Heterogeneity and complexity of a simulated terrestrial environment account for superiority of the altruistic gene

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Abstract

Recent research on the notion of altruism in terrestrial life has focused on certain altruistic behaviors, which are regarded as beneficial to animal life, especially with respect to individual animal species. Such findings throw light on individual-oriented mechanisms and their evolution in helping to clarify so-called intentional interactions between individuals based on discrimination of other individuals and remembered information as advanced by developments in biological information processing, ranging from molecular recognition to activation of the neural system. In 2006, Nowak classified these mechanisms into five types. In the current study, we have zeroed in on the process of autolysis universally observed in all terrestrial lives, as characterized by genetically programmed death accompanied by altruistic self-decomposition, whose model we call the "programmed self-decomposition model (PSD Model)". In our view, altruistic phenomena target no specific individuals yet prove beneficial to the ecosystem, in part and as a whole. Using our PSD Model we ran evolutionary simulations of altruistic phenomena in the SIVA Series, which is an artificial life system designed to resemble a terrestrial ecosystem, and one that excludes both discrimination of individuals and interactions between individuals. In our simulations no individual-oriented evolutionary mechanism was observable while the ecosystem-oriented mechanism positively contributed to the evolution of the altruistic gene. Our research has thus sought to determine factors that promote superior evolutionary characteristics of altruistic phenomena in a terrestrial ecosystem model. The current study argues that the high heterogeneity and complexity of a terrestrial environment and the eternality of evolutionary time play an important role in the selective process of programmed death in the terrestrial ecosystem, which is accompanied by altruistic self-decomposition. Based on the above findings, we investigated the inseparable relationship existing between a terrestrial ecosystem and the altruistic gene.

Introduction

We previously modeled autonomous death that comprises a universal attribute of terrestrial life, as programmed self-decomposition (PSD) (Oohashi et al. 1987, 2009). Our research centers on a series of studies that delve into the existence of autonomous death through experiments in the field of molecular cell biology using existing living organisms as subjects; concurrently, in carrying out evolutionary simulations of Artificial Life (ALife), we raise the possibility that mortal organisms having autonomous death are superior to immortal organisms (Oohashi et al. 1987, 1999, 2001, 2009, 2011, 2014; Maekawa et al. 2011). The essence of our PSD model zeroes in on the process of autolysis (Odum 1971), which is universally observed in terrestrial lives including unicellular organisms, as phenomena with respect to recycling of autonomous material in a terrestrial ecosystem. Conventionally autolysis has been regarded as deregulated, natural disintegration with increasing entropy. We have redefined autolysis as a type of autonomous, altruistic phenomenon beneficial to an ecosystem, in part or as a whole. We thus regard autolysis as an active biochemical process built into cellular genetic programming by which a cell consumes its own metabolic energy. In view of this autolytic process, we posit that life individuals autonomously decompose themselves into components; in other words, cells hydrolyze biological polymers into biological monomers so that the materials they consume and the spaces where they exist can be optimally reutilized by all other life individuals, including adversaries and competitors, and, by means of that event, can thereby return to the environment and thus contribute to the restoration of the entire ecosystem.

Recent research on the concept of altruism in terrestrial life has focused on certain altruistic behaviors regarded as beneficial to animal life, especially with respect to individual animal species (Haldane 1932; Hamilton 1963; Price 1970). Based on these many previous researches, Martin A. Nowak has provided a useful framework that classifies the mechanisms of evolution of cooperation under five types (Nowak 2005, 2006, 2011, 2012). His rules quite adequately account for altruistic phenomena that targets only specific individuals or groups. Nowak's five rules for these mechanisms require, as prerequisite functions, discrimination of other individuals and reference to remembered information, as advanced by developments in biological information processing, ranging from molecular recognition to activation of the neural system. Such altruistic behavior is realized by the individual-oriented mechanisms whose actual property is the intentional interaction between individuals based on such rules. The terrestrial lives that Nowak's framework of altruistic behavior encompasses are limited to relatively evolved animals that deploy biological control systems that enable the discrimination between individuals and the remembering of an individual's experience (Oohashi et al.

2014), at least as chemical messengers, and, ideally, a central nervous system sufficiently robust for formation intention.

We have redefined an altruistic phenomenon as being a phenomenon by which a life individual renders certain biological benefits to a part of the ecosystem including individuals as well as to the ecosystem as a whole, regardless of any biological benefit for or disadvantage to itself (Oohashi et al. 2011, 2014). In our view, the recipient of a contribution should not only be limited to a specific individual or a group of individuals; but rather, include the ecosystem, in part or as a whole. Consequently, we put forth the programmed self-decomposition model as an ecosystem-oriented altruistic phenomenon that emerges even for very primitive life individuals equipped with only the fundamental principle of terrestrial life, namely, self-reproduction and self-decomposition regulated solely by a genetic program, and without any functionality by which to discriminate between individuals (Oohashi et al. 2014). Considering that the essential quality of the PSD consists of autolysis and that organelles (lysosome) executing PSD exist in every eukaryote cell, it would be possible for PSD to serve as a mechanism universally existing in terrestrial lives, and for it to exist as a universal basic mechanism for all eukaryotes, including animals that produce the individual-oriented altruistic behavior proposed by Nowak.

Based on the conceptual clarification of altruistic phenomena, we constructed a simulator system SIVA Series equipped with primitive artificial life in an ecosystem designed to resemble a terrestrial ecosystem, and one that excludes both discrimination of individuals and interactions between individuals. Through a series of simulation studies, we showed many conditions whereby evolutionary adaptation is promoted by means of altruism even in extremely primitive lives equipped only with the basic principle of terrestrial life, that is, the self-reproduction and self-decomposition regulated solely by a genetic program (Oohashi et al. 1987, 1999, 2001, 2009, 2011, 2014; Maekawa et al. 2011). Especially noteworthy is our finding that the gene of altruistic death accompanied by programmed self-decomposition can be acquired through the evolution of immortal lives, and the lives that acquire the gene of altruistic death sometimes are overwhelmingly superior to immortal lives (Oohashi et al. 2014, Maekawa et al. 2011). Accordingly, we regard altruistic death accompanied by programmed self-decomposition as a sophisticated survival strategy acquired as the fruit of evolution. We thus categorize lives that have completed this evolution as altruistic mortal lives and more primitive lives that have yet to complete such evolution as non-altruistic immortal lives.

This study examined the possible reasons why altruistic phenomena of programmed self-decomposition brought forth evolutionary superiority in terrestrial ecosystem models. We therefore hypothesized that the high heterogeneity and complexity of terrestrial environments and the eternality of evolutionary time of a terrestrial ecosystem played important roles in the selective process of programmed death, which is accompanied by altruistic self-decomposition in terrestrial ecosystems. In our experimental models using artificial lives, we carried out experiments that tested our hypothesis and obtained positive results. Here we describe the results.

Methods

1) Design of the SIVA simulator and its virtual environment

In the present study, we again used SIVA-T05 as an evolution simulator. Its construction and functions are the same as those utilized in a previous report (Oohashi et al. 2009).

To simulate the characteristics of a terrestrial environment using a limited amount of materials distributed in a finite space, the virtual space of SIVA-T05 is designed to be a two-dimensional lattice consisting of 16x16 (= 256) spatial blocks. A single spatial block is defined as 8x8 (= 64) pixels for habitation points. One habitation point is occupied by one virtual life individual (VLI) and vice versa (Figure 1a). Environmental conditions can be independently defined for each spatial block and those of the 64 habitation points in the same spatial block are configured to always be homogeneous. Since all VLIs in one spatial block share identical environmental conditions, the population of VLIs in that block significantly affects local conditions.

In the present study, the temperature gradient and the initial distribution of four kinds of virtual inorganic biomaterials making up the VLIs were set to be heterogeneous or homogenous across the whole ecosystem according to experimental conditions (see next section). No substances other than virtual inorganic biomaterials existed in the initial environment.
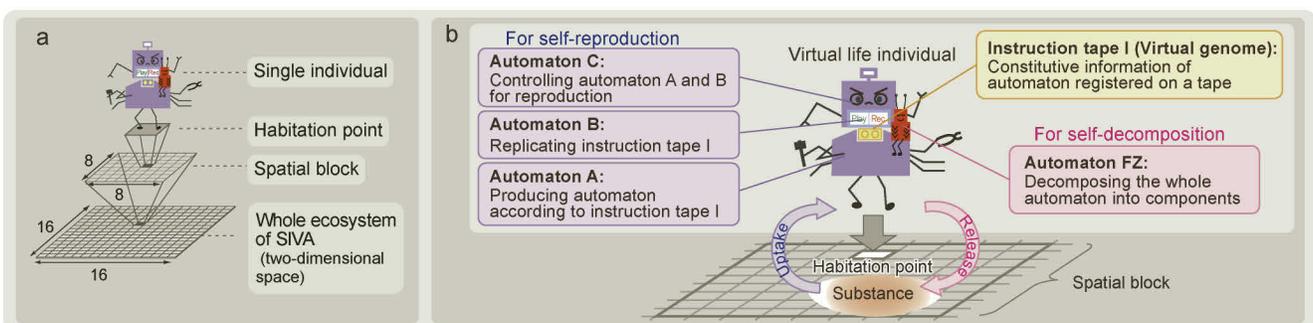
Figure 1. Environmental design and life activities of virtual life individuals (VLIs) of the virtual ecosystem SIVA-T05. a) Environmental design. b) Relationship between life activities of virtual life individuals (VLIs) and the environment.

2) Structure and behavior of artificial life

Structure of a virtual life individual. As in the previous report (Oohashi et al. 2009), we designed a virtual life individual (VLI) based on Oohashi's self-reproductive, self-decomposable (SRSD) automaton model (Figure 1b) that took von Neumann's self-reproductive automaton model (Von Neumann 1951) as its prototype (Figure 2). Oohashi's automaton G is described as $G = D + FZ + I_{D+FZ}$, where $D = A + B + C$. Here, automaton A produces automata according to instructions on data tape I (that is, a virtual genome). Automaton B reads and replicates data tape I. Automaton C sets the copy of data tape I replicated by automaton B into new automata produced by automaton A and separates these as automaton D. Automaton FZ, which is a modular subsystem plugged into automaton D, decomposes 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} carries an instruction 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 AChem (Dittrich et al. 2001; Suzuki 2004) so as to realize the above-mentioned logical behaviors and, as faithfully as possible, to reflect the principles of terrestrial life and its subsequent reproduction. We constructed a VLI from four classes of virtual biomolecules: virtual inorganic biomaterials (VI), that are four kinds of substances distributed in the environment; virtual organic biomaterials (VO); virtual biological monomers (VM); and, virtual biological polymers (VP). Any molecules in the latter three classes consist of combinations of the four kinds of VI. A virtual genome in the VP class consists of virtual nucleotides belonging to the VM class. The virtual protein in the VP class is produced according to a sequence of virtual nucleotides that determines the primary sequence of virtual amino acids belonging to the VM class (Oohashi et al. 2009). We developed a SIVA language that actualizes virtual life activities by recognizing the sequence of the virtual amino acids contained in the virtual protein as coded program sentences then executes the specific life activity. According to given conditions, this SIVA language reproduces, divides, and decomposes a VLI.

Each VLI expresses its life activities by executing all sentences satisfying their execution conditions in the VLI during one Time Count (TC), the unit of virtual time in SIVA-T05. The order for a VLI in the virtual ecosystem to express its 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.
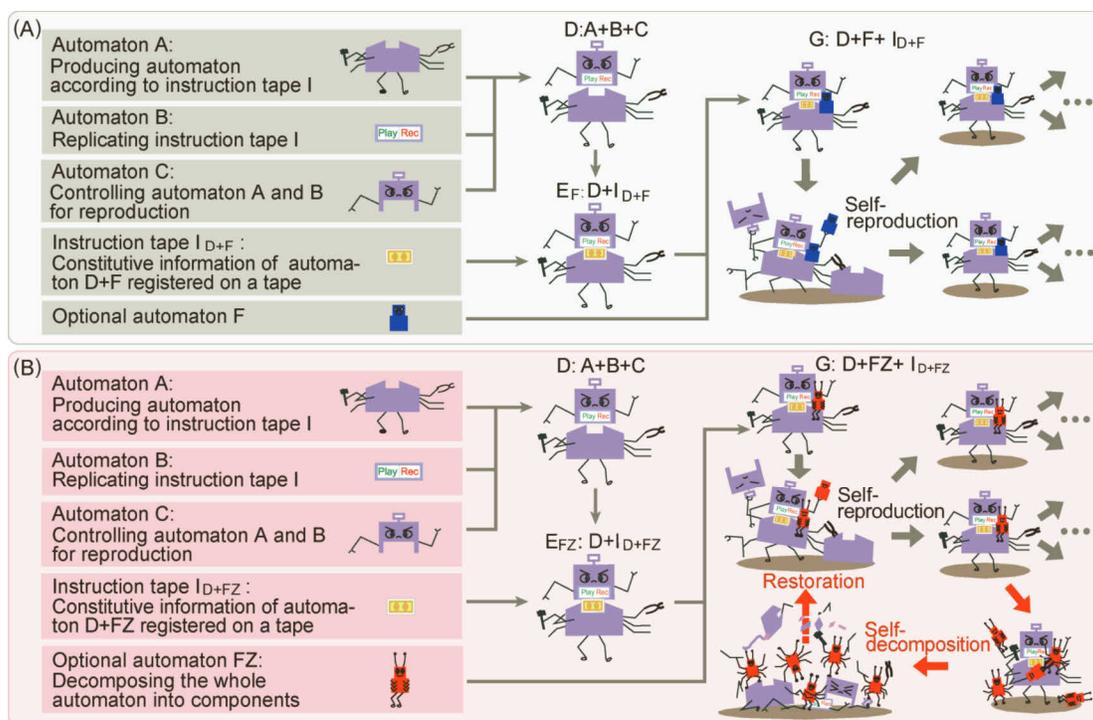

Figure 2. Von Neumann's self-reproductive automaton and Oohashi's self-reproductive, self-decomposable automaton.
(A) Von Neumann's self-reproductive automaton model. This is an immortal type model without an autonomous mechanism for the restoration of the environment to its original state. (B) Oohashi's self-reproductive, self-decomposable (SRSD) automaton model. This model uses von Neumann's self-reproductive automaton model as its prototype. It has a programmed mechanism contributing to the restoration of the environment to its original state through autonomous individual death with self-decomposition, which is an essential feature of terrestrial life. Two activation modes are defined for the self-decomposition automaton FZ. The first one is activated by a signal input from outside, indicating unconformity between the life and its habitation environment. The second mode constitutes the end of the life span.

Therefore, we use "passage duration" as a virtual time unit, which corresponds to the value of TC divided by 5 (Oohashi et al. 2009).

Behavior of virtual life individuals. A VLI executes its life activities by consuming materials from the virtual environment (Oohashi et al. 2009). Activities of each VLI are so designed as to depend on the amount of material available as well as the temperature in the inhabited spatial block. Namely, optimum environmental conditions are defined for each VLI a priori. Activities of a VLI decrease when environmental conditions of the habitation point move away from VLI optimum points. A VLI cannot express its life activities when environmental conditions markedly deviate from the optimum, and, in the case of a mortal organism, it decomposes itself just as it does when it has lived out its life span. Materials released by the decomposition of a VLI are restored to the environment and become utilizable by other individuals as well as the space that were occupied by the VLI.

When VLIs reproduce, point mutation can occur at a predefined probability during replication of the virtual genome. Mutations may alter the optimum environmental conditions for a VLI such as temperature and the composition of the VIs. In addition, VLIs which can use only VI for self-reproduction, which requires a greater amount of energy, can evolutionarily become those which can also use VM, which requires smaller amount of energy. In other words, the evolution of the material uptake function is also installed. These mutations enable the VLI to live in an environment where it originally could not live. That is to say, evolutionary adaptation to the environment can occur.

3) Experimental setting

To evaluate the hypothesis that the high heterogeneity of terrestrial environments and the eternality of the evolutionary time of a terrestrial ecosystem played an important role in the selective process of programmed death, which is accompanied by altruistic self-decomposition of the terrestrial ecosystem, we employed artificial life in three experimental conditions in which different initial distributions of VIs and temperature were employed as shown in Figure 3: experimental condition A: initial distribution of both VIs and temperature optimal level for VLIs was homogenous throughout the whole environment; experimental condition B: initial distribution of

VIs was homogenous whereas initial distribution of temperature was heterogeneous; and, experimental condition C: initial distributions of both VIs and temperature were heterogeneous. Under each experimental condition, we seeded an altruistic mortal VLI and a non-altruistic immortal VLI in spatial blocks in the midst of the simulation space whose environmental conditions were most suitable for these VLIs to start simulations of their reproduction and evolution. We conducted 100 simulations of 800 passage durations with a mutation rate of 0.005 and observed changes in the size of habitation area and number of VLIs. Since mutation occurs at each reproduction according to the configured mutation rate under the current experimental conditions, we calculate the approximate magnitude of the mutations that occur during the simulation by means of the total number of reproductions. Therefore, we aggregated the number of reproductions for both mortal VLIs and immortal VLIs to compile the cumulative mutation index.

Results

Figure 4 shows the typical transition pattern of distribution of VLIs, their number, and the cumulative mutation index of more than 800 passage durations for each of three conditions set according to the level of environmental heterogeneity. Table 1 shows the ratio of survival of VLIs up to either the 400th passage duration or the 800th passage duration, average and standard deviation ratio of number of mortal VLIs to that of immortal VLIs at the 400th and at the 800th passage duration when immortal VLIs survived, and the cumulative mutation index for both mortal VLIs and immortal VLIs at the 800th passage duration of a typical example as seen in Figure 4.

Under Condition A, when both substances and temperature were homogeneous, immortal VLIs were greater in number with continued reproduction but after the 200th passage duration, the VLIs filled the entire simulation space and entered a stable phase. On the other hand, mortal VLIs reproduced themselves until the 10th passage duration after the onset of simulation. However, when passage duration exceeded 10, reproduction of mortal VLIs stagnated that reduced their number so that there were twice as many immortal VLIs as mortal VLIs at the 15th passage duration. After 20 passage durations, the number of mortal VLIs once again increased at a rate of increase similar to that of immortal
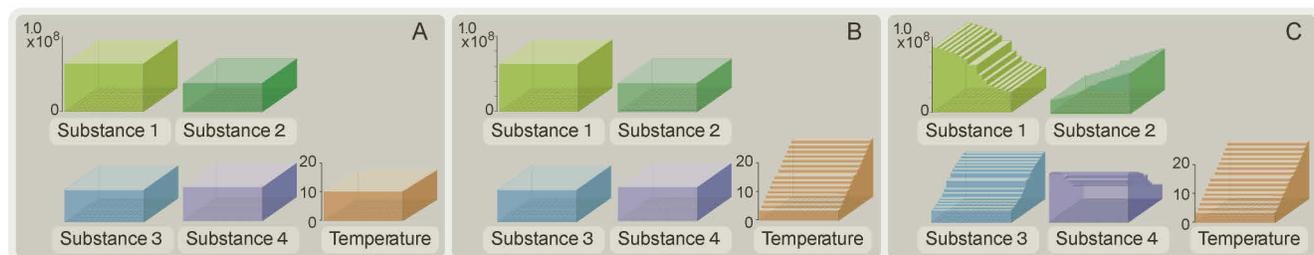
Figure 3.   Three experimental conditions showing initial distribution pattern of virtual inorganic biomaterials (VIs) and temperature. A) VIs: homogeneous, Temperature: homogeneous. B) VIs: homogeneous, Temperature: heterogeneous. C) VIs: heterogeneous, Temperature: heterogeneous.
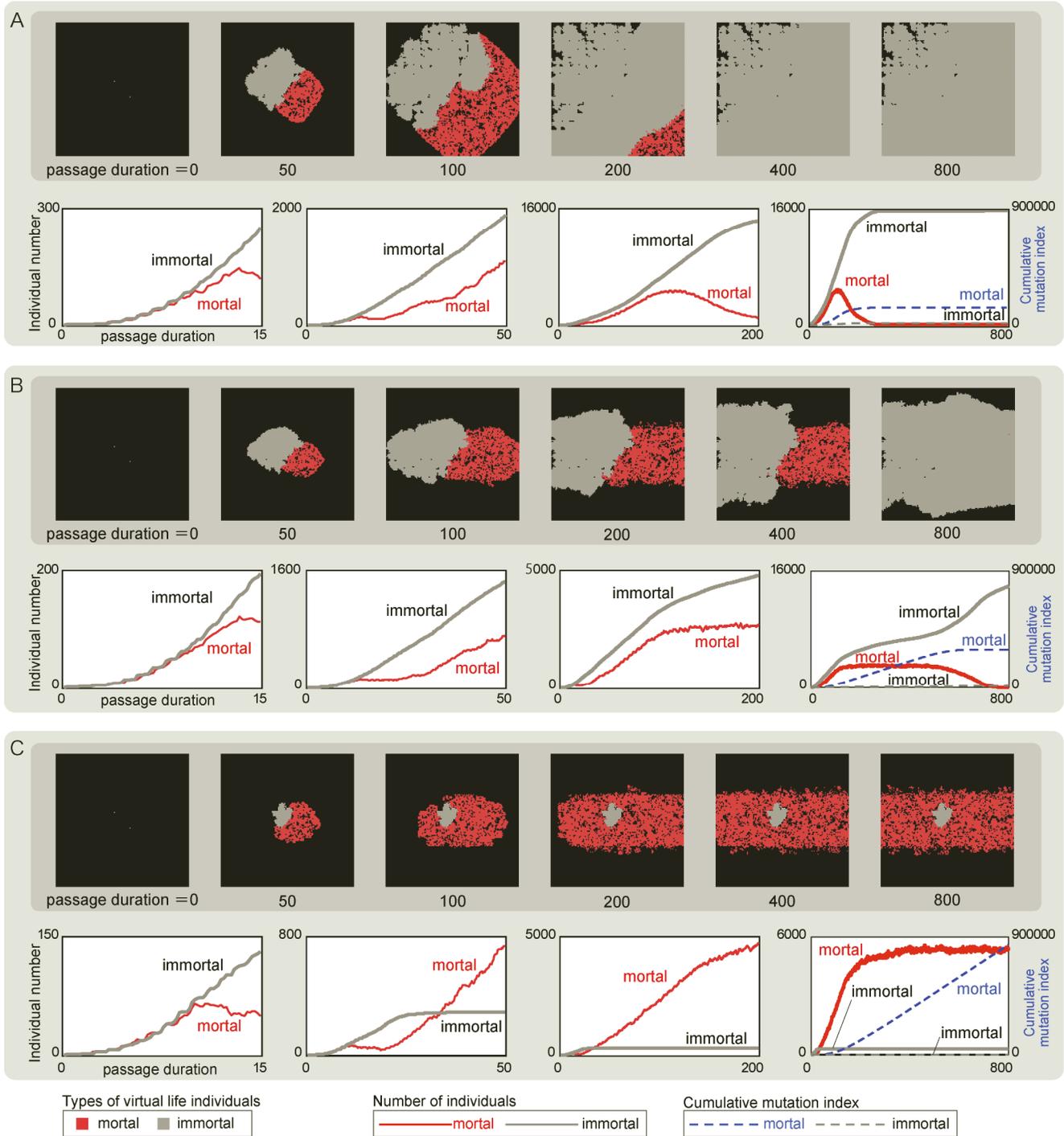
Figure 4. Altruistic gene became more superior as heterogeneity and complexity of the environment became greater. Successive changes in individual distribution (upper panels), the number of individuals (solid lines in lower panels), and the cumulative mutation index (dotted lines in the lower right panel) of mortal and immortal virtual life individuals (VLIs) simulated under each experimental condition: A) VIs: homogeneous, Temperature: homogeneous. B) VIs: homogeneous, Temperature: heterogeneous. C) VIs: heterogeneous, Temperature: heterogeneous.

Table 1: The superiority of the mortal VLIs led by the increase in heterogeneity and complexity in environmental conditions.

Condition		400th passage duration		800th passage duration		Cumulative mutation index	
Substance (VIs)	Temperature	Ratio of survival (mortal VLIs)	Average and SD ratio of number (mortal VLIs / immortal VLIs)	Ratio of survival (mortal VLIs)	Average and SD ratio of number (mortal VLIs / immortal VLIs)	Typical values	Ratio (mortal VLIs / immortal VLIs)
A homo-geneous	homo-geneous	0%	0	0%	0	mortal 133910 immortal 15910	8.4
B homo-geneous	hetero-geneous	8%	0.19±0.17	0%	0	mortal 294747 immortal 13100	22
C hetero-geneous	hetero-geneous	11%	18±2.1	11%	18±2.0	mortal 840945 immortal 291	2890

VLIs. However, mortal VLIs increased until the 120th passage duration at which time they entered a reduction phase and died out after the 200th passage duration. Such a tendency was commonly observed in all of the 100 simulations executed, and mortal VLIs never survived until the 400th passage duration in any of the simulations. However, while the cumulative mutation index at the 800th passage duration of immortal VLIs was 15910, that of mortal VLIs reached 133910, 8.4 times that of the immortal VLIs. That finding shows that the magnitude of the cumulative mutation of mortal VLIs was much higher than that of immortal VLIs.

Under Condition B, when the temperature was heterogeneous while the initial distribution of substances was homogeneously distributed, immortal VLIs steadily increased and maintained a greater number than mortal VLIs. After reaching the 100th passage duration, the increase of the immortal VLIs slowed down then accelerated once again after the 600th passage duration in parallel with the decrease of mortal VLIs. In contrast, mortal VLIs started to reproduce but its number deceased at around the 10th passage duration. Then, at the 20th passage duration, mortal VLIs increased once again until reaching a plateau at around the 120th passage duration. At the same time, mortal VLIs remained constant in number and well-balanced with respect to reproduction and decomposition up to the 500th passage duration, and began to decrease at the 600th passage duration then dying out at the 800th passage duration. The ratio of survival rate of mortal VLIs at the 400th passage duration was 8%, but the number of mortal VLIs was, on average, 0.19 times that of immortal VLIs, which shows the absolute superiority of immortal VLIs to mortal ones in all trials. Furthermore, when we extended the evolutionary time of the simulation, mortal VLIs died out before reaching the 800th passage duration without exception. However, while the cumulative mutation index at the 800th passage duration of immortal VLIs was 13100, that of the mortal VLIs was 294747, which reached 22 times that of immortal VLIs. This finding shows that the magnitude of the cumulative mutation of mortal VLIs was even higher than that of immortal VLIs as compared to Condition A.

Under Condition C, when both temperature and initial distribution of substance were heterogeneous, immortal VLIs began reproduction in the same way as they did in Condition A and Condition B, but ceased reproduction after the 25th

passage duration, and were completely surpassed by mortal VLIs at the 30th passage duration. There was no notable change observed either in number or size of the area in which the immortal VLIs existed until they reached the 800th passage duration. On the other hand, mortal VLIs started to reproduce but its number deceased at around the 10th passage duration. Then, at the 20th passage duration, mortal VLIs increased once again and surpassed immortal VLIs in number at around the 30th passage duration, and continued to increase in number and size of the area in which they existed. At the 200th passage duration, the rate of increase declined but maintaining a stable balance between reproduction and decomposition up to the 800th passage duration. The number of trials in which mortal lives survived until the 400th passage duration increased from 8 to 11 out of 100 trials. They survived until the 800th passage duration. Both at the 400th and 800th passage duration, the number of mortal VLIs was, on average, 18 times greater than the number of immortal VLIs, which shows the overwhelming prosperity of the former. While the cumulative mutation index at the 800th passage duration of immortal VLIs was 291, that of mortal VLIs was 840945 (2890 times). This shows that the greatest magnitude of cumulative mutation was accumulated in mortal VLIs among the three environmental conditions with respect to heterogeneity. As shown above, when an environment is more heterogeneous and complex, the survival rate of mortal VLIs increases and the duration of survival becomes longer so that mortal VLIs overwhelm immortal VLIs even in the number of individuals in a heterogeneous and complex condition. The cumulative mutation was observed to be markedly greater for mortal VLIs than for immortal ones. Furthermore, it is noteworthy that even when mortal VLIs overwhelmed immortal ones in the final stage under a heterogeneous and complex experimental environment, immortal VLIs dominated mortal ones at the initial stage, up to the 30th passage duration without exception. This indicates that a certain length of time for evolution and prosperity is necessary before mortal VLIs can surpass and overwhelm immortal ones.

Discussion

Using the SIVA Series, an artificial life system designed to resemble a terrestrial ecosystem that excludes both

discrimination of individuals and interactions between individuals, we examined factors that promote superior evolutionary characteristics of altruistic phenomena and a gene having altruistic properties.

Our results showed that immortal lives without altruistic properties are overwhelmingly more prosperous than altruistic mortal lives in a more homogeneous and simple artificial ecosystem with a shorter reproductive evolutionary time. On the other hand, the more heterogeneous and complex an environment having a longer reproductive evolutionary time is, the more dominant the altruistic mortal lives become over non-altruistic immortal lives. That is, when the substances necessary for reproduction of individual life and the temperature necessary for emergence of life-form activities were homogeneously distributed under simple environmental conditions at the initial stage, altruistic mortal lives were overwhelmed by non-altruistic immortal lives and never survived up to 400th passage duration in any of 100 trials. When, at the initial stage, the temperature was heterogeneous while the substances were homogeneously distributed as above, mortal lives survived up to the 400th passage duration in 8 out of 100 trials. Note, however, that the number of immortal lives exceeded the number of mortal lives at the 400th passage duration in all those 8 trials. Furthermore, when we extended the evolutionary time of the simulation, the mortal lives died out before reaching the 800th passage duration in all 8 trials.

On the other hand, when the temperature was heterogeneous and the initial distribution of substances necessary for living organisms was heterogeneously distributed to increase the complexity of environmental conditions, the number of trials in which mortal lives survived until the 400th passage duration increased from 8 to 11 out of 100 trials. Noteworthy, in all of the 11 trials in which mortal lives survived, mortal lives were clearly inferior to immortal lives initially but the situation eventually reversed, and, at the 400th passage duration, the number of mortal lives was, on average, 18 times greater than those of immortal lives; i.e., the mortal lives overwhelmingly prospered. These results show that an increase in heterogeneity and complexity of environmental conditions significantly improved the superiority of mortal lives with respect to immortal lives.

From the temporal aspect, it was observed that, at the initial stage, under initial conditions either homogeneous or heterogeneous, immortal lives were dominant over mortal lives in all cases, and, only when mortal lives were able to escape from extinction did they overwhelmingly dominate immortal lives without exception, although a long evolutionary time span was required. Such results indicate that if a long reproductive evolutionary time span accompanies high heterogeneity and complexity of environment, the altruistic mortal lives will become superior with respect to non-altruistic immortal lives.

These results support our hypothesis that given a sufficiently long evolutionary time span, the high heterogeneity and complexity of the terrestrial environment plays an important role in the evolutionary selection of the gene with programmed death accompanied by altruistic self-decomposition in the terrestrial ecosystem.

Life forms accustomed to existing in an optimal environment in a heterogeneous ecosystem have a greater chance of encountering an unconformable environment as these life forms continue to reproduce and increase the size of the area in which they exist.

An unconformable environment is nothing but an environment in which reproduction is made difficult or impossible. To survive therein, such life forms must undergo evolutionary adaptation, thus acquiring novel life activity that is amenable to such environmental conditions. Immortal lives in such an environment would have no further chance to produce new individuals when the area possible for reproduction is completely filled. Therefore, before an area appropriate for reproduction fills up, there must be a mutation that provides evolutionary adaptation enabling survival in an adjacent area. Otherwise, both reproduction and evolution are blocked. As the heterogeneity in the environment increases, or as the areas with survivable homogeneous environmental conditions decrease, reproduction becomes difficult for an immortal life and the possibility of evolutionary occlusion increases.

On the other hand, mortal lives can continue the alternation of generation, even within a small area, by returning substances and space to the environment through self-decomposition and recycling. Therefore, mortal lives always possess the potential to achieve novel evolutionary adaptation by accumulating mutations without falling into the blockage of evolution. Alteration in characteristics by mutation in this case emerges as a change in the balance of the inorganic substances necessary for reproduction, an acquisition of the function of monomer intake, and a shift in optimal temperature. Thus, as the heterogeneity and complexity of environmental conditions increase, the activities of immortal lives decreases, and, at the same time, mortal lives attain superiority.

In simulations in which the initial conditions of the environment were set to be highly heterogeneous, the mortal lives overwhelmingly prospered. However, even in such cases, immortal lives were, as is natural, dominant at the initial stage of the simulation without exception. It was noteworthy that the situation completely reversed later and altruistic mortal lives that had been weak became superior.

The temporal pattern of the number of life individuals along the time line of reproductive evolution displayed particular characteristics. Under all conditions, mortal lives smoothly began reproduction and increased until the 10th passage duration at which time they entered a reduction phase. The number of mortal lives remained small for a time, then, prior to the 30th passage duration, reverted to the increase phase. When the environmental conditions became heterogeneous, the number of mortal lives monotonically increased, overwhelming the number of immortal lives.

Mutations accumulate during the alternations of generation. These mutations stochastically occur in all directions and do not necessarily acquire an evolution appropriate to a particular time and place. The environmental conditions to which the life forms must adapt are continuously changing. Therefore, a longer period, that is, eternal time, is necessary for an individual to acquire the characteristics appropriate for the varying environmental conditions conducive to mortal life as to ensure superiority within the whole ecosystem.

Non-altruistic immortal lives show superiority within a shorter time span. However, when environmental conditions are heterogeneous and complex, the prevalence of immortal lives is reduced and blocked while, over a longer time span,

altruistic mortal lives show significant superiority. This finding is highly suggestive for discussing the superiority of the altruistic gene in an ecosystem resembling a terrestrial one. The actual terrestrial ecosystem has consisted of multidimensional, multifaceted heterogeneous and complex environments microscopically and macroscopically throughout the Earth's entire several-billion-year history. The simulations under study here show that, in such environments, even primitive life forms having simple altruistic mechanisms for decomposing themselves so that they can contribute to the ecosystem in part and as a whole possess evolutionary potential for producing a teeming variety of genes and characteristics. Our results further suggest that the altruistic gene with characteristics physically appropriate for a terrestrial ecosystem endowed with high complexity and eternal time can be evolutionarily selected, can prosper and, as a result, can provide the basis for the Earth's biological diversity.

Nowak's framework (2006) of altruistic phenomena quite validly explains the altruistic behavior of higher species of animals. As a basis of such a highly developed individual-oriented altruism, the ecosystem-oriented altruism mechanism without intention is universally available to all terrestrial lives and thus functions as the basic mechanism for existent terrestrial life. This suggests that the Earth's environment might well possess the optimum characteristics for selecting the altruistic gene.

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