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1996. 7. 18

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Abstract

Our study is being carried out based on a paradigm that ``death is achieved by the maturity of living organisms, thus being the fruit of evolution.'' We previously proposed a biological hypothesis ``programmed self-decomposition (PSD) model[1,2]'' which assumes that a self-decomposition mechanism is programmed in each cell of all living organisms on earth, and that the mechanism contributes to the restoration of the ecosystem to its original state. To examine this hypothesis, we adopted two different approaches: experiments on virtual life forms and those on actual life forms. In this paper, the design and behavior of a new simulator ``SIVA-3'' developed on the basis of the PSD model is examined. We also include a summary of the PSD model itself and that of studies done on actual living organisms. The PSD model is formulated as an evolutionally advancing variation of von Neumann's immortal self-reproductive automaton model. We conducted simulations of virtual lives implemented according to these two models. The results suggest the validity of our concept of a self-decomposition mechanism not only for the restoration of the ecosystem but also for evolutionary adaptation of ALife that exists in an environment that is heterogeneous and limited with respect to space and substance. Results of biochemical investigations may suggest that actual living organisms are really provided with a self-decomposition mechanism, and that self-decomposition is a controlled process driven by a genetic programme.

1 Introduction

We are very interested in the broader significance implied in the notion of the ``death of living organisms.'' For instance, if a study can be based on the negatively stated paradigm that ``death is caused by a flaw or incompleteness of living organisms, thus a problem to be overcome,'' then one may also be carried out based on the positively stated paradigm that ``death is achieved by the sophistication or maturity of living organisms, thus being the fruit of evolution.''

Our research is based on the latter paradigm. In this article, we are reporting on ``SIVA-3'' computer simulations that investigate the advantage of life based on the ``programmed self-decomposition model,'' that we previously proposed[1,2], from the viewpoint of evolutionary adaptation. An outline of the model itself and the results of biochemical examinations of living organisms are also provided.

2 Fundamental model: ``Programmed self-decomposition''

2.1 Restoration mechanism of the terrestrial ecosystem

While the terrestrial ecosystem forms an open system in the sense that energy is supplied by the sun and wasted heat is released into extraterrestrial space, it still can be characterized as being almost closed, in that space and substance are both limited. The activities of life, however, can hardly be maintained without using up a given amount of substance and energy and occupying a given amount of space from the environment in which it exists. Accordingly, to maintain the stability of that terrestrial life activity, the space and substance removed from the environment by the activity of life itself have to be returned to the environment. That is, ``restoration of the ecosystem to its original state'' must occur to the degree that the activities of life have affected the ecosystem so that a fatal change in the environmental conditions will be avoided.

The mechanism of restoring the terrestrial ecosystem to its original state has conventionally been explained by the principle of biological circulation called the *food chain* — mutually giving oneself as food to other living organisms and depending upon metabolic activity to attain restoration of the environment as a whole.

We have set up a new hypothesis that is complementary to that of the food chain. In the present terrestrial ecosystem, while such a mechanism of restoring the environment to its original state is occurring, another hidden mechanism is fundamentally built into every living organism by which each cell of that organism positively decomposes itself so as to contribute to the restoration of the environment.

The phenomenon of decomposing oneself by one's own force is observed in life on earth. Called ``autolysis,'' it has so far been recognized as a process of destruction of living organisms randomly directed from a state of order to one of disorder. For instance, E.P. Odum stated in his publication, ``Fundamentals of Ecology''[3], that the recirculation process of nutrients consists of (1) primary excretions of animals (predation in a wide sense), (2) decomposition of minute organic waste by microorganisms, and (3) direct circulation to plants by the action of symbiotic bacteria. He also mentioned autolysis as ``appropriate to the fourth major recirculation process which does not contain metabolic energy.'' This is a representative description of the concept of autolysis.

Our hypothesis, on the other hand, looks at such a phenomenon as a controlled biochemical process for the given purpose of restoration of the environment to guarantee effective utilization of restored nutrients and space. To distinguish this process from autolysis, we call it ``self-decomposition.''

A controlled process generates a condition with a smaller degree of probability. A comparable amount of energy has to be injected in for this process. If there is to be a controlled biochemical process, it thus has to be accompanied by a process in which a given amount of metabolic energy is consumed. The conventional approach, such as Odum's, of regulating autolysis as a process that does not contain metabolic energy, does not regard autolysis as a controlled process. This is different from the concept of self-decomposition raised by us.

2.2 Theoretical definition of self-decomposition

We have developed the concept of a self-reproductive and self-decomposable automaton[1] through the modification of von Neumann's self-reproductive automaton model.

Von Neumann proposed on two occasions his mathematical model of life, the ``self-reproductive automaton[4,5].'' We have adopted the simpler and more basic model proposed at the Hixon Symposium in 1948[4] for the development of our concept.

It can be summarized as follows:

(a) Automaton A constructs another automaton according to instruction I.
(b) Automaton B makes a copy of instruction I.
(c) Mechanism C combines A and B and functions as follows:
  (1) let A construct another automaton according to I.
  (2) let B make a copy of I and insert it into the automaton constructed above.
  (3) separate the new automaton from the system $A+B+C$.
(d) Automaton D consists of $A+B+C$.
(e) Instruction I_D describes automaton D.
(f) Automaton E consists of $D+I_D$, which can reproduce itself.
(g) Instruction I_{D+F} describes automaton D plus another given automaton F.
(h) Automaton E_F consists of $D+I_{D+F}$, which can reproduce itself and construct another automaton F.

This model expresses the sequence of self-reproduction of life as a physical machine and its evolution in that process, without falling into a vicious circle. Automaton E can be compared to a cell of actual life, and instruction I to its DNA.

This model continues to self-reproduce as long as there is enough space, materials and energy, and its structure remains intact unless it is attacked by external forces. It is immortal.

On the contrary, living organisms on earth die without exception, and unless special measures are taken, they degrade into components after death. This is the essential difference between von Neumann's model and terrestrial life. So taking account into the ideas presented here, we have developed the following model, using von Neumann's model as a prototype, in which the process of ``death and decomposition'' is already programmed in.

This new model can be expressed as a variation of von Neumann's self-reproductive automaton E_F. To be more specific:

(a) Automaton FZ, which has the ability to disjoint the whole system into component elements, is a modular subsystem comparable to von Neumann's automaton F.
(b) Instruction I_{D+FZ} describes automaton D plus automaton FZ.
(c) Automaton E_{FZ} is a system comparable to von Neumann's automaton E_F whose instruction I_{D+F} is replaced by instruction I_{D+FZ}.
(d) Automaton G is a system composed of E_{FZ} and FZ. viz.

$$G = E_{FZ}+FZ$$
$$= D+FZ+I_{D+FZ}$$

This system G can reproduce itself, and thus makes FZ as a subsystem within the system.

FZ has the ability to disjoint G into finite elements. These elements are sized and structured in such a way that the entire ecosystem that G belongs to may take advantage of them collectively.

FZ's mode of action can be one of the following three:

(1) Its production is normally restricted. With the input of a particular message, the restriction is lifted, and the production activated.
(2) Its operation is normally restricted. With the input of a particular message, the restriction is lifted, and the operation activated.
(3) (1) and (2) together.

Furthermore, if, after a certain amount of time has passed or a certain set of events has occurred, there is still no message input to trigger an action, (1), (2), or (3) will happen automatically. The ``certain message'' referred to above is provided, evidently, when it becomes impossible for G to further multiply itself or to maintain its structure — that is, when it is on the verge of extinction. If G is not given such a message for a certain period of time, G puts FZ into operation. Therefore, we regard G as having a programme of spontaneous and inevitable "death and decomposition" installed *a priori.*

System G composed as described above not only reproduces itself, but also has the ability to put an end to its own life and to return to its origins — that is, to contribute to restore the ecosystem to its original state. We tentatively call this system a "self-reproductio~self-decomposition (SRSD) system" and call the theoretical model under discussion a "programmed self-decomposition (PSD) model."

3 A study on virtual life — "SIVA-3"

3.1 Motivation

Since terrestrial life and the ecosystem are made up of such complex elements and their interactions, if these were to be artificially and faithfully reproduced, enormous time and effort would have to be spent. On the other hand, they represent a valuable point of references, because numerous conceivable hypotheses have been thoroughly examined. Accordingly, if a mechanism can be plugged into a model by extracting and purifying it from one latent in actual life forms and/or the ecosystem, an extremely effective result might be attained.

With this in mind, we have been doing computer simulations that fully utilize mechanisms latent in actual life forms and the ecosystem, in parallel with research on living organisms. In this section, we created virtual individuals modelled on von Neumann's self-reproductive automaton and on our SRSD system, bred each of them in a limited virtual space with an environmental heterogeneity, and investigated the effect of the self-decomposition mechanism on the self-reproductive automata, especially in terms of their evolutionary adaptation to the heterogeneous environmental conditions.

3.2 Major characteristics

We previously developed the simulator series "SIVA (Simulator for Individuals of Virtual Automata)"[2] to examine the PSD model. Our newest simulator SIVA-3 has been developed to extract the effective latent components of the mechanism held in actual life forms and the ecosystem, to simplify them without losing their essence, and to model them within the limitations of our computer's capacity. SIVA-3 incorporates in its framework the following points.

(1) The structure of virtual life is designed to correspond to the virtual molecular level, and the simulation conditions are set up to be attained within a realistic time.

(2) Both the limited virtual environment and virtual life are constructed with limited virtual substances consisting of four kinds of virtual elements as a common material group. Accordingly, the material circulates between the environment and life.

(3) Both the body structure of the virtual life and the information carrier structure that controls life processes were constructed with these same common virtual elements. Accordingly, the substance and the information are defined as being fully equivalent to each other in virtual life.

In addition, in line with the PSD model, SIVA-3 is constructed with the additional point below.

(4) The environmental conditions of the internal regions in virtual space are designed to differ respectively, and individuals are provided with the possibility of advancing from one region to another by evolutionary adaptation. Consequently, there is a possibility in this system of carrying out selection and evolution without the exclusive and competitive struggle for existence.

3.3 Designing of models

Designing of the environment We intend to observe the difference between the evolutionary adaptability of both life that self-decomposes and life that does not, so we introduced an environmental heterogeneity into the model to induce evolutionary adaptation. This means that the virtual space designed here is to have a plural number of internal regions, each with differing conditions. These conditions range from those with the maximum conformity for primitive life, to those with the minimum conformity, that is, under a condition in which it is impossible for primitive life to survive or reproduce itself unless it adapts to the condition of taking many evolutionary steps.

The virtual substances in SIVA-3 are restricted to four types of virtual elements, A, B, C and D, and the virtual space in SIVA-3 is assumed to be a 2-dimensional lattice of 16x16 spatial blocks, as shown in Figure 1. Each block consists of 8x8 pixels, therefore,

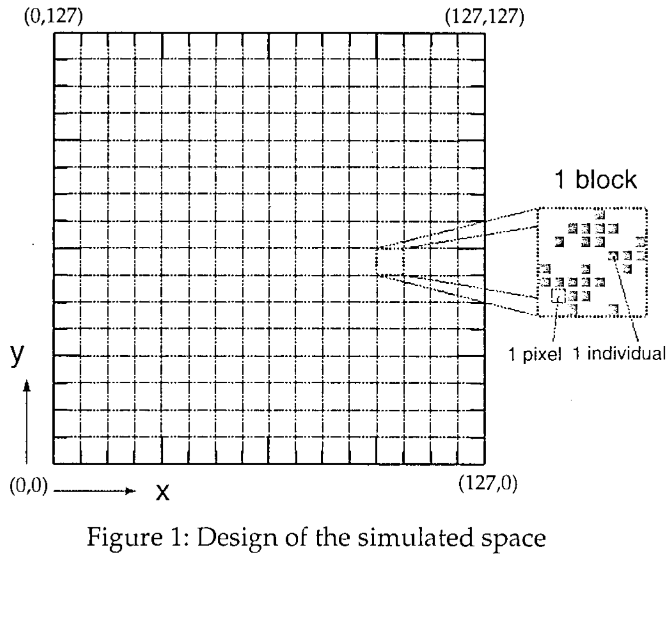

Figure 1: Design of the simulated space

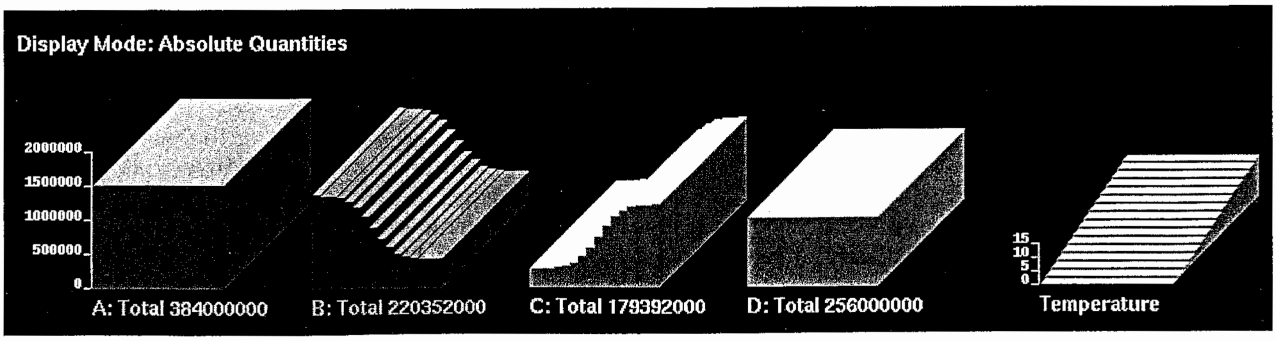

Figure 2: Initial state of environmental heterogeneity

the space of SIVA-3 consists of 128x128 pixels in all. One pixel is defined as a spatial unit that one individual of virtual life must occupy to exist.

Environmental heterogeneity is introduced into blocks on the basis of two criteria: the quantity of substance and temperature. Each block has four parameters, representing the existential quantities of respective elements by non-negative integer values. It also has four values of initial quantities of respective elements. For the purpose of maintaining heterogeneity in the environment of substance, only the differences between the initial and current values of existential quantities of free (not biomolecular) elements diffuse among neighboring blocks. The temperature in each block is set in a range from 0 to 15, and it generates no diffusion among blocks. There is no correlation between the quantity of substances and the temperature. The initial state of environmental heterogeneity used in the current experiments is shown in Figure 2.

```
Name
[term relation term]* command ...
[term relation term]* command ...
...
```

*: Parts of [] can be omitted.

Figure 3: Structure of a VP

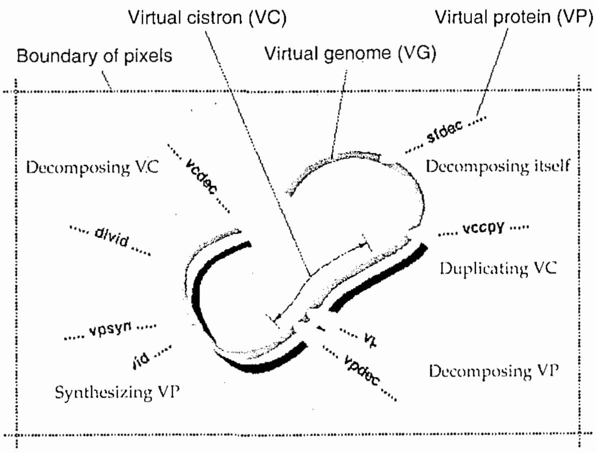

Figure 4: Structure of a virtual individual

Designing of the activities of life ``Virtual nucleic acid (VNA)'' is defined as a module of unified function covering the functions of actual nucleic acid, such as preservation, duplication and transcription of genetic information.

A ``virtual protein (VP)'' is defined as a subsystem corresponding to actual intracellular subsystems and enzymes, which have their own appropriate vital functions, such as composition, decomposition and conversion of life structure. A VP can be directly synthesized, according to the description in VNA, by the action of the other VP. The general structure of the VP is shown in Figure 3. A VP includes some commands which decide the function of the VP itself. Details of the definition and the implementation of the VP will be shown in another report.

A continuous region in VNA, which describes one VP, is called a ``virtual cistron (VC),'' and a set of all VCs included in one virtual life individual is called a ``virtual genome (VG).'' It is assumed that the VG is a ring in which all the VCs are chained, like the circular DNA of actual life, and all the VPs always stick to one of the VCs in the VG, react with the VC, and when nec-

```
VP A
vpsyn  (* Synthesize a VP.)
movef  (* Move forward on the VG.)

VP B
vccpy  (* Make a copy of the VC.)
movef  (* Move forward on the VG.)

VP C
pnum >= pdbl cnum >= cdbl divid
  (* If both the copying of VG and the synthesizing of VPs are completed,
  divide the individual.)

VP FZ
cnum = 0 sfdec
  (* If there is no VC, decompose itself.)
stat = UNFIT vpdec vcdec
  (* If the stat is UNFIT, decompose the VP and the VC.)
time > 20 vpdec vcdec
  (* If the age of the individual is greater than 20, decompose the VP and
  the VC.)
```

*: Meanings

Figure 5: The SRSD system in SIVA-3

essary, move back and forth along the VG. We also assume a copy of VG is formed near the original VG with the same ring-shape. The structure of a virtual individual is illustrated in Figure 4.

A status variable `stat`, which indicates the internal status of the individual, is incorporated in every virtual life. The initial value of a `stat` is defined as `FIT`, and it becomes `UNFIT` when the VP in the individual cannot function normally because of inconsistencies with the environment.

The SRSD system is designed as shown in Figure 5. The functions of the VPs in this system are as follows, respectively: (1) The VP *A* synthesizes VPs according to the VC. (2) The VP *B* makes a copy of the VG from the original VG. (3) The VP *C* divides the individual into two when the copying of the VG and the synthesizing of the VPs are all completed. (4) The VP *FZ* begins to decompose the VP and the VC to elements A, B, C and D when the `stat` changes from `FIT` to `UNFIT`, or when the individual lives longer than 20 TC (Time Count). These VPs act in parallel. The VP *A*, VP *B*, VP *C* and VP *FZ* correspond to the automaton *A*, *B*, *C* and *FZ* in the theoretical SRSD system respectively.

In the case of terrestrial life, the order of the 20 kinds of amino acids, that make up protein, is expressed by an arrangement of unit consisting of three nucleotide characters on DNA, called `codon.' The translation rule between codon and amino acid is common for all kinds of terrestrial life, with some exceptions. We decided to emulate this coding rule in SIVA-3 by regarding `command`, `term` and `relation` in a VP as ``virtual amino acid (VAA),'' and by expressing the type of the VAA according to the arrangement of the ``virtual codon (Vcod)'' on VNA in which elements A, B, C and D are arranged.

The consumption of substances in the environment occurs on synthesizing of a VP and on copying of a VC. When a VP is synthesized, it consumes the amount of substance equal to the multiplication of the *aminosize* by the number of the element characters A, B, C and D described in the VC that makes up the VP. On the other hand, when the VC is copied, it consumes the amount of elements equivalent to the number of characters A, B, C and D incorporated into the copied VC.

Mutation Three types of mutations actually observed in terrestrial life, namely substitution, duplication and loss, were introduced into the life forms in SIVA-3. Each of these mutations is conceivable in the following two instances: (1) When the VC is copied, substitution will occur at a probability of *misvcrate* per character of A, B, C and D. (2) When a division of the individual takes place, crossover between the original VG and the copied VG will occur at two points. Duplication and loss of VGs will take place at a probability of it *miscsrate* per crossing point caused by divergence of the crossing points.

If these mutations make an incomprehensible or unexecutable arrangement of VAA, they are completely ignored so that the life activity of the individual will not be brought to a stop.

Evolutionary adaptation In SIVA-3, there exists an optimal environment for each individual in its relation to the environment, and when the environment deviates from the optimal level, survival and self-reproduction of the individual can not be carried out in the normal way. The individuals were provided with a characteristic dependent on environmental conditions, such as the dependency of the command `vpsyn` (which synthesizes the VP according to the VC) and `vccpy` (which makes a copy of the VC) on substances, and `divid` (which divides the individual into two) on temperature.

`Vpsyn` and `vccpy` are executed in the normal way when there is enough substance to execute the command. If there is insufficient substance, the `stat` in the individual will change from `FIT` to `UNFIT`.

Mutation, that is changes in the order and the length of the character sequence in the VG, will change the optimum compositional ratio of environmental elements in the individual, and cause an evolutionary adaptation away from the original optimum substantial condition of the environment.

`Divid` is executed when the difference between the optimal temperature and the temperature inside the block is small, as long as there is a vacancy in the adjacent pixels, and the `stat` is `FIT`. If `divid` is not executed normally, the `stat` will change to `UNFIT`.

There are 16 different types of `divid`, each with a different optimal temperature, so evolutionary adaptation toward thermal heterogeneity can occur when the `divid` inside an individual mutates and changes itself into one having a different optimal temperature.

3.4 Experiments

Method SIVA-3 was implemented on a SPARC Station 20 with the X Window System. The simulator was set up so that the spatial reproduction, the evolution of life and the various kinds of information related to both could be graphically observed on the display in real time.

We made a preliminary comparison with some restrictions on SIVA-3 between a primitive life form (PSD model) and a pre-primitive life form (pre-PSD model). The pre-PSD model was a modified PSD model having a precursory programme of self-decomposition which had not yet developed its activity evolutionally. It was observed how the states of reproduction and evolution of the two models differed, when each of them was cultured in the identical limited virtual environment.

The probability of crossover, or *miscsrate*, is set at 0 to keep evolution process simple. In addition, masking against mutation was applied to the VCs of those individuals that correspond to automaton *A*, *B*, *C* and *FZ* when such individuals are regarded as included in von Neumann's self-reproductive automata or our SRSD systems, so as to prevent individuals from losing the function of that portion. Experiments without such restrictions will be shown in another report.

During the current experiment, *aminosize* was set at

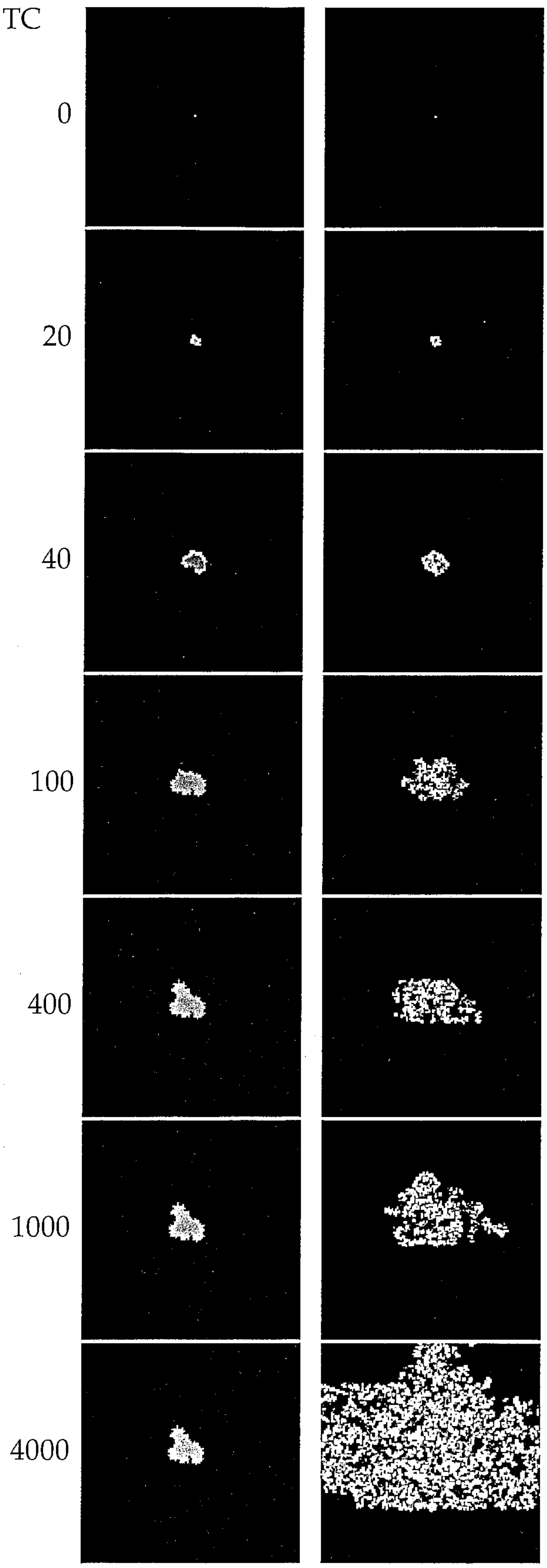

Figure 6: Transition of spatial distribution of individuals (left : pre-PSD model, right : PSD model)

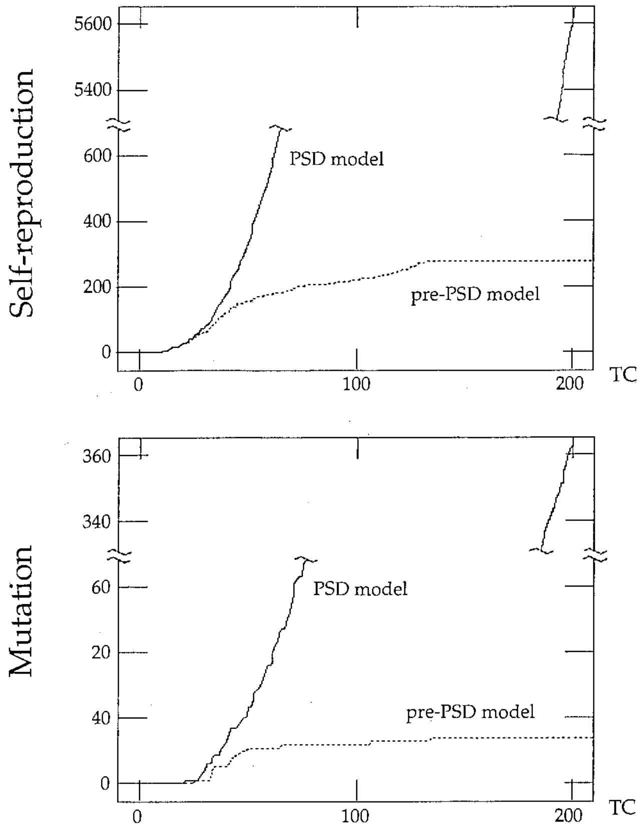

Figure 7: Accumulated frequencies of self-reproduction and mutation

100, and the probability of substitution on the VC, or *misvcrate*, was set at 1/2000.

We have experimented with virtual individuals based on the PSD model and those based on the pre-PSD model to find out which one is more advantageous and in what way. The pre-primitive life forms and the primitive life forms are simulated from 0 to 4000 TCs.

Results Changes in the spatial distribution of individuals are shown in Figure 6. The bright spot in each figure represents a single virtual life individual whose `stat` is `FIT`. A dark gray spot indicates those whose `stat` has changed to `UNFIT`. In addition, the frequencies of self-reproduction and mutation are counted to evaluate the evolutionary adaptability of these two kinds of virtual lives. The results of adding up them are shown in Figure 7.

At the initial stage, individuals of the pre-PSD model exponentially multiplied in space by self-reproduction. During the reproductive process, however, the substance inside the block was rapidly consumed and became inconsistent with the synthesis of the VP or the copying of the VC. Then, the `stat` changed to `UNFIT`, and individuals that had lost reproductive ability began to increase in number. Nevertheless, these individuals could do nothing but self-reproduce, so they could not return space and substances to the environment. Consequently, without making any favorable turn, all the individuals completely stopped self-reproduction when TC reached 137, before adapting and advancing to regions where the environment differed in temperature or substance.

In the meantime, individuals of the PSD model made use of the self-decomposition mechanism to bring space and substance back to the environment, when the environment became inconsistent or a given span of life had expired. Using the returned space and substance as a resource, self-reproduction was repeated within the same region. As a result, the reproduction of entire individuals was stabilized and retained, the repetition of copying increased and life was eventually benefited by a greater opportunity for mutation. Because of this effect, as time passed, we could observe that the individuals that had adapted evolutionally to the heterogeneous materials or temperatures started to appear one after the other, reproducing themselves and multiplying.

The results of the abovementioned experiments suggest that the effectiveness of a self-decomposition mechanism is well worth noting, from the viewpoint of continuous self-reproduction and evolution consuming limited resources existing within a limited space over a long period of time.

4 A study on actual life forms

4.1 *FZ* in actual life forms

The correlation between our theoretical model above and actual life on earth must be explained. Molecular biologists compare the prototype of our model — von Neumann's model as a whole ($E=D+I_D$) — to an independent single cell, and the instruction (I_D) to DNA in the cell. It may be appropriate to adopt this analogy for our model as well. However, the question is whether or not we can find any intracellular organ to which we may compare with little discrepancy our newly proposed decomposition function module *FZ*. As mentioned above, *FZ* functions to decompose system *G* into components in such a way that the entire ecosystem that system *G* belongs to may take advantage of those components collectively. The benefit to the entire ecosystem resulting from this process reaches the maximum level at the point where the feasibility of collective re-utilization of the decomposition products is fully achieved while the release of free energy is kept at the minimum level.

We have examined various modular subsystems that exist in the bodies of living creatures on the earth. One organelle named ``lysosome,'' that envelops in a compact way various kinds of hydrolytic enzymes, turned out to be very interesting in view of the current study. In the process of hydrolysis, i.e. decomposition of biological polymers into monomers — such as protein into amino acids — the collective utilization of decomposed components by the ecosystem is almost fully achieved, and the loss of free energy is very small compared to other biochemical decomposition processes. Therefore, the process of hydrolysis from polymers to monomers is ideal to be defined as a process of decomposition involving the action of *FZ*.

Lysosome is probably an ideal material to be assumed to be *FZ*. We can also define the production of lysosome as comparable to the production of *FZ*, and the release of enzymes from particles into cytoplasm resulting from the rupture of the lysosomal membrane as comparable to the outset of the activities of *FZ*. Thus, we can obtain high compatibility between the phenomena of actual cells and our theoretical model[1].

Moreover, actions such as decay, parasitism or predation, which have become concrete parts of food chain, are all based on digestion — an element derived from ``decomposition of others'' — , regeneration, and reuse of space. Accordingly, the origin of these life activities could be sought for a self-decomposing functional system including lysosome. In other words, ``decomposition of others'' could be conceived as a result of the evolutionary expansion of self-decomposition toward the external environment, in order to make decomposition of other beings possible. In addition, it might be possible to assume that food chain was formed by a highly developed as well as a highly organized mechanism of self-decomposition.

4.2 Biochemical investigation

We have investigated the biochemical model of self-decomposition mentioned above, using a monocellular organism, *Tetrahymena pyriformis* strain W, as the experimental organism[1,2,6]. In these experiments, we induced cultured cells to extinction in a short time (Fig.8). Typical hydrolases of lysosome increased in the process of cell decomposition (Fig.9). However, both of the cell decomposition processes and an increase of lysosomal hydrolases were obviously inhibited when nutrients and oxygen were removed from the culture medium, or when actinomycin D (a transcriptional inhibitor) was injected into it to inhibit genetic regulations (Fig.8,9).

These results may suggest that living organisms are really provided with a self-decomposition mechanism, and that self-decomposition is a controlled process driven by a genetic programme and requiring both nutrients and oxygen.

5 Summary

We examined a hypothetical ``programmed self-decomposition model'' by which a self-decomposing mechanism programmed into cells of all living organisms on earth contributes to the restoration of the ecosystem to its original state. Experiments on both virtual life forms and actual life forms were carried out in parallel to examine the hypothesis. These attempts are beginning to support the effectiveness and the possibility of the existence of a self-decomposition mechanism.

Acknowledgments

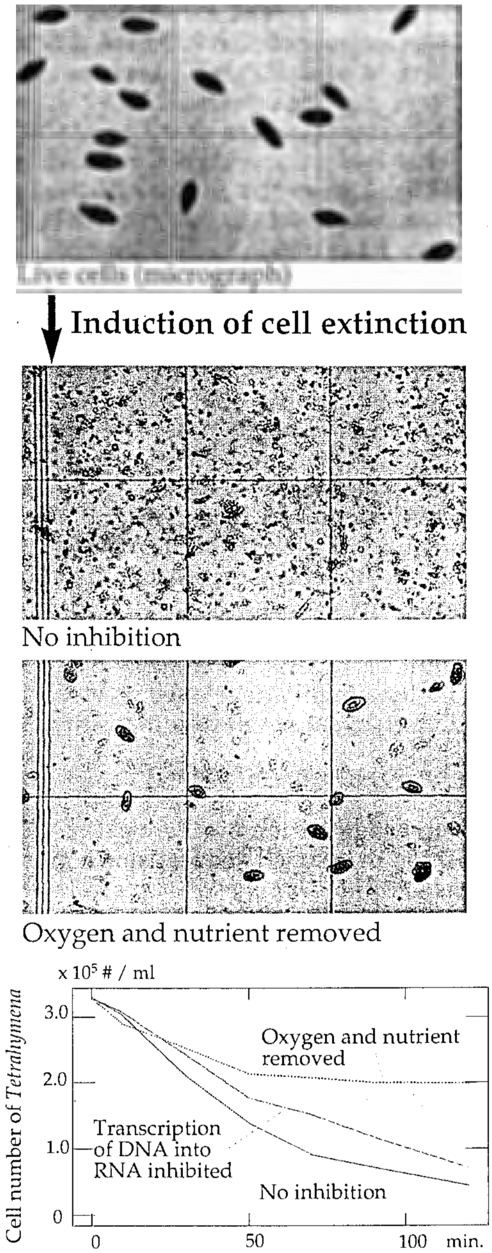

Figure 8: Transition of the cell number after induction of cell extinction

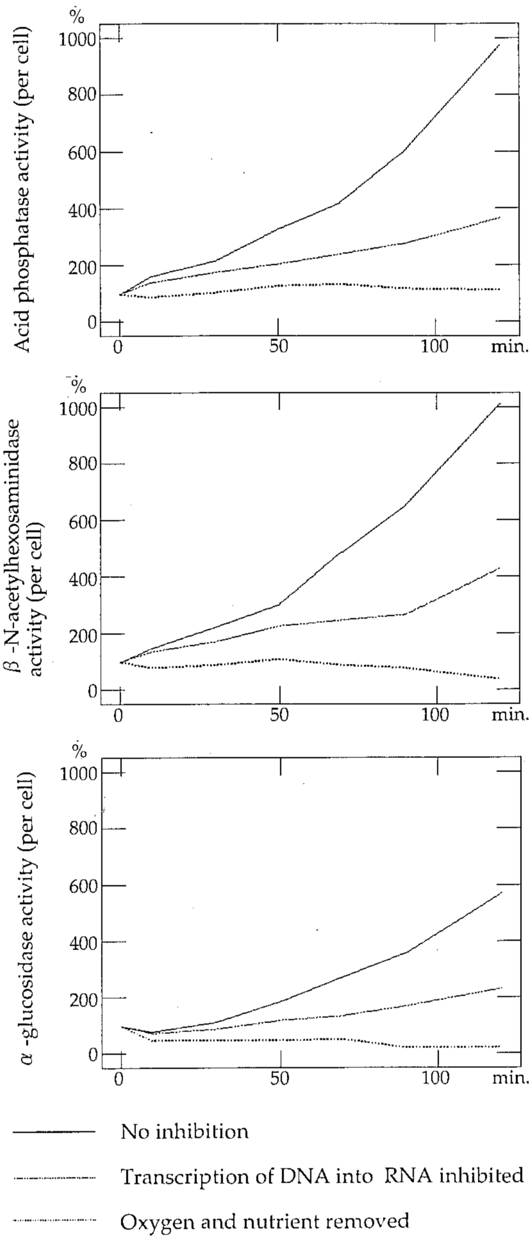

Figure 9: Activation of typical lysosomal hydrolases' activities after induction of cell extinction

We would like to thank the following professors, scholars and colleagues for their indispensable help with our research: Masayuki Sato, Yoshio Oyanagi, Kazuo Murakami, Norie Kawai, Emi Nishina, Yoshitaka Fuwamoto, Satoshi Nakamura, Daisuke Nakata, Takashi Kikuta, Akiko Toma, Kumiko Hiraki, Junko Ooguchi and Michiko Noguchi.

References

[1] Oohashi T., Nakata D., Kikuta T. and Murakami K. (1987) Programmed self-decomposition model, Kagakukisoron kenkyuu, Vol.18, No.2, pp.79-87 (in Japanese)

[2] Oohashi T., Sayama H., Ueno O. and Maekawa T. (1995) Programed self-decomposition model and artificial life, Proceedings of the 1995 International Workshop on Biologically Inspired Evolutionary Systems, pp.85-92

[3] Odum E.P. (1971) Fundamentals of Ecology, Third ed., W.B. Saunders Company, Philadelphia, pp.104-105

[4] Von Neumann J. (1948) The general and logical theory of automata. In cerebral mechanisms in behavior — The Hixon symposium (ed. Jeffress L.A., 1951) John Wiley & Sons, Inc., New York, pp.1-41

[5] Von Neumann J. (1966) Theory of Self-reproducing Automata (edited and completed by Burks A.W.), The University of Illinois Press

[6] Ueno O., Ooguchi J. and Oohashi T. (1993) Research on conditions of inducing cell death for investigation of `programmed self-decomposition model,' Seikagaku, p.959 (in Japanese)