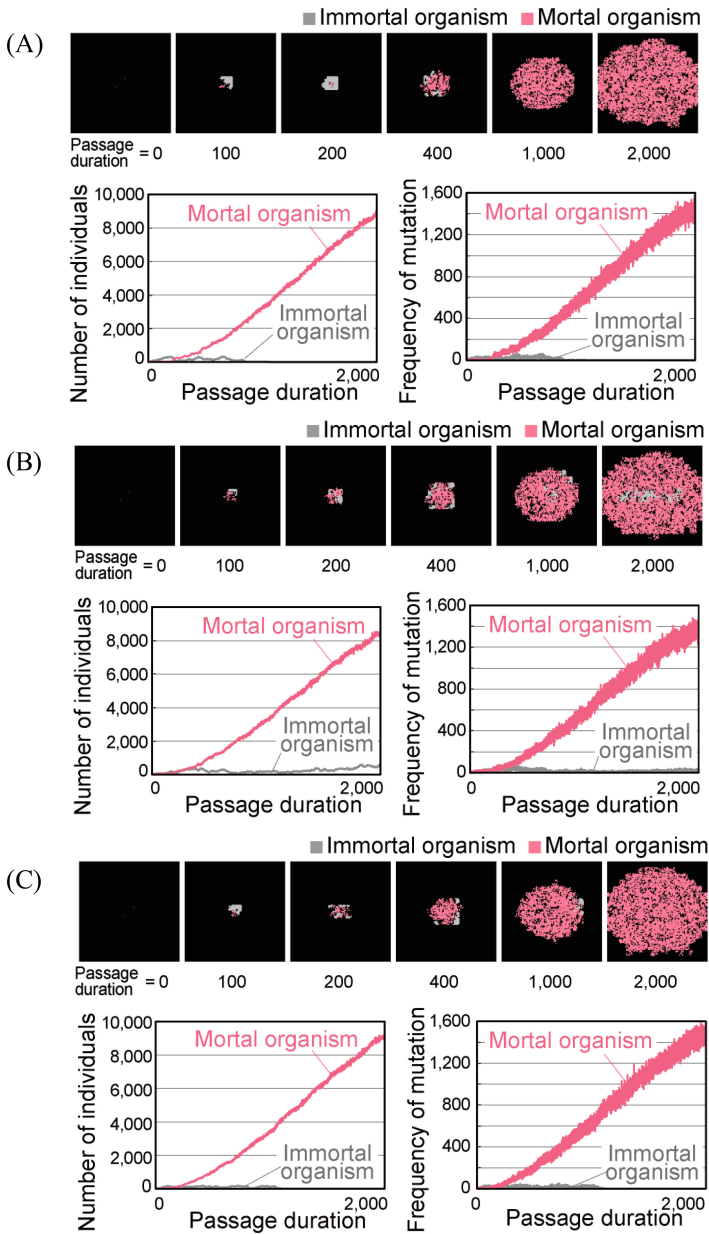
The rescue introduced the release of inactive space and resources to the environment. Activation of proliferation and evolution was observed with no regard to the mortal or immortal. The summary of the following transition up to long-time 2000 passage durations is shown in Table 2.

**Table 2.** Percentage of each existence status of rescued immortal VIOs and mortal VIOs resulting from 200 simulations

	Immortal: inert again Mortal: extinct	Immortal: survival Mortal: prosperous	Immortal: extinct Mortal: prosperous
Threshold condition A	11.5%	24%	42%
Threshold condition B	1.5%	0.5%	79.5%

**Threshold Condition A.** In 11.5% of the 200 simulations, mortal VIOs went extinct, and immortal VIOs stopped proliferation after they were released from inertness by the residuals of the lysing activity. In 66% of the simulations, on the other hand, mortal VIOs became prosperous. A typical example of successive changes in VIO distribution, number of individuals, and frequency of mutation is shown in Fig. 3(A). It was observed that the remaining self-decomposition module of the mortal VIOs





**Fig. 3.** Successive changes in VIO distribution, number of individuals, and frequency of mutation. Upper: VIO distribution; left lower: number of individuals; right lower: frequency of mutation. (A) Typical example in condition A. (B) Another example in condition A. (C) Typical example in condition B.

successfully decomposed the inert immortal VIOs from the early phase of the simulation. The rescued immortal VIOs initiated self-reproduction using the materials and space restored to the environment, developed their acuity of evolutionary adaptation, and were able to enter an environment in which they could not have originally survived. In the later phase of the long-time simulation, however, mortal VIOs surpassed immortal VIOs, which became naturally extinct at the end. Such cases were observed in 42% of the simulations. Some cases were also observed in which immortal VIOs survived together with dominant mortal VIOs. Figure 3(B) shows an example of successive changes in VIO distribution, number of individuals, and frequency of mutation. The immortal VIOs rescued from inertness kept repeating self-reproduction and decomposition by the remaining lysing activity among the overwhelmingly prosperous populations of mortal VIOs and survived as a minority up to the end of the simulation. Such cases were observed in 24% of the simulations.

**Threshold Condition B.** Threshold condition B was the stronger condition in which the threshold levels almost corresponded to the trigger conditions for the self-decomposition of mortal VIOs. Although the ratio of the rescue from the inertness in this condition was slightly higher than that in condition A as mentioned above, the following long-time transition of the simulations in condition B differed substantially than that in condition A. Percentage of extinction of mortal VIOs and re-inertness of immortal VIOs was 1.5% of all simulations. Percentage of coexistence as a minority of immortal VIOs with mortal VIOs was 0.5%. For immortal VIOs, a typical example of successive changes in VIO distribution, number of individuals, and frequency of mutation is shown in Fig. 3(C). The remaining self-decomposition module of the mortal VIOs successfully decomposed the inert immortal VIOs from the early phase of the simulation. The rescued immortal VIOs initiated self-reproduction but became naturally extinct, whereas mortal VIOs became more prosperous in the middle phase of the simulation. Such cases were observed in 79.5% of the simulations.

## 4 Discussion

The results of the present study show that the decomposition of inert immortal VIOs by the residuals of lysing activity after the self-decomposition of mortal VIOs could rescue immortal organisms from inertness, allow immortal organisms to restart self-reproduction, and re-utilize inactive and unavailable space and resources.

Although the observed decomposition and re-utilization of resources looks like predation, both are never the same. The mortal VIO, who provided the lysing activity was already dead and had been decomposed, would not be able to utilize the materials and space which were returned to the environment from the decomposed immortal VIOs. Any neighbor VIO belonging to the ecosystem has an equal chance to utilize the materials and space. Consequently, the observed phenomenon in the present study is not predation but nothing less than an altruistic phenomenon.

However, it is unlikely that kin selection can adequately explain this phenomenon, because the possible recipients are many and unspecified organisms include

competitors. The fact that the individual who actualized the altruistic phenomenon is already dead looks like far from mutualistic symbiosis or mutual benefit.

In most cases in our previous simulations in which immortal and mortal lives coexisted in a finite, heterogeneous environment like the global one, when the immortal lives occupied the inhabitable space and lost the chance to reproduce and evolve, all life activities ceased. The ecosystem at that stage must find solutions for problems both within a part of the ecosystem and in the system as a whole.

One problem within part of the ecosystem is the suspension of reproduction of immortal organisms, which are crucial members of the entire system. One of the apparent solutions to this problem may be for immortal organisms to change into altruistic mortal organisms. As discussed previously [13], the probability of this emergence and the survival is rare but cannot be denied. Another possible solution would be to restore the space necessary for reproduction through predation and removal of immortal organisms occupying the habitation space by other immortal or mortal organisms. However, this cannot be the optimal solution for immortal organisms. The optimal solution for immortal organisms may be for useless immortal organisms at an evolutionary standstill to be decomposed into reusable parts by external forces and life materials and for their habitation space to be recycled, so that reproduction and evolution may resume. However, the problem for the entire ecosystem is that the area non-reversibly occupied by immortal organisms is fixed as a wasteland without life activities, which is equal to depriving the ecosystem of habitation space. The optimal solution to this problem is also the decomposition of immortal organisms.

These problems can be overcome if the decomposition of the immortal but inactive organisms into a reusable condition by external forces offers the optimal solution for problems both within a part of the ecosystem and in the system as a whole. Therefore, the ideal solution could be the decomposition of the immortal organisms, especially those that are old or have deficits, by external forces utilizing the altruistic self-decomposition function of the co-existing mortal organisms, which would constitute an extremely altruistic contribution.

In the current simulation experiment, as expected, the immortal organisms were freed from a standstill, resumed reproduction, recovered and accelerated evolutionary adaptation, and advanced into originally uninhabitable areas. In the wasteland occupied by immortal organisms, the recycling of materials and space was resumed, and thus, the ecosystem was no longer deprived of habitation space. Mortal organisms that altruistically contributed to such an optimal solution, suffered no disadvantages with regard to existence, reproduction, or evolution as the price of altruism. Instead, the recycled materials and space would be useful for mortal organisms, as well. To make this point clear, we conducted a long-time simulation up to 2000 passage durations which is a remarkable length among our studies. They prospered extensively as the simulation proceeded, and by the end, they surpassed the immortal organisms that had been the beneficiaries before becoming extinct in many cases. This finding clearly demonstrated the superiority of the altruistic mortal gene.

The results of this experiment using a SIVA simulator equipped with a finite, heterogeneous environment support the idea that the global environment has a property that enables the selection and development of lives that bestow an extremely altruistic contribution to the ecosystem through solving problems within the ecosystem and those

affecting the system as a whole. Together with the findings from a previous study [14] in which organisms that make a greater altruistic contribution prosper more extensively, the suggestion that altruistic organisms possess greater evolutionary superiority is notable.

The simulation provides reasonable answers to two important questions: why are all living individuals predestined to die without exception and why do no immortal lives exist on this planet? The answers are that mortal lives endowed with altruistic self-decomposition emerged through the evolutionary refinement of more primitive immortal lives, which possessed only self-preservation and self-reproduction. Because of their superiority, these mortal lives surpassed immortal lives and by prospering caused the latter, according to the nature of things, to become extinct, which in turn enabled the mortal lives to expand into the entire global environment. This explanation could be the reason why there is no genealogy of immortal lives on the earth because they were unable to overcome the process of natural selection. The predestined autonomous death of living individuals is proof that we have inherited the altruistic mortal gene that overcame and extinguished primitive egoistic immortal lives and expanded the global environment by becoming the victor in the evolutionary process of natural selection.

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