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Genetic Representation for Evolvable Artificial Creature

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Abstract—**This paper proposes a genetic representation method to evolve artificial creature's personality by using artificial genome and evolutionary generative algorithm. The genome consists of computer-coded chromosomes. Based on the internal architecture, the chromosomes are designed for the genetic representation. They are composed of the fundamental genes, internal state related genes, and behavior related genes as essential components, which represent the personality and are used for the animal-like evolution in the simulated environment. To get a desired personality (genome), a proper fitness function is designed and genetic operators are applied to the population (genomes). The artificial creature, Rity, is developed in a virtual world of PC to test the effectiveness of this representation scheme.**

I. Introduction

A number of artificial creatures, called interactive creatures, autonomous agents, synthetic characters, software robots, or 3D avatars, are significantly increasing to stimulate humans in real-time interaction. Most previous works, however, dealt with behavior selection and learning mechanisms based on motivation. The concept of evolution and genetic representation were not considered [1]-[6]. Recently, the emphasis has been on the role of genetic encoding and how different types of genotype-phenotype representations allow for greater evolvability of personality. Since it is difficult to establish a general scheme for evolving personality a desired, there have been investigations on genetic representation, fitness function and genetic operators, and how they affect the evolutionary process in the simulated environment. This evolutionary process has been developed for the genetic robot called Rity (software robot) in RIT lab, KAIST in order to generate a desired personality [7].

The significance of having a diverse personality was noted by a psychologist, Andrew Ortony. He quoted "Personality is a determiner of, not merely a summary statement of, behavior" [8]. He also claimed that to build truly believable emotional agents, it is required to identify a generative mechanism that has the power to compose states and behaviors by varying a few parameters. In this regard, the artificial creature's personality is crucial in building a reliable emotional agent. In general, an emotional artificial creature has a variety of internal states, internal and external sensors, which both influence the internal state and show a different behavior externally according to the internal state.

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Study of the artificial creature's personality can be divided into three categories: an implementation of the artificial creature and its simulated environment, its personality model, and an evolutionary generative algorithm for the personality model. This paper focuses on evolving the artificial creature's personality by using its computer-coded genomes and evolutionary generative algorithm in a simulated environment. The artificial creature, Rity, is developed in a 3D virtual world to observe the outcome of Rity's reactions according to its genome (personality) obtained through evolution [5]-[7].

The first part of this paper introduces the internal architecture and the genetic representation of Rity. The artificial genome, which is composed of chromosomes designed by the fundamental genes, the internal state related genes, and the behavior related genes, have the capability of animal-style evolution. The second part of this paper proposes a method on how to obtain the genome for a desired personality through evolution by applying genetic operators.

This paper is organized as follows: Section II describes the essential components of an artificial creature with its internal architecture. In Section III, artificial chromosomes and its genome are investigated and three types of genes are introduced. Section IV proposes a method to initialize population of genomes representing personality trait, while maintaining five classified individual traits. In Section V, genetic operators and fitness function are presented. Section VI describes simulation results and concluding remarks follow in Section VII.

II. Artificial Creature

This section introduces a software robot, Rity, which is developed to fulfill the requirements for an artificial creature. The artificial creature is defined as an agent that behaves autonomously driven by its own motivation, homeostasis, and emotion. It must be able to interact with humans and its environment in real time. The artificial dog, Rity, is made up of a set of computerized DNA (Deoxyribonucleic Acid) codes, the world's first robotic chromosome, that have their own personality and ability to reproduce and evolve as a distinct species [7].

Similar to humans, Rity holds several essential internal state components such as motivation, homeostasis, and emotion. It is an intelligent software robot that lives inside the virtual world of a computer network, but interfaces with the real world through the peripheral hardware attached to the network: cameras, input devices, screens, and audio systems [9], [10]. In this way, it is represented on the screen visually as a dog and may interact with humans based on stimuli that it receives from its peripheral sensors. Figure 1 illustrates the

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internal architecture of Rity. It is a general one, which is composed of five primary modules:

- Perception Module: perceives the environment with virtual or real sensors.
- Internal State Module: defines motivation, homeostasis, and emotion.
- Behavior Selection Module: selects a proper behavior for the perceived information.
- Learning Module: learns from interaction with people.
- Motor Module: executes a behavior and expresses emotion.

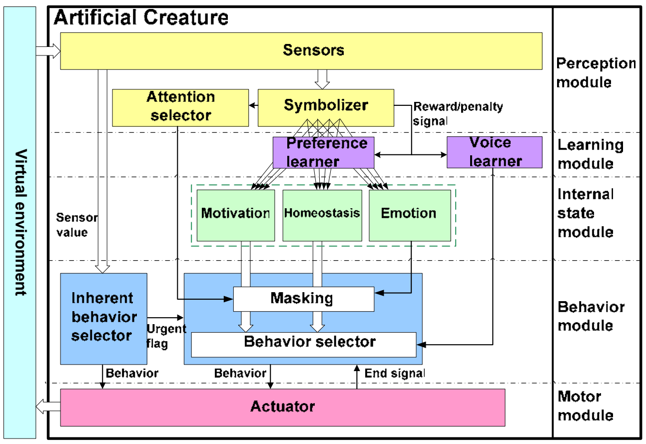


Fig.1 Internal architecture of artificial creature, Rity

A. Perception Module

The perception module includes the sensor unit, symbol unit, sensitivity unit and attention selector. This module can recognize and assess the environment and subsequently send the information to the internal state module. Rity has a number of virtual sensors for determining light, sound, temperature, touch, vision, gyro and time. Using these sensors it can recognize 47 types of perception information through the symbolizing process, which influence internal state. The stimulus vector, S, is defined as:

$$S^T = A^T P = [\alpha_1\rho_1, \alpha_2\rho_2, ..., \alpha_y\rho_y] = [s_1, s_2, ..., s_y],\ 0 \le s_q \le 1 \quad (1)$$

where y is the total number of perceived information, A and P represent the perception vector and the sensitivity vector, respectively. The attention selector is to provide the focus of attention to prevent Rity from performing an improper behavior.

B. Internal State Module

The internal state module defines the creature's internal state with the motivation unit, the homeostasis unit and the emotion unit. In Rity, motivation is composed of six states: curiosity, intimacy, monotony, avoidance, greed and the desire to control. Homeostasis includes three states: fatigue, hunger and drowsiness. Emotion includes five states: happiness, sadness, anger, fear and neutral. In general, the number of internal states depends on an artificial creature's architecture.

Since there are six states for motivation, the motivation vector, M, is defined as:

$$M^T(t) = [m_1(t), m_2(t), ..., m_6(t)] \quad (2)$$

where $m_k(t)$ represents kth state in the internal state module. Each motivation state is updated by:

$$m_k(t+1) = m_k(t) + \{\lambda_k(\overline{m}_k - m_k(t)) + S^T \cdot W_k^M(t)\} \quad (3)$$

where W_k^M is a weight matrix connecting S to kth state in the internal state module, $\overline{m}_k$ is the mean value of kth state, and λ_k is the kth state gain. Similarly, the homeostasis units and the emotion units are updated by using state vector $H(t)$ and W_k^H, where k = 7, 8, 9, and state vector $E(t)$ and W_k^E, where k = 10, 11,…, 14, respectively.

C. Behavior Selection Module

The behavior selection module is used to choose a proper behavior based on Rity's internal state and indirectly on the stimulus vector. When there is no command input from a user, various behaviors can be selected probabilistically by introducing a voting mechanism where each behavior has its own voting value. The algorithm is described as follows:

i) Determine the temporal voting vector, V_{temp} using M and H.

ii) Calculate voting vector V by masking using V_{temp} attention, command and emotion tasks.

iii) Calculate a behavior selection probability, $p(b)$, by using V.

iv) Select a proper behavior b with $p(b)$ from a selection of various behaviors.

D. Learning Module

The learning module is incorporated to be intelligent and interactive with both human beings and its environment. It is composed of two distinct units: the preference and voice learning units. Using these units, Rity is able to train in the same manner as a real pet would be trained [5], [6].

E. Motor Module

The motor module incorporates virtual actuators to execute the selected behavior in the virtual 3D environment. Rity is expressed as a 3D virtual pet with 12 degrees of freedom. Figure 2 shows an image of computer screen showing Rity, which is developed in Visual C++ and OpenGL. The bottom right window shows the visual information of a recognized face, whereas the top right window shows a graphical representation of Rity's internal states.

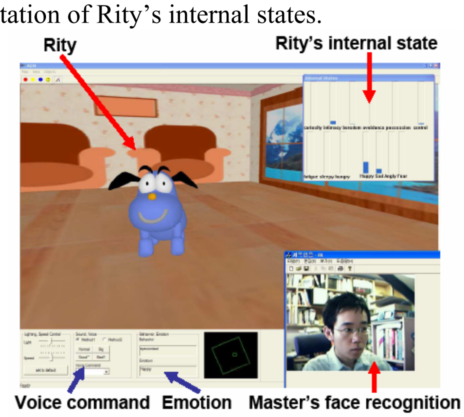


Fig.2 Rity and its virtual 3D environment

III. ARTIFICIAL CHROMOSOME AND GENOME

This section presents a method to build an artificial creature that would be capable of animal-style evolution. Due to the existence of the pleiotypic and polygenic nature of the genotype, a single gene influences multiple phenotypic characters (pleiotypic nature) and a single phenotypic character is directly inspired by multiple genes (polygenic nature). To reflect this complexity to Rity's chromosomal coding, a sophisticated weighting system is embodied to avoid a purely mechanistic response.

Rity is made up of 14 artificial chromosomes (Figure 3), which has the possibility of passing its traits to its offspring. The genes in the figure are originally represented by real numbers. Like a DNA analysis, the positive genes and the negative genes are normalized to brightness values from 0 to 255, which are expressed to black-and-white and red-and-white rectangles, respectively. The darker the color is, the higher its value is. In the figure, chromosomes c_1 - c_6 are related to each state in motivation, c_7 - c_9 to homeostasis, and c_{10} - c_{14} to emotion as mentioned in section II. Given a set of c artificial chromosomes, the kth artificial chromosome, c_k, consists of three gene vectors: the fundamental gene (F-gene) vector, x_k^F, the internal state related gene (I-gene) vector, x_k^I, and the behavior related gene (B-gene) vector, x_k^B, and is defined as:

$$\mathrm{c}_k = \begin{pmatrix} \mathrm{x}_k^F \\ \mathrm{x}_k^I \\ \mathrm{x}_k^B \end{pmatrix}, k = 1,2,...,c \quad (4)$$

with

$$\mathrm{x}_k^F = \begin{pmatrix} x_{1k}^F \\ x_{2k}^F \\ \vdots \\ x_{wk}^F \end{pmatrix}, \mathrm{x}_k^I = \begin{pmatrix} x_{1k}^I \\ x_{2k}^I \\ \vdots \\ x_{yk}^I \end{pmatrix}, \mathrm{x}_k^B = \begin{pmatrix} x_{1k}^B \\ x_{2k}^B \\ \vdots \\ x_{zk}^B \end{pmatrix} \quad (5)$$

where w, y, and z are the dimensions of the F-gene vector, I-gene vector, and B-gene vector, respectively. In Rity, $w = 5$, $y = 47$, $z = 77$, and $c = 6 + 3 + 5 = 14$. These values are equivalent to the ability to perceive 47 different types of stimuli and to respond to 77 different behaviors.

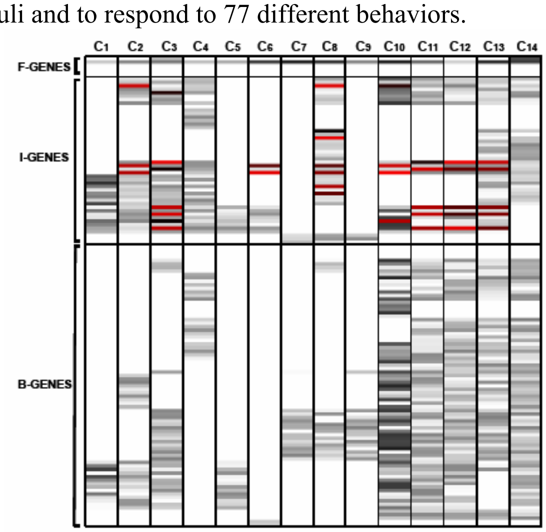


Fig.3 Artificial chromosomes of Rity

The F-gene vector represents fundamental characteristics of Rity, including genetic information such as volatility, initial and mean value, $\overline{m}_k$, and the decay rate of each internal state. The I-gene vector represents its internal preference by setting the weights of W_k^M (t). The preference can be modified and trained on-line by adapting the weights like pet training. The B-gene vector includes genetic codes related to output behavior by setting the weights.

A genome, g, represents an artificial chromosomal set with genetic codes determining an artificial creature's personality and is defined as:

$$\mathrm{g} = [\mathrm{c}_1 \;\; \mathrm{c}_2 \;\; \dots \;\; \mathrm{c}_c] \quad (6)$$

where c is the number of artificial chromosomes in the genome. This 2D representation has advantages of representing essential characteristics of three types of genes intuitively, reproducing the evolutionary characteristics of real creatures, and enabling users to easily insert or delete other types of chromosomes and genes related to an artificial creature's personality and other information.

IV. INITIALIZING POPULATION

The genome is used to produce an artificial creature's personality by applying evolutionary techniques. In order to fulfill the artificial creature's personality as a truly believable emotional agent, the evolutionary generative algorithm should be provided [11]. It is an identifiable generative mechanism that characterizes many internal states and their behaviors by simply varying several parameters through a graphical user interface (GUI). In addition, it is designed based on the five classified individual traits in the trait space defined by McCrae and Costa [12]:

- Extroverted (as opposed to introverted): sociable, warm, and talkative
- Agreeable (as opposed to antagonistic): forgiving, good-natured, and soft-hearted
- Conscientious (as opposed to negligent): hard working, well organized, and reliable
- Openness (as opposed to closed)
- Neuroticism (as opposed to emotional stability)

The initial population is then derived according to the user's preference via GUI and is of the form:

$$P(0) = \mathrm{g}_i^t\Big|_{t=0} = \{\mathrm{g}_1^0, \mathrm{g}_2^0, \dots, \mathrm{g}_n^0\}, i = 1,2,...,n. \quad (7)$$

Ψ is defined to denote the gains of I-genes and B-genes:

$$\Psi = \begin{bmatrix} \psi_{11}^I & \psi_{12}^I & \cdots & \psi_{1c}^I \\ \psi_{21}^I & \psi_{22}^I & \cdots & \psi_{2c}^I \\ \vdots & \vdots & \ddots & \vdots \\ \psi_{y1}^I & \psi_{y2}^I & \cdots & \psi_{yc}^I \\ \hline \psi_{11}^B & \psi_{12}^B & \cdots & \psi_{1c}^B \\ \psi_{21}^B & \psi_{22}^B & \cdots & \psi_{2c}^B \\ \vdots & \vdots & \ddots & \vdots \\ \psi_{z1}^B & \psi_{z2}^B & \cdots & \psi_{zc}^B \end{bmatrix} \quad (8)$$

Since both format and scale of genes are distinctly different from each other, each F-gene, x_{wk}^{F0}, is initialized individually. Each I-gene, x_{qk}^{I0}, is initialized as follows:

$$x_{qk}^{I0} = U[0, I_{\max}]\lambda_{qk}^{I} \tag{9}$$

$$\lambda_{qk}^{I} = \begin{cases} \dfrac{\psi_{qk}^{I}}{\lambda_{c1}^{I}}, & \text{if } m_{qk}^{I} \geq 0 \\ \dfrac{\lambda_{c2}^{I}}{\psi_{qk}^{I}}, & \text{if } m_{qk}^{I} < 0 \end{cases} \tag{10}$$

where m_{qk}^{I} is the qth I-gene mask of the kth artificial chromosome, I_{max} is the upper bound of I-genes, λ_{c1}^{I} and λ_{c2}^{I} are the I-gene control constants for balancing between positive genes and negative genes. Similarly, each B-gene, x_{rk}^{B0}, is initialized as follows:

$$x_{rk}^{B0} = U[0, B_{\max}]\lambda_{rk}^{B}, \; 0 < \lambda_{rk}^{B} \leq 1 \tag{11}$$

$$\lambda_{rk}^{B} = \frac{\psi_{rk}^{B}}{\lambda_{c}^{B}} \tag{12}$$

where B_{max} is the upper bound of B-genes, and λ_{c}^{B} is the B-gene control constant.

V. Genetic Operators and Fitness Function

Crossovers are performed only between parental genes of the same kind, length, and chromosomal order for the following selected genomes g_1^t and g_2^t:

$$g_1^t = [c_{11}^t \mid c_{12}^t \mid \cdots \mid c_{1k}^t \mid \cdots \mid c_{1c}^t] = \begin{bmatrix} x_{11}^{Ft} \mid x_{12}^{Ft} \mid \cdots \mid x_{1k}^{Ft} \mid \cdots \mid x_{1c}^{Ft} \\ x_{11}^{It} \mid x_{12}^{It} \mid \cdots \mid x_{1k}^{It} \mid \cdots \mid x_{1c}^{It} \\ x_{11}^{Bt} \mid x_{12}^{Bt} \mid \cdots \mid x_{1k}^{Bt} \mid \cdots \mid x_{1c}^{Bt} \end{bmatrix} \tag{13}$$

$$g_2^t = [c_{21}^t \mid c_{22}^t \mid \cdots \mid c_{2k}^t \mid \cdots \mid c_{2c}^t] = \begin{bmatrix} x_{21}^{Ft} \mid x_{22}^{Ft} \mid \cdots \mid x_{2k}^{Ft} \mid \cdots \mid x_{2c}^{Ft} \\ x_{21}^{It} \mid x_{22}^{It} \mid \cdots \mid x_{2k}^{It} \mid \cdots \mid x_{2c}^{It} \\ x_{21}^{Bt} \mid x_{22}^{Bt} \mid \cdots \mid x_{2k}^{Bt} \mid \cdots \mid x_{2c}^{Bt} \end{bmatrix} \tag{14}$$

In this case, x_{1k}^{Ft} in c_{1k}^t can crossover only via x_{2k}^{Ft} of the same F-genes in c_{2k}^t. Based on this philosophy, two kinds of crossover schemes are possible. Firstly in the general crossover scheme (Figure 4), F-, I-, B-gene crossovers are carried out together by the same crossover rate, τ_x, between two selected parents to produce two general offspring. On the other hand, in the independent crossover scheme (Figure 5), F-, I-, B-gene crossover operators with independent rates τ_x^F, τ_x^I, and τ_x^B are applied to the selected two parents. In the same manner, mutation operators are implemented.

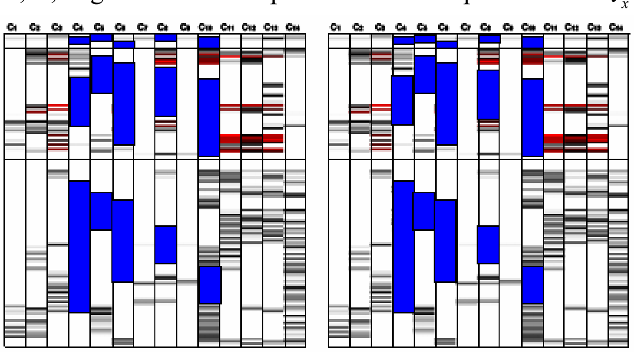


Fig.4 General crossover scheme

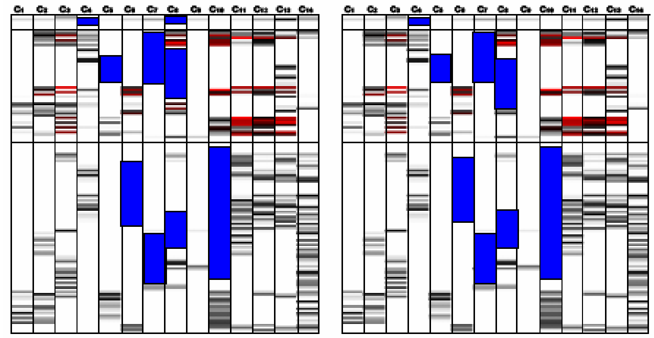


Fig.5 Independent crossover scheme

Although this section shows only two kinds of crossover operators as examples, it should be noted that various crossover operators along with mutation operators can be developed for this 2D representation.

A fitness function is composed of the artificial creature's internal and external outputs. Considering fitness candidates related to internal states and fitness candidates related to behaviors, the following fitness function is defined for evolutionary generative algorithm:

$$\begin{aligned} \Phi(j\Delta T, g) = C - \rho\Bigg[& \sum_{k=1}^{6} (1/\varphi_k^I)\left|\varphi_k^I - \Phi_{pk}^{M}(j\Delta T, g)\right| + \\ & \sum_{k=1}^{9} (1/\varphi_k^I)\left|\varphi_k^I - \Phi_{pk}^{H}(j\Delta T, g)\right| + \\ & \sum_{k=10}^{14} (1/\varphi_k^I)\left|\varphi_k^I - \Phi_{pk}^{E}(j\Delta T, g)\right| + \\ & \sum_{k=1}^{14} (1/\varphi_k^B)\left|\varphi_k^B - \Phi_{fk}^{BG}(j\Delta T, g)\right| \Bigg] \end{aligned} \tag{15}$$

with the normalized gains, φ_k^I of ψ_k^I and φ_k^B of ψ_k^B:

$$\varphi_k^I = \psi_k^I \Big/ \sum_{l=1}^{14} \psi_l^I \tag{16}$$

$$\varphi_k^B = \psi_k^B \Big/ \sum_{l=1}^{14} \psi_l^B \tag{17}$$

where $\Phi_{pk}^{M}(j\Delta T, g)$, $\Phi_{pk}^{H}(j\Delta T, g)$, and $\Phi_{pk}^{E}(j\Delta T, g)$ are the percentages of possession of the kth internal state and $\Phi_{fk}^{BG}(j\Delta T, g)$ is the percentage of the frequency of the kth behavior group. C is a constant and ρ is the scaling factor for percentage. $(1/\varphi_k^B)$ is the k-th I-penalty weight which boosts the convergence rate of Φ_{pk}^{M}, Φ_{pk}^{H}, and Φ_{pk}^{E}.

VI. Experimental Results

The personalities of both an agreeable artificial creature and an antagonistic one were generated by applying evolutionary generative algorithm. The population (genomes) size and the generation number were 10 and 1,000, respectively. The best fitness value was not updated frequently for 1,000 generations, but increased slowly without failure.

The genes were represented by real numbers; values of F-genes range from 1 to 500, I-genes from 0 to 5,000, and

Internal state			Agreeable personality		Antagonistic personality	
Upper	Lower	k	I-gain ψ_k^I	B-gain ψ_k^B	I-gain ψ_k^I	B-gain ψ_k^B
Motivation	Curiosity	1	50	50	20	20
	Intimacy	2	80	80	20	20
	Monotony	3	50	50	50	50
	Avoidance	4	20	20	80	80
	Greed	5	20	20	80	80
	Control	6	10	10	70	70
Homeostasis	Fatigue	7	20	20	20	20
	Drowsiness	8	20	20	20	20
	Hunger	9	20	20	20	20
Emotion	Happiness	10	80	80	20	20
	Sadness	11	50	50	50	50
	Anger	12	20	20	80	80
	Fear	13	20	20	80	80
	Neutral	14	50	50	20	20

Table.I Preference gains for agreeable and antagonistic personalities

B-genes from 1 to 1,000. The results with the independent variation scheme are shown in this section. I- and B- gene crossover rates were set to be 0.1 and 0.2, respectively, and both I- and B- gene mutation rates to 0.05. Since I- and B-genes are critical to the personality variation, F-genes were fixed in this experiment. Table I shows the user's preference gains, where each gain varies between 0 and 100.

Figures 6 and 7 show the results of both agreeable and antagonistic personalities, respectively. Best fitness among 10 genomes and their average values were displayed at every generation. Due to the large number of genes, the best fitness did not modify frequently for 1,000 generations, but certainly increased slowly without any failure. By the genetic operators, the average fitness fluctuated in high magnitude and this shows the good performance of the evolutionary generative algorithm.

Figure 8 shows the comparison between initial and final Rity's genomes of both agreeable and antagonistic personality. For agreeable personality, I-genes and B-genes of chromosomes c_2 and c_{10}, which are related to the internal states of intimacy and happiness, had changed darker, while I-genes and B-genes of chromosomes c_4, c_5, c_6, c_{12}, and c_{13}, which are related to the internal states of avoidance, greed, desire to control, anger, and fear, had adjusted to lighter

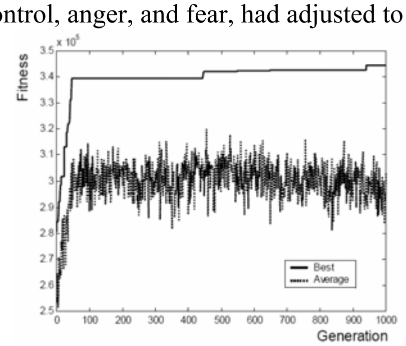


Fig.6 Best fitness and average fitness of agreeable personality

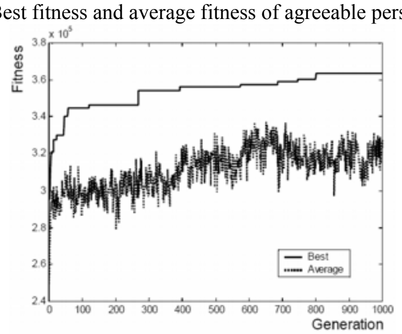


Fig.7 Best fitness and average fitness of antagonistic personality

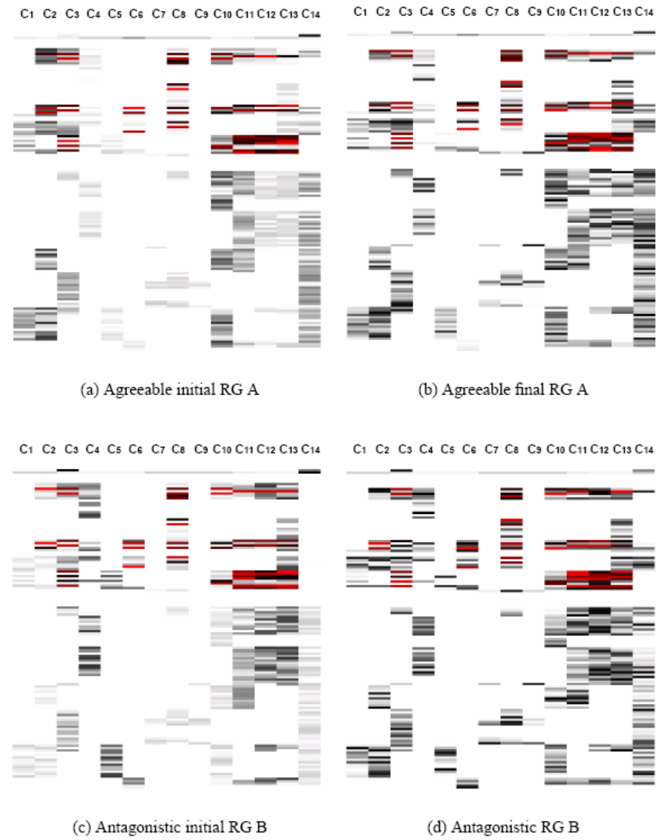


Fig.8 Initial and final chromosomes, c_k , represents the kth chromosome

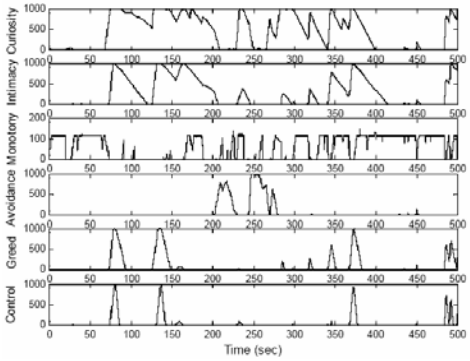
intensity. I-genes and B-genes of chromosomes c_4, c_5, c_6, c_{12}, and c_{13} had modified to darker intensity, whereas I-genes and B-genes of chromosomes c_1, c_2, c_{10}, and c_{14} had adjusted to lighter intensity for antagonistic personality.

The internal states of these two personalities are shown in Figures 9 and 10, respectively. X-axis represents time where Y-axis represents the strength of each chromosome. It was clearly observable that happiness dominates for agreeable personality whereas sadness, anger, and greed dominate for antagonistic personality as time increases. Consequently, the final genome of each personality had different structures that represent strengthened characteristics according to a user's preference. In addition, it was possible to obtain all five individual traits, which is defined by McCrae and Costa, in the similar way.

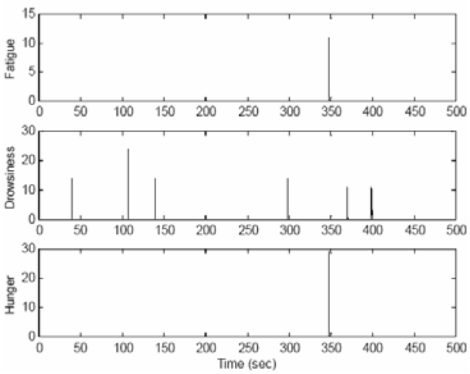
VII. CONCLUSIONS

In this paper, evolving an artificial creature's personality by using computer-coded genomes and an evolutionary generative algorithm was proposed. It was developed in a three-dimensional virtual world to observe the trait of Rity according to its genome. The genetic representation of Rity was made by the artificial genome, which is composed of the fundamental genes, the internal state related genes, and the behavior related genes. In this way, the artificial genome was designed as the basic building blocks for an artificial life form.

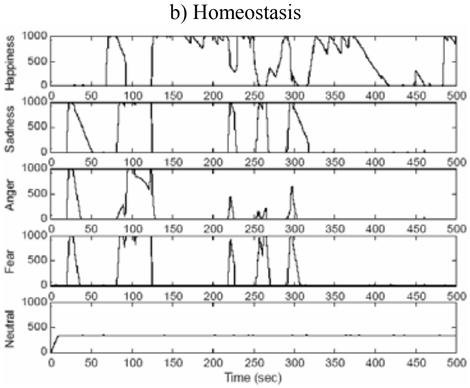
The evolutionary generative algorithm optimized the genome to obtain a desired personality by using genetic operators under the provided fitness function in a simulated environment. This procedure allowed for reproduction through artificial means, completing the process of design for a fully functional life form.



a) Motivation

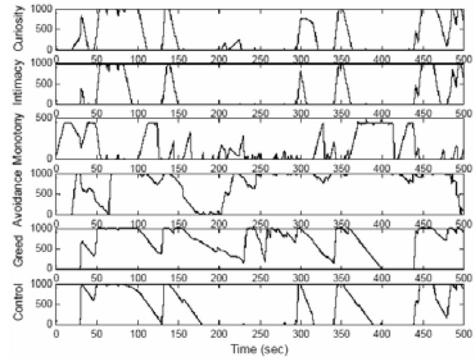


b) Homeostasis

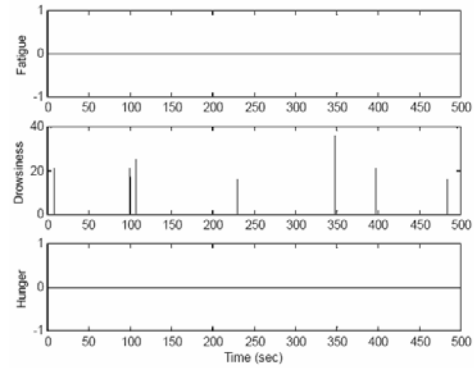


c) Emotion

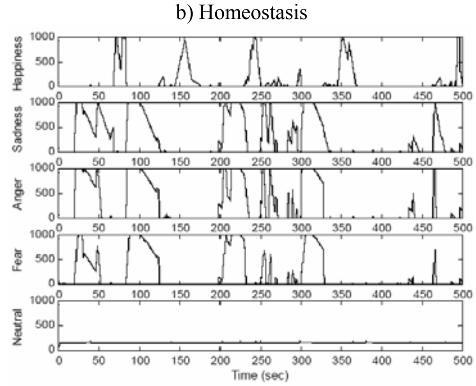
Fig.9 Internal states of the agreeable artificial creature



a) Motivation



b) Homeostasis



c) Emotion

Fig.10 Internal states of the antagonistic artificial creature

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