'92 KACC 1992. 10. 19~21

AN APPROACH TO MODELING A BIONIC SELF ORGANIZATION AND FUNCTIONAL EXPRESSION

- Simulation based on mutual action -

Hiroshi YOKOI and Yukinori KAKAZU
Institute of Precision Engineering, Hokkaido University, w8-n13, kitaku, Sapporo, 060 Japan

ABSTRACT

This study is concerned how to construct a model of life as physical/ mathematical representation. This model is called here a bionic model and vibrating potential field is introduced as fundamental world background of the model. Namely, required information creating/ processing/ controlling are done on this field. Especially this paper reports how to realize the simulation of a bionic self organization and its functional expression based on the mutual actions among a set of life units.

1. INTRODUCTION

Almost life has adaptive function to a gently changing of environment. This is said to be supported by a mechanism of functional expression from DNA. An ability of life depends on a secretion and shapes of a cell and a life. But the secretion and the shapes are also depending on the ability of life and also environment. In other word, relations among cells, life and environments are complementary and recurrent structures. This paper is interested in how to realize such structures and tries to describe the mechanism of life's functional expression in computer.

Before describing the functional expression without limiting the domain, this paper will define a unit as a minimum object and will describe a mathematical model on interactions among units. In this mathematical model, every unit 's ability is set by referring to medium of memory called DNA and express the function. Besides, transfer of information between units, to give diversity, is given by a vibrating potential fields, and each unit has peculiar frequency so its mutual action is on each property.

2. Expression of a mutual action

This section enumerates some mathematical model on mutual action. In Quantum chemistry field, there are many significant method to calculate some physical properties which based on Schrödinger equation. To calculate a movement of molecular is come to N-bodies problem of classical mechanics so that there are used to be the Monte Carlo (MC) method. This method is using probability to decide a molecular properties. Furthermore there is Molecular Dynamic (MD) method which decides a molecular property definitely. On the other hand, there is Molecular Mechanics (MM) method which is available for a calculation of Molecular property in liquid condition.

A table below shows a concept of MC, MD, MM method in table.1.

2.1 Potential function

A faculty of MC, MD, MM method depends on potential function of atom or molecular. Potential function depends on arrangement of the circumference objects, but on many objects Eq. (1) can be described 2-body approximation except for metal and semiconductor.

$$F_i(r_1, r_2, r_3, r_N) = \sum_{i=1}^{N} f(r_i, r_j) \qquad (1)$$

method	input	process	output
MC	Atoms potential, Number of particle, Temperature, Initial arrangement	Stochastic process	Particle position Molecular structure
MD	Force among atoms, Number of particle, Size of base cell, A unit of time, Initial arrangement, Initial velocity	Classical mechanics	Details of a particle position per unit time, Molecular structure,
MM	Atoms potential in molecular Number of particle, Size of base cell, Bond energy offormation, Initial arrangement, Freedom, Symmetry properties	Classical mechanics	Atom position, Molecular structure, Energy of molecular structure.

Table 1. An outline of MC, MD, MM method.

And also equation below show.

LJ potential :

$$\Phi_{ij}(r) = 4\varepsilon_{ij}\{(\frac{\sigma_{ij}}{r})^{12}-(\frac{\sigma_{ij}}{r})^{6}\} \quad (2)$$

BMH potential :

$$\Phi_{ij}(r) = \frac{z_i z_j e^2}{r}+A_{ij}b\cdot\exp(\frac{\sigma_i+\sigma_j-r}{\rho})-\frac{C_{ij}}{r^6}-\frac{D_{ij}}{r^8} \quad (3)$$

H_2O's potential :

$$\Phi_{ij}(R_{ij})= 4\varepsilon_{ij}\{(\frac{\sigma_{ij}}{R_{ij}})^{12}-(\frac{\sigma_{ij}}{R_{ij}})^{6}\}+S(R_{ij})\sum_{i=1}^{4}\sum_{j=1}^{4}\frac{q_i q_j}{r_{ij}} \quad (4)$$

3. A structure of functional expression

In this section, we introduce the conceptual model of functional expression. The functional expression is the selection of the suitable faculty for environment. A unit is introduced as the most basic to computation. Each unit has some faculties, and can select it depending on Environment. The faculty is described by a potential function in the section 5. A totally faculty which expressed by a connected units has a complementary relation to relative location of each unit, and is defined by units interaction which depends on the units relative location (Fig.1).

By setting a group problem, environment are introduced. Environment are constructed with unit and groups of units as texture or system. In this style, environment contains all transfer of information.

Fig.2 shows concept of environment where many sort of units, textures and systems are mixed. Each element which has been used for modeling is set as follows. The unit is the smallest object which can generate vibrating potential field, and has medium of memory called DNA to act. Texture is group of units. DNA generates a functional element D which depend on a state S of environment E with interacting to state S. D expresses function at E by interacting to S. Under this establishment, a functional relation of status space is as follows.

state S : $S(D) = \int f(d)dv$,

internal state Sin : $S_{in} = \lambda_1 S(B)+\lambda_2 S(C)+\lambda_3 S(D)$,

expressed function : $D(r) = \Gamma(S_{in}, DNA, F(r))$. (5)

Where, dv is solid measure element. The integral range is defined by neighbor d which depends on D. Sin is inner product of a state and suitable weight line λ_i, where state is decided by boundary B, connection C and other functional element D.

4. Mathematical model of interaction

Until now, it has been described that mathematical model which describes interaction among units suitable for problem. In this section, a mathematical expression of the Vibrating Potential Method (VPM) is proposed. It is constructed by a vibrating potential field (VPF) and the law of movement. Any objects that concern us are set as a unit, the problem and restricted conditions are translated into the potential functions and the VPF is described by these potential functions. This method deals with a case where an interaction force acts upon the center of gravity and the direction of a unit, and can achieve a stable state as a solution through interaction.

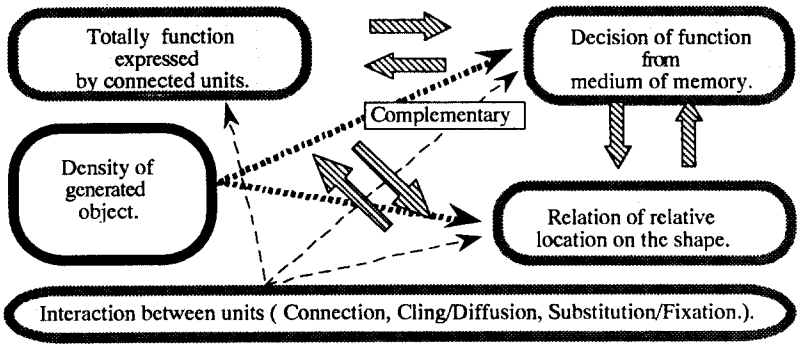


Fig.1 Structure of functional expression

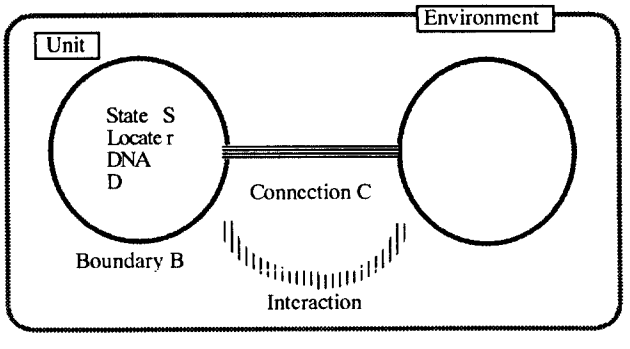


Fig. 2 Concept of environment.

In concrete terms, the VPF is constructed by the potential functions ($h_i(r,n)$ and $w_i(r,n)$) that a unit puts on each harmonic wave axis (unit coordinates axis $\psi(\phi)$ or $\chi(\phi)$). These equations ((6)-(19)) describe the movement of units.

$$H(r) = \sum_i \sum_j h_{ij}\psi_{ij} + \sum_i \sum_j w_{ij}\chi_{ij} + \sum_i \sum_j d_{ij}\tau_{ij} \tag{6}$$

Where, $H(r,n)$: the environment function for a field. $h_i(r,n)$: the potential function of a unit.
$w_i(r,n)$: the wave function that a unit puts on a field.
$r(t)$: the position vector: $r(t) = (r_x, r_y, r_z)$.
$n(t)$: the direction vector: $n(t) = (n_x, n_y, n_z)$.
$v(t)$: the velocity vector: $v(t) = \dot{r}(t)$.
$\omega(t)$: the angular velocity vector: $\omega(t) = \dot{n}(t)$.

As long as it doesn't affect the parity of the units, any method may be selected. To attain mutual cooperation in the movement of units, we used the following information processing method: For our purpose, we have selected Lagrange's equation of motion. This model deals with a case where an interaction force acts upon the center of gravity and the direction of a unit. Lagranjan L is defined as eq(7) by using the VPF H as a potential.

$$\mathfrak{L} = \left(\frac{1}{2} v(t) \cdot p(t) + \frac{1}{2} \omega(t) \cdot q(t)\right) \cdot \psi(\phi) - H(r,n) \tag{7}$$

Lagrange's equations of motion are represented in eq(8).

$$\frac{d}{dt}\left(\frac{\partial \mathfrak{L}}{\partial \dot{\vartheta}}\right) - \frac{\partial \mathfrak{L}}{\partial \vartheta} = 0, \ \{\vartheta = (v_x, v_y, v_z, \omega_x, \omega_y, \omega_z)\} \tag{8}$$

From this VPF and Lagrange's equation of motion, momentum p and angular momentum q can be derived by using a convolution as follows:

$$\dot{p}(t) = M \cdot \oint \frac{\partial \oint H(r,n,\phi)\psi(\phi)\, d\phi}{\partial r} dz \tag{9}$$

$$\dot{q}(t) = I \cdot \oint \frac{\partial \oint H(r,n,\phi)\psi(\phi)\, d\phi}{\partial n} dz \tag{10}$$

$$\frac{f(D)}{dt} = \sum_i \sum_j \{\frac{1}{2\pi}\int_{-\pi}^{\pi} H(r_{ij})\tau_{ij} d\phi\} \tag{11}$$

Where, $\oint dz$: the curvilinear integral at $\left[\frac{\partial h_{ij}(r)}{\partial r}\right]_{r=z} = 0$ z : named as the control point. f(D) is density of produced object by functional element D.
M : the inertia mass: $M = (m_x, m_y, m_z)$.

I: the tensor of inertia: $I = \begin{bmatrix} I_x & -I_{xy} & -I_{xz} \\ -I_{xy} & I_y & -I_{yz} \\ -I_{zx} & -I_{zy} & I_z \end{bmatrix}$.

$$E_{ij} = \xi(\frac{q_{ij}}{2\pi}\int_{-\pi}^{\pi} H(r_{ij})\psi_K d\phi + \gamma) + \delta \tag{12}$$

E_{ij} is interaction energy acts on unit.

Where, $\frac{q_{ij}}{2\pi}\int_{-\pi}^{\pi} H(r_{ij})\psi_K d\phi$ is a strain energy on ψk nearby unit i.

$$\xi^{-1}(E_{ij}) = aE_{ij}^3 + bE_{ij}^2 + cE_{ij} + d\cdot\tan E_{ij} \tag{13}$$

Unit communication is mediated by the VPF H in eq(6). However, since the description of H is only a summation of the unit information, and the objects that we are dealing with have many properties, the information from it alone would be confused. Therefore, to avoid this confusion, we prepared the unit coordinate axes to be at a right angle to each other. Each unit coordinates axis is described as a wave equation. Boundary conditions should be different for each property to avoid confusion.

$$\frac{\kappa(a)}{2}\frac{\zeta(\phi)^2}{d\phi^2} + E_\phi\zeta(\phi) = 0, \quad (\zeta(\phi) = \psi(\phi), \chi(\phi)) \tag{14}$$

$$\zeta(\phi) = 0, \ (|\phi| = a, b) \tag{15}$$

Where, $\psi(\phi), \chi(\phi)$: unit coordinates axis.
$E\phi$: Interaction energy.
$\kappa(a)$: Parameter which determines the spatial distance among unit coordinates axes.
a, b : Initial coefficient.
The change rule of interaction axes is determined by coefficients a and b in eq(15). The unit coordinates axis is in conformity to wave eq(14). There are two benefits to this type of expression of interaction axes. One is that the VPF can maintain different kinds of interaction by using this expression, and the other is that each unit can achieve interaction through an easy operation.

5. Potential function of unit.

Information exchange in this model is represented as an interaction among the Potential functions of units in the VPF. The Potential Function works as an information that propagates to other units and informs those other units as to the status of the objective unit. The potential functions of a unit are defined as follows: Each potential function is defined by the distance between two units. There are two types of potential function of a unit. One is the unit potential function, and the other is the unit wave function. One of the properties of a unit is represented by a unit potential function $h_i(r,n)$ as in eq(16). By this potential function, each unit can express basic behavior such as the closing together and repulsion of other units. Each potential function is defined by the distance between two units.

$$h_i(r,n) = \sum_{n=0}^{3} \frac{(-1)^n B_n(r,n)\cdot q_n}{\alpha_n + (r_i - r)^{2n/k}} \tag{16}$$

Another property for each unit is the capability to propagate a unit wave from the unit boundary as in eq(17). Each unit gets an amplitude of the unit wave in the VPF by the value $k_i(r,n)$.

$$w_i(r,n) = B_n(r,n)\left(W^{|r_i - r|}\right)\exp(j\cdot\omega_0|r_i - r| - \kappa_0 t) \tag{17}$$

$$k_i(r,n) = k_0 + \frac{k_1}{2\pi}\left|\frac{d}{dt}\int H(r_i, n_i)\cdot\chi(\phi)\, d\phi\right| \tag{18}$$

Density field is set to express a phenomenon of density diffusion of generated objects by functional element.

$$\frac{\partial \rho(r,n)}{\partial t} = a\left(\frac{\partial^2}{\partial r_x^2}+\frac{\partial^2}{\partial r_y^2}+\frac{\partial^2}{\partial r_z^2}\right)\rho(r,n) \qquad (19)$$

a is coefficient of diffusion. The density of functional element generated which is given by the units come to be boundary condition of Eq. (19)
Here, each unit gets an amplitude of the potential in the VPF by the value $k_i(r,n)$. k_0 is the basic value of $k_i(r,n)$. W is the dumping factor. ω_0 is the space frequency. κ_0 is the wave number. α_k, n and k_1 are the constant. $B_k(r,n)$ is an effective coefficient that determines a unit's figure.Here, $q_{ijn}=(q_{ij1}, q_{ij2},..., q_{ijn})$ is constant of interaction strength. k_{ij}^0 is basic value of k_{ij}. w and w_d is dumping factor. w is space frequency. k is wave number. α, n and k_1 are constant. $B(n_{ij}, n_{ij})$ is an effective coefficient.

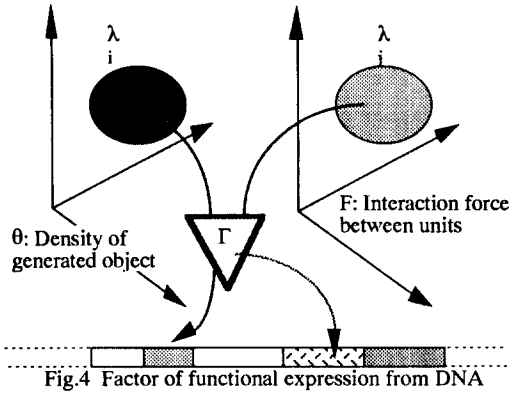


Fig.4 Factor of functional expression from DNA

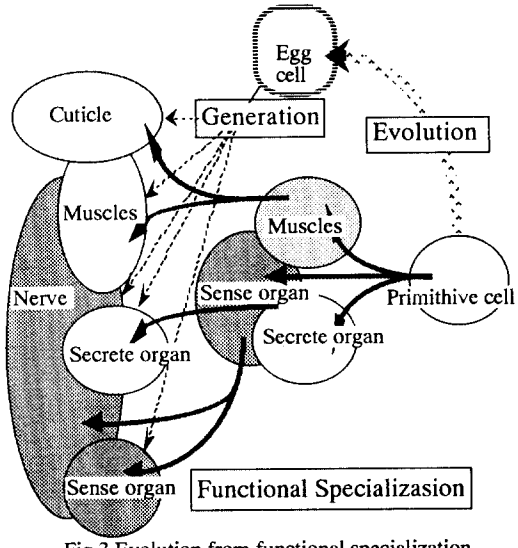


Fig.3 Evolution from functional specialization

6. Setting a style of functional expression.

In the biology field, there are many important knowledge for functional specialization and evolution process so that this section tries to construct a general form of evolution mechanism. Evolution is a transfer the primitive cell to the egg cell under relating function. From the primitive cell, each cell changes in quality with functional specializing. Each cell keeps relation to other function in this process, and it become specialist for the function. This is a functional specializing process. On the other hand, Egg cell generates and becomes group of specialized cells. In this sense, this process is same as the primitive cell's. Namely, Egg cell inherits a style of specialized cell's position by inheriting functional specializing order.

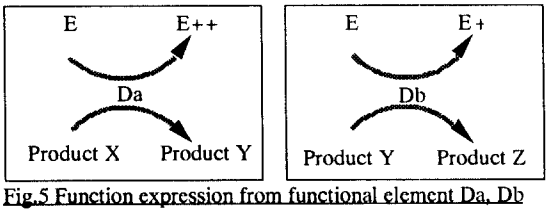


Fig.5 Function expression from functional element Da, Db

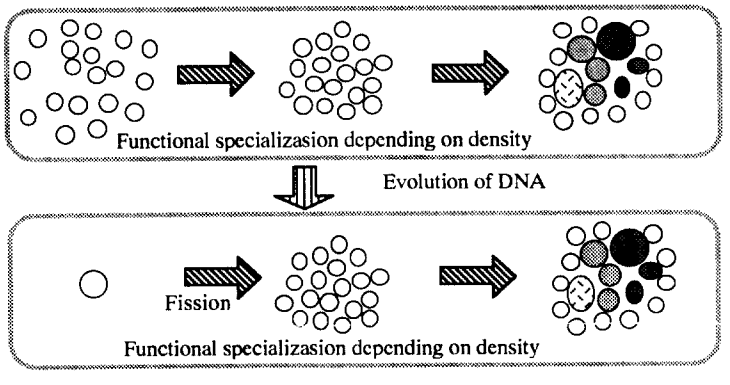


Fig.7 A style of functional specialization

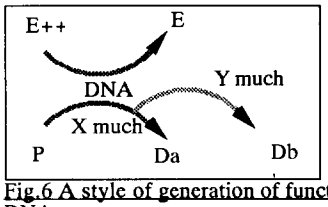


Fig.6 A style of generation of functional element from DNA

Expression ability of each expression place on each unit's DNA depends on generated objects' density q and interaction force F among units (Fig. 4), so that there is need to decide a faculty of DNA and functional element should be generated. Fig.5 shows the faculty of functional element Da, Db. Fig.6 shows the relation between density q surrounding DNA and functional element should be generated. E, E+, E++ are medium of energy in unit. X, Y, Z are materials and products that are influenced by functional element nearby unit. P is material in unit.
Furthermore, functional specialization is able to classify two form. one is depending density form, the other is depending DNA form. Depending density form expresses function with being unrelated to position information at group of units. Depending DNA form expresses function with being restricted by position information.

7. Results

The computer simulation of a functional specialization of unit by the bionic model is indicated in Fig7, Fig8 and Fig9. A hypothesys of the computation is that a unit has a faculty of functional expression depending on density of its surroundings. Each unit is set that it repeat action of producing process.
Fig.7 displays an appearance of products density diffusion. And functional specialization is appeared on the mathematical model of mutual action then fig 8 displays that's state of affairs. Where, a number of thirty units are set, and each unit are set a rule of production and changing its own properties. The rule is that each unit changes its scale and a sort of product depending on products density surrounding.
Furthermore, fig.9 displays another state of affairs under another rule. The rule is that each unit changes its form (potential function) depending on products density surrounding. The computer simulation shows a process of interaction between units and changing its form. a) is a initial arrengiment of units and g) is stable state where units connect each othere and constract the fiver like structures.
These simulations shows that bionic model can achive the functional specializaion process depending on its surroundings.

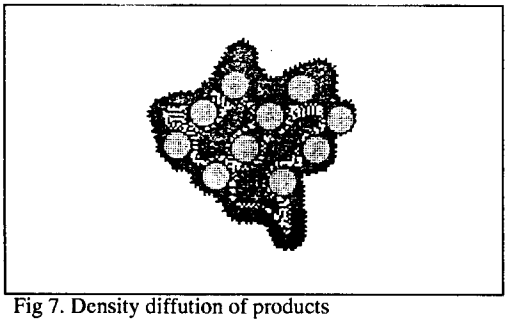


Fig 7. Density diffution of products

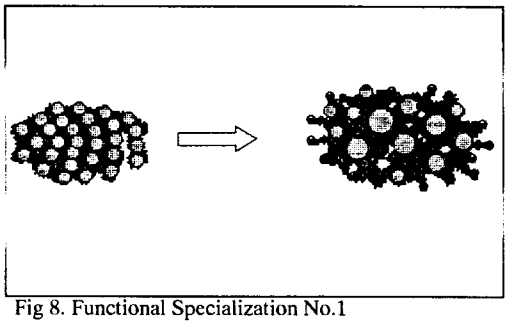
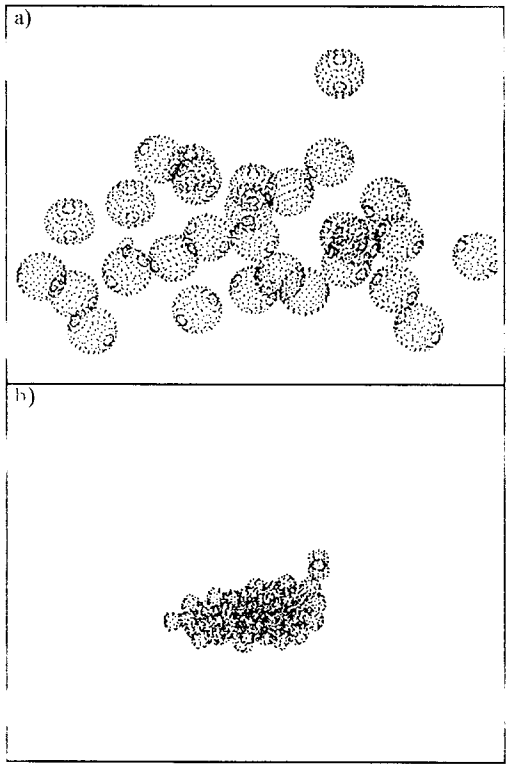
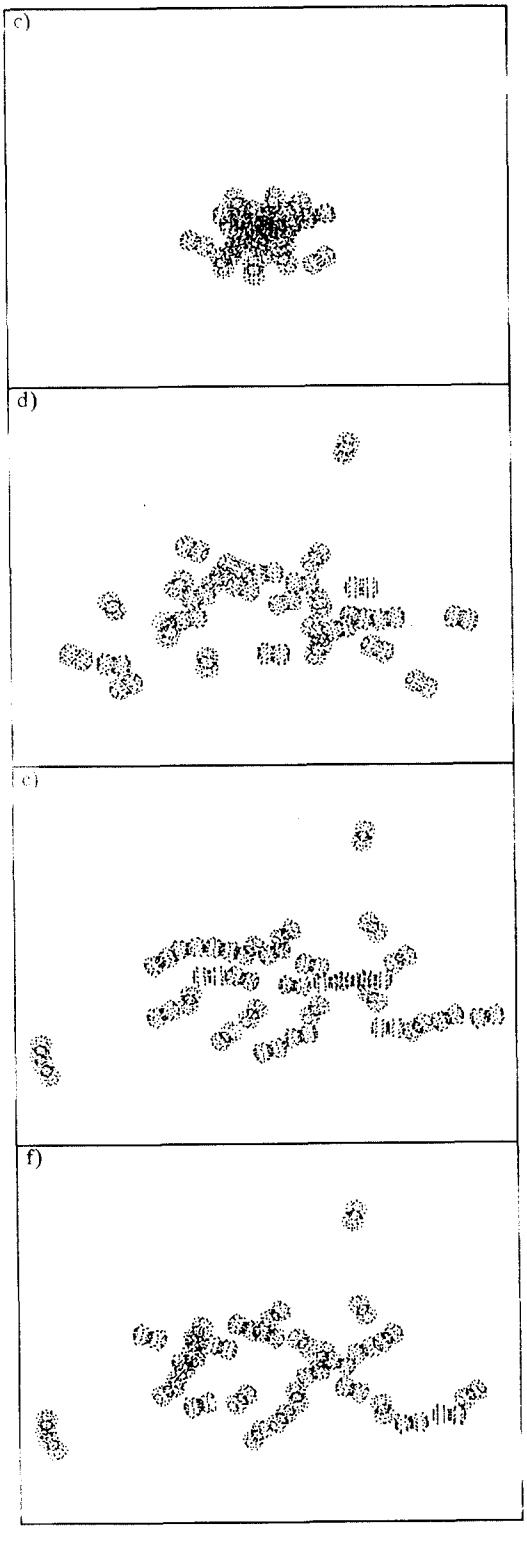


Fig 8. Functional Specialization No.1





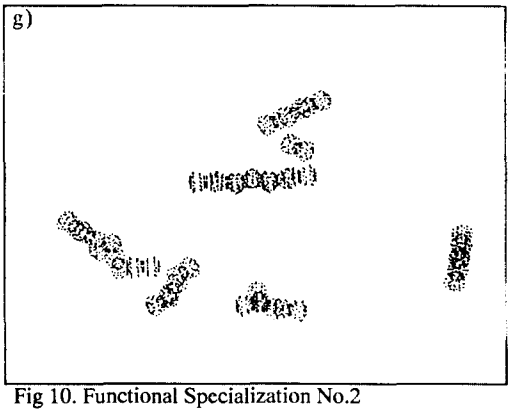


Fig 10. Functional Specialization No.2

8. Conclusion

The mathematical model of mutual action which enable to realize the functional specialization by introducing the density field and state space. Each unit gets information from vibrating field and density field, and expresses function. All field are changed by units, and each unit is influenced again. This phenomenon is verified by computation. After this, functional specialization depending on DNA should be express in this mathematical model in which DNA evaluates by getting relation between a field's status and the function that DNA should express.

Reference

1) S. Koide, "Quantum mechanics (I)",Syoukabo, (1969).
2) Alexander L.Fetter, John Dirk Walecka, "Quantum theory of many-particle systems", McGraw-Hill, Inc. (1971)
3) Attila Szabo, Neil s. Ostlund,"Modern Quantum Chemistry : Introduction to Advanced Electronic Structure Theory", Macmillan Publishing Co.,Inc. (1982)
4) H.Yokoi, Y.Kakazu, "A study on bionic modeling - Simulation of units fission by interaction on vibrating potential field -"Proc. 89th Annual Convention IEICE 6-1 (in Japanese).
5) H. Yokoi, Y. Kakazu, "An Approach to the Traveling Salesman Problem by a Bionic Model," Heuristics, The Journal of Knowledge Engineering, IAKE (International Association of Knowledge Engineers) 1992.
6) H.Yokoi and Y. Kakazu, "An Approach to Autonomous Design of Link Mechanism by a Bionic Model", SICICI'92 (Singapore International Conference on Intelligent Control and Instrumentation), Singapore, 17-21 February 1992.
Proceedings of SICICI'92, p266 - p271.
7) H.Yokoi and Y. Kakazu, "An Approach to the Spatial Nesting Problem by a Vibrating Potential Method", PPSN'92 (Parallel Problem Solving from Nature), Brussels, 28-30 September 1992.
Proceedings of PPSN'92.